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CENTRAL RECEIVER SOLAR THERMAL POWER SYSTEM, PHASE 1

Volume 7: Pilot Plant Cost and Commercial Plant Cost and Performance Preliminary Design Report

MASTER

Work Performed Under Contract No. EY-76-C-03-1110

Martin Marietta Corporation
Denver, Colorado

U.S. Department of Energy

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Solar Energy

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FOREWORD

This document comprises Volume VII of the seven-volume Central Receiver Solar Thermal Power System Pilot Plant Preliminary Design Report. The complete report consists of the following volumes.

I. Executive Overview
II. System Description and System Analysis
III. Collector Subsystem
IV. Receiver Subsystem
V. Thermal Storage Subsystem
VI. Electrical Power Generation/Master Control Subsystems and Balance of Plant
VII. Pilot Plant Cost and Commercial Plant Cost and Performance

The work described herein was performed during the period of July 1975 through May 1977 by the Martin Marietta Corporation (Denver, Colorado) in accordance with ERDA Contract EY 76-C-03-1110 under the technical direction of Sandia Laboratories (Livermore, California).

Four organizations, each with major subsystem responsibilities, combined forces to perform the preliminary design and subsystem research experiments. The team is led by Martin Marietta Aerospace of Denver, Colorado, who is the integrator for the overall effort and collector subsystem designer. Bechtel Corporation, San Francisco, California, is responsible for the electrical power generation subsystem and the architect-engineer tasks; Foster Wheeler Energy Corporation, Livingston, New Jersey, is responsible for the receiver subsytem; and the engineering experiment station of the Georgia Institute of Technology is responsible for the thermal storage subsystem.

The prime contract was under the overall direction of George Kaplan, ERDA Division of Solar Energy. Robert Hughey of the ERDA, San Francisco field office was the contract administrator. Sandia Laboratories technical direction was provided by Clifford Selvage, Allan Skinrood and William Moore.

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CONTENTS

FIGURES

ABBREVIATIONS AND ACRONYMS

A	Ampere
BTU	British Thermal Unit
^oC	Degrees Celsius
CF	Cubic Feet
CS	Collector Subsystem
CRT	Cathode Ray Tube
DHS	Data Handling System
EPGS	Electrical Power Generation Subsystem
ERDA	Energy Research and Development Administration
^oF	Degrees Fahrenheit
fps	Feet Per Second
ft	Feet
FW	Feedwater
g, kg	Gram, Kilogram
gal	Gallon
hr	Hour
I/F	Interface
in	Inch
j	Joule
K	Kelvin
KVA	Kilovolt-Ampere
KV	Kilovolt
l	Liter
lbs	Pounds
LF	Linear Feet
m, mm	Meter, Millimeter
MCS	Master Control System
min	Minutes
MMC	Martin Marietta Corporation
mph	Miles Per Hour
Pa, kPa	Pascal, Kilopascal
PCS	Plant Control System
psf	Pound Per Square Foot
psia	Pound Per Square Inch-Absolute
psig	Pound Per Square Inch-Gage
rad	Radian
RAM	Random Access Memory
RH	Relative Humidity
ROM	Read Only Memory
RS	Receiver Subsystem
s	Second
SF	Square Feet
SRE	Subsystem Research Experiment
STTF	Solar Thermal Test Facility
TSS	Thermal Storage Subsystem
W_e, kW_e, MW_e	Watt, Kilowatt, Megawatt-Electrical
W_t, kW_t, MW_t	Watt, Kilowatt, Megawatt-Thermal

I. INTRODUCTION

This volume of the CRSTPS Preliminary Design Report contains the economic analysis of both the 10 MW_e pilot plant and a 150 MW_e commercial plant. The design basis upon which these economic analyses were developed are the 10 MW_e Pilot Plant Preliminary Design and the 150 MW_e Commercial Plant Conceptual Design both of which are contained in Volumes I through VI of this report. The 150 MW_e commercial plant size was determined by economic analysis to be the most cost effective plant size. These economic analyses were prepared by Martin Marietta. Inputs were provided by Bechtel Corporation for the electrical power generation subsystems and for architect-engineering aspects of the plants; Foster-Wheeler Energy Corporation for the receiver subsystems; and Georgia Institute of Technology for the thermal storage subsystem.

The format, cost breakdown structure, for presenting the cost estimates was provided by Sandia Laboratories, Livermore, California (Reference 1). In some cases cost data is provided to a lower level than required by the cost breakdown structure.

For cost estimating purposes, the pilot plant site near Barstow, California, was utilized while Inyokern, California, was utilized as the site for the commercial plant. The commercial plant estimate assumes this to be the first such plant with subsequent plants to be built at the rate of one per year. Both the pilot plant and commercial plant estimates are based upon 1977 mid-fiscal year average dollars. All of the cost estimates presented herein are considered best estimates of expected costs.

Summary descriptions of both the 10 MW_e pilot plant and the 150 MW_e commercial plant are given in Section II, followed by a discussion in Section III of the groundrules and assumptions used. The detailed pilot plant and commercial plant cost estimates are presented in Sections IV and V respectively. Finally, Section VI presents the commercial plant performance data.

Within the Pilot Plant Preliminary Design as described in previous volumes the collector subsystem is a single module of the 15 module collector subsystem for the commercial plant. This size module containing 1554 heliostats is recommended for the pilot plant in order to eliminate entirely all scaling risk for both the collector subsystem and the receiver subsystem when going from the pilot plant to the commercial plant. However, since a collector field containing only

1325 heliostats will meet all of the pilot plant performance requirements, the cost for this configuration is included in detail in Section IV. The somewhat more costly collector subsystem configuration containing 1554 heliostats has also been priced and the cost differential is provided in Section IV.

II. SYSTEM DESCRIPTIONS

A. PILOT PLANT

1. General Description

The key features of the 10 MW_e Pilot Plant design concept are shown on the artist's rendering, Figure II.A-1, which is representative for the selected Barstow, California, plant site. This view looking northwest, shows the field of heliostats positioned north of a central receiver tower, with the sun in an afternoon position.

Greater subsystem details are shown on the plot plan, Figure II.A-2. The general layout is governed by the area and positioning requirements for the collector subsystem with respect to the receiver subsystem. The heliostats are symmetrically located about a north-south line from the receiver tower. The receiver is positioned at the south edge of the collector field.

The receiver intercepts the focused solar radiation from the collector field and converts this energy into steam. It is similar in function to the boiler of a conventional fossil fuel plant, and includes waterwall and steam (superheater) tube panels for transfer of solar thermal energy into superheated steam. The receiver is positioned such that the centerpoint of the cavity aperture is at a height of 90 meters and the plane of the north facing aperture is 64m (210 ft) to the south of the front row of heliostats. The selected geometrical relationship of the receiver and the heliostats within the collector subsystem are key to system performance. The aperture of the receiver cavity is 7.5 x 7.5m (24.6 x 24.6 ft). The receiver is hung from the top of the tower. The suspension design, in conjunction with the tower design characteristics, will assure that the receiver will withstand the specified operational and survival wind and seismic activity requirements. The receiver tower is constructed of octagonal steel framing and is enclosed in a corrulated metal cladding.

A collector subsysyem of 1325 heliostats will meet the minimum specified performance requirements for the pilot plant. This minimum field size, for which detailed costs are presented in Section IV, can be accommodated in 36 rows as indicated in Figure II.A-2. Note that a full, commercial plant sized heliostat field module (1554 heliostats) is recommended for the Pilot Plant design to

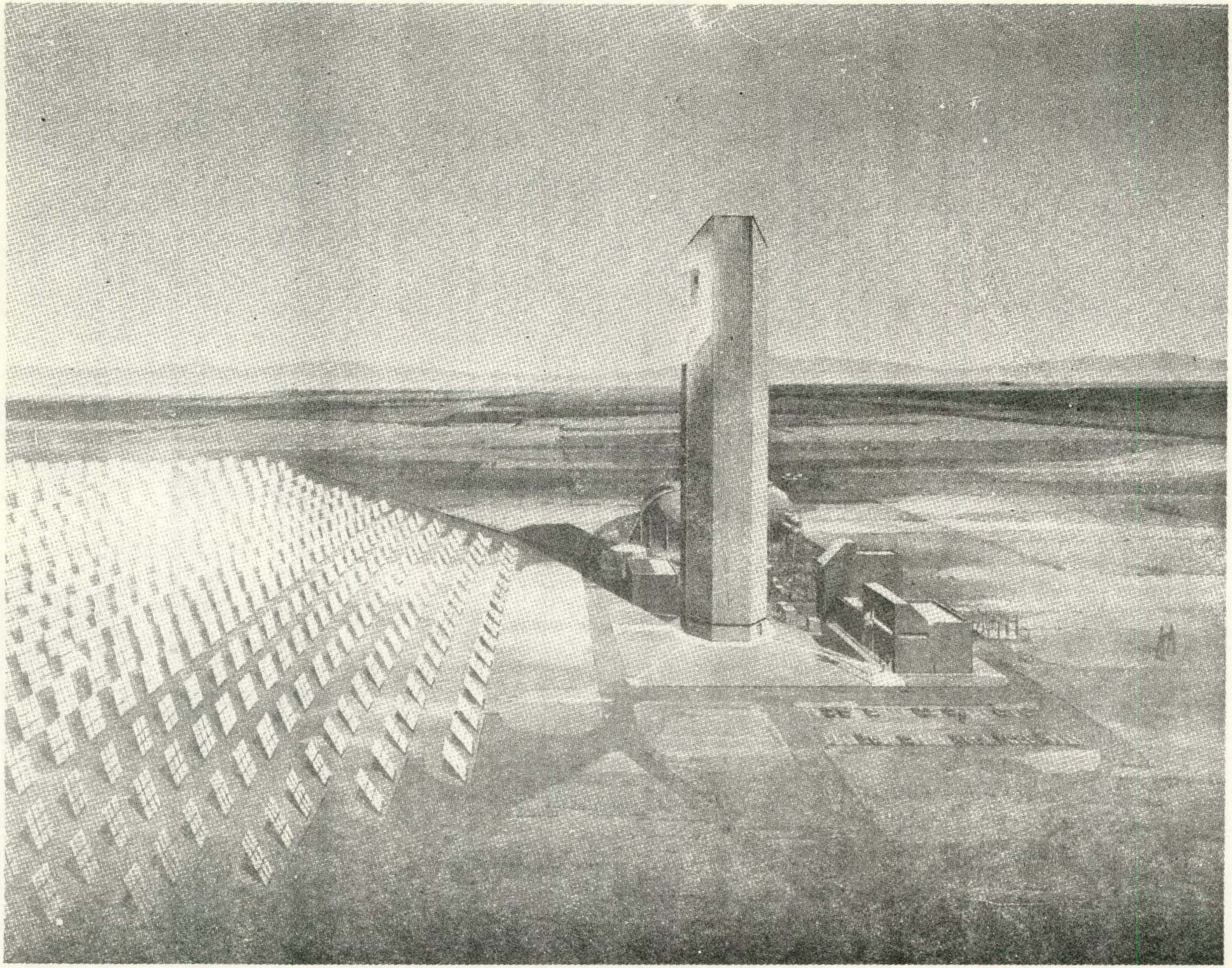

Figure II.A-1 Pilot Plant Artist Rendering

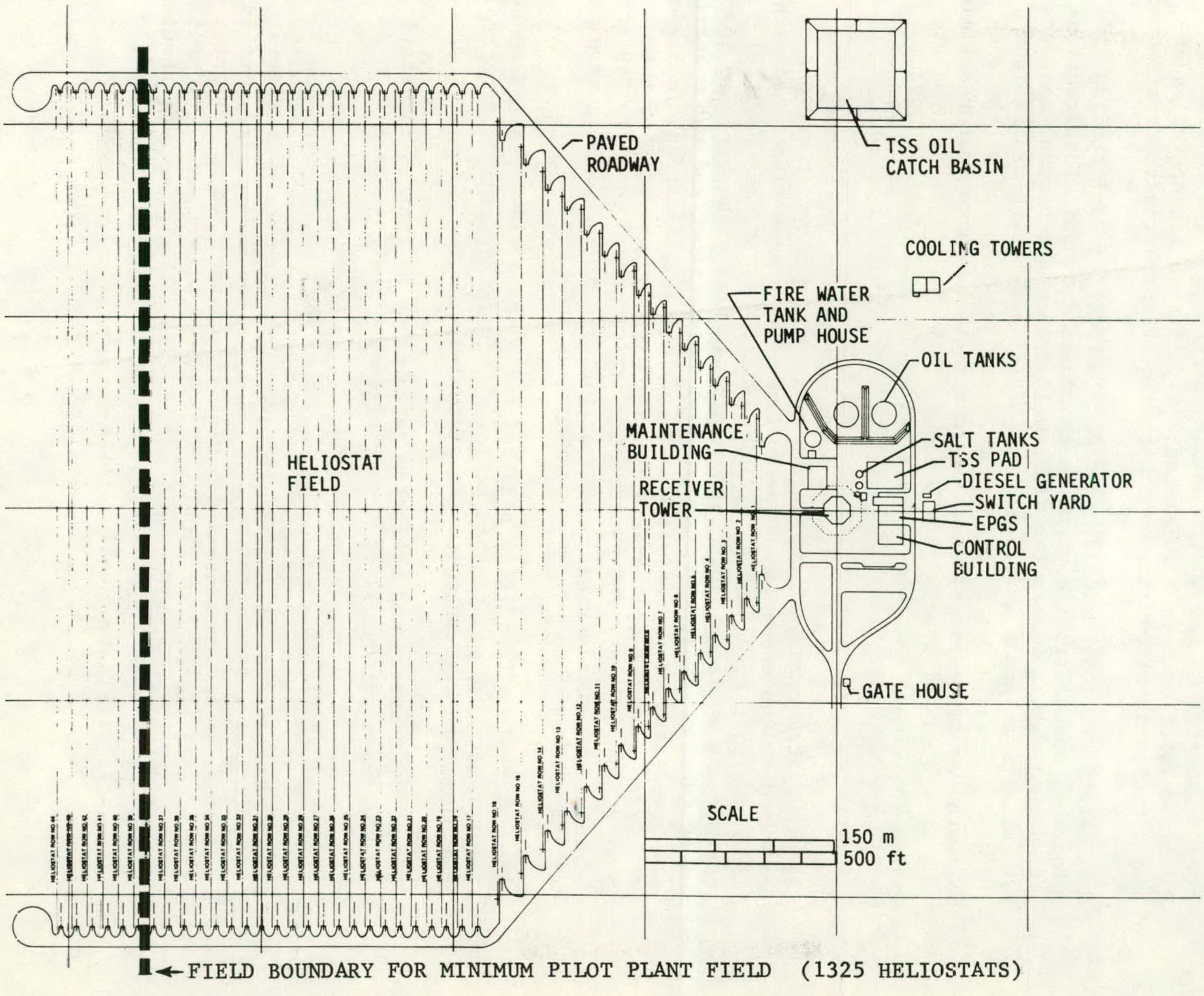

Figure II.A-2 Pilot Plant Plot Plan

achieve a one-for-one performance correlation with the commercial plant. This can be achieved by the addition of eight heliostat rows. The cost of the additional heliostats is given in Section IV and relates only to acquisition, installation and operation of the additional heliostats; no other Pilot Plant hardware is affected.

Heliostats are geometrically spaced to minimize mutual shading and blocking, and to provide maintenance access to each. The locations of the heliostats within the field will follow the natural contours of the site at grade level so that special contouring of the land is not required, Paved turn-around areas are provided at the ends of each row but surfaced roads are not required throughout the field due to the use of special low pressure tires on all-terrain maintenance vehicles. The total area required for the field of 1325 heliostats is approximately 244,000 m^2 (60 acres).

The locations of the electrical power generation and thermal storage subsystem components with respect to the receiver tower are governed by the economic and performance advantages associated with minimum piping runs, and by minimum isolation distances required for storage media fluids. Thermal storage heat exchangers are located in close proximity to both the receiver tower and the electrical power generation subsystem. The molten salt is stored in 5.79m (19.0 ft) diameter cylindrical tanks located at the edge of the heat exchanger pad. The hydrocarbon oil is stored in 17.7m (58 ft) diameter spherical tanks located at the edge of the plant general arrangement.

The other plant facilities required for a stand alone plant such as fire protection, maintenance buildings, administration, and control buildings are also shown on the plot plan.

Pilot Plant system and subsystem performance is treated in detail in Volumes I through VI of this Preliminary Design Report.

2. Collector Subsystem

The 1325 heliostat collector field configuration shown in Figure II.A-3 extends 457m (1500 ft) in the north-south direction, and is a maximum of 660.4m (2166.6 ft) wide (to centerlines of outermost heliostats). Spacing of rows and columns vary as a result of heliostat spacing optimization analyses to reduce the effects of shading and blocking and to keep maximum heliostat-to-receiver projection distances within acceptable limits.

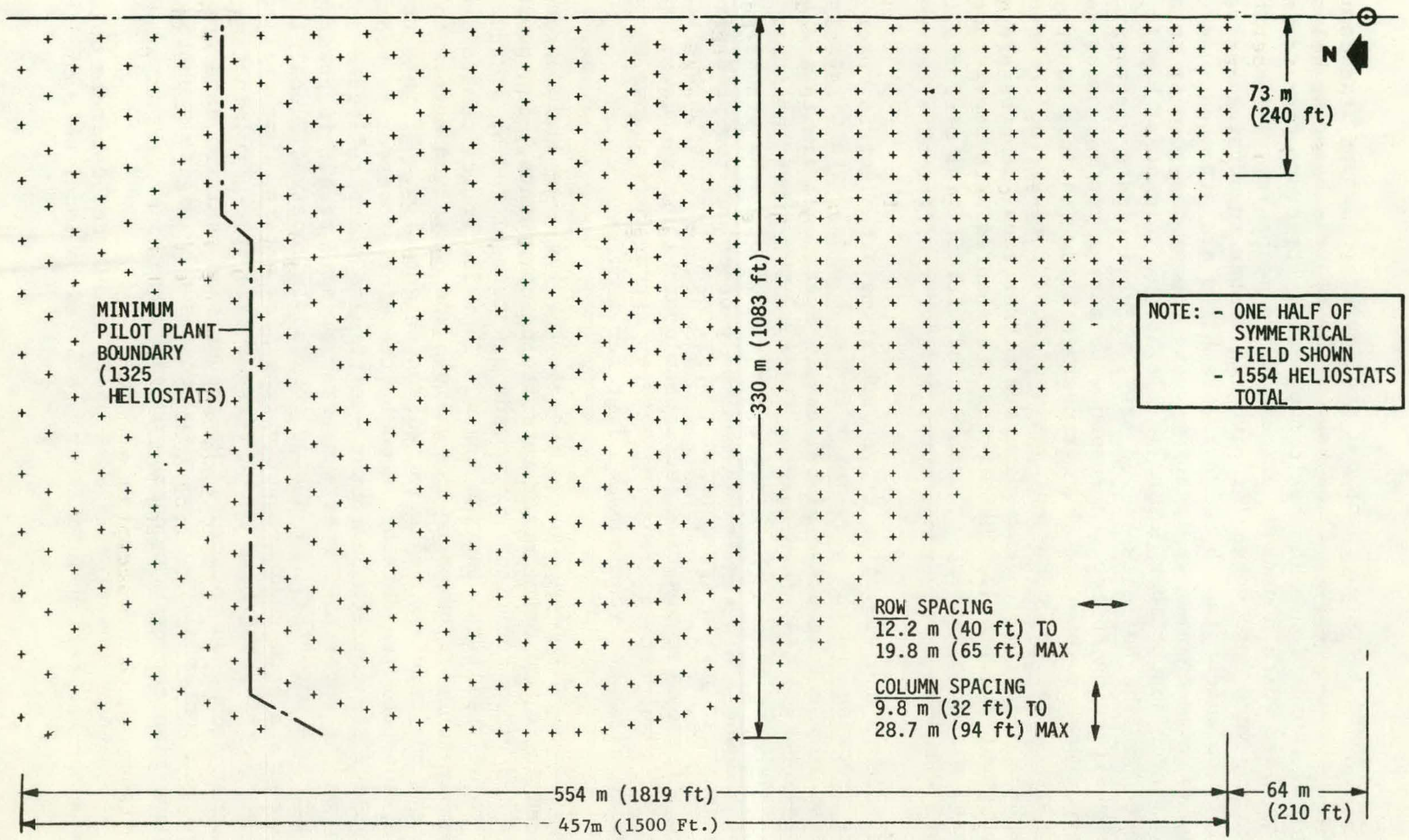

Figure II.A-3 Collector Subsystem Configuration/Dimensions

All heliostats are of identical configuration except for mirror focal lengths. Figure II.A-4 shows the major subassemblies and a typical foundation. The basic supporting structure consists of a fixed base which houses an azimuth drive mechanism, a (azimuth) rotating yoke, and a tubular pivoting member supporting six bar joists to which nine (9) mirror assemblies are attached. An elevation drive mechanism is located at the top of the yoke to rotate the mirror support bar joists in elevation. A control box is mounted on the heliostat fixed base, which includes electronics for positioning control in response to master control and local microprocessor inputs. The mirrors are 2.13m (84 in.) square, and are by design, permanently fixed focus for particular areas of the heliostat field. Five discrete mirror focal lengths are used throughout the field. The mirrors are mounted with provisions for manual mirror alignment of each mirror, for initial mirror alignments with the receiver aperture, and for realignment after repairs.

The azimuth and elevation drive mechanisms are electric motor driven (one tracking and one slew motor for each axis) with direct gear drives to the respective gimbal axes. Rotational limits are $\pm 110^{o}$ in azimuth and 180^{o} in elevation (tilt). The stowed position of the heliostat places the mirrors horizontal with the ground surface, facing down. This results in maximum protection from precipitation and blowing particulate matter; reduces wind loading on the structure and provides positive, safe beam control for shutdown. The bar joist supports and spacing between mirror rows allows the mirrows to clear the yoke support legs for stowing.

The local electronics control subassembly includes a microprocessor, stored logic and drive motor interfacing components. Sun position data and other positioning commands are transmitted by a hardwire net to all heliostat control boxes. The electronics control subassembly controls power to the aximuth and elevation motors to achieve the required heliostat mirror orientation. If in a tracking mode, sun position data are used by the microprocessor to repeatedly calculate the correct heliostat position to place reflected solar flux on the receiver. Position error signals result in power pulses to activate motor(s). If a stow command is received, local logic implements a stow sequence activating slew motors, that will cause the reflected solar beam to traverse a safe track, culminating in a mirror face down position. Heliostat axes position data are furnished continually to the microprocessor by digital, photo-optical position sensors (encoders) on each axis.

The heliostat foundation is a stepped, reinforced concrete column; dimensions and design details are tailored to local soil conditions.

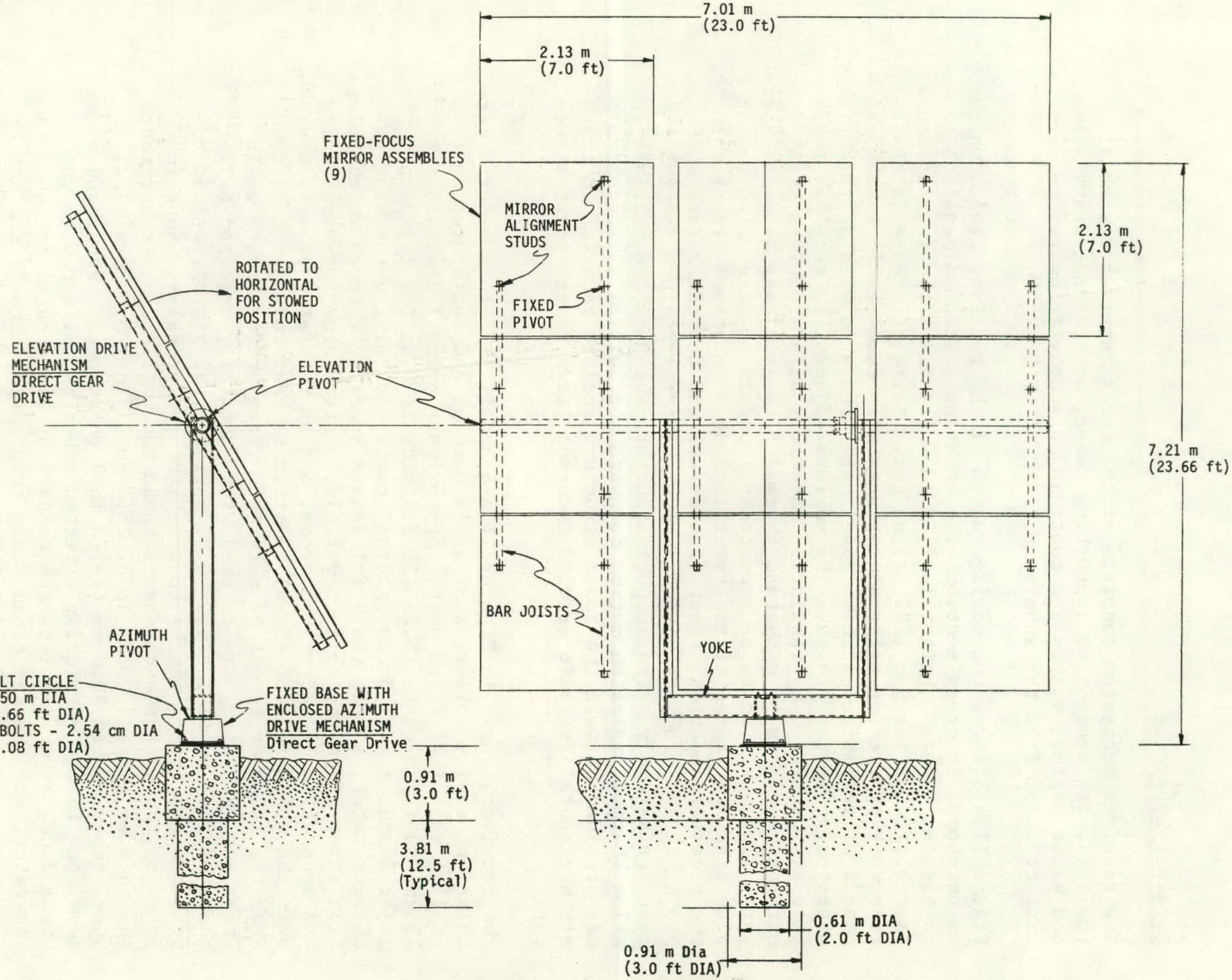

Figure II.A-4 Heliostat Configuration

3. Receiver Subsystem

The receiver subsystem consists of the solar receiver assembly (boiler), its respective supporting tower, and the necessary steam and water piping, valves and controls to supply feedwater to, and extract steam from the subsystem.

Figure II.A-5 shows the configuration of the receiver tower, which is octagonal in cross section with constant section dimensions top to bottom. Overall height is 112m (367 ft) and a receiver aperture is centered at the 90m (295 ft) height. Basic structure is a steel framework covered on external surfaces with commercial, corrugated panels of galvanized steel. Panels are precoated with a protective asbestos/polymeric finish. The regions adjacent to receiver aperture are protected by insulation materials with stainless steel external surfaces to withstand thermal flux spillover from the aperture. The tower rests on a concrete foundation, also octagonal in plan view. Features of the tower include a personnel elevator to the receiver location, riser (feedwater) and downcomer (steam) piping to and from the boiler, and a support structure for the receiver assembly. The support structure suspends the receiver to allow thermal expansion motion downward and laterally. Snubbers are provided between the tower structure and the receiver to transmit horizontal (seismic or wind induced) loads to the tower structure.

The receiver, shown in Figures II.A-6 and II.A-7, ia a natural circulation, cavity boiler, similar in concept and configuration to a small fossil fuel fired unit. Approximate overall dimensions are 19.2m (63 ft) high by 15.2m (50 ft) wide by 9.8m (32 ft) deep. The major features include an internal cavity containing the heat exchanger tubes, a 7.5m (24.6 ft) square aperture through which solar flux enters from the collector field, a steam drum for manifolding and separation of water from steam, and an insulated closure door over the aperture (not shown) to minimize heat loss and cool down when the receiver is out of service. Three active cavity walls (rear and two sides) are covered with vertically oriented boiler tubes of 38.1 mm (1-1/2 in.) O.D. carbon steel piping, welded together along their lengths to constitute water walls. Superimposed on the center sections of these tube walls are six horizontal superheater platens, made up of 25.4 mm (1 in.) O.D. stainless steel tubes spaced 28.6 mm (1-1/8 in.) on centers. Saturated steam developed in the vertically oriented tubes is delivered to the steam drum, water droplets are removed by centrifugal action in a separator, and the saturated steam then passes through the hotter superheater tubes to develop final steam conditions for use in the turbine.

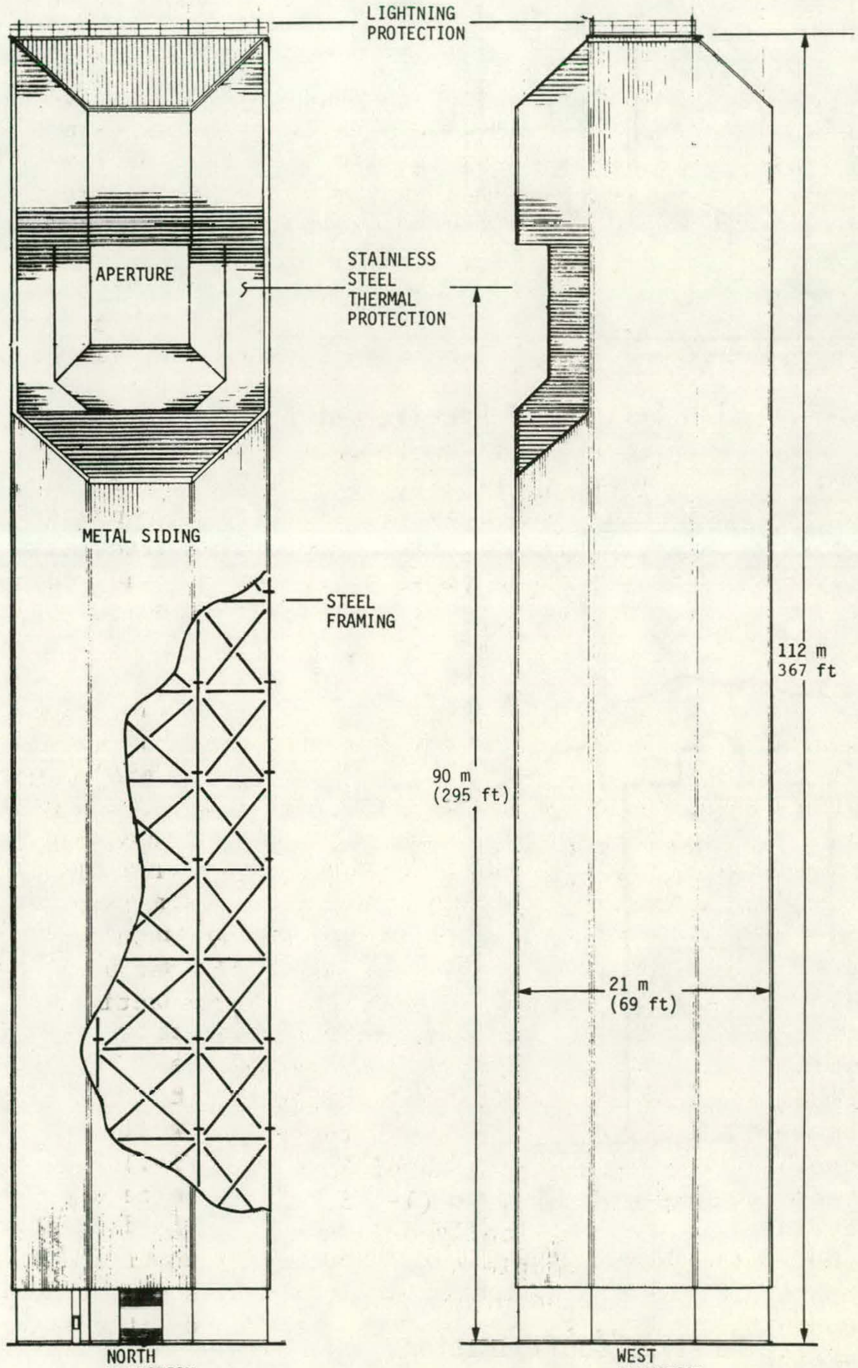

Figure II.A-5 Receiver Tower Configuration

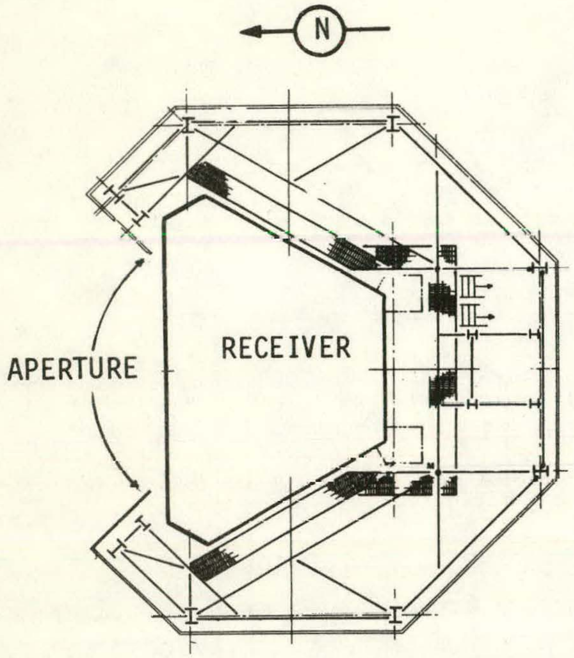

Figure II.A-6 Plan Section of Receiver at Aperture

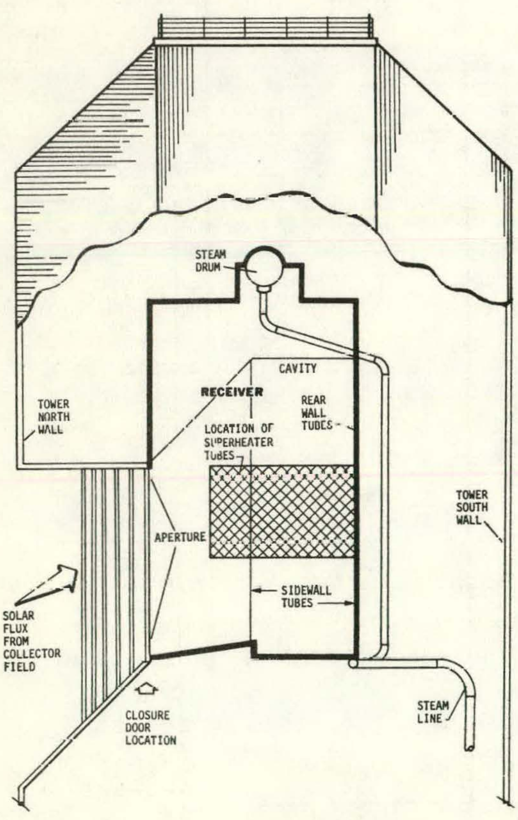

Figure II.A-7 Receiver Configuration

The inner surfaces of the receiver cavity not lined with boiler tubes (the floor, roof and portions of the side walls) are either steel coated with reflective material or refractory insulating materials, depending on the intensity of incident solar flux on the particular surface. The outside surface of the entire cavity, as well as the steam drum and exterior piping, is encased in insulation.

4. Thermal Storage Subsystem

The Plant Thermal Storage Subsystem (TSS) consists of insulated tanks for containment of the thermal storage (fluid) media, heat exchangers to transfer thermal energy to and from the storage media, and the necessary piping, pumps and control elements to satisfy intra-subsystem interface requirements and to interface with other Pilot Plant subsystems. The major interfaces with the Receiver and EPGS subsystems are: charging steam (from the receiver to place thermal energy into storage); admission steam (delivered to the admission port of the turbine when extracting energy from storage); feedwater supply (from the EPGS conditioning units to the TSS boiler when extracting energy from storage) and condensate return (from the TSS condenser to EPGS feedwater conditioning units).

Figures II.A-8 through II.A-11 show plan and elevation views of the major storage and heat exchanger elements located generally south and east of the receiver tower area. Heat exchanger components are located on a paved pad area; oil storage tanks are positioned in an earthen oil spill containment area.

The two oil tanks are spherical in configuration, 17.6m (57.8 ft) in diameter, with an overall height above ground level of 20m (66 ft). A total quantity of 2336 m^3 (82,500 ft^3) of oil is stored in the two tanks. Oil spill containment dikes are configured to confine an oil spill to the vicinity of a single tank, and to route spills to a remote earthen catch basin 236m (775 ft) east of the tanks.

