SAN/1110-77-2(Vol.2)
Distribution Category UC-62

CENTRAL RECEIVER SOLAR THERMAL POWER SYSTEM, PHASE 1: PRELIMINARY DESIGN REPORT

Volume 2. System Description and System Analysis

April 1977

Work Performed Under Contract No. EY-77-C-03-1110

Martin Marietta Corporation
Denver, Colorado

U.S. Department of Energy

Solar Energy

NOTICE

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Microfiche $3.00

FOREWORD

This document comprises Volume II 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 April 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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ABBREVIATIONS AND ACRONYMS

A	Ampere
BTU	British Thermal Unit
^{o}C	Degrees Celsius
CS	Collector Subsystem
CRT	Cathode Ray Tube
DHS	Data Handling System
EPGS	Electrical Power Generation Subsystem
ERDA	Energy Research and Development Administration
^{o}F	Degrees Fahrenheit
fps	Feet Per Second
ft	Feet
FW	Feedwater
g, kg	Gram, Kilogram
gal	Gallon
hr	Hour
ID	Identification
I/F	Interface
in	Inch
j	Joule
K	Kelvin
KVA	Kilovolt-Ampere
KV	Kilovolt
l	Liter
lbs	Pounds
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
SRE	Subsystem Research Experiment
STTF	Solar Thermal Test Facility
TSS	Thermal Storage Subsystem
TTY	Teletype
W_e, kW_e, MW_e	Watt, Kilowatt, Megawatt-Electrical
W_t, kW_t, MW_t	Watt, Kilowatt, Megawatt-Thermal

I. INTRODUCTION

The Central Receiver Solar Thermal Power System design features of the Martin Marietta team have been established to achieve the highest performance consistent with minimized capital and operating costs, and timely development of solar power technology.

The CRSTPS plant is made up of five major subsystems, the collector, receiver, and thermal storage, which are unique to the solar application, and the electrical power generation and master control, which are currently commercial. Energy flow through the plant starts with the solar energy intercepted by the heliostats of the collector subsystem. The solar energy is reflected in a concentrated beam to the receiver. Within the receiver subsystem the solar energy is converted to thermal energy in the form of superheated steam and is transmitted to the thermal storage and electrical power generation subsystems. Conversion of thermal energy from either the receiver or the storage system to electricity takes place in the turbine and generator of the electrical power generation subsystem. Energy flow in the thermal storage subsystem is from steam to sensible heat in the storage fluids during charging and from the sensible heat of the fluids to steam during discharge.

A modular north field concept for the central receiver was selected for high performance, flexibility and reliability to provide a cost effective approach for the generation of electricity using solar energy. Subsystem concepts were selected from proven designs and materials to provide a low technical risk for development. Steam cycle state points were selected to optimize performance and cost while utilizing existing state-of-the-art hardware and designs. The recommended Pilot Plant Configuration is one full scale collector-receiver module of the commercial plant thus providing a truly representative and meaningful Pilot Plant Program. The designs utilized in the commercial and pilot plants have been demonstrated by subsystem research experiments which were scale models of the total subsystem, including all components and controls. Design, construction and testing of the full subsystem configuration truly demonstrated the complete operational and performance characteristics of the total subsystem.

A. COMMERCIAL PLANT

Basic features of the commercial solar power plant have been established to achieve the highest performance consistent with minimized capital and operating cost, and timely development of solar power technology.

Strongly contributing to these goals is the modular collector-receiver which provides maximum optical performance and thermal energy conversion efficiency. Key features of the plant include integrated collector-receiver modules featuring cavity receiver steam generators, focused heliostats, north field collector geometry, moderate slant ranges and a short tower.

The two stage thermal storage uses sensible heat for storage. The storage materials, hydrocarbon oil for steam generation and molten salt for superheating, are both used commercially for heat transport fluids. The high temperature steam generated by the molten salt stage provides for a miximum efficiency power cycle. The major uncertainty associated with the thermal storage system is the lack of long term oil decomposition rate data for the storage oil at the storage temperatures and therefore the associated life cycle economics. Currently, tests are planned which will determine the decomposition rate of the oil and the effects of a side-stream processor on the decomposition rates. Oil decomposition and a candidate all salt storage system is discussed in detail in Volume V, Thermal Storage Susbystem.

Power generation utilizing a dual admission turbine maximizes performance and operating flexibility. This turbine permits operation from the receiver and/or thermal storage and supports the various modes of operation and cyclic requirements of a solar plant.

The recommended 150 MWe Commercial Plant size was selected based on the primary economic scaling influences. The versatile modular design provides added reliability and operational flexibility. The modular design is adaptable to larger topographical variations and accommodates plant sizes up to 300 MWe without variations in the basic collector-receiver module.

B. PILOT PLANT

The recommended pilot plant design and configuration is derived directly from the commercial plant. Maximum use of full scale subsystems and components will provide invaluable technical and economical data that is directly applicable to commercial plant design. The use of one complete collector-receiver module of the commercial plant will verify combined subsystem performance and eliminate scaling concerns and other associated risks.

The collector subsystem including the number of heliostats, field layout and controls will be identical to a commercial plant module. The receiver subsystem including the north facing cavity receiver and tower will also be identical to the commercial plant module. In addition to subsystem and component sizing being one-to-one between the pilot and commercial plants the related solar flux patterns, steam state conditions, and flow conditions will be identical.

The thermal storage subsystem utilizes the same heat storage materials, operates at the same temperatures, utilizes the same heat exchanger heat transfer coefficients and generates the same steam state points as the commercial plant.

The Pilot Plant has the same mode of operation as the commercial plant thereby demonstrating all of the operational characteristics for all plant configurations and modes. The power generating portion of the plant includes a dual admission turbine operating at the same steam state points as for the commercial turbine.

II. REQUESTED PERFORMANCE SUMMARY TABULATION

This section consists of Table II.A-1 which is the tabulation of the data and information items requested by Sandia to be included as a section of this volume. Since the information requested is primarily discussion items, rather than discrete data points, the tabulation references the paragraph location in the volume where the information is discussed.

Table II.A-1 REQUESTED PERFORMANCE SUMMARY TABULATION

Requested Data	Data Location In Volume: Commercial	Data Location In Volume: Pilot Plant
A. Plant design characteristics, including but not limited to:	See Below	
1. Schematic and flow diagrams for all modes of plant operation.	III.C.1	IV.C.1
2. Physical Characteristics:		
o Number of Heliostats	III.E.1	IV.D.1
o Collector Field Dimensions	III.E.1	IV.D.1
o Tower Height	III.F.1	IV.E.1
o Receiver Dimensions	III.F.1	IV.E.1
o Storage Materials	III.G.1	IV.F.1
o Operating Termperatures and pressures	See requested data Item A.4	
3. Stair Step presentation of system energy balance, both at the		IV.B.2.a
o design point and	III.B.2.a	IV.B.2.b
o on a yearly basis	III.B.3.a	IV.B.3.a
4. Nominal characteristics and maximum and minimum operating for:		
o Collector Subsystem	III.B.4.a	IV.B.4.a
o Receiver Subsystem	III.B.4.b	IV.B.4.b
o Thermal Storage Subsystem	III.B.4.c	IV.B.4.c
o Electrical Power Generation Subsystem	III.B.4.d	IV.B.4.d
5. Subsystem Efficiencies	III.B.2.d	IV.B.2.d
6. Auxiliary power requirements for all modes of operation	III.B.2.d.4)	IV.B.2.d.4)

Table II.A-1 REQUESTED PERFORMANCE SUMMARY TABULATION

Requested Data	Data Location in Volume: Commercial	Data Location in Volume: Pilot Plant
B. Design Rationale and Evolution	See Below	
1. EPGS Cycle Choice	III.B.1	IV.B.1
2. Material Choice for Thermal Storage	III.G.1	IV.F.1
3. Receiver Configuration	III.A.3.b III.F.1	IV.E.1
4. Tracking error requirements	III.B.2.d.1)f)	IV.B.2.d.1)f)
5. Receiver Spillage	III.A.3.b III.B.2.d.1)g)	IV.B.2.d.1)g)
6. Mirror Field Optimization	III.A.3.a III.A.3.c III.A.3.d III.A.3.e	IV.B.2.a IV.B.2.b
7. Tower Height	III.A.3.d	
8. Equipment cycling and life-time requirements	III.c.4	
9. Maintenance and operating cost versus equipment cost	Cost to be reported in Volume VII.	
10. Storage charge rate (Commercial)	III.B.2.c	
C. Annual Energy Calculation	III.B.3.b	IV.B.3.b
D. Analysis and models employed to characterize transient plant operation including:	See Below	
1. Startup		IV.C.2.a
2. Transition from mode to another		IV.C.2.b
3. Emergency Conditions		IV.C.3
4. Shutdown		IV.C.2.b

Table II.A.1 REQUESTED PERFORMANCE SUMMARY TABULATION (Concluded)

Requested Data	Data Location in Volume: Commercial	Data Location in Volume: Pilot Plant
5. Response time on individual subsystems		IV.C.2.b
6. Cloud Transients		IV.C.2.b
E. Plant Control System	III.C.2	IV.C.4
F. Plant Safety Considerations	III.C.3	IV.C.5

III. COMMERCIAL PLANT

A. COMMERCIAL PLANT DESCRIPTION

The commercial plant is modular in design consisting of 15 collector-receiver modules for the recommended 150 MWe plant size. The modular design of the collector and receiver subsystems provides versatility of design such that topographical site variations and sizing variations over broad limits can be accommodated by the basic design approach.

Inherent in the modular design approach is increased plant operating flexibility and reliability. The modular design also provides the shortest development path to the commercial plant by providing solar subsystems that are full scale at the pilot plant stage. Key also to attaining early development and commercial acceptance are the low risk features of the design. Within the modules, the north field collector of focused heliostats transmits focused sunlight over moderate slant ranges maximizing optical performance. The cavity receiver is designed for maximum performance with flux levels consistent with commercial power system steam generators. The shortened tower is the one clear case where economics benefitted at the expense of energy collection efficiency, with the savings in tower costs being greater than the cost of extra heliostats required to replace the reduced capacity.

Timely development is assured by the virtual elimination of a scaling difference between the commercial and pilot plants in the solar subsystems. It is further enhanced by use of a conventional moderate pressure, non-reheat turbine and use of commercial heat transport fluids in the thermal storage subsystem. Maximized performance, while operating from stored energy, is provided by the molten salt superheating stage of the thermal storage subsystem.

The general description of the commercial plant below is followed by the rationale for selection of the 150 MWe plant size and the rationale for selection of the commercial plant modular configuration.

1. <u>General Description</u>

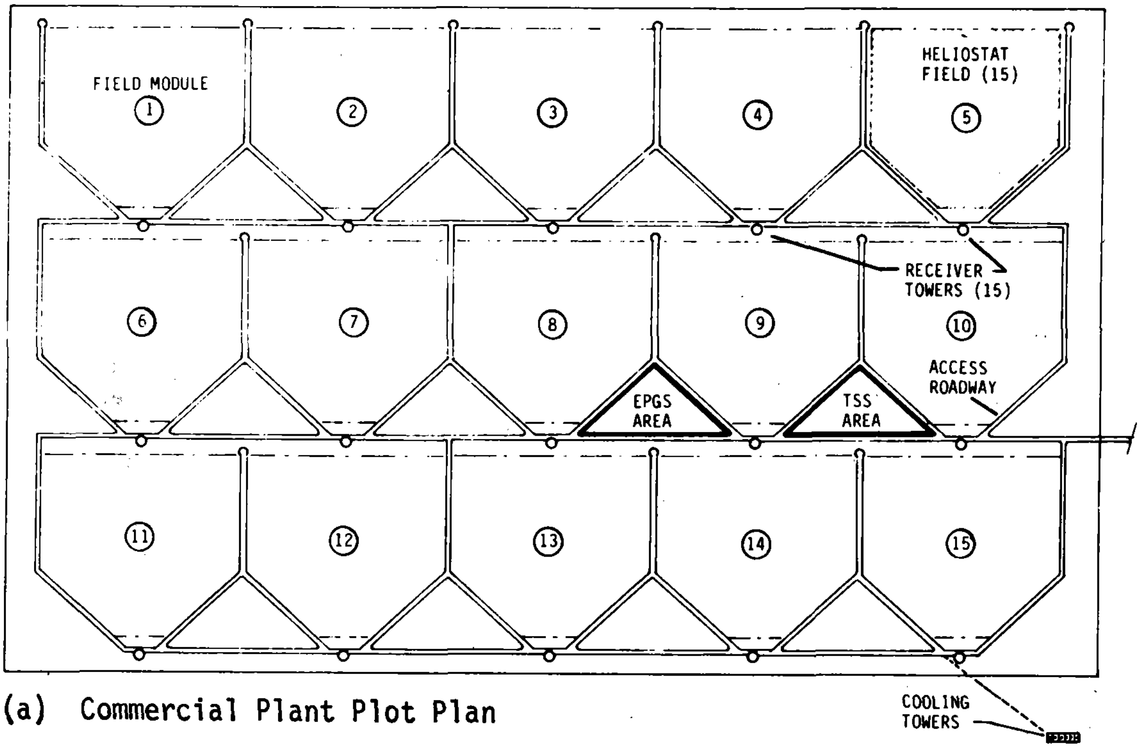
a. Requirements and Capabilities - The commercial plant is capable of a peak net electrical power output of 150 MW and simultaneously charging thermal storage. This peak output capability is provided when operating from the receiver. The plant is capable of 70% of peak, or 105 MWe net electrical output, when operating from thermal storage alone. Combined operation from both the receiver and thermal storage is 70% or greater of peak net electrical output. The thermal storage capacity must be sized to provide three hours of operation at 105 MWe net subsequent to starting and loading the turbine from thermal storage.

The ERDA defined design point for purposes of sizing is defined as that time of year when the peak thermal output from the receiver, at the turbine generator, is at a maximum, assuming an insolation of 950 watts/square meter, a wind speed of 3.5 meters/second and a wet and dry bulb temperature of 23 and 28°C respectively. These conditions provide maximum power output at noon throughout the winter season. The design point is defined as noon solar time on winter solstice.

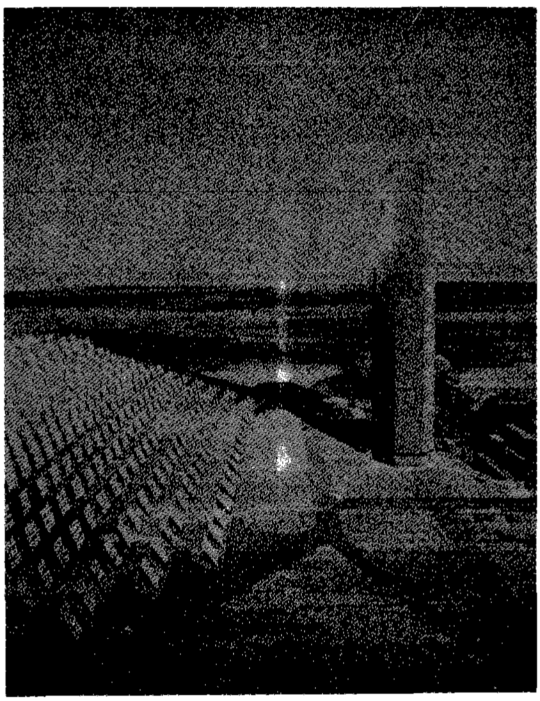
The design point is used for sizing subsystems. The collector subsystem is sized to provide 150% of the thermal power necessary to generate the peak net electrical output of 150 MWe when operating from the receiver alone at the design point. The excess thermal power is used to charge thermal storage. Throughout the year the excess available for charging thermal storage varies with the actual insolation value, the time of day and day of the year. The receivers are sized to accept the maximum output of the collector subsystem throughout the year.

b. General Arrangement - The general arrangement of the commercial plant is shown in Figure III.A-1. The predominant features of view a. show the 15 collector-receiver modules. View b. shows an artist rendering of one collector-receiver module. Each module contains 1554 heliostats and a tower mounted receiver. Each module is a fully operational independent entity and the performance of each collector-receiver module contributes equally to the total performance of the collector subsystem and the receiver subsystem. The receivers are located on towers at the south edge of each module.

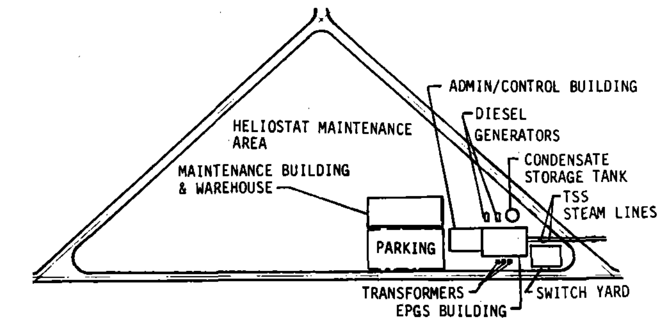
View c. shows the general arrangement of the electrical power generation portion of the plant and the related facilities that are common to all aspects of the plant. This portion of the plant is located in the triangle between module 8 and 9. View d. shows the general arrangement of the thermal storage subsystem including the storage media tanks, heat exchanger pads and related piping. This portion of the plant is located in the triangle between modules 9 and 10.



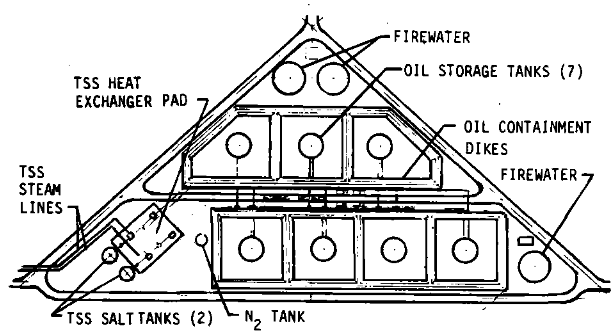
(a) Commercial Plant Plot Plan



(b) Collector Module



(c) Electric Power Generation Plant



(d) Thermal Storage Subsystem

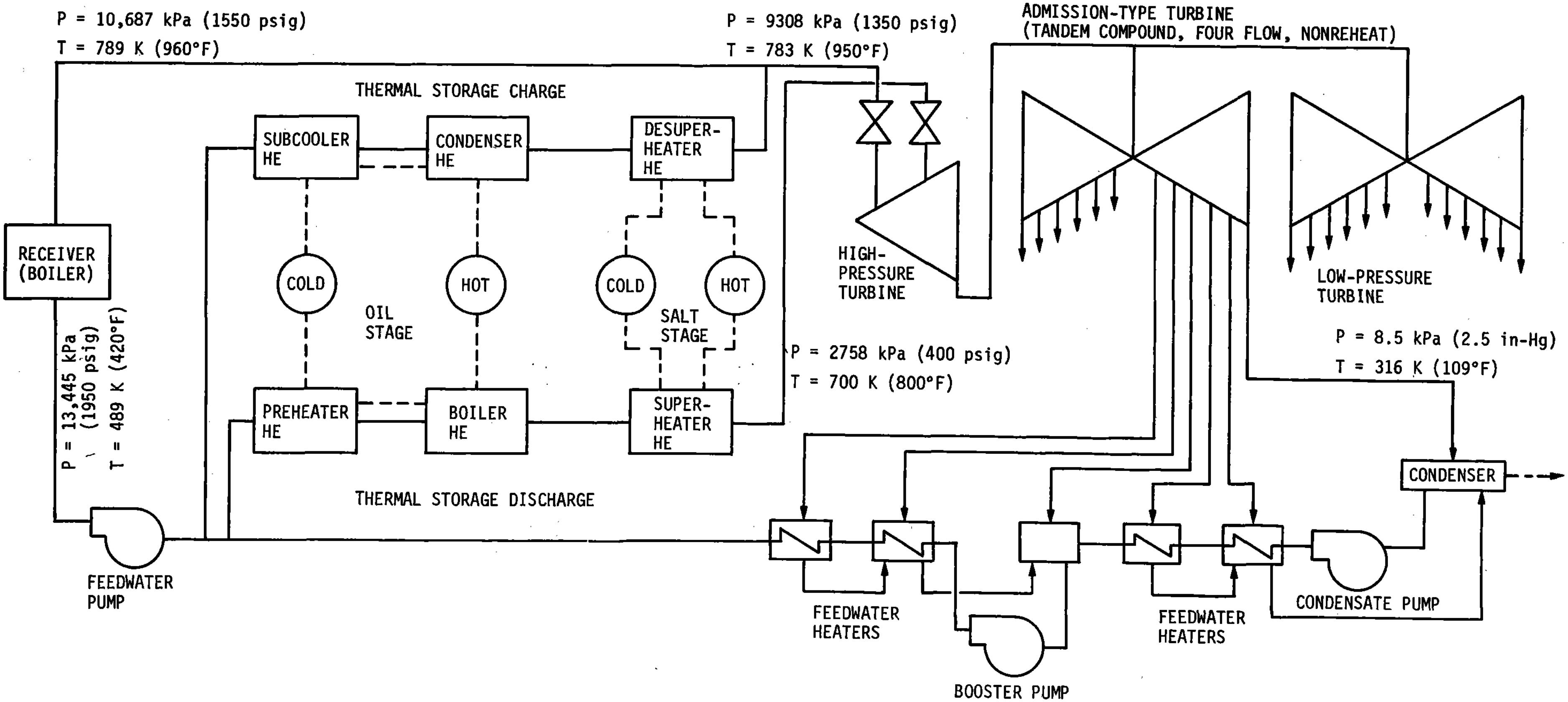
Figure III.A-1 Martin Marietta Team Commercial Central Receiver Solar Thermal Power Plant Configuration

The arrangement of the collector-receiver modules relative to the power generation portion of the plant is based on optimization of cost of steam piping as it inter-relates with pressure drop and subsystem design and performance characteristics. With the modular concept the general arrangement can easily be rearranged to accommodate a specific site topography, or if desired, to accommodate a different size plant.

c. Operational Configuration - The plant is configured such that steam from the receiver in each module is manifold together to operate into a single turbine and/or charge the thermal storage as required. Figure III.A-2 is the commercial plant schematic showing the interrelation of the receiver, thermal storage and electrical power generation subsystems. The primary steam conditions are also shown. A discussion of each major operating mode is discussed in section III.C.1.

The collector subsystems, not shown on the schematic, focuses and directs the insolation from each collector module field to its respective receivers for the generation of steam. The receivers are natural circulation boilers utilizing a steam drum to separate steam from the boiler section before going to the superheater. Temperature is controlled by attemperators in the superheater section. As shown the thermal storage consists of two stages, a salt stage for high temperature storage (superheat) and oil for lower temperature storage (steams latent heat of condensation plus some subcooling). For charging (removing energy from steam and storing it), three heat exchangers are used to remove the superheat from the steam, to condense the steam and to subcool the condensate. For discharging (removing energy from storage and generating steam for production of electrical power) three different heat exchangers are used to preheat the feedwater to generate steam and to add superheat to the steam. The electrical power generation subsystem utilizes a dual admission type of turbine. The turbine consists of a high pressure section and low pressure section in tandem. Condensing is provided by wet cooling. Five feedwater heaters are used to condition the condensate.

As discussed in section III.C.1 all required modes of operation can be satisfied, including operation from the receiver only, operating from the thermal storage, operating from both the receiver and thermal storage, operating from the receiver while charging thermal storage, the dual mode of simultaneously charging and discharging thermal storage, and charging thermal storage only, plus transition modes. Operationally the modular concept



MAIN STREAM	ADMISSION STREAM
160 MW_e (GROSS)	117 MW_e (GROSS)
HEAT RATE = 9655 KJ/kW-hr (9151 Btu/kW-hr)	HEAT RATE = 11741 KJ/kW-hr (11128 Btu/kW-hr)

Figure III.A-2 Commercial Plant Schematic provides desirable flexibility and redundancy since each module is an independent entity and as such may either be operating or not at any particular time. This flexibility virtually eliminates down time of the plant required for maintenance. In addition, during plant construction and startup, modules can be brought on line and generating electricity while others are under construction if that is desirable.

2. Commercial Plant Size Selection

A commercial plant size of 150 MWe was selected after considering plant sizes between 100 and 300 MWe. Historically power plant size have been driven larger due to economics. For the solar plant, cost is fairly flat, as is shown in Figure III.A-3, from 100 MWe to larger than 150 MWe, and then increase. The major influences as discussed below were considered. Other factors such as fixed cost of building, with increased plant size, were not included. These and other similar factors will tend to show larger plant sizes as more cost effective but will not be strong drivers.

Factors contributing to the overall economics of scale of the commercial plant include elements of cost which are sensitive as well as those that are insensitive to scale. Elements include both capital equipment and operating costs. In capital equipment, for example, the collector-receiver costs are direct linear functions of scale (or constant $/KW) and therefore insensitive, while electric power generation equipment cost benefits from increased scale. Field steam piping costs suffer from increased scale. Operating costs associated with plant operation benefit from scale while maintenance costs of the collector field do not.

The 150 MW_e plant sizing is based on a trade-off of those factors that are sensitive to plant size. Conversion of operating labor costs, derived from Figure III.A-4a to equivalent capital costs is made to enable comparison on the same baseline, dollars per kilowatt capital cost. (This conversion was made on the basis of a capital equipment purchase which would have the same cost as the operating cost over 30 years. The operating cost is divided by 2.914 to obtain the equivalent capital cost, based on a 9 percent yearly interest rate). Turbine cost as a function of plant size is shown in Figure III.A-4b.

Figure III.A-3 shows the combined effect of the major scaling influences. The turbine generator's declining cost with scale, the piping's rising cost with scale, and the operating manpower's

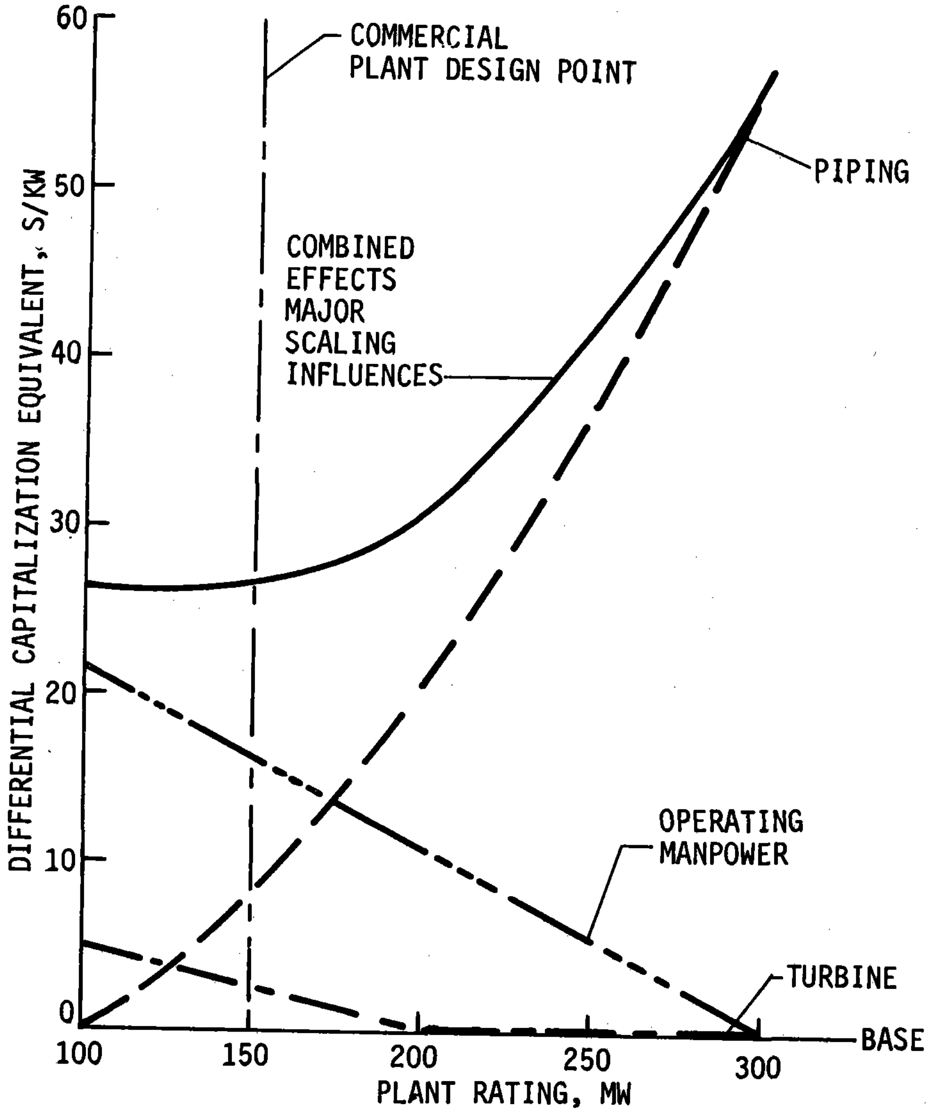
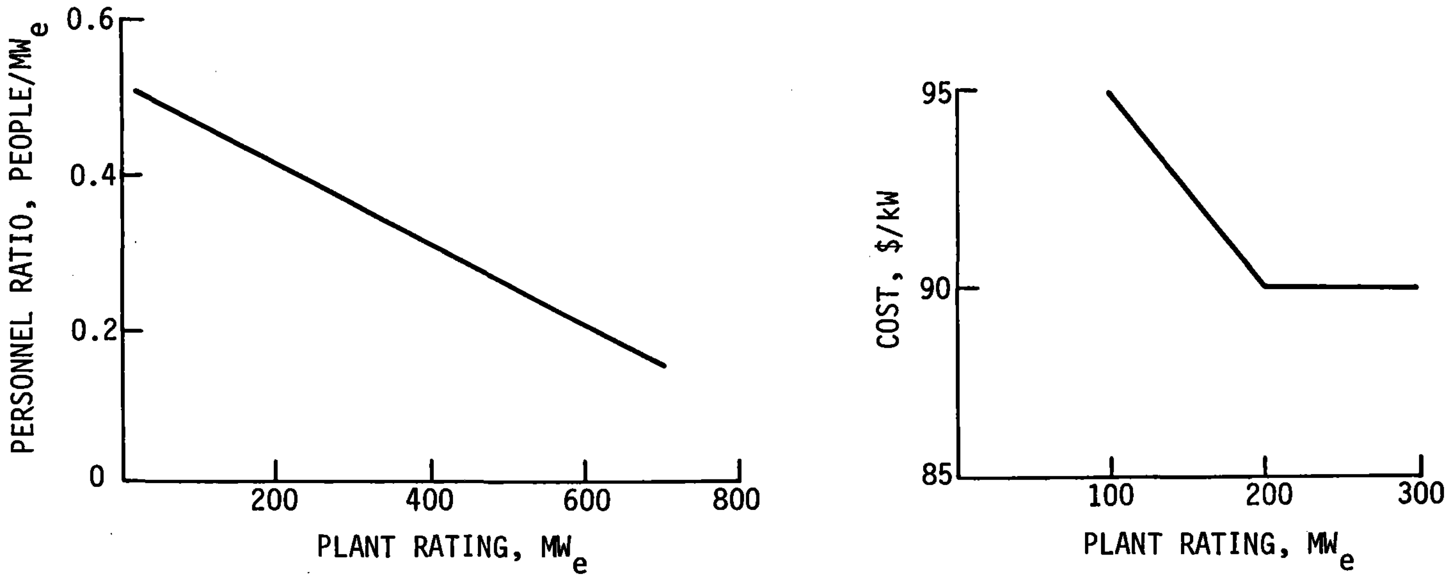


Figure III.A-3 Economic Scaling Influences



(a) Personnel Ratio Versus Plant Rating

(b) Turbine Cost Versus Plant Rating

Figure III.A-4 Commercial Plant Manpower and Turbine Cost declining cost with scale, all results in a very flat curve in the 100-150 MWe range followed by a break upward above 150 MWe.

As can be seen from Figure III.A-3 the piping cost is a significant influence in selecting the plant size. To develop the piping curve a parametric study of plant size, module arrangements, pipe length, pipe diameter and piping pressure drop was conducted. Figure III.A-5 shows the results of this study. A piping pressure drop of 200 psi was selected for the commercial plant and was included in the plant size selection study.

150 MWe was selected for the commercial plant size on the basis of: the foregoing combined influences study; the recognition that fixed plant facilities, not yet considered, will also benefit from larger scale; and that a 150 MWe admission type turbine generator can be assembled from existing hardware.

3. Selection of the Commercial Plant Modular Configuration

The selection of a modular concept utilizing focused heliostats to reflect solar energy over moderate slant ranges into a cavity receiver from a north field collector subsystem results in an optimum solar thermal power plant configuration.

Key considerations in selecting this concept are discussed in the following paragraphs III.A.3a. through e. Paragraph a. discusses the advantages of the north field collector subsystem geometry over that of surrounding fields. Paragraph b. discusses the key advantages of the enclosed cavity receiver working in conjunction with the focused heliostats in the north field. Paragraph c. discusses selection of the module size as a function of the primary driver of receiver size, tower height and collector field size. Paragraph d. discusses the optimization of tower height for the selected module size as a function of the interrelated cost and performance of collector field layout and the receiver aperture height. Paragraph e. discusses the optimization of the location of the heliostats within the collector field for the selected tower height. These combined itterative studies summarize the basis of selecting the modular concept.

a. North Field Collector Geometry - The north side collector geometry was selected to maximize the area utilization of the collector. Since the heliostat's basic function is to bisect the angle between the incoming sunlight and the reflected beam to the receiver, design of a collector which minimizes this angle minimizes the angle between the heliostat normal and the sunlight,

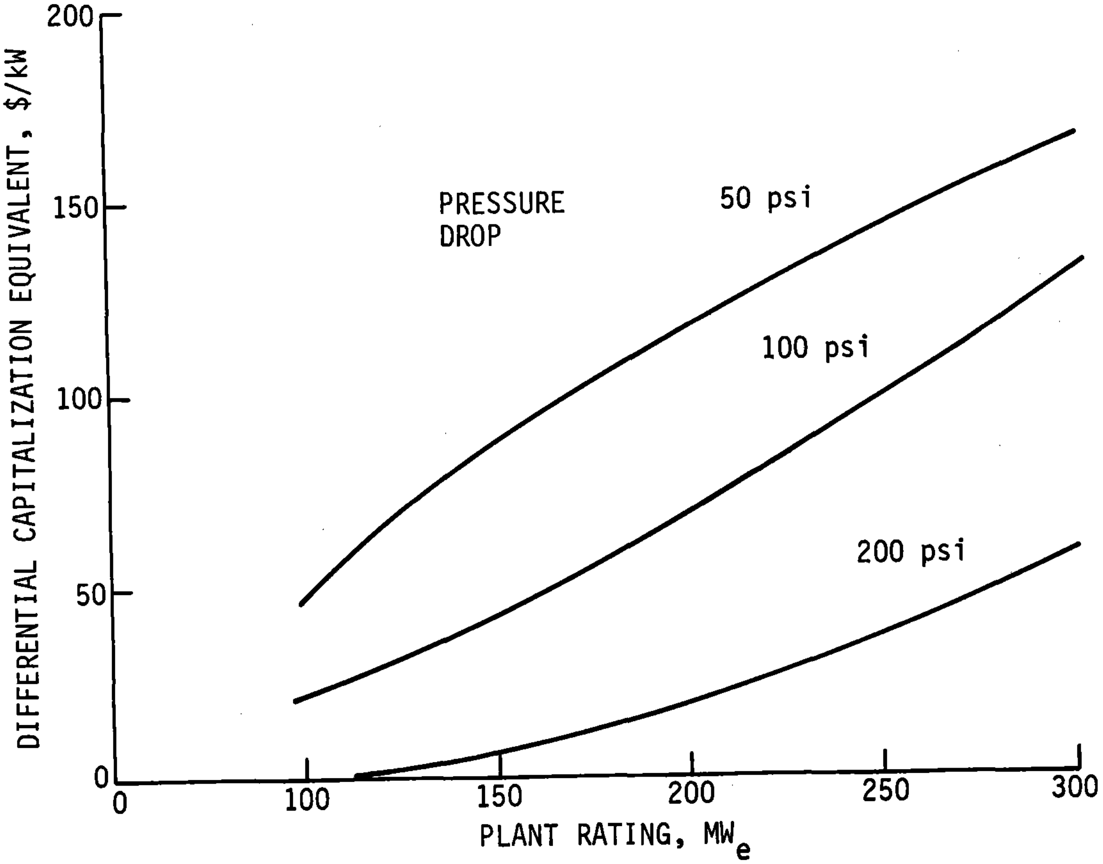


Figure III.A-5. Commercial Plant Steam Piping Cost thereby maximizing heliostat area efficiency.

Figure III.A-6 illustrates the basic effect which favors heliostats located in the north field over those at corresponding positions in the south field. The geometric patterns for noon on the solstices and equinox are shown for the centerline heliostat at row 1 and row 10 both north and south of the tower. For the north field heliostats the angle between the incoming solar beam and reflected focused beam is consistently a small acute angle generally yielding a half angle cosine (beams to the heliostat normal) greater than 0.9. For south field heliostats the major angle (solar to reflected) is consistently larger and grows progressively as the position of the heliostat moves away from the tower. The south field angles frequently become obtuse with resultant half angles greater than 45^{o} reducing the area effectiveness cosine below 0.7.

An early design goal of the central receiver was to achieve competitive performance with on-axis tracking collectors. Due to focal zone and support structure shadowing, the best of these systems attained an area utilization factor of 0.88. For this reason the goal of the central receiver was to achieve a comparable area efficiency (effective cosine of the heliostat angle normal to the sun) throughout the bulk of the operating day and year. This goal was only approachable with the north field collector geometry which did yield the desired performance for the September to March half of the year and only mildly compromised it in the other half. A reduction in this performance parameter of three percent was accepted late in the program, the net result of the tower height reduction design modification and the offsetting effects of the field layout using 41 m^2 heliostats.