The two salt storage tanks are cylindrical in section, with hemispherical top and bottom domes. Tank diameter is 5.8m (19 ft), height is 8.1m (26.5 ft), and they contain a total of 120 m^3(4,260 ft^3) of thermal storage media.

Liquid nitrogen storage is provided to supply gaseous nitrogen to occupy all ullage space in both the oil and salt circuits, for improved safety and to help control deterioration of thermal storage media properties.

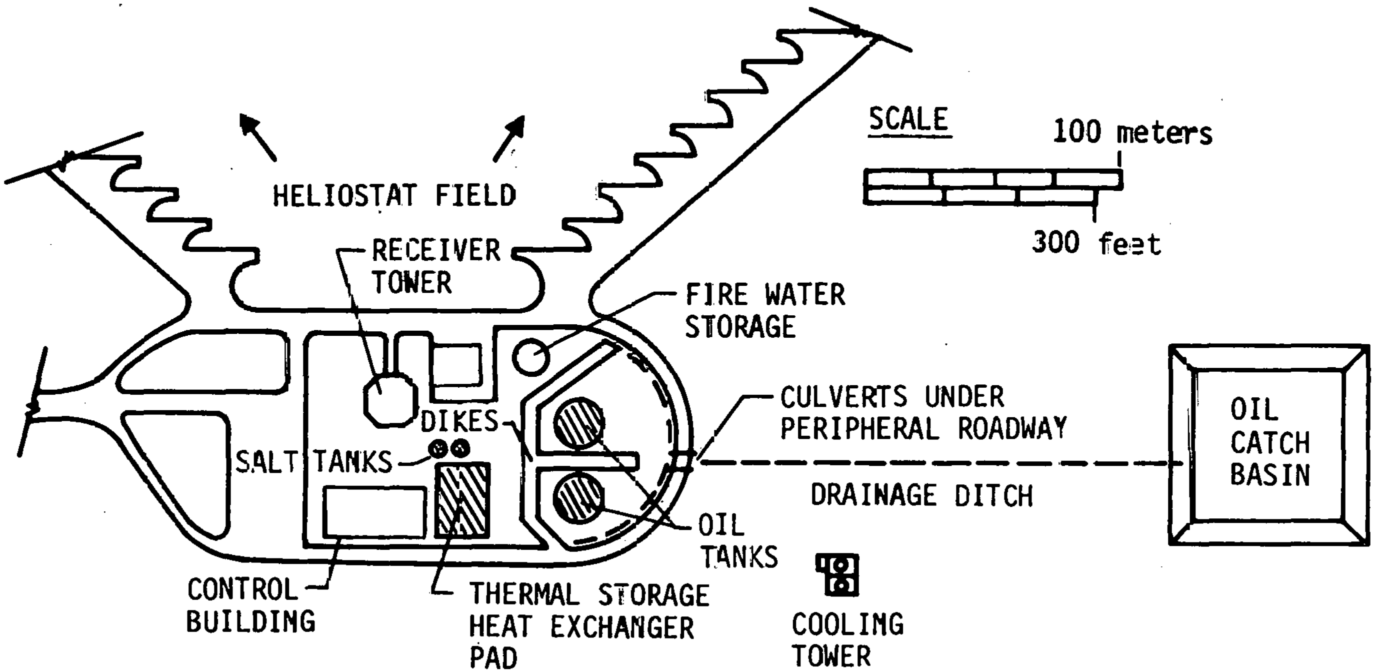

Figure II.A-8 Thermal Storage Subsystem, General Arrangement

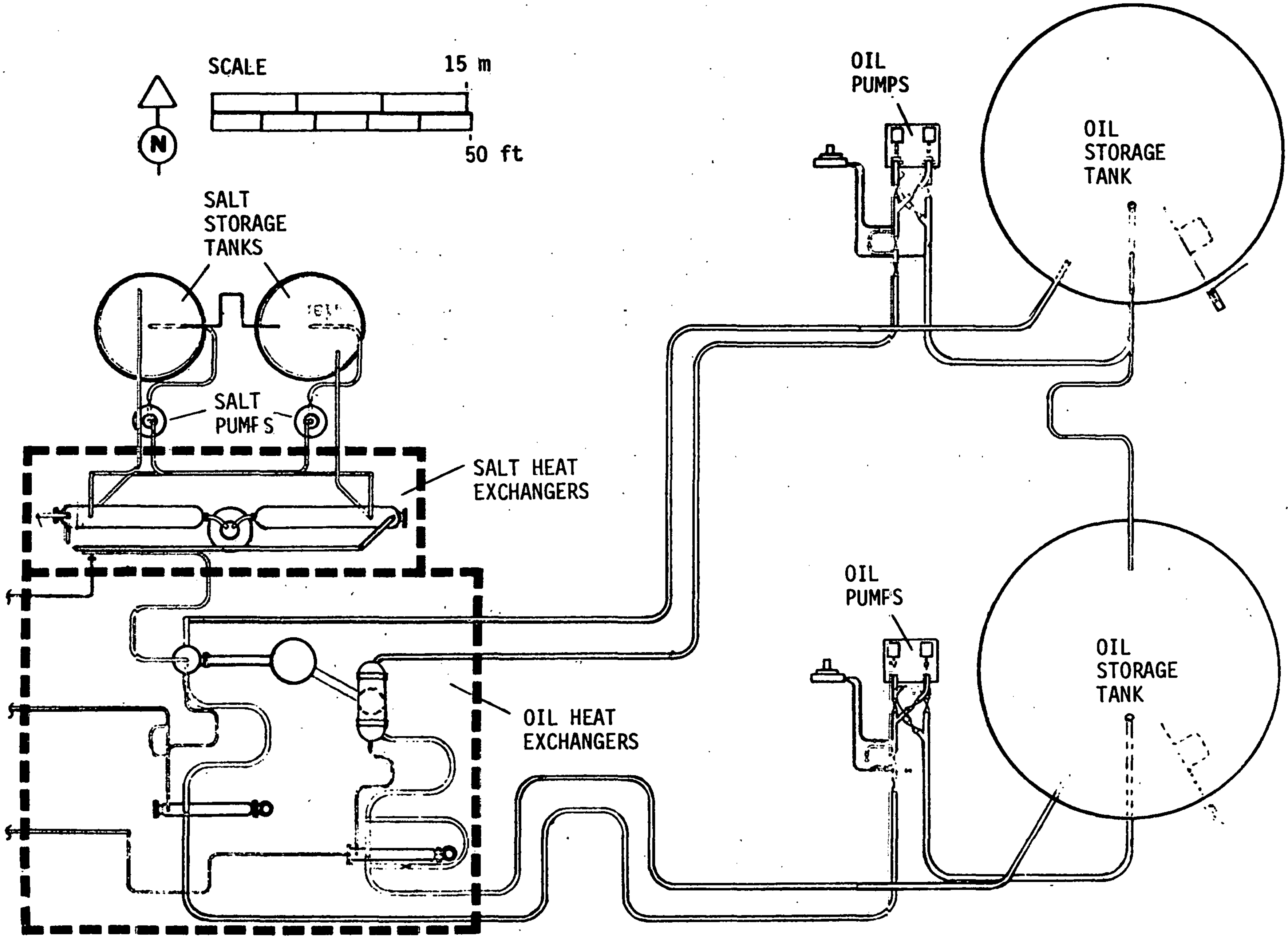

Figure II.A-9 Thermal Storage Subsystem - Plan View of Components

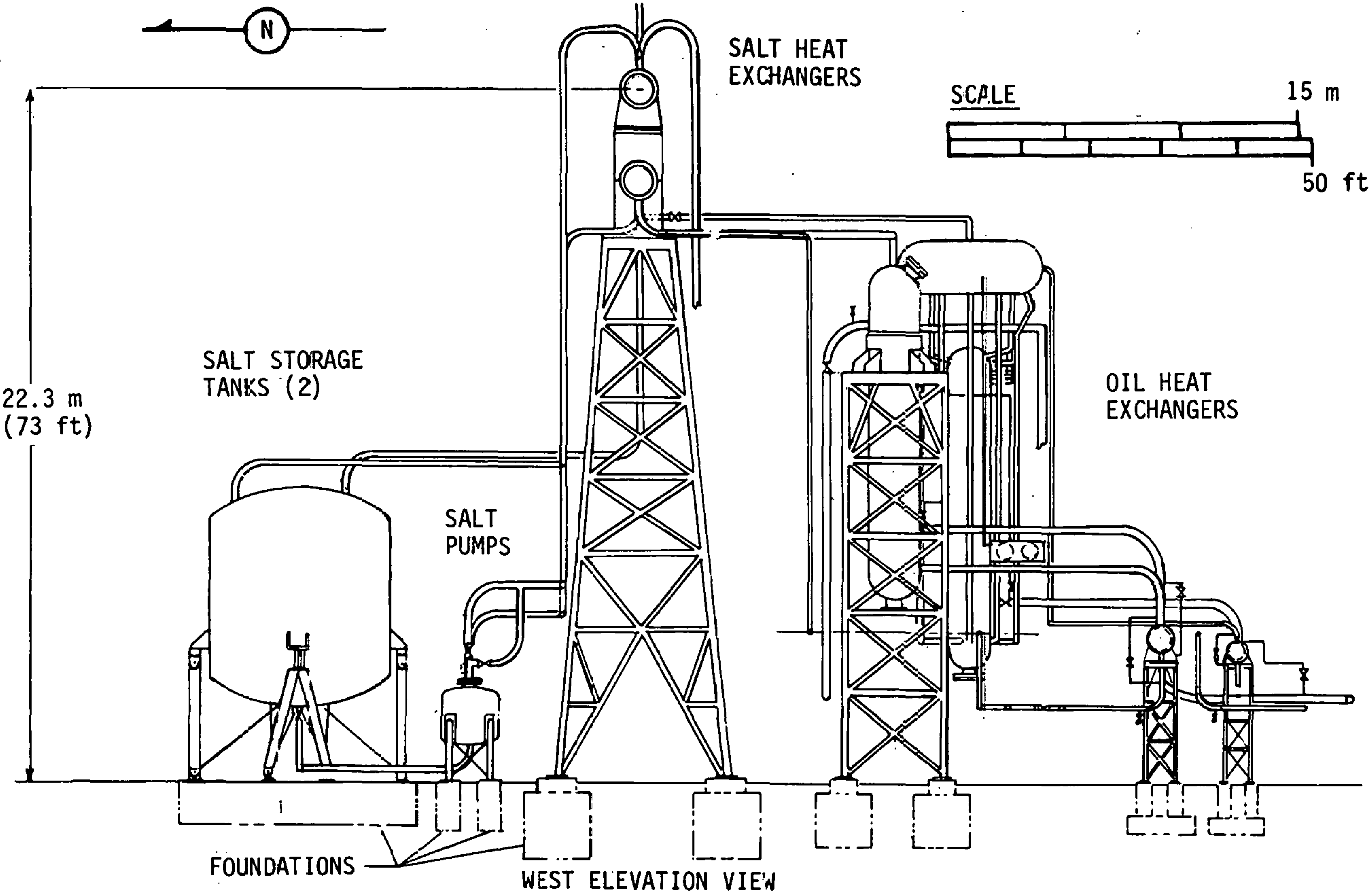

Figure II.A-10 TSS Salt Storage and Heat Exchangers

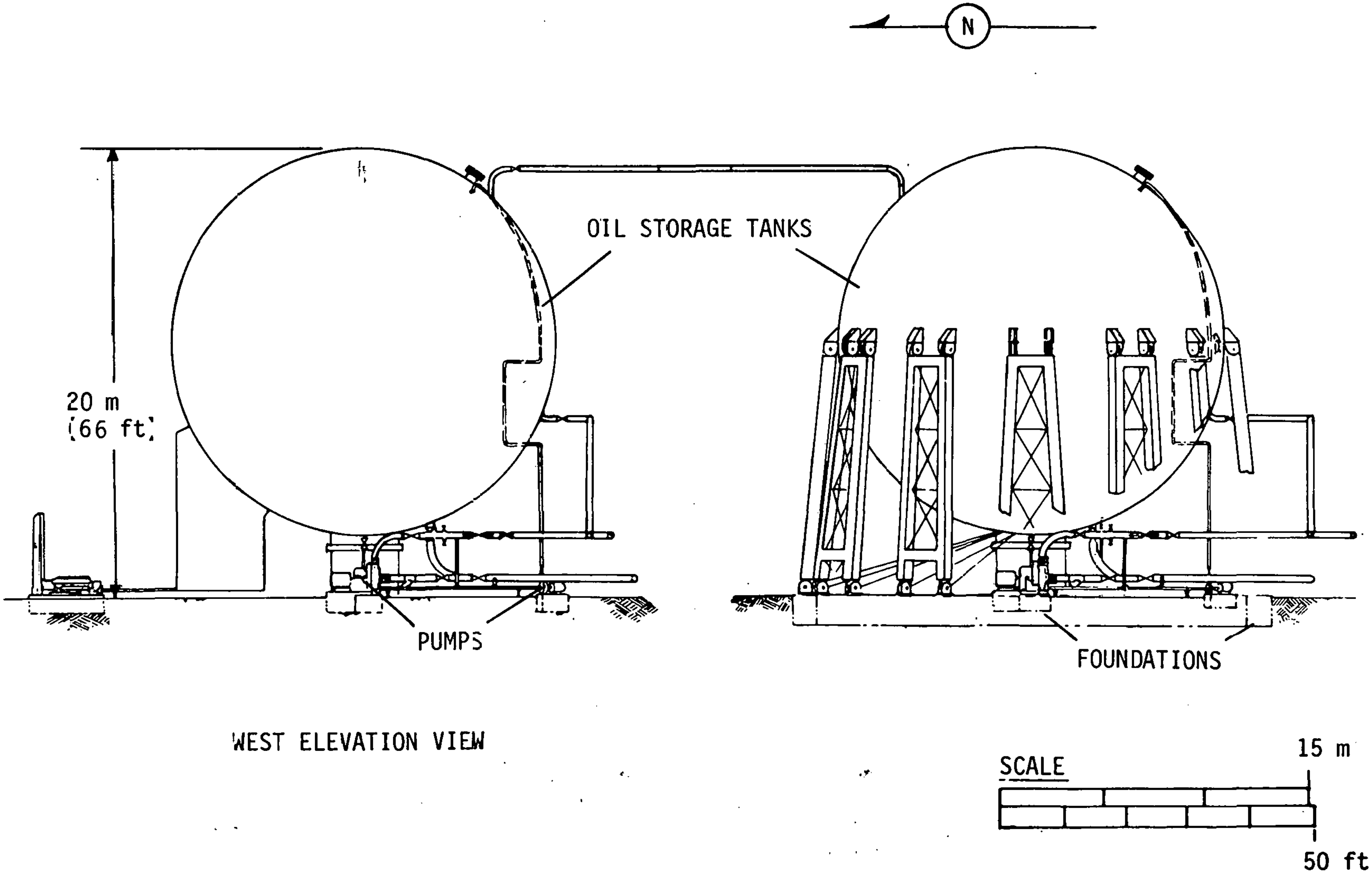

Figure II.A-11 TSS Oil Storage Tanks

Six (6) heat exchangers are employed in the subsystem, including a preheater, boiler and superheater in the admission steam (discharging) circuit; and a desuperheater, condenser and subcooler in the charging circuit. This configuration permit simultaneous charge and discharge of the subsystem. Both the salt and oil storage media are used in their fluid phases; thermal storage is accomplished over ranges of temperature changes (sensible heat).

The thermal storage salt is an inorganic compound consisting of an eutectic mixture of 40% $NaNO_2$, 7% $NaNO_3$, and 53% KNO_3, with a melting point of 415 K (288°F) It is available as a commercial product, and has been in common use for heat transfer applications for over 35 years. The thermal storage oil is a commercial heat transfer fluid identified as EXXON Caloria HT 43. It is formulated from a stable paraffin base petroleum, fortified with a high temperature oxidation inhibitor. The material has the general appearance and properties of lubricating oil, presenting no toxicity hazards or special handling requirements. It has a flash point of 420°F and a pour point of +15°F.

5. Electrical Power Generation Subsystem (EPGS)

The EPGS includes the turbine-generator set, feedwater pumping and conditioning equipment, condenser, wet cooling tower, steam and water piping, and the necessary valves and control elements for subsystem operation. Figure II.A-12 shows the general locations of the EPGS major components. An elevation detail of the EPGS building is shown in Figure II.A-13. The turbine-generator set is located on an open air deck, supported by an isolated, pedestal, concrete foundation/support structure. Ancillary equipment, including feedwater pumps and four (4) feedwater heaters, is installed in an adjacent, three-level building, east of the turbine deck. External siding, where used, is 18 ga. corrugated steel with a prefinished protective surface.

Cooling water for the condenser is piped to and from a two unit wet (evaporative) cooling tower (Figure II.A-14) located approximately 180m (600 ft) east of the condenser. The location of the cooling tower was chosen in conjunction with Barstow, California, wind data to place it downwind of the heliostat field for the large majority of the time. Water droplet fallout from the cooling tower plume onto the mirror surfaces is thus avoided during prevailing wind conditions. Fallout deposition during unusual wind conditions is minimized by cooling tower design (to reduce water droplets in the plume), and by the 168m (550 ft) separation distance to the nearest heliostat.

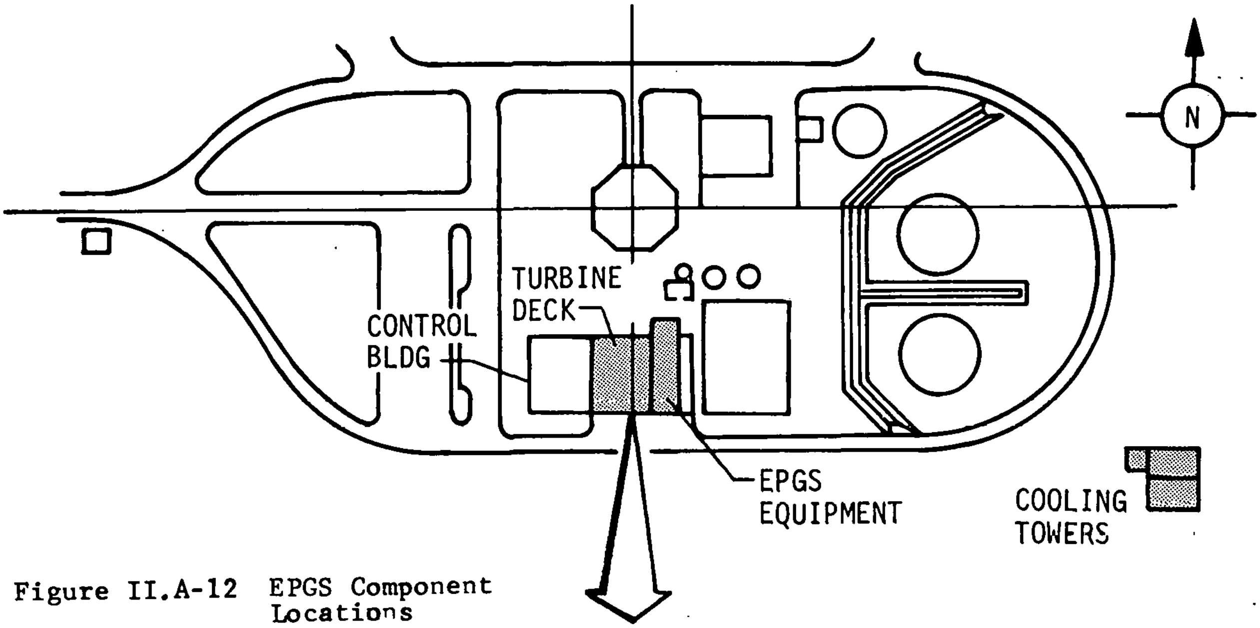

Figure II.A-12 EPGS Component Locations

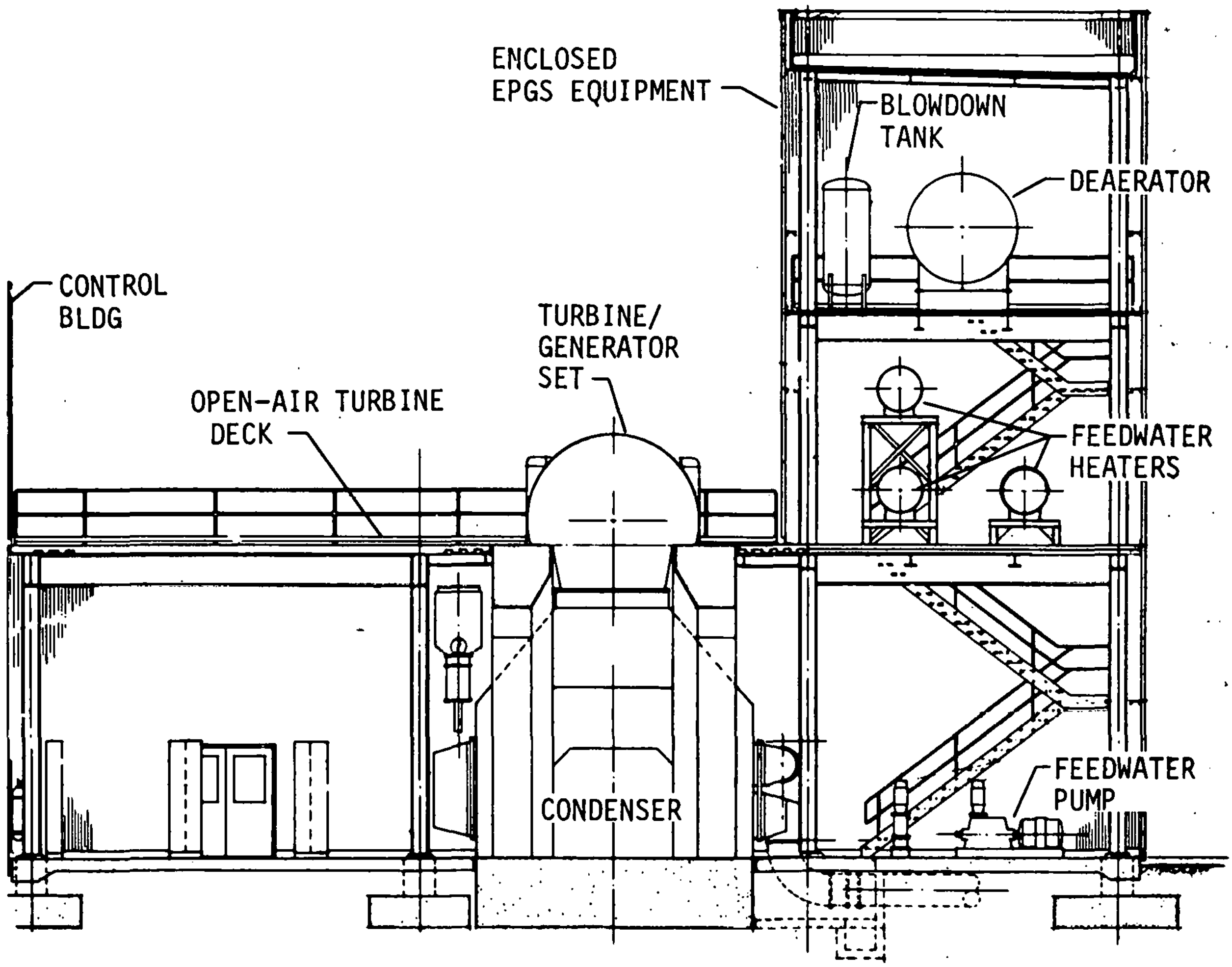

Figure II.A-13 EPGS Building, South Elevation

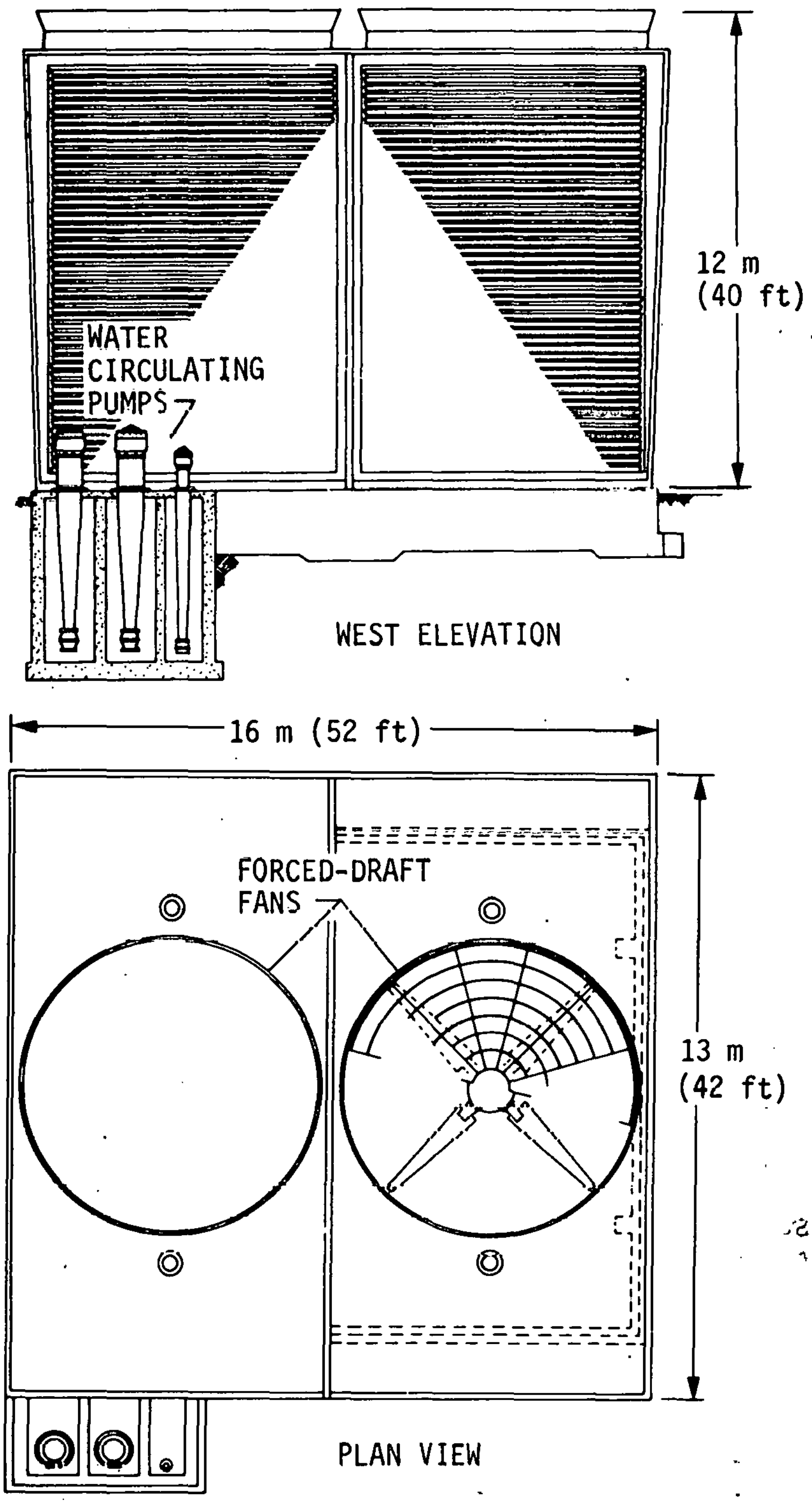

Figure II.A-14 Pilot Plant Cooling Tower

EPGS Turbine

The turbine selected for the Pilot Plant application is a General Electric admission type unit, rated at 12.5 MW_e output, and commercially available with only minor modifications, mainly relating to the admission gear. Figure II.A-15 shows a cross section of a typical unit of this size and type. It is a single flow, non-reheat configuration with an electrohydraulic control system operating partial arc control valves at both the main and admission steam inlets.

The 12.5 MW_e standard size closely matches that required to supply the specified 10 MW_e net, plus the plant auxiliary loads. The admission port improves operating efficiency at reduced loads from thermal storage steam. Under these lower temperature/pressure conditions, steam is admitted four stages downstream of the main steam admission point.

Four conventional uncontrolled extraction points will be provided downstream of the admission valve gear in the turbine casing for use in feedwater heating and conditioning.

6. Master Control Subsystem

As in a conventional power plant, operation of the Solar Thermal Pilot Plant will be carried out by the control operators. The operators are assisted in this important function by the pilot plant master control system (MCS). The MCS is modeled after a typical control system in a fossil fuel power plant and is comprised of the subsystem controls, the plant control system element, and the data handling system. By industry standards, the plant is small (10 MW_e), and elaborate controls are not required. Figure II.A-16 is a layout of the Pilot Plant control room, which is located in the control building adjacent to the EPGS building. All master control, subsystem control, and data handling equipment is located in this control room.

The Master Control Subsystem enables the control operators to safely control plant operations and is characterized by the following performance features.

a. Controls are maximized within subsystems, and subsystem control is essentially autonomous.

b. The MCS has emergency control capability to respond immediately to subsystem alarm conditions (by subsystem control elements), and to initiate a response to system level alarm conditions.

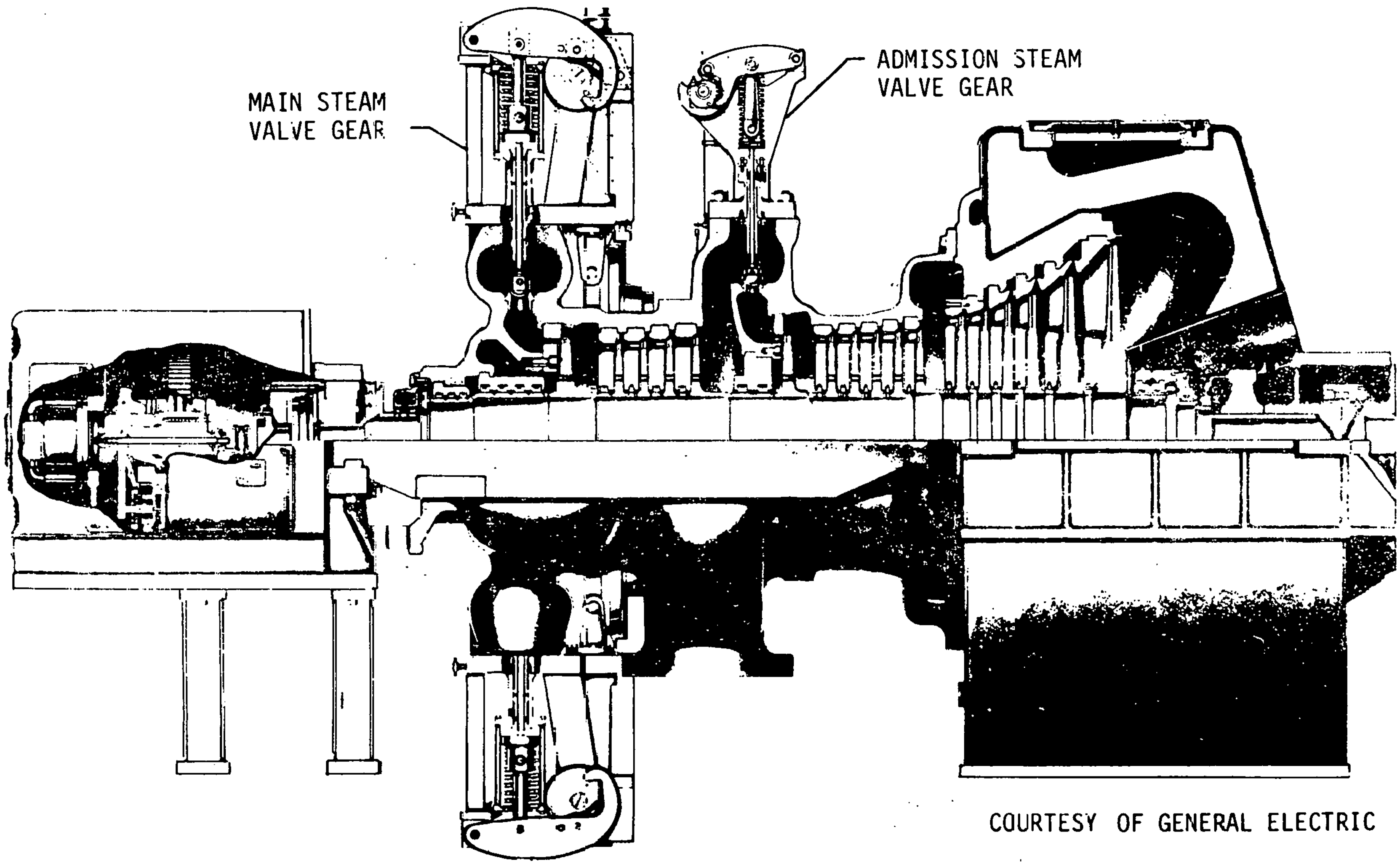

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Figure II.A-15 12.5 MW Pilot Plant Turbine

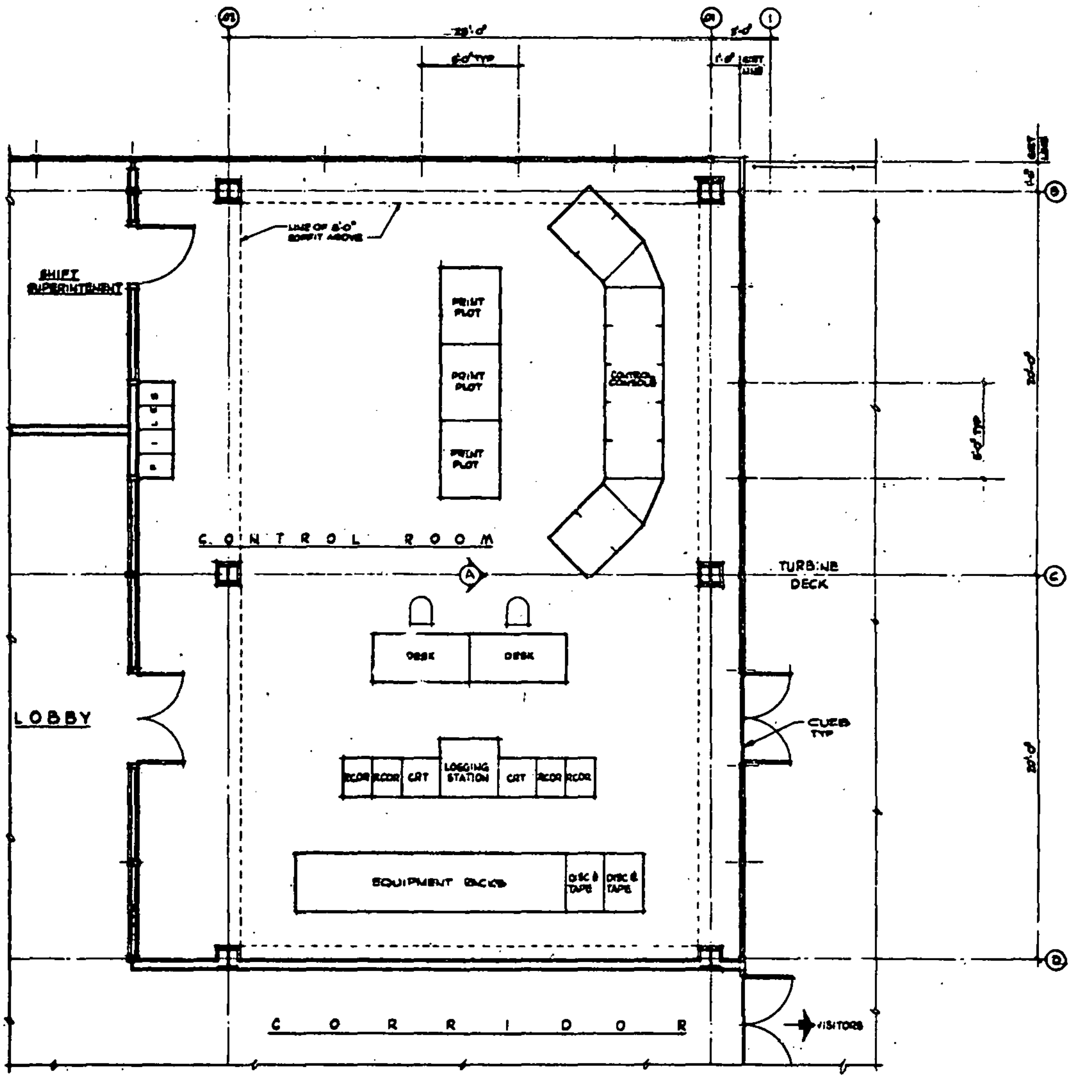

Figure II.A-16 Control Room Layout

c. The MCS provides a capability to coordinate system level operations by control through subsystem control elements.

d. Integrated Pilot Plant operations are accomplished by manually implementing written procedures which define operational profiles and sequences for steady state mode control and for transition between modes.