Data for the two positions shown and for corresponding positions 20 and 30 rows north and south are listed in Table III.A-1. The increasing advantage of the north field positions with module size is illustrated. The north field margin is greater in the winter with low sun angles, 1.42:1 (Row 1) to 2.75:1 (Row 30), and narrows in the summer, 1.07:1 (Row 1) to 1.19:1 (Row 30). Annual variation in the area efficiency is substantially smaller for the north field. For the north field the advantage of the best cosine of the year over the worst cosine of the year ranges between factors of 1.02 and 1.18 while for the corresponding south field it ranges between factors of 1.34 and 1.95.

The basic north side geometry advantage has been consistently verified in analysis of module designs with full surrounding layout, and tower south of center surrounding layout and the north side

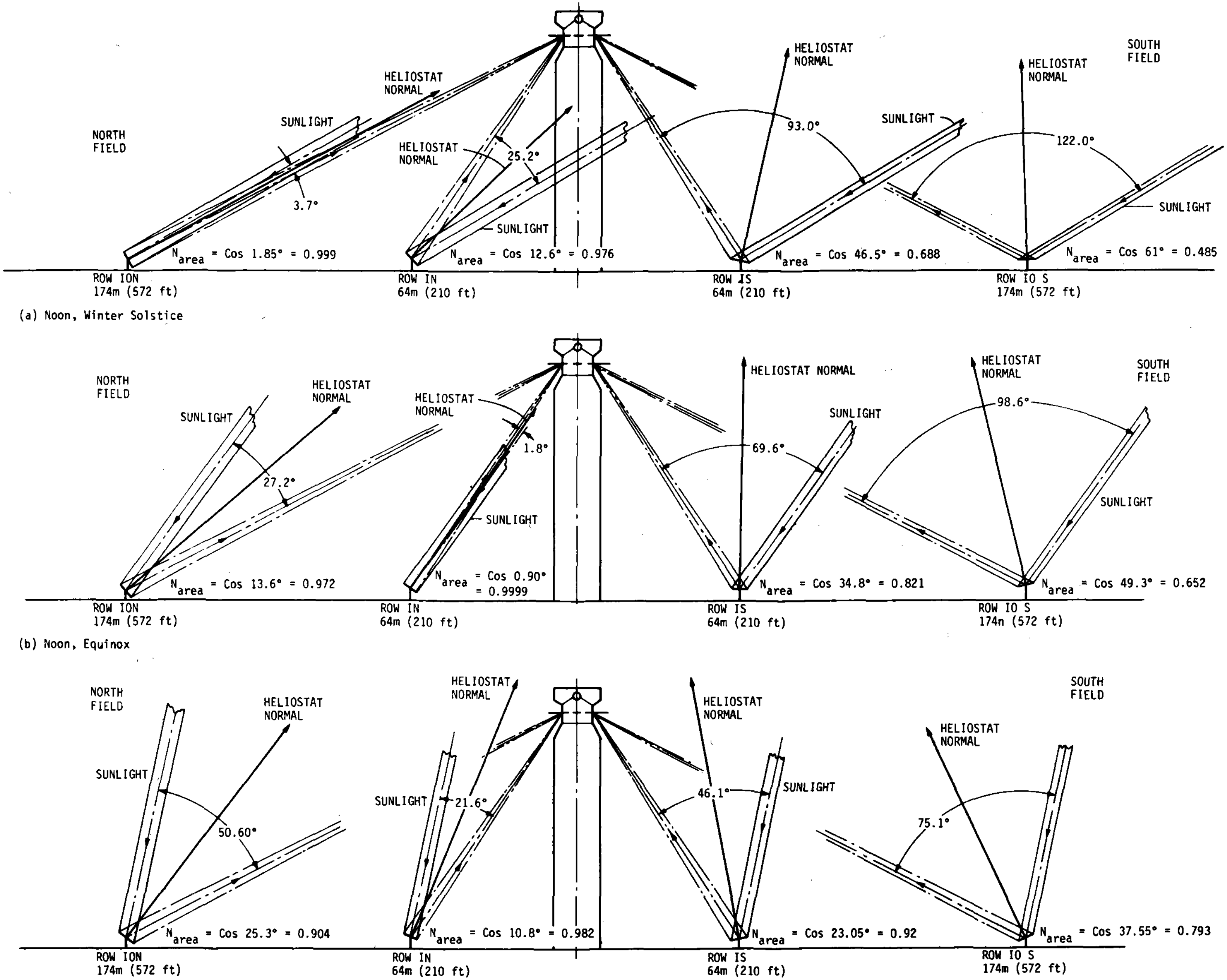


Figure III.A-6 Reflection Angle/Area Efficiency Comparison Corresponding North and South Heliostat Positions

Table III.A-1 Area Efficiency Comparison for Corresponding North and South Field Heliostats, 90 m (295 ft) Tower

Position in Collector Module	Time of Year	Noon Geometric Area Efficiency (Cosine)		North/South Area Efficiency Ratio
		North Field	South Field	
Row 1, Position 1 64 m (210 ft)	Winter Equinox Summer	0.976 0.999 0.982	0.688 0.821 0.920	1.42 1.22 1.07
Row 10, Position 1 174 m (572 ft)	Winter Equinox Summer	0.999 0.972 0.904	0.485 0.652 0.793	2.06 1.49 1.14
Row 20, Position 1 326 m (1069 ft)	Winter Equinox Summer	0.990 0.942 0.854	0.390 0.569 0.724	2.54 1.66 1.18
Row 30, Position 1 448 m (1469 ft)	Winter Equinox Summer	0.985 0.930 0.835	0.358 0.540 0.700	2.75 1.72 1.19

collector layout integrated for the complete year on an hourly increment. East and west fields yield an intermediate performance between the north and south.

b. <u>Cavity Receiver Design Selection</u> - The cavity configuration was selected for the commercial/pilot plant receiver to minimize total thermal losses during operation, thereby maximizing overall energy collection and conversion efficiency. Solar energy is aimed and focused by the collector field into a relatively small aperture (605 ft^2) in the side of the cavity. The peak heat flux in the aperture plane is of the order of $3MW/m^2$, much too high to impose upon any type of boiler surface. Therefore, the boiler surfaces are located at a distance of 9.1 m behind the aperture plane where the energy pattern has been expanded and the peak heat flux level dropped to a tolerable level below 0.7 MW/m^2. The active boiler surfaces were sized and configured to cover the major portion of the expanded energy pattern (about $192m^2$). Only a small portion of the energy which is reflected and reradiated from the large boiler surface escapes through the small aperture - the major portion is reradiated back to the boiler by the cavity enclosure. Likewise, air convection heat losses are greatly reduced by the shielding effect of the enclosure.

The aperture was sized to accommodate two divergent considerations. The opening must be large enough to capture most of the reflected energy from all heliostats. However, increasing the aperture size also increases thermal losses from the cavity by radiation and convection. Therefore, the optimum aperture size is that which allows the most energy to enter and yet minimizes direct radiation and convection losses from the cavity. The selection of focused heliostats, operating over moderate slant ranges, permits a minimum aperture size and therefore enhances the receiver efficiency. The 7.498-m (24.6-ft) square aperture selected for the pilot-plant receiver captures an annual average of 97.7 percent of the energy projected from the heliostat field and loses about 6 percent by radiation and convection from the cavity.

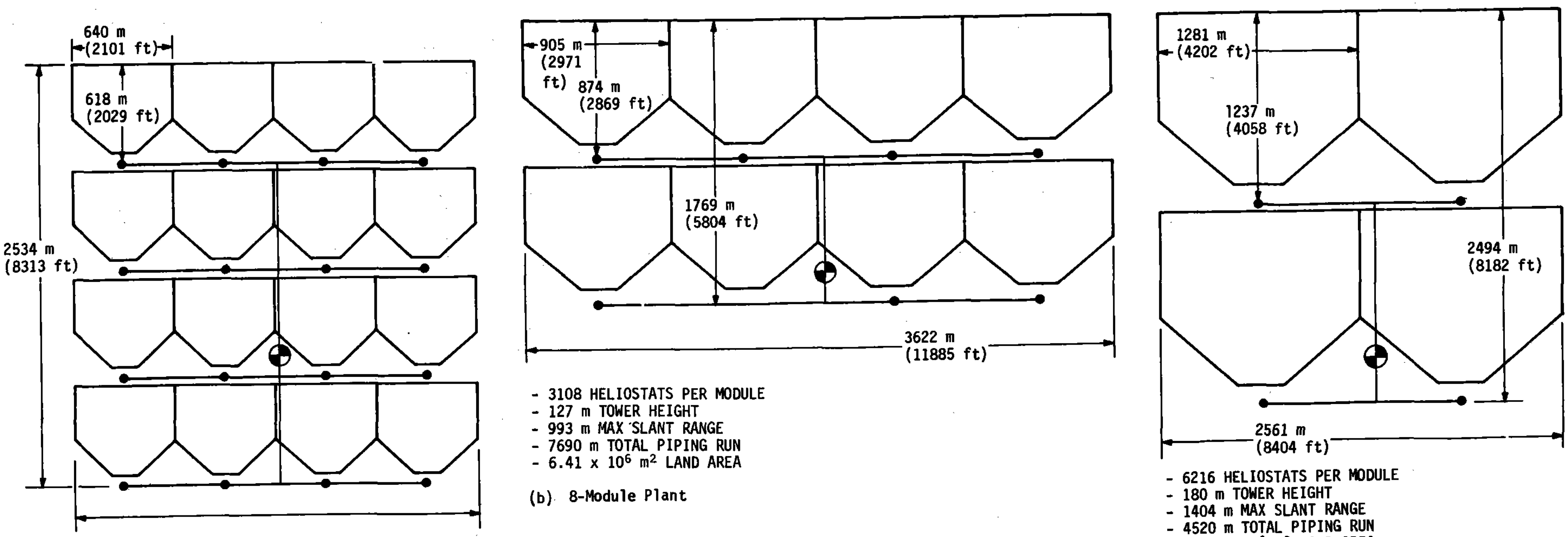
The depth and width of the cavity and the orientation of the three active walls with respect to the aperture were established to attain a reasonable compromise between receiver size and active surface heat-flux distribution. A larger cavity could result in lower peak heat fluxes and a somewhat more uniform distribution of energy over the active walls, but it would also be heavier (a detriment to tower design), costlier, and less efficient as a result of increased heat losses through the insulated walls. The entire cavity is insulated to reduce losses through the walls to a negligible level (less than 0.5%) and an insulated door covers the aperture during non-operative periods (overnight and durations of extensive cloudiness) to further conserve energy and optimize restart time. This cavity design results in a reduction in total thermal loss by a factor of approximately one-fourth (¼), as compared to an equivalent exposed surface receiver.

c. Collector/Receiver Module Size - The collector/receiver module selected for the original baseline design consisted of 1718 heliostats with a total mirror area of 63,841 m^2 and a receiver externally mounted on a concrete tower with an aperture height of 137.2 m. The module has evolved to one of 1554 heliostats with a total mirror area of 63,666 m^2 and an internally mounted receiver on a steel tower with an aperture height of 90 m.

In order to assess the impact of the current module performance and cost data on the module size, the effects of increasing the module size by a factor of two and a factor of four were examined. Figure III.A-7 shows the three "commercial configurations" used in the trade-off. For this study the reference plant was increased to 16 modules to enable size plants with the double and quadruple size modules being evaluated. Land area requirements for all three plants are very close, differing by only 1.5 percent from the largest to the smallest.

The scale sensitive variable factors in the collector and receiver subsystems were established as the receivers, towers, piping, and heliostats. Figure III.A-8 and Table III.A-2 show the trade-off data, the differential costs being listed in the table. Receiver and piping favor the larger module size while heliostat and tower costs favor the smaller module. The combined curve shows a low point for the double size module, 2.2 million dollars lower in capital cost than the plant with the smallest module. This margin alone is not sufficient to justify design concept modification at this time due to two considerations. The first is that the design and re-qualification of a larger receiver for the commercial plant would more than offset the apparent margin, and the second is the sensitivity of the apparent margin to the assumption on heliostat unit cost. Should heliostat costs not reach the assumed $4000 per unit the margin is decreased, disappearing altogether for $8000 per unit heliostats.

d. Tower Height Selection - One of the drivers in determining collector-receiver module performance and cost is the receiver tower aperture height. The aperture height selected for the preliminary design collector-receiver module, 90 m, was the



- 1554 HELIOSTATS/MODULE
- 90 m TOWER HEIGHT
- 707 m MAX SLANT RANGE
- 11240 m TOTAL PIPING RUN
- 6.49 x 10^6 m^2 LAND AREA

(a) 16-Module Plant

- 3108 HELIOSTATS PER MODULE
- 127 m TOWER HEIGHT
- 993 m MAX SLANT RANGE
- 7690 m TOTAL PIPING RUN
- 6.41 x 10^6 m^2 LAND AREA

(b) 8-Module Plant

- 6216 HELIOSTATS PER MODULE
- 180 m TOWER HEIGHT
- 1404 m MAX SLANT RANGE
- 4520 m TOTAL PIPING RUN
- 6.39 x 10^6 m^2 LAND AREA

(c) 4-Module Plant

Figure III.A-7 Commercial Plant Configuration for Module Size Tradeoff

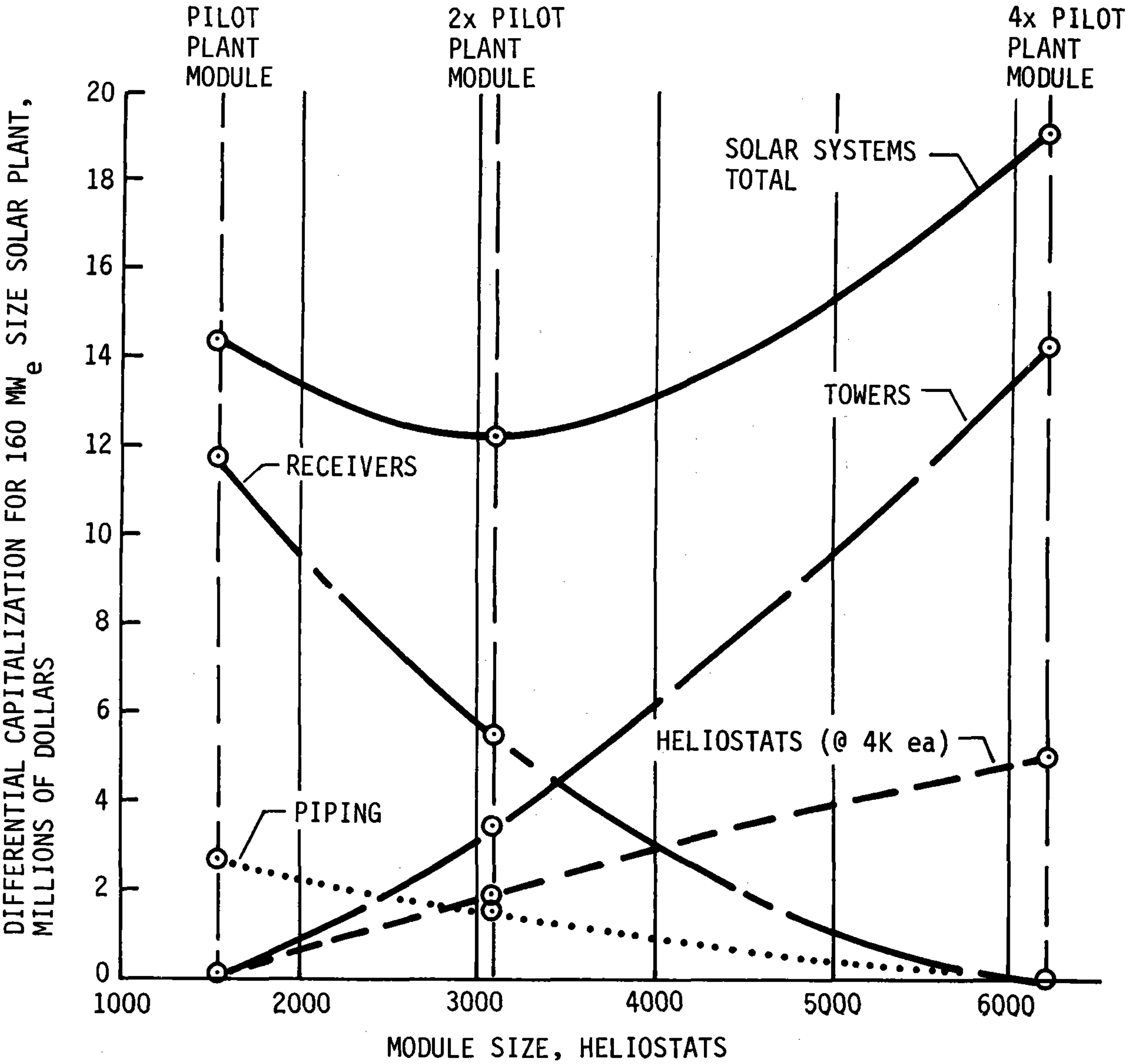


Figure III.A-8 Module Size Trade-Off Factors

Table III.A-2 Module Size Parametric Data Summary

	10 MW_e + Storage 16 Modules 1554 Heliostats		20 MW_e + Storage 8 Modules 3108 Heliostats		40 MW_e + Storage 4 Modules 6216 Heliostats	
	Total	Relative	Total	Relative	Total	Relative
Heliostats Cost (Atmospheric Attenuation Impact Using 4K per Heliostat)	99.46M	Base	101.32M	1.86M	104.43M	4.97M
Receiver Cost	48.48M	11.74	42.20M	5.46M	36.74M	Base
Tower Costs	38.88M	Base	42.32M	3.44M	53.16M	14.28M
Piping	17.10M	2.70	15.88M	1.48M	14.40M	Base
Total Solar Systems	203.9M	14.44	201.7	12.24	208.7	19.25

result of an optimization study which investigated the effects of varying receiver tower aperture height on plant performance and cost. The optimization minimized collector-receiver module cost per unit energy (on an annual basis) while maintaining near optimum module performance. The analysis was initially conducted based upon cost and performance data for the conceptual design collector-receiver module. The analysis was then updated to reflect the final configuration of the preliminary design collector-receiver module.

Any change in receiver tower aperture height can potentially affect the efficiency of other portions of the module, and thus affect the overall module performance. Areas of potential performance change include collector field cosine, heliostat blocking, tower shadow, piping losses and receiver efficiency. An examination of performance sensitivity in each of these areas to aperture height showed field cosine, heliostat blocking and tower shadow to be the only significant drivers. The combined effect of these three factors, as shown in Figure III.A-9, is relative module performance as a function of tower aperture height. Performance is shown relative to the conceptual design collector-receiver module.

Collector-receiver module costs were considered, along with performance, in the aperture height selection. Module costs associated with changing aperture height include the fixed costs of the receiver, collector field and horizontal piping and the variable cost of the tower, and riser/downcomer piping.

The relative module cost per unit energy, which is a combination of the performance data, shown in Figure III.A-9, and the cost data discussed above, is presented in Figure III.A-10. The relative cost is shown as a function of tower aperture height for heliostat costs ranging from $3,000 to $5,000. The solid curves represent the analysis results for the conceptual design and the dashed curves the results for the preliminary design. The aperture height selection of 90m, based upon the cost data of Figure III.A-10 and the performance data of Figure III.A-9, meets the goal of minimizing the module cost per unit energy while maintaining a near optimum performance level.

e. <u>Collector-Receiver Module Layout</u> - The performance and overall effectiveness of a collector field is dependent upon many factors including basic field geometry, field size, receiver type, receiver aperture height and heliostat layout within the field. The previous sections have discussed the selected module size, north field

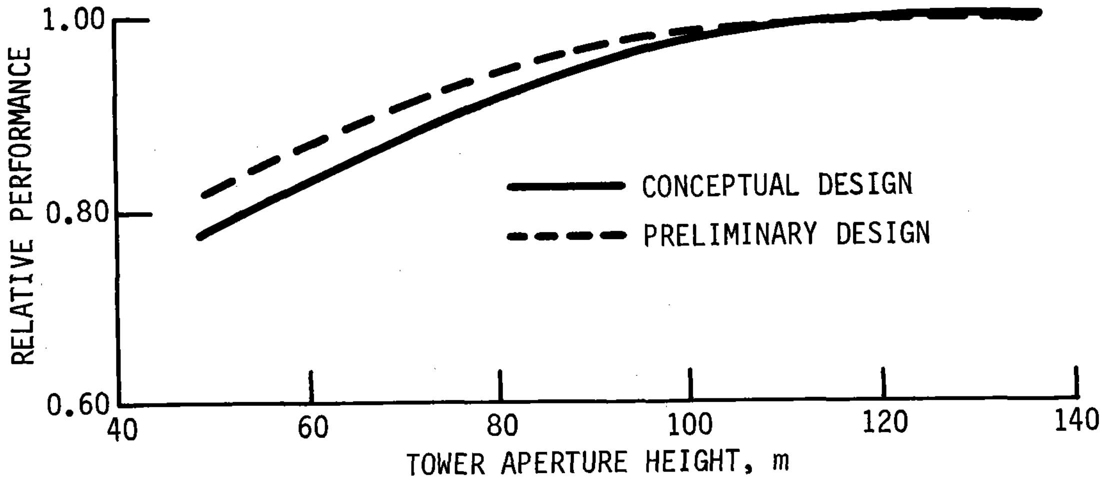


Figure III.A-9 Relative Module Performance

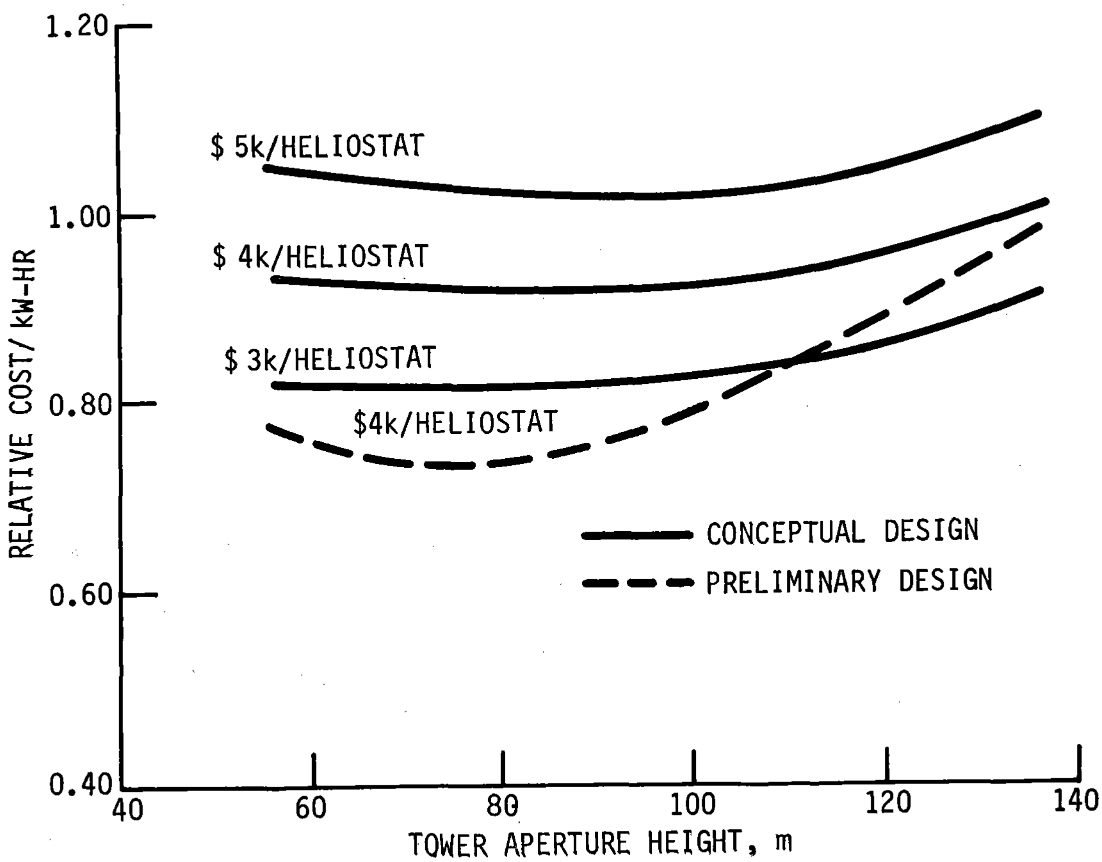


Figure III.A-10 Relative Module Cost Per Kilowatt-Hour geometry, cavity receiver and 90m receiver aperture height. This section discusses the collector field layout for the north field collector-receiver module.

The basic goal involved in the collector field design was to minimize the module cost per unit energy (on an annual basis) while providing efficient land utilization. Several different field layouts were evaluated to determine their relative performance and cost for the selected module configuration. The field designs evaluated included radial fields, linear fields and radial/linear fields containing as few as 1400 and as many as 1800 heliostats. The selected field layout, Figure III.A-11, showed a substantially lower (approximately 8%) module cost per unit energy than the conceptual design field and costs 2% to 6% lower than the other field configurations evaluated.

The selected field layout, as can be seen in Figure III.A-11, is a combination of linear and linear/radial design. The first 16 rows of the field are linear in nature, while rows 17 through 44 are linear/radial (the heliostats are located at the intersection of radial lines and straight rows). The heliostat placement within the field can best be described by discussing each of the three zones of the field.

1) <u>Zone I</u> - The zone nearest the tower, Rows I through 9, has constant row spacing of 12.2m (40 ft.) and constant heliostat spacing within the rows of 9.8m (32 ft.). The row spacing was selected to maximize heliostat density and minimize the effect of heliostat shading over the year. The spacing within the row is the minimum allowable spacing due to the heliostat size.

2) <u>Zone II</u> - The next zone of the field, rows 10 through 16, has variable row spacing ranging from 12.8m (42 ft.) to 19.8m (65 ft.). The heliostat spacing within the row is the same as Section I, 9.8m (32 ft.). The spacing was selected for each row to maximize heliostat density while minimizing the yearly effect of heliostat blocking. However, as the distance from the tower increases this method of minimizing blocking becomes inefficient and a transition to Zone III occurs.

3) <u>Zone III</u> - The last zone of the field, rows 17 through 44, has constant row spacing of 12.2m (40 ft.) and variable heliostat spacing within the rows ranging from 12.2m (40 ft.) to 28.8m (94.5 ft.). The heliostats in this

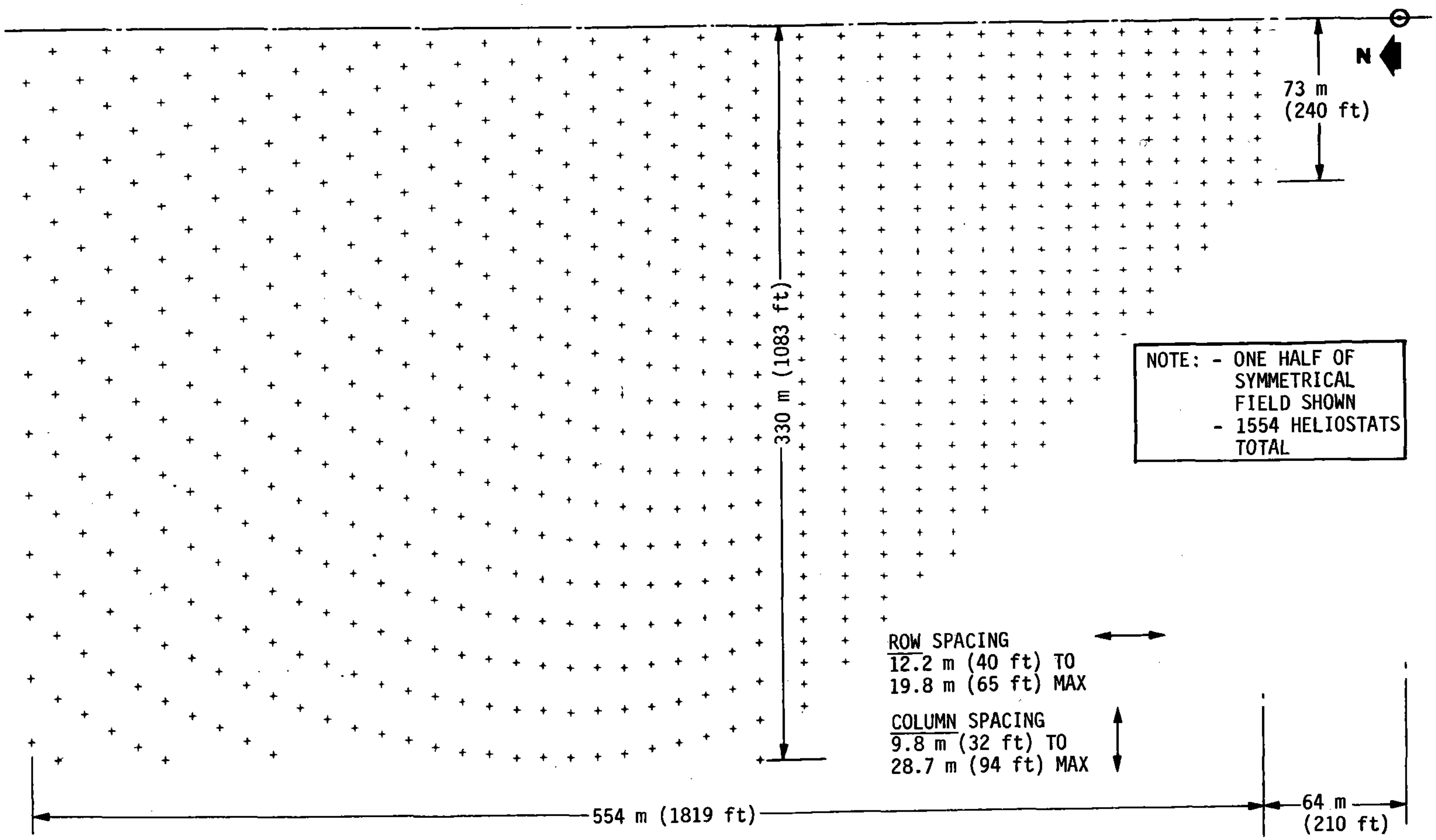


Figure III.A-11 Collector Receiver Module Field Layout zone are aligned radially with the aperture, on alternating rows. The spacing is such that the beam from a heliostat is blocked by a heliostat two rows in front, as opposed to the row directly in front as is the case in Zone II. This spacing scheme maximizes density while minimizing yearly blocking for this far portion of the field.

B. COMMERCIAL PLANT PERFORMANCE

1. Cycle Choice for the Electrical Power Generation Subsystem (EPGS)

a. Selected Cycle - The selected EPGS cycle shown on the commercial plant schematic (Figure III.A-2) resulted from the requirements of the solar plant as discussed below. The cycle is made up of two steam sources (receiver and thermal storage), condensing by water cooling and conventional uncontrolled turbine extraction for feedwater heating. The cycle state point for main steam is 9308 kPa (1350 psig) and 783 K (950^{o}F) and the admission steam is 2758 kPa (400 psig) and 700 K (800^{o}F). The cycle condensing pressure is 8.5 kPa (2 1/2 HgA).

b. Requirements and Constraints Effective Cycle Choice - There are several basic requirements for a solar plant that effect the cycle choice. First is the requirement for daily cyclic operation of the plant. This places practical constraints on the cycle through the choice of a turbine. Temperature limits of 783 K (950^{o}F) allows the use of more ductile steel which is recommended for turbines in cyclic operation. Pressure limits of 9308 kPa (1350 psig) reduces the thickness of the turbine casing, thereby reducing its thermal stresses caused by cycling.

The requirement of the solar plant to utilize thermal storage defined the requirement for an additional steam source. In addition the thermal storage source of steam must operate the turbine at 70% or greater of the rated performance from main steam. A review of available turbine type to accommodate dual steam sources is shown in Figure III.B-1. The admission turbine type was selected over the mixed pressure or induction turbine to minimize throttling losses while providing operational flexibility and cyclic capabilities. The steam conditions for the admission point are selected to provide a close match to the expansion line of the main steam.

The required modes of operation for the solar plant include operation on main steam, on thermal storage steam, charging thermal storage and various combinations of these modes. These requirements place certain practical limits on the steam state conditions between thermal storage charging, which is from the receiver and thermal storage discharging which is the admission steam to the turbine. These limits include such things as the minimum temperature and pressure allowable at the turbine admission point (from thermal storage) without added performance penalty when operating on main (receiver) steam.

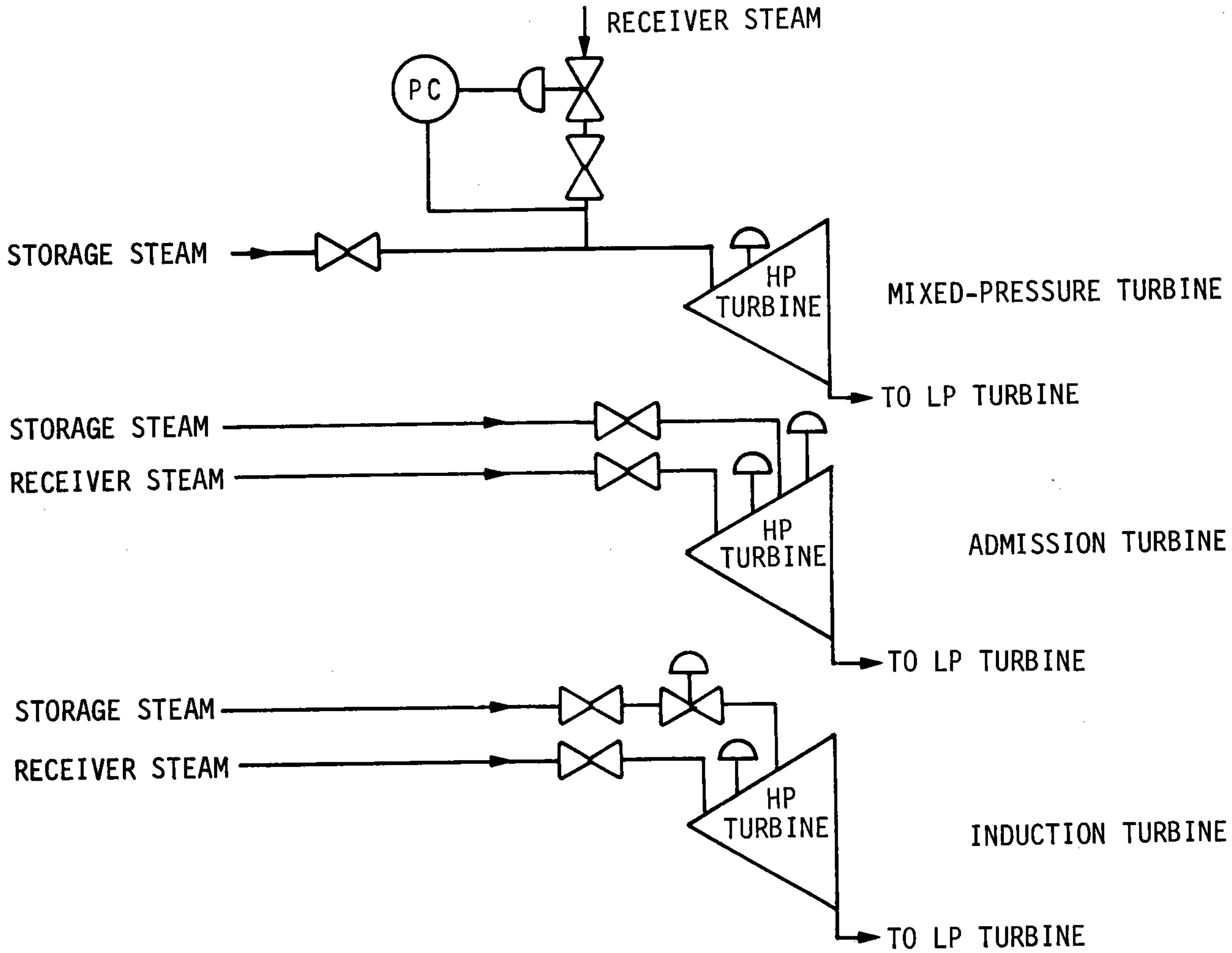


Figure III.B-1. Turbine Types Considered

Water cooling sets the selected condensing pressure for the cycle. The number of feedwater heaters in the cycle is determined by the economics associated with increased plant efficiency.

c. EPGS Cycle Choice Considerations - Based on the above requirements and constraints several studies were performed to establish the selected EPGS cycle. Studies to select the main steam state point were based on turbine and receiver operating temperature and pressure limits coupled with the field steam piping cost and pressure drop study discussed above under III.A-2.

Selection of the admission steam state point was based on a trade study of cost and performance of the thermal storage, electrical power generation and collector subsystems. Drivers in the study centered around: the reduced capital cost of thermal storage with increased pressure differential between charging and discharging; the decrease in turbine efficiency with decreasing pressure at the admission point; and the additional heliostats required to charge thermal storage as the turbine efficiency decreases. This portion of the study selected the admission point pressure. The study also included the increased turbine performance at higher admission point temperatures. This portion of the study selected the admission point temperature. Throughout the study admission point temperature and pressure limits were set by the turbine cycle matching requirements for the turbine expansion line end points.