To the maximum extent possible, plant control capabilities reside within the subsystem controls, and these controls are integrated by a system level control element designated the plant control system (PCS). Subsystem controls perform the majority of the plant control functions inasmuch as these controls have been designed to maintain stable operations over the wide range of conditions expected during a plant's daily operational cycle. The receiver subsystem (RS), thermal storage subsystem (TSS), and electrical power generation subsystem (EPGS) controls are all implemented with conventional hardwired logic and controllers. The heliostats are controlled by a minicomputer, and that control represents the only computer controlled element of the pilot plant. Because of the critical nature of heliostat control, the collector subsystem control minicomputer is backed up by the data handling system (DHS) minicomputer.

The Plant Control Subsystem (PCS) coordinates the subsystem controls and provides a system level emergency response capability to the operators. The MCS encompasses all subsystem control elements, the PCS as well as the data handling and data logging functions. The data handling system has been designed to be completely independent of the controls; if the DHS were removed, the plant control activities would continue unaltered.

A major portion of the pilot plant's data handling will be implemented using a minicomputer with disc mass storage capabilities. This approach recognizes the capabilities of digital computer systems to handle efficiently the moderate to large quantities of data generated by the Solar Thermal Pilot Plant in a cost effective manner. In addition to using the digital computer, some of the plant's data display and "logging" will be accomplished using strip chart or other pen recorders.

The data handling system computer functions as the backup to the CS control computer. If a CS control computer anomaly is detected, the data handling activities are suspended while the collector subsystem control software is loaded on the redundant computer by the control operator, and heliostat control is continued from the back-up machine. The plant's automatic data logging capability is diminished until the CS control computer capability has been restored.

B. COMMERCIAL PLANT

1. General Description

A plot plan for the 150 MW_e Commercial Plant is shown in Figure II.B-1. The Commercial Plant includes 15 identical heliostat fields with their associated 15 (identical) receivers and receiver towers. Common Electrical Power Generating and Thermal Storage Subsystems are located in two triangular areas among the heliostat fields. The locations of these subsystems and of the cooling towers are the result of piping run studies to reduce costs and to optimize performance, consistent with the need to locate the cooling towers downwind of the heliostat fields.

Note from the plot plan that access roadways are provided around the perimeters of all heliostat fields for required maintenance access.

Each collector field and its associated receiver and tower constitutes one module of the Commercial Plant, capable of independent incremental steam generation for delivery to the EPGS or to the TSS for storage. Each collector field requires 1554 heliostats for a plant total of 23,310. The plot plan is oriented so that each heliostat field is positioned north of its respective receiver tower. Each commercial collector/receiver module is identical to the recommended pilot plant subsystems.

Summary subsystem descriptions are presented below; details and system and subsystem performance data are included in Volumes I through VI of the Preliminary Design Report. Performance data is also presented in Section VI of this report.

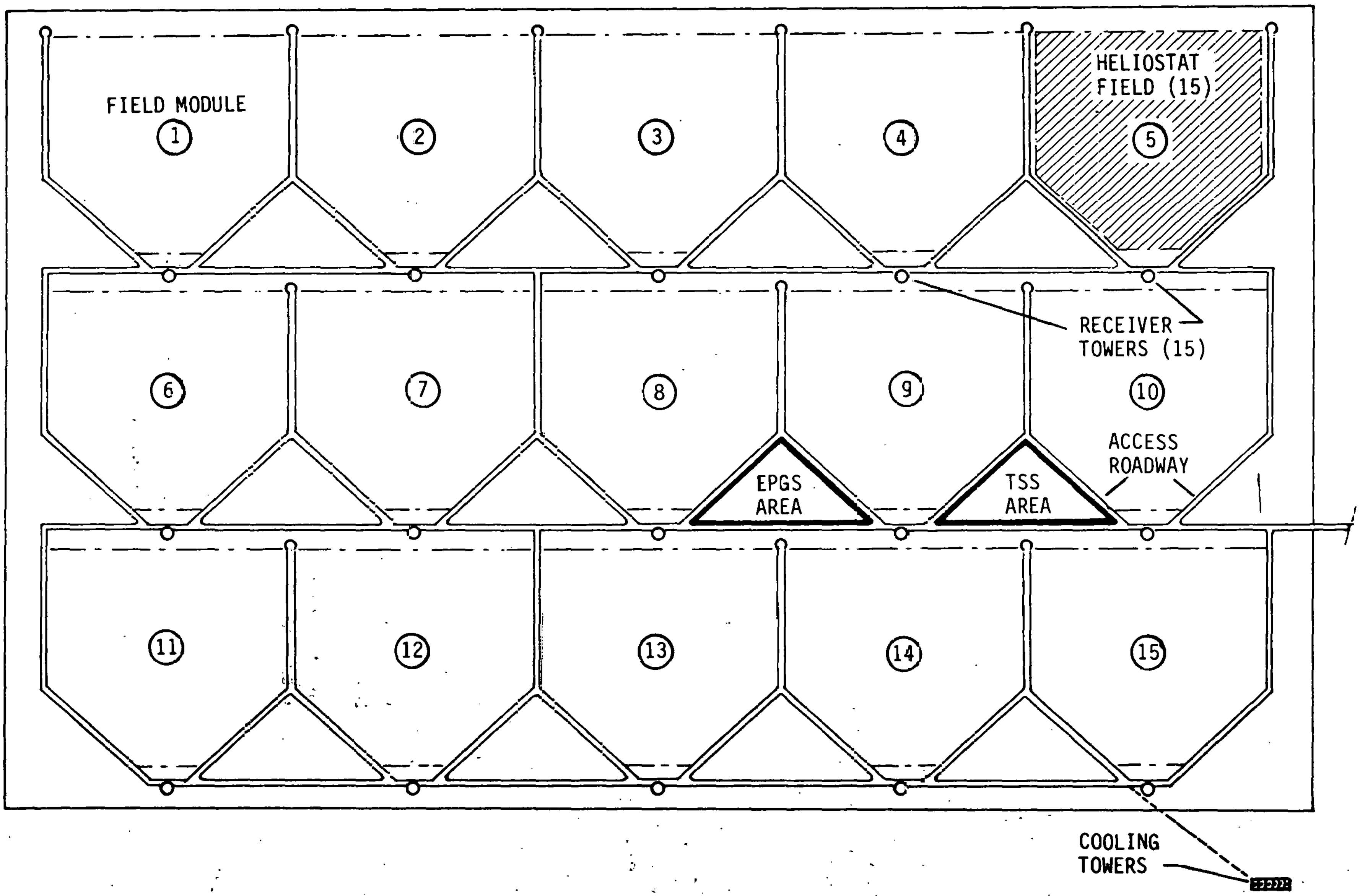

Figure II.B-1 Commercial Plant - General Arrangement

2. Collector Subsystem Module

Each of the collector fields, constituting one module of the commercial plant, includes 1554 heliostats arranged as shown in Figure II.A-3. The field extends 618.4m (2029 ft) north of the receiver tower aperture, and is a maximum of 660.4m (2166.6 ft) wide (to centerlines of outermost helistats).

3. Receiver Subsystem Module

The Commercial Plant includes 15 receivers mounted on receiver towers located at the south edges of the respective 15 heliostat fields. Each receiver, tower and the associated piping and module control elements are identical with the Pilot Plant receiver subsystem, described in Section II.A.3.

4. Thermal Storage Subsystem (TSS)

The Commercial Plant Thermal Storage Subsystem (TSS) consists of insulated tanks for containment of the thermal storage (fluid) media, heat exchangers to transfer thermal energy to and from the storage media, and the necessary piping, pumps and control elements to satisfy intra-subsystem interface requirements and to interface with other Commercial Plant Subsystems. The major interfaces with the Receiver and EPGS subsystems are: charging steam (from the receiver to place thermal energy into storage); admission steam (delivered to the admission port of the turbine when extracting energy from storage); feedwater supply (from the EPGS conditioning units to the TSS boiler when extracting energy from storage) and condensate return (from the TSS condenser to EPGS feedwater conditioning units).

Figure II.B-2 shows a plot arrangement for the major storage and heat exchanger components located within a single, 800,000 m^2 (20 acres) triangular area within the overall commercial plot. A total of seven (7) low temperature (oil) storage tanks, and two (2) high temperature (salt) tanks are required.

A liquid nitrogen storage tank shown in the figure supplies gaseous nitrogen to occupy all ullage space in both the oil and salt circuits, for improved safety and to help control deterioration of thermal storage media properties. The figure does not show piping details, valves, or pumps.

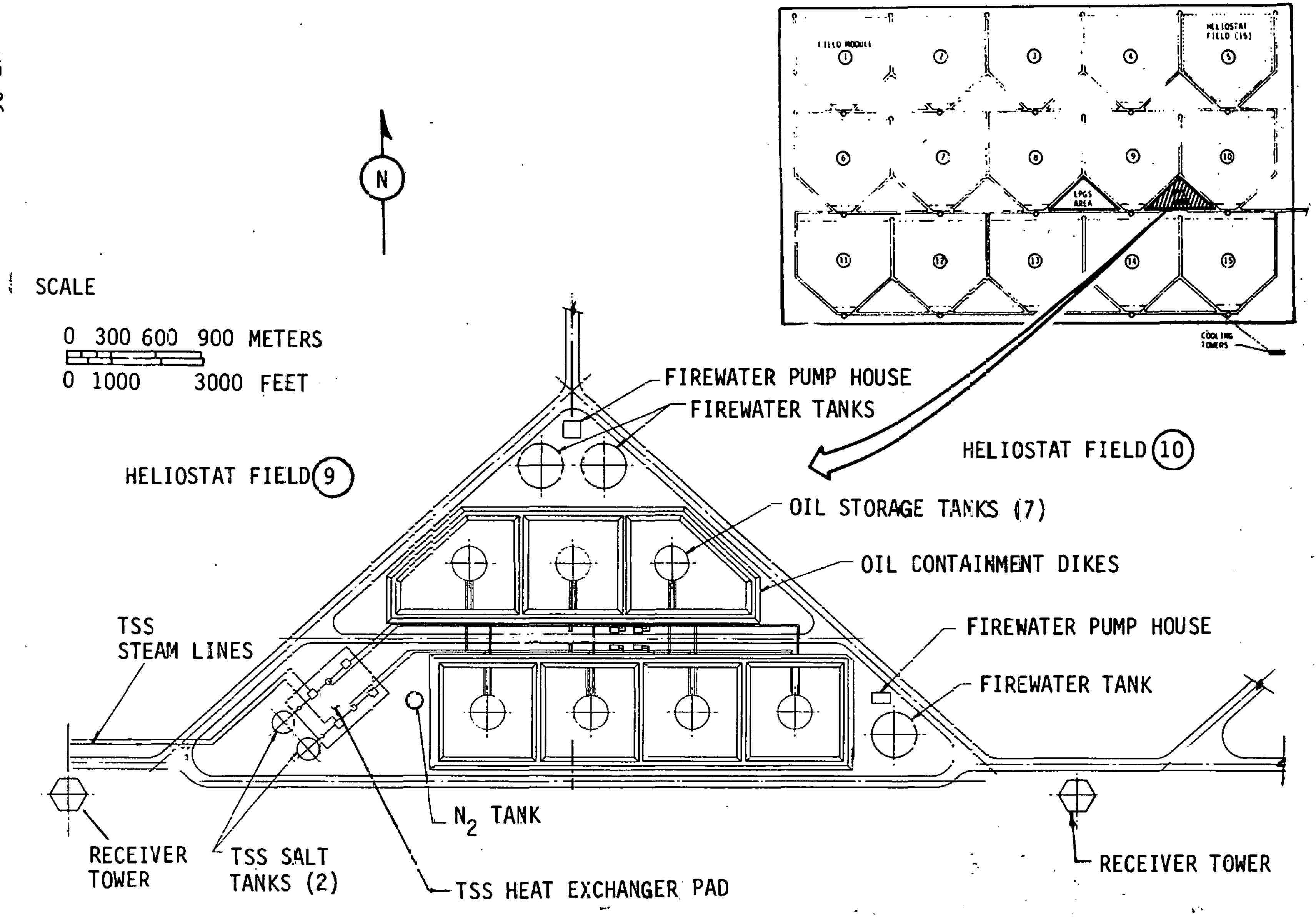

Figure II.B-2 Thermal Storage Subsystem (TSS)

Oil tanks are spherical, 23.1m (75.8 ft) in diameter, with a maximum elevation of approximately 27.4m (90 ft) above ground level. A total of 32,800 m^3 (1.16×10^6 ft^3) of thermal storage media are stored in the seven tanks. Each of the tanks is surrounded by an earthen dike system, typically 61m (200 ft) square, to safely contain accidental spills. The containment basins formed by the dikes are sized to hold the entire capacity of the respective tanks.

The salt storage tanks are spherical in configuration; tank diameter is 15.8m (52 ft). They contain a total of 1560 m^3 (55,100 ft^3) of thermal storage media.

Six (6) heat exchangers are employed in the subsystem, including a preheater, boiler and superheater in the admission steam (discharging) circuit; and a desuperheater, condenser and subcooler in the charging circuit. Salt storage is used to either supply superheat to delivered steam (discharging), or to remove superheat from steam generated from collector field energy (charging). Oil storage is used to either deliver saturated steam to the superheater (discharging), or to remove heat from saturated steam from the desuperheater (charging). Pumps and piping are configured to permit simultaneous charging and discharging of the thermal storage subsystem.

The total volume of oil stored is sufficient to fill six of the seven oil tanks. A one-empty-tank concept is employed to maximize storage tank utilization. In operation, when the system is being charged, cold oil from one of the full tanks is heated and routed to the one empty tank. When full, cold oil is supplied by another tank and hot oil is routed to the just-emptied tank. This valving process continues until six tanks contain hot oil and the seventh is empty. Discharging the system is accomplished by a similar valving sequence ending with six tanks full of cold oil, and a seventh empty.

The total volume of salt stored can be contained in either of the two salt storage tanks. One is filled with hot salt when the system is in the charged state; the other is filled with cold salt when the system is in the discharged state.

Both the salt and oil storage media are used in their fluid phases; thermal storage is accomplished over ranges of temperature changes (sensible heat). The thermal storage salt is an inorganic compound consisting of an eutectic mixture of 40% $NaNO_2$, 7% $NaNO_3$, and 53% KNO_3, with a melting point of 415 K (288^oK).

The salt is available as a commercial product, and has been in common use for heat transfer applications for over 35 years. The salt is maintained in a molten state at all times in the system. During periods of TSS inactivity, auxiliary steam is supplied to the system to maintain the salt molten state. The salt is non-flammable and requires no special handling with respect to toxicity. Molten salt spill flow will be limited by solidification, which will occur at 415 K (288°K).

The thermal storage oil is a commercial heat transfer fluid identified as EXXON Caloria HT 43. It is formulated from a stable paraffine base petroleum, fortified with a high temperature oxidation inhibitor. The material has the general appearance and properties of lubricating oil, presenting no toxicity hazards or special handling requirements. It has a flash point of 420°F and a pour point of +15°F.

Fire control facilities are also included in the TSS triangular plot area, including water storage tanks, pumping equipment and the necessary water distribution piping.

5. Electrical Power Generation Subsystem (EPGS)

The Electrical Power Generation Subsystem (EPGS) for the commercial plant consists of a single turbine/generator set, feedwater pumping and conditioning equipment, condenser, wet cooling towers, steam and water piping, and the necessary valves, control elements and auxiliary equipment for subsystem operation. Figure II.B-3 shows the triangular area within the plant plot plan where most of these components are located, and the general arrangement of installations in this area. Six cooling tower units are located in the southeast corner of the plot plan, consistent with generally westerly or north-westerly prevailing wind conditions. It is most desirable to place the cooling towers downwind of the heliostat fields to minimize deposition of fallout water droplets from the cooling tower plumes, and to locate the towers to avoid significant shadowing of heliostats by cold weather (visible) plume conditions.

The turbine/generator set is located on an open air deck, supported by an isolated, concrete pedestal foundation/support structure. Ancillary equipment, including five (5) feedwater heaters, is installed in a multi-level enclosed structure adjacent to the turbine deck. Another adjacent building contains the central control equipment.

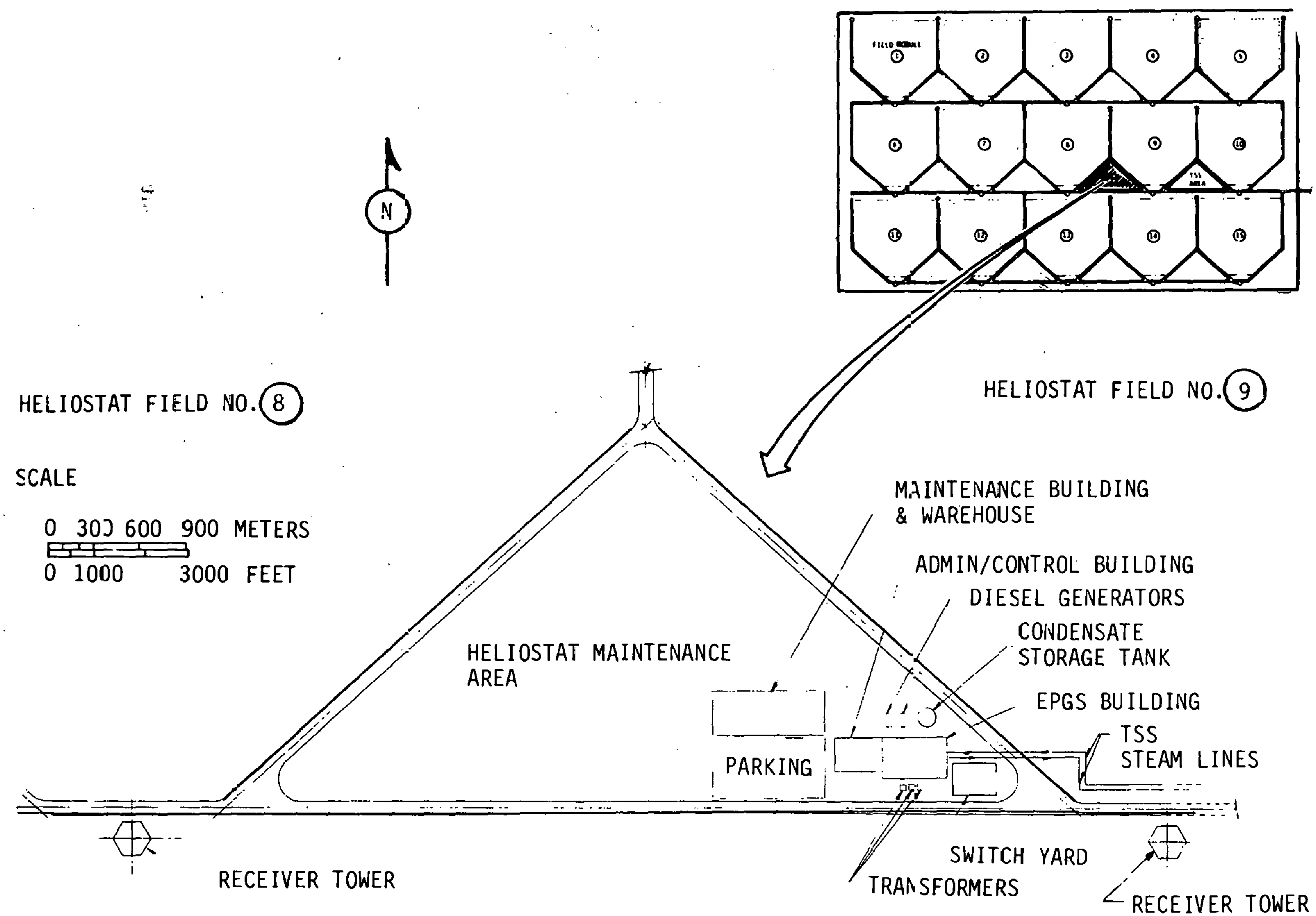

Figure II.B-3 Electrical Power Generation Subsystem

The turbine selected for the commercial plant application is a General Electric admission type unit, rated at 160 MW_e output, and can be built using existing component designs. The 160 MW_e standard size closely matches that required to supply 150 MW_c plus the plant auxiliary loads.

Figure II.B-4 shows a cross section of a typical unit of this size and type. It is technically described as an automatic extraction, non-reheat, tandem compound, four flow unit. The single flow, high pressure section on the left is in tandem with two parallel, double flow, low pressure sections on the right. The general area where internal admission valve gear will be added to the high pressure section is indicated in the figure. This admission port improves operating efficiency at reduced loads when operating on thermal storage steam. Under these lower temperature/pressure conditions, steam is admitted several stages downstream of the main steam mission point. Extraction nozzles will be provided downstream of the admission valve gear in the turbine casing to supply steam for use in feedwater heating and conditioning.

6. <u>Master Control Subsystem</u>

The Commercial Plant master control system functions in the same way as the Pilot Plant control system. The design and operational philosophies are the same for both Pilot and Commercial Plants.

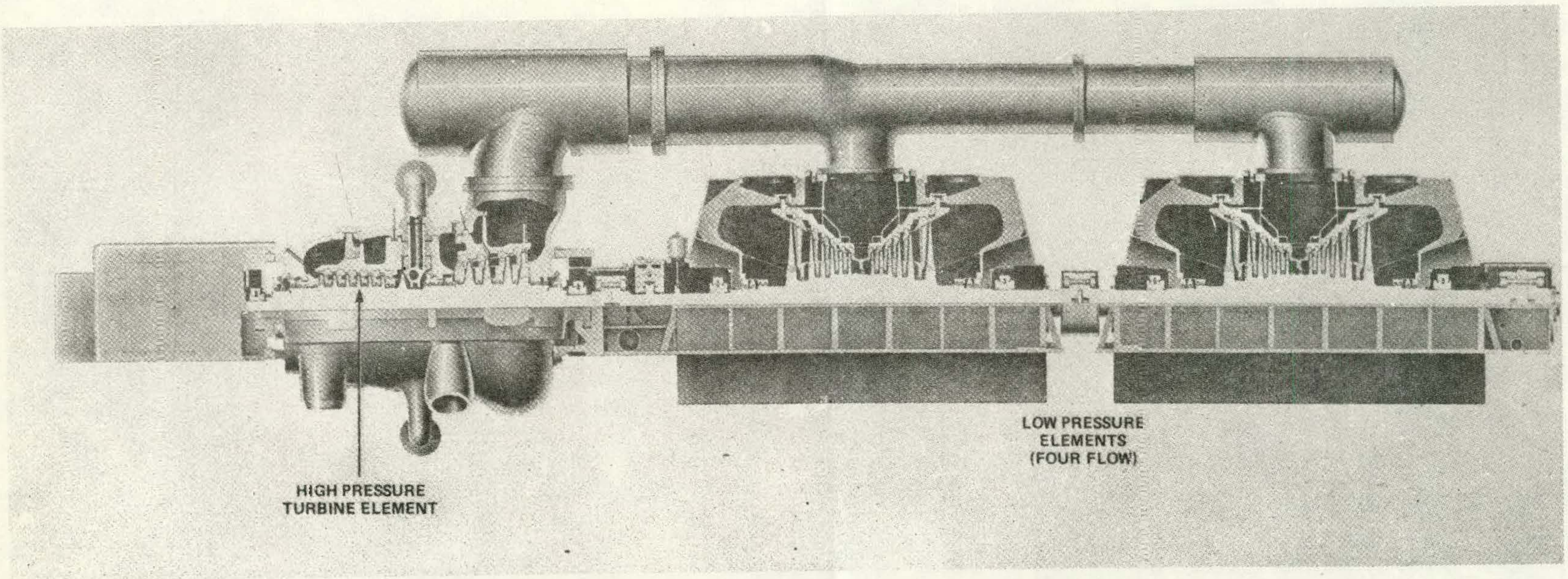

Figure II.B-4 Typical Commercial 160 MW_e Turbine Courtesy of General Electric Co.

III. COSTING GROUNDRULES

The cost estimates presented in Sections IV and V have been developed on the basis of the requirements set forth by ERDA in Reference 1. The following additional groundrules and assumptions were established for the costing exercise:

1. Cost estimates are given in mid-fiscal 1977 dollars.

2. The fee for the construction of the pilot and commercial plants is 8% for the solar portions, 13% for the A&E design and 1% for the EPGS/BOP field construction.

3. The commercial plant storage charge rate is sized to accept the excess thermal power from the receiver over that required to operate the plant at peak net electrical output including auxiliary losses required in charging thermal storage.

4. Contingency is money which is expected to be spent and represents an allowance for uncertainties in quantities, pricing methods and labor, and it cannot be considered as a source of funds for overruns or additions to the project scope. Contingency does not cover cost increases due to acts of God, strikes, fixed price contract failure, etc.

5. The cost of the following items has not been included:

   a. Construction management
   b. Environmental impact assessment
   c. Seismic surveys
   d. Building or highway relocations or access road or service utility extensions
   e. Owners engineering costs
   f. Two-year test program development

6. Integrated plant construction schedules were developed by the Martin Marietta Team. These schedules, shown in Figures III-1 and III-2 for the pilot plant and commercial plant respectively, were the basis for project manpower estimates.

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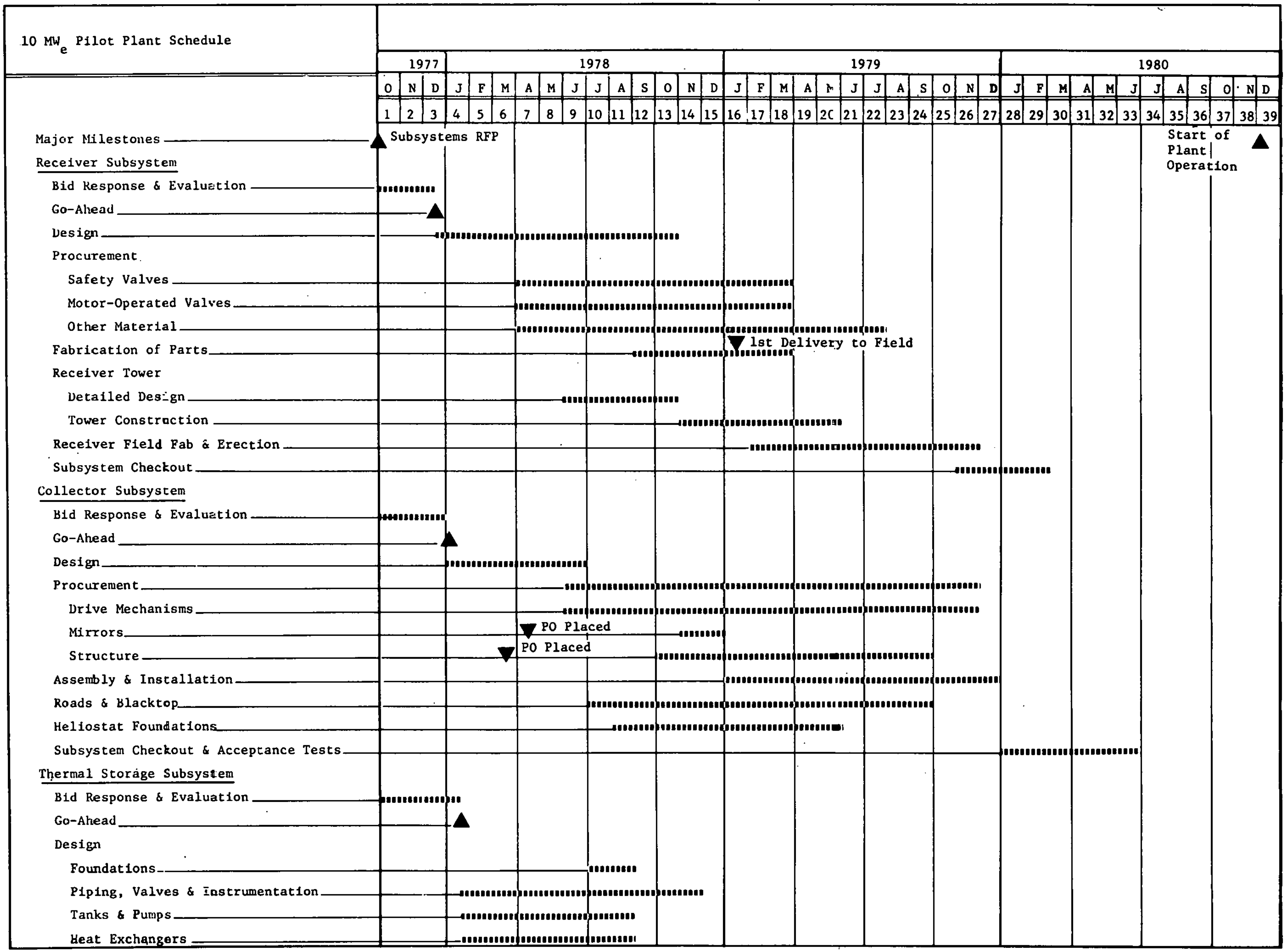

Figure III-1 10 MW_e Pilot Plant Schedule

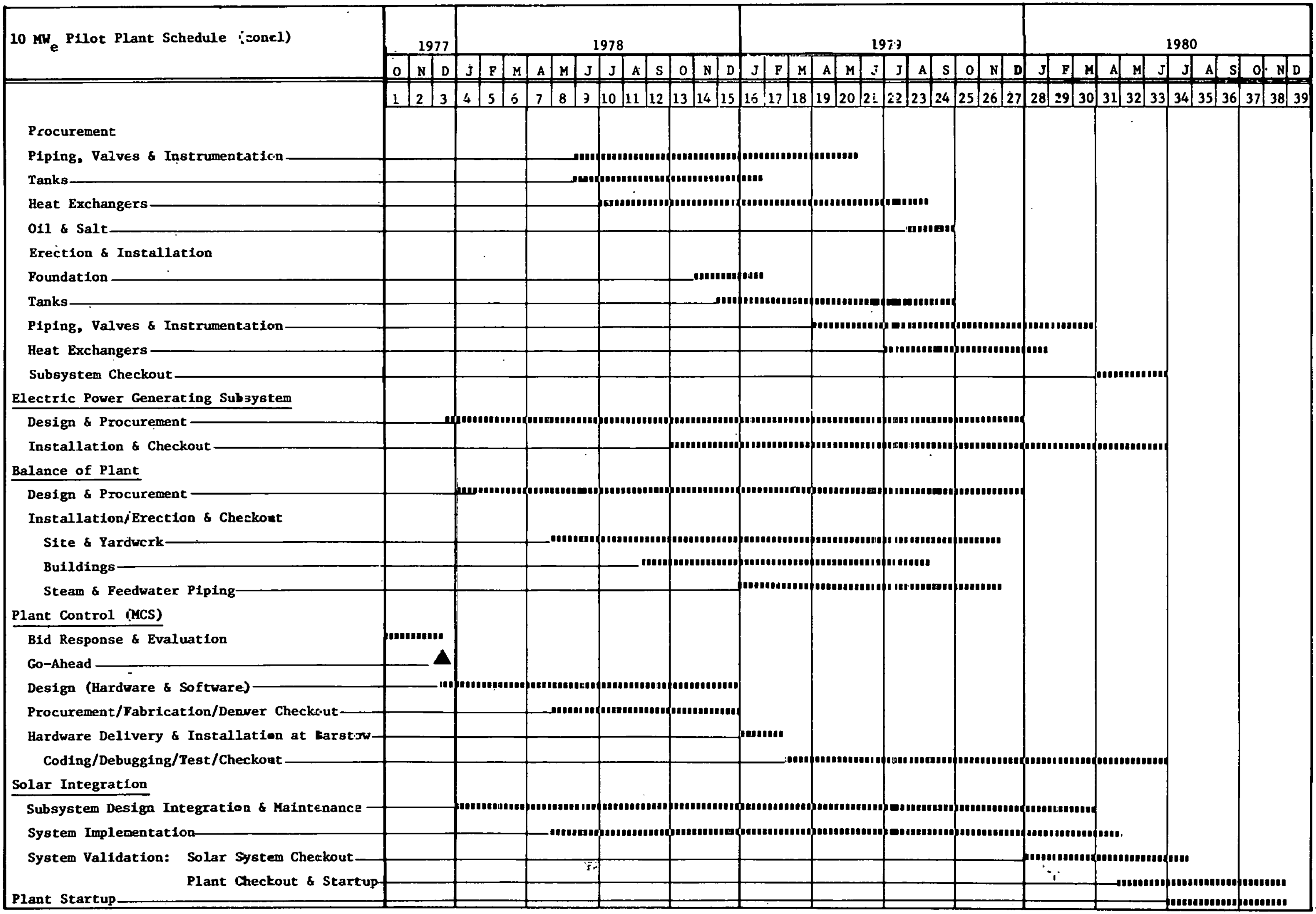

Figure III-1 (Continued)

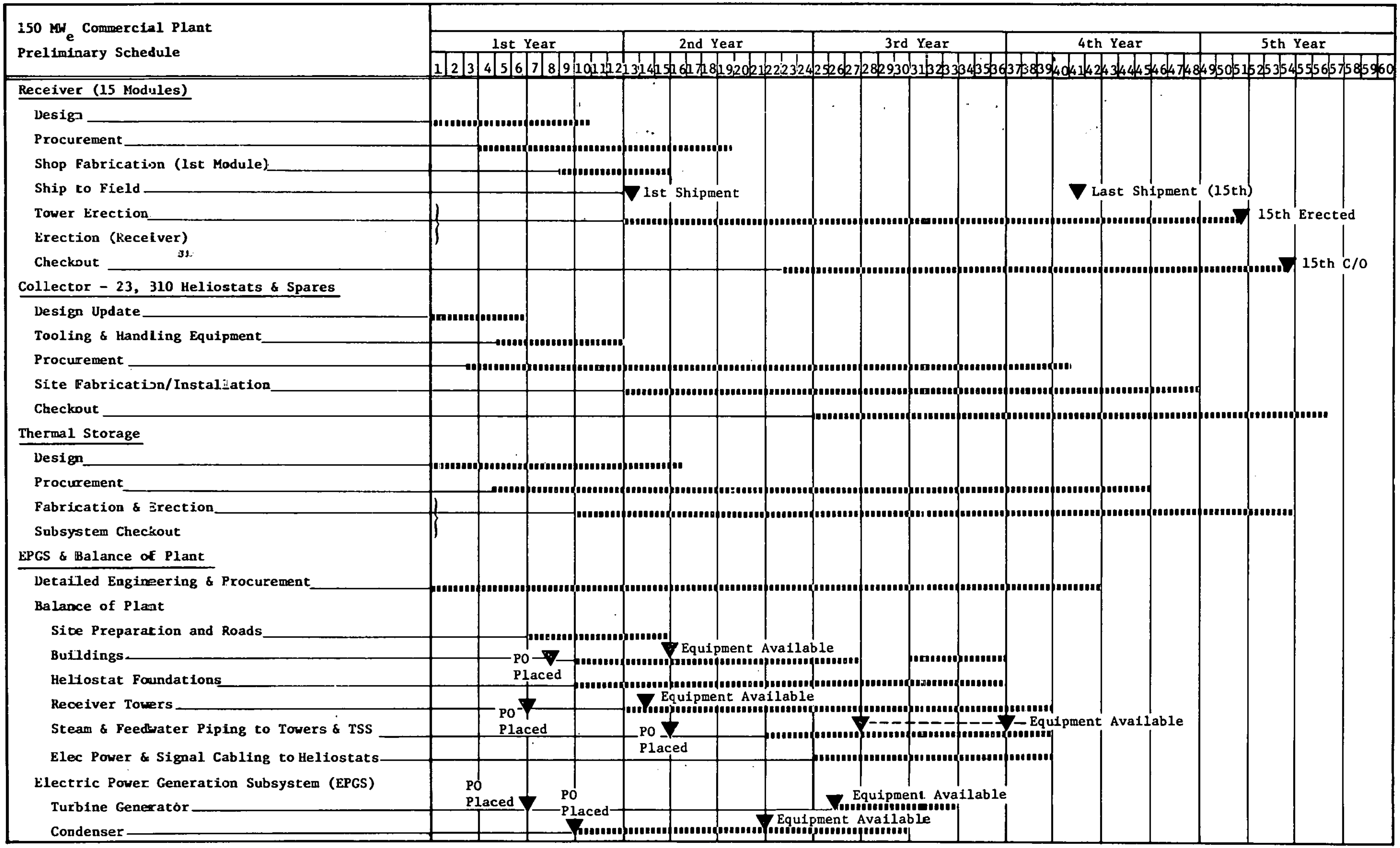

Figure III-2 150 MWe Commercial Plant Preliminary Schedule

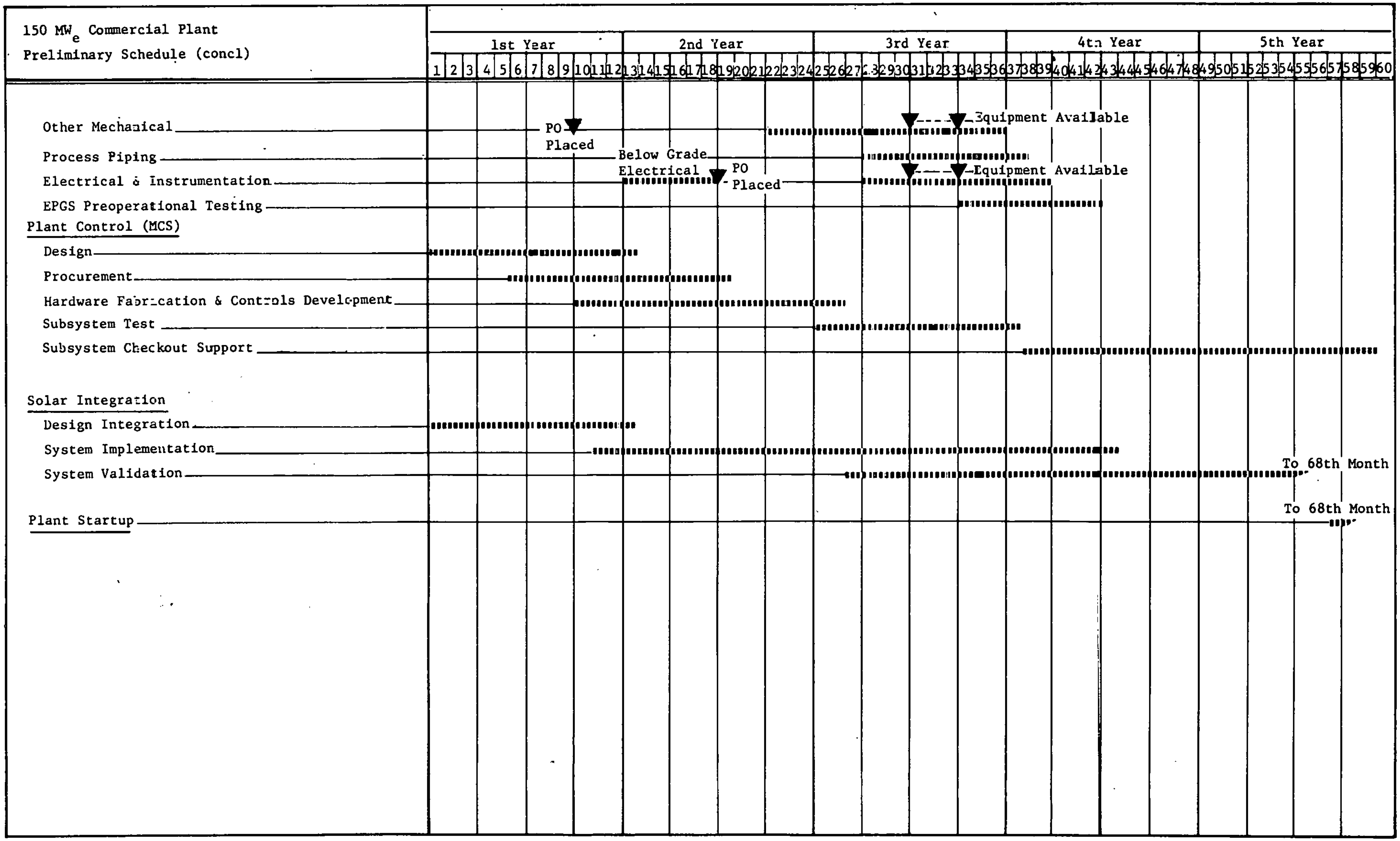

Figure III-2 (Continued)

IV. PILOT PLANT COST ESTIMATES

A. PILOT PLANT DETAILED COST

The total cost of the 10 MWe Central Receiver Solar Thermal Power Plant has been estimated to be $69,753,000.

Pilot Plant costs are shown at the summary account level in Table IV.A-1 and detailed costs are given in Table IV.A-2 at or below the required account levels. Background information for these costs is presented in Appendix A - Basis for Pilot Plant Cost Estimates.

Certain items in the original cost breakdown structure (Reference 1, Attachment C) have been omitted from Tables IV.A-1 and IV.A-2. The omitted items and the reasons for their omission are listed in Table IV.A-3.

B. PILOT PLANT TWO-YEAR TEST PROGRAM COSTS

The estimated cost for operation and maintenance of the pilot plant and supporting a test program for a period of two years is shown in Table IV.B-1.

The total cost is estimated at $3,330,000. Basis for the costs is given in Appendix A - Basis for Pilot Plant Cost Estimates.

C. TIME-PHASING OF PILOT PLANT COSTS

The pilot plant costs have been time-phased over the plant design/construction period and the two-year test program. The total time span includes parts or all of the fiscal years 1978 through 1983. The costs were spread on the basis of the plant construction schedule, Figure III.C-1, in terms of both committed and spent dollars.

Material and subcontract costs are defined as committed on the day the contract is signed. Material costs were defined as spent 30 days after delivery.* Labor dollars were defined as committed on the first day of the fiscal year in which they were spent.

*For some items, earnest money is spent before delivery.

Figures IV.C-1 and IV.C-2 give the results at the summary account level for committed and spent dollars respectively.

D. COST OF PROPOSED 1554 HELIOSTAT PLANT

The collector field priced in A. above contains the 1325 heliostats required to meet all of the specified design requirements. However, as discussed in the previous sections, a field of 1554 heliostats is the recommended configuration because 1) it better simulates an operational pilot plant and 2) it represents a full-scale commercial plant module.

The difference in cost for collector equipment (4190.1), spare parts (8040.63), and contingency (8300) is $4,124,000. Thus, the total cost for the recommended 1554 heliostats pilot plant is $73,877,000.

TABLE IV.A-1. PILOT PLANT COST SUMMARY

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT (1)	LABOR (2)	TOTALS
4100	Yardwork	465,000	52,000	517,000
4103	Turbine Building	249,000	147,000	396,000
4105	Administration (Control) Building	530,000	172,000	702,000
4108	Warehouse (Included with 4141)	--	--	--
4141	Maintenance (Warehouse) Building	76,000	36,000	112,000
4144	Fire Pump House(4)	10,000	--	10,000
4145	Condensate Pump House(4)	9,000	--	9,000
4146	Gate House(4)	6,000	5,000	11,000
4180	Control Building (Included with 4105)	--	--	--
4190.1	Collector Equipment	15,182,000	4,208,000	19,390,000
4190.2	Receiver and Tower System	4,414,000	5,789,000	10,203,000
4190.3	Thermal Storage Equipment	6,959,000	3,341,000	10,300,000
4190.4	Thermal Storage Material	855,000	21,000	876,000
4300	Turbine Plant Equipment	3,479,000	710,000	4,189,000
4401	Electric Plant Equipment	756,000	650,000	1,406,000
4402	Plant Master Control Equipment	731,000	1,382,000	2,113,000
4500	Miscellaneous Plant Equipment	601,000	273,000	874,000
8000	Distributables	2,014,000	1,325,000	3,339,000
8100	Indirects		6,208,000	6,208,000
8300	Contingency			9,098,000
	TOTAL PILOT PLANT COSTS			69,753,000

NOTES: (1) Subcontracted work is included in the Material/Equipment column.

(2) Design and engineering costs are shown in the labor column.

(3) Design costs shown in accounts 8100.4 and 8100.5 are repetitive and non-additive.

(4) Items added to Sandia Cost Breakdown Structure.

TABLE IV.A-2. PILOT PLANT DETAILED COST BREAKDOWN

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT(1)	LABOR(2)	TOTALS	
4100	Yard Work	465,000	52,000		517,000
4100.1	Grading, General Excavation/or Fill, and Landscaping	40,000	--	40,000	
4100.2	Roadways, Fencing and Lighting				
4100.21	Roads	257,000	--	257,000	
4100.22	Sidewalks	10,000	--	10,000	
4100.23	Parking	18,000	--	18,000	
4100.24	Retaining Walls, Bridges, and Culverts	10,000	--	10,000	
4100.25	Fences and Gateways	83,000	--	83,000	
4100.26	Yard Lighting	35,000	38,000	73,000	
4100.3	Sanitary Sewer System				
4100.31	Connection to Existing System	12,000	14,000	26,000	
4100.4	Yard Drainage and Storm Sewer System (Surface Drainage Only, included in 4100.1)				
4103	Turbine Building	249,000	147,000		396,000
4103.1	Substructure	19,000	35,000	54,000	
4103.2	Superstructure	170,000	56,000	226,000	
4103.4	Building Mechanical	30,000	--	30,000	
4103.5	Lighting and Building Service Power System	20,000	56,000	76,000	
4103.6	Painting	10,000	--	10,000	
4105	Administration (and Control) Building	530,000	172,000		702,000
4105.1	Substructure	20,000	36,000	56,000	
4105.2	Superstructure	302,000	49,000	351,000	
4105.4	Building Mechanical	156,000	7,000	163,000	
4105.5	Lighting and Building Service Power System	29,000	80,000	109,000	
4105.6	Painting	23,000	--	23,000	
4108	Warehouse (Included in 4141)	--	--		
4141	Maintenance (and Warehouse) Building	76,000	36,000		112,000
4144	Fire Pump House(4)	10,000	--		10,000
4145	Condensate Pump House(4)	9,000	--		9,000

TABLE IV.A-2. PILOT PLANT DETAILED COST BREAKDOWN (Continued)

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT(1)	LABOR(2)	TOTALS	
4146	Gate House(4)	6,000	5,000		11,000
4180	Control Building (Included in 4105)	--	--		--
4190	Solar Plant Equipment				
4190.1	Collector Equipment	15,182,000	4,208,000		19,390,000
4190.11	Reflective Unit				7,523,000
4190.111	Reflective Surface	671,000	--	671,000	
4190.112	Mirror Backing Structure	4,560,000	--	4,560,000	
4190.113	Heliostat Support Structure	2,292,000	--	2,292,000	
4190.12	Drive Unit				6,281,000
4190.121	Azimuth Drive (Assembly)	2,678,000	--	2,678,000	
4190.122	Elevation Drive (Assembly)	2,394,000	--	2,394,000	
4190.123	Motors	421,000	--	421,000	
4190.124	Position and Limit Indicators	507,000	--	507,000	
4190.125	Emergency Power Supply (Included in 4300.7)				
4190.126	Power Distribution Equipment and Wiring From Electric Plant	146,000	135,000	281,000	
4190.13	Sensor/Calibration Equipment				
4190.133	Calibration Equipment	104,000	47,000		151,000
4190.14	Control/Instrumentation Equipment				1,875,000
4190.141	Field Control/Electronics	877,000	835,000	1,712,000	
4190.142	Computer Hardware	66,000	--	66,000	
4190.143	Signal Distribution Equipment and Wiring	30,000	67,000	97,000	
4190.15	Foundations and Site Preparation				588,000
4190.151	Foundation - Heliostats	384,000	186,000	570,000	
4190.152	Site Preparation	18,000	--	18,000	

TABLE IV.A-2. PILOT PLANT DETAILED COST BREAKDOWN (Continued)

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT[1]	LABOR[2]	TOTALS	
4190.16	Design and Engineering Costs (Collector Subsystem)				1,622,000
4190.161	Design				
4190.1611	Reflective Unit (Design Costs)	--	123,000	123,000	
4190.1612	Drive Unit (Design Costs)	--	52,000	52,000	
4190.1613	Calibration Equipment (Design Cost)	--	92,000	92,000	
4190.1614	Control Equipment (Design Cost)	--	334,000	334,000	
4190.1615	Foundation and Site Preparation (Design Cost)	--	70,000	70,000	
4190.162	Engineering Support During Manufacturing, Installation and Checkout	--	951,000	951,000	
4190.18	Field Assembly, Installation and Checkout				1,067,000
4190.181	Heliostat and Control Equipment				
4190.1811	Field Assembly	--	581,000	581,000	
4190.1812	Installation and Checkout	--	458,000	458,000	
4190.182	Calibration Equipment				
4190.1821	Field Assembly	--	8,000	8,000	
4190.1822	Installation and Checkout	--	12,000	12,000	
4190.1823	Calibration	--	8,000	8,000	
4190.19	Lightning Protection	34,000	32,000		66,000
4190.20	Project Management[4] (Collector Subsystem)	--	217,000		217,000
4190.2	Receiver and Tower Unit	4,414,000	5,789,000		10,203,000
4190.21	Receiver Unit				4,428,000
4190.211	Absorber Unit				
4190.2111	Absorber	211,000	422,000	633,000	
4190.2112	Drum	34,000	59,000	93,000	
4190.2113	Doors, Casing, Lining, Insulation	160,000	105,000	265,000	
4190.212	Piping	156,000	35,000	191,000	
4190.213	Support Structure, Platform, etc	457,000	--	457,000	
4190.214	Instrumentation and Control on Receiver and Tower	115,000	1,000	116,000	
4190.215	Packing and Transportation	60,000	--	60,000	
4190.216	Field Erection and Installation	633,000	1,980,000	2,613,000	

TABLE IV.A-2. PILOT PLANT DETAILED COST BREAKDOWN (Continued)

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT (1)	LABOR (2)	TOTALS	
4190.22	Riser and Horizontal Feedwater Piping to Receiver				72,000
4190.221	From Turbine Generator Building				
4190.2211	Piping	13,000	14,000	27,000	
4190.2212	Hangers, Valves, Pipe Supports, etc	6,000	12,000	18,000	
4190.2213	Insulation	13,000	--	13,000	
4190.222	From Thermal Storage - Additional Piping Over That in 4190.221				
4190.2221	Piping	3,000	3,000	6,000	
4190.2222	Hangers, Valves, Pipe Supports, etc	2,000	3,000	5,000	
4190.2223	Insulation	3,000	--	3,000	
4190.23	Downcomer and Horizontal Steam Piping from Receiver				526,000
4190.231	To Turbine Generator Building				
4190.2311	Piping	88,000	163,000	251,000	
4190.2312	Hangers, Valves, Pipe Supports, etc	112,000	46,000	158,000	
4190.2313	Insulation	28,000	--	28,000	
4190.232	To Thermal Storage - Additional Piping Over That in 4190.231				
4190.2321	Piping	11,000	21,000	32,000	
4190.2322	Hangers, Valves, Pipe Supports, etc	43,000	10,000	53,000	
4190.2323	Insulation	4,000	--	4,000	
4190.24	Tower and Platform				2,397,000
4190.241	Tower	1,616,000	364,000	1,980,000	
4190.242	Platforms (Included with 4190.241)	--		--	
4190.243	Elevator and Other Accessories	280,000	26,000	306,000	
4190.244	Lighting	20,000	19,000	39,000	
4190.245	Lightning Protection	10,000	4,000	14,000	
4190.246	Blowdown and Drain Lines from Boiler(4)	16,000	42,000	58,000	
4190.25	Tower Foundation and Site Preparation				597,000
4190.251	Foundation	320,000	228,000	548,000	
4190.252	Excavation	--	49,000	49,000	

TABLE IV.A-2. PILOT PLANT DETAILED COST BREAKDOWN (Continued)

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT(1)	LABOR(2)	TOTALS	
4190.26	Design Cost (Receiver Subsystem)				1,929,000
4190.261	Tower and Foundation (Design Cost)	--	708,000	708,000	
4190.262	Receiver (Design Cost)		1,093,000	1,093,000	
4190.263	Riser, Downcomer, Horizontal Piping (Design Cost)	--	128,000	128,000	
4190.27	Project Management(4) (Receiver Subsystem)	--	254,000		254,000
4190.3	Thermal Storage Equipment	6,959,000	3,341,000		10,300,000
4190.31	Thermal Storage Unit				3,177,000
4190.311	Storage Tanks and Heaters	2,905,000	1,000	2,906,000	
4190.312	Insulation (Storage Tanks)	249,000	--	249,000	
4190.313	Ullage Maintenance Equipment	22,000	--	22,000	
4190.314	Fluid Maintenance Equipment*				
4190.32	Circulation Equipment				2,039,000
4190.321	Piping and Supports for Media (and Intrasubsystem Steam & Water)	621,000	388,000	1,009,000	
4190.322	Valves, Strainers, Filters, etc	493,000	--	493,000	
4190.323	Pumps	90,000	34,000	124,000	
4190.324	Insulation (Pipes, Valves, Filters, etc)	219,000	--	219,000	
4190.325	Steam Drums	73,000	42,000	115,000	
4190.326	Water/Steam Piping between Thermal Storage and Turbine Generator Building	63,000	16,000	79,000	
4190.33	Heat Exchangers				2,173,000
4190.331	Attemperators	11,000	--	11,000	
4190.332	Steam Generator Heat Exchangers (Discharging)	804,000	8,000	812,000	
4190.333	Thermal Storage Heat Exchangers (Charging)	1,115,000	8,000	1,123,000	
4190.334	Insulation (Heat Exchangers and Drum)	90,000	--	90,000	
4190.335	Support Structures	50,000	87,000	137,000	
4190.34	Instrumentation and Controls (Field)	95,000	4,000		99,000

*Due to the uncertainty associated with oil decomposition rates, it is not known if a side stream processor is required. If future test data indicates a side stream processor is required for the 2 to 5 year pilot plant operation, its cost can be added to the 4190.3 account at an approximate value of $828,000.

TABLE IV.A-2. PILOT PLANT DETAILED COST BREAKDOWN (Continued)

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT[1]	LABOR[2]	TOTALS	
4190.35	Foundations and Site Preparation				145,000
4190.351	Tank Foundation	1,000	2,000	3,000	
4190.352	Other Foundations	13,000	50,000	63,000	
4190.353	Dikes or Emergency Containment Structures	3,000	--	3,000	
4190.354	Site Preparation	14,000	--	14,000	
4190.355	Safety Protection Equipment	28,000	34,000	62,000	
4190.36	Design Cost (Thermal Storage Subsystem)				2,331,000
4190.361	Home Engineering[4]		1,339,000	1,339,000	
4190.362	Field Engineering[4]		992,000	992,000	
4190.37	Project Management (Thermal Storage System[4]		336,000		336,000
4190.4	Thermal Storage Material	855,000	21,000		876,000
4190.41	Inorganic Material Cost	164,000	--	164,000	
4190.42	Organic Material Cost	555,000	--	555,000	
4190.43	Delivery	114,000	--	114,000	
4190.44	Handling at Site	22,000	21,000	43,000	
4300	Turbine Plant Equipment	3,479,000	710,000		4,189,000
4300.1	Turbine Generator				2,326,000
4300.11	Turbine Generator and Accessories	2,150,000	70,000	2,220,000	
4300.12	Foundations (Includes T/G Pedestal)				
4300.121	Concrete (Including Forms, Reinforcing, and Embedded Iron)	36,000	57,000	93,000	
4300.14	Lubricating System (Included with 4300.11)	--	--	--	
4300.17	Weather-Proof Housing (Included with 4300.11)	--	--	--	
4300.18	Seal Steam Lines	4,000	9,000	13,000	
4300.2	Heat Rejection System				821,000
4300.21	Heat Rejection Equipment	568,000	--	568,000	
4300.22	Heat Rejection Equipment Installation	--	253,000	253,000	

TABLE IV.A-2. PILOT PLANT DETAILED COST BREAKDOWN (Continued)

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT(1)	LABOR(2)	TOTALS	
4300.3	Condensing Systems				153,000
4300.31	Condensate System				
4300.311	Pumps, Drives, and Controls	11,000	2,000	13,000	
4300.312	Condensate Storage Tank	7,000	2,000	9,000	
4300.313	Piping, Valves, and Fittings	20,000	30,000	50,000	
4300.314	Insulation	10,000	--	10,000	
4300.315	Foundation, Supports, Hangers, Bases, Inserts, and Screens	5,000	26,000	31,000	
4300.32	Turbine Bypass System	29,000	11,000	40,000	
4300.4	Feed-Heating System				660,000
4300.41	Regenerative Heat Exchangers				
4300.411	Closed Heaters	92,000	5,000	97,000	
4300.412	Open Heaters (Deareator)	20,000	2,000	22,000	
4300.413	Heater Insulation	4,000	--	4,000	
4300.414	Heater Foundations, Supports, Bases, Inserts	1,000	1,000	2,000	
4300.42	Pumps				
4300.421	Main Feed Pumps and Drives	85,000	16,000	101,000	
4300.422	Auxiliary Feed Pumps and Drives	85,000	16,000	101,000	
4300.423	Drains, Pumps, and Drives	2,000	2,000	4,000	
4300.424	Pump Insulation	2,000	--	2,000	
4300.425	Pump Foundations, Supports, Bases, Inserts	2,000	4,000	6,000	
4300.43	Piping and Tanks				
4300.431	Feedwater Piping	143,000	66,000	209,000	
4300.432	Drains and Coolers (Included in 4300.431)	--	--	--	
4300.433	Drains and Flash Tanks (Included in 4300.431)	--	--	--	
4300.434	Extraction, Drain, and Vent Piping, Valves and Fittings	9,000	5,000	14,000	
4300.435	Insulation	35,000	--	35,000	
4300.436	Hangers, Supports, and Inserts	14,000	49,000	63,000	
4300.5	Water Circulation/Treatment Equipment				195,000
4300.51	Make-up Treatment System				
4300.512	Ion Exchange System	22,000	4,000	26,000	
4300.513	Filters and Separator Systems (Included in 4300.512)	--	--	--	
4300.514	Pumps and Drives (Included in 4300.512)	--	--	--	

TABLE IV.A-2. PILOT PLANT DETAILED COST BREAKDOWN (Continued)

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT (1)	LABOR (2)	TOTALS	
4300.515	Piping, Valves, and Fittings	4,000	14,000	18,000	
4300.516	Storage Tank	4,000	2,000	6,000	
4300.517	Hangers, Foundations, Supports, Bases, Inserts & Screens	4,000	6,000	10,000	
4300.52	Chemical Treatment and Condensate Purification				
4300.521	Chemical Storage and Additional Equipment (Included in 4300.522)	--	--	--	
4300.522	Condensate Demineralizer and Filter System	50,000	18,000	68,000	
4300.524	Resin Storage, Regeneration, and Additional Systems (Included in 4300.522)	--	--	--	
4300.525	Boiler Blowdown and Fluid Sampling Systems	13,000	2,000	15,000	
4300.526	Pumps and Drives (Included in 4300.522)	--	--	--	
4300.527	Piping, Valves, and Fittings	10,000	18,000	28,000	
4300.528	Insulation	6,000	--	6,000	
4300.529	Hangers, Foundations, Supports, Bases, Inserts, and Screens	4,000	14,000	18,000	
4300.6	Auxiliary Boiler (Seal and Trace Steam)(4)	28,000	6,000		34,000
4401	Electric Plant Equipment	756,000	650,000		1,406,000
4401.1	Switchgear				328,000
4401.11	Generator Circuit Switchgear				
4401.111	Generator Switchgear	23,000	2,000	25,000	
4401.112	Generator Neutral Grounding Equipment (Included in 4401.111)	--	--	--	
4401.113	Generator Current and Potential Transformers (Included in 4401.111)	--	--	--	
4401.114	Generator Surge Arrestors (Included in 4401.111)	--	--	--	
4401.115	Excitation Switchgear (Included in 4401.111)	--	--	--	
4401.116	Special Screens, Bases, Foundations, Inserts, or Supports (Not Required: Installed in T/G Building)				
4401.12	Station Service				
4401.121	Station Switchgear	219,000	15,000	234,000	
4401.122	Station Motor Control Centers Centrally Located	47,000	22,000	69,000	
4401.123	Systems Neutral Grounding Devices (Included in 4401.121 and 4401.122)	--	--	--	

TABLE IV.A-2. PILOT PLANT DETAILED COST BREAKDOWN (Continued)

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT (1)	LABOR (2)	TOTALS	
4401.124	Separately Mounted Station Service Devices (Included in 4401.121 and 4401.122)	--	--	--	
4401.125	Special Screens, Bases, Foundations, Inserts, or Supports (Included in 4401.121 and 4401.122).	--	--	--	
4401.2	Station Service Equipment				209,000
4401.21	Station Service and Startup Transformers				
4401.211	Station Service Transformers	116,000	14,000	130,000	
4401.212	Station Startup Transformers (Included in 4401.211)	--	--	--	
4401.213	Transformer Foundations, Walls, and Related Structures	6,000	10,000	16,000	
4401.214	Voltage Regulation Equipment (Included in 4401.211)	--	--	--	
4401.215	Insulating Oil Storage and Treating Equipment (Included in 4401.211)	--	--	--	
4401.22	Low Voltage Unit Substations and Lighting Transformers (Included in 4401.122)	--	--	--	
4401.23	Auxiliary Power Sources	55,000	8,000	63,000	
4401.4	Protective Equipment				69,000
4401.41	General Station Grounding System				
4401.411	Ground Conductors and Connectors for Equipment	16,000	26,000	42,000	
4401.412	Ground Wells, Mats, and Roads	16,000	--	16,000	
4401.42	Fire Protection Equipment	8,000	3,000	11,000	
4401.5	Electrical Structures and Wiring Containers				560,000
4401.51	Concrete Tunnels for Cables, Trenches, and Envelopes	5,000	--	5,000	
4401.52	Cable Trays and Supports	30,000	96,000	126,000	
4401.53	Conduit	85,000	271,000	356,000	
4401.54	Other Structures	20,000	53,000	73,000	
4401.6	Power Wiring				240,000
4401.61	Generator Circuit Wiring	8,000	4,000	12,000	
4401.62	Station Service Power Wiring	102,000	126,000	228,000	
4402	Plant Master Control Equipment	731,000	1,382,000		2,113,000
4402.1	Computer	37,000	--	37,000	
4402.2	Peripheral Equipment	28,000	--	28,000	

TABLE IV.A-2. PILOT PLANT DETAILED COST BREAKDOWN (Continued)

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT (1)	LABOR (2)	TOTALS	
4402.3	Control Panels and Boards	178,000	2,000	180,000	
4402.4	Interface Equipment	12,000	33,000	45,000	
4402.5	Software Design and Development	--	235,000	235,000	
4402.6	Software/Hardware Test	--	122,000	122,000	
4402.7	Hardware Design	--	105,000	105,000	
4402.8	Control Wiring				
4402.81	Control Wiring from Collector Field (Included in 4190.143).	--	--	--	
4402.82	Control Wiring from Thermal Storage	6,000	15,000	21,000	
4402.83	Control Wiring from Receiver	5,000	13,000	18,000	
4402.84	Control Wiring from EPGS	30,000	67,000	97,000	
4402.9	Special Test Program Instrumentation	435,000	565,000	1,000,000	
4402.10	Project Management (Master Control System)(4)	--	225,000	225,000	
4500	Miscellaneous Plant Equipment	601,000	273,000		874,000
4500.1	Transportation and Lifting Equipment				417,000
4500.112	Other Cranes, Hoists, Monorails	62,000	1,000	63,000	
4500.13	Roadway Equipment	35,000	--	35,000	
4500.17	Collector Maintenance, Assembly, Handling Equipment	262,000	57,000	319,000	
4500.2	Air and Water Service Systems				323,000
4500.21	Air Systems				
4500.211	Compressed Air	20,000	22,000	42,000	
4500.222	Fire Pumps, Drives, and Accessories	24,000	7,000	31,000	
4500.224	Mirror Wash, Domestic, and Fire Water Tanks	67,000	13,000	80,000	
4500.229	Water Distribution Systems	69,000	101,000	170,000	
4500.3	Communications Equipment				99,000
4500.31	Local Communication Systems	26,000	45,000	71,000	
4500.32	Signal Systems	10,000	18,000	28,000	
4500.4	Furnishings and Fixtures				35,000
4500.41	Safety Equipment	6,000	5,000	11,000	
4500.42	Shop, Laboratory, and Test Equipment	2,000	1,000	3,000	
4500.43	Office Equipment and Furnishings	10,000	1,000	11,000	
4500.44	Environmental Monitoring Equipment - Meteorological	7,000	2,000	9,000	
4500.46	Cleaning Equipment	1,000	--	1,000	

TABLE IV.A-2. PILOT PLANT DETAILED COST BREAKDOWN (Continued)

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT(1)	LABOR(2)	TOTALS	
8000	Distributables	2,014,000	1,325,000		3,339,000
8030	Contractor Field Office Personnel and Supplies	110,000	435,000		545,000
8040	Other Construction Items				
8040.1	Insurance, Injuries, and Damage	30,000	--		30,000
8040.2	Insurance, Construction Equipment, and Autos	3,000	--		3,000
8040.3	Temporary Construction				913,000
8040.31	Site Access and Improvements	8,000	7,000	15,000	
8040.32	Buildings and Structures	646,000	89,000	735,000	
8040.33	Electricity and Water	54,000	109,000	163,000	
8040.34	Communications Equipment (In Account 8040.33)	--	--	--	
8040.4	Construction Equipment	425,000	24,000		449,000
8040.5	Construction Services				877,000
8040.51	Purchased Utilities	133,000	--	133,000	
8040.52	Security, Watchmen, and Guards	22,000	7,000	29,000	
8040.53	Education and Testing Programs for Labor Force	10,000	10,000	20,000	
8040.54	Materials Receiving and Storage	6,000	135,000	141,000	
8040.55	Inspection and Testing of Construction Materials	1,000	1,000	2,000	
8040.56	Site Cleanup	4,000	250,000	254,000	
8040.57	Operation and Maintenance of Const. Facilities & Equipment	28,000	210,000	238,000	
8040.58	Storm Protection and Repairs	12,000	48,000	60,000	
8040.6	Spare Parts				522,000
8040.61	Turbine Plant Equipment Spares	104,000	--	104,000	
8040.62	Electrical Plant Equipment Spares	37,000	--	37,000	
8040.63	Collector Equipment Spares	268,000	--	268,000	
8040.64	Receiver Equipment Spares	13,000	--	13,000	
8040.65	Thermal Storage Equipment Spares	100,000	--	100,000	

TABLE IV.A-2. PILOT PLANT DETAILED COST BREAKDOWN (Continued)

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT[1]	LABOR[2]	TOTALS	
8100	Indirects		6,208,000		6,208,000
8100.1	Architectural Engineering Services				1,440,000
8100.11	Preliminary Design Services (Title I)	--	329,000	329,000	
8100.12	Detailed Design Services (Title II)	--	824,000	824,000	
8100.13	Engineering Support During Construction (Title III)	--	287,000	287,000	
8100.3	Solar Subsystem Integration Contractor				3,365,000
8100.31	Compatibility Analysis[4]	--	1,026,000	1,026,000	
8100.32	Program Planning[4]	--	135,000	135,000	
8100.33	Program Control and Monitoring Functions[4]	--	901,000	901,000	
8100.34	Subsystem Design Verification Functions[4]	--	115,000	115,000	
8100.35	Solar System Checkout[4]	--	380,000	380,000	
8100.36	Program Management (Solar Integration Contract)[4]	--	588,000	588,000	
8100.37	Industrial and Systems Safety[4]	--	220,000	220,000	
8100.41	Collectors (Repeats costs in 4190.16)				
8100.411	Collector Design Costs[4]		671,000(3)		
8100.412	Collector Engineering Support Costs[4]		951,000(3)		
8100.42	Receivers (Repeats costs in 4190.26)				
8100.43	Storage (Repeats costs in 4190.36)				
8100.431	Storage Home Engineering[4]		1,339,000(3)		
8100.432	Storage Field Engineering[4]		992,000(3)		
8100.5	Master Control Design				
8100.51	Software Design (repeats costs in account 4402.5)	--	235,000(3)		
8100.52	Hardware Design (repeats costs in account 4402.7)	--	105,000(3)		
8100.53	Software/Hardware Test (repeats costs in account 4402.6)	--	122,000(3)		
8100.6	Plant Startup Costs				1,403,000
8100.61	Collectors[4]	--	301,000	301,000	
8100.62	Receivers[4]	--	235,000	235,000	
8100.63	Thermal Storage[4]	--	440,000	440,000	

TABLE IV.A-2. PILOT PLANT DETAILED COST BREAKDOWN (Continued)

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT[1]	LABOR[2]	TOTALS
8100.64	EPGS/BOP[4]	--	240,000	240,000
8100.65	Master Control System[4]	--	27,000	27,000
8100.66	Solar Integrator[4]	--	160,000	160,000
8300	Contingency			9,098,000

Table IV.A-3. Pilot Plant CBS Items Not Included

	CBS Item	Note
4000	Land and Land Rights	1
4000.1	Land and Privileges Acquisitions	1
4000.11	Land and Surveys	1
4000.12	Easements and Right-of-Way	1
4000.13	Clearing Land, Including Demolition of Structures	1
4100.5	Waterfront Improvements	2
4100.6	Roads Constructed to Connect the Project Site with Public Roads	3
4100.7	Railway Access	2
4100.8	Water Access Facilities	2
4100.9	Air Access Facilities	2
4106	Circulating and Service Water Pumphouse (at Water Source)	4
4106.1	Substructure	4
4106.2	Superstructure	4
4106.4	Building Mechanical System	4
4106.5	Electrical	4
4106.6	Painting	4
4142	Water Treatment Building	2
4142.1	Substructure	2
4142.2	Superstructure	2
4142.4	Building Mechanical System	2
4142.5	Electrical	2
4142.6	Painting	2
4143	Sewage Treatment	4
4143.1	Substructure	4
4143.2	Superstructure	4
4143.4	Building Mechanical System	
4143.5	Electrical	4
4143.6	Painting	4
4170	Thermal Storage Structure	2
4170.1	Substructure	2
4170.2	Superstructure	2
4170.4	Building Mechanical System	
4170.5	Electrical	
4170.6	Painting	2

Table IV.A-3. (Continued)

	CBS Item	Note
4190.114	Protective Enclosures	2
4190.131	Sensor Unit	2
4190.132	Sensor Tower	2
4190.134	Wiring Between Heliostat and Sensor	2
4190.17	Packing Containers and Transportation to Power Plant Site	2
4190.171	Containers for Shipping	2
4190.172	Transportation	2
4300.122	Structural Steel (Turbine Generator)	2
4300.13	Standby Exciters (Turbine Generator)	2
4300.15	Gas System	2
4300.151	Hydrogen	
4300.152	Carbon Dioxide	2
4300.16	Reheaters	2
4300.23	Exhaust Ducts from Turbine to Heat Rejection Equipment	2
4300.24	Evaporation Pond for Cooling Tower Blowdown	5
4300.511	Evaporator System (Make-up Treatment)	2
4300.523	Condensate and Demineralized Stored Water Treatment System	2
4401.3	Switchboards	2
4500.111	Turbine Building Crane	2
4500.12	Railway Equipment	2
4500.13	Roadway Equipment	?
4500.14	Watercraft	2
4500.15	Vehicle Maintenance Equipment	2
4500.16	Receiver Maintenance Assembly and Handling of Parts Receiver	2
4500.18	Thermal Storage Equipment for Maintenance, Assembly, and Handling of Thermal Storage Material and Parts	2
4500.212	Subatmospheric Air	2
4500.221	Water Supply Pumps and Drives	2
4500.223	Water Conditioning System	2
4500.225	Station Service Pumps and Drives	2
4500.226	Domestic Water Treatment Equipment	2
4500.227	Domestic Water Pumps and Drives	2
4500.228	Water Heating Equipment	2
4500.45	Dining Facilities	2

Table IV.A-3. (Continued)

	CBS Item	Note
7000	Quality Assurance	2
8040.35	Aggregate Plant	2
8040.36	Concrete Batch Plant	2
8040.7	Federal and State Taxes - Field Payroles	6
8040.8	Foreign Duties and Taxes	2
8100.2	Construction Management	7

NOTES:

1. Letter Skinrood to Blake, December, 1976, Attachment A (Reference 1).
2. Item not required in plant design being costed.
3. Letter Skinrood to Blake, December 15, 1976, Attachment C (Reference 1).
4. Letter DuVal to Blake, et al, Pilot Plant Site Parameter, November 3, 1976 (Reference 2).
5. Available at Pilot Plant site.
6. Included in field labor cost.
7. This item is considered to be a government cost item as part of the SPO office.