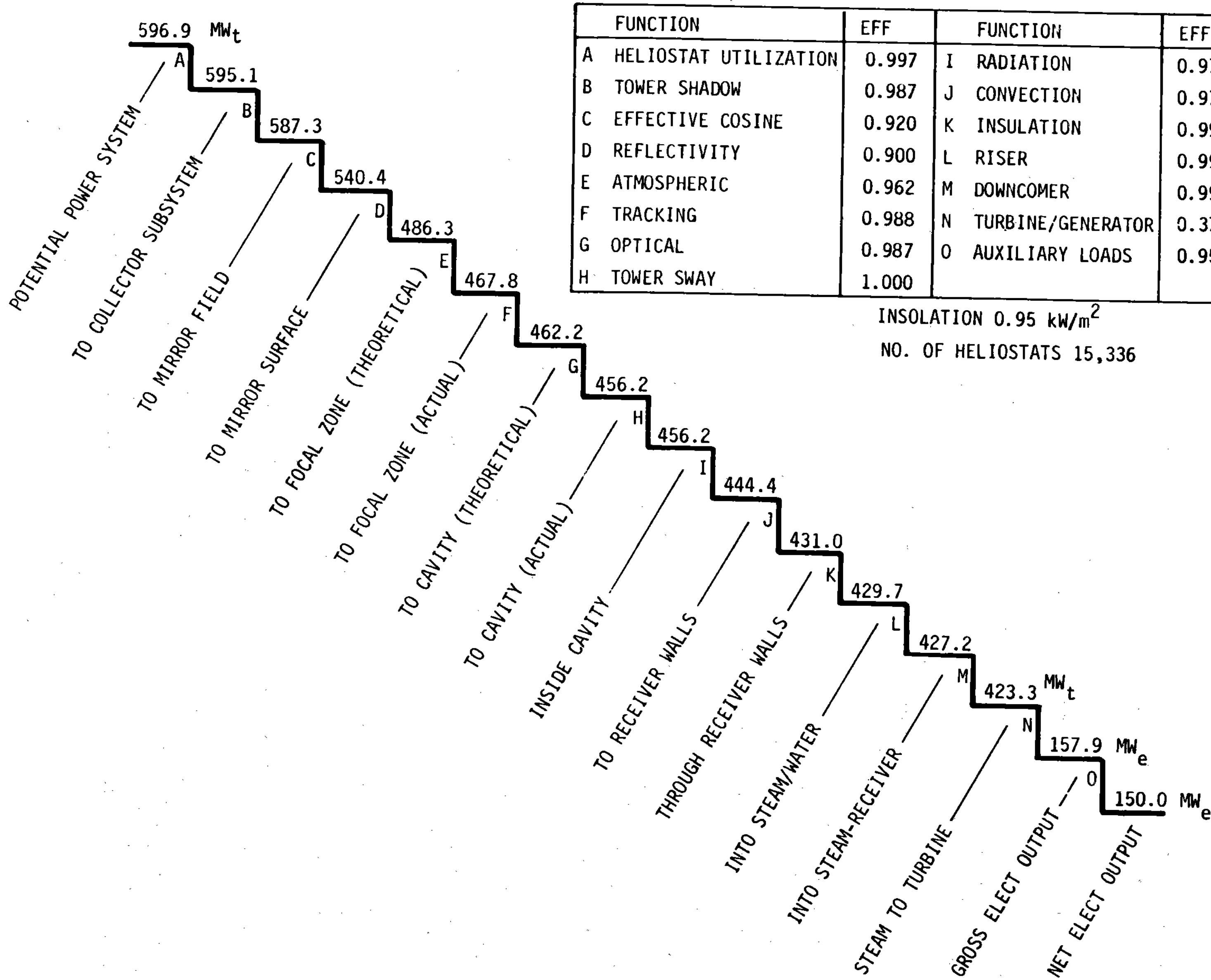
Reheat was considered not to be practical for solar power plants where long reheat pipe runs would be necessary. These runs would extend from the turbine to the receiver and back down to the turbine. They would require large diameter, alloy steel pipe. The considerable additional cost of this piping is not considered justifiable.

2. Commercial Plant Design Point Performance

The commercial plant concept includes 15 commercial plant collector/receiver modules of 1554 heliostats, for a total of 23,310 heliostats. These 15 modules, along with the thermal storage and electrical power generation subsystems, make up a 150 MW_e commercial plant with a storage capacity of 3 hours. The plant has a solar multiple rating of approximately 1.5, where solar multiple is defined as the ratio of the design point receiver output, at the turbine/TSS, to the power required to produce the design point net output of 150 MW_e.

a. Design Point Performance Profiles - The ERDA defined commercial plant design point is noon on the day of most favorable collector cosine (winter solstice for the MMC concept) at Inyokern, California. The environmental conditions at the design point are defined as an insolation of 0.95 kW/m^2, wet bulb temperature of 23°C (73°F), dry bulb temperature of 28°C (82°F) and a wind velocity of 3.5 m/sec (8 mph). Figure III.B-2 shows the performance profile (stair-step) for a 150 MWe commercial plant with a solar multiple of 1.0 at the design point. The profile depicts the power flow through the plant from the potentially collectable (all mirrors normal to sun) incident solar radiation through the net electrical output power. It identifies and quantifies all the losses involved in the conversion of solar input power into usable electric power for the commercial plant. This profile shows that 15,336 heliostats are needed to supply the 596.9 MW_t potential power to the system required to produce a net electrical output of 150 MW_e. The letters on the performance profile are keyed to the inset table which shows the system efficiency between two locations. These efficiency factors are discussed in Section III.B.2.d. A second performance profile, shown in Figure III.B-3, calculates the minimum additional heliostats required to supply sufficient energy to charge storage to provide for the required three hours of storage operation. This profile is based on the plant capability to charge storage for approximately 6.8 hours on a winter solstice day while also generating 150 MW_e for the same period. The insolation and efficiencies shown represent the average values for the 6.8 hour period. As shown in the profile the number of heliostats required to charge thermal storage is 6790. The full complement of heliostats in the plant was established at 23310, 1184 more than the sum of the two minimums. These added units expand the time for rated operation from the momentary design point to 6.8 hours for a winter day and 8.5 hours for equinox and summer days.

b. Winter Solstice Day Performance - In order to get a clear picture of the commercial plant performance it is useful to examine the plant performance over the entire design point day. Figure III.B-4 shows the thermal power available to the turbine and/or thermal storage as a function of time for a winter solstice day. The performance is shown for the 15 module commercial plant (solar multiple = 1.5). The curve is based on winter solstice insolation data normalized to 0.95 kW/m^2 at noon. The dashed line across the curve at 435 MW_t represents the turbine thermal input required to produce a net plant output of 150 MWe while charging storage; thus, for sustained operation at 150 MWe, the area under the dashed line for the curve represents the energy available for direct conversion into electrical power and the area above the dashed line represents

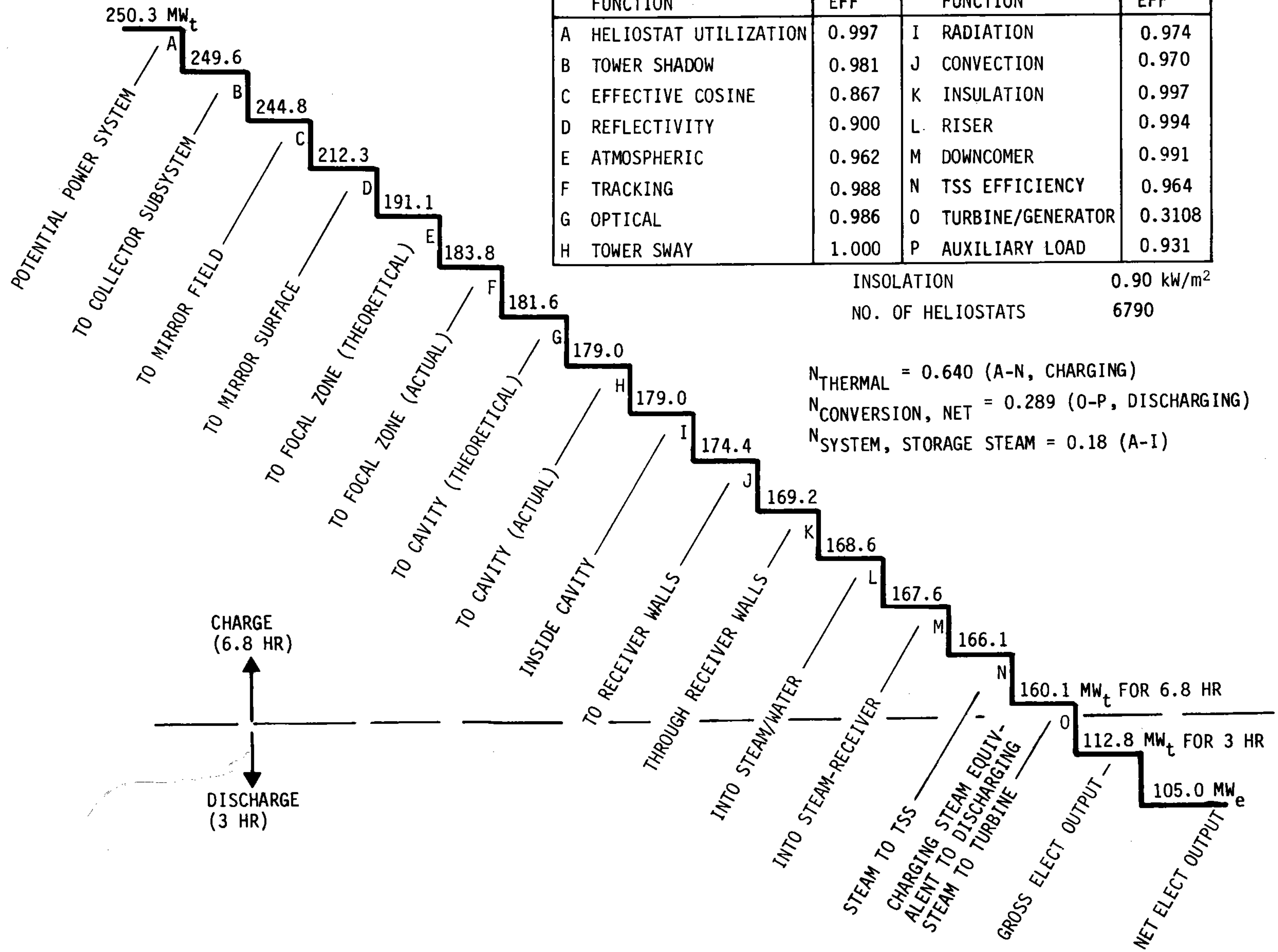


	FUNCTION	EFF		FUNCTION	EFF
A	HELIOSTAT UTILIZATION	0.997	I	RADIATION	0.974
B	TOWER SHADOW	0.987	J	CONVECTION	0.970
C	EFFECTIVE COSINE	0.920	K	INSULATION	0.997
D	REFLECTIVITY	0.900	L	RISER	0.994
E	ATMOSPHERIC	0.962	M	DOWNCOMER	0.991
F	TRACKING	0.988	N	TURBINE/GENERATOR	0.3730
G	OPTICAL	0.987	O	AUXILIARY LOADS	0.950
H	TOWER SWAY	1.000			

INSOLATION 0.95 kW/m^2

NO. OF HELIOSTATS 15,336

Figure III.B-2 Commercial Plant Design Point Performance Profile, Solar Multiple = 1.0



	FUNCTION	EFF		FUNCTION	EFF
A	HELIOSTAT UTILIZATION	0.997	I	RADIATION	0.974
B	TOWER SHADOW	0.981	J	CONVECTION	0.970
C	EFFECTIVE COSINE	0.867	K	INSULATION	0.997
D	REFLECTIVITY	0.900	L	RISER	0.994
E	ATMOSPHERIC	0.962	M	DOWNCOMER	0.991
F	TRACKING	0.988	N	TSS EFFICIENCY	0.964
G	OPTICAL	0.986	O	TURBINE/GENERATOR	0.3108
H	TOWER SWAY	1.000	P	AUXILIARY LOAD	0.931

INSOLATION 0.90 kW/m^2

NO. OF HELIOSTATS 6790

$N_{THERMAL}$ = 0.640 (A-N, CHARGING)

$N_{CONVERSION,\ NET}$ = 0.289 (O-P, DISCHARGING)

$N_{SYSTEM,\ STORAGE\ STEAM}$ = 0.18 (A-I)

Figure III.B-3 Commercial Plant Energy Balance for Charging and Discharging

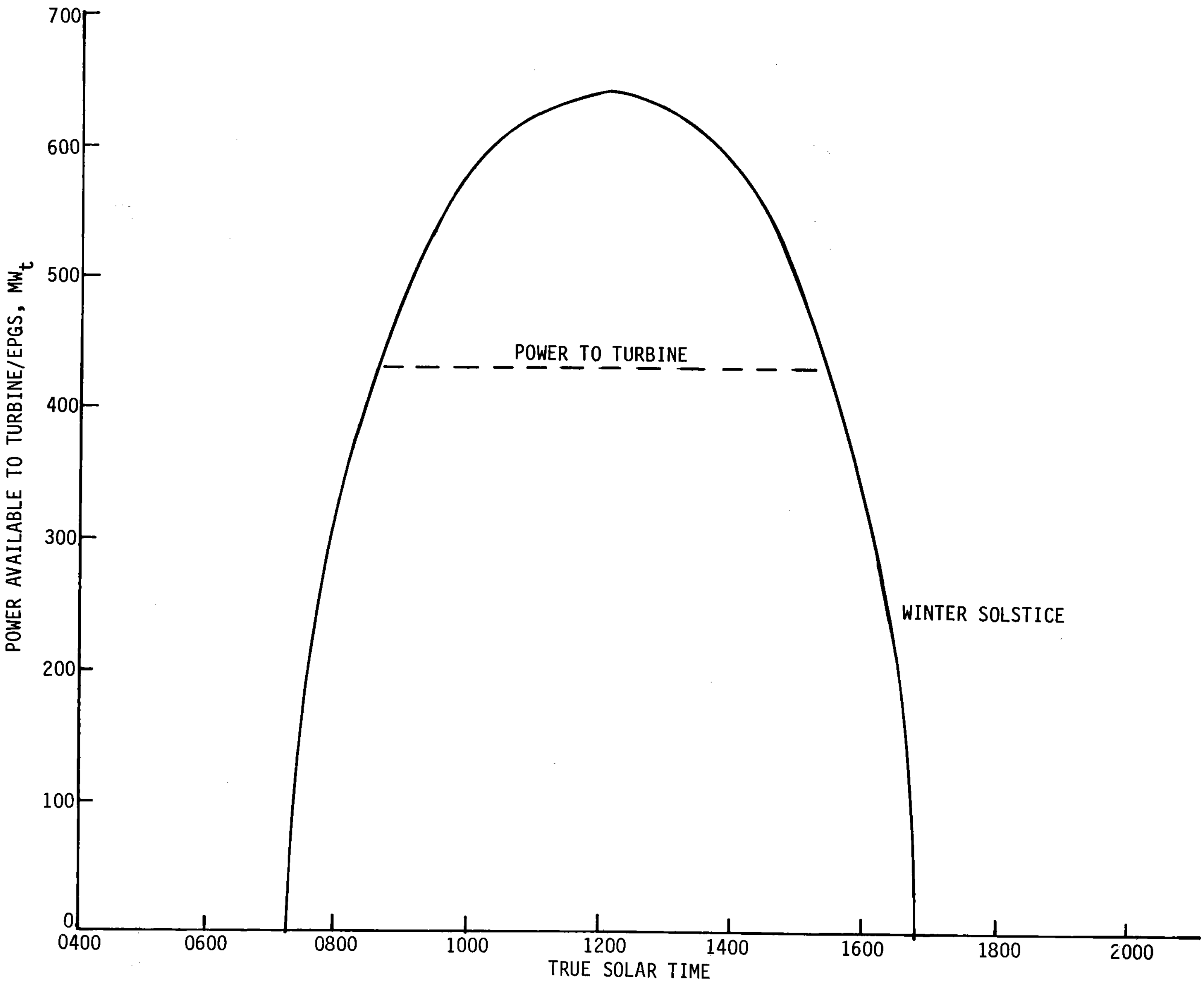


Figure III.B-4 Winter Solstice Day Performance the energy available for charging thermal storage. On the design point day described, the commercial plant will produce 3755 MW_t-hr of thermal energy for the generation of electrical energy and additional 1027 MW_t-hr of thermal energy for charging thermal storage. This is the equivalent of about 2.8 hours of storage capacity when operating at 105 MW_e net. The maximum power available for charging thermal storage on the design point day is 210 MW_t.

c. Design Point Performance from Thermal Storage - The commercial plant, when operating solely from thermal storage, must be capable of producing 105 MWe net electrical output for three hours minimum. In addition, the thermal storage subsystem must have sufficient capacity to start the turbine from a hot start condition.

The commercial plant thermal storage subsystem is capable of supplying the 87 MW_t-hr required for hot turbine startup followed by 363 MWt for three hours to the electrical power generation subsystem which, in turn, is capable of producing 112.8 MWe gross electrical output. 112.8 MWe gross minus the plant auxiliary load of 7.8 MWe produces the required 105 MWe net electrical output. The thermal storage subsystem maximum charge rate of 241.5 MWe is capable of accepting all power in excess of that required to generate 150 MWe throughout the year under design point conditions.

d. Subsystem Efficiencies - This section discusses the commercial plant design point subsystem efficiencies in terms of the efficiency factors shown in the performance profiles of Section III.B.2.a. In addition the thermal storage subsystem efficiency is discussed.

1) Collector Subsystem - The overall collector subsystem commercial plant design point efficiency is 0.764; which is made up of the efficiency factor discussed below. A thorough discussion of the atmospheric, tracking and optical efficiency factors is presented in Volume III.

   a) Heliostat Utilization - It is assumed, for purposes of sizing the collector subsystem, that 5 heliostats per module will be down for maintenance at any given time. This corresponds to a 0.3% loss or an efficiency factor of 0.997.

   b) Tower Shadow - This is the power loss resulting from the shadow of the receiver tower moving across the collector field. Table III.B-1 shows the effect of tower shadow on the 21st day of each month for each hour of the day. The portion of the field shaded at

Table III.B-1 Fraction of Collector Field Shaded by Tower

	TIME OF DAY														
MONTH/DAY	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
JAN 21				.000	.024	.015	.012	.010	.012	.015	.024	.000			
FEB 21			.000	.000	.000	.009	.007	.006	.007	.009	.000	.000	.000		
MAR 21			.000	.000	.000	.003	.003	.003	.003	.003	.000	.000	.000		
APR 21		.000	.000	.000	.000	.001	.001	.001	.001	.001	.000	.000	.000	.000	
MAY 21		.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	
JUNE 21	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
JULY 21		.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	
AUG 21		.000	.000	.000	.000	.001	.000	.000	.000	.001	.000	.000	.000	.000	
SEPT 21		.000	.000	.000	.000	.002	.001	.001	.001	.002	.000	.000	.000	.000	
OCT 21			.000	.000	.000	.008	.006	.005	.006	.008	.000	.000	.000		
NOV 21				.000	.023	.014	.012	.009	.012	.014	.023	.000			
DEC 21				.000	.028	.020	.014	.013	.014	.020	.028	.000			

noon on winter solstice is 0.013 which represents an efficiency factor of 0.987.

c) Effective Cosine - The effective cosine for the collector subsystem is shown in Table III.B-2 for the 21st day of each month for each hour of the day. The collector field effective cosines shown are the combined effect of the cosine of the angle of solar incidence on the mirror surface shown in Table III.B-3, the shading of the sun from one heliostat by another shown in Table III.B-4, and the blocking of the reflected solar insolation leaving a heliostat and going to the receiver shown in Table III.B-5. Each effective cosine shown is an average for the total collector field. The values are determined using the Houston Solar Flux Computer Program and are a function of the location of the plant site, the field layout, the location and height of the receiver aperture, the time of year, and the time of day. The effective cosine for noon winter (design point) is 0.920.

d) Reflectivity - The mirror reflectivity is dependent upon mirror used and the cleanliness of the mirror surface. The 0.900 reflectivity used in the stair-step is the average reflectivity between washings of low iron float glass mirrors with a "clean" reflectivity of 0.910.

e). Atmospheric - The atmospheric efficiency factor accounts for the power lost due to atmospheric absorption between the mirror surface and the receiver cavity. It depends upon relative humidity, ambient temperature and transmission distance. The value calculated for the commercial plant module at 30% R.H. and 20°C (75°F) is 0.962.

f) Tracking - The tracking efficiency factor of 0.988 is the result of heliostats pointing off the target during operation. The tracking is a composite of both static errors, and errors which vary with wind velocity. The static errors include errors due to heliostat manufacturing and installation, mirror focusing and alignment, encoder resolution, sun position and computational errors. The variable error component is heliostat structural deflection which is a function of wind velocity.

Table III.B-2 Collector Field Effective Cosine (Includes Cosine, Shading, and Blocking)

	TIME OF DAY														
MONTH/DAY	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
JAN 21				.708	.827	.896	.921	.928	.921	.896	.827	.708			
FEB 21			.614	.785	.861	.893	.913	.920	.913	.893	.861	.785	.614		
MAR 21			.600	.760	.834	.873	.894	.902	.894	.873	.834	.760	.600		
APR 21		.371	.579	.729	.802	.844	.867	.875	.867	.844	.802	.729	.579	.371	
MAY 21		.502	.602	.714	.781	.819	.842	.850	.842	.819	.781	.714	.602	.503	
JUNE 21	.475	.524	.611	.708	.771	.807	.830	.838	.830	.807	.771	.708	.611	.524	.475
JULY 21		.510	.605	.712	.778	.816	.838	.847	.838	.816	.778	.712	.605	.510	
AUG 21		.404	.583	.726	.799	.840	.863	.871	.863	.840	.799	.726	.583	.404	
SEPT 21		.116	.589	.755	.829	.869	.890	.898	.890	.869	.829	.755	.589	.116	
OCT 21			.616	.786	.859	.891	.911	.919	.911	.891	.859	.786	.617		
NOV 21				.717	.835	.899	.921	.928	.921	.899	.835	.717			
DEC 21				.665	.783	.880	.910	.920	.910	.880	.783	.665			

Table III.B-3 Collector Field Cosine

	TIME OF DAY														
MONTH/DAY	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
JAN 21				.861	.903	.934	.953	.959	.953	.934	.903	.861			
FEB 21			.787	.843	.888	.921	.941	.948	.941	.921	.888	.843	.787		
MAR 21			.757	.816	.863	.898	.919	.926	.919	.898	.863	.816	.757		
APR 21		.650	.721	.782	.830	.866	.888	.895	.888	.866	.831	.782	.721	.650	
MAY 21		.622	.693	.754	.802	.838	.859	.866	.859	.838	.802	.754	.693	.622	
JUNE 21	.530	.610	.681	.741	.789	.824	.846	.853	.846	.824	.789	.741	.681	.610	.530
JULY 21		.619	.690	.750	.799	.834	.855	.863	.855	.834	.799	.751	.690	.619	
AUG 21		.645	.717	.777	.826	.861	.883	.890	.883	.861	.826	.777	.717	.645	
SEPT 21		.683	.752	.811	.859	.894	.915	.922	.915	.894	.859	.811	.752	.683	
OCT 21			.784	.840	.885	.919	.939	.946	.939	.919	.885	.840	.784		
NOV 21				.860	.902	.933	.952	.959	.952	.933	.902	.860			
DEC 21				.867	.907	.937	.956	.962	.956	.938	.907	.867			

Table III.B-4 Fraction of Field Shaded

	TIME OF DAY													
MONTH/DAY	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
JAN 21				.142	.055	.010	.004	.003	.004	.010	.055	.142			
FEB 21			.176	.036	.000	.000	.000	.000	.000	.000	.000	.036	.176		
MAR 21			.170	.036	.005	.000	.000	.000	.000	.000	.005	.036	.170		
APR 21		.402	.162	.037	.007	.000	.000	.000	.000	.000	.007	.037	.162	.402	
MAY 21		.169	.102	.027	.004	.000	.000	.000	.000	.000	.004	.027	.102	.169	
JUNE 21	.085	.122	.077	.021	.002	.000	.000	.000	.000	.000	.002	.021	.077	.122	.085
JULY 21		.154	.094	.025	.003	.000	.000	.000	.000	.000	.003	.025	.094	.154	
AUG 21		.347	.153	.036	.007	.000	.000	.000	.000	.000	.007	.036	.153	.347	
SEPT 21		.805	.178	.037	.006	.000	.000	.000	.000	.000	.006	.037	.178	.805	
OCT 21			.172	.032	.000	.000	.000	.000	.000	.000	.000	.032	.171		
NOV 21				.131	.044	.006	.003	.002	.003	.006	.044	.131			
DEC 21				.197	.107	.032	.018	.014	.018	.032	.107	.197			

Table III.B-5 Fraction of Field Blocked

	TIME OF DAY													
MONTH/DAY	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
JAN 21				.027	.029	.030	.030	.030	.030	.030	.029	.027			
FEB 21			.025	.028	.029	.030	.030	.029	.030	.030	.029	.028	.025		
MAR 21			.024	.027	.028	.028	.027	.027	.027	.028	.028	.027	.024		
APR 21		.019	.022	.024	.025	.025	.024	.023	.024	.025	.025	.024	.022	.019	
MAY 21		.017	.019	.020	.022	.022	.020	.019	.020	.022	.022	.020	.019	.017	
JUNE 21	.013	.015	.017	.019	.020	.020	.019	.017	.019	.020	.020	.019	.017	.015	.013
JULY 21		.016	.018	.020	.021	.021	.020	.019	.020	.021	.021	.020	.018	.016	
AUG 21		.019	.022	.023	.024	.024	.023	.022	.023	.024	.024	.023	.022	.019	
SEPT 21		.021	.024	.026	.028	.028	.027	.026	.027	.028	.028	.026	.024	.021	
OCT 21			.025	.027	.029	.030	.029	.029	.029	.030	.029	.028	.025		
NOV 21				.027	.029	.030	.030	.030	.030	.030	.029	.027			
DEC 21				.027	.029	.030	.030	.030	.030	.030	.029	.027			

g) Optical - The optical efficiency factor includes all aperture spillage losses due to the size and shape of the reflected image. This optical efficiency (also referred to as aperture efficiency) varies as a function of time of day and time of year as shown in Figure III.B-5. The value for noon winter is 0.987.

h) Tower Sway - The tower sway efficiency factor accounts for losses due to movement of the tower aperture. At the design point wind speed of 3.5 m/s (8 mph) there is virtually no tower movement and thus an efficiency factor of 1.00.

2) Receiver Subsystem - The overall receiver subsystem commercial plant design point efficiency is 0.928; which is made up of the following efficiency factors:

a) Radiation - The radiation efficiency factor for the receiver includes losses due to solar and infrared radiation. The loss varies as a function of power into the receiver cavity as shown in Figure III.B-6. The efficiency for the design point power level is 0.974.

b) Convection - The convection efficiency factor takes into account heat loss due to atmospheric air circulation in and out of the cavity. The convective loss varies as a function of ambient temperature and wind velocity as shown in Figure III.B-7. The loss at design point conditions represents an efficiency factor of 0.970.

c) Insulation - The insulation efficiency factor accounts for the heat loss through the insulated receiver exterior walls and varies as a function of ambient temperature as shown in Figure III.B-8. The loss at design point temperature represents an efficiency factor of 0.997.

d) Tower Riser - The tower riser loss is that loss of heat associated with transporting the feedwater from the electrical power generation subsystem to the receiver. The efficiency for the commercial plant is 0.994.

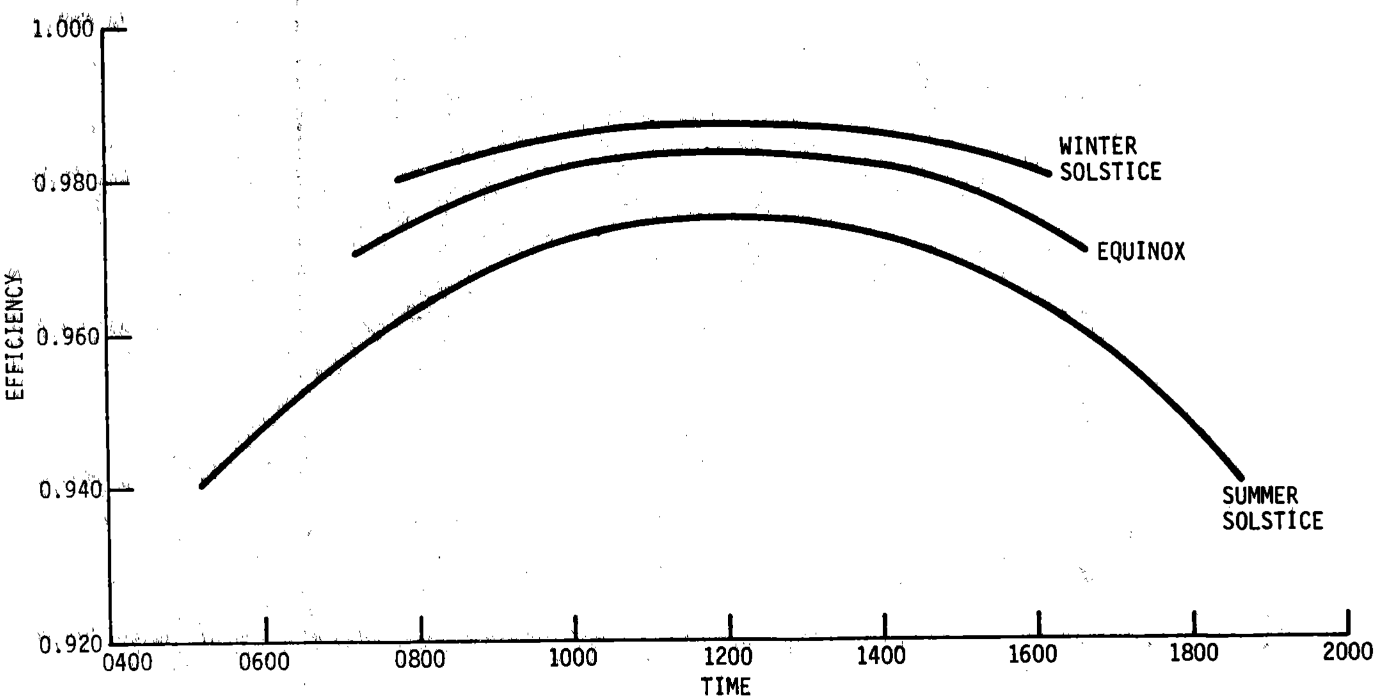


Figure III.B-5 Collector/Receiver Module Optical Efficienty Factor

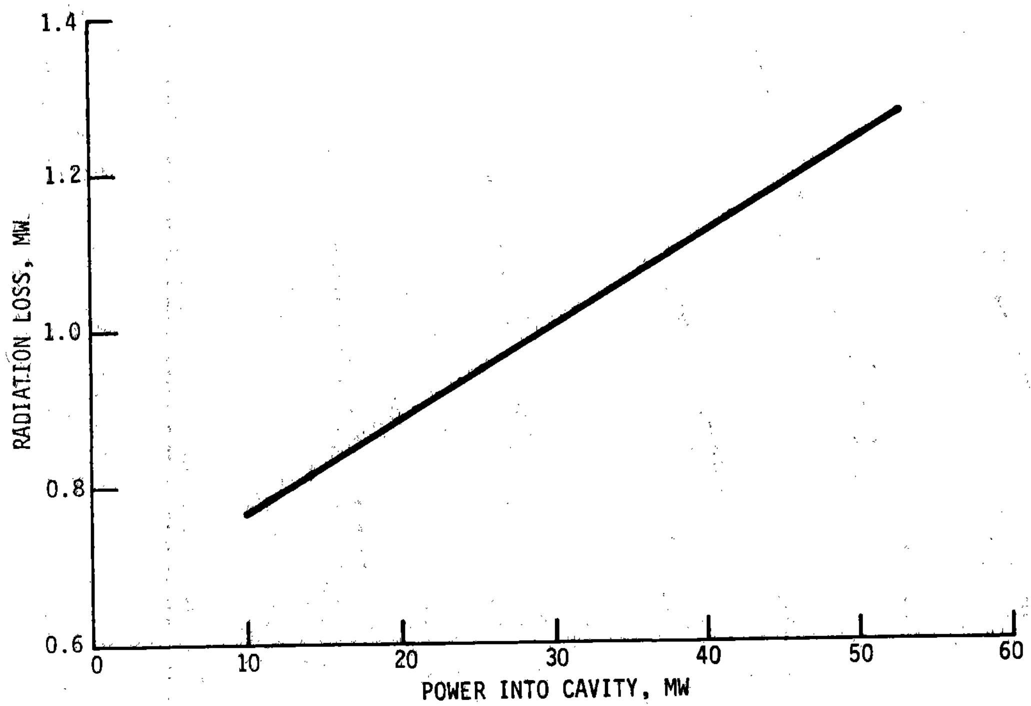


Figure III.B-6 Receiver Radiation Loss

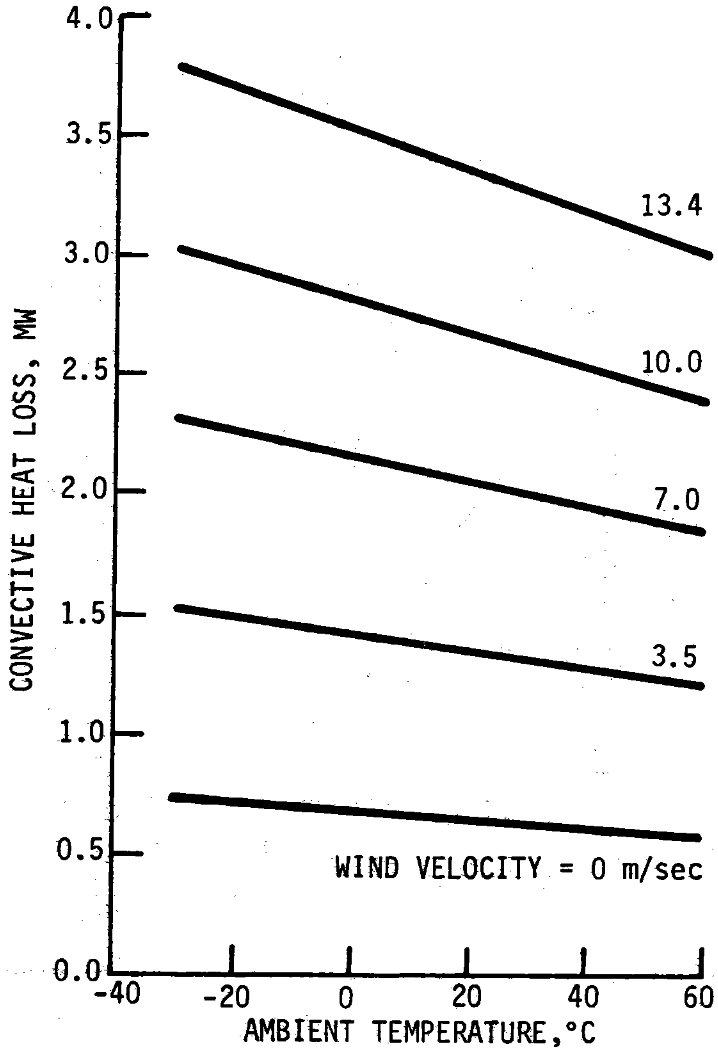


Figure III.B-7 Receiver Convective Loss

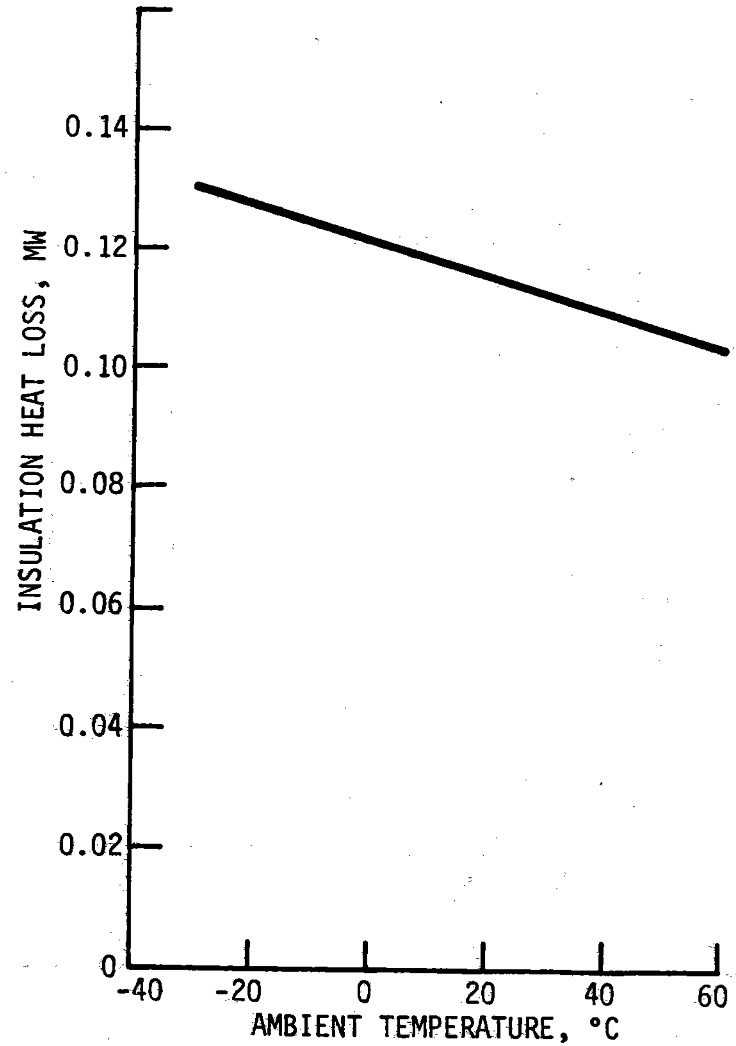


Figure III.B-8 Receiver Insulation Loss

e) Tower Downcomer - The tower downcomer loss is that loss associated with transporting the superheated steam from the receiver to the turbine in the electrical power generation subsystem. The efficiency for the commercial plant is 0.991.

3) Electrical Power Generation Subsystem - The overall EPGS commercial plant design point efficiency is 0.3730 which is the efficiency equivalent of the gross cycle heat rate.

4) Plant Auxiliary Loads - The commercial plant auxiliary loads are those parasitic electrical loads required to operate the plant. The auxiliary loads vary as a function of steam flow rate, ambient temperature, wind velocity and operating mode. Table III.B-6 shows the commercial plant auxiliary loads for the basic steady state operational modes. The load for "receiver operation only" is 7965 KW which represents a design point efficiency of 0.950.

5) Thermal Storage Subsystem - Assessable thermal storage subsystem efficiency is a combination of the effects from the TSS and the reduced EPGS efficiency while operating on storage steam. Effective daily storage efficiency is 0.964 (energy retrieved/charging energy supplied) multiplied by 0.817 (increased heat rate and auxiliaries fraction effect) for a net efficiency of 0.787.

3. Commercial Plant Yearly Performance

The commercial plant performance at the ERDA specified design point, as well as the plant performance over the winter solstice design point day was discussed in Section III.B.2. However, of much greater importance is the commercial plant yearly performance, both in terms of total annual energy production and performance variations over the year. The commercial plant collector/receiver module, which forms the basis of the commercial plant, was designed to maximize annual energy production and minimize, to the extent possible, plant performance variations throughout the year.

a. Yearly Performance Variation - Six additional performance profile (stairstep) charts, similar to those presented in Section III.B.2, were prepared to illustrate the commercial plant yearly performance variation. These profiles, shown in Figures III.B-9 through III.B-15, show the plant performance at noon for each month of the year. The profiles, which were prepared on the basis of producing 150 MWe net output at each point, show that the excess

Table III.B-6 Commercial Plant Auxiliary Loads

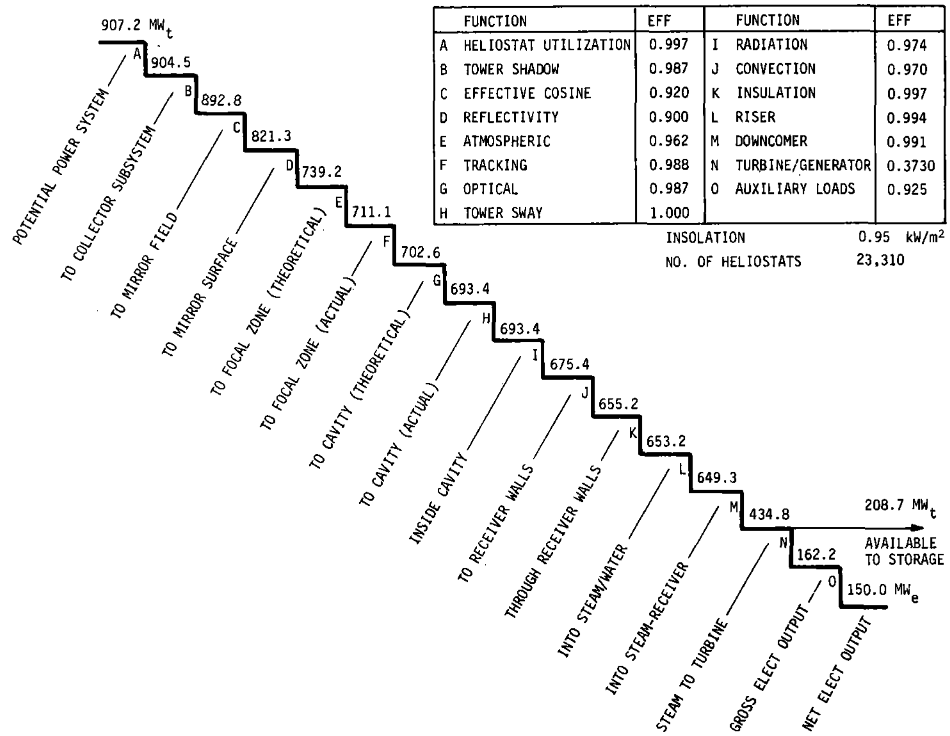
AUXILIARY LOADS - kWe

	OPERATIONAL MODES					
	RECEIVER OPERATION ONLY	RECEIVER OPERATION & CHARGE TSS	RECEIVER OPERATION & DISCHARGE TSS	CHARGE TSS AND DISCHARGE TSS	DISCHARGE TSS	CHARGE TSS
COLLECTOR	769 (1)	769 (1)	769 (1)	769 (1)	0	769 (1)
RECEIVER	30 (1)	30 (1)	30 (1)	30 (1)	0	30 (1)
THERMAL STORAGE	0	2439	3649	6054	3649	2439
ELECTRICAL POWER GENERATION	7160 (2)	8852 (2)	7160 (2)	7160 (3)	4154	2700
CONTROLS	6	6	6	6	6	6
TOTAL	7965	12096	11614	14019	7809	5944

NOTES: 1. ASSUMES ALL 15 FIELDS IN OPERATION.

2. BASED ON 150 MW_e NET OUTPUT

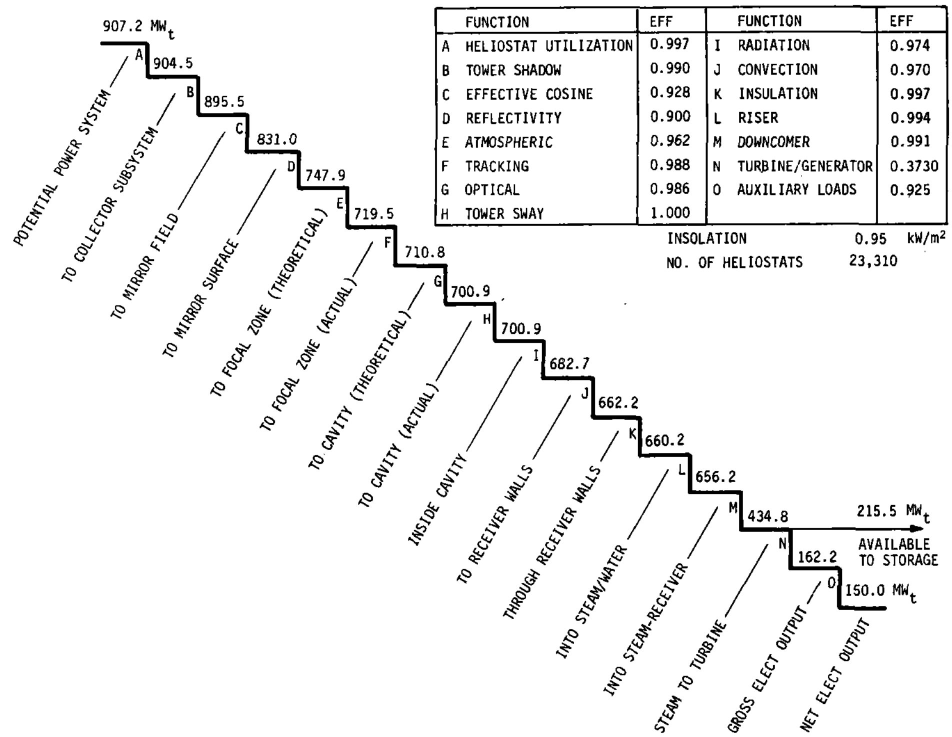
3. BASED ON 105 MW_e NET OUTPUT.



	FUNCTION	EFF		FUNCTION	EFF
A	HELIOSTAT UTILIZATION	0.997	I	RADIATION	0.974
B	TOWER SHADOW	0.987	J	CONVECTION	0.970
C	EFFECTIVE COSINE	0.920	K	INSULATION	0.997
D	REFLECTIVITY	0.900	L	RISER	0.994
E	ATMOSPHERIC	0.962	M	DOWNCOMER	0.991
F	TRACKING	0.988	N	TURBINE/GENERATOR	0.3730
G	OPTICAL	0.987	O	AUXILIARY LOADS	0.925
H	TOWER SWAY	1.000			

INSOLATION 0.95 kW/m²
NO. OF HELIOSTATS 23,310

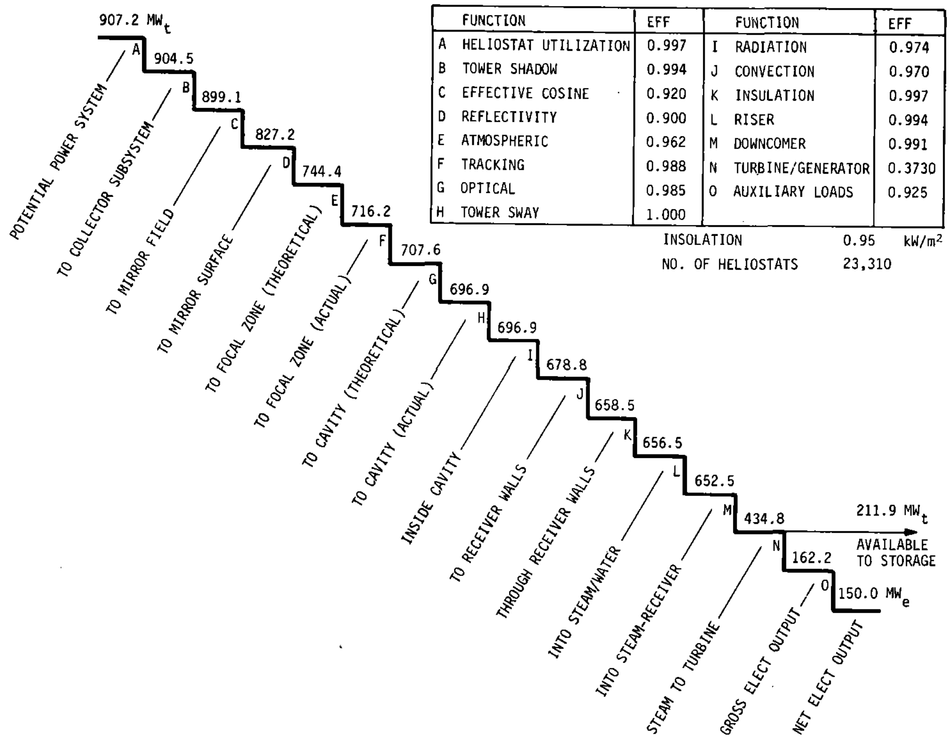
Figure III.B-9. Commercial Plant Performance Profile - Noon, December 21 (Design Point)



	FUNCTION	EFF		FUNCTION	EFF
A	HELIOSTAT UTILIZATION	0.997	I	RADIATION	0.974
B	TOWER SHADOW	0.990	J	CONVECTION	0.970
C	EFFECTIVE COSINE	0.928	K	INSULATION	0.997
D	REFLECTIVITY	0.900	L	RISER	0.994
E	ATMOSPHERIC	0.962	M	DOWNCOMER	0.991
F	TRACKING	0.988	N	TURBINE/GENERATOR	0.3730
G	OPTICAL	0.986	O	AUXILIARY LOADS	0.925
H	TOWER SWAY	1.000			

INSOLATION 0.95 kW/m²
NO. OF HELIOSTATS 23,310

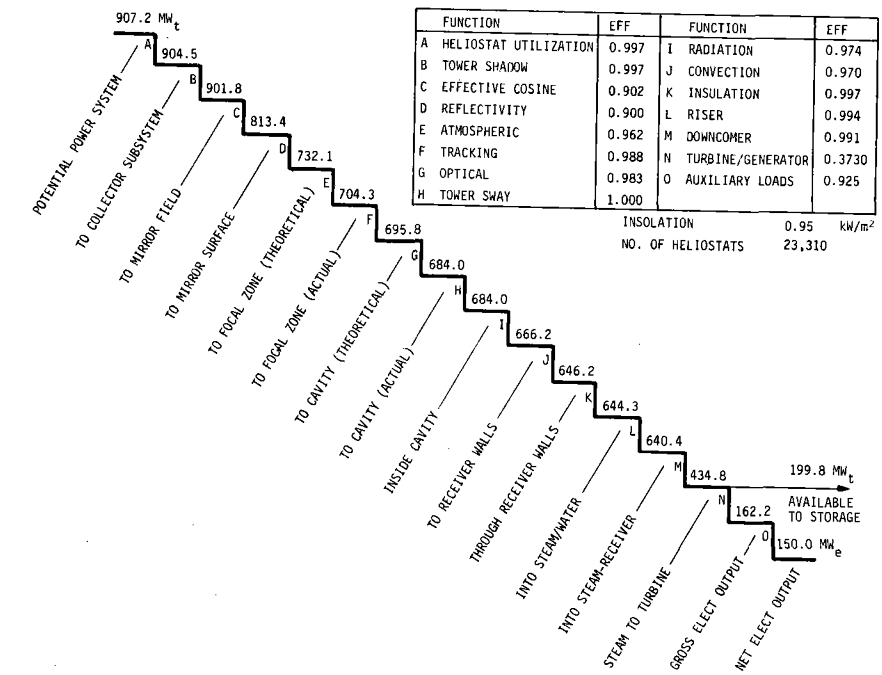
Figure III.B-10. Commercial Plant Performance Profile - Noon, January 21 (November)



FUNCTION	EFF	FUNCTION	EFF
A HELIOSTAT UTILIZATION	0.997	I RADIATION	0.974
B TOWER SHADOW	0.994	J CONVECTION	0.970
C EFFECTIVE COSINE	0.920	K INSULATION	0.997
D REFLECTIVITY	0.900	L RISER	0.994
E ATMOSPHERIC	0.962	M DOWNCOMER	0.991
F TRACKING	0.988	N TURBINE/GENERATOR	0.3730
G OPTICAL	0.985	O AUXILIARY LOADS	0.925
H TOWER SWAY	1.000		

INSOLATION 0.95 kW/m²
NO. OF HELIOSTATS 23,310

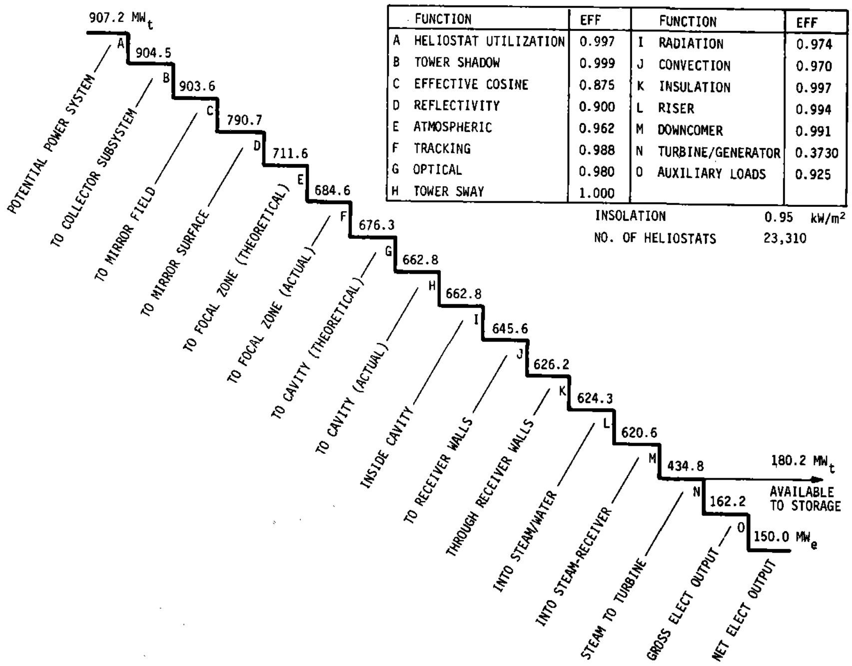
Figure III.B-11. Commercial Plant Performance Profile - Noon February 21 (October)



FUNCTION	EFF	FUNCTION	EFF
A HELIOSTAT UTILIZATION	0.997	I RADIATION	0.974
B TOWER SHADOW	0.997	J CONVECTION	0.970
C EFFECTIVE COSINE	0.902	K INSULATION	0.997
D REFLECTIVITY	0.900	L RISER	0.994
E ATMOSPHERIC	0.962	M DOWNCOMER	0.991
F TRACKING	0.988	N TURBINE/GENERATOR	0.3730
G OPTICAL	0.983	O AUXILIARY LOADS	0.925
H TOWER SWAY	1.000		

INSOLATION 0.95 kW/m²
NO. OF HELIOSTATS 23,310

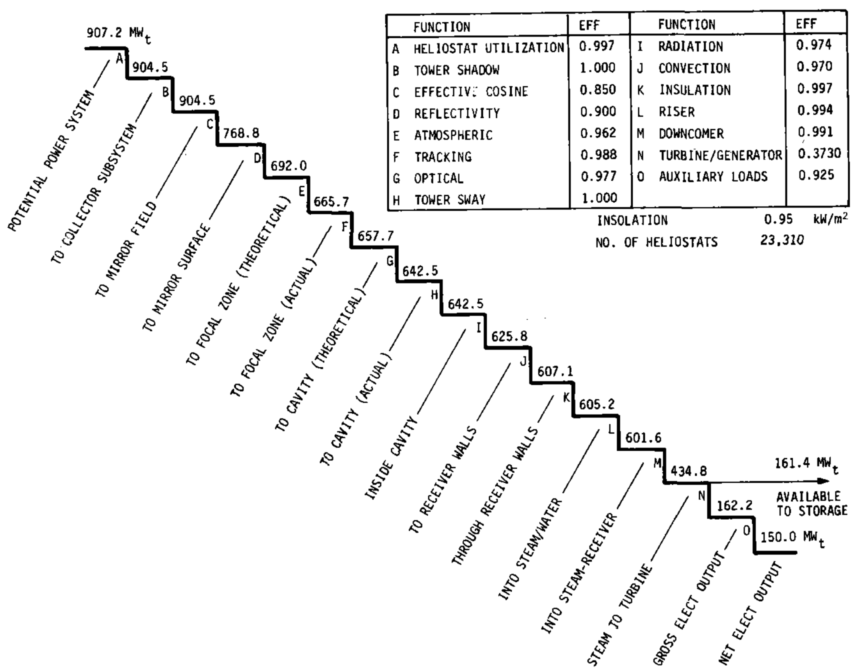
Figure III.B-12. Commercial Plant Performance Profile - Noon, March 21 (September)



	FUNCTION	EFF		FUNCTION	EFF
A	HELIOSTAT UTILIZATION	0.997	I	RADIATION	0.974
B	TOWER SHADOW	0.999	J	CONVECTION	0.970
C	EFFECTIVE COSINE	0.875	K	INSULATION	0.997
D	REFLECTIVITY	0.900	L	RISER	0.994
E	ATMOSPHERIC	0.962	M	DOWNCOMER	0.991
F	TRACKING	0.988	N	TURBINE/GENERATOR	0.3730
G	OPTICAL	0.980	O	AUXILIARY LOADS	0.925
H	TOWER SWAY	1.000			

INSOLATION 0.95 kW/m²
NO. OF HELIOSTATS 23,310

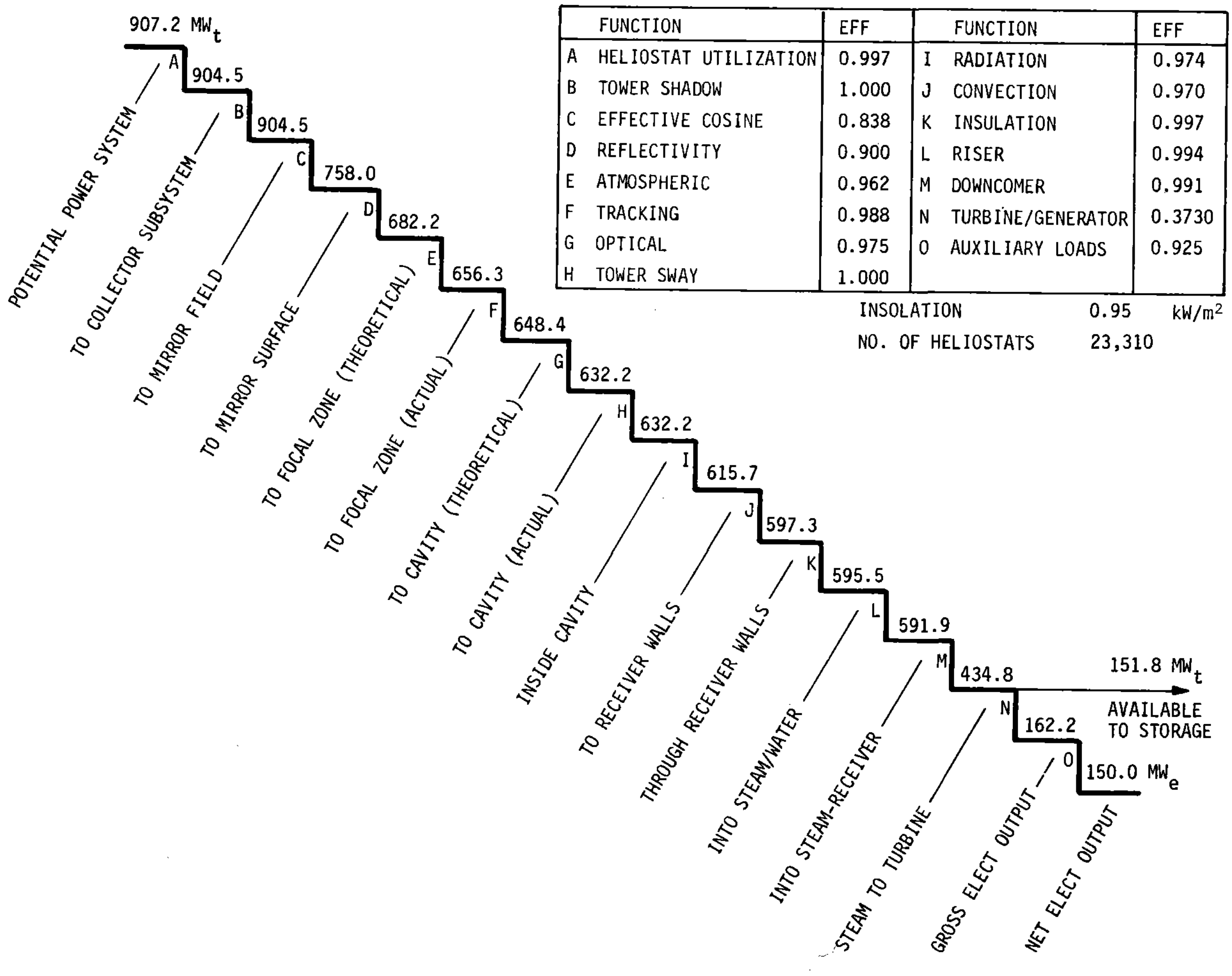
Figure III.B-13. Commercial Plant Performance Profile - Noon, April 21 (August)



	FUNCTION	EFF		FUNCTION	EFF
A	HELIOSTAT UTILIZATION	0.997	I	RADIATION	0.974
B	TOWER SHADOW	1.000	J	CONVECTION	0.970
C	EFFECTIVE COSINE	0.850	K	INSULATION	0.997
D	REFLECTIVITY	0.900	L	RISER	0.994
E	ATMOSPHERIC	0.962	M	DOWNCOMER	0.991
F	TRACKING	0.988	N	TURBINE/GENERATOR	0.3730
G	OPTICAL	0.977	O	AUXILIARY LOADS	0.925
H	TOWER SWAY	1.000			

INSOLATION 0.95 kW/m²
NO. OF HELIOSTATS 23,310

Figure III.B-14. Commercial Plant Performance Profile - Noon, May 21 (July)



	FUNCTION	EFF		FUNCTION	EFF
A	HELIOSTAT UTILIZATION	0.997	I	RADIATION	0.974
B	TOWER SHADOW	1.000	J	CONVECTION	0.970
C	EFFECTIVE COSINE	0.838	K	INSULATION	0.997
D	REFLECTIVITY	0.900	L	RISER	0.994
E	ATMOSPHERIC	0.962	M	DOWNCOMER	0.991
F	TRACKING	0.988	N	TURBINE/GENERATOR	0.3730
G	OPTICAL	0.975	O	AUXILIARY LOADS	0.925
H	TOWER SWAY	1.000			

INSOLATION 0.95 kW/m^2

NO. OF HELIOSTATS 23,310

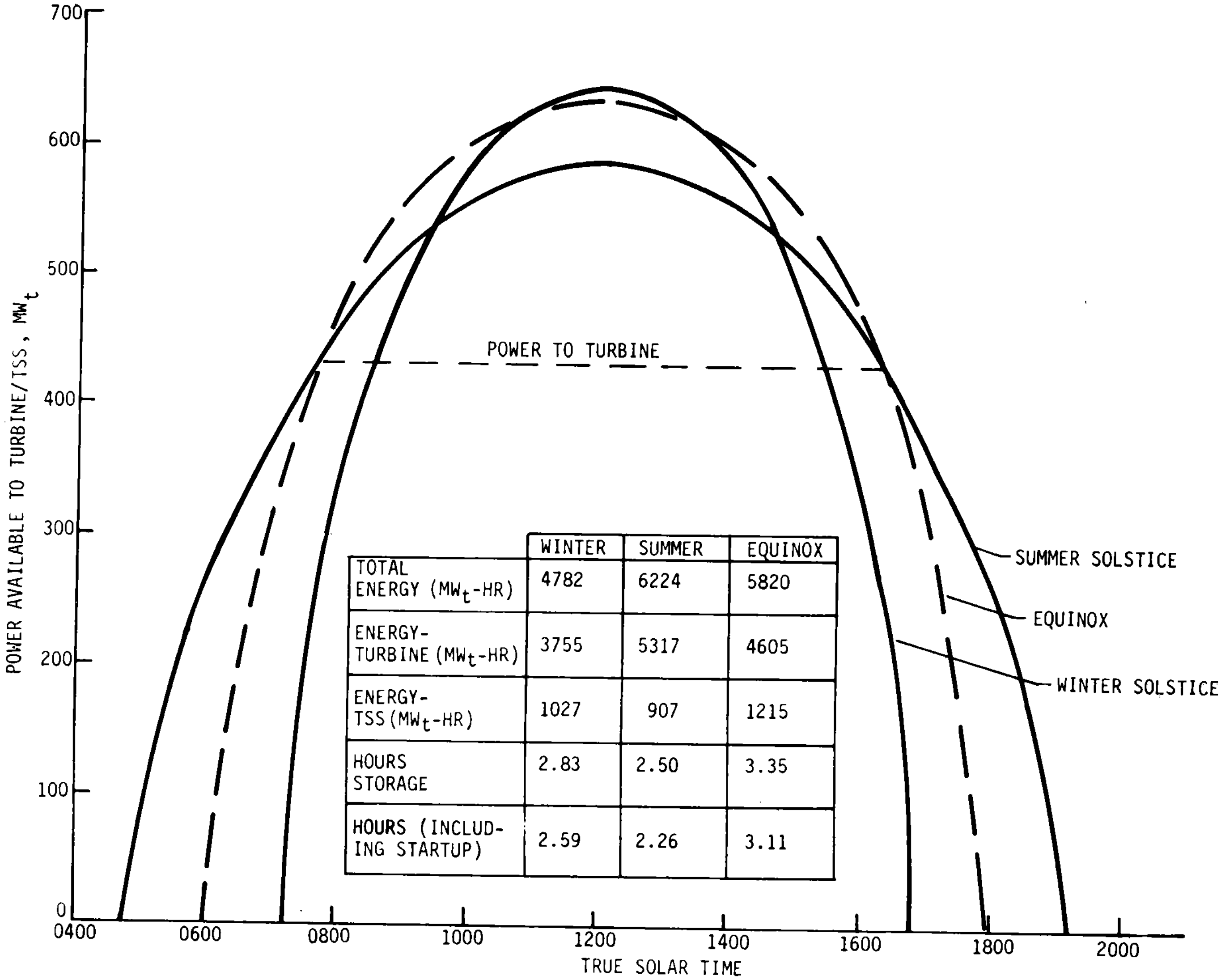
Figure III.B-15 Commercial Plant Performance Profile - Noon, June 21 power available for charging storage ranges from 151.8 MW_t in the summer to 211.9 MW_t in the winter.

The daily plant performance for summer solstice and equinox, as well as winter solstice, is shown in Figure III.B-16. These curves are based upon insolation data normalized to 0.95 kw/m^2 at noon. The inset on the figure shows the total energy generated on each day as well as the capability of the system to charge thermal storage. The curves show that plant peak power is delivered on winter, the maximum total energy on summer and the maximum energy for charging storage is available at equinox. It also shows the plant capability for charging storage ranges from 907 MW_t - hr (2.5 hours) in the summer to 1215 MW_t-hr (3.4 hours) at the equinox.

b. Commercial Plant Annual Energy (Inyokern, 1963) - In addition to examining commercial plant performance variations over the year, the total annual energy production must be considered in evaluating overall plant performance. Therefore, the commercial plant total annual electrical output was calculated using the 1963 Inyokern data base supplied by the Aerospace Corporation.

The annual energy was calculated using the efficiency factors discussed in Section III.B.2.d. A power calculation was performed for each daylight hour using the Inyokern insolation data and the efficiency factors appropriate for the particular time of day and day of the year. The power was integrated over each day and then summed for the year. Losses due to receiver start-up and minimum receiver flowrate were also considered in the energy calculation.

The monthly and yearly energy production for the commercial plant, using the 15 commercial plant collector/receiver modules, is shown in Figure III.B-17. The upper curve shows the potential energy to the system. This is the product of the mirror area and the insolation and therefore includes no system losses. The yearly total potential energy is 3,051,200 MW_t-hr or 3195 kW_t-hr per square meter of mirror area. The second curve is the reflected energy which includes losses due to heliostat utilization, tower shadow, field cosine, Heliostat shading and blocking and mirror reflectivity. The yearly total reflected energy is 2,099,000 MW_t-hr or 2198 kW_t-hr per square meter of mirror area. The third curve, receiver output, is the energy available at the base of the tower. It takes into account tracking, optical and atmospheric absorption losses as well as tower sway, receiver radiation, convection and insulation, and riser and downcomer losses. The total receiver output is 1,743,000 MW_t-hr or 1825 kW_t-hr per square meter of mirror area. The lower curve is the commercial plant net electrical output and includes



	WINTER	SUMMER	EQUINOX
TOTAL ENERGY (MW_t-HR)	4782	6224	5820
ENERGY-TURBINE (MW_t-HR)	3755	5317	4605
ENERGY-TSS (MW_t-HR)	1027	907	1215
HOURS STORAGE	2.83	2.50	3.35
HOURS (INCLUDING STARTUP)	2.59	2.26	3.11

Figure II.B-16 Commercial Plant Seasonal Performance

YEARLY TOTALS	TOTAL ENERGY	ENERGY PER M^2 OF MIRROR
POTENTIAL ENERGY TO SYSTEM	3,051,200 MW_t-HR	3195 kW_t-HR/m^2
REFLECTED ENERGY	2,099,000 MW_t-HR	2198 kW_t-HR/m^2
RECEIVER OUTPUT	1,743,000 MW_t-HR	1825 kW_t-HR/m^2
NET ELECTRICAL OUTPUT	578,540 MW_e-HR	606 kW_e-HR/m^2

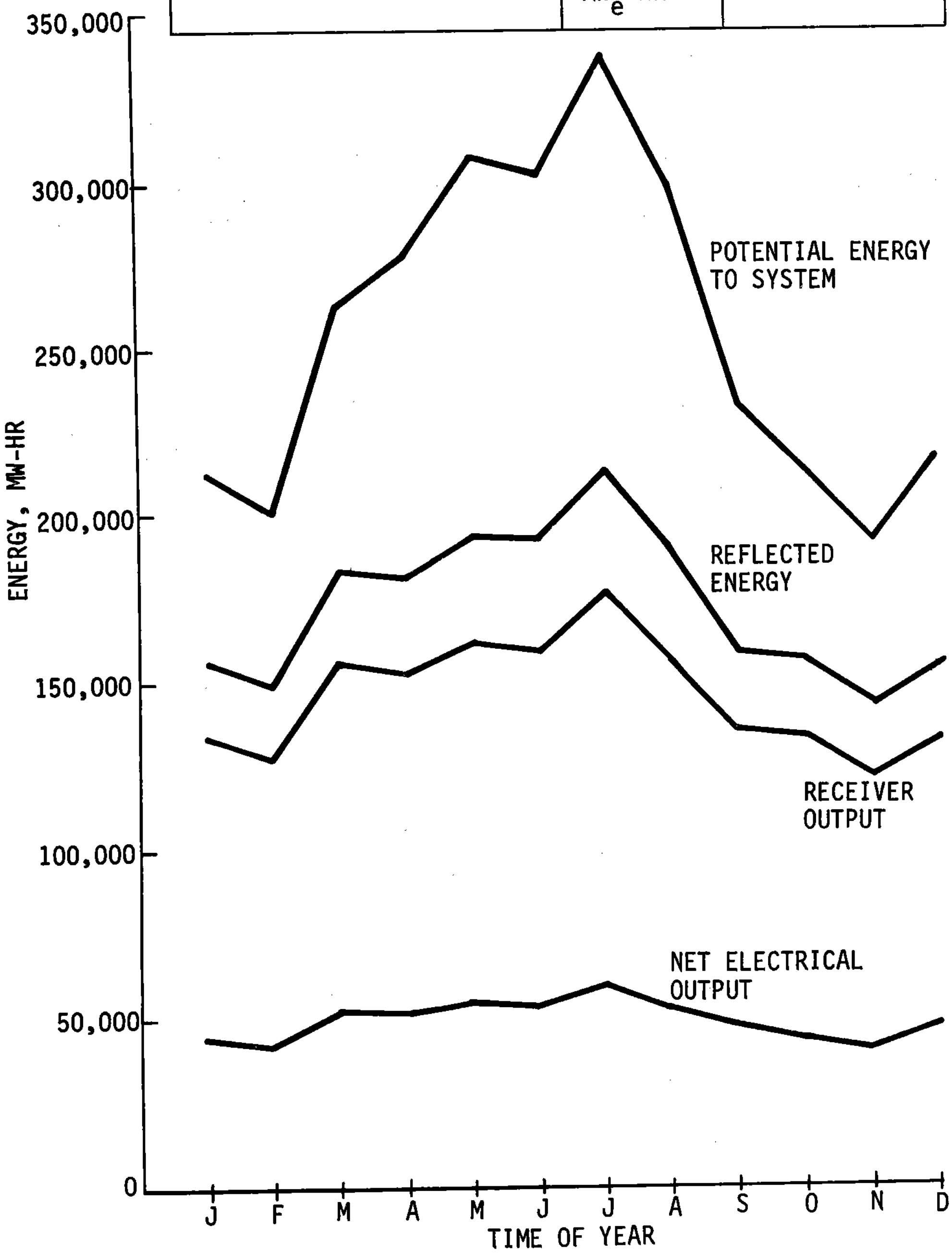


Figure III.B-17 Commercial Plant Annual Energy the turbine/generator efficiency and the plant auxiliary loads. The yearly total net electrical output is 578,540 MW_e-hr or 606 kW_e-hr per square meter of mirror area. Of the total electrical energy produced, 88.4% was directly converted by the turbine/generator and 11.6% was converted via thermal storage. It should be noted that the relatively small variation in electrical output over the year is the result inherent performance characteristics of the north collector field.

4. Subsystem Characteristics

This section summarizes in tabular form the salient operational characteristics of each commercial plant subsystem, including including design point, maximum and minimum performance data. Note that data for the collector and receiver subsystems are presented for one module and also for the total.

a. Collector Subsystem

1) Heliostat Control Power Input

Operating Mode	Average Power Input (KWe) Module	Subsystem
Tracking	51	765
Slew	590	8,850
Emergency Shutdown	590	8,850

2) Potential and Delivered Power - The potential power is that amount available at the mirror surface if normal to the insolation. The delivered power is that amount that passes through the receiver aperture.

	Minimum (12:00 Summer Solstice, 0.95 KW/m²)	Design Point (12:00 Winter Solstice, 0.95 KW/m²)	Maximum (12:00 Winter Solstice, 1.02 KW/m²)
Potential Power (MWth)			
Module	60.5	60.5	64.9
Subsystem	907.2	907.2	974.1
Delivered Power (MWth)			
Module	42.1	46.2	52.3
Subsystem	632.2	693.4	784.5

b. Receiver Subsystem

1) Power Into Receiver - The power into the receiver is the amount that passes through the aperture and into the cavity in MWth.