TABLE IV.B-1. PILOT PLANT TWO YEAR TEST PROGRAM COST

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT	LABOR	TOTALS
1000	Operations and Maintenance		384,000	560,000
2000	Test Program Technical Support		2,296,000	2,296,000
3000	Spare Parts	474,000		474,000
	TOTAL COST			3,330,000

Account Number	Description	FY 1978	FY 1979	FY 1980	FY 1981	FY 1982	FY 1983
4100	Yard Work	388	129				
4103-4146	Buildings	287	993				
4190.1	Collector Equipment	16,214	2,348	828			
4190.2	Receiver and Tower System	5,336	4,285	582			
4190.3	Thermal Storage Equipment	2,195	7,582	523			
4190.4	Thermal Storage Material		91	785			
4300	Turbine Plant Equipment	2,854	1,285	50			
4401	Electric Plant Equipment	951	425	30			
4402	Plant Master Control Equipment	726	967	420			
4500	Miscellaneous Plant Equipment	430	444				
8000	Distributables	2,635	699	5			
8100	Indirects	2,465	1,977	1,381	385		
8300	Contingency	5,014	3,428	652	4		
1000-3000	Two-Year Test Program	276	23	188	1,462	1,234	147
	TOTAL COMMITTED DOLLARS	39,771	24,676	5,444	1,851	1,234	147

Figure IV.C-1. Time Phasing of Committed Dollars ($ Thousands)

Account Number	Description	FY 1978	FY 1979	FY 1980	FY 1981	FY 1982	FY 1983
4100	Yard Work	388	129				
4103-4146	Buildings	247	993				
4190.1	Collector Equipment	1,977	16,565	828			
4190.2	Receiver and Tower System	4,535	5,088	580			
4190.3	Thermal Storage Equipment	2,059	5,814	2,427			
4190.4	Thermal Storage Material		68	808			
4300	Turbine Plant Equipment	1,640	2,400	149			
4401	Electric Plant Equipment	500	852	54			
4402	Plant Master Control Equipment	488	1,040	585			
4500	Miscellaneous Plant Equipment	330	445	99			
8000	Distributables	1,560	1,520	259			
8100	Indirects	2,465	1,521	1,630	592		
8300	Contingency	2,469	5,471	1,112	46		
100-3000	Two-Year Test Program	23	276	188	1,462	1,234	147
	TOTAL SPENT DOLLARS	18,681	42,182	8,719	2,100	1,234	147

Figure IV.C-2. Time Phasing of Spent Dollars ($ Thousands)

V. COMMERCIAL PLANT COST ESTIMATES

A. COMMERCIAL PLANT DETAILED COSTS

1. First Plant

The total cost of the first 150 MWe commercial power plant has been estimated to be $453,300,000.

The plant costs are shown at the summary account level in Table V.A-1 and the detailed cost breakdown is given in Table V.A-2. Background information for these costs is presented in Appendix B - Basis for Commercial Plant Cost Estimates.

Certain items in the original cost breakdown structure (Reference 1, Attachment C) have been omitted from Tables V.A-1 and V.A-2. The omitted items and the reasons for their omission are listed in Table V.A-3.

2. Non-Recurring Cost of First Plant

The detailed cost estimate presented previously in this section represents an estimate of a "first" commercial plant. Thus, it can be expected that some cost savings (in constant dollars) would be realized on the construction of subsequent identical plants. This non-recurring cost has been estimated at $17,000,000.

In arriving at this figure, it was assumed that all subsequent plants would be of exactly the same design and constructed at the same site and that all procurements were from the same vendors and contractors. The non-recurring costs are tabulated in Table V.A-4 at the subsystem level. This table also indicates the source of the cost. Approximately 60% of the cost is for non-recurring development and tooling while 40% is for non-recurring design and project management.

B. EFFECT OF PLANT SIZE (COST CURVES)

The installed cost of a "first" commercial plant has been estimated for a range of plant sizes. The data are presented in Figure V.B-1 as a function of specific thermal storage capacity and solar multiple,

Table V.A-1 COMMERCIAL PLANT COST SUMMARY

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT (1)	LABOR (2)	TOTALS
4000	Land and Land Rights	1,030,000		1,030,000
4100	Yardwork	3,250,000	120,000	3,370,000
4103	Turbine Building	510,000	290,000	800,000
4105	Administration/Control Building	650,000	150,000	800,000
4108	Warehouse (Included in 4141)			
4141	Maintenance/Warehouse Building	280,000	100,000	380,000
4144	Fire Pump House (4)	30,000		30,000
4145	Condensate Pump House (4)	20,000		20,000
4146	Gate House (4)	10,000		10,000
4180	Control Building (Included with 4105)			
4190.1	Collector Equipment	141,730,000	23,480,000	165,210,000
4190.2	Receiver and Tower System	58,000,000	36,674,000	95,410,000
4190.3	Thermal Storage Equipment			51,010,000
4190.4	Thermal Storage Material	10,340,000	140,000	10,480,000
4300	Turbine Plant Equipment	21,850,000	2,310,000	24,160,000
4401	Electric Plant Equipment	2,430,000	2,380,000	4,810,000
4402	Plant Master Control Equipment	840,000	1,220,000	2,060,000
4500	Miscellaneous Plant Equipment	2,270,000	900,000	3,170,000
5309	Transmission Plant	420,000	30,000	450,000
8000	Distributables	13,370,000	670,000	14,040,000
8100	Indirects		15,930,000	16,930,000
8300	Contingency			59,130,000
	Total Pilot Plant Costs			453,300,000

Notes:

(1) Subcontracted work is included in the Material/Equipment column.

(2) Design and engineering costs are shown in the labor column.

(3) Design costs shown in accounts 8100.4 and 8100.5 are repetitive and non-additive.

(4) Items added to Sandia Cost Breakdown Structure.

TABLE V.A-2 COMMERCIAL PLANT DETAILED COST BREAKDOWN

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT (1)	LABOR (2)	TOTALS	
4000	Land and Land Rights	1,030,000			1,030,000
4000.1	Land and Priviledge Acquisition				
4000.11	Land and Surveys	1,030,000		1,030,000	
4000.12	Easements and Rights-of-Way (Included in 4000.11)				
4000.13	Clearing Land and Demolition (assumed clear)				
4100	Yard Work	3,250,000	120,000		3,370,000
4103	Turbine Building	510,000	290,000		800,000
4105	Administration/Control Building	650,000	150,000		800,000
4108	Warehouse (Included in 4141)				
4141	Maintenance/Warehouse Building	280,000	100,000		380,000
4144	Fire Pumphouse (4)	30,000			30,000
4145	Condensate Pumphouse (4)	20,000			20,000
4146	Gatehouse (4)	10,000			10,000
4180	Control Building (Included in 4105)				
4190	Solar Plant Equipment				
4190.1	Collector Equipment	141,730,000	23,480,000		165,210,000
4190.11	Reflective Unit				75,210,000
4190.111	Mirror	9,010,000		9,010,000	
4190.112	Mirror Assembly	35,400,000		35,400,000	
4190.113	Heliostat Support Structure	30,800,000		30,800,000	
4190.12	Drive Unit				50,310,000
4190.121	Azimuth Drive Assembly	19,300,000		19,300,000	
4190.122	Elevation Drive Assembly	16,920,000		16,920,000	
4190.123	Motors	4,640,000		4,640,000	
4190.124	Position and Limit Indicators	5,740,000		5,740,000	
4190.125	Emergency Power Supply (Included in 4401.23)				
4190.126	Power Distribution Equipment from Electric Plant	1,940,000	1,770,000	3,710,000	
4190.13	Sensor/Calibration Equipment				930,000
4190.133	Calibration Equipment	810,000	120,000	930,000	
4190.14	Control/Instrumentation Equipment				20,160,000
4190.141	Field Control Electronics	10,300,000	8,470,000	18,770,000	
4190.142	Computer Hardware	100,000		100,000	
4190.143	Signal Distribution Equipment and Wiring	410,000	880,000	1,290,000	

TABLE V.A-2 COMMERCIAL PLANT DETAILED COST BREAKDOWN (Continued)

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT (1)	LABOR (2)	TOTALS	
4190.15	Foundation and Site Preparation				8,760,000
4190.151	Foundation	6,080,000	2,480,000	8,560,000	
4190.152	Site Preparation	200,000		200,000	
4190.16	Collector Subsystem Design and Engineering Costs				1,430,000
4190.161	Design Costs		420,000	420,000	
4190.162	Engineering Support During Manufacturing, Installation, and Checkout		1,010,000	1,010,000	
4190.18	Field Assembly, Installation and Checkout				7,940,000
4190.181	Heliostat and Control Equipment		7,700,000	7,700,000	
4190.1811	Field Assembly		3,000,000	3,000,000	
4190.1812	Installation and Checkout		4,700,000	4,700,000	
4190.182	Calibration Equipment		240,000	240,000	
4190.1821	Field Assembly		70,000	70,000	
4190.1822	Installation and Checkout		100,000	100,000	
4190.1823	Calibration		70,000	70,000	
4190.19	Lightning Protection	80,000			80,000
4190.20	Project Management (4)		390,000		390,000
4190.2	Receiver and Tower System	58,480,000	36,930,000		95,410,000
4190.21	Receiver Unit				40,080,000
4190.211	Absorber Unit				
4190.2111	Absorber	2,540,000	4,530,000	7,070,000	
4190.2112	Drum	400,000	640,000	1,040,000	
4190.2113	Doors, Casing, Lining, Insulation	1,940,000	1,130,000	3,070,000	
4190.212	Piping	1,880,000	370,000	2,250,000	
4190.213	Support Structure, Platforms, Etc.	5,520,000		5,520,000	
4190.214	Instrumentation and Control on Receiver and Tower	1,150,000		1,150,000	
4190.215	Packing and Transportation	730,000		730,000	
4190.216	Field Erection and Installation	4,250,000	15,000,000	19,250,000	

TABLE V.A-2 COMMERCIAL PLANT DETAILED COST BREAKDOWN (Continued)

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT[1]	LABOR[2]	TOTALS	
4190.22	Riser and Horizontal Feedwater Piping to Receiver				2,220,000
4190.221	From Turbine Generator Building	1,770,000	450,000	2,220,000	
4190.222	From Thermal Storage (Included in 4190.326)				
4190.23	Downcomer and Horizontal Steam Piping From Receiver				9,650,000
4190.231	To Turbine Generator Building	6,840,000	2,810,000	9,650,000	
4190.232	To Thermal Storage (Included in 4190.326)				
4190.24	Tower and Platform	26,660,000	6,030,000		32,690,000
4190.25	Tower Foundation and Site Preparation	4,800,000	3,380,000		8,180,000
4190.26	Receiver Subsystem Design Cost				2,330,000
4190.261	Tower and Foundation		300,000	300,000	
4190.262	Receiver		240,000	240,000	
4190.263	Riser, Downcomer, Horizontal Piping		1,790,000	1,790,000	
4190.27	Project Management[4]		260,000		260,000
4190.3	Thermal Storage	44,150,000	6,860,000		51,010,000
4190.31	Thermal Storage Unit				16,420,000
4190.311	Storage Tanks and Heaters	14,050,000		14,050,000	
4190.312	Insulation	2,330,000		2,330,000	
4190.313	Ullage Maintenance Equipment	40,000		40,000	
4190.314	Fluid Maintenance Equipment (*)				
4190.32	Circulation Equipment for Storage Media and Water/Steam				10,180,000
4190.321	Piping & Supports	3,140,000	1,200,000	4,340,000	
4190.322	Valves, Strainers, Filters, etc.	2,040,000		2,040,000	
4190.323	Pumps	1,030,000	140,000	1,170,000	
4190.324	Insulation	940,000		940,000	
4190.325	Steam Drums	190,000	110,000	300,000	
4190.326	Water/Steam Piping Between TSS and Turbine	1,070,000	320,000	1,390,000	

(*) No fluid maintenance equipment has been priced. If a side steam processor is found to be necessary, its cost can be added at approximately $2,030,000

TABLE V.A-2 COMMERCIAL PLANT DETAILED COST BREAKDOWN (Continued)

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT[1]	LABOR[2]	TOTALS	
4190.33	Heat Exchangers				19,630,000
4190.331	Attemperators	40,000		40,000	
4190.332	Steam Generator Heat Exchangers	10,900,000	270,000	11,170,000	
4190.333	Thermal Storage Heat Exchangers	7,670,000	200,000	7,870,000	
4190.334	Insulation	190,000		190,000	
4190.335	Support Structure	140,000	220,000	360,000	
4190.34	Instrumentation and Control Located at Thermal Storage Unit	220,000	10,000		230,000
4190.35	Foundation and Site Preparation				380,000
4190.351	Tank Foundations (Included in 4190.311)				
4190.352	Other Foundations	30,000	130,000	160,000	
4190.353	Dikes or Emergency Containment Structures	50,000		50,000	
4190.354	Site Preparation (Included in 4100.11)				
4190.355	Safety Protection Equipment	80,000	90,000	170,000	
4190.36	Design Cost		3,830,000		3,830,000
4190.37	Project Management[2]		340,000		340,000
4190.4	Thermal Storage Material	10,340,000	140,000		10,480,000
4190.41	Inorganic Material Cost	1,260,000		1,260,000	
4190.42	Organic Material Cost	7,410,000		7,410,000	
4190.43	Delivery	1,550,000		1,550,000	
4190.44	Handling at Site	120,000	140,000	260,000	
4300	Turbine Plant Equipment	21,850,000	2,310,000		24,160,000
4300.1	Turbine Generators				16,530,000
4300.11	Turbine Generator and Accessories	15,600,000	450,000	16,050,000	
4300.12	Foundations (Includes T/G Pedestal)	120,000	190,000	310,000	
4300.13	Standby Exciters	10,000		10,000	
4300.14	Lubricating System	10,000	10,000	20,000	
4300.17	Weather-Proof Housing	130,000	10,000	140,000	

TABLE V.A-2 COMMERCIAL PLANT DETAILED COST BREAKDOWN (Continued)

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT (1)	LABOR (2)	TOTALS	
4300.2	Heat Rejection System				5,050,000
4300.21	Heat Rejection Equipment	4,050,000		4,050,000	
4300.22	Installation Cost		1,000,000	1,000,000	
4300.3	Condensing Systems				290,000
4300.31	Condensate System	90,000	110,000	200,000	
4300.32	Turbine Bypass System	60,000	30,000	90,000	
4300.4	Feed-Heating System				1,520,000
4300.41	Regenerative Heat Exchangers	510,000	20,000	530,000	
4300.42	Pumps	250,000	90,000	340,000	
4300.43	Piping and Tanks	400,000	250,000	650,000	
4300.5	Water Circulation/Treatment Equipment				630,000
4300.51	Make-up Treatment System	130,000	40,000	170,000	
4300.52	Chemical Treatment and Condensate Purification Systems	370,000	90,000	460,000	
4300.6	Auxiliary Boiler (Seal and Trace Steam)(4)	120,000	20,000		140,000
4401	Electric Plant Equipment	2,430,000	2,380,000		4,810,000
4401.1	Switchgear				1,070,000
4401.11	Generator Circuits	270,000	60,000	330,000	
4401.12	Station Service	670,000	70,000	740,000	
4401.2	Station Service Equipment				330,000
4401.21	Station Service and Startup Transformers	140,000	20,000	160,000	
4401.22	Low Voltage Unit Substation and Lighting Transformers	(Included in	Buildings)		
4401.23	Auxiliary Power Sources	120,000	20,000	140,000	
4401.3	Switchboards	20,000	10,000	30,000	
4401.4	Protective Equipment				480,000
4401.41	General Station Grouping System	180,000	140,000	320,000	
4401.42	Fire Protection Equipment	20,000	20,000	40,000	
4401.43	Cathodic and Freeze Protection	100,000	20,000	120,000	
4401.5	Electrical Structure and Wiring Containers	720,000	1,790,000		2,510,000
4401.6	Power Wiring	190,000	230,000		420,000

TABLE V.A-2 COMMERICAL PLANT DETAILED COST BREAKDOWN (Continued)

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT(1)	LABOR(2)	TOTALS
4402	Plant Master Control	840,000	1,220,000	2,060,000
4402.1	Computer	60,000		60,000
4402.2	Peripheral Equipment	40,000		40,000
4402.3	Control Panel and Boards	490,000	10,000	500,000
4402.4	Interface Equipment	120,000	40,000	160,000
4402.5	Software Design and Development		300,000	300,000
4402.6	Software/Hardware Test		160,000	160,000
4402.7	Hardware Design		140,000	140,000
4402.8	Control Wiring			
4402.81	From Collector Field (Included in 4190.143)			
4402.82	From Thermal Storage	10,000	20,000	30,000
4402.83	From Receiver	110,000	180,000	290,000
4402.84	From EPGS	10,000	20,000	30,000
4402.10	Project Management (4)		350,000	350,000
4500	Miscellaneous Plant Equipment	2,270,000	900,000	3,170,000
4500.1	Transportation and Lifting Equipment	1,200,000	40,000	1,240,000
4500.2	Air and Water Service Systems	800,000	740,000	1,540,000
4500.3	Communications Equipment	70,000	90,000	160,000
4500.4	Furnishing and Fixtures	200,000	30,000	230,000
5309	Transmission Plant	420,000	30,000	450,000
8000	Distributables	13,370,000	670,000	14,040,000
8030	Contractor Field Office Personnel and Supplies	240,000	670,000	910,000
8040	Other Construction Items			
8040.1	Insurance (Project)	200,000		200,000
8040.2	Insurance (Equipment)	20,000		20,000
8040.3	Temporary Construction	2,440,000		2,440,000
8040.4	Construction Equipment	3,420,000		3,420,000
8040.5	Construction Services	5,000,000		5,000,000
8040.6	Spare Parts	2,050,000		2,050,000

TABLE V.A-2 COMMERCIAL PLANT DETAILED COST BREAKDOWN (Continued)

ACCOUNT NUMBER	DESCRIPTION	MATERIAL/ EQUIPMENT (1)	LABOR (2)	TOTALS	
8100	Indirects				16,930,000
8100.1	Architectural Engineer Services				10,110,000
8100.11	Preliminary Design Services (Title I)		1,630,000	1,630,000	
8100.12	Detailed Design Services (Title II)		4,500,000	4,500,000	
8100.13	Engineering Support During Construction (Title III)		3,980,000	3,980,000	
8100.3	Solar Subsystem Integration Contractor		3,580,000		3,580,000
8100.4	Engineering and Design of Solar Subsystems				
8100.41	Collectors		14,340,000 (3)		
8100.42	Receivers		2,330,000 (3)		
8100.43	Storage		3,830,000 (3)		
8100.5	Master Control Design				
8100.51	Software Design		300,000 (3)		
8100.52	Hardware Design		140,000 (3)		
8100.53	Software/Hardware Test		160,000 (3)		
8100.6	Plant Startup Costs		3,240,000		3,240,000
8300	Contingency				59,130,000

Table V.A-3. Commercial Plant CBS Items Not Included

	CBS Item	Note
4106	Circulating and Service Water Pumphouse (at Water Source)	2
4142	Water Treatment Building	1
4143	Sewage Treatment	2
4170	Thermal Storage Structure	1
4190.114	Protective Enclosures	1
4190.131	Sensor Unit	1
4190.132	Sensor Tower	1
4190.134	Wiring Between Heliostat and Sensor	1
4190.17	Packing Containers and Transportation to Power Plant Site	1
4300.16	Reheaters	1
4300.23	Exhaust Ducts from Turbine to Heat Rejection Equipment	1
4401.3	Switchboards	1
7000	Quality Assurance	1
8040.7	Federal and State Taxes - Field Payroles	3
8040.8	Foreign Duties and Taxes	1
8100.2	Construction Management	4

1. Item not required in plant design being costed.
2. Letter DuVal to Blake, et al, Pilot Plant Site Parameter, November 3, 1976.
3. Included in field labor cost.
4. This item is considered to be a government cost item as part of the SPO office.

Table V.A-4. Commercial Plant Non-Recurring Cost

Subsystem	Non-Recurring Cost (Dollars)	Source*
EPGS/BOP**	6,000,000	Development/Tooling Costs for piping bellows, high pressure feedwater heaters and pumps, Design costs.
Receiver	300,000	Design and project management costs.
Thermal Storage	7,300,000	Vendor design and tooling costs for major equipment such as tanks and heat exchangers and contractor design, field engineering and project management costs.
Collector System	2,800,000	Development/tooling costs for mirror backing structure and drive units. Purchase price of reusable construction equipment. Design and project management costs.
Master Control System	500,000	Software/Hardware design and project management costs.
TOTAL	16,900,000	

*Indicates the class of cost where non-recurring costs occur and does not necessarily imply that all of the cost in that class is non-recurring.

**Includes non-recurring design costs for heliostat foundations and receiver towers and tower foundations.

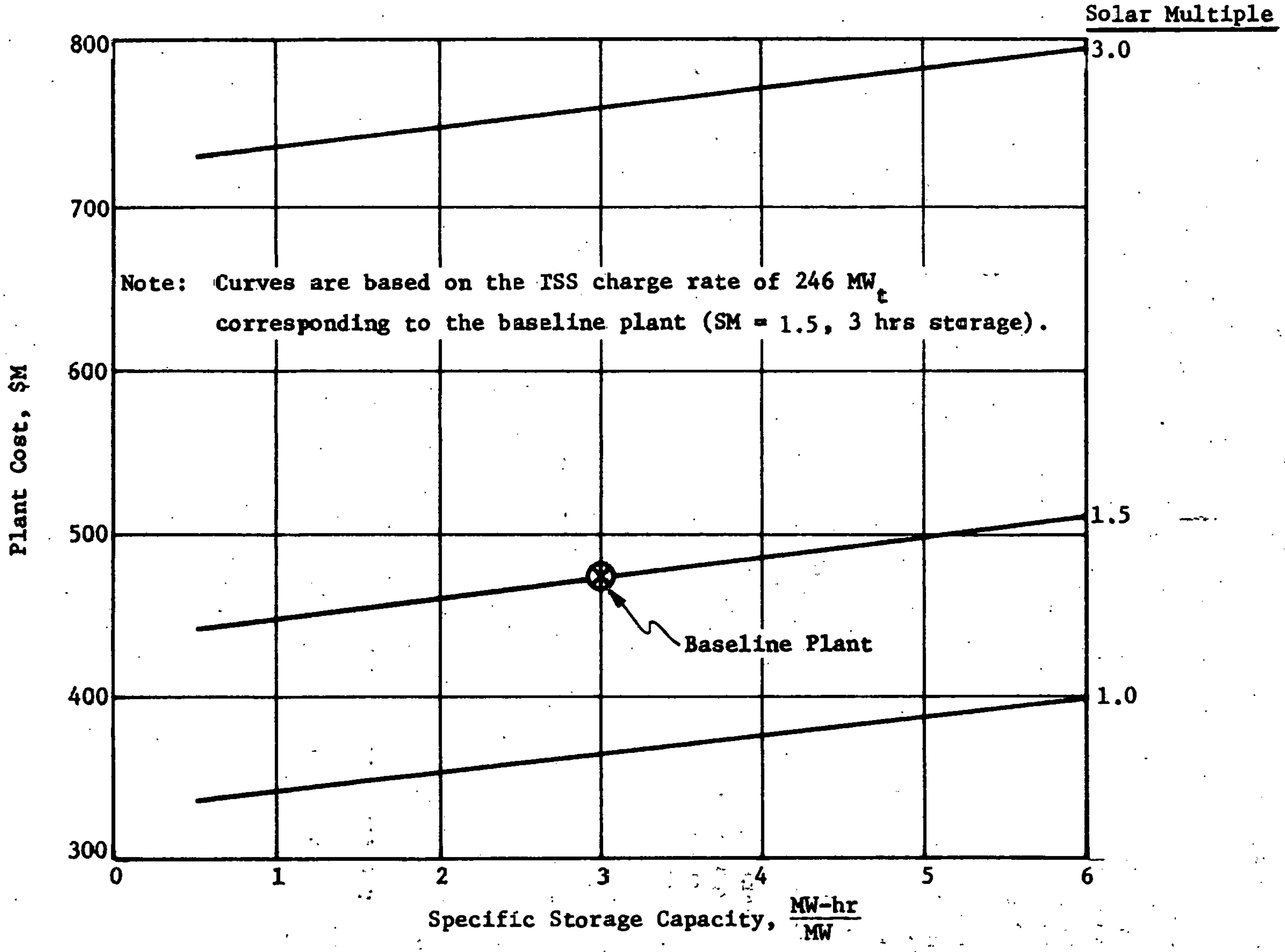

Figure V.B-1 Commercial Plant Cost Data Curves and in Figure V.B-2 as a function of thermal storage charge rate. The data in Figure V.B-1 were computed on the basis of a maximum thermal storage charge rate of 246 MWt--the design point or baseline plant value. The cost differences shown in Figure V.B-2 must be added to the overall cost shown in Figure V.B-1 to obtain the total plant cost for a different charge rate. This was done because various plant use strategies could call for varying storage charge rates for a given solar multiple. In this way, it is not necessary to define a specific relation between solar multiple and charge rate.

In varying the solar multiple, the cost differentials are mainly the result of the number of heliostats, towers, and receivers. Cost differentials between storage capacities result primarily from the cost of oil tanks and piping, salt tanks, and the storage fluids themselves. Varying the thermal storage charge rate results in cost changes due primarily to increased or decreased heat exchanger requirements.

In general, the cost curves shown in Figures V.B-1 and V.B-2 were derived by comparison with the baseline plant for which the detailed estimate was presented in paragraph A of this section. This plant cost is indicated in Figure V.B-1.

Costs of other plants were estimated in basically the same way as were the costs for the baseline plant as indicated in Appendix B. The major difference was in estimating material/equipment costs. Since vendor quotes were obtained only for the baseline plant, the cost of materials in increased or decreased quantities and equipment of differing capacity or size was estimated on the basis of learning curves, cost scaling "laws", and historical production data.

Labor costs were derived for all plants either by estimating the actual manpower required for design, installation, and checkout or by applying historical percentages based on installed cost of construction work or similar projects.

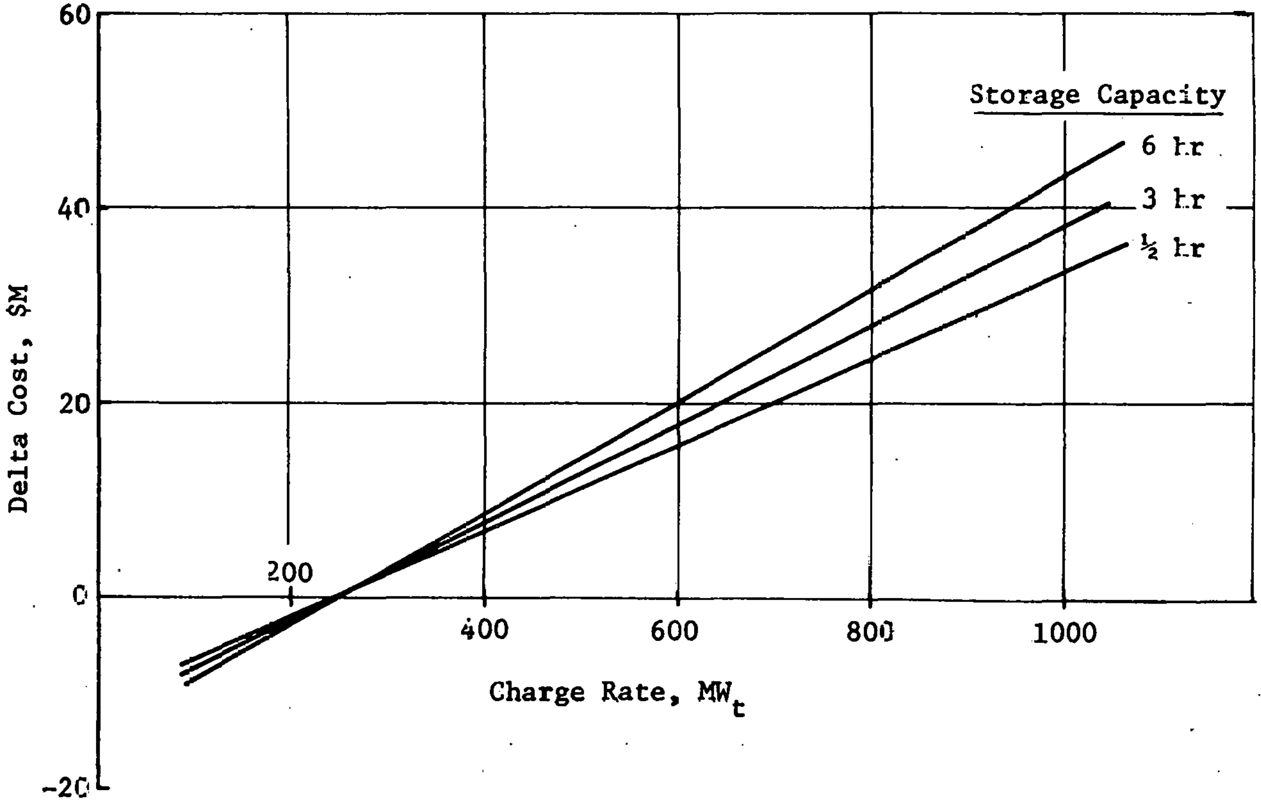

Figure V.B-2 Thermal Storage System Charge Rate Cost Differential

C. ANNUAL OPERATION AND MAINTENANCE COSTS

Annual operations and maintenance costs for the 150 MW_e commercial plant have been estimated at $2,385,000. The costs are shown in Table V.C-1 at the subsystem level and the basis of the estimate is discussed in the following paragraphs.

1. EPGS/BOP

Data on operating and maintenance costs for power plants vary widely depending on the size, capacity factor, and complexity of the plant. Typical figures are:

- 2 mills/KWH for large coal plants without scrubbers (EPRI, Bechtel)

- 1.5 mills/KWH for small (60 MW_e) coal plants (FPC)

- 0.5 mills/KWH for geothermal steam plants (PG&E Geysers Plant)

The Geysers geothermal plant is not considered to be typical because it has an unusually high capacity factor (70%) and is relatively simple in operation. It was assumed that without a boiler, a large coal plant costs 1 mill/KWH. To this was added 1/2 mill/KWH for daily cycling (Basis: EPRI) and another 1/2 mill/KWH was added in consideration of the plants' operation for only 42% of the capacity of an equivalent fossil-fired plant, giving a total cost of 2 mills/ KWH. The following assumptions were made regarding annual power production:

- 150 MW_e for 8 hours per day

- 105 MW_e for 3 hours per day

- 65% capacity factor.

The resulting annual cost is $750,000 including an allowance for tower maintenance.

2. Receiver

Operation and maintenance costs were estimated by assuming a level of manpower effort required to operate and maintain the receivers. It was also assumed that acid cleaning of each receiver would be required once every 5 years. Finally, it was assumed that 25% of the spare parts inventory would be expended per year. The resulting cost is $350,000. This is equivalent to about 1 mill/KWH which supports the assumption made previously in the EPGS/BOP estimate regarding boiler O&M costs.

3. Thermal Storage System and Collector System

Operation and maintenance costs were estimated by assuming a level of manpower effort required to operate and maintain these systems. It was assumed that 25% of the spare parts inventory would be expended per year. Because of the large number of heliostats and the continuous requirement for mirror washing the costs for the collector system are significantly higher than for either the receiver or thermal storage systems.

Table V.C-1. Commercial Plant Annual Operations and Maintenance Costs

Subsystem	Annual Cost (Dollars)	Approximate Mills/KWH*
EPGS/BOP	750,000	2.1
Receiver	350,000	1.0
Thermal Storage	325,000	0.9
Collector System	960,000	2.7
TOTAL	2,385,000	6.7

*Assumes 150 MW_e for 8 hours/day, 105 MW_e for 3 hours/day, and a plant capacity factor of 65%.

Conventional power and process plant facility costs are not directly proportional to the plant capacity or output. Therefore, it is not to be expected that the cost of the 150 MW_e commercial plant would be 15 times the cost of the 10 MW_e pilot plant. In fact, the commercial plant cost is in proportion to the capacity raised to approximately the 0.7th power. Thus, the cost differs slightly from the well known "six-tenths-factor rule" (Reference 3) for estimating capital equipment costs. This is to be expected for the following reasons:

1. The pilot plant requirements are somewhat different from those of the commercial plant as follows: The collector subsystem for the pilot plant is not required to support three hours of thermal storage operation; land costs were not required for the pilot plant; and transmission plant costs were not required for the pilot plant.

2. The six-tenth-factor rule applies mainly to the purchase price and installation costs of process equipment such as turbines, pumps, heat exchangers, tanks, etc. For the solar plant there is a higher fraction of total cost associated with piping, wiring, concrete and the material prices of which vary more nearly linearly with quantity than do the prices of equipment with capacity.

3. In arriving at the commercial plant costs, advantage was taken not only of economics of scale, but also of anticipated cost savings due to quantity material buys, automated manufacturing facilities, effects of learning on labor costs, and design improvements.

Economies of Scale

Economies of scale are evident in the cost of the turbine-generator set and other major EPGS equipment, and in the costs of the thermal storage tanks and heat exchangers.

Mass Production

The effects of mass production in reducing costs have been factored into the commercial plant costs. Cost reductions due to quantity buys of materials, use of learning curves or labor manhours, automated manufacturing facilities, and anticipated design improvements for reducing costs have been realized primarily in the collector field and receiver/tower costs.

VI. COMMERCIAL PLANT PERFORMANCE DATA

A. INTRODUCTION/PLANT DESCRIPTION

Commercial Plant performance estimates requested by ERDA (Reference 1) are presented in this section. The data correspond directly to the baseline Commercial Plant described in Section II, and for which the detailed cost estimate was provided in Section V. For reference, the description of the Commercial Plant is summarized in Table VI.A-1.

The performance data are presented in Subsection B and are listed in numberical order corresponding to the reference letter (Reference 1).

B. PERFORMANCE DATA

1. Collector Subsystem Performance

Effect of Sun Position (Azimuth/Elevation)

The performance of the collector system is shown in Figure VI.B-1 as a function of azimuth and elevation angles of the sun. The data are expressed as the percent of direct normal insolation into the cavity,

$$\frac{DN_c}{DN_f} \times 100$$

where: DN_c = redirected power into receiver cavity

and: DN_f = direct normal insolation x mirror surface area

The performance data include the effects due to the following:

Cosine losses
Heliostat blocking and shading
Tower shadow
Tracking error including both static and wind induced errors
Mirror reflectivity including effect of washing frequency
Optical losses including beam size and shape and aberration.

Table VI.A-1. Commercial Plant Description

Design Point	
Site:	Inyokern, California
Direct Normal Insolation:	950 watts/m^2
Best Sun Angle:	Noon on Winter Solstice
Wind Speed:	3.5 m/s at 10m
Wet Bulb Temperature:	23^{o}C
Dry Bulb Temperature:	28^{o}C
Rated Output, Receiver Steam:	150 MW_e
Rated Output, Storage Steam:	105 MW_e for 3 hours
No. Collector Modules:	15
No. Heliostats:	23,310
Mirror Area:	9.56 x 10^5 m^2 (10.28 x 10^6 ft^2)
Land Use:	3,393 x 1.894m (11,133 x 6,214 ft)
Receiver Type:	Natural Circulation Boiler, North Facing, Horizontal Cavity
No. Receivers:	15
Maximum Receiver Input (Each):	52.3 MW_t
Maximum Receiver Steam (Each):	49.6 MW_t
Receiver Steam Conditions:	10,783 kPa (1550 psig) 789 K (960^{o}F)
Storage Type:	Two Stage Sensible Heat Salt & Oil
No. Tanks:	9
Volume of Tankage:	291,750 m^3 (1.07 x 10^6 ft^3)
Storage Steam Conditions:	2,855 kPa (400 psig) 700 K (800^{o}F)
Total Stored Capacity:	1189 MWH_t
Turbine Heat Rate - Receiver Steam (Gross)	9,655 kJ/kW-hr (9151 Btu/kW-hr)
Turbine Heat Rate - Storage Steam (Gross)	11,741 kJ/kW-hr (11,128 Btu/kW-hr)
Inlet Steam Conditions (Receiver Steam, Design Point)	9308 kPa (1350 psig) 783^{o}K (950^{o}F)

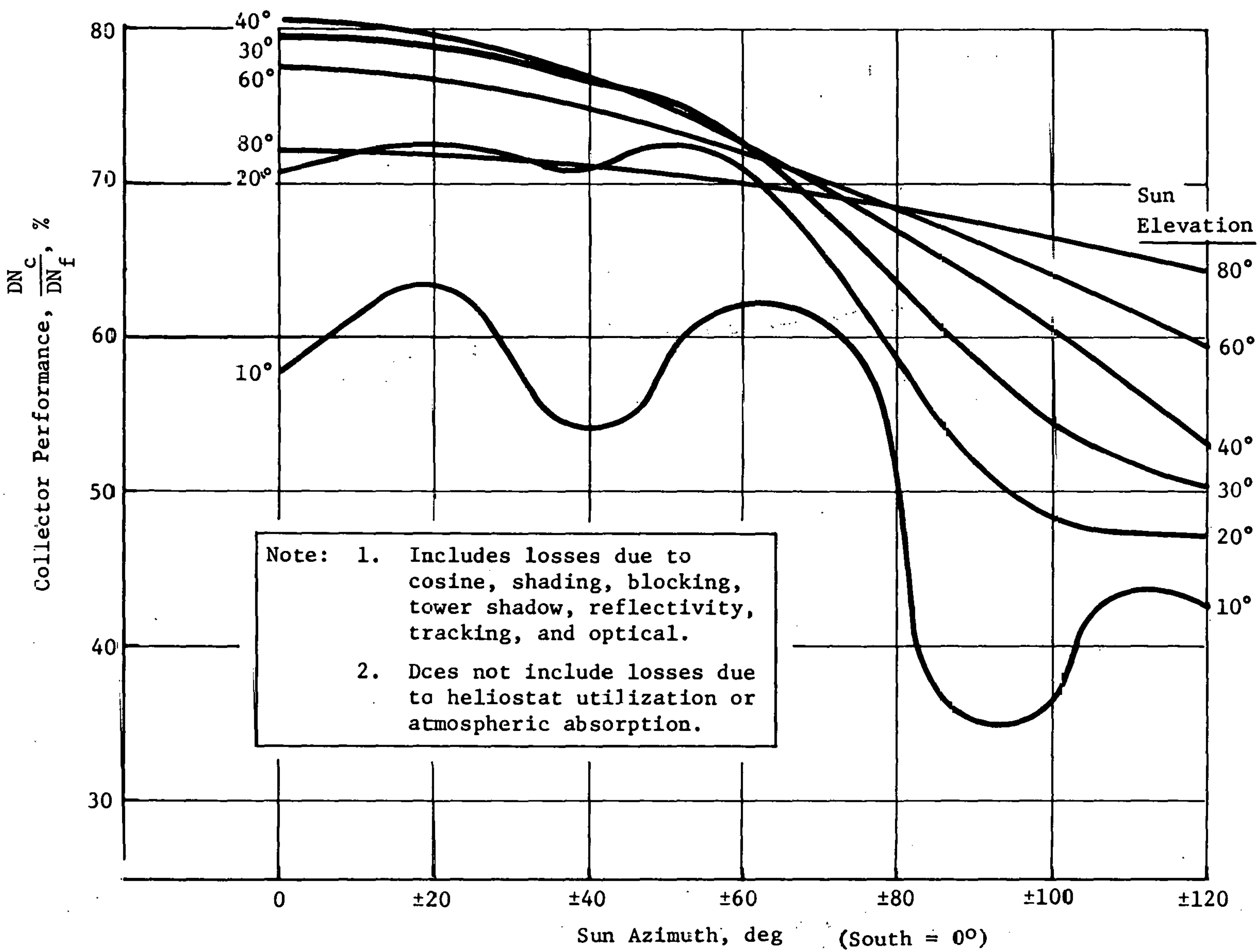

Figure VI.B-1 Collector Subsystem Performance

The data do not include effects due to heliostat outage (utilization) or atmospheric attenuation.