	Minimum (For Rated Steam)	Design Point (2:00 PM Winter Solstice, 0.95 KW/m^2)	Maximum (12:00 Winter Solstice, 1.02 KW/m^2)
Module	8.5	46.2	52.3
Subsystem	127.5	693.4	784.5

2) Output Steam Properties

	Minimum Performance	Design Point Performance	Maximum Performance
Temperature, K(°F)	789 (960)	789 (960)	789 (960)
Pressure, kPa (psig)	10,687 (1,550)	10,687 (1,550)	10,687 (1,550)
Module Flow kg/hr(lb/hr)	8,892 (19,600)	65,300 (144,000)	73,980 (163,100)
Subsystem Flow kg/hr(lb/hr)	133,380 (294,000)	979,800 (2,160,000)	1,109,700 (2,446,500)

3) Feedwater Properties

	Minimum Performance	Design Point Performance	Maximum Performance
Temperature K(°F)	467 (380)	503 (445)	522 (480)
Pressure kPa(psig)	1,089 (1,580)	1,255 (1,820)	1,345 (1,950)
Module Flow kg/hr(lb/hr)	8,964 (19,760)	65,970 (145,440)	74,735 (164,760)
Subsystem Flow kg/hr(lb/hr)	134,460 (296,400)	989,600 (2,181,600)	1,121,025 (2,471,400)

c. Thermal Storage Subsystem

1) Storage Media Temperatures

	Charged		Discharged	
Salt, K (°F)	755	(900)	544	(519)
Oil, K (°F)	568	(563)	511	(460)

2) Charging Steam Conditions

	Minimum Performance	Design Point Performance	Maximum Performance
Temperature K(^oF)	780 (945)	780 (945)	780 (945)
Pressure kPa (psig)	8,860 (1,285)	8,860 (1,285)	8,860 (1,285)
Flowrate kg/hr(lb/hr)	74,000 (163,000)	321,500 (708,700)	369,700 (815,000)

3) Discharging Steam Conditions

	Minimum Performance	Design Point Performance	Maximum Performance
Temperature K (^oF)	701 (802)	701 (802)	701 (802)
Pressure kPa (psig)	2,999 (435)	2,999 (435)	2,999 (435)
Flowrate kg/hr(lb/hr)	111,000 (244,000)	553,000 (1,220,600)	553,000 (1,220,600)

4) Power Capability (MWth)

	Minimum Performance	Design Point Performance	Maximum Performance
Charge	48.3	210	241.5
Discharge	72.8	363.8	363.8

5) Total Stored Energy Capability 1189 MWth-hr.

d. Electrical Power Generation Subsystem

1) Operating From Receiver Only (Main Steam)

	Design Point	Maximum
Net Electrical Power Output, MWe	150	150
Gross Electrical Power Output, MWe	160	160
Turbine Cycle Gross Heat Rate, KJ/KWH (BTU/KWH)	9,655 (9,151)	9,655 (9,151)

	Design Point	Maximum
Steam Inlet Conditions:		
Pressure, kPa(psig)	9,308 (1,350)	9,308 (1,350)
Temperature, K (^oF)	783 (950)	783 (950)
Flow Rate, kg/hr(lb/hr)	618,434 (1,363,400)	618,434 (1,363,400)
Exhaust Pressure kPa, (in Hg)	8.5 (2.5)	8.5 (2.5)

2) Operating From Thermal Storage Only (Admission Steam)

	Design Point	Maximum
Net Electrical Power Output, MWe	105	108.5
Gross Electrical Power Output, MWe	112.8	116.6
Turbine Cycle Gross Heat Rate, KJ/KWH/(BTU/KWH)	11,741 (11,128)	11,741 (11,128)
Steam Inlet Conditions:		
Pressure, kPa(psig)	2,758 (400)	2,758 (400)
Temperature, K (^oF)	700 (800)	700 (800)
Flow Rate, kg/hr(lb/hr)	553,700 (1,220,600)	574,500 (1,266,600)
Exhaust Pressure, kPa (in hg)	8.5 (2.5)	8.5 (2.5)

C. COMMERCIAL PLANT OPERATION

1. Modes of Operation

There are many possible operational configurations for the plant. These operational configurations are derived from the steady state modes of operation, standby and overnight modes, transitions from one mode to another, plus the various submodes to the basic steady state modes in which the subsystems can be placed. The true flexibility and operational capability of the plant is defined by combinations of the steady state, transition and subsystem submodes of operation.

However, it is important to understand the major basic steady state modes of operation around which the plant is designed. There are six of these basic steady modes of operation as described in paragraphs a. through f. below. Transition between modes will be discussed further under the pilot plant in Section IV.

Scenarios of operation for a particular day are dependent on the utilities power requirements for the day and the strategy selected to accomplish those requirements. The selected scenarios will utilize one or more of the six basic steady state modes of operation plus the appropriate transition modes and submodes for the subsystem. The selected scenarios for any given day will be determined by such things as; the state of charge of thermal storage and the desired state of charge at the end of the day; the desired load profile to be generated throughout the day; the insolation profile for the day; operational status of the plant, etc. Some examples of operational scenarios are shown and discussed in Section IV.C.2, Transient Plant Operations.

The six operational modes discussed below are by no means the only operational modes of the plant. They do encompass the major steady state operational modes and thus the capability to satisfy the primary performance requirements of the plant. Each of the six operational modes discussed below is accompanied by a separate schematic/flow diagram. The solid heavy line indicates the flow of the steam/water working fluid for the particular mode under discussion. The dashed heavy lines represent the flow of oil and salt line of thermal storage subsystem. Since the low pressure portion of the turbine has four sections, the conventional uncontrolled extractions for feedwater heating and the last stage flow to the condenser are shown in Figure III.C-1 for only one section, as typical. The other three sections are terminated with arrows only.

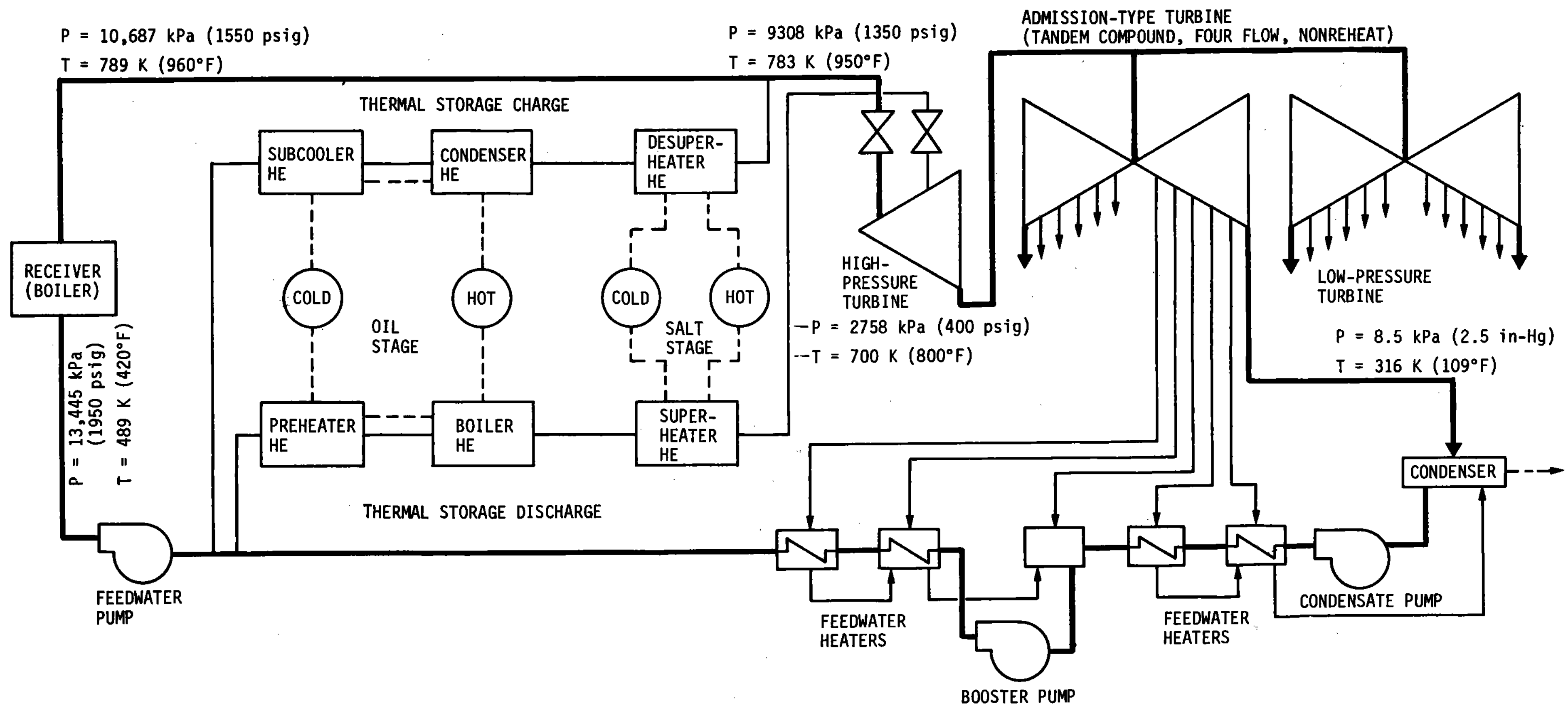


Figure III.C-1 Receiver Operating Turbine Only

a. Receiver Operating Turbine Only - This mode of operation will normally be used either in the morning or afternoon or during periods of low insolation. This mode is used when the desire is to generate and deliver all the receiver subsystem capability directly to the grid. The electrical output in this mode can be up to the peak 150 MWe net electrical capability of this plant. If, with the available insolation, the collector and the receiver subsystems can generate more than 150 MWe net, then portions of the collector subsystem will have to be turned down. The flow path for this mode of operation is also the same as a plant morning startup from the receiver.

As shown in Figure II.C-1 the steam flow path is from the receiver to the main steam throttle valve in the turbine. After leaving the low pressure sections of the turbine, the steam is condensed and the condensate is heated in the feedwater heaters and the feedwater is pumped directly back to the receiver subsystem. For this mode of operation the thermal storage subsystem is not operating either in charge or discharge. This mode of operation is similar to that for a conventional plant in that there is only one source of steam and it is all being delivered to the turbine main steam throttle valve.

b. Receiver Operating Turbine and Receiver Charging Thermal Storage - This mode of operation will be the predominant mode of operation throughout the day on a sunny day. The receiver subsystem is capable of providing the maximum electrical output plus provide additional steam for charging thermal storage. The electrical output for this mode of operation can be up to the 150 MWe net capability when operating from receiver alone.

As shown in Figure III.C-2 steam from the receiver is split and a portion sent to the turbine main steam throttle valve and a portion to the thermal storage for charging. The steam delivered to the thermal storage is desuperheated, condensed, and subcooled and the condensate is joined with the feedwater from the turbine and pumped back to the receiver. As shown the discharge portion of thermal storage is not operational for this mode.

c. Receiver and Thermal Storage Operating the Turbine - This mode of operation will normally be used if the required load cannot be satisfied by the output of the receiver alone. As stated above, when operating from receiver alone, the peak output is 150 MWe net and when operating from thermal storage alone, the peak output is 105 MWe net. This combined mode of operation can produce up to

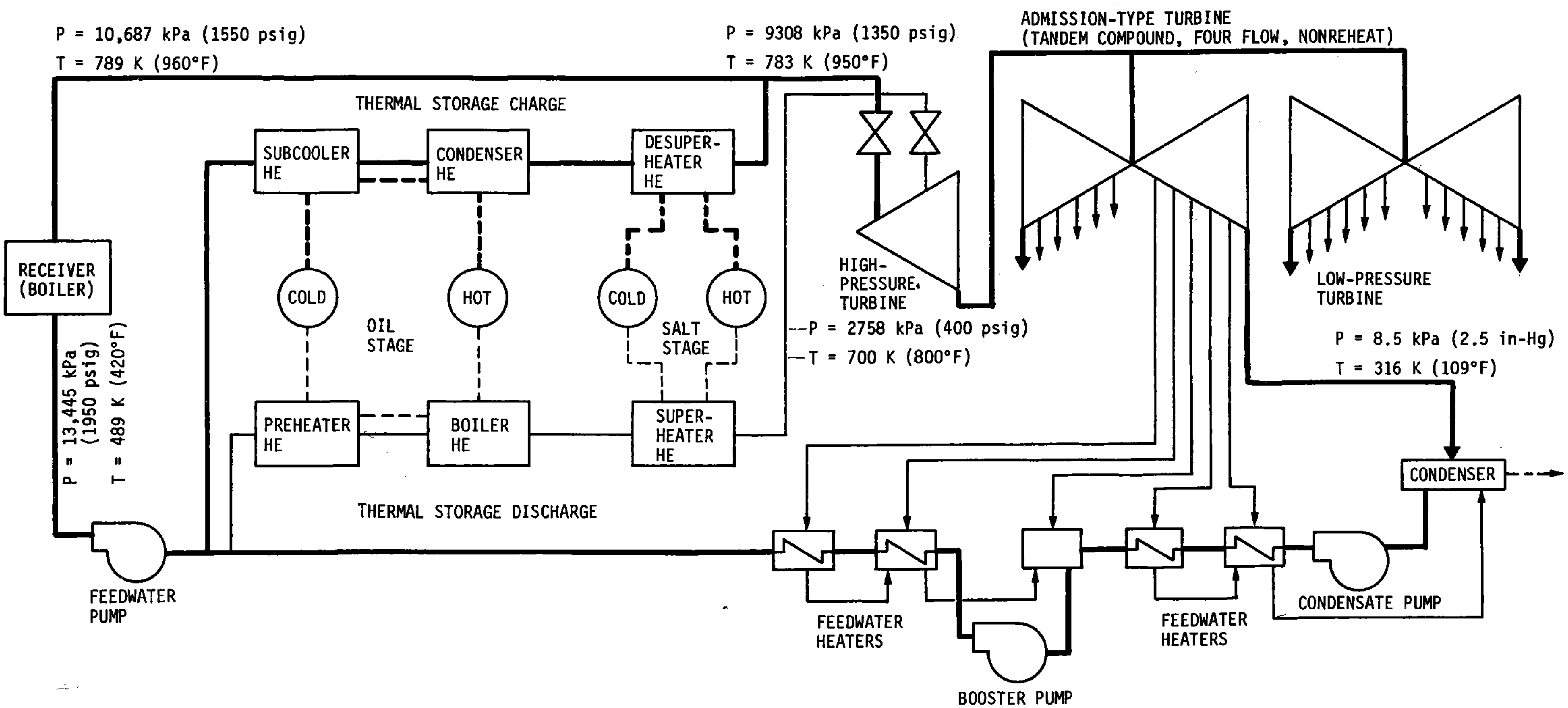


Figure III.C-2 Receiver Operating Turbine and Receiver Charging Thermal Storage

105 MWe net for any combination of receiver and thermal storage steam flow, and greater than 105 MWe net for some combinations.

As shown in Figure III.C-3 steam from the receiver is provided to the turbine main steam throttle valve simultaneously with steam from the thermal storage to the turbine admission steam throttle valve. Steam from both sources is simultaneously routed through the turbine, the steam is condensed and the condensate is heated in the feedwater heaters. After leaving the final feedwater heater, the feedwater is split and a portion is delivered to the thermal storage for further generation of steam and the remainder is pumped to the receiver for further generation of steam. In this mode all subsystem components are operational except for the charge portion of thermal storage.

d. Receiver Charging Thermal Storage and Thermal Storage Operating the Turbine - This mode provides for simultaneous charging and discharging thermal storage. However, by simultaneous charging and discharging thermal storage, the electrical power is generated at the lower efficiency of the turbine admission point rather than the higher efficiency of the turbine main steam point. It is an alternate mode to operating back and forth between the modes shown in Figures III.C-2 and III.C-3. The main advantage of this configuration is to provide rapid transitions between these modes. If it were desired to use this configuration to flow all receiver steam to the thermal storage and none of the receiver steam to the turbine, the thermal storage heat exchangers would have to be sized to accept the full flow of the receiver subsystem. This is not required for plant operation since the receiver flow goes simultaneously to the turbine and the thermal storage. The thermal storage charge heat exchangers are sized for fully charging storage any day of the year. If the thermal storage charge heat exchangers were required to accept the full receiver flow, it would require significantly increasing the heat exchanger sizes in the charge portion of thermal storage, which is not necessary and is not cost effective. The electrical output in this configuration is up to 105 MWe net which is the turbine capability when operating from thermal storage alone.

As shown in Figure III.C-4, all of the steam from the receiver is provided to the thermal storage for charging and all of the steam provided to the turbine is from the thermal storage discharging. This combination provides essentially two isolated closed loops like the Receiver Charging Thermal Storage Only of Figure III.C-5 and the Thermal Storage Operating Turbine Only of Figure III.C-6. As shown, all subsystems are operating and the steam generated by

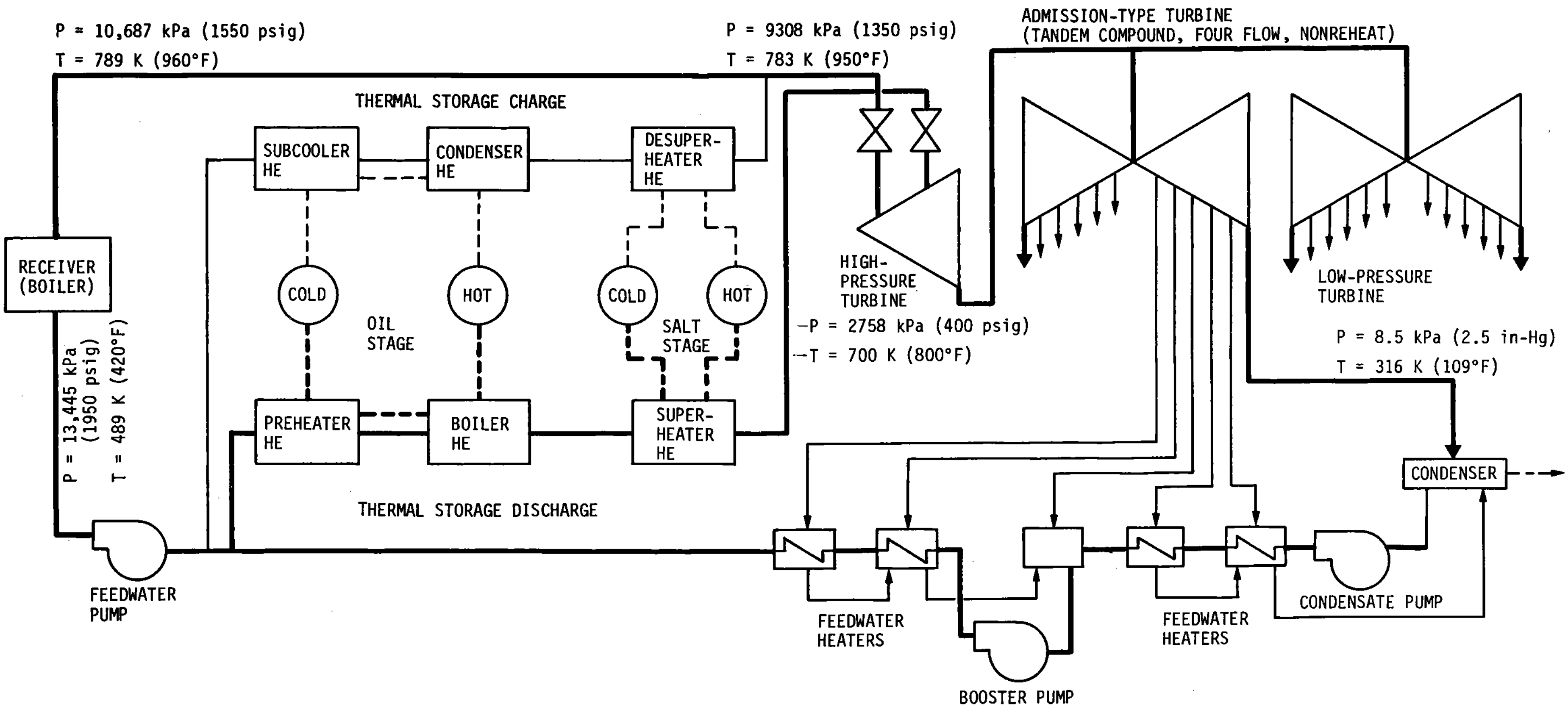


Figure III.C-3 Receiver and Thermal Storage Operating the Turbine

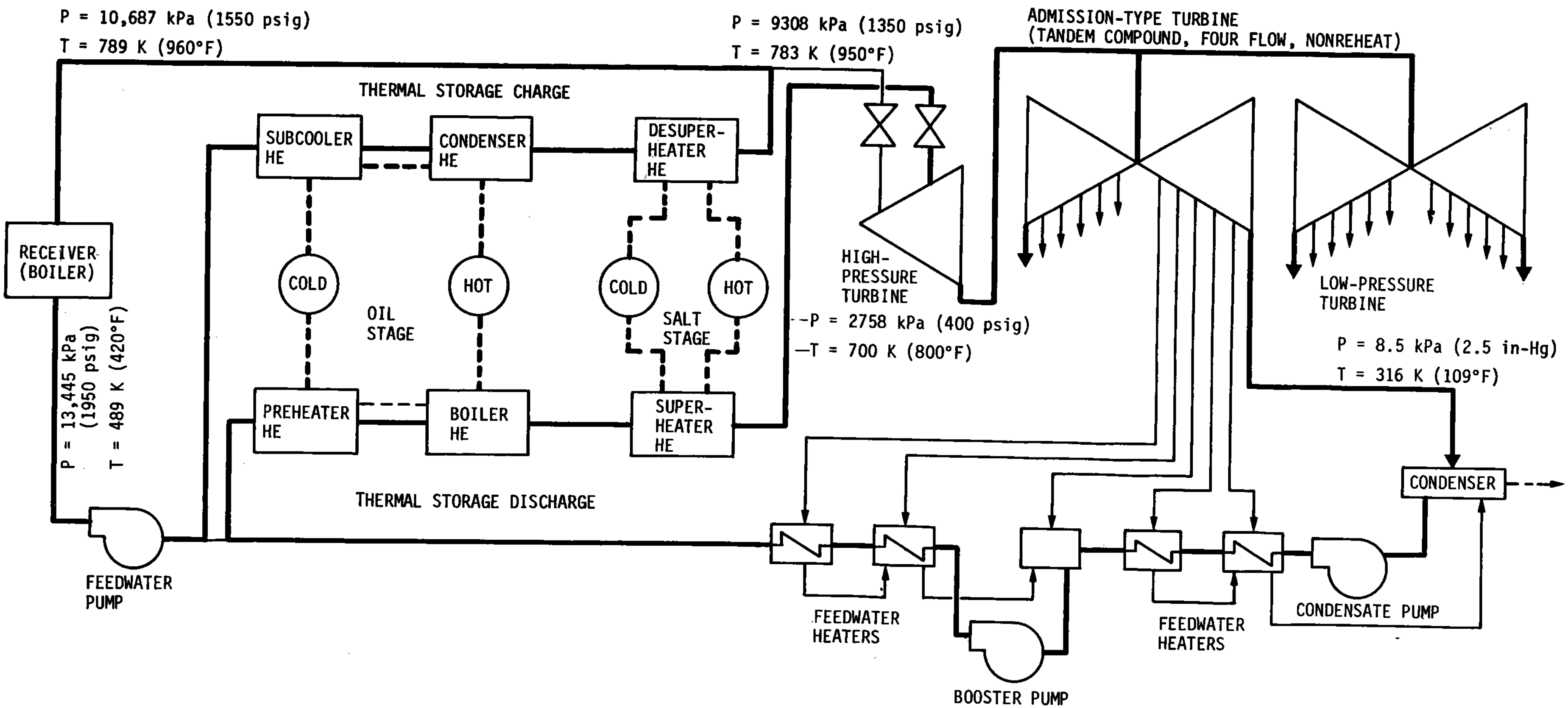


Figure III.C-4 Receiver Charging Thermal Storage and Thermal Storage Operating the Turbine the receiver for charging thermal storage is essentially in a closed loop separate from the steam generated by the thermal storage for operating the turbine.

e. Receiver Charging Thermal Storage Only - This mode of operation will normally be used when the operating strategy indicates that it is more advantageous to store energy for later use than to generate electrical power at the present time. No electrical power is being generated in this mode.

As shown in Figure III.C-5, the receiver is generating steam which is being used to charge thermal storage. The steam enters the salt stage where superheat is removed and then passes to the oil stage where the steam is condensed and the condensate subcooled. After the condensate leaves the thermal storage, it is pumped back to the receiver for steam generation. During this mode neither the discharge portion of thermal storage nor the electrical power generation turbine, condenser and feedwater heaters are operating. The high pressure feedwater pump returns the condensate to the receiver.

f. Thermal storage Operating Turbine Only - This mode of operation will normally be used in periods of no insolation. The electrical output can be up 105 MWe net, which is 70% of the peak net electrical output of the plant.

As shown in Figure III.C-6, the thermal storage subsystem is generating steam and providing it to the turbine admission steam throttle valve. Feedwater is delivered to the discharge portion of the thermal storage where it is preheated and boiled by the oil stage and superheat is added by the salt stage. After the steam passes through the turbine and condenser, the condensate is heated by the feedwater heaters and is pumped back to thermal storage to continue the cycle. Neither the charge portion of the thermal storage nor the receiver is operating in this mode.

2. Plant Control System

Our design concept for the master control system reflects the modular nature of the commercial plant. The commercial plant is comprised of 15 fields or modules each which is essentially a duplicate of the pilot plant collector and receiver subsystems. The control concept for each of the commercial modules derives from the pilot plant control of the collector and receiver subsystems. For a more detailed discussion of pilot plant module controls, see Volume VI and Section III of this volume. The control system is structured to accommodate 15 fields, a thermal storage subsystem and an electrical

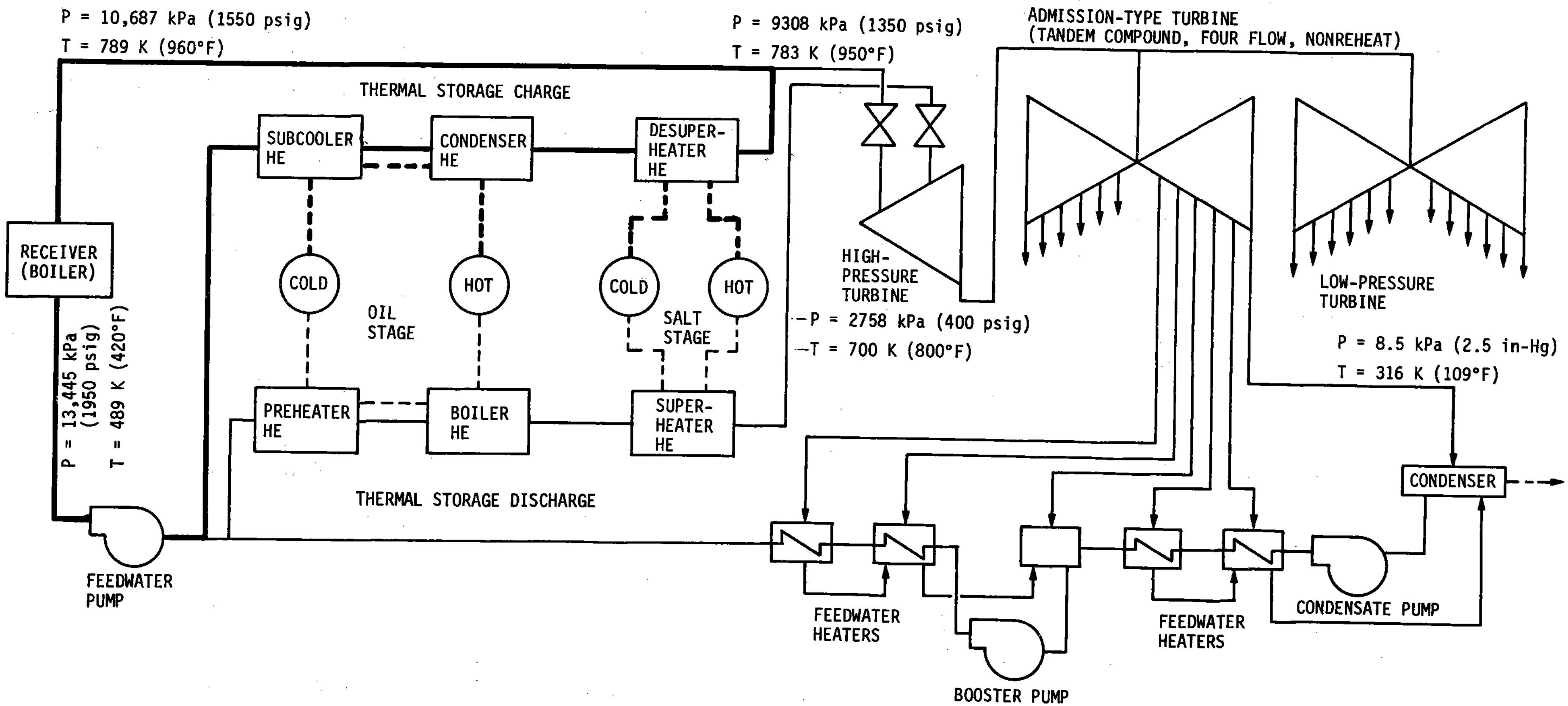


Figure III.C-5 Receiver Charging Thermal Storage Only

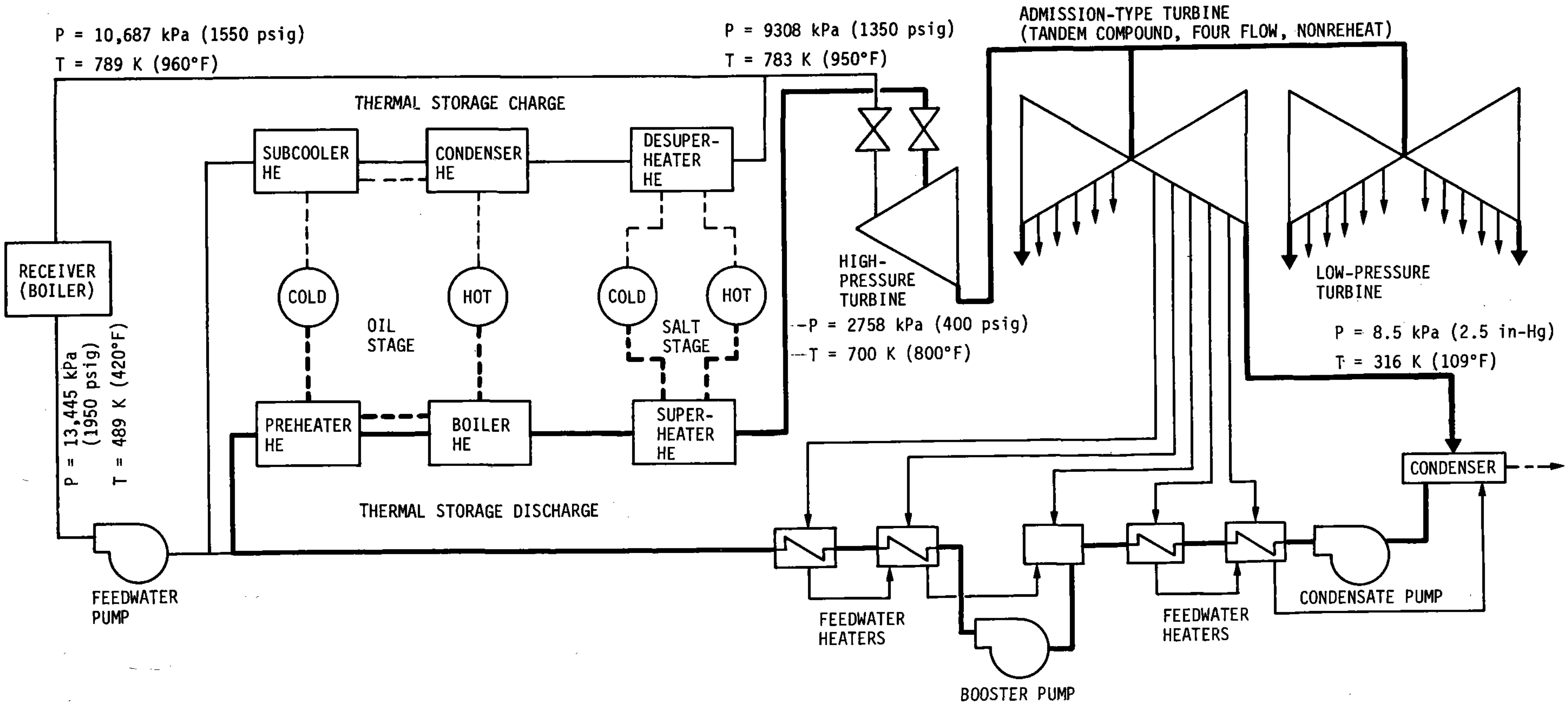


Figure III.C-6 Thermal Storage Operating Turbine Only power generation subsystem. Control of the various parts of the plant are coordinated by the plant control system which incorporates sequencing functions, plant status displays, system level emergency action capabilities, the capability of configuring the plant in any mode or to cause transition between modes and control of the steam manifold--the interface between the fields and the EPGS and/or TSS.

Our design of the master control system is simple, is user oriented, and is a system which employs state of the art hardware control logic to the degree possible. It is a system designed to give the control operators the capability to operate the plant on a daily cycle and to control the plant in any of several steady state modes and in transition between modes.

The collector and receiver portions of each field are operated in concert, and since during startup (and shutdown) all the fields will be proceeding in parallel through mode transitions, the sequencing capabilities are of necessity more automated than for the pilot plant. In fact, the fifteen fields are initialized by the control operator with a single command from the collector subsystem control computer which brings the heliostats to a standby position in preparation for focusing on the receivers. The control operator then puts each field on-line after establishing the readiness of the receivers. The control operators have the capability of controlling entire fields or segments of a given field.

The receiver subsystem, thermal storage subsystem, and electrical power generation subsystem are all controlled with conventional hardwired logic and controllers. The collector subsystem control computer represents the only computer controlled element of the plant. Because of the critical nature of heliostat control, the computer is backed up by the data handling system (DHS) computer. In the event of a collector subsystem control computer anomaly, heliostat control is automatically switched to the backup machine. The plant's automatic data logging capability is diminished until the control computer capability has been restored. Each individual heliostat will maintain control in the event of loss of control commands from the computer, and the heliostat will automatically stow itself.

In summary, the general requirements for the commercial plant master control system are to:

a. Provide the capability to the control operators to safely control the entire plant operations for all modes and for transitions between modes;

b. Detect, alarm, and respond to emergency conditions;

c. Acquire, process, store and retrieve, and output data for all plant elements. Processing includes production of logs, summaries and performance calculations.

3. Safety Considerations

The commercial plant will not contain any additional solar unique hazards beyond those that exist in the pilot plant as discussed in IV.C.5. The hazards that will exist are independent interactions within the individual field modules and do not result in a hazard potential increase with size. Size of the commercial plant creates a personnel access control problem which is primarily a management concern more than a safety problem. All of these hazards will be eliminated or safely controlled by extensions of the methods, procedures and personnel controls used for the pilot plant. The solar unique hazards associated with the pilot plant are summarized in paragraph IV.C.5 and the composite effect of these hazards within a commercial plant are summarized as follows:

a. Solar Beam Movement and Control - The method selected to control and safely move solar beams in a pilot plant becomes an even more significant safety consideration when applied to a commercial plant. We have selected a full-time beam control system which will control each module independently and maintain the beams within a selected beam corridor (path) which is selected in relationship to the integrated commercial plant operational areas. The layout of the commercial plant complements the selected control system by providing natural corridors for beam movement within the limits of the site. Field modules 11 through 15, located on the southern extremes of the site, will require some additional beam path analysis to ensure that hazardous ground reflections will not be projected beyond the site perimeter fence. This should not be a major concern as several of the beam control options discussed in paragraph IV.C.5.a can be used to safely eliminate this hazard.

b. Beam Failure Control Modes - The potential failure modes that exist in the pilot plant will also be present in the commercial plant with no significant increase in hazard potential. The potential failure modes of: (1) loss of normal power; (2) loss of computer control; and (3) individual heliostat component failure; present the same conditions as the pilot plant except for number of modules effected. Multiple module failures from a single event should not cause an additive hazardous beam condition as the individual module separation distances and beam control corridors should effectively eliminate all but low level beam convergence.

4. Reliability

It is recognized that for solar thermal power production to be successful and acceptable as a source of reliable energy, it must reflect the image of dependability that is associated with contemporary fossil fuel plants.

Our design of the commercial plant has been influenced significantly by reliability considerations throughout the conceptual design phase. A failure mode and effects analysis for the system was completed early in the program and design features have been incorporated at the system and subsystem levels to circumvent unacceptable failure modes, to eliminate system single point failures, and to reduce system scheduled and unscheduled down time to a practical minimum. Proven designs, materials and processes are employed throughout. Although the solar power concept, *per se*, represents new technology, no new subsystem technology need be developed as a condition of success.

a. System Reliability - The commercial plant includes fifteen collector-receiver subsystem modules configured to provide inherent reliability advantages at the system level. These modules are independent entities operating in parallel redundancy and providing the flexibility to operate with or without selected modules as required. The failure of a receiver or of an entire heliostat field would have minimal impact on plant output. Power output would, of course, be reduced by the proportion provided by the out-of-service module, but repair can procede while the plant is delivering most of its rated capacity. Our system concept effectively provides multiple redundancy for much of the solar-peculiar hardware, and takes maximum advantage of proven power generation equipment and state-of-the art technology for the non-redundant components.

b. Subsystem Reliability

1. Collector Subsystem Reliability - Collector subsystem analyses, including a failure modes and effects analysis have indicated the relative insensitivity of a module's performance to random failures of individual heliostats. Failure of a single heliostat (or several scattered throughout the field) has only a small incremental effect on the system power output, and individual reflected solar beams do not constitute a direct hazard to personnel. Accordingly, the design approach for the collector subsystem has been to, (1) positively control those failure modes that could result in concentrated flux levels of damaging proportions, (2) provide a low risk,

cost-effective heliostat design having an inherent low failure rate, and (3) include design features to minimize the impacts of unavoidable service and infrequent repairs.

Due to the high sensitivity of the total plant cost to individual heliostat cost, it would not be cost effective (or technically feasible) to design the heliostat assembly so conservatively that no failures would be expected in a field of 1554 units for a 30-year lifetime. However, our baseline design has the potential of approaching this goal to a practical limit, through a combination of design margins and serviceability features.

Those failure modes that could cause unacceptable, displaced flux levels include failures of the central control system computer or interruption of power or data bus control to the entire field or to a segment of the field. Computer failure modes are controlled by providing completely redundant computers, "reasonableness" self-check of transmitted data, and over-temperature instrumentation and alarms which will initiate manual override control of the heliostat field. Loss of data to any heliostat will initiate an automatic, safe stow sequence controlled by a preprogrammed local microprocessor. Loss of electrical power to the field is controlled by a floating battery supply to provide uninterrupted power to the electronic control elements, and by a diesel generator set which provides drive motor power to stow the heliostat field in the event of continued power interruption.