The oscillatory behavior of the data at lower elevation angles is the result of the close-in perimeter heliostats alternately shading and unshading multiple interior heliostats because of the low sun angles and field geometry.

Error Summary

A summary of collector field errors is presented in Table VI.B-1 in terms of the percent of power in the redirected beam which misses the receiver aperture, i.e., percent spillage.

Only structural deflection is a function of wind speed, and no identified source of error is a function of ambient temperature.

Losses due to gravity (structural deflection due to weight) and mirror aberration are functions of the time of year and time of day (i.e., sun position) and are given in Table VI.B-1 for 3 times of day on winter solstice, summer solstice, and the equinox.

A thorough discussion of the collector subsystem performance analysis is given in Volume II, Section III and Volume III, Section IV of this Preliminary Design Report.

2. Receiver Subsystem Performance

Maximum Permissible Power Into Cavity

The maximum permissible power into the receiver cavity is 52.3 MW_t/receiver.

Thermal Radiation Loss

Thermal power is lost due to both solar and infrared radiation back through the receiver aperture. Figure VI.B-2 shows the total radiation loss as a function of power into the cavity.

Convection Loss

Convective losses through the aperture due to air density gradients and wind are shown in Figure VI.B-3 as a function of both ambient temperature and wind speed at a height of 10 meters. For a given wind speed, this loss is a function primarily of the difference between the internal cavity temperature and the ambient temperature. Because the loss varies by only a few percent over the operating range of steam output rate, it is not shown as a function of power into the cavity.

Table VI.B-1. Error Summary (Percent Spillage)

Source	Independent of Wind & Temp.	Wind Speed(1), m/s: 0	1	3.5	8	12
Structural Deflection to Wind		0	0	0.1	0.6	3.6
Beam Size	1.0					
Tracking (No Wind)	0.3					

Spillage Due to Aberration(2), %

	Winter Solstice	Equinox	Summer Solstice
8 am	0.26	0.44	0.73
Noon	0.03	0.0	0.07
4 pm	0.26	0.44	0.73

Spillage Due to Structural Deflection (Weight Only)(2), %

	Winter Solstice	Equinox	Summer Solstice
8 am	0.40	0.02	0.02
Noon	0.10	0.0	0.09
4 pm	0.40	0.03	0.02

(1) Equal probability of wind from any direction has been assumed.

(2) Assumes mirrors are aligned for noon on vernal equinox.

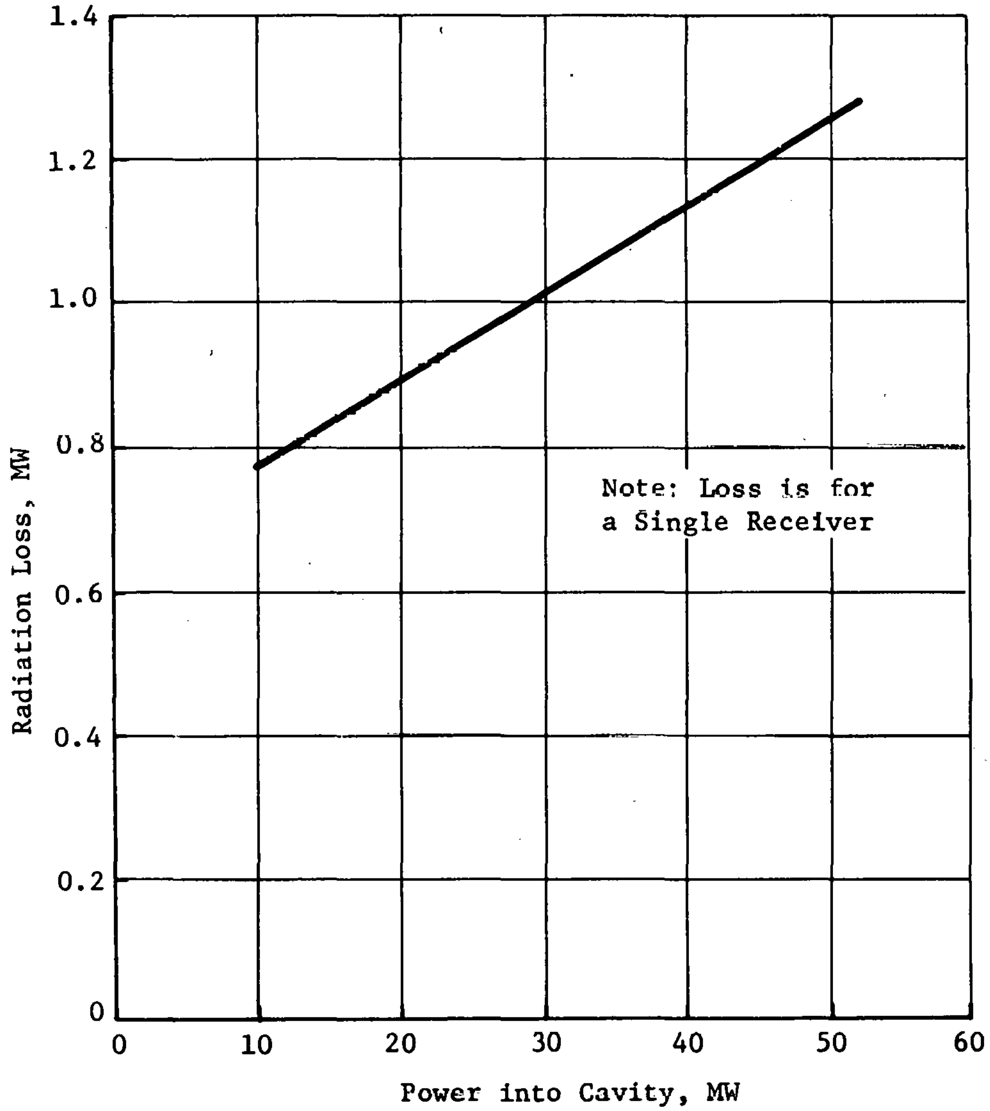

Figure VI.B-2 Receiver Radiation Heat Loss through Aperture

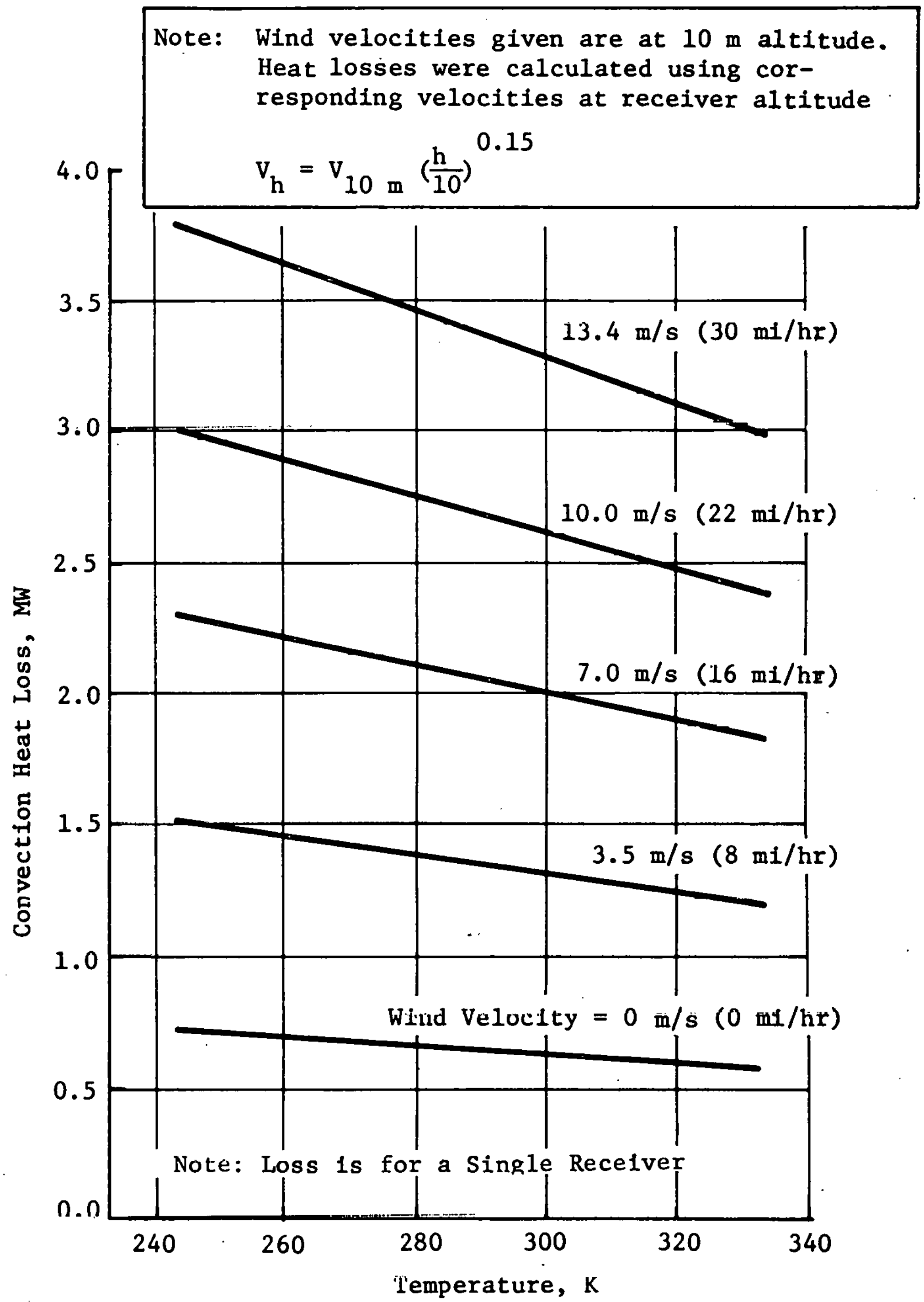

Figure VI.B-3
Receiver Convection Heat Loss through Aperture

Conduction Loss

Although not specifically requested, we have included an estimate of the conduction loss through the cavity walls for completeness. The total conduction loss is shown in Figure VI.B-4 and consists of losses through the insulation material and structural paths such as receiver hangers and seismic load snubbers.

Piping Thermal Loss

The steam and feedwater piping thermal losses are shown in Figure VI.B-5 as a function of ambient temperature and at design wind speed. When charging thermal storage approximately 4400 feet of additional pipe are required resulting in the increased loss as shown. The losses were computed by accounting for combined conduction, natural convection, and radiation heat loss for the vertical tower piping, and combined conduction and forced convection heat loss for the horizontal external piping.

3. Receiver Mass Flow

Figure VI.B-6 shows the total receiver steam flowrate (15 receivers) as a function of the power at the entrance to the turbine building. All losses up to that point have been accounted for. The maximum total receiver power is 728 MWt at the entrance to the turbine building. The minimum flow shown corresponds to the minimum with all 15 receivers operating. Lower flows can be obtained by operating less than 15 receivers.

4. Efficiency of Charging Thermal Storage

The efficiency of charging the thermal storage system is defined as the ratio of the power transferred into storage to the power available at the entrance to storage. This ratio is essentially equal to one. Note that heat is continuously lost from the thermal storage unit but that the rate is extremely small. The total diurnal heat loss is given in item 18.

5. Thermal Electric Conversion Gross Cycle Efficiency

The EPGS gross cycle efficiency is shown in Figure VI.B-7 as a function of turbine mass flowrate. Curves are given for both operation directly from the receiver and from thermal storage alone. The design point ambient wet bulb temperature of 23°C has been assumed.

At a fixed ambient wet bulb temperature the condenser back pressure will vary as a function of the heat rejection duty of the cooling towers. This varying back pressure is shown on the efficiency curves in Figure VI.B-7.

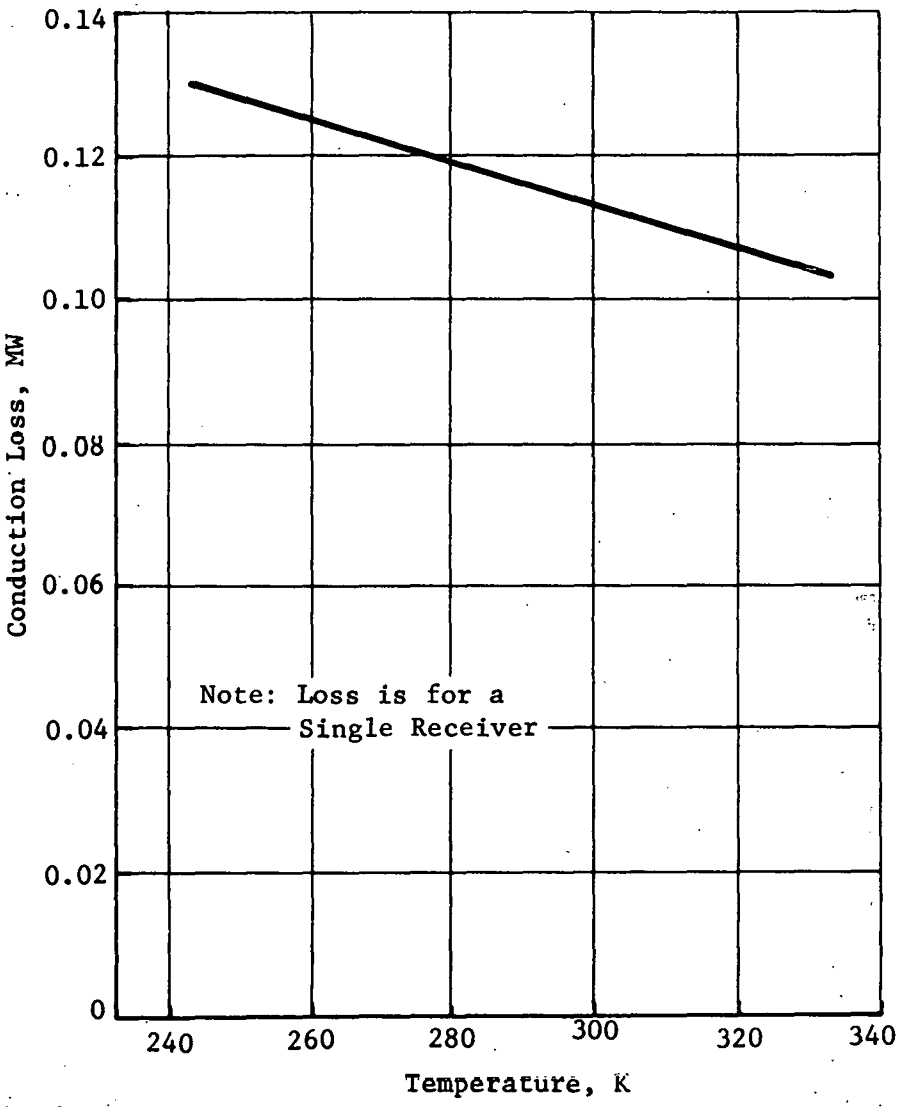

Figure VI.B-4
Receiver Conduction Heat Loss through Cavity Walls

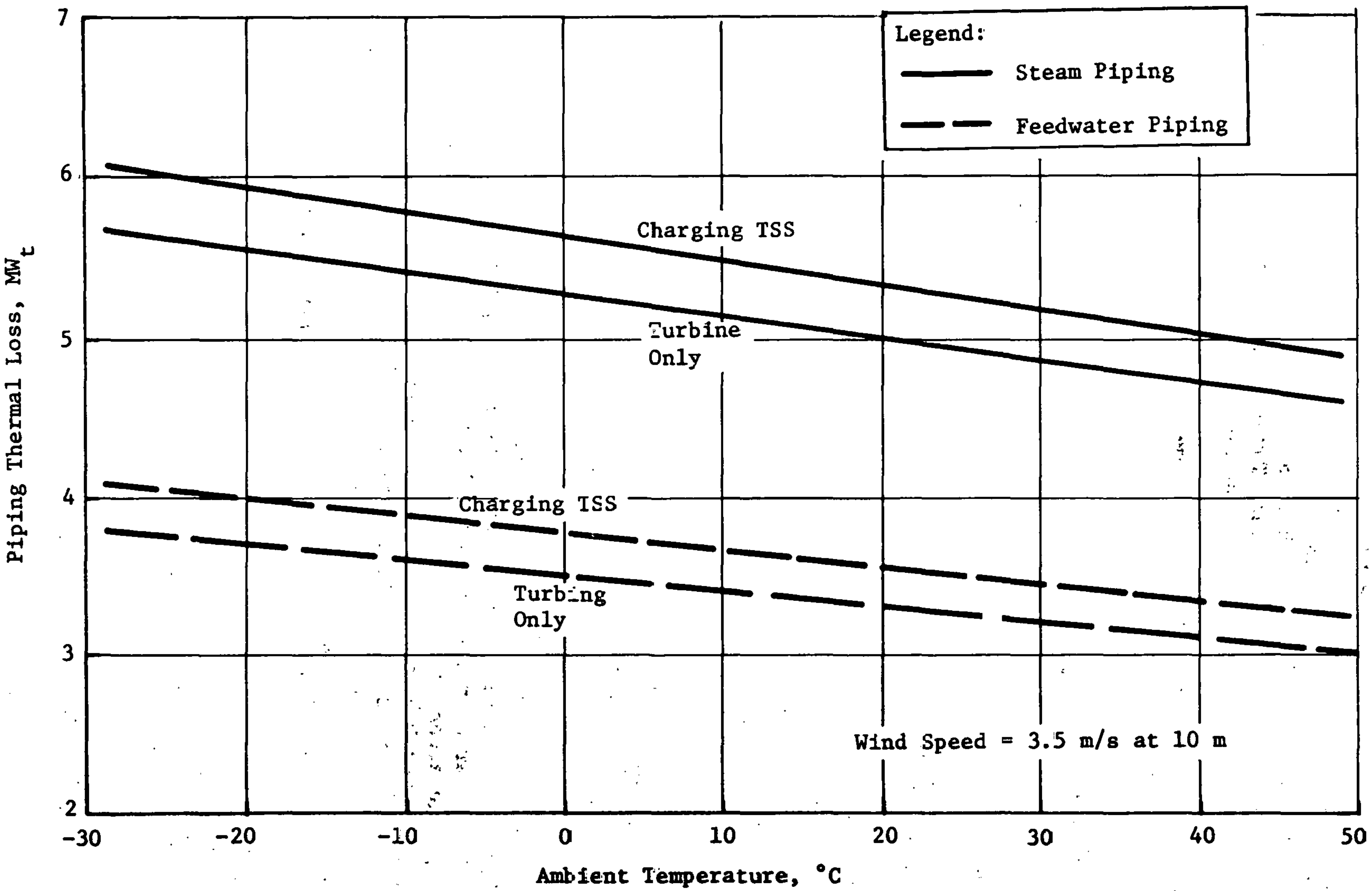

Figure VI.B-5
Commercial Plant Thermal Piping Losses

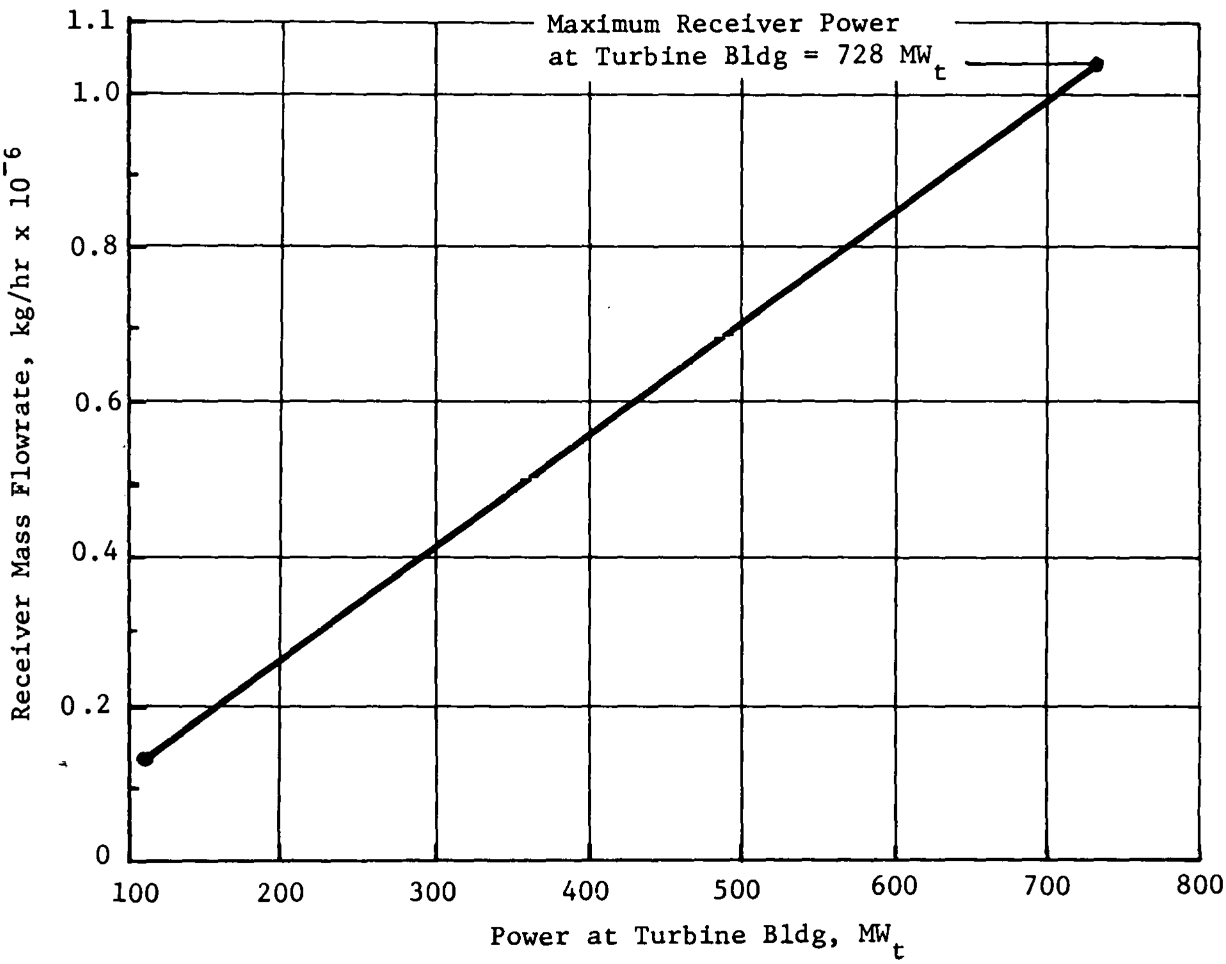

Figure VI.B-6 Receiver Mass Flow

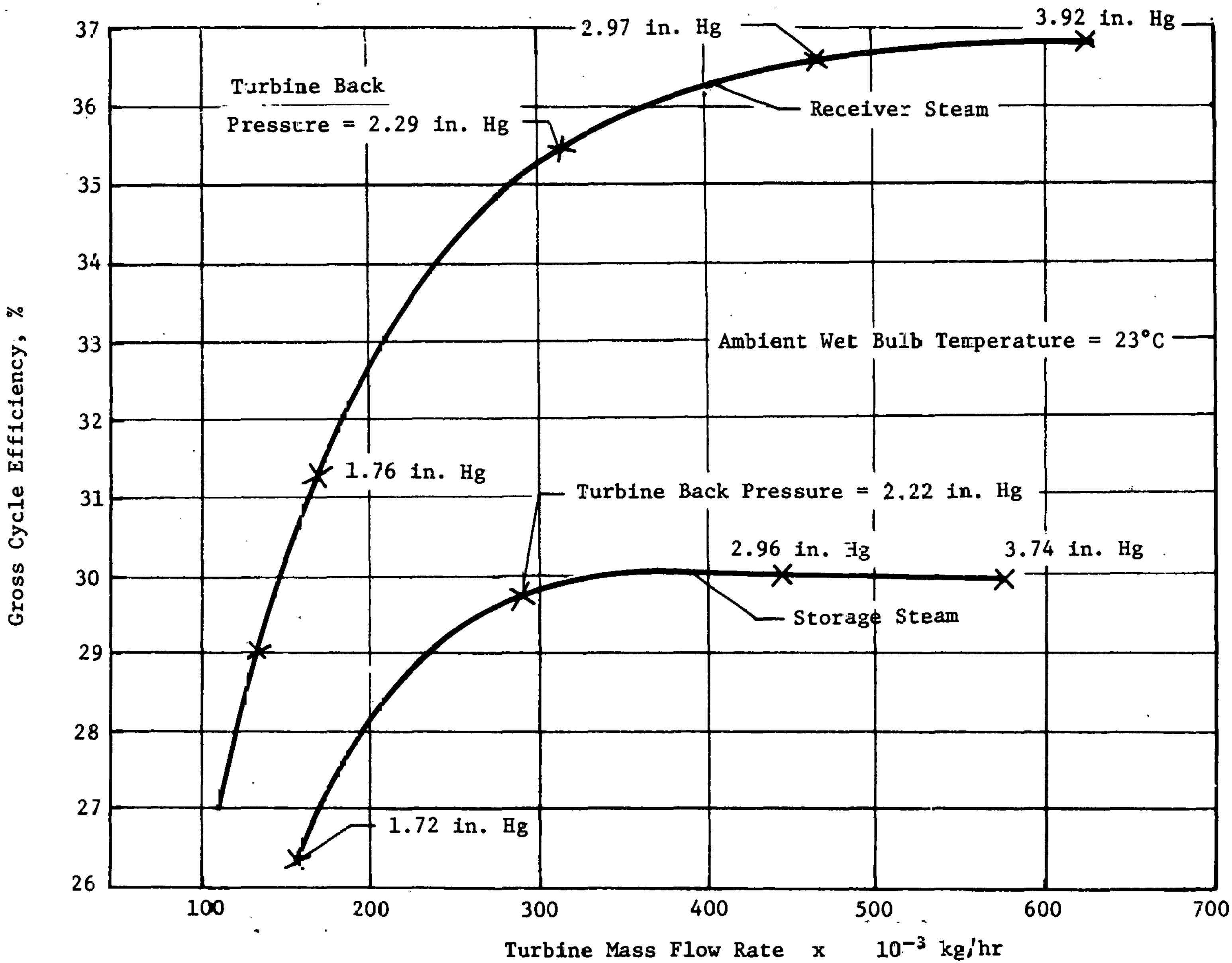

Figure VI.B-7
Gross Cycle Efficiency as a Function of Mass Flow Rate

The maximum and minimum allowable turbine flowrates are given in Table VI.B-2 below.

Table VI.B-2. Maximum/Minimum Turbine Mass Flowrates

Maximum (kg/hr)	
Receiver Steam,	617,400
Storage Steam,	574,500
Minimum (kg/hr)	
Receiver Steam,	62,000
Storage Steam,	62,000

6. Thermal Electric Conversion Net Cycle Efficiency on Receiver Steam Only

Figure VI.B-8 shows estimated net thermal electric conversion efficiency as a function of output power level and ambient wet bulb temperature for operation directly from the receiver. All auxiliary power requirements are accounted for in the net output except those for the receiver feedwater pumps, collector field, and thermal storage charge system.

The maximum net output is a function of the ambient wet bulb temperature as shown along the 100% line in Figure VI.B-8. The minimum net outputs are approximately 10% of the maximum values.

7. Thermal Electric Conversion Net Cycle Efficiency on Thermal Storage Steam Only

Figure VI.B-9 shows estimated net thermal electric conversion efficiency as a function of output power level and ambient wet bulb temperature for operation directly from thermal storage. All auxiliary power requirements are accounted for in the net output including the thermal storage discharge load but excluding the collector field and thermal storage charge auxiliary loads. The feedwater pumps are not required when operating from thermal storage only.

The maximum net output is a function of the ambient wet bulb temperature as shown in Figure VI.B-9. The minimum net outputs are approximately 10% of the maximum values.

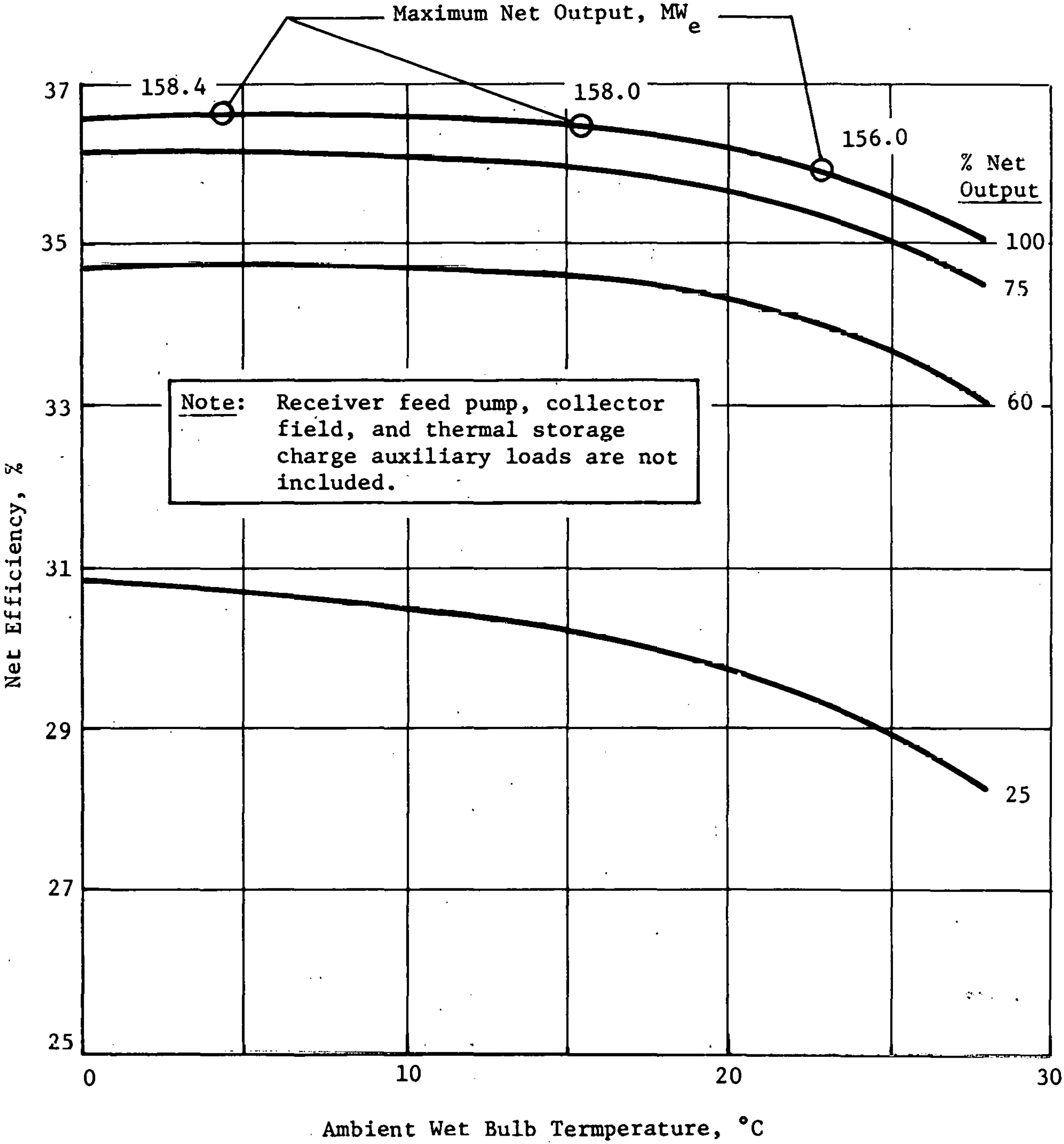

Figure VI.B-8
Net Thermal Electric Conversion Efficiency, Receiver Steam

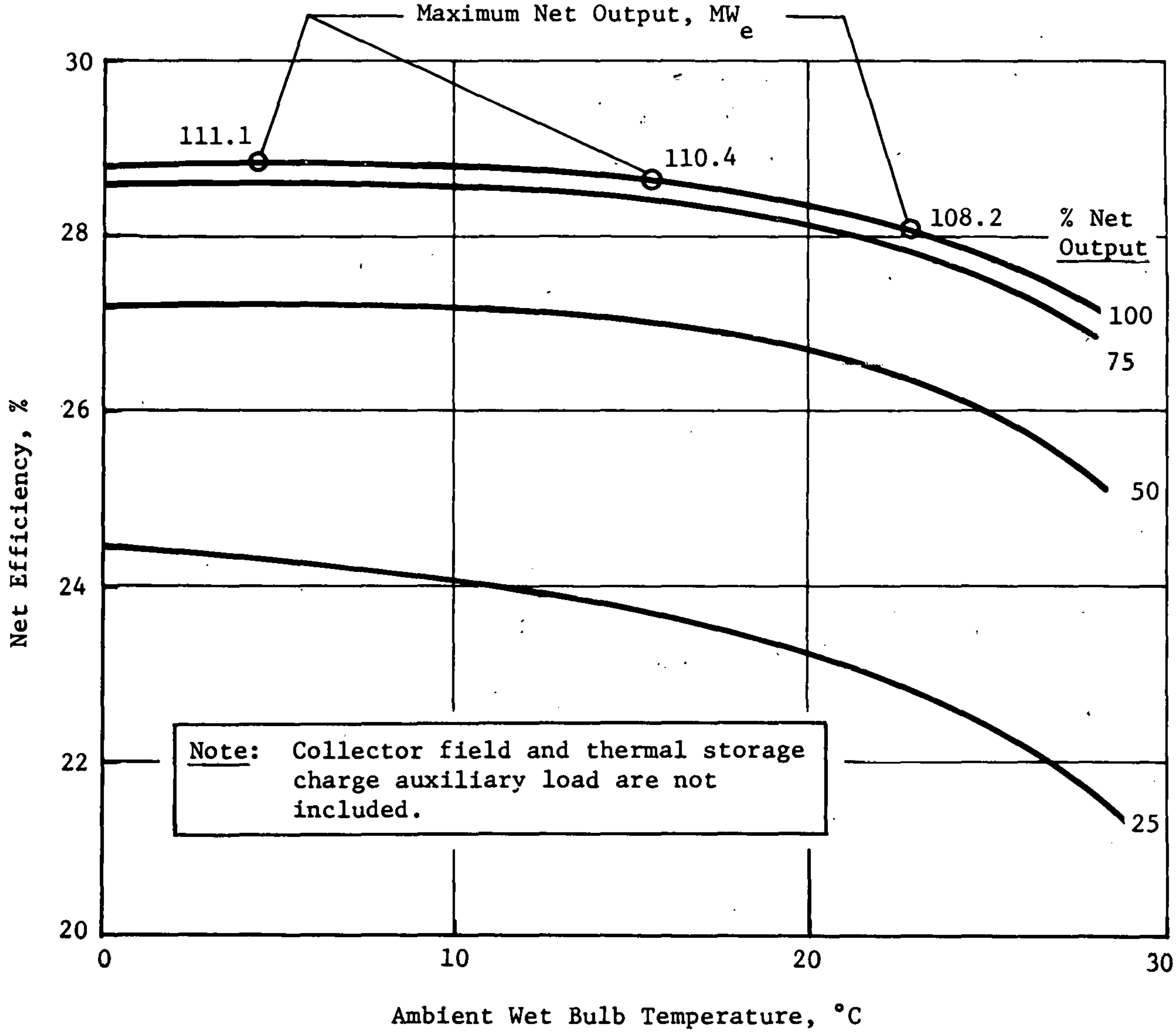

Figure VI.B-9
Net Thermal Electric Conversion Efficiency, Storage Steam

8. Maximum Rate of Change of Turbine Output

The General Electric Company states that the permissible rate of change of turbine-generator output level is a function of the associated temperature changes in the turbine casing. Data supplied by General Electric as applicable to the commercial turbine were used to derive the turbine loading times given in Table VI.B-3 (as discussed in item 12) for zero to full load after an overnight shutdown. The corresponding average rate of change is approximately 3% per minute. A discussion of the use of the GE data is given in Section III.B-3c of Volume VI of the Preliminary Design Report.