The heliostat assembly includes proven reliable commercial components and employs conventional, state-of-the-art materials and manufacturing processes. No new technology, component development or unique assembly procedures need be developed.

The mechanically active components of the heliostat that could significantly contribute to wearout and downtime include the drive motors and their integral reduction gearing, the direct connected, gimbal drive gear mechanisms, and the azimuth and elevation bearings. The entire drive train mechanism, including the bearings, is conservatively designed to meet the specified environmental (wind) conditions presented in Section V B., and to maintain alignment (gear lash) tolerances over a 30 year service life. These components are expected to be operated through a total of 13,000 cycles during this period. A cycle is defined as a sequence including unstowing, tracking during sunlight hours, and stowing. Replacement of these components can be performed if needed, but major disassembly of the structure is required.

Alternating current induction and synchronous motors are employed in the drive motor assemblies. These have no high failure rate features (e.g. brushes, commutators, start/run switches), which would contribute to a short life. Each tracking motor is expected to experience approximately 340 on/off cycles per hour while in the tracking mode, but this type of service should not significantly contribute to wearout since the motor assemblies are operated well within their published and demonstrated performance limits. Drive motor units are readily serviced (replaced) as assemblies, without major disassembly or significant downtime.

The electronics control box mounted on the heliostat base is normally serviced by replacing plug-in circuit boards or plug-in discrete components within the box. Motor control interfacing components include solid state devices for all current switching service and electro-mechanical relays for direction and motor selection. The relays do not make or break during current flow, eliminating arcing erosion; and duty cycles have been minimized to assure long life. There are no components employed that have predictable wearout characteristics, over the expected service life span, and replacement repairs for random failures can be routinely performed with a minimum of field and labor downtime.

An individual mirror replacement can be performed as a minor maintenance item. This requires selection of a mirror with the proper focus for a particular field position, and a post-installation alignment procedure. Our stowage mode, which places the mirrors face down during system inactivity and during high wind or precipitation conditions, provides maximum protection against soiling or deterioration of the mirror surfaces, contributing to a low maintenance concept.

All service and maintenance functions except mirror alignment can be performed while the system is in operation. Mirror alignment can be performed at night.

2. Receiver Subsystem Reliability - The design of the receiver and related plumbing and controls represents a nature technology which has evolved over many years of application and experience in utility and marine steam-pressure plants. No new technology is required in the design, construction, operation or maintenance of the receiver subsystem.

   The use of a natural circulation design, and large heat exchanger tubes simplifies the system, eliminating the need for circulating pumps.

A reservoir of water in the receiver protects boiler and superheater tubes against overheating and burnout in the event feedwater flow is interrupted. This reservoir can provide adequate water to prevent damage for one minute (worst case conditions) if feedwater is cut off completely. This provides ample time for the heliostat control system to defocus the heliostat field to a safe condition.

Redundant steam drum water level sensors and controls are provided to assure a safe water level at all times. All critical control valves can be manually overridden from the control room in response to instrumentation and an alarm system which continually monitors temperatures, pressures and flow rates.

The receiver, in normal operation, is subjected to extensive temperature variations and cycling because of changing cloud conditions, diurnal startup and shutdown, and due to modulation of thermal flux inputs to meet operating requirements. It has been estimated that 13,000 hot starts and 1300 cold starts will be experienced over the required 30 year lifetime of the assembly. Hot starts are the more routine daily startups after a previous day's operation. Insulated aperture closure doors are closed overnight to retain heat within the cavity. This and the considerable mass of the receiver minimizes startup thermal excursions. Cold starts are from periods of prolonged inactivity and include those startups from as low as ambient temperatures. With the cavity design of the receiver, transient cloudy periods do not result in thermal cycles of significance.

The baseline design of the receiver, and particularly the more critical superheater tubes and related plumbing, has been verified with respect to lifetime requirements through extensive analyses, including elevated temperature fatigue analysis, creep life (inelastic) analysis; and is in strict compliance with all applicable portions of the ASME code. The high-temperature fatigue curves of the Nuclear Code (ASME Code Case 1592) were used to evaluate fatigue life. The conservatism of these curves in conjunction with the finite-element elastic-plastic analysis method used in evaluation enhances the reliability of cyclic life predictions. The receiver tubing has been designed to accomodate expected pressure and temperature-caused excursions within elastic limit capabilities, through such conventional techniques as expansion loops from tube headers and allowing higher temperature tubes to bow over significant lengths.

Routine maintenance on the receiver should be minimal because there are few moving parts. Overnight shutdown affords time for periodic lubrication of the cavity door mechanism and repacking and reseating of valves that can be isolated from receiver pressure. With proper feedwater conditioning, acid cleaning of the boiler will be required at intervals of not less than 3 to 5 years, based on previous experience with fossil-fueled boilers operating under similar conditions.

Since the receiver is similar to a fossil-fueled boiler in design, arrangement, and materials, repairs can be made using techniques familiar to operators of conventional steam generators. Doors are provided for easy access to the cavity, superheater header enclosures and the upper enclosure, which contains the upper waterwall headers and riser tubes. Tubes can be replaced by cutting length-wise through the fins on both sides of the defective section and across the tubes at both ends of the section. Access to the front of the tubes is through the cavity, and access to the rear is by removing sheathing and insulation of the enclosure. After the defective section is cut out, a replacement section of the same dimensions is welded into place, which is a conventional boiler tube repair technique.

Platforms around the outside of the receiver provide access to the drum, spray attemperators, and access doors to the receiver interior.

The inside of the steam drum is accessible through manways located at each end. Components of the drum internals, such as separators and driers, are bolted into place for easy removal and replacement, although this is seldom necessary. Isolation valves are provided to allow replacement of water level gauges while the subsystem is under pressure.

No special jigs, tools, or lifting devices are needed for receiver maintenance and no unusual skills are required of maintenance personnel; only the usual skills of machinists, welders, pipefitters, riggers, electricians, and technicians on the staff of the power station.

The receiver tower structure and foundation are designed according to the requirements of the applicable industrial codes and standards, such as AISC-1969, ACI 318-71 and ANSI A58.1-72. The wind and seismic design parameters were evaluated from criteria provided by ERDA. Wind and seismic loads were obtained from these design parameters by conservative derivations. The selection of commonly used structural steel grades, concrete, reinforcing steel, and standard construction methods contributes to the reliability of the receiver tower design.

The elevator and stairway arrangements were designed to meet the OSHA requirements to assure safe access to the upper tower levels.

Exterior sheet metal cladding protects the access ways in the tower from reflected solar radiation and thus ensures personnel safety.

3. Thermal Storage Subsystem Reliability - The reliability criterion governing thermal storage subsystem design, derived from a failure modes and effects analysis, is to provide complete redundancy for those active components that cannot be repaired/replaced during an overnight period. This has resulted in redundant oil transport pumps. Because of their size and the necessary installation designs they require longer than overnight to replace. Failure of any single oil pump will not interrupt system operation; the failed pump may be replaced during operation by closing isolation valves associated with that pump. Salt pumps are modular, flange mounted units which install directly to the salt storage tanks. Redundant pumps are not provided since replacement can be performed overnight, using a flange-mounted replacement assembly, maintained ready in spares inventory. Failure of a salt pump could interrupt thermal storage performance for a maximum of one day's operation.

All control valves incorporate provisions for redundant, manual operation. Block valve configurations are provided for each control valve to allow bypass of a failed-closed or failed-open control valve and continued control via manual valves in response to subsystem instrumentation.

All control and stop valves are welded in place to obviate those failure modes associated with seals and plumbing connections. Although the stop valves are not installed in redundant configurations, they can all be isolated and repaired or rebuilt in place (e.g. replacement of steam seals, of valve seats or complete actuating assemblies) with minimal disruption to subsystem operation. A failure modes and effects analysis of the subsystem has established that any of the control or stop valves can fail open or closed without creation of a hazardous condition, or without causing propogation failures of related components.

Pressure vessels, heat exchangers and basic piping of the subsystem are all conservatively designed to the ASME Boiler and Pressure Vessel Code requirements without deviations. Storage media pressures are low and the operating temperatures are well within ranges that can be handled by conventional design practices and available components. Heat exchangers experience diurnal temperature excursions when cycling from standby to operating conditions. Fortunately, in normal operation this variation in temperature is kept quite small due to the mass of the components and the insulation design. In fact, auxiliary steam is provided to the salt circuit components if required to maintain temperatures above the melting point of the media. The only occasions when the subsystem will experience temperature excursions of consequence are when components are taken out of service for major maintenance or repair. Allowance has been made in the design margins for these infrequent temperature cycles. The subsystem design provides for access to and replacement of all major components, using conventional tools and techniques in common use in the industry. Failure rates of these components are expected to be so low that redundancy would not be cost effective.

Both storage media fluids are commercially available heat transfer materials that have been proven in varied industrial applications over many years of service. Each is used below recommended temperature limits and neither presents a toxicity hazard or requires special handling. Additional experience has been gained in using these materials in our thermal storage research experiment which was successfully completed during this design phase. Thie experiment consisted of a scaled, operating system using the salt and oil storage media under the same state conditions that they will be used in the full size subsystem. Results of the experiment have verified that these media can be reliably applied under our application conditions without requiring development of new technology.

4. Electrical Power Generating Subsystem Reliability - The non-solar portion of the plant consists of strictly conventional power generating hardware and auxiliary equipment. All components are commercially available and will require a minimum of modifications for the solar power application. This type of equipment benefits from a long history of design evolution and has reached a very high demonstrated level of relabililty. We have taken every advantage of component selection practices and system configuration techniques

that have proven most successful in conventional commercial power plant practice. Redundancy and failed part isolation techniques have been applied in the design of those valve and control elements that experience has shown is beneficial to minimize subsystem down time. Full flow, completely redundant feedwater pumps are utilized to circumvent loss of water to the receivers, which would otherwise require total system shutdown.

One operational aspect associated with solar plant service, that of diurnal cyclic operating conditions, has been the subject of special attention. Commercial steam turbines can be subjected to limited thermal cycling without adversely affecting life. As thermal cycling becomes more severe, turbine life is shortened. The daily thermal cycling to which the commercial plant turbine will be subjected, together with additional thermal transient conditions due to intermittent clouds, will impose thermal stresses which need to be considered in establishing final turbine design and operating requirements. Thermal cycling vs. equipment life is expressed for each turbine by a cyclic life expenditure curve relating the rate of temperature change and the amount of temperature change to life expenditure. An example of this type of curve is shown in Figure III.C-7 for a large commercial turbine. For the particular turbine represented by the data, up to 56°C (100°F) step temperature changes and 111°C/hr (200°F/hr) rate changes could be imposed on the turbine repeatedly without any appreciable loss of turbine life. However, it is expected that a 166°C (300°F) overnight cooldown will be typical for the commercial plant turbine. Based on a single 166°C (300°F) cycle per day over a 30 year lifetime requirement, it can be concluded from the curve that to achieve the (approximate) 0.01 life expenditure rate, the start up time should be a minimum of 1.1 hour (153°C/hr. or 275°F/hr). The infrequent cold starts can be controlled procedurally by controlling the startup times to avoid unacceptable accumulation of life expenditure.

If it is found that faster startups will be required than are consistent with the characteristics of the particular turbine selected and the required lifetime requirements, certain turbine design measures can be taken to satisfy operational goals. These relate to use of more ductible steels, thinner casing thicknesses, the addition of heating elements or additional insulation, and reductions in maximum operating temperatures/pressures.

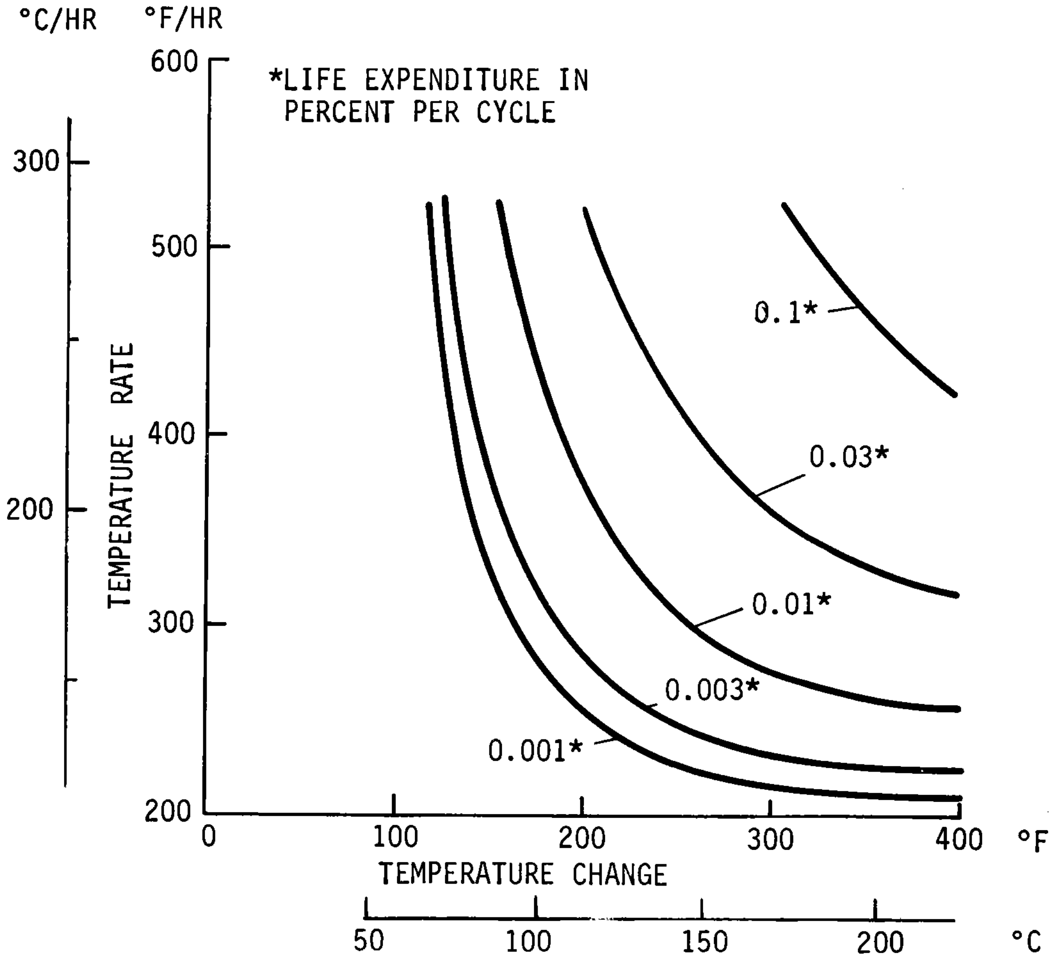


Figure III.C-7 Typical Commercial Turbine Cyclic Life Expenditure Curve

These measures are presently employed on peaking units which are often subjected to diurnal cycling similar to that expected in a solar thermal power plant.

Like all equipment of its type, the turbine will require periodic inspection and maintenance within its projected 30 year life.

D. ENVIRONMENTAL IMPACT

The design of the Central Receiver power generation concept described herein has been influenced by the recognition of a goal to minimize environmental impacts and still maintain consistency with the major cost and operational performance parameter goals. Our baseline design constitutes on optimum approach to reducing the effects on the environment to irreducible minimums for a practical solar commercial power plant. Environmental influencing factors summarized here, and presented in more detail for the Pilot Plant in Appendix A are considered easily acceptable when compared with alternative power generating concepts. No significant pollution, biological or meteorological effects are indiginous to the concept. Unavoidable factors of significance all pertain to land preemption, to aesthetic perceptions (the existance and appearance of power generating installations on land areas that might otherwise remain pristine in nature), and to consequential socio-economic influences attendant with plant construction and operation.

1. Collector Subsystem

The collector subsystem includes the more dominant features of the solar power plant with respect to environmental factors. The deployment of 23,310 individual heliostats in ordered matrices on the land surface is a basic design requirement of the concept. This creates what is perhaps the only environmental intrusion of significance associated with the plant --- that of land preemption. Following is a brief summary of all the identified Collector Subsystem environmental factors to be assessed.

a. Collector Field Area - The fifteen collector subsystem modules represent the most land-intensive feature of the commercial plant. The heliostats occupy a total of over 4.6 million m^2 (1100 acres), which constitutes over 70% of the total site area. This area, along with the necessary perimeter access roadways and security fencing must be committed to the plant site; there is no apparent common use potential. Mitigation of this dominant environmental feature hinges on a rational approach to plant site selection. A selection process is indicated, whereby those areas that are acceptable on technical basis are further screened to avoid projected conflicts with more valued land utilization, and to minimize intrusion into areas having recognized biological, historical or archeological values.

b. Topographic Modifications - Installations and modification affecting the pre-existing topography of the heliostat fields includes roadway paving, drainage grading, heliostat foundations, trenching for cabling, and security fence installations. These modifications will contribute to irreversible changes to the surface which may be at issue, depending upon particular site conditions. The total disrupted area has been held to a minimum (approximately 17% of the total heliostat field areas) by the decision to use low pressure tires on construction and maintenance vehicles in lieu of extensive heliostat row paving. This also will reduce the effects on existing vegetation, although it is expected that larger ground animals will be effectively excluded from the area. Drainage of the collector fields will be designed to avoid creation of adverse erosion problems beyond site boundaries.

c. Heliostat Shading - The microclimate of the collector fields will be modified by the shading effects of the ground surface by the heliostats. This can affect greater than 30% of the ground surface during morning and evening hours in summer. This could result in minor changes to local biology. Species not normally indiginous to the area may be attracted to the cooler, shaded area. A judgement of the merits or disadvantages of the results would be specific-site dependent.

d. Mirror Washing - Periodic mirror washing will contribute to total water used by the plant and provides added moisture to the soil in heliostat field areas. Water quality of the area will be preserved by our mirror washing approach which utilizes demineralized water without chemical cleaning agents.

Total water used for washing mirrors will be approximately 2.4 million liters (630,000 gal.) per month. This is based on an estimated requirement of 102 liters (27 gal.) per heliostat and a wash frequency of once per month. The availability and impacts of using this quantity of water (in addition to that required by other plant functions) will be site dependent.

The water dispersed in the heliostat field will constitute an irrigation effect that may contribute to modified site biology.

e. Spurious Reflections - It is expected that occasional stowing/unstowing of heliostats will be required under sunlight conditions. The reflected sunlight, sweeping regions off the tower structure could create distracting flashes visible for long distances from the plant site. This feature may be objectionable to those in visual range of the phenomenon, and could constitute a close range hazard under certain conditions. Adverse effects will be avoided by positive control of mirror movement operations to minimize or eliminate objectionable paths, by providing opaque fencing for the near ground level regions, and by procedural control of on-site personnel during mirror stowing operations.

2. Receiver Subsystem

The primary features of the Receiver Subsystem to be considered in assessing impacts on the environment are the high thermal flux levels associated with the receiver; and the receiver tower, which places the receiver in the required elevated position for efficient concentration of energy. The receiver is comparable in design and operation to its boiler counterpart in a fossil fuel plant, with the notable absence of combustion product pollutants. The design and operation requires no new or unproven technology. The receiver tower is a basic design requirement of the central receiver power plant concept, and the towers of a commercial plant will be the most prominent visual features to a ground observer. Our modular concept has enabled us to optimize the tower aperture height at only 90 m (295 ft.), resulting in an overall tower height of 113 m (370 ft.). This height minimizes visual prominence, bringing tower height below that of many stacks of contemporary fossil fuel power and industrial plants. Impact potential appears to be minimal; none should raise significant environmental issues in the implementation decision process.

a. Receiver Heat Flux - Heat flux levels present in the receiver cavity and in external areas leading to the aperture would be lethal to intruding birds and insects in flight. However, the operating experience of a comparable Solar Furnace Research facility in France indicates that birds in flight sense the presence of damaging flux levels and avoid flight into these regions. Insects do intrude and are consumed.

b. Tower Height Appearance - The presence of the 15 towers associated with the commercial plant will require a variance from the FAA marking in accordance with their requirements, and locations recorded on air navigation charts. Satisfaction of these requirements should be routine unless a proposed site should interfere with an existing or planned airport approach area.

Our proposed tower design includes external surface geometry, finish and color that contributes to an aesthetically non-intrusive appearance when viewed against natural background surroundings. Although the tower cannot be deleted from the system design concept, the external treatment could be tailored for particular sites to minimize visual conflicts with natural settings.

c. Land Commitment/Topographic Modifications - Tower foundation requirements are not significant when considering the entire commercial plant plot. Land area affected is approximately 1500 m^2 (16,000 ft^2) per tower; foundation depth is typically 4.2 m (14 ft.).

d. Receiver Blowdown - The receiver (boiler) will require continuous blowdown during operation to avoid build up of contaminants unacceptable to the efficient operation of the steam circuit equipment. This effluent will be comparable to that from a fossil fuel plant. Total blowdown quantity is estimated as 8100 Kg (17,850 lb)/hour; contaminants will be less than 100 parts per million. Environmentally safe disposal of this effluent will depend upon the specific site, but will typically be combined with TSS boiler blowdown products and routed to evaporating ponds for concentration and ultimate collection of contaminants.

e. Accident Potential - Catastrophic failure of boiler, piping or support structure could endanger life in the vicinity of a tower. The receiver and piping are designed and operated in accord with applicable construction and pressure vessel codes. In all normal operating respects the receiver poses no more of an accident hazard than fossil fuel plant boilers, which have proven highly reliable in service. Hazard potentials which are peculiar to the solar plant include those system failures and procedural errors that will cause solar energy to be focused onto receiver or tower areas at such flux levels for such durations as to exceed structural design limits. Failure modes which could propogate to these conditions are positively controlled in plant design by fail safe features in the heliostat control logic, and by over-temperature alarms/controls in the receiver subsystems.

3. Thermal Storage Subsystem (TSS)

The thermal Storage Subsystem concept described herein should present no significant concerns with respect to impacts to the environment. Although the thermal storage concept represents new technology at the subsystem level, all elements of the design, including the storage media, involve materials and processes which are well proven in industrial applications. There are no special handling or toxicity problems and the elevated temperatures of the storage media can be handled routinely with existing technology. The subsystem is essentially benign with respect to unwanted emissions or effluents and there are no intrusions on biological factors except for the possibilities of accidental spills (discussed below) and the indirect effects of land pre-emption.

a. Land Commitment/Topographic Modifications - The commercial plant requires an area of approximately 80,000 m^2 (20 acres) for installation of thermal storage components. Installations will require foundations or other surface modifications over much of the area, which effectively pre-empts local flora and fauna. Surface drainage will be modified locally, but drainage control installations will be designed to avoid creation of erosion problems outside the plant site boundaries.

b. Aesthetics - Oil and salt storage tanks, heat exchangers, and the associated plumbing all contribute to the visual impact of the overall commercial plant installations. Although aluminum or aluminized coatings are projected for use over external surfaces, less obtrusive surface treatments may be employed for particular plant settings, if required.

c. Heat Loss to Atmosphere - Heat losses through the insulated surfaces of thermally charged tanks and other components will contribute to redistribution of thermal energy from the collector field to the thermal storage subsystem area. Some of this heat loss is effectively delayed in time and released to the atmosphere after sunset, which will tend to reduce diurnal temperature excursions for a very localized area. This effect, involving temperature differentials of $6^{o}C$ ($10^{o}F$) is considered insignificant with respect to meteorological factors, and probably so for the local biology.

d. Thermal Storage Blowdown - The Thermal Storage subsystem boiler will require continuous blowdown during operation to avoid buildup of contaminants unacceptable to the efficient operation of the steam circuit equipment. This effluent will be comparable to that from a fossil fuel plant. Blowdown contaminants will be less than 100 parts per million. Environmentally safe disposal of this effluent will depend upon the specific site, but will typically be combined with main boiler blowdown products and routed to evaporating ponds for concentration and ultimate collection of contaminants.

e. Accident Potential - Catastrophic failure of heat exchangers, oil or salt tanks, or piping could endanger life or persons on the plant site and could affect local biology and water and air quality. Steam circuit state conditions (temperatures and pressures) are lower than when operating on receiver energy. Salt and oil storage and piping circuits are operated at low pressures under a 69 KPa (10 psig) Nitrogen ullage blanket.

Accident potential of the subsystem containment and pressure vessels will be controlled mainly by conservative design, compliance with all applicable design/construction and operating codes, and the inert gas (N_2) blanket used in the storage media systems.

Propogation of an accident occurrence to a hazardous or environment contaminating event is controlled by location and separation of the components. Oil storage tanks have separate containment basins designed to safely confine spilled fluids or consequential fire to localized areas, and also to facilitate recovery of spills, assuring that only limited area of the soil will be affected. Spilled salt will solidify at 415K ($288^{o}F$), which effectively prevents intrusion into the soil and also facilitates recovery.

E. COMMERCIAL COLLECTOR SUBSYSTEM DESCRIPTION

1. Collector Subsystem Layout (150 MW_e)

The Collector subsystem for the Commercial Plant is comprised of fifteen (15) identical heliostat fields, each constituting an independent module, along with a tower-mounted receiver subsystem for each of the modules. Figure III.E-1 shows the collector field layout for the 15 fields, the location of the TSS and EPGS subsystems, and the interconnecting access roadways. The plant includes a total of 23,310 heliostats (15 fields of 1554 heliostats each), requiring a site 3393 m (11,133 ft.) wide by 1894 m (6214 ft.) deep. Each heliostat field is positioned north of its respective receiver tower.

2. Collector Subsystem Module

Each of the collector fields, constituting one module of the commercial plant, includes 1554 heliostats arranged as shown in Figure III.E-2. The field extends 618.4 m (2029 ft.) north of the receiver tower aperture, and is a maximum of 660.4 m (2166.6 ft.) wide (to centerlines of outermost heliostats).

Spacings 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.

3. Heliostat Configuration

All heliostats are of identical configuration except for mirror focal lengths. Figure III.E-3 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 tope 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 2.13 m (84 in.) square, and are by design, permanently fixed focus for particular areas of the heliostat 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.

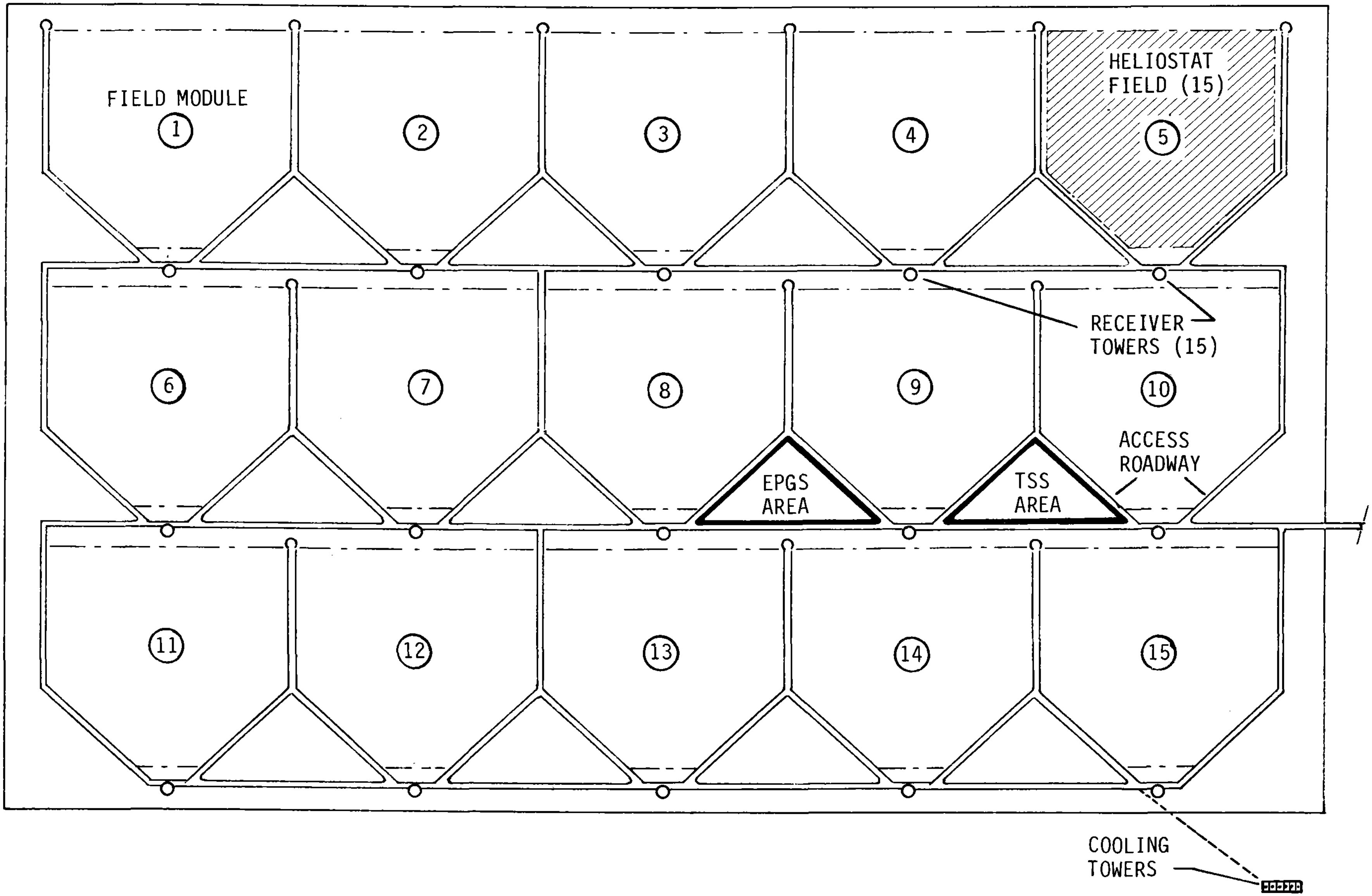


Figure III.E-1 Commercial Plant - General Arrangement

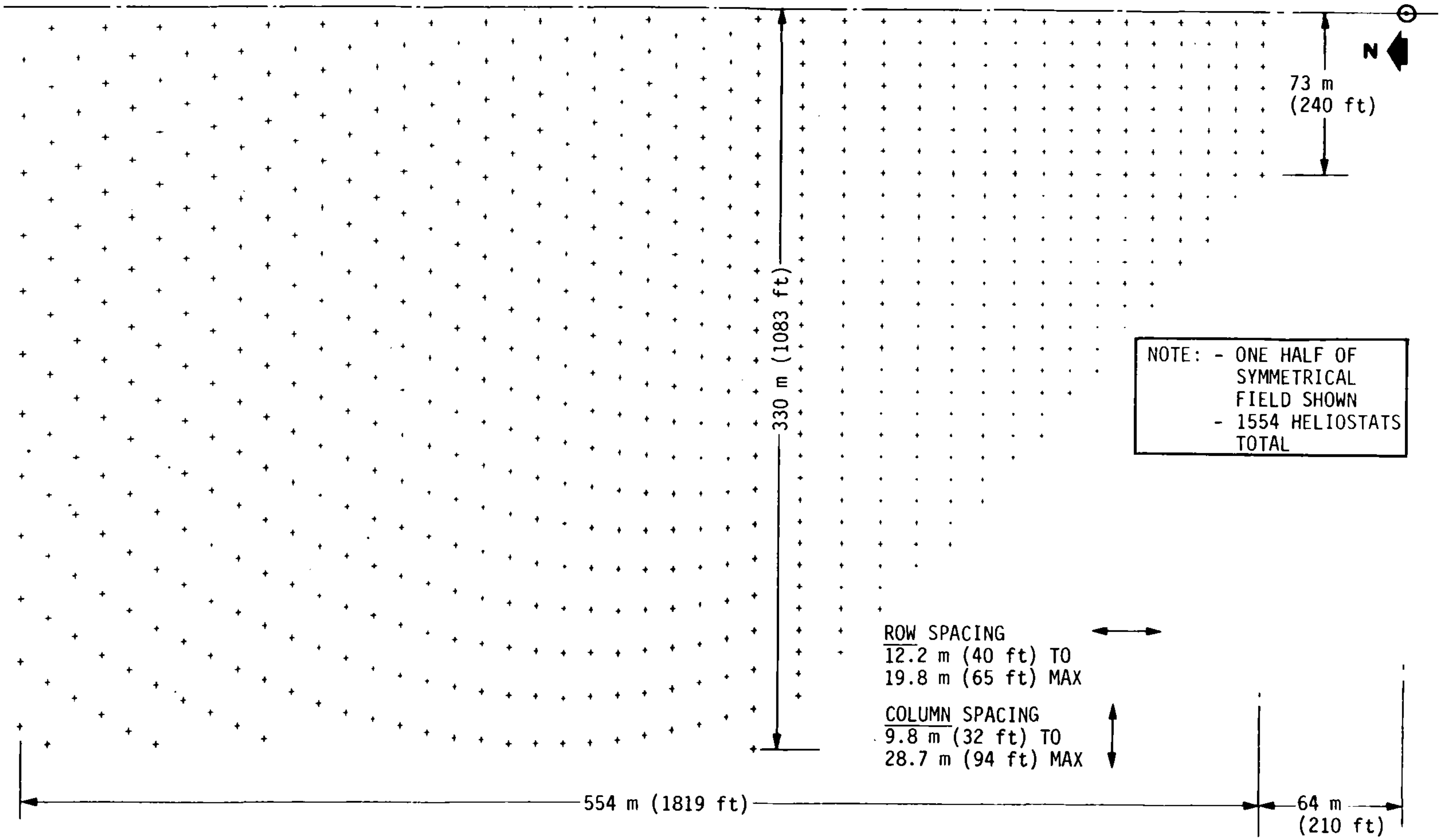


Figure III.E-2 Collector Module Configuration/Dimensions

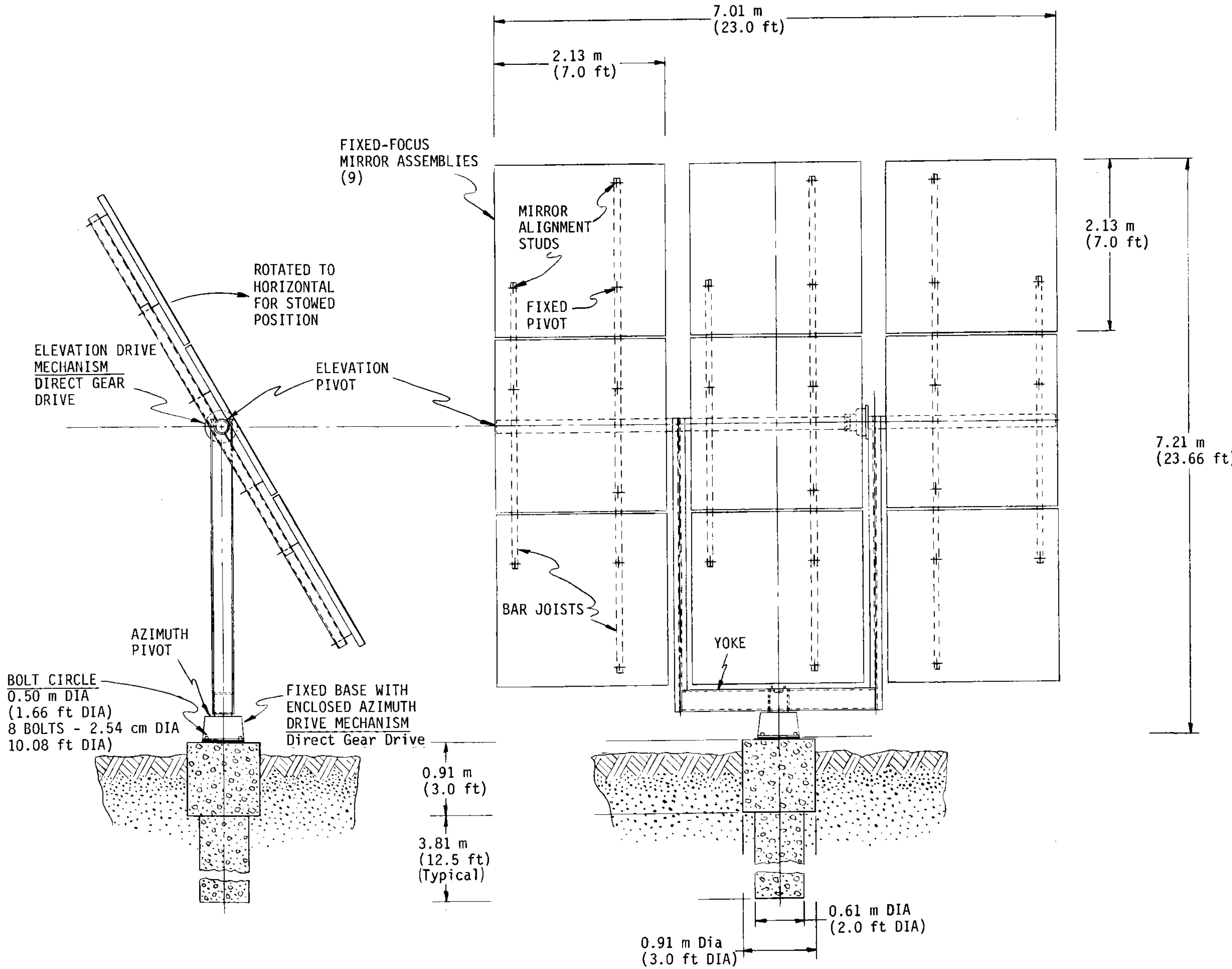


Figure III.E-3 Heliostat Configuration

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 $\pm 110^{\circ}$ in azimuth and 180° 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 mirrors to clear the yoke support legs for stowing.

The local electronics control subassembly includes a mircoprocessor, 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 azimuth 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 on each axis.

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

Figure III.E-4 is a photograph of a full scale heliostat which is one of four built and placed in operation at the Martin Marietta facility in Denver in the performance of a heliostat subsystem research experiment (SRE) project.

These are of similar size and configuration to the designs proposed for our pilot plant and commercial plant operations and have provided empirical bases for design refinements to reduce production costs. These SRE assemblies have been successfully operated in conjunction with a calorimeter target under wide ranges of climatic conditions and have effectively verified our basic design and water drive concept.

Additional experience has been gained in the design and production of 222 heliostats of similar design which are being provided under separate contract to ERDA for use at the Albuquerque Solar Thermal Test Facility.

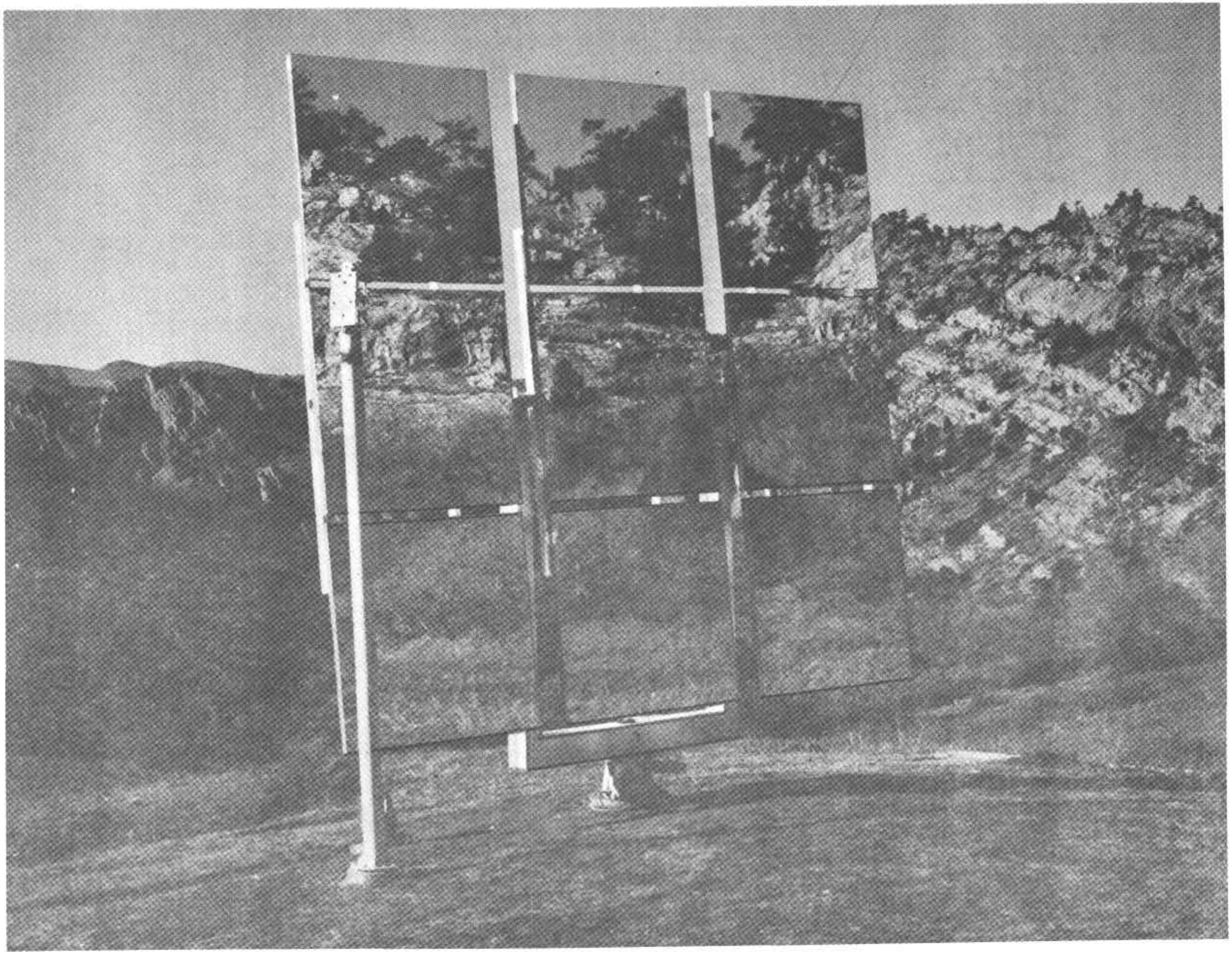


Figure III.E-4 SRE Heliostat Installed at Denver Facility

F. COMMERCIAL RECEIVER SUBSYSTEM DESCRIPTION

1. Receiver Subsystem Configuration

The receiver subsystem for the commercial plant consists of fifteen (15) Solar Thermal Receivers (boilers), their respective supporting towers, and the necessary steam and water piping, valves and controls to supply feedwater to, and extract steam from the subsystem. All fifteen receivers are identical for each module of the commercial plant; the pilot plant receiver subsystem is also identical with one commercial plant module.

Figure III.F-1 shows the configuration of the receiver tower; Figure III.E-1 shows the locations of the fifteen towers at a commercial plant site. The tower is octagonal in cross section with constant section dimensions top to bottom. Overall height is 113 m (370 ft.) and a receiver aperture is centered at the 90 m (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 272,158 kg (300 tons) 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 III.F-2 and III.F-3, is a natural circulation, cavity boiler, similar in concept and configuration to a small fossil fuel fired unit. Approximate overall dimensions are 19.2 m (63 ft.) high by 15.2 m (50 ft.) wide by 9.8 m (32 ft.) deep. The major features include an internal cavity containing the heat exchanger tubes, a 7.5 m (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

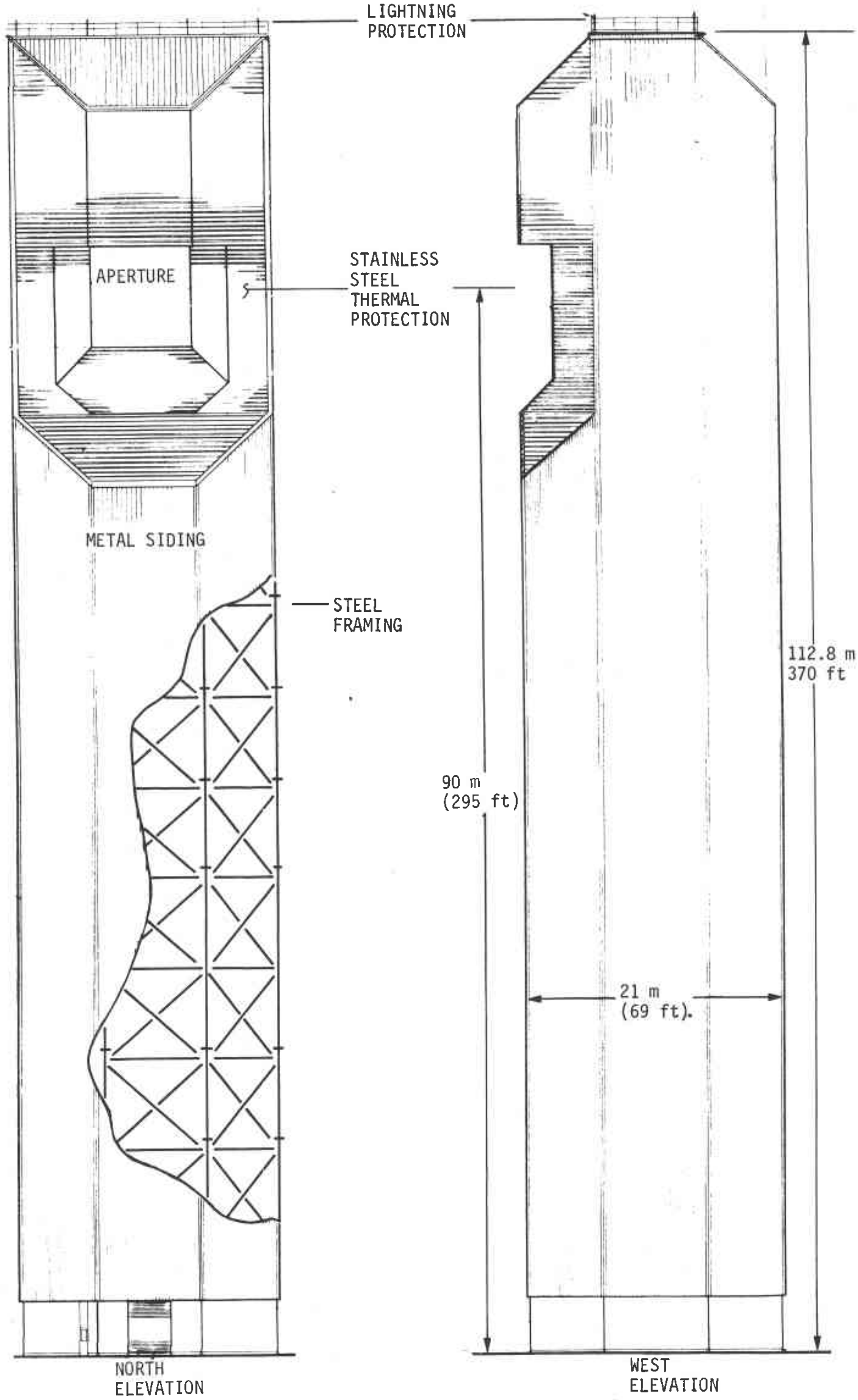


Figure III.F-1 Receiver Tower Configuration

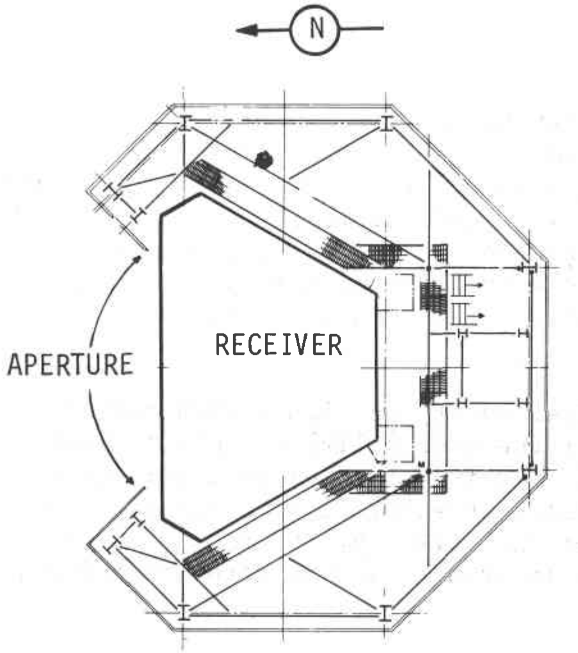


Figure III.F-2 Plan Section of Receiver at Aperture

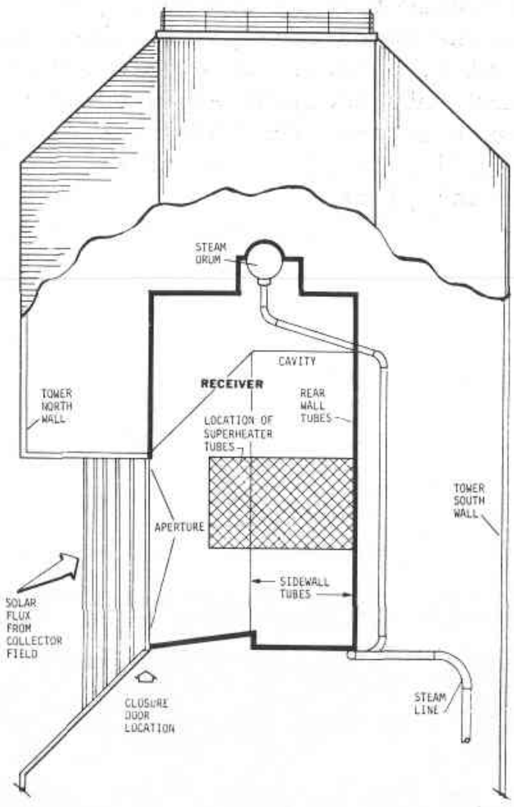


Figure III.F-3 Receiver Configuration

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.

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 weatherproofed insulation.

Figure IV.F-4 is a photograph of a scaled receiver rated at 5 MW_{th} which was constructed under the Receiver Subsystem Research Experiment (SRE) program and has undergone radiant thermal testing at the Albuquerque facility. The SRE Receiver is of the same general configuration as that proposed for the commercial plant. The similarity extends to the cavity configuration, natural circulation, and the use of water wall and superheater tube sections emplaced on three active walls. The test experience gained from this unit, and the subsequent pilot plant program will effectively eliminate receiver development risk for the commercial plant.

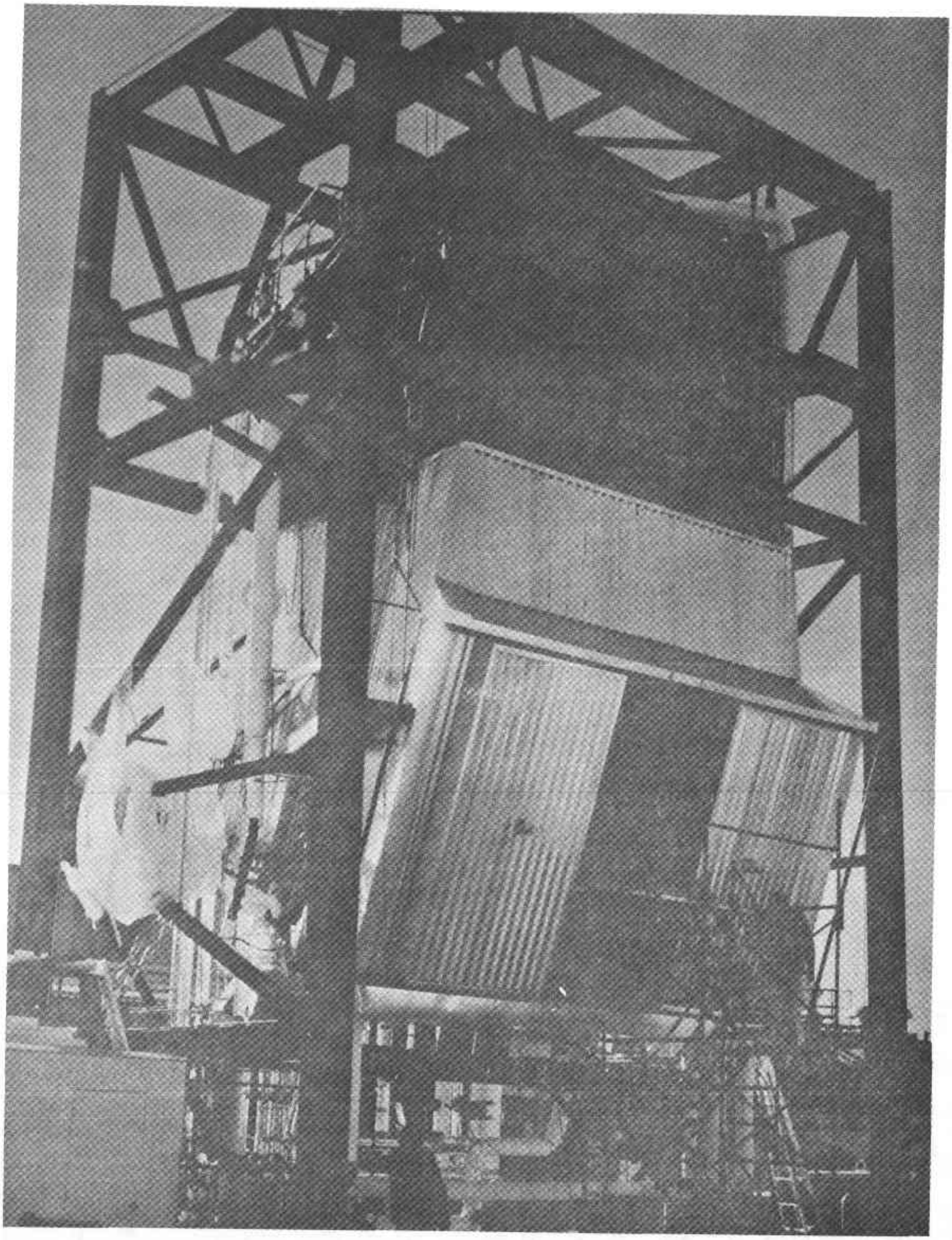


Figure III.F-4 SRE Receiver ($5mw_t$) Installed at STTF

G. COMMERCIAL THERMAL STORAGE SUBSYSTEM DESCRIPTION

1. Thermal Storage Subsystem Layout

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 III.G-1 shows a plot arrangement for the major storage and heat exchanger components located within a single, 80,000 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.

Oil tanks are spherical, 23.1 m (75.8 ft.) in diameter, with a maximum elevation of approximately 27.4 m (90 ft.) above ground level. A total of 30,000 m^3 (1.06×10^6 ft^3) of thermal storage media are stored in the seven tanks. Each of the tanks is surrounded by an earthen dike system, typically 61 m (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 15.8 m (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

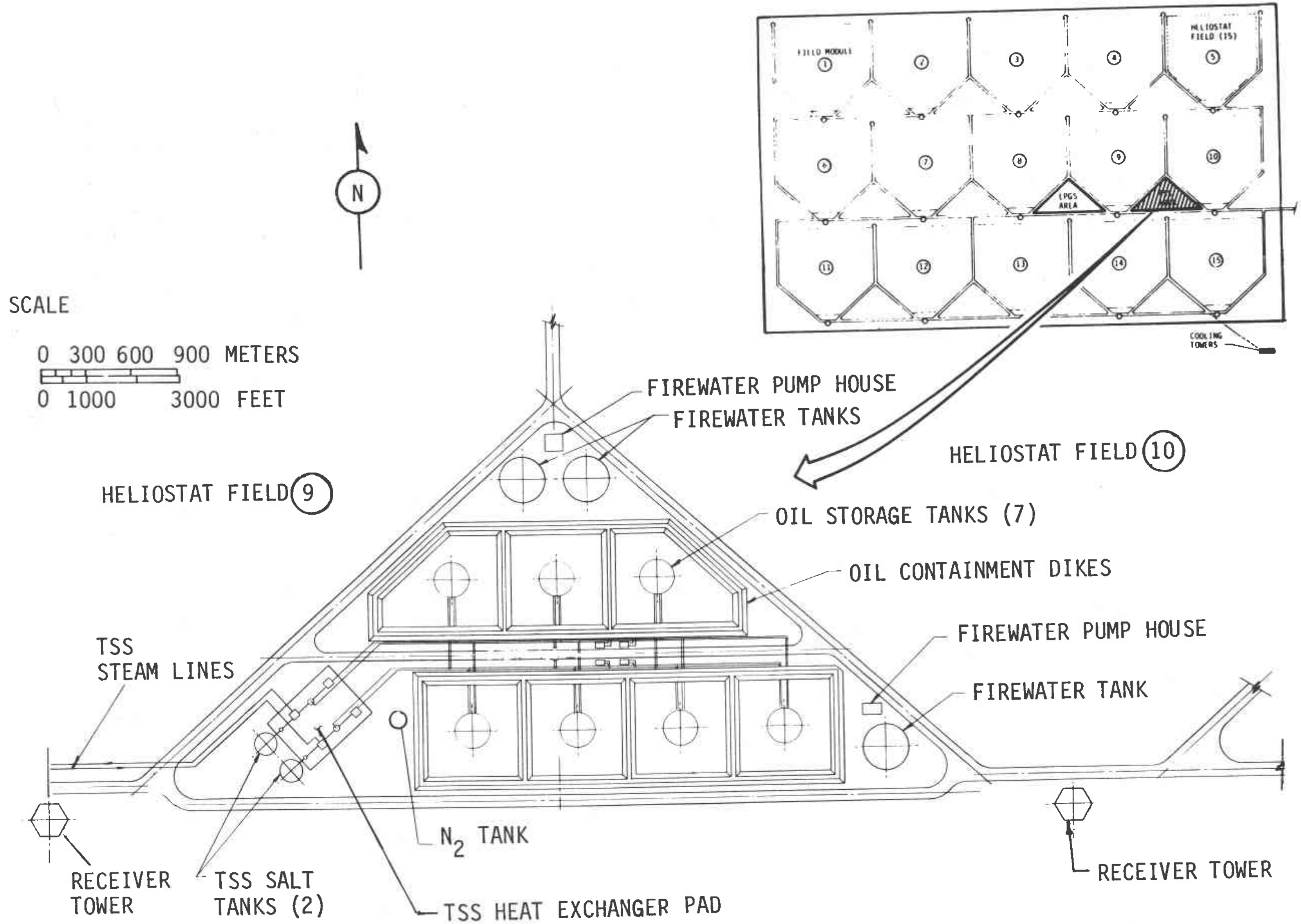


Figure III.G-1 Thermal Storage Subsystem (TSS) generated from collector field energy (discharging). Oil storage is used to either deliver saturated steam to the superheater (discharging), or to remove heat from saturated steam from the desuperheater (charging). Pumps and piping are configured to permit simultaneous charging and discharging of the thermal storage subsystem, adding to the flexibility of commercial plant operation.

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°F).

The salt is available as a commercial product (Dupont HITEC), 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 its 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°F).

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.

A fluid maintenance unit (side-stream processor) is included in the oil system to remove products of decomposition which will accumulate over long periods of use. This approach to circumvention of small but cumulative deterioration effects has been determined to be a more cost effective approach than progressive or periodic oil replacement. If allowed to accumulate, these parasitic high and low boiling compounds will adversely affect pumping and heat transfer characteristics. A flow of oil from storage is continually routed through the side-stream processor which consists of a boiler and a condenser section to selectively remove the highest and lowest fractions, respectively, by a vacuum destillation process. During the day, when receiver steam is available, the side stream processor is steam heated; at night it is fueled using the products of decomposition that have been extracted from the oil. The condenser is cooled with receiver feedwater which contributes to overall plant operating efficiency. Operation of the pilot plant, which will have a similar fluid maintenance unit, will provide the needed data on long term decomposition rates to finalize the commercial unit size and flow rate requirements.

The selection of HITEC and Caloria HT 43 as storage media for the TSS was based on cost, technical risk and required performance factors. Both of these materials have been well proven in industry, they are readily available in commercial quantities, and properties are well known and documented. Application in our baseline design for sensible heat storage requires no new technology and presents minimum technological risk.

Figure III.G-2 is a photograph of a scale thermal storage subsystem which was constructed and successfully operated at Georgia Institute of Technology as a subsystem research experiment (SRE) during this concept development phase. This scale subsystem, rated at 2 MW_{th}, used the same salt and oil thermal storage media and was operated over similar ranges of temperatures as is proposed for the commercial TSS. The experience gained in the operation of this scale subsystem has technically verified our baseline TSS concept and allows proceeding with the pilot plant and the larger commercial plant configurations on a minimum development risk basis.

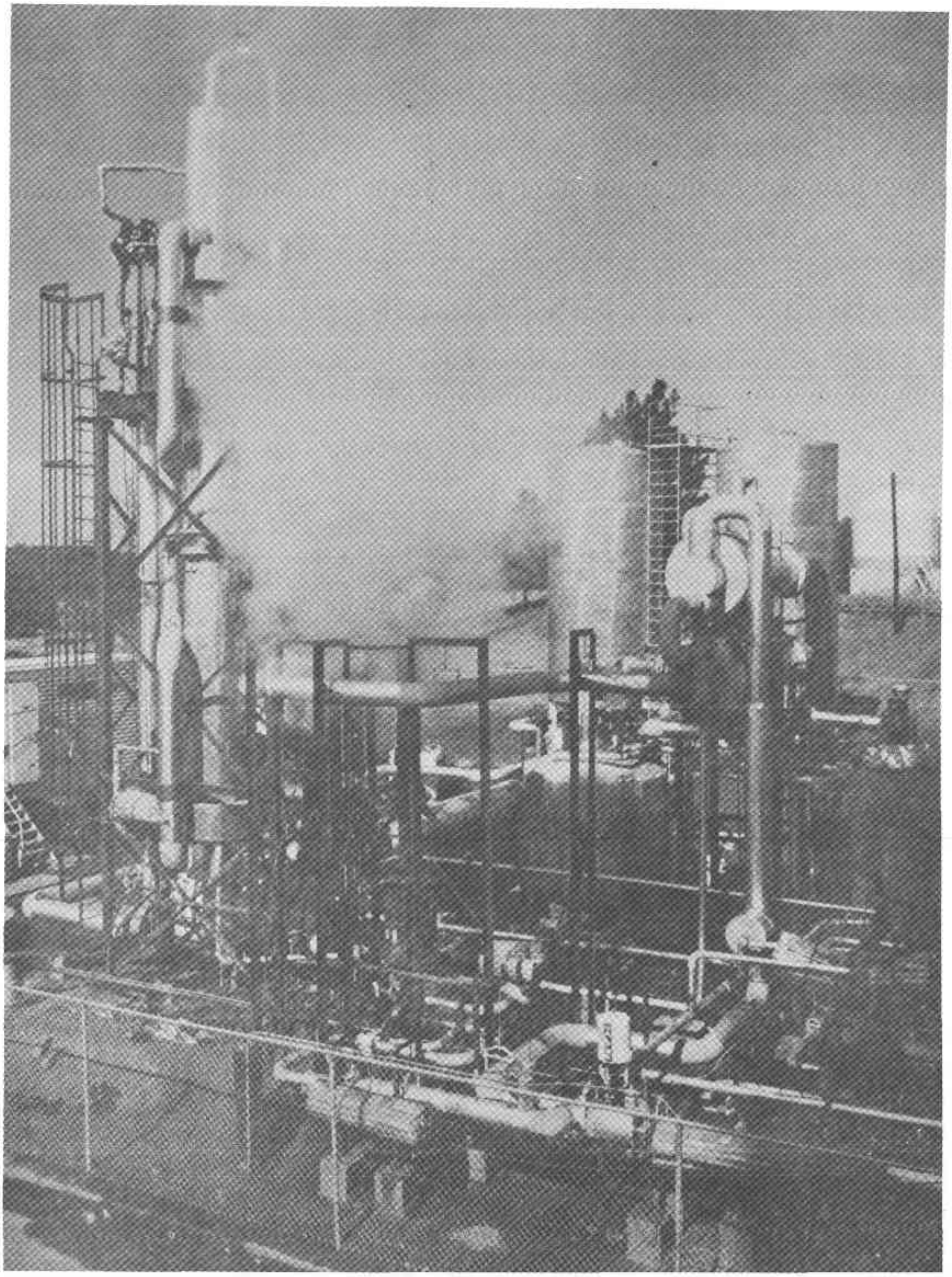


Figure III.G-2 Scale SRE Thermal Storage Subsystem ($2mw_t$)

H. COMMERCIAL ELECTRICAL POWER GENERATION SUBSYSTEM (EPGS) DESCRIPTION

1. Electrical Power Generation Subsystem Layout

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 III.H-1 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 shown in the southeast corner of the plot plan, consistent with generally westerly or northwesterly prevailing wind conditions. The location of the cooling towers and the location of the EPGS triangle may require changes to optimize the site arrangement for other 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.

2. EPGS Turbine

The turbine selected for the commercial plant application is a General Electric admission type unit, rated at 160 MWe output, and commercially available with minor modifications to the basic design. The 160 MWe standard size closely matches that required to supply 150 MWe plus the plant auxiliary loads.

Figure III.H-2 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

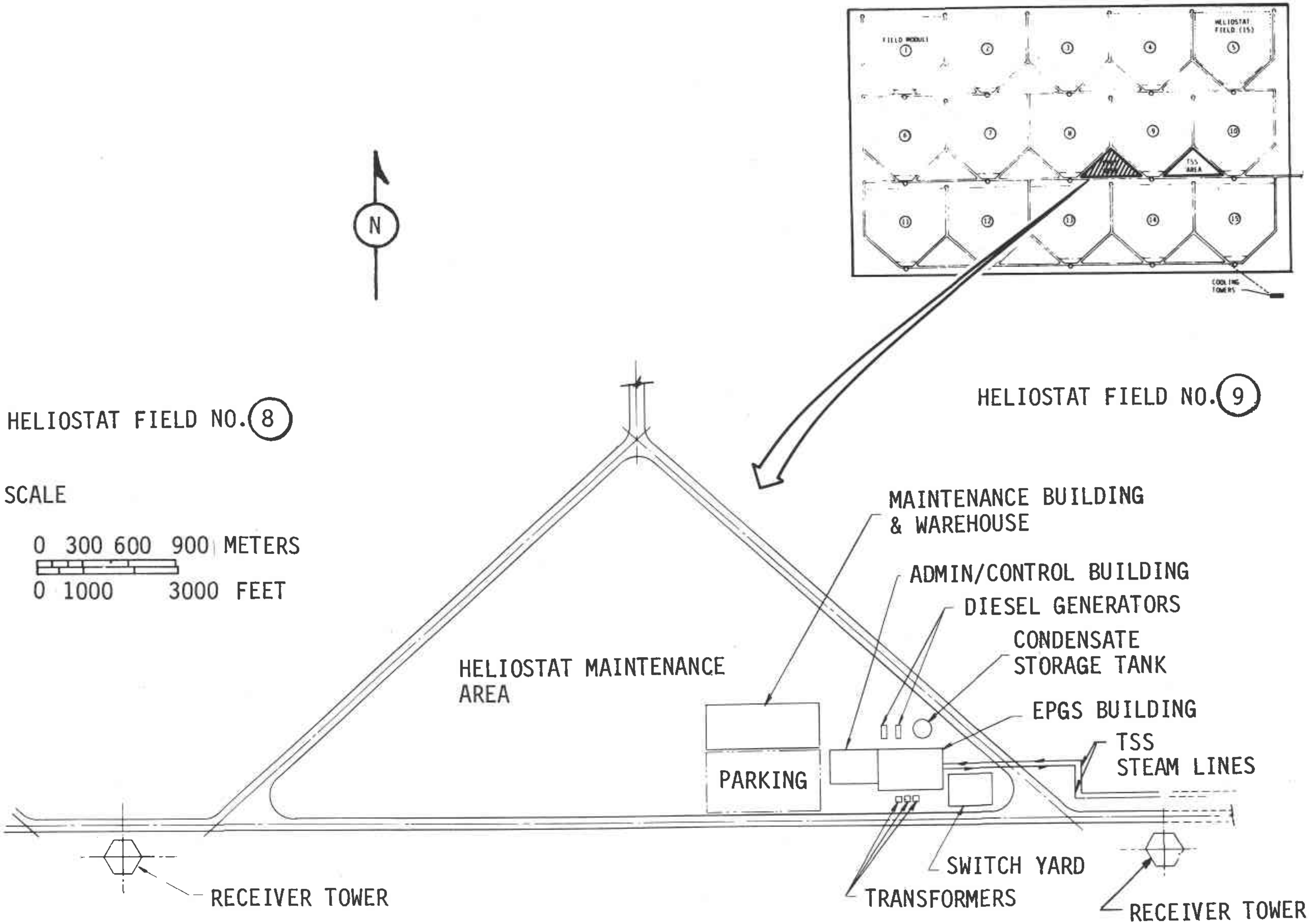
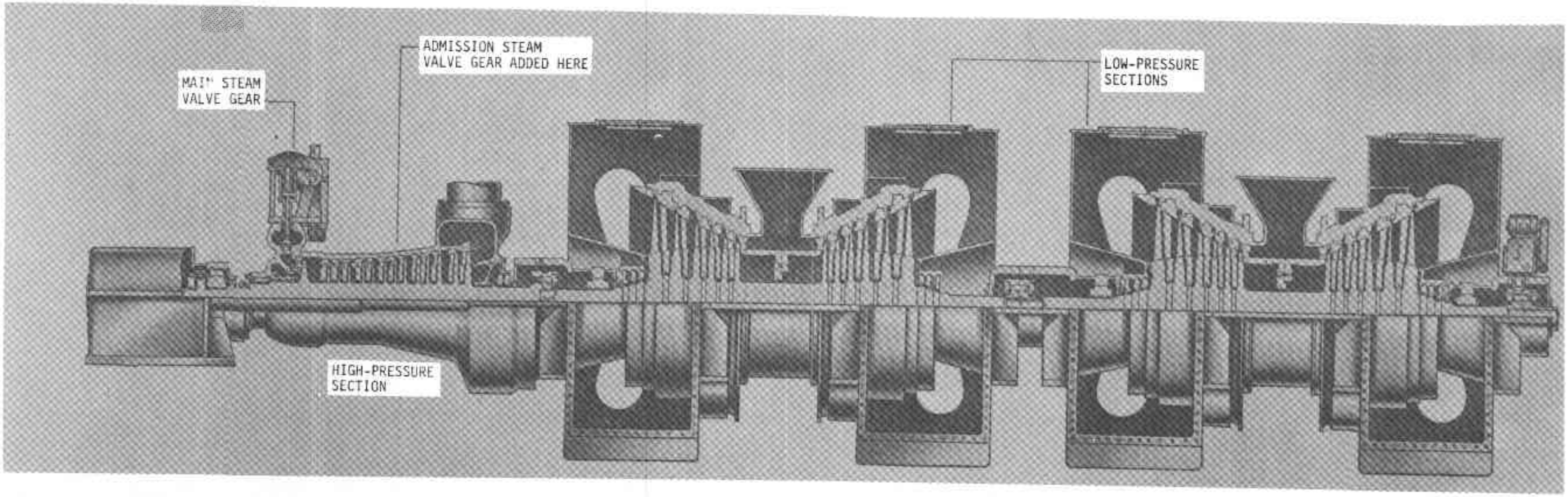


Figure III.H-1 Electrical Power Generation Subsystem



Courtesy of General Electric Co.

Figure III.H-2 Typical Commercial 160 MW_e Turbine storage steam. Under these lower temperature/pressure conditions, steam is admitted several stages downstream of the main stream admission 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.

IV. PILOT PLANT

A. PILOT PLANT DESCRIPTION

The pilot plant configuration includes one full collector-receiver module of the commercial plant. As such the pilot plant capability exceeds the requirement to generate 10 MWe net electrical power at the design point. In addition to generating the required 10 MWe net, the pilot plant will also provide a significant amount of charge for thermal storage, which is sized for three hours of operation at 7MWe net electrical output.

The use of the commercial plant collector-receiver module provides a one-for-one match between the pilot and commercial plants and essentially eliminates scaling of the collector subsystem and the receiver subsystem and all of the related geometry, and thermal interfaces between the collector and receiver subsystems. The thermal storage subsystem for the pilot plant will utilize the commercial plant operating temperatures and pressures for the steam/water working fluid, the same storage material and temperatures and will use the same heat exchanger coefficients and the same type heat exchangers, all of which will permit direct scaling from the pilot plant to the commercial. Thus the pilot plant will provide both technical and economic data that is directly applicable to the commercial plant system and subsystem designs.

The pilot plant has preserved the key features of the commercial plant design. The enclosed cavity receiver steam generator provides the maximum sunlight to steam conversion efficiency. The focused heliostats enable the use of a small aperture for the receiver cavity which allows minimum receiver losses. The north field collector subsystem geometry provides the maximum optical energy collection efficiency. The moderate slant range provides the maximum collector efficiency. The short tower permits the best economic configuration for the plant. The thermal storage use of sensible heat storage and commercial transport fluids provide for low technical risk and the molten salt stage in thermal storage provides maximum efficiency in the power cycle.

The system configuration, controls and electrical power generation subsystem for the pilot plant provides all of the operational modes of the commercial plant and permits testing of the system and subsystem in all operational configurations and modes.

1. General Arrangement

The key features of the Martin Marietta team concept for solar thermal power plants is shown on the artist rendering of Figure IV.A-1. The perspective is looking from the northwest and shows the relative position of the heliostats with respect to the receiver cavity aperture for an afternoon sun position.

The location of subsystem are shown on the plot plan in Figure IV.A-2. The general layout of the plot plan is governed by the collector subsystem north field design feature relative to the receiver subsystem. The heliostats are symmetrically located about a north-south line from receiver-tower. The receiver is located at the south edge of the collector field.

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 in a conventional manner. The receiver tower is constructed of octagonal steel framing and is enclosed in a corrugated metal cladding.

The collector subsystem located in the field to the north of the receiver is one full commercial plant module and as such contains 1554 heliostats. Approximately 15% less is required to produce the design point specification requirement. Each heliostat has $41m^2$ ($441\ ft^2$) of mirror surface consisting of nine fixed focused mirror facets. The area covered by the 1554 heliostats is $308,219m^2$ (76 acres) and is divided into 44 rows that are spaced to minimize the shading and blocking, and to provide access for the heliostats. Within these rows the heliostats are also spaced to minimize shading and blocking. The locations of the heliostats within the field will follow the natural contour of the site at grade level such, that special contouring of the land is not required. The collector subsystem design is adaptable to a wide range of topographies. As indicated on the plot plan, turn arounds are provided at the end of each row but surfaced roads are not required throughout the field with the use of special low pressure tires for all-terrain vehicles.