Once the turbine has been operating on rated steam long enough to reach equilibrium temperatures, the power output level can be changed as fast as the control valves will allow. It takes less than one second to open the throttle valves from zero to full flow.

9. Auxiliary Power Requirements for Charging Thermal Storage

The auxiliary power requirements, L, for charging thermal storage is shown in Figure VI.B-10 as a function of the storage charge rate, CR.

10. Auxiliary Power Requirements for Receiver Feedwater Pumps

The auxiliary power requirements for the receiver feedwater pumps are shown in Figure VI.B-11 as a function of the maximum receiver flowrate. Two pump trains are required above 40% of full flow.

11. Auxiliary Power Requirements for Collector Field

The average collector field auxiliary load is 769 KW_e.

12. Startup Times

Items 12, 13, and 14 of the requested data (Reference 1) have been combined into this item.

For our plant design, the turbine can accept receiver steam at a flowrate and pressure less than that required for charging the thermal storage system. Thus, startup time can be defined as the time required, after the receiver is first radiated, to produce steam at sufficient temperature, pressure, and mass-flow to use in the turbine generator. Additional time is then required to produce steam suitable for use in charging thermal storage.

Assuming an overnight shutdown, the average receiver startup time for turbine steam is about 17 minutes, and the additional time to start of thermal storage charge is about 43 minutes.

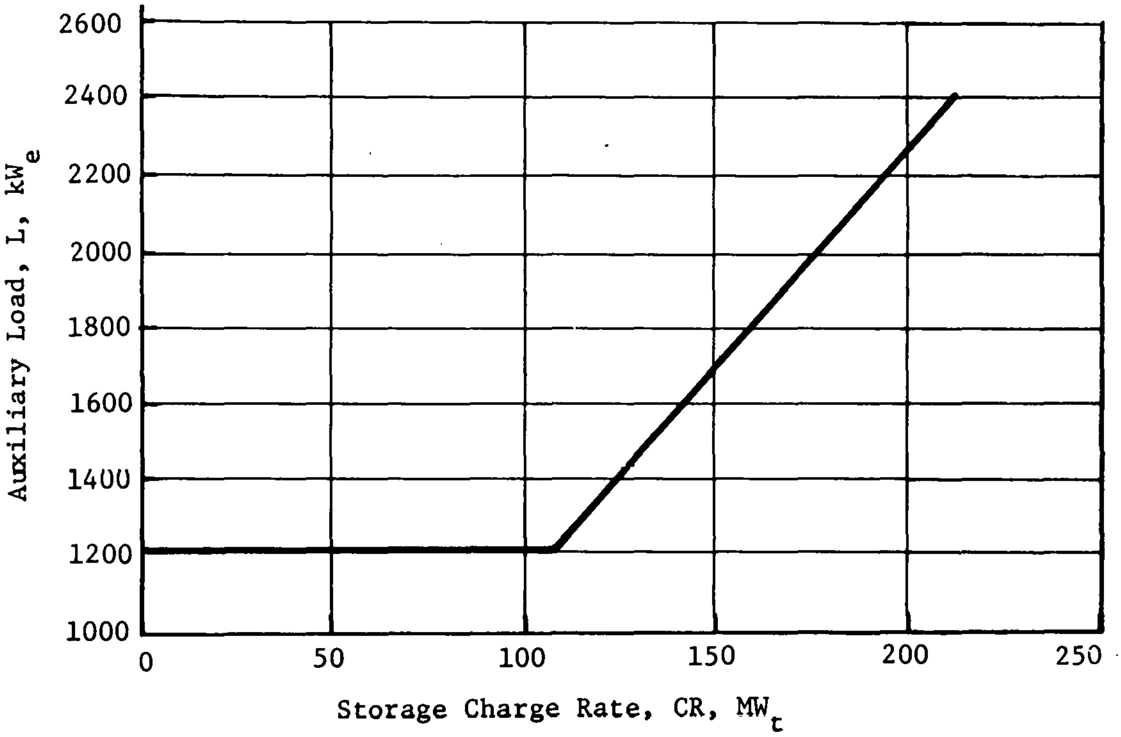

Figure VI.B-10
Thermal Storage Charge Auxiliary Power Requirement

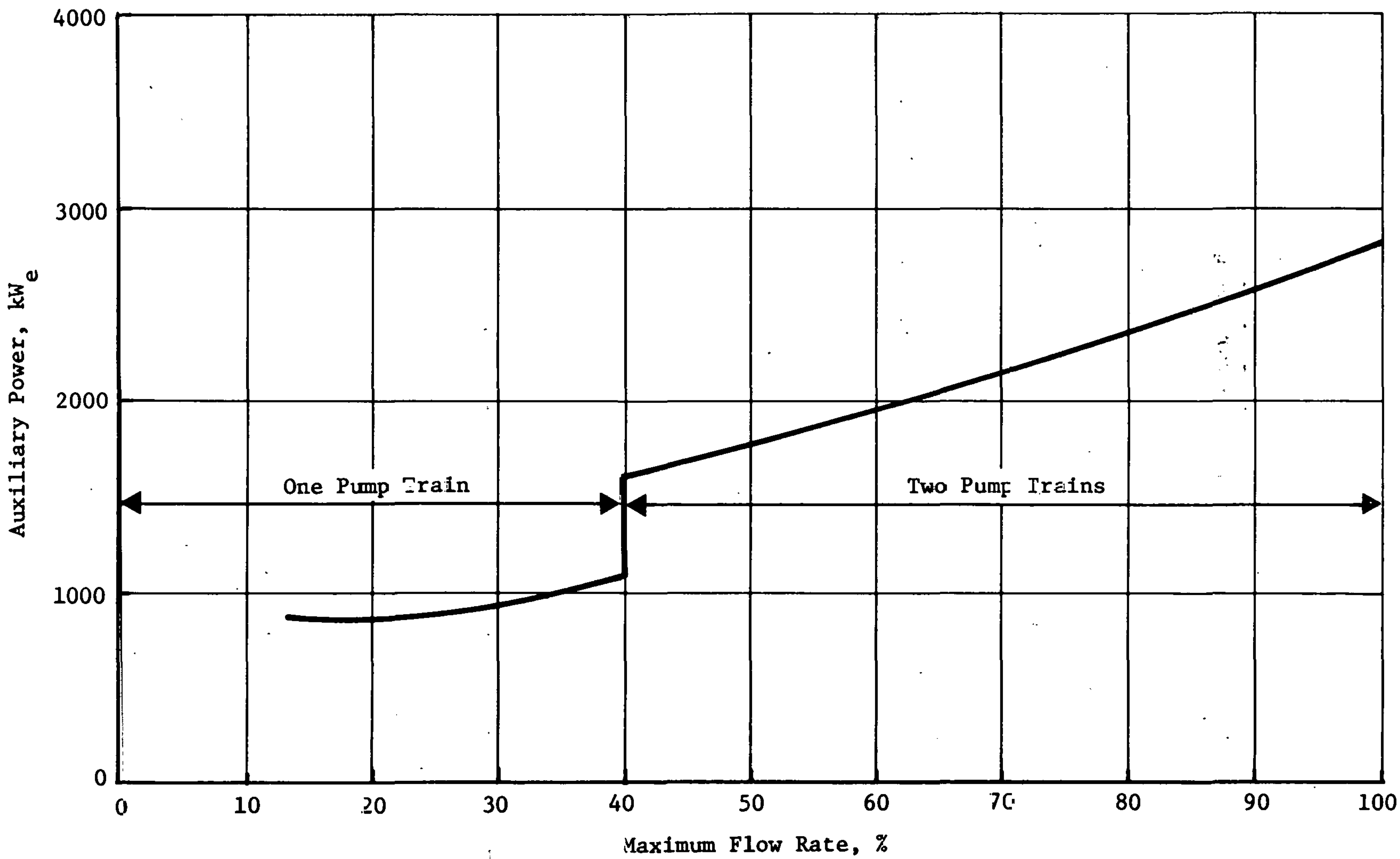

Figure VI.B-11
Feedwater Pump Auxiliary Power Requirement

Once receiver steam is available, the turbine can be synchronized and the load brought up. The time to synchronization is approximately 17 minutes and the time to load the turbine generator to rated output is about 33 minutes.

When starting the turbine from storage steam, synchronization takes approximately 17 minutes and the time to load the turbine to rated output (70% of peak) is about 18 minutes.

The plant startup times after an overnight shutdown are summarized in Table VI.B-3.

Table VI.B-3. Plant Startup Times

Receiver Startup to Turbine Steam Conditions	17 Minutes
Additional Startup to Thermal Storage Steam Conditions	43 Minutes
Turbine Startup from Receiver Steam	
- To Synchronization	17 Minutes
- From Zero to Full Load (Peak)	33 Minutes
Turbine Startup from Storage Steam	
- To Synchronization	17 Minutes
- From Zero to Full Load (70% Peak)	18 Minutes
Total Plant Startup from First Insolation to Peak Turbine Load	67 Minutes

13. See 12.

14. See 12.

15. Mode Change Time Lags

The time lags in switching operation from 1) receiver only to receiver and thermal storage, 2) receiver only to thermal storage only, and 3) from thermal storage only to receiver only are all essentially zero. This is as a result of the close match between the receiver steam temperature at the turbine admission point and the thermal storage steam temperature at the admission point.

A time lag in switching from thermal storage charge to thermal storage discharge is not applicable to our system since charge and discharge can occur simultaneously and independently.

16. Simultaneous Thermal Storage Charge and Discharge

The plant is capable of simultaneously charging and discharging thermal storage.

17. Startup and Maintenance Energy Requirements

Start From Receiver After Overnight Shutdown

The thermal energy used in starting up the turbine when operating from receiver only is approximately 220 $MW\text{-}HR_t$. Of this amount, approximately 30% is used to bring up the receiver and synchronize the turbine and the rest to bring the load up to rated output. The energy used in shutting down the turbine is essentially zero.

Start From Thermal Storage After Overnight Shutdown

The thermal energy used in starting up the turbine when operating from thermal storage is approximately 85 $MW\text{-}HR_t$. Of this amount approximately 20% is used to synchronize the turbine. The energy used in shutting down the turbine is essentially zero.

Overnight Thermal Maintenance Energy Requirements

The receiver requires no thermal energy for overnight maintenance. The turbine requires approximately 16 $MW\text{-}HR_t$ per day for seal steam, and the thermal storage unit requires approximately 0.3 $MW\text{-}HR_t$ per day for trace steam to prevent freezing of the salt. However, the current plant design assumes that this energy will be supplied by an auxiliary boiler. Thus, there is no requirement for thermal storage capacity for equipment protection only.

Cold Start from Receiver

A cold start (i.e., plant at ambient temperature) requires approximately 4 hours for the production of usable turbine steam and 3.8 hours for turbine startup to full load for a total of approximately 7.8 hours. The thermal energy required in starting the turbine is approximately 2500 $MW\text{-}HR_t$. Of this amount approximately 50% is used to bring up the receiver to usable steam conditions and the rest is used to synchronize the turbine and bring the load up to rated output.

18. Diurnal Thermal Storage Energy Loss

The daily heat loss from the thermal storage system is shown in Figure VI.B-12 as a function of the daily average ambient temperature and storage system size. The loss shown represents the total heat loss for the oil and salt system lines, tanks and heat exchangers. The oil system contributes approximately 85-90% of the total heat loss. It is assumed that the system completes one full charge and one full discharge per day.

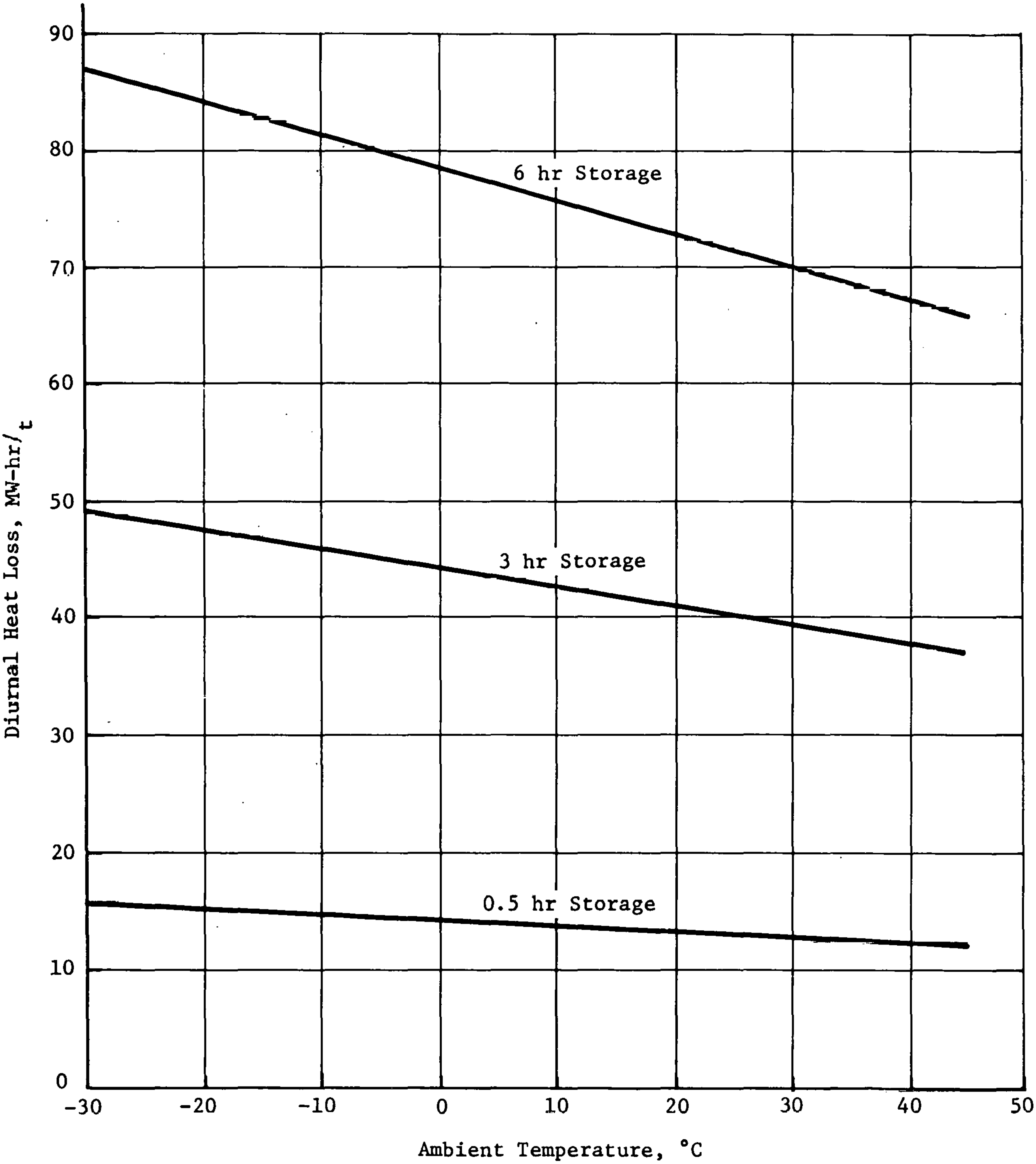

Figure VI.B-12
Diurnal Thermal Storage Energy Loss

REFERENCES

1. Sandia Letter, Skinrood to Blake, dated December 15, 1976, Subject: Cost and Performance Data for Pilot and Commercial Plants, Attachments A, B, C.

2. ERDA/SAN Letter, DuVal to Blake, Subject: Pilot Plant Site Parameters, dated November 3, 1976.

3. Peters, M. and Timmerhaus, K., Plant Design and Economics for Chemical Engineers, 2nd Edition, 1968, McGraw-Hill, New York.

APPENDIX A

BASIS FOR PILOT PLANT COST ESTIMATES

This appendix gives background information for the costs shown in Section IV. In general, the information presented here provides additional detail on what is included in a particular account and the source of the estimated dollar value. General groundrules and bases are discussed below, followed by specific bases at the individual account level. This Appendix should be used in conjunction with the plant description given in Section II.

- Material/Equipment costs include all applicable shipping charges.

- Normal industrial quality assurance practices are assumed throughout the procurement and construction phases of the program, and the costs are included in the purchase price of procured items and in the labor costs for field operations.

- General and Administrative charges and fees are prorated over all material/equipment and labor costs. Overhead charges for the solar portions of the plant are prorated over salaried labor costs while overhead charges for the EPGS/BOP are included as distributables in account 8000.

- Labor manpower estimates are based on pilot plant preliminary designs, program plans, and program schedules developed by Martin Marietta in conjunction with its subcontractors, Bechtel Corporation, Foster-Wheeler Energy Corporation, and the Georgia Institute of Technology.

- All labor rates, whether salaried or union contract, were derived to fully reflect the labor function (i.e., engineer accountant, electrician, etc) and location of work (i.e., Denver, Barstow, etc).

- Contingency is money which is expected to be spent, and represents an allowance for uncertainties in quantities, pricing methods and labor, and it cannot be considered as a source of funds for overruns or additions to the project scope. An average value of 15% of the total plant cost has been assigned to this estimate.

o Cost of the two-year test program is based on 1 shift per day, 5 days per week.

4100 General site grading is not required. Selective contouring of site for surface drainage is included in this account (surface drainage of collector field is in account 4190.152). Estimate also includes cost of roads, parking, walkways, perimeter fencing, and permanent yard lighting. Pricing is based on recent Bechtel work and published pricing data.

4103 Turbine-generator building occupies 4,700 SF of ground floor area, and encloses 150,000 CF of space. Building superstructure is comprised of structural steel frame, uninsulated corrugated asbestos-lined steel siding, and minimal interior finish. Reinforced concrete and structural steel are estimated on the basis of Bechtel experience. Siding and floor-decking estimates are based on price information obtained from suppliers.

4105 Administration and control building is comprised of two floors, each of 4,500 SF area. Total enclosed volume of the building is 153,000 CF. Superstructure is a steel frame covered by corrugated siding, insulated interior paneling, and partitions. The substructure is reinforced concrete. Estimating procedures similar to those employed for estimating the turbine-generator building were employed for estimating this building.

4141 Maintenance and warehouse building, 3000 SF in area, was estimated as a single floor, warehouse type, rigid-frame, prefabricated steel structure with sloping roof, corrugated metal siding, roofing, and insulation; the estimate is based on vendor prices as well as on Bechtel experience.

4144 A 400-SF prefabricated steel building was estimated for housing the fire pumps. Estimated cost includes subcontractor-erected prefabricated superstructure on foundation work by contractor. The subcontract rates are obtained from suppliers-erectors of prefabricated buildings.

4145 Condensate pumphouse is 300 SF prefabricated structure estimated in a manner similar to that used for estimating the fire pump house.

4146 Gate house, a 300-SF concrete block structure with austere interior finish, was estimated based on Bechtel experience.

4190.111 Mirror material consists of 84" x 84" float glass panels including silvering of back surfaces. Cost based on vendor quotations and includes a 2% allowance for mirror breakage after delivery.

4190.112 Mirror assembly cost includes all tooling and fabrication of the mirror backing structure and attachment of mirrors thereto. Cost is based on quotation from Martin Marietta Baltimore manufacturing facility. Also included is the price of assembly support studs based on vendor quote.

4190.113 The heliostat support structure consists of the yoke structure, cantilever and main shafts, bar joists, and hardware kits. Cost is based on vendor quote and includes all tooling, welding, and machining done prior to delivery to the site.

4190.121
4190.122 The cost of gear boxes, associated accessories, and hardware is based on vendor quotations.

4190.123 The cost of slew motors, tracking motors, and tracking motor mounting adapters is based on vendor quotations.

4190.124 Cost of optical encoders (position indicators) is based on vendor quotation. Cost of limit switches is based on recent procurements by Martin Marietta.

4190.126 Collector field power distribution includes wire and cable of various gauges, transformers, and distribution panels to serve the heliostats. Most cabling is to be directly buried by machine (ploughed). Pricing is based on vendor information as well as Bechtel experience.

4190.133 Calibration equipment includes tower-mounted laser and target with associated control electronics plus alignment control electronics. Cost is based on actual costs for the Solar Thermal Test Facility (STTF) in Albuquerque.

4190.141 Includes all heliostat-mounted control electronics and box, data select transceiver, repeaters, yoke cables, and drive cables. Parts listed were derived from a modified design of the Albuquerque STTF equipment, and parts costs were obtained from current catalogs. Fabrication costs were taken from a Martin Marietta Electronics Manufacturing Facility quotation.

4190.142 Cost is based on vendor quote for the dedicated collector subsystem control computer system including peripherals and accessories. The data handling system computer priced in 4402 Master Control Equipment is identical and serves as the collector field backup unit.

4190.143 Collector field signal distribution wiring includes multi-conductor wire and cable. Pricing is based on vendor information as well as Bechtel experience.

4190.15 Includes cost of boring excavation, reinforcing cage and concrete work, partial framework, and other miscellaneous work required for construction of heliostat foundations. Boring and reinforcing cage costs are based on information obtained from subcontractors and suppliers and judgment on possible site labor operations. Contouring of the collector field for proper drainage is estimated on the basis of Bechtel experience.

4190.161 This account includes the cost of all engineering analysis, design, experimentation, and drafting through the completion of engineering drawings and specifications with allowances for computer, supplies, and travel costs. Costs are based on pilot plant preliminary design, program plans, and schedules developed by Martin Marietta, and make use of current Martin Marietta Finance Department records for labor manhour rates and overhead. Foundation and wiring design cost provided by Bechtel.

4190.162 This account includes all field engineering and test technicians required to monitor and support the field assembly, installation, and checkout of the collector field. Home engineering support and computer and travel costs are also included. Plant startup and project management costs are in other accounts. The costs are based on the pilot plant program plans and construction schedules developed by Martin Marietta and make use of current Martin Marietta Finance Department records for labor rates and overhead.

4190.18 Includes the cost of all labor associated with heliostat assembly, installation, and checkout at the Barstow site. Startup and project management costs are not included in this account. Barstow area union craft labor costs, including allowance for federal/state payroll taxes, workmen's compensation insurance, and all other benefits required by current union agreements were used.

4190.19 Includes lightning arrestors installed on heliostats and the cost of grounding grid. Costs are based on vendor and contractor quotes.

4190.20 Project management includes a Barstow site-manager and all technical and administrative services such as cost accounting, procurement, planning/scheduling, reproduction, etc. Costs are based on Martin Marietta Finance Department records and estimating procedures. The project management organization includes an overall project manager throughout the entire pilot plant program. However, the cost of this management is not included here, since it is included in the Martin Marietta overhead rate.

4190.2111* Absorber - Includes waterwall panels, waterwall headers, superheater tube panels, and superheater headers.

4190.2112 Drum - Includes drum, complete with drum internals, manways, and nozzles.

4190.2113 Doors, housing, lining, insulation - Includes all insulation on enclosure, cavity door, piping and drum; cavity door complete with drive motor and mechanism; cavity lining; buckstay system; internal receiver supports and hangers; sheathing and lagging covering the insulation; freeze protection for drain and instrument lines.

4190.212 Piping - Includes downcomers, feeders, risers, and superheater transfer piping; attemperator piping, spray nozzles, and venturis; feedwater and steam piping; vent, drain, and safety valve piping; blowdown and chemical feed piping; all piping supports; vent and drain valves.

4190.213 Support structure, platform, etc - Includes top supporting steel grid from which receiver is suspended, plus snubbers, and snubber attachments to tower structure.

4190.214 Instrumentation and control on receiver - Includes thermocouples and thermowells, pressure and flow transmitters; feedwater and attemperator control valves; feed stop and check valves; attemperator block valves; water column and gauge; remote water level sensor; pressure gauge; superheater and drum safety valves. Instrumentation and control of the receiver tower includes seismographic accellerometer units, temperature transmitters, wiring, and cable. Pricing is based on vendor information as we as Foster-Wheeler and Bechtel experience.

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* For accounts 4190.211 through 4190.216, 4190.26 and 4190.27, see Foster-Wheeler cost basis at the end of this basis.

4190.215 Packing and Transportation - Includes costs of freight from Foster-Wheeler shops to plant site on Foster-Wheeler manufactured items only. Labor costs for packing are included in the labor costs for manufacturing each item. Freight costs on vendor-supplied items are included with the costs of those items.

4190.216 Field erection and installation - Includes field craft labor and burden, taxes, consumable materials, tooling, equipment rental, field supervision, field accounting, home office supervision, travel and living expenses, alkaline boil-out and acid cleaning by subcontractor, painting of heating surface with radiation-absorbing paint.

4190.22 Carbon-steel piping was estimated for feedwater piping from high-pressure feedwater pumps to receiver, and from TSS subcooler to high-pressure feedwater pumps. Estimate includes cost of piping, fittings, valves, insulation, and supports, and is based on the assumption that 2-1/2 inch diameter and larger pipes requiring fabrication are shop-fabricated and shipped to the jobsite in the form of spools; and that all other piping is shipped to the jobsite in precut, random, or manufactured length and are subsequently fabricated and welded in the field. Shop-fabrication unit costs are based on information from several suppliers and Bechtel's experience on recent purchases. Installation labor is based on Bechtel experience.

4190.23 Low-alloy steel piping for the main steam line connecting receiver boiler to turbine stop valve, and to TSS desuperheater. Procedure for estimating these lines is similar to that explained for feedwater lines under account 4190.22.

4190.24 Material and erection of receiver tower steel superstructure were estimated on the basis of recent Bechtel experience, using appropriate average unit costs. Corrugated asbestos-lined siding used as covering for the superstructure frame is to be subcontracted and is estimated accordingly, based on supplier-subcontractor price information. Elevator cost is based on vendor information; all other costs are based on recent Bechtel purchases and general experience. Lightning protection for the receiving tower is included and is priced based on vendor information and Bechtel experience.

4190.25 Estimate of receiving tower foundation includes costs of reinforced concrete, formwork, excavation, and backfill; all based on Bechtel's recent price experience for similar work.

4190.26 This account includes the cost of all Martin Marietta engineering analysis, experimentation, design and field support associated with the specification, procurement, and erection of the receiver and tower subsystem through checkout. Costs are based on pilot plant preliminary design, program plans, and schedules developed by Martin Marietta, and make use of current Martin Marietta Finance Department records and procedures. The account also includes Foster-Wheeler mechanical design and drafting, subcontracted drafting, functional engineering (thermal/hydraulic and structural analysis), reproduction, and computer charges for engineering and design of the receiver unit. The account also includes Bechtel engineering and design of the tower and foundation structures, the riser and downcomer and horizontal steam and feedwater piping and piping supports.

4190.27 Includes Martin Marietta technical and administrative services such as cost accounting, procurement, planning and scheduling, reproduction, etc. Costs are based on Martin Marietta Finance Department records and estimating procedures. The account also includes Foster-Wheeler project manager, estimating, quality control, contract administration, and living expenses.

4190.311 Includes Storage Tanks T-1, T-2, T-3 and T-4, erected complete on-site including foundations and site preparation. Support structure 2-hour fire protection coating is included. Prices are based on vendor quotation. Salt Pump Sump Tanks with steam coils, f.o.b. fabricator, including support structures, are estimated based on research experiment costs for salt tanks plus 10% escalation and 2% transportation costs.

4190.312 This account includes 14-inch thick mineral wool insulation for the salt storage tanks and pump sumps, as well as 10-inch thick mineral wool insulation for the oil storage tanks. The latter insulation includes a PVC (aluminized) mastic seal coating on the exterior, and both are to be applied by the sub-contractor. Estimates based on prices furnished by national insulation contractor, for material and labor to install. Total cost is computed based on the surface area of the storage tanks.

4190.313 This account includes one 1500-gallon tank with controls, pressure gages, and regulators, delivered to site and installed. An initial nitrogen charge is included. Estimate based on quotation from the Linde Division of National Carbon Co.

4190.321 Comprises all piping materials, including labor costs for shop fabrication and field fabrication and installation for the oil, salt, steam, water, and steam trace/steam heat lines. Also included are installation of all valves, strainers, supports, etc; and connection to major equipment such as tanks, pumps, and heat exchangers. Georgia Tech estimates based on "take-offs" from preliminary design drawings of all piping, valves, connections, supports (estimated number), and miscellaneous hardware in lines and extension of labor costs using methodology made available by Bechtel. Current quotations obtained on pipe hangers, pipe fittings, and seismic arrestors.

4190.322 This account includes all valves (control, isolation, bleed, blow-down, by-pass, etc, except those included as part of the ullage maintenance equipment), and strainers. Labor for installation is included under 4190.321. Estimates based on quotations from suppliers and current catalog prices.

4190.323 This account includes charge and discharge pumps for the salt and oil systems, as well as installation costs which include materials and labor. Estimates based on supplier quotations to performance specifications; the costs are estimated from experience and reference to Peters and Timmerhaus (Reference 3).

4190.324 Includes contractor-installed mineral wool insulation 7 inches thick on the salt and steam piping (8 inches thick on discharge steam piping) with mineral wool and glass foam insulation 7 inches thick on the oil piping. Insulation on valves, strainers, and pumps is also included. Estimates based on material and installation costs furnished by national insulation contractor, AC&S, Inc.

4190.325 Comprised in this account are a steam separation drum, including internals, and the erection of the drum onto a support structure. Priced by Georgia Tech and Foster Wheeler on the basis of weight and research experiment hardware.

4190.326 Admission steam piping and feedwater piping from high-pressure feedwater pump to TSS was estimated in a manner similar to that described for account 4190.22.

4190.331 Includes purchased cost of mechanical atomizer injector, as well as piping, fittings, and construction labor to build complete unit. Estimates based on quotations from supplier. Assembly and welding labor estimated based on "rule of thumb" of "20 diameter inches welding" per manday obtained from mechanical contractor.

4190.332 Included are Heat Exchangers DHE1, DHE2, DHE3, DHE4, and DHE5. Estimates for the first three were based on designs generated by Georgia Tech. Costs were determined by using budgetary pricing numbers obtained from Foster Wheeler Energy Corporation. A secondary comparison was made with estimated costs derived in November 1976 using Peters & Timmerhaus (Reference 3) as a basis. Installation costs based on information from Bechtel. The estimates for the latter two heat exchangers were based on designs and prices furnished by Aerofin Corporation. Installation based on experience with Research Experiment.

4190.333 Included are heat exchangers (CHE1, CHE2, CHE3 and CHE4. Estimates for the first three are based on Georgia Tech designs and budgetary pricing from Foster Wheeler. A secondary comparison was made with estimated costs devised using Peters & Timmerhaus (Reference 3) as a basis. Cost of the CHE4 exchanger was based on designs and prices furnished by Aerofin Corporation.

4190.334 This account includes 14 inch thick mineral insulation with PVC (aluminized) head coating and aluminum lagging on straight sections for CHE1 and DHE1; 10-inch thick mineral wool or glass foam insulation with the same coating and lagging for CHE2, CHE3, DHE2, DHE3 and steam drum. Insulation and installation labor provided by national insulation contractor, AC&S, Inc.

4190.335 Includes support structures for heat exchangers and pumps, as well as ladders and walkways. Preliminary design weights compiled and man-hours to construct estimated by Georgia Tech. Heights, material weights, and installation labor estimated based on Peters & Timmerhaus (Reference 3) charts.

4190.34 This account comprises instrumentation located in field including flow sensors, pressure sensors, level sensors, and temperature sensors. Also included here are devices which are required to control valves, but which are not physically part of the valve mechanism. The account also includes conductor conduits, including interface junction boxes located in field near TSS and individual device conductors to point of connection. Estimates based on quotation from Foxboro Co. and on Georgia Tech. experience based on actual costs of the Research Experiment Installation

4190.351 This account includes only the salt sump-tank foundations cost based on estimated manpower and current concrete prices. The cost of the oil and salt storage tanks is included in 4190.311.

4190.352 This account includes all heat exchanger and pump foundations. Estimates based on current concrete quotations and manhours from Peters & Timmerhaus (Reference 3).

4190.353	Includes dikes and containment structures and was estimated based on Bechtel earthwork cost data.
4190.354	Site preparation estimates were based on Bechtel experience and published estimating data.
4190.355	Comprises fixed fire protection system, including spray nozzles for oil storage tank and heat transfer equipment and automatic detection devices. Also includes selected fire hydrants located appropriately about the site. Based on budgetary estimates from Bechtel.
4190.36	Includes design engineering and quality assurance costs through the completion of engineering drawings and specifications, including engineering analysis, support to field operations in drawing maintenance, supplier monitoring, engineering analysis, and preparation of operating procedures, together with associated computer and travel costs and allowances for supplies, overhead costs, and fees. Also includes on-site field engineering, technicians and quality assurance personnel to monitor and support construction and checkout of the Thermal Storage Subsystem. The design and engineering estimate was based on the Preliminary Design of Pilot Plant. Burdened man month cost and unit travel/relocation costs supplied by Martin Marietta.
4190.37	Similar to 4190.20
4190.41	Estimated cost of salt medium to store heat energy based on quotation from Park Chemical Co.
4190.42	Includes oil required to store deliverable energy, provide for circuit hold-up volume and tank minimum residual volume, start-up energy, and 20 hour hold-time energy. This estimate is based on a current quotation from the Exxon Corporation.
4190.43	Included in this account is rail freight on salt from Chicago to Barstow, California, and on oil from Houston to Barstow. Salt shipped trailer-container "piggyback"; oil shipped in tank car. Based on current rail freight rates according to the quantities required under accounts 4190.41 and 4190.42.

4190.44 Includes salt handling at site from trailer to tank-loading facility, and operation of loading equipment. Also includes drum turner and bucket elevator, and the oil transfer from a rail tank car to the oil storage tanks. Estimated on basis of labor requirements to unload trailers, open drums, and operate machinery. Estimate consistent with industrial operating practices. Drum turner and bucket elevator quoted by suppliers. Oil transfer based on contract price from Petroleum Transport Co.

4300 Estimated cost of the turbine-generator unit is based on information furnished verbally and via a published price book by General Electric. The condenser, cooling tower, feedwater heaters and pumps, demineralizers, and other major EPGS equipment have been estimated on the basis of price information furnished by suppliers of such equipment. Minor equipment has been estimated from recent purchases of similar equipment by Bechtel, with reasonable allowances for equipment not shown on sketches or the major equipment list. Piping quantities within the EPGS are extracted roughly from information available in the form of piping and instrumentation diagrams and equipment location drawings for the EPGS; quantities thus obtained were priced. As an alternative approach, allowances were made for piping within the EPGS by reference to cost records for small existing fossil-fueled power plants. In a final step, the results of both methods were compared and found to be close enought to establish confidence. Allowances for instrumentation within the EPGS are based on reference to cost records for fossil-fueled power plants. Also included in this account is a small gas/oil fired boiler for supplying saturated seal and TSS trace steam.

4401 This account includes switchgear for the generator and station service circuits, station transformers and distribution equipment serving the EPGS and other subsystems, and all station service power wiring containers. Lightning protection for the receiver tower and collector field are included in accounts 4190.254 and 4190.19 respectively. Estimates of electrical work were based on supplier information as well as Bechtel experience In addition, this account includes a standby diesel-generator with all accessories to be used for all plant emergency power requirements and priced by vendor quote.

4402.1	See 4190.142.
4402.2	See 4190.142.
4402.3 and 4402.4	Control room panels, boards, and interfacing cables are included in this account. The estimated cost is based on preliminary system design and catalog prices.
4402.5 through 4402.7	The master control system design, development, test, and integration cost is based on pilot plant preliminary design, program plans, and schedules developed by Martin Marietta, and makes use of internal costing techniques for software development manpower, and finance department records and procedures for labor costs.
4402.8	Control wiring from control room to all subsystems except the collector (see 4190.143) is priced here. Based on vendor information and Bechtel experience.
4402.9	No special test program instrumentation required for thermal storage subsystem, EPGS, or BOP. For receiver subsystem, special test instrumentation includes cost of thermocouples, flow and pressure sensors, flow and pressure transmitters, heat flux meters, strain gages, displacement indicators, residual strain indicators, tubings and fittings, wiring, valves multiplexer on tower, and heat tracings of instrument lines for freeze protection. Includes engineering, preparation of installation drawings, and field installation. Also includes extra shop fabrication costs associated with instrumentation. For the Collector Subsystem, an allowance was added for such items as additional field wind sensors, radiometers, etc, which may be required to adequately characterize field performance.
4402.10	Similar to 4190.20.
4500.1	Transportation and lifting equipment for the EPGS and BOP includes a permanently installed overhead hydraulic travelling crane for the maintenance and warehouse building. Vendor quotations have been obtained for this crane. Also in this account is collector subsystem maintenance equipment permanently

associated with the pilot plant, including a complete mirror-cleaning set, mirror module assembly, and yoke assembly transporters (trailers), mirror module handling tools, yoke assembly vertical holding stands, mirror module welding fixture and sling, heliostat work stands, heliostat control electronics stimulator, a 2½ ton semi-tractor, a 4 ton, 20-foot boom crane, forklifts, pickup trucks, two-way radios, and miscellaneous small tools. Costs of mirror cleaning and heliostat handling and support fixtures include design and fabrication labor based on Martin Marietta manufacturing estimates. Costs of other items are based on vendor quotes. A forklift and two pickup trucks for general plant use have also been priced.

4500.2 Air system compressors and distribution lines, service water and fire water lines, fire pumps, dual purpose fire and domestic water tank and mirror-washing water tank were estimated based on vendor-supplied information.

4500.3 Communication equipment includes intercom and plant telephone network covering all reasonable locations, and an allowance for alarm and signal systems serving the entire pilot plant. Pricing is based on Bechtel experience.

4500.4 Furnishing and fixtures include: allowances for safety equipment (portable fire extinguishers, first-aid station); EPGS/BOP shop, laboratory, and test equipment; office equipment and furniture, environmental monitoring station with control room readout and recording, and cleaning equipment. Pricing is based on Bechtel experience and published cost information.

8030 Distributable costs for the contractor field office personnel and supplies include all salaries, fringes, and benefits for the supervisory, engineering, accounting, and other personnel, as well as all field office furniture and supplies required to support construction of the EPGS and BOP only. All distributable accounts were estimated with reference to construction experience on similar facilities. Such experience shows that distributable costs maintain close historical relationships to direct field labor costs, and the various categories of distributable costs may be expressed as percentages or factors or direct field labor manhours. Factors were derived and utilized to estimate distributable costs required for the pilot plant EGPS and BOP field construction operations.

8040.1 Various insurance requirements include public liability and property damage insurance, employer's liability insurance, and fire and theft insurance. These are estimated on a percentage basis, as described for account 8030.

8040.2 Includes construction equipment and auto insurance.

8040.3 Net cost (including salvage) of temporary buildings and structures required during construction, including a 60,000 SF heliostat assembly building, temporary utility equipment and lines within the construction site, and temporary communications equipment based on vendor quotes and Bechtel experience.

8040.4 Includes rental or purchase (less salvage) of all construction equipment required during construction, except that required and supplied by subcontractors, in which cases such costs are included as part of subcontract cost of supplying and installing these facilities.

8040.5 Includes purchased utilities and is estimated on a percentage basis as described in account 8030.

8040.61 Based on utility experience, it was estimated that an appropriate initial inventory of turbine plant equipment spare parts would be equal to 3% of the total turbine plant equipment estimate.

8040.62 Spare parts for electrical plant equipment were estimated at approximately 3% of the electrical plant equipment estimate.

8040.63 Includes all collector system spares required through plant startup less 40% of the cost of a spare calibration equipment set which has been allocated to the 2-year test program. Spares are ordered along with the original parts, and their cost basis is the same.

8040.64 Receiver Subsystem spare parts include packing and seats for all valves, replacement water level gage glasses, parts for remote-reading TV system, drum manway gaskets, spare tubing for superheater and waterwalls.

8040.65 For the TSS, spare components include motors, pumps, valve actuators and controllers, instrumentation, gaskets, and spare parts kits to permit local repair during plant startup operations. Estimates based on costs obtained from supplier quotations. Quantities established by engineering judgment, with the objective of minimizing system downtime in the event of a hardware malfunction.

8100.1 Architectural Engineer Services for EPGS and BOP were estimated with reference to Bechtel experience with such services on a variety of sizes and types of power plants. The cost of such services were estimated in terms of percentages of the installed cost of construction work. This account includes the estimated cost of preliminary engineering, optimization studies, specifications, detail engineering, vendor drawing and specification reviews, site investigations, support to vendors, procurement and expediting services, planning, scheduling and cost engineering, construction and acceptance testing definitions, project management, and fee on these services.

8100.3 This account gives the cost of the systems engineering and integration function for the solar portion of the pilot plant. The content of the subaccounts is described below:

8100.31 This task includes preparation of detailed specifications, interface control documents, and dynamic and static performance modeling to insure compatibility of solar subsystem with the non-solar portions of the plant.

8100.32 This task consists of the preparation, maintenance and updating of management plants (management, configuration control, procurement, etc.) and technical control plans (Reliability, quality assurance, safety, maintenance, etc.) for the solar portion of the plant.

8100.33 This task provides for maintaining control of program management and technical progress. Includes design reviews, schedule status reports, configuration and interface control documentation and supporting system analyses.

8100.34 Includes preparation of integrated test plans for design validation, review of subsystem contractor test procedures and test data, and independent analysis of test data.

8100.35 This task provides for preparation of subsystem checkout procedures, summary report of checkout operations and results, and acceptance of solar portion of plant.

Also included are the costs of engineering and program management (including technical and administrative services), with allowances for computer, supply, and travel costs. All costs are based on current Martin Marietta finance department records and standard estimating procedures.

8100.4 See 4190.16, 4190.26 and 4190.36.

8100.5 See 4402.5, 4402.6 and 4402.7.

8100.61 Collector subsystem startup costs include all engineering support and other technical and administrative costs associated with a 5-month plant startup period. Basis is similar to that of accounts 4190.162 and 4190.20.

8100.62 Includes salaries, travel, and living expenses for FWEC service engineers plus per diem charges and expense for vendor service engineers.

8100.63 Engineers, operators, technicians, and maintenance personnel required to operate and maintain the Thermal Storage Subsystem for 5 months during plant startup, including computer time, travel, relocation, and allowance for supplies, overhead costs, and fees.

8100.64 EPGS and BOP startup costs include home office development of procedures and manuals for plant startup; and materials, supplies, labor, and supervision of checkout and startup operations. The estimated costs of these services and operations were developed from historical experience on other power plant projects.

8100.65 Similar to 8100.61.

8100.66 Provides for the solar/non-solar integration and checkout resulting in acceptance of the pilot plant. Includes preparation of checkout procedures, test operations personnel, performance evaluation, and training in operation and maintenance of solar portion of the plant.

8300 Included in the estimate is a contingency that exists within the conceptual design in quantity, pricing, or productivity that is under the control of the contractor and within the scope of the project as defined. Implicitly, the contingency will be expended during the design and construction of the project, and it cannot be considered as a source of funds for overruns or additions to the project scope.

1000 The estimated costs of operating and maintaining the collector field and master control subsystems are based on program plans developed by Martin Marietta for a two-year test program period. Costs for personnel relocation are included where applicable. All costs are based on current Martin Marietta finance department records and procedures. Operation and maintenance of the receiver subsystem includes Foster Wheeler's best estimate of utility operating and maintenance labor and material costs. Operation and maintenance costs of the Thermal Storage Subsystem during the two-year test program include cost of engineers, operators, technicians and maintenance personnel, travel costs, allowances for supplies, overhead costs, and fees. Operation and maintenance costs for EPGS and BOP include operators, maintenance personnel, supervision supplies, utilities, and other costs, and were estimated with reference to utility experience on small power plants.

2000 Includes all engineering, technician, and management support required for the technical conduct of the two-year test program for all subsystems including engineering costs for assisting ERDA/SCE in defining requirements, collecting data, and evaluating results.

3000 This account covers the cost of Collector Subsystem spares sufficient for a two-year test operations period. See 8040.63. Includes the cost of one extra set of spare parts for the Receiver Subsystem. Spare parts required for the Thermal Storage Subsystem to minimize downtime during two-year test program beyond those parts inventorized for plant startup. Includes pump kits, valve kits, actuators, controllers, and instrumentation. Make-up storage oil required for two-year test program estimated at 5500 gallons per month. No additional spares beyond the initial inventory in accounts 8040.61 and 8040.62 and the maintenance costs in account 1000.4 are considered necessary for the EPGS and BOP.

BASIS FOR FOSTER WHEELER COSTS

The estimates for Account No. 4190.2, Receiver Unit, are based on the receiver preliminary design drawings, engineering specifications, and design information obtained by consultation with the design engineers involved. Applicable estimating standards were used, modified where necessary after Manufacturing Engineering review.

Material costs were estimated by preparing a bill of materials based upon the receiver drawings and specifications, in quantities by type required, and pricing these materials from current mill pricing data or by actual recent costs of similar materials.

Shop labor costs were generated by an estimate of productive manhours for each mark number item to be included in the receiver, using Industrial Engineering curves and standards developed in FWEC manufacturing plants by accepted time and motion study procedures plus historical production data. Productivity factors were applied as necessary for each operation. The dollar costs were calculated from the productive manhours using shop labor and overhead rates by "cost center" as furnished by the FWEC Accounting Department. The FWEC manufacturing plants are organized into "cost centers" where similar or essentially combined operations are performed to complete a series of staged functions in making the completed sub-assembly. Rework hours and dollars were estimated based upon historical data for each item.

Transportation costs were based on freight rates furnished by the FWEC Traffic Department based upon current data.

Subcontracted items (items, such as the support structure, designed by FWEC but purchased from an outside vendor) were estimated by a take-off of weight from the receiver drawings and priced by recent pricing experience.

General accessory items fully engineered by outside vendors were estimated from price lists or by vendor quotation. Vent valves, drain valves, snubbers and all items under Account Nos. 4190.214 and 4402.3 were priced by vendor quotation.

Field erection and installation costs were estimated by the FWEC Construction Department. Field material, equipment and tooling costs were developed based on actual recent costs of similar steam generator construction projects. Field labor costs were generated by an estimate of manhours for each assembly operation using curves and standards plus area labor productivity factors developed from previous steam generator construction cost experience. Applicable craft labor wage rates for the Barstow area plus allowances for benefits, insurance, taxes, etc, were applied to the estimated man-hours. Costs of field supervision, field accounting, travel and living expenses and home office supervision were based on the scope and schedule of the project. Alkaline boil-out and acid cleaning costs were obtained by vendor quotation.

Design and Project Management were estimated by the departments that will perform these functions, based upon their appraisal of the work to be performed and the schedule time involved. Current labor rates and departmental overhead rates were furnished by the FWEC Accounting Department. No provision was made in the design estimate for a detailed dynamic seismic analysis of the receiver. Cost of a static seismic analysis was included.

Cost of spare parts was estimated based upon vendor recommendations for the various items of accessory equipment plus an allowance for spare boiler and superheater tubes.

Start-up costs were estimated by the FWEC Service Department based upon experience.

APPENDIX B

BASIS FOR COMMERCIAL PLANT COST ESTIMATES

This appendix gives background information for the costs shown in Section V. In general, the information presented here provides additional detail on what is included in a particular account and the source of the estimated dollar value. General groundrules and bases are discussed below, followed by specific bases at the individual account level.

- Material/Equipment costs include all applicable shipping charges.
- Normal industrial quality assurance practices are assumed throughout the procurement and construction phases of the program, and the costs are included in the purchase price of procured items and in the labor costs for field operations.
- General and Administrative charges and fees are prorated over all material/equipment and labor costs. Overhead charges for the solar portions of the plant are prorated over salaried labor costs while overhead charges for the EPGS/BOP are included as distributables in account 8000.
- Labor manpower estimates are based on commercial plant preliminary designs, program plans, and program schedules developed by Martin Marietta in conjunction with its subcontractors, Bechtel Corporation, Foster-Wheeler Energy Corporation, and the Georgia Institute of Technology.
- All labor rates, whether salaried or union contract, were derived to fully reflect the labor function (i.e., engineer accountant, electrician, etc) and location of work (i.e., Denver, Inyokern, etc).
- Contingency is money which is expected to be spent, and represents an allowance for uncertainties in quantities, pricing methods, and labor, and it cannot be considered as a source of funds for overruns or additions to the project scope. An average value of 20% of the total plant cost has been assigned to this estimate.

4000 Land requirements for the 150 MW_e commercial scale plant are estimated to comprise 2,050 acres (approximately 2.3 miles by 1.4 miles). Land is estimated to cost $500 per acre. It was assumed that clearing and removal of existing cover and any existing features is not necessary.

4100 This account includes general site grading to gentle contours such as to preclude the necessity for an extensive storm sewer system. Also in this account is the cost of all roads, parking and walkways within the plant site, including approximately 33,000 square yards of asphaltic concrete paved surface serving the EPGS, TSS and other facilities, and 430,000 SY of bituminous soil cement for roads serving the collector fields. Included also is 40,000 linear feet (LF) of perimeter fencing and outdoor lighting around the EPGS, TSS and other facilities, but not within the collector fields.

4103 The Turbine building occupies approximately 11,000 square feet (SF) of ground area and enclosures approximately 264,000 cubic feet (CF) of space. The structure is steel frame and siding with concrete slab, and the estimated cost includes building mechanical services (plumbing, ventilating), electrical convenience service (lighting and receptacles) and modest architectural finishes. All unit costs were derived from the detailed estimate of the pilot plant turbine building by appropriate adjustments considering the relative sizes of the two buildings.

4105 The administration and control building was estimated in a manner essentially similar to that described above for the turbine building, but with reference to the administration and control building estimated for the pilot plant.

4141 The 25,000 SF maintenance and warehouse building was estimated in terms of the area unit costs derived from those of the pilot plant maintenance and warehouse building.

4144 Fire pump houses were estimated as subcontracted, prefabricated structures having a total of 1200 SF of area.

4145	The 1500 SF condensate pump house was estimated as a subcontracted, prefabricated structure.
4146	Gate house was estimated as a 300 SF concrete block structure.
4190.111	Mirror material consists of 84" x 84" float glass panels including silvering of back surfaces. Cost based on vendor quotations and includes a 2% allowance for breakage after delivery.
4190.112	Mirror assembly cost includes all tooling and fabrication of the mirror backing structure and attachment of mirrors thereto. Cost is based on quotation from Martin Marietta Baltimore manufacturing facility for the pilot plant with unit cost reductions assumed due to quantity buys, automated facilities, and labor learning curves.
4190.113	The heliostat support structure consists of the yoke structure, cantilever and main shafts, bar joists, and hardware kits. Cost is based on vendor quote for the pilot plant with reductions assumed due to design improvements and approximately 10% weight reductions.
4190.121 4190.122	The cost of gear boxes, associated accessories, and hardware is based on vendor quotations and anticipated labor cost reductions due to learning (90% learning curve).
4190.123	The cost of slew motors, tracking motors, and tracking motor mounting adapters is based on vendor quotations and anticipated savings due to quantity buys.
4190.124	Cost of optical encoders (position indicators) is based on vendor quotation. Cost of limit switches is based on recent procurements by Martin Marietta.
4190.126	Includes over 2 million LF of wire and cable of various gauges, transformers, and distribution panels to serve 15 heliostat fields. Materials and equipment were priced at 10% of the unit price levels used for the pilot plant, and installation labor was estimated using a 95% learning curve. Cabling is to be direct buried by machine.

4190.133 Calibration equipment includes tower-mounted laser and target with associated control electronics plus alignment control electronics. Cost is based on actual costs for the Solar Thermal Test Facility (STTF) in Albuquerque and anticipated cost reductions due to learning (85% learning curve on labor).

4190.141 Includes all heliostat-mounted control electronics and box, data select transceiver, repeaters, yoke cables, and drive cables. Parts lists were derived from a modified design of the Albuquerque STTF equipment, and parts costs were obtained from current catalogs. Fabrication costs were taken from a Martin Marietta Electronics Manufacturing Facility quotation with appropriate considerations for quantity buys.

4190.142 Cost is based on vendor quote for the dedicated collector subsystem control computer system including peripherals and accessories. The data handling system computer priced in 4402 Master Control Equipment is identical and serves as the collector field backup unit.

4190.143 Includes over 1 million LF of multi-conductor wire and cable priced at 10% of the unit price levels used for the pilot plant, and installation labor was estimated using a 95% learning curve.

4190.15 Includes cost of boring excavation, reinforcing cage and concrete work, partial formwork, and other miscellaneous work required for construction of heliostat foundations. Estimates were made at unit costs slightly lower than for the pilot plant, with due regard for the increase in quantities. Unit material costs were reduced approximately 10% (mainly for reduced fabrication cost for reinforcing steel, although actual material quantities are not unusually large for power plant work). Installation unit manhour rates were reduced by approximately 15% from those estimated for the pilot plant.

4190.161 This account includes the cost of all engineering analysis, design, experimentation, and drafting through the completion of engineering drawings and specifications with allowances for computer supplies, and travel costs. Site data and therefore the heliostat foundation was assumed the same as for the pilot plant. Costs are based on commercial plant preliminary design, program plans, and schedules developed by Martin Marietta, and make use of current Martin Marietta Finance Department records for labor manhour rates and overhead.

4190.162 This account includes all field engineering and test technicians required to monitor and support the field assembly, installation, and checkout of the collector field. Home engineering support and computer and travel costs are also included. Plant startup and project management costs are in other accounts. The costs are based on the commercial plant program plans and construction schedules developed by Martin Marietta and make use of current Martin Marietta Finance Department records for labor rates and overhead.

4190.18 Includes the cost of all labor associated with heliostat assembly, installation, and checkout at the site. Startup and project management costs are not included in this account. Barstow area union craft labor costs, including allowance for federal/state payroll taxes, workmen's compensation insurance, and all other benefits required by current union agreements were assumed to apply to the Inyokern area.

4190.19 Includes lightning arrestors installed on heliostats and the field grounding grid.

4190.20 Project management includes a site-manager and all technical and administrative services such as cost accounting, procurement, planning/scheduling, reproduction, etc. Costs are based on Martin Marietta Finance Department records and estimating procedures. The project management organization includes an overall project manager. However, the cost of this management is not included here, since it is included in the Martin Marietta overhead rate.

4190.2111* Absorber - Includes waterwall panels, waterwall headers, superheater tube panels, and superheater headers.

4190.2112 Drum - Includes drum, complete with drum internals, manways, and nozzles.

***For accounts** 4190.211 through 4190.216, 4190.26 and 4190.27 see **Foster-Wheeler** cost basis at the end of Appendix A.

4190.2113 Doors, housing, lining, insulation - Includes all insulation on enclosure, cavity door, piping and drum; cavity door complete with drive motor and mechanism; cavity lining; buckstay system; internal receiver supports and hangers; sheathing and lagging covering the insulation; freeze protection for drain and instrument lines.

4190.212 Piping - Includes downcomers, feeders, risers, and superheater transfer piping; attemperator piping, spray nozzles, and venturis; feedwater and steam piping; vent, drain, and safety valve piping; blowdown and chemical feed piping; all piping supports; vent and drain valves.

4190.213 Support structure, platform, etc - Includes top supporting steel grid from which receiver is suspended, plus snubbers, snubber attachments to tower structure.

4190.214 Instrumentation and control on receivers - Includes thermocouples and thermowells, pressure and flow transmitters; feedwater and attemperator control valves; feed stop and check valves; attemperator block valves; water column and gauge; remote water level sensor; pressure gauge; superheater and drum safety valves. Instrumentation and control of the receiver tower includes seismographic accelerometer units, temperature transmitters, wiring, and cable. Pricing is based on vendor information as well as Foster-Wheeler and Bechtel experience.

4190.215 Packing and transportation - Includes cost of freight from Foster-Wheeler shops to plant site on Foster-Wheeler manufactured items only. Labor costs for packing are included in the labor costs for manufacturing each item. Freight costs on vendor-supplied items are included with the costs of those items.

4190.216 Field erection and installation - Includes field craft labor and burden, taxes, consumable materials, tooling, equipment rental, field supervision, field accounting, home office supervision, travel and living expenses, alkaline boil-out and acid cleaning by subcontractor, painting of heating surface with radiation-absorbing paint.

4190.22 Approximately 40,000 LF of feedwater piping of various diameters and wall thicknesses, including bellows and hinges for thermal expansion, valves, insulation, and supports, are included in this account. Material prices were based on information obtained from several piping suppliers and recent Bechtel purchases, and for field runs, it was assumed that mill run piping of double random lengths would be delivered for field fabrication. Installation labor was based on Bechtel experience in installing refinery pipeway lines, with adjustments for heavy walls. It was assumed that provision for thermal expansion deflections will be accommodated by means of bellow hinges designed for pressures and diameters beyond the current state of development. Prices estimated for these items were developed in consultation with current suppliers of bellow hinges for similar applications, but at lower pressures and smaller diameters.

4190.23 Approximately 40,000 LF of receiver steam piping was estimated following procedures similar to those for the feedwater piping, with regard to the different allow materials required.

4190.24 Estimated costs of fifteen towers were based on detailed estimates for the pilot plant tower.

4190.25 Estimate of receiver tower foundation includes costs of reinforced concrete, formwork, excavation, and backfill. Pilot plant material costs reduced 10% and labor hours by 20%

4190.26 This account includes Foster-Wheeler mechanical design and drafting, subcontracted drafting, functional engineering (thermal/hydraulic and structural analysis), reproduction, and computer charges for engineering and design of the receiver unit. The account also includes the cost of Bechtel engineering and design of the tower and foundation structures, the riser and downcomer and horizontal steam and feedwater piping and piping supports, based on Bechtel experience. Tower, tower foundation and receiver designs were assumed identical to the pilot plant designs.

4190.27 Includes Foster-Wheeler project manager, estimating, quality control, contract administration costs, and living expenses.

4190.311 Includes salt tanks (2) and oil tanks (7) erected complete on-site including foundations and site preparation and support structure fire protection coating. Prices based on vendor quotation. Also includes cost salt pump sump tanks with steam coils based on research experiment costs plus 10% escalation and 2% transportation costs.

4190.312 This account includes 14-inch thick mineral wool insulation for the salt storage tanks and pump sumps, as well as 10 inch thick mineral wool insulation for the oil storage tanks. The latter insulation a PVC (aluminized) mastic seal coating on the exterior and both are to be applied by a sub-contractor. Estimates based on prices furnished by national insulation contractor, for material and labor to install. Total cost is computed based on the surface area of the storage tanks.

4190.313 This account includes one 1500-gallon LN2 tank with controls, pressure gages, and regulators, delivered to site and installed. An initial nitrogen charge is included. Estimate based on vendor quotation.

4190.321 Comprises all piping materials, including labor costs for shop fabrication and installation for the oil, salt, steam, water, and steam trace/steam heat lines. Also included are installation of all valves, strainers, supports, etc; and connection to major equipment such as tanks, pumps, and heat exchangers. Georgia Tech estimates based on "take-offs" from preliminary design drawings of all piping, valves, connections, supports (estimated number), and miscellaneous hardware in lines and extension of labor costs using methodology made available by Bechtel. Current quotations obtained on pipe hangers, pipefittings, and seismic arrestors where possible. Preliminary designs were generated on piping supports outside of commercially available sizes and costs were estimated by experience

4190.322 This account includes all valves (control, isolation, bleed, blow-down, by-pass, etc) except those included as part of the ullage maintenance equipment, and strainers. Labor for installation is included under 4190.321. Estimates based on quotations from suppliers and current catalog prices.

4190.323 This account includes charge and discharge pumps for the salt and oil systems, as well as installation costs which include materials and labor. Pump estimates based on supplier quotations to performance specifications; the installation costs were estimated from experience and reference to Peters and Timmerhaus (Reference 3).

4190.324 Includes contractor-installed mineral wool insulation 7 inches thick on the salt and steam piping (8 inches thick on discharge steam piping) with mineral wool and glass foam insulation 7 inches thick on the oil piping. Also includes insulation on valves, strainers, and pumps. Estimates based on material and installation costs furnished by a national insulation contractor.

4190.325 This account includes the cost of a steam separation drum, including internals, and the erection of the drum onto the support structure. Drum size estimate made by Georgia Tech based on pilot plant. ASME Section I design derived by Georgia Tech. Priced by Georgia Tech on the basis of weight. The erection of the drum estimated by Georgia Tech based on Research Experiment experience.

4190.326 Steam and feedwater lines between the TSS and EPGS were estimated in a manner similar to the lines to the towers, considering the different lengths, diameters, materials, and wall thicknesses.

4190.331 Includes purchased cost of mechanical atomizer injector, as well as piping, fittings, and construction labor to build complete unit. Estimates based on quotations from supplier. Assembly and welding labor estimated based on "rule of thumb" of "20 diameter inches welding" per manday obtained from mechanical contractor.

4190.332 Included are Heat Exchangers DHE1, DHE2, DHE3, DHE4, and DHE5. Estimates for the first three were based on designs generated by Georgia Tech. Costs were determined by using budgetary pricing numbers obtained from Foster-Wheeler Energy Corporation. A secondary comparison was made with estimated costs derived in November 1976 using Peters & Timmerhaus

(Reference 3) as a basis. Installation costs based on information from Bechtel. The estimates for the latter two heat exchangers were based on designs and prices furnished by Aerofin Corporation. Installation based on experience with Subsystem Research Experiment.

4190.333 Included are Heat Exchangers CHE1, CHE2, CHD3, and CHE4. Estimates for the first three were based on designs generated by Georgia Tech. Costs were determined by using budgetary pricing numbers obtained from Foster-Wheeler Energy Corporation. Installation costs based on information from Bechtel. The estimate for CHE4 was based on designs and prices furnished by Aerofin Corporation. Installation based on experience with Subsystem Research Equipment and reference to Peters and Timmerhaus (Reference 3).

4190.334 This account includes 14 inch thick mineral insulation with PVC (aluminized) head coating and aluminum lagging on straight sections for CHE1 and DHE1; 10-inch thick mineral wool or glass foam insulation with the same coating and lagging for CHE2, CHE3, and DHE2. Insulation and installation costs provided by vendor quote.

4190.335 Includes support structures for heat exchangers and pumps, as well as ladders and walkways. Preliminary design weights compiled and man-hours to construct estimated by Georgia Tech. Heights, material weights, and installation labor estimated based on Peters & Timmerhaus charts (Reference 3).

4190.34 This account includes instrumentation located in the field including flow sensors, pressure sensors, level sensors, and temperature sensors. Also included here are devices which are required to control valves, but which are not physically part of the valve mechanism. The account also includes conductor conduits, including interface junction boxes located in field near TSS and individual device conductors to point of connection. Estimates based on quotation from Foxboro Company and Georgia Tech experience based on actual costs of the Subsystem Research Experiment Installation.

4190.351 Includes salt sump tank foundation only. Storage tank foundation costs are included in account 4190.311.

4190.352 This account includes all heat exchanger foundations and all pump foundations. Estimated based on current concrete quotations and manhours from Peters & Timmerhaus (Reference 3).

4190.353 Includes dikes and containment structures and was estimated based on Bechtel earthwork cost data and dimensions indicated on sketches.

4190.355 Cost of fixed fire protection system including oil storage tank water spray nozzles and heat transfer equipment water spray nozzle system with automatic detection devices. Includes fire hydrants located appropriately about the site. Based on vendor quote for pilot plant and extended to cover multiple tank commercial field.

4190.36 Includes design, engineering, and quality assurance costs through the completion of engineering drawings and specifications; support to field operations in drawing maintenance, supplier monitoring, engineering analysis, and preparation of operating procedures; associated computer and travel costs and allowances for supplies, overhead costs, and fees. Also includes on-site field engineering, technicians and quality assurance personnel to monitor and support construction and checkout of the Thermal Storage Subsystem. The design and engineering estimate was based on the preliminary design of the commercial plant. Burdened man month cost and unit travel/relocation costs estimated by Martin Marietta.

4190.37 Includes Martin Marietta technical and administrative services such as cost accounting, procurement, planning and scheduling, reproduction. Costs are based on Martin Marietta Finance Department records and estimating procedures.

4190.41 Estimated cost of salt medium to store thermal energy based on quotation from Park Chemical Company.

4190.42 Includes oil required to store deliverable energy, provide for circuit hold-up volume and tank minimum residual volume, start-up energy, and 20 hour hold-time energy. This estimate is based on a current quotation from the Exxon Corporation.

4190.43 Included in this account is rail freight on salt from Chicago to Inyokern, California, and on oil from Houston to Inyokern. Salt shipped trailer-container "piggyback"; oil shipped in tank car. Based on current rail freight rates according to the quantities required under accounts 4190.41 and 4190.42.

4190.44 Includes salt handling at site from trailer to tank-loading facility, and operation of loading equipment. Also includes drum turner and bucket elevator, and the oil transfer from a rail tank car to the oil storage tanks. Estimated on basis of labor requirements to unload trailers, open drums, and operate machinery. Estimate consistent with industrial operating practices. Drum turner and bucket elevator quoted by suppliers. Oil transfer based on contract price from Petroleum Transport Company.

4300 The estimated cost of the turbine generator was based on verbal information from General Electric. The condenser feedwaterheaters and pumps, demineralizers, and other major EPGS equipment were estimated in consultation with suppliers of such equipment. Minor equipment was estimated from recent purchases of similar equipment, with reasonable allowances for equipment not shown on sketches or the major equipment list. Allowances for piping and instrumentation within the EPGS were estimated by reference to cost records for fossil-fueled power plants. Ratios were developed to represent the cost of piping and instrumentation for feedwater, condensate, heat rejection, and water treatment systems in relation to the equipment within these systems. Auxiliary boiler for seal and trace steam is also included.

4401 This account includes switchgear for the generator and station service circuits, as well as station service transformers and distribution equipment serving the EPGS and all other subsystems except the collector subsystem. Wiring for the collector subsystem in an account 4190.143. All other power distribution equipment and cabling, including that for the receiver and thermal storage subsystems and general plant power, is included here. Also included is a diesel generator system for general plant emergency power.

4402.1	See 4190.142.
4402.2	See 4190.142.
4402.3	Control room panels and boards are included in this account. The estimated cost is based on preliminary system design and catalog prices.
4402.4 through 4402.7	The master control system design, development, test, and integration cost for the commercial plant is based on an extension of the pilot plant master control system and makes use of internal costing techniques for software development, manpower and finance department records, and procedures for labor costs.
4402.8	Control wiring from control room to the various subsystems is included. Cost is based on approximate distances of subsystems from control room and Bechtel experience.
4402.10	Similar to 4190.20.
4500.1	Transportation and lifting equipment for the EPGS and balance of plant includes one permanently installed 40-ton capacity gantry crane over the turbine generator, based on vendor quotes, and an allowance for miscellaneous permanently installed hoists elsewhere in the turbine building and other structures. Collector subsystem maintenance equipment permanently associated with the commercial plant includes a complete mirror-cleaning set, mirror module assembly, and yoke assembly transporters (trailers), mirror module handling tools, yoke assembly vertical holding stands, mirror module welding fixture and sling, heliostat work stands, heliostat control electronics stimulator, a 2½ ton semi-tractor, a 4 ton, 20-foot boom crane, forklifts, pickup trucks, two-way radios, and miscellaneous small tools. Costs of mirror cleaning and heliostat handling and support fixtures

include design and fabrication labor based on Martin Marietta manufacturing estimates. Costs of other items are based on vendor quotes. General plant mobile equipment includes several forklifts and pickup trucks.

4500.2 Air system compressors and distribution lines, service water and fire water lines, fire pumps, dual purpose fire and domestic water tank and mirror-washing water tank were estimated based on vendor-supplied information.

4500.3 Communications equipment includes intercom and plant telephone stations at 50 locations, and an allowance for alarm and signal systems serving the entire commercial plant. Priced on basis of Bechtel experience.

4500.4 Furnishing and fixtures include: allowances for safety equipment (portable fire extinguishers, first-aid station); EPGS/BOP shop, laboratory, and test equipment; office equipment and furniture, environmental monitoring station with control room readout and recording, and cleaning equipment. Pricing is based on Bechtel experience and published cost information.

5309 This account includes only the main transformer (13.8 KW/69 KV, 170 MVA) and its associated instruments and controls and foundation. Based on vendor quotes.

8030 Distributable costs for the contractor field office personnel and supplies include all salaries, fringes, and benefits for the supervisory, engineering, accounting, and other personnel, as well as all field office furniture and supplies required to support construction of the EPGS and BOP only. All distributable accounts were estimated with reference to construction experience on similar facilities. Such experience shows thqt distributable costs maintain close historical relationships to direct field labor costs, and the various categories of distributable costs may be expressed as percentages or factors of direct field labor manhours. Factors were derived and utilized to estimate distributable costs required for the pilot plant EPGS and BOP field construction operations. This account also includes an allowance for the field office furniture and supplies for the thermal storage, collector and master control subsystem and for the solar integrator staff.

8040.1 Various insurance requirements include public liability and property damage insurance, employer's liability insurance, and fire and theft insurance. These are estimated on a percentage basis, as described for account 8030.

8040.2 Includes construction equipment and auto insurance.

8040.3 Net cost (including salvage) of temporary buildings and structures required during construction, including a 100,000 SF heliostat assembly building, temporary utility equipment and lines within the construction site, and temporary communications equipment.

8040.4 Includes rental or purchase (less salvage) of all construction equipment required during construction, except that required and supplied by subcontractors, in which cases such costs are included as part of subcontract cost of supplying and installing these facilities.

8040.5 Includes purchased utilities and is estimated on a percentage basis as described in account 8030.

8040.6 Based on utility experience, it was estimated that an appropriate initial inventory of turbine plane equipment spare parts would be equal to 2% of the total turbine plant equipment estimate. Spare parts for electrical plant equipment were estimated at approximately 2% of the electrical plant equipment estimate. Also included are all collector system spares required through plant startup. These spares are ordered along with the original parts, and their cost basis is the same. Receiver Subsystem spare parts include packing and seats for all valves, replacement water level gage glasses, parts for remote-reading TV system, drum manway gaskets, spare tubing for superheater, and waterwalls. For the TSS, spare components include motors, pumps, valve actuators and controllers, instrumentation, gaskets, and spare parts kits to permit local repair during plant startup operations. Estimates based on costs obtained from supplier quotations. Quantities established by engineering judgment, with the objective of minimizing system downtime in the event of a hardware malfunction.

8100.1 Architectural Engineer Services for EPGS and BOP (exclusive of such services associated solely with Collector, Receiver, or Thermal Storage Subsystem facilities) were estimated with reference to Bechtel experience with such services on a variety of sizes and types of power plants. The cost of such services was estimated in terms of percentages of the installed cost of all construction work. This account includes the estimated cost of preliminary engineering, optimization studies, specifications, detail engineering, vendor drawing and specification reviews, site investigations, support to vendors, procurement and expediting services, planning, scheduling and cost engineering, construction and acceptance testing definitions, project management, and fee on these services.

8100.3 This account gives the cost of the systems engineering and integration function for the solar portion of the pilot plant. The content of the subaccounts is explained under this account number in Appendix A.

8100.6 Plant startup costs include all engineering and other technical and administrative costs, travel and living expenses, development of procedures and manuals, computer time, and supplies, etc, necessary for the plant startup.

8300 Included in the estimate is a contingency that exists within the conceptual design in quantity, pricing, or productivity that is under the control of the contractor and within the scope of the project as defined. Implicitly, the contingency will be expended during the design and construction of the project, and it cannot be considered as a source of funds for overruns or additions to the project scope. An average value of 15% of the project cost has been assigned to the commercial plant estimate.

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