The thermal storage and electrical power generation subsystems are located relative to the receiver tower in a general arrangement

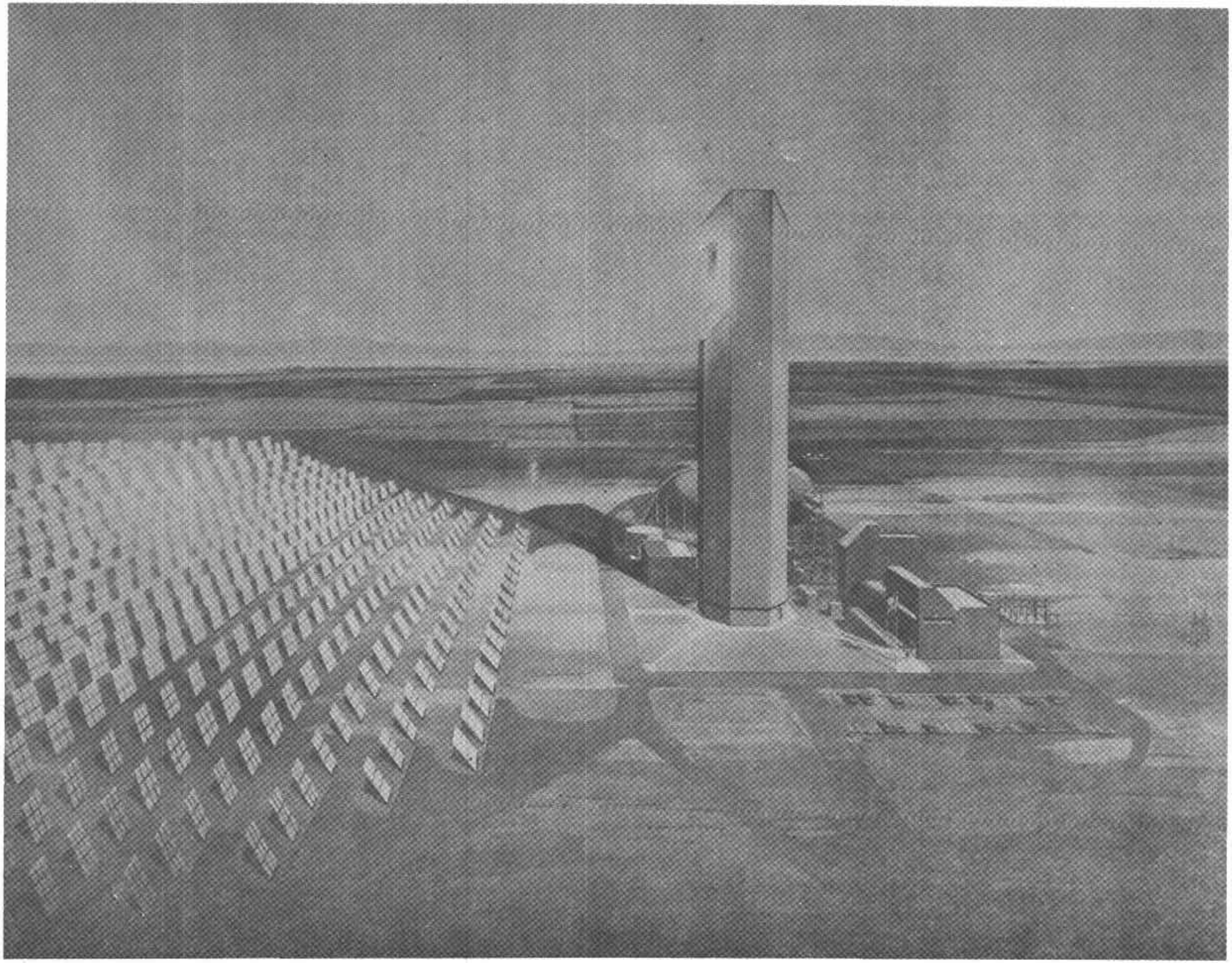


Figure IV.A-1 Pilot Plant Artist Rendering

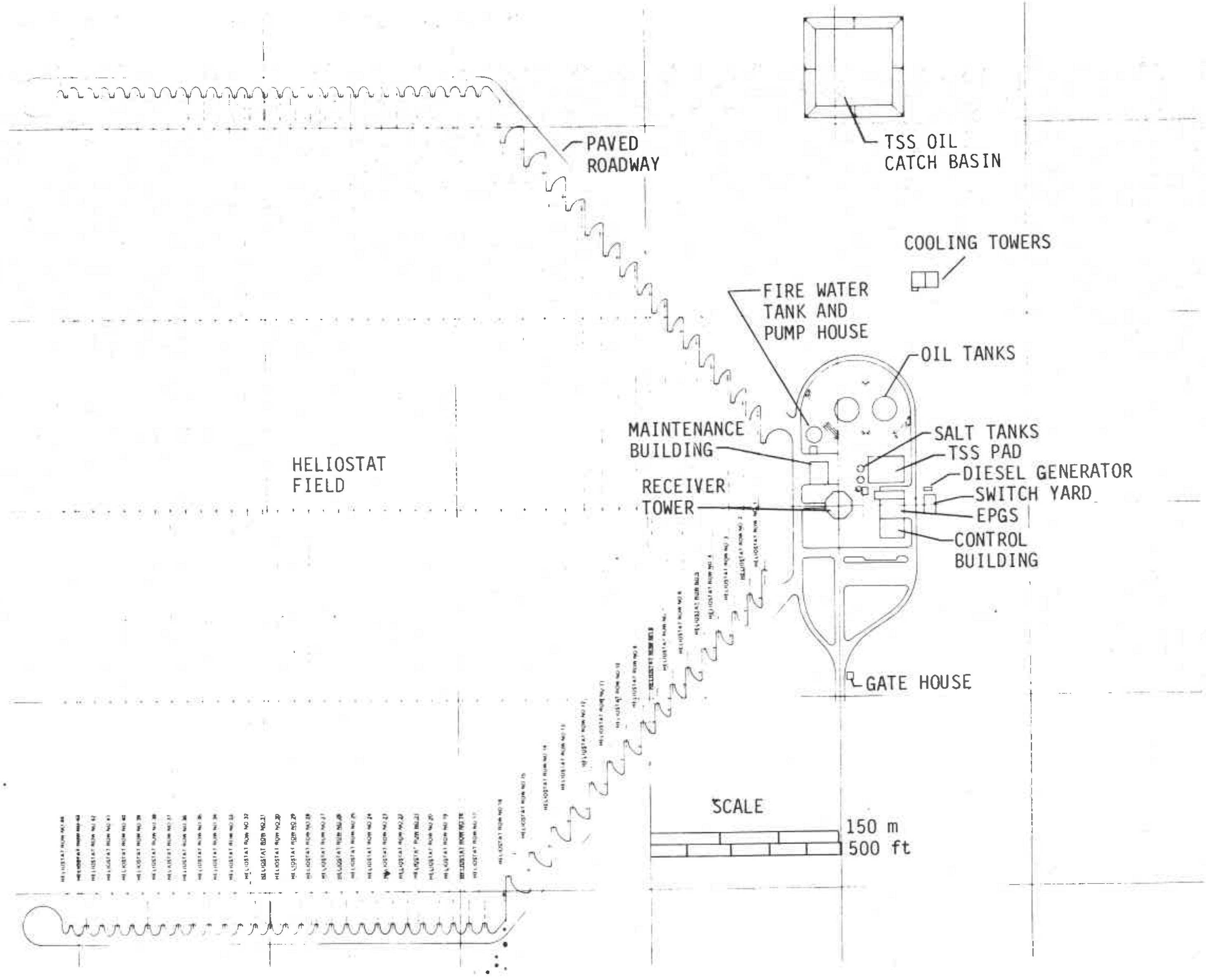


Figure IV.A-2 Pilot Plant Plot Plan

that minimize piping runs and pressure and temperature drop while providing the isolation desired for the storage media. 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.

2. <u>Functional Description</u>

The pilot plant capability exceeds the requirement to generate 10 MWe net electrical power when operating from receiver steam only at the design point. The pilot plant meets the requirement to generate 7 MWe net electrical output when operating from both receiver steam and thermal storage steam. The selected turbine has the capability to generate in excess of 7MWe net when operating on thermal storage only. This capability exists with the selected high performance steam condition available from the salt stage of thermal storage.

The design point for providing 10MWe net, when operating with the receiver alone, is 2:00 p.m. solar time on the day of least favorable overall collector field cosine, with an insolation value of 0.95 KW/m^2. The day of least favorable cosine is summer solstice for this north field configuration. The dry bulb and wet bulb temperatures are to be 28°C and 23°C respectively and the wind speed is to be 3.5m/sec. at 10 meters elevation. Since the pilot plant is on full collector-receiver module of the commercial plant, more than 10 MWe net can be generated under design point conditions and the excess thermal power will be used to charge thermal storage as discussed later in the pilot plant performance section.

The thermal storage capacity must be sized to provide three hours of design point operation subsequent to starting and loading the turbine from the thermal storage. Also sufficient capacity is to be provided to shutdown the turbine. This capability is to be available after a 20 hour hold limit from when thermal storage was charged.

The pilot plant is designed to meet the above requirements and provide the operational modes necessary to perform combination of these requirements while charging thermal storage on clear days, cloudy days, low insolation days or during periods of no insolation such as night time. The operational modes are discussed later in the pilot plant operation section. Figure IV.A-3 is the pilot plant schematic which shows functionally the operation of each subsystem, as discussed below:

a. <u>Collector Subsystem</u> - The collector subsystem not shown on the schematic, uses computer controlled open loop tracking to reflect the sun energy into the receiver which is shown schematically in the upper left corner of Figure IV.A-3. Each heliostat is driven in azimuth and elevation to direct the reflected beam to a single point which is the center of the receiver aperture. This simple single point aim strategy is utilized throughout each day and throughout the year.

b. <u>Receiver Subsystem</u> - As the concentrated beam from the collector subsystem passes through the cavity aperture it impinges on the interior cavity walls where the boiler water walls and superheater tubes are located. The boiler (water walls), as shown on the schematic, receive the solar energy and generate steam which is sent to the steam drum. Through natural circulation water is provided from the steam drum to the water walls to continue steam generation. Feedwater is furnished to the boiler from the tower riser piping. Steam separation is accomplished internal to the steam drum and the saturated steam is delivered to the superheater. Superheater output steam temperature is controlled as required by spray attemperators at two locations in the superheaters. Attemperator spray is obtained from the feedwater supply. A conventional three element feedwater regulator provides the necessary flow control for the receiver as shown on Figure IV.A-3, the receiver pressure is controlled either by the turbine main steam throttle valve or by FCV 13 at the inlet to the thermal storage, depending on the mode of operation. The steam leaving the receiver is delivered either to the turbine, to the thermal storage or both. During periods when the receiver is not operating stop valves seal the flow in and out of the receiver and the cavity is closed with an insulated door across the aperture. This nonoperating configuration seals up the receiver, minimizes heat loss and rate of cool down, provides for a faster restart and minimizes thermal cycling.

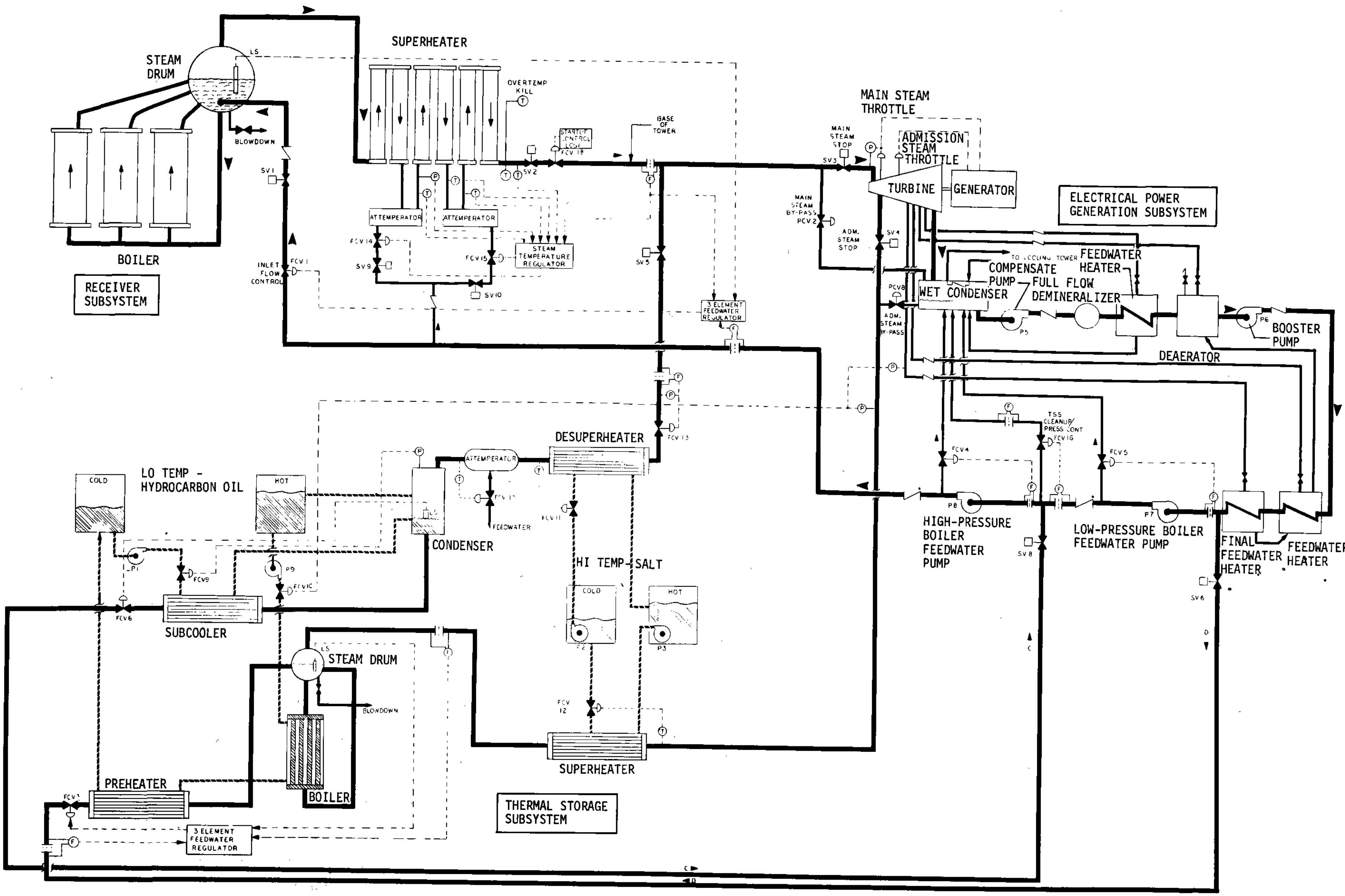


Figure IV.A-3 Pilot Plant Schematic

c. Thermal Storage Subsystem - The thermal storage subsystem, as shown in Figure IV.A-3, consists of two stages. Both stages are used for extracting energy from the steam generated in the receiver (charge) or for generating steam from the electrical power generation subsystem feedwater (discharge). The energy extracted from the steam is stored as sensible heat in either a molten salt, or a hydrocarbon oil, depending on temperature. The molten salt is used for high temperature storage (steam's superheat) and the oil is used for low temperature storage (steam's latent heat of condensation plus some subcooling). The oil and molten salt are stored in insulated tanks. The stored energy is used later to generate superheated steam for generation of electrical power. Separate heat exchangers are used for the extraction of energy from the steam (charging) and for generation of superheated steam from feedwater (discharging).

When the subsystem is being charged (energy extracted from the steam), steam from the receiver is diverted at the base of the tower to the thermal storage subsystem via control valve FCV 13 as shown in Figure IV.A-3. This valve, operating on pressure control, insures that pressure at the turbine is not reduced below turbine operating conditions due to thermal storage charging. In addition to pressure control, flow control of FCV 13 can be initiated if a specific rate of charge is desired into thermal storage. In the salt stage the desuperheater heat exchanger removes most of the superheat from the steam and it is stored as sensible heat in the molten salt. This is accomplished by flowing the salt from the cold tanks to the hot tanks and counter-current to the steam flow. During this charge mode, the flow of salt is controlled by the steam exit temperature from the heat exchanger. Steam from this first stage is sent to a spray attemperator to assure that the temperature of the superheated steam entering the condenser will not cause the oil to overheat. Feedwater provided to this desuperheater is controlled by the exit temperature of the attemperator.

In the oil stage, the steam enters a condensing heat exchanger where the latent heat is removed and stored as sensible heat in a hydrocarbon oil. The steam pressure in the condensing heat exchanger controls the rate of flow of oil through FCV 9 which, in turn, controls the rate of condensation. The water exiting the condenser is slightly subcooled and is further subcooled in the subcooler heat exchanger. Condensate flow is controlled by FCV 6 as a function of liquid level in the condenser. The condensate from the subcooler heat exchanger is provided to the suction of the high pressure boiler feedwater pump (P8) and returned to the receiver steam drum via the tower riser piping.

When the subsystem is being discharged (producing superheated steam for the generation of electrical power) feedwater is provided from the low pressure boiler feedwater pump (P7) to the preheater heat exchanger. The feedwater enters the heat exchanger and is preheated prior to entering the boiler heat exchanger. Oil is now flowing from the hot tanks through the boiler to the preheater and then to the cold tank. The flow of oil (which can be compared to the firing rate of a boiler) is controlled via FCV 10 by the pressure of the superheated steam leaving the thermal storage subsystem. The flow of feedwater into the thermal storage subsystem is controlled by a three element feedwater regulator similar to those used in conventional boilers. The steam is separated and enters the next heat exchanger where the superheat is added from the molten salt. Blowdown is provided to maintain steam purity requirements. The flow of salt from the hot tank to the cold tank is controlled by the exit temperature of the superheated steam. This superheated steam is sent to the admission steam point on the turbine for the generation of electrical power.

If desired both the charge and discharge functions described above can be performed simultaneously.

d. <u>Electrical Power Generation Subsystem</u> - The electrical power generation subsystem consists of conventional power plant components. As shown in Figure IV.A-3, the turbine is an admission type machine which accepts high pressure, high temperature main steam from the receiver and/or lower pressure and temperature admission steam from the thermal storage. The subsystem contains four stages of feedwater heating using uncontrolled extraction from the turbine and a water cooled condenser.

As shown in Figure IV.A-3, superheated steam is provided down the tower from the receiver to the turbine main steam throttle valve for conversion to electrical power. A main steam bypass valve is provided to divert the superheated steam to the condenser; if not required by the turbine or thermal storage; or is unacceptable to the turbine; or in the event of overpressure of the main steam. Desuperheaters are provided at the condenser to accommodate the superheated steam. After leaving the turbine and the condenser, the condensate is pumped through the feedwater heaters, increased in temperature and pressure, and returned to the receiver or to the thermal storage subsystem or both, depending on the mode of operation. For the mode of operation where the electrical power generation subsystem is generating from the receiver alone and the thermal storage subsystem is neither charging or discharging, all feedwater is returned to the receiver from the high pressure boiler feedwater pump (P8).

When superheated steam is being provided by the thermal storage subsystem, it is accepted by the turbine admission steam throttle valve. An admission steam bypass valve is also provided which serves a similar function to the main steam bypass valve. After passing through the turbine and the condenser, the condensate is pumped through the feedwater heaters, and provided back to the thermal storage subsystem.

If both the receiver subsystem and the thermal storage subsystem are generating steam, the feedwater is proportionally sent to both subsystems. For the mode of operation where the receiver subsystem is supplying steam both to the turbine for electrical power generation and to the thermal storage subsystem for charging, all feedwater is provided back to the receiver by the high pressure boiler feedwater pump (P8).

B. PILOT PLANT PERFORMANCE

1. Cycle Choice for the Electric Power Generation Subsystem

The selected cycle for the EPGS is shown on the pilot plant system schematic (Figure IV.A-3). The steam state points are 9308 kPa (1350 psig) and 783 K (950°F) for main steam and 2758 kPa (400 psig) and 700 K (800°F) for admission steam which are the same as for the commercial plant. In addition the same state points at the receiver outlet will be maintained in the pilot plant as for the commercial plant, by controlling the pressure drop in the steam downcomer. The EPGS cycle for the pilot plant was selected to match the EPGS cycle for the commercial plant. The rationale for selecting the commercial plant EPGS cycle was discussed under paragraph III.B.1. The basic difference in the two cycles is four feedwater heaters in the pilot plant rather than five feedwater heaters for the commercial plant. The turbine cycle in the pilot plant is more complex than normally recommended for 10 MWe power plants due to the cost leverage available in the collector and receiver subsystems. In lowering the total pilot plant cost it is important to recognize the cost trade leverage available in the collector and receiver since their cost per kilowatt is more than that for the EPGS. Utilizing this leverage results in a more efficient EPGS with added EPGS cost but results in a more cost effective total plant.

The commercial plant cycle was chosen for the pilot plant to obtain performance data for the solar subsystems that will be directly applicable to the commercial plant. The collector and receiver for the pilot plant is one full scale commercial plant collector-receiver module. The thermal storage utilizes the same storage materials and temperature, the same heat exchanger types and coefficients, and the same steam conditions. Taking all of these factors into consideration, both the technical and economic data gathered for the pilot plant will be invaluable in projecting the cost and performance of the commercial plant.

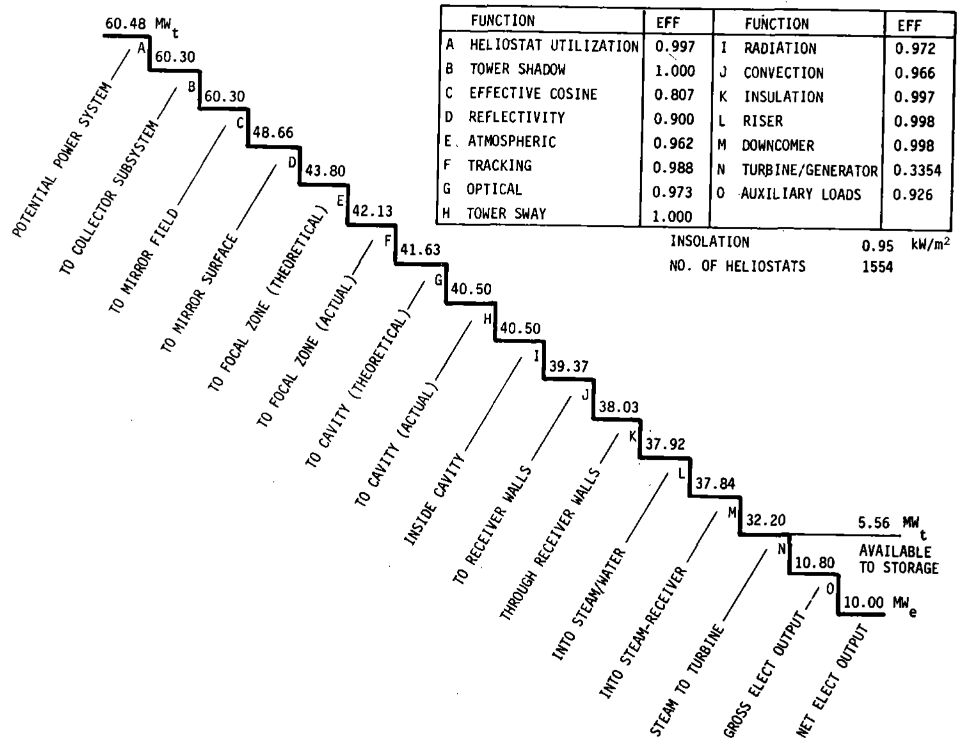
2. Pilot Plant Design Point Performance

The Pilot Plant Preliminary Design includes a full commercial plant module containing 1554 heliostats. This commercial plant module, along with the pilot plant thermal storage and electrical power generation subsystems, makes up a pilot plant which exceeds the minimum pilot plant requirements in that it is capable of producing 10 MWe net electrical power at the design point while simultaneously charging thermal storage.

a. Design Point Performance Profiles - The ERDA defined pilot plant design point is 2:00 PM on the day of least favorable collector cosine (summer solstice for the MMC concept) at Inyokern, California. The environmental conditions at the design point are defined as an insolation of 0.95 KW/m^2, wet bulb temperature of 23°C (73°F), dry bulb temperature of 28°C (82°F) and a wind velocity of 3.5 m/sec (8 mph). The Pilot Plant Design Point Performance, using the full 1554 heliostat commercial plant modules, is illustrated in the Pilot Plant Performance Profile (stair-step) shown in Figure IV.B-1. The profile depicts the power flow through the pilot plant from the potentially collectable (all mirrors normal to the sun) incident solar radiation through the net electrical output power and the thermal power available for storage. It identifies and quantifies all the losses involved in the conversion of solar input power into usable electric power for the pilot plant. This Pilot Plant Performance Profile shows a potential solar input power of 60.48 MW_t is converted to the required 10 MWe of net electrical power while providing an additional capability of supplying 5.56 MW_t for charging thermal storage. The letters on the performance profile are keyed to the inset table which shows the system efficiency between the two locations. These efficiency factors are discussed in Section IV.B.2.d.

A second performance profile is shown in Figure IV.B-2. This profile shows the minimum number of heliostats required to meet the ERDA design point requirement of producing 10 MWe net electrical output. Using the same efficiency factors shown in Figure IV.B-1, and the 10 MWe output requirement, the required potential power to the system was calculated. This required input power of 51.57 MW_t, together with the design point insolation and heliostat mirror area, results in a minimum heliostat requirement of 1325.

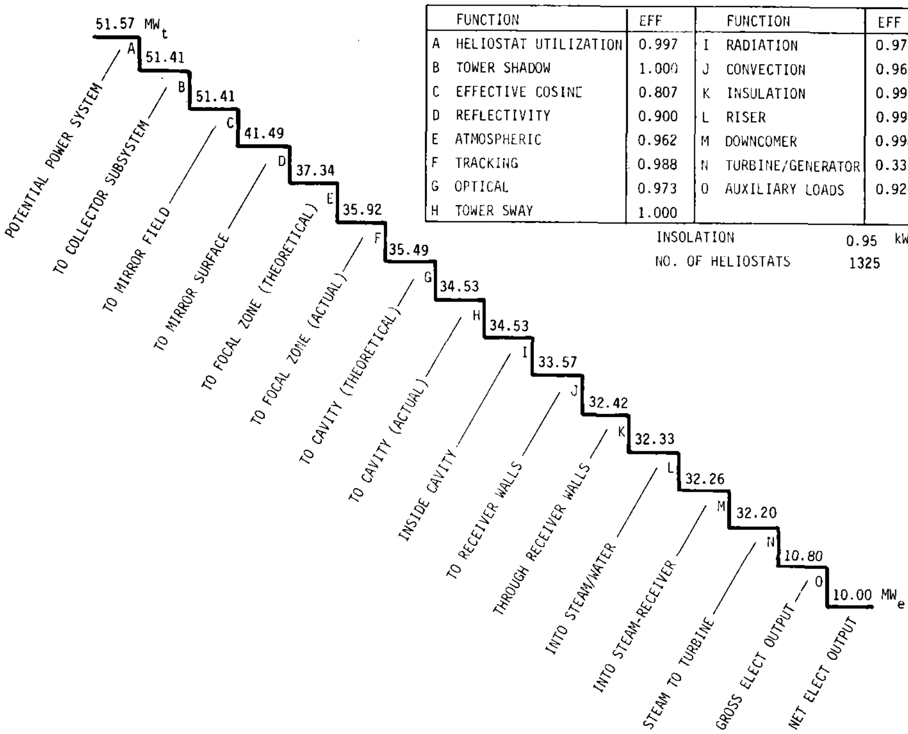
It is recommended that the pilot plant utilize the full collector-receiver module (1554 heliostats) in order to provide one-for-one scaling of the collector subsystem, the receiver subsystem and the critical thermal and geometrical interfaces between the two subsystems. This will essentially eliminate scaling concerns between the pilot plant and commercial plant. In addition utilization of the commercial collector-receiver module provides the capability to charge thermal storage a significant amount while generating 10 MWe net electrical, as discussed in Section IV.B.2.b and IV.B.3.a below.



	FUNCTION	EFF		FUNCTION	EFF
A	HELIOSTAT UTILIZATION	0.997	I	RADIATION	0.972
B	TOWER SHADOW	1.000	J	CONVECTION	0.966
C	EFFECTIVE COSINE	0.807	K	INSULATION	0.997
D	REFLECTIVITY	0.900	L	RISER	0.998
E	ATMOSPHERIC	0.962	M	DOWNCOMER	0.998
F	TRACKING	0.988	N	TURBINE/GENERATOR	0.3354
G	OPTICAL	0.973	O	AUXILIARY LOADS	0.926
H	TOWER SWAY	1.000			

INSOLATION 0.95 kW/m^2
NO. OF HELIOSTATS 1554

Figure IV.B-1 Pilot Plant Design Point Performance Profile - 1554 Heliostats



	FUNCTION	EFF		FUNCTION	EFF
A	HELIOSTAT UTILIZATION	0.997	I	RADIATION	0.972
B	TOWER SHADOW	1.000	J	CONVECTION	0.966
C	EFFECTIVE COSINE	0.807	K	INSULATION	0.997
D	REFLECTIVITY	0.900	L	RISER	0.998
E	ATMOSPHERIC	0.962	M	DOWNCOMER	0.998
F	TRACKING	0.988	N	TURBINE/GENERATOR	0.3354
G	OPTICAL	0.973	O	AUXILIARY LOADS	0.926
H	TOWER SWAY	1.000			

INSOLATION 0.95 kW/m^2

NO. OF HELIOSTATS 1325

Figure IV.B-2 Pilot Plant Design Point (Minimum Heliostats)

b. Summer Solstice Day Performance - In order to get a clear picture of the Pilot Plant Performance and to compare the two pilot plant configurations presented, it is useful to examine the plant performance over the entire design point day. Figure IV.B-3 shows the thermal power available to the turbine and/or thermal storage as a function of time for a summer solstice day. The performance is shown for the two pilot plant configurations discussed, the full commercial module of 1554 heliostats and the minimum required module of 1325 heliostats. The curves shown are based on a summer solstice insolation curve normalized to 0.95 KW/m^2 at 2:00 PM. The dashed line across the curves at 32.20 MW_t represents the turbine thermal input required to produce a net plant output of 10 MWe; thus, for sustained operation at 10 MWe, the area under the dashed line for each curve represents the energy available for direct conversion into electrical power and the area above the dashed line represents the energy available for charging thermal storage. On the design point day described, the pilot plant using the full commercial module of 1554 heliostats will produce 380 MW_t-hr of thermal energy for the generation of electrical energy and an additional 39 MW_t-hr of thermal energy for charging thermal storage. This is the equivalent of about 1.4 hours of storage capacity. The pilot plant using the minimum of 1325 heliostats will produce 350 MW_t-hr for the generation of electrical energy but only an additional 4 MW_t-hr for charging thermal storage, which is the equivalent of less than 0.2 hours of storage capacity. It is clear that the pilot plant using the full commercial module of 1554 heliostats, which is larger than that required to meet the minimum ERDA requirements, will provide much greater operational flexibility for the pilot plant and will be capable of more closely simulating the operation of the commercial plant.

c. Design Point Performance from Thermal Storage - The pilot plant, when operating solely from thermal storage, is required to produce 7 MWe net electrical output for 3 hours minimum. In addition, the thermal storage subsystem must have sufficient capacity to withstand a 20 hour hold between charging and discharging and to start the turbine from a hot start condition.

The Pilot Plant Thermal Storage Subsystem is capable, after a 20 hour hold period, of supplying the 6.5 MW_t-hr required for hot turbine start-up followed by 27.2 MW_t for 3 hours to the electrical power generation subsystem which, in turn, is capable of producing 7.6 MWe gross electrical output. 7.6 MWe gross minus the plant auxiliary load of 0.6 MWe produces the required 7.0 MWe net electrical output. The maximum thermal storage charge rate is 34.8 MW_t which is in excess of the 30 MW_t required.

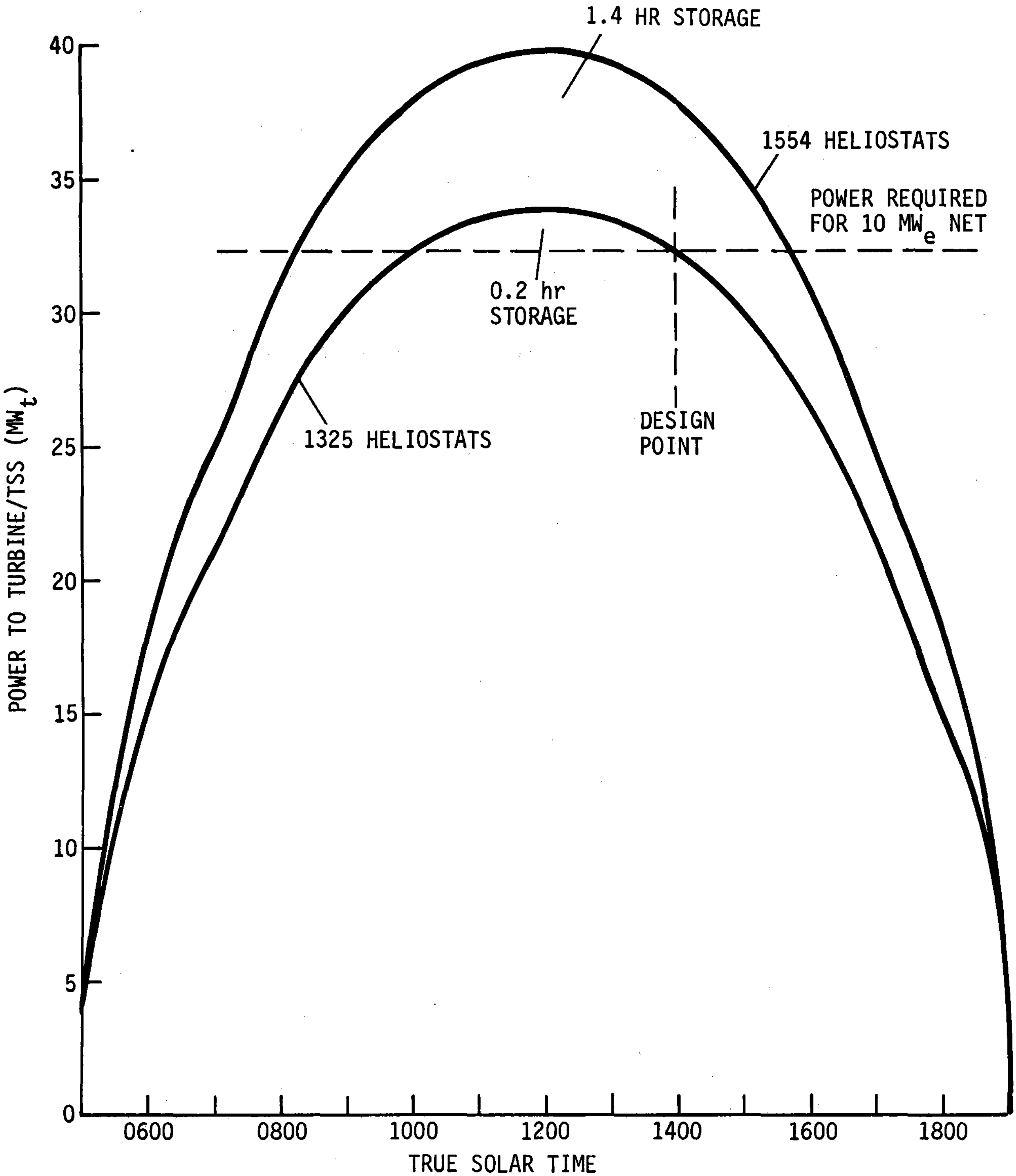


Figure III.B-3 Pilot Plant Summer Solstice Day Performance

d. Subsystem Efficiencies - This section discusses the Pilot Plant Design Point Subsystem efficiencies in terms of the efficiency factors shown in the performance profiles of Section IV.B.2.a. In addition the thermal storage subsystem efficiency is discussed.

1) Collector Subsystem - The overall collector subsystem pilot plant design point efficiency is 0.670, which is made up of the efficiency factors discussed below. A thorough discussion of the atmospheric, tracking and optical efficiency factors is presented in Volume III.

a) Heliostat Utilization - It is assumed, for purposes of sizing the collector field, that 5 heliostats will be down for maintenance or calibration at any given time. This corresponds to a 0.3% loss or an efficiency factor of 0.997.

b) Tower Shadow - This is the power loss resulting from the shadow of the receiver tower moving across the collector field. Due to the sun position, there is no tower shadow loss on summer solstice making the efficiency factor 1.00. Table III.B-1 shows the effect of tower shadow on the 21st day of each month for each hour of the day.

c) Effective Cosine - The effective cosine for the collector subsystem is shown in Table III.B-2 for the 21st day of each month for each hour of the day. The collector field effective cosines shown are the combined effect of the cosine of the angle of solar incidence on the mirror surface shown in Table III.B-3, the shading of the sun from one heliostat by another shown in Table III.B-4, and the blocking of the reflected solar insolation leaving a heliostat and going to the receiver shown in Table III.B-5. Each effective cosine shown is an average for the total collector field.

The values are determined using the Houston Solar Flux Computer Program and are a function of the location of the plant site, the field layout, the location and height of the receiver aperture, the time of year, and the time of day. The effective cosine for 2:00 PM summer (design point) is 0.807.

d) Reflectivity - The mirror reflectivity is dependent upon the type of mirror used and the cleanliness of the mirror surface. The 0.900 reflectivity used in the stair-step is the average reflectivity between washings of low iron float glass mirrors with a "clean" reflectivity of 0.910.

e) Atmospheric - The atmospheric efficiency factor accounts for the power lost due to atmospheric absorption between the mirror surface and the receiver cavity. It depends upon relative humidity, ambient temperature and transmission distance. The value calculated for the commercial plant module at 30% R.H. and 24°C (75°F) is 0.962.

f) Tracking - The tracking efficiency factor of 0.988 is the result of heliostats pointing off the target during operation. The tracking is a composite of both static errors, and errors which vary with wind velocity. The static errors include errors due to heliostat manufacturing and installation, mirror focusing and alignment, encoder resolution, sun position and computational errors. The variable error component is heliostat structural deflection which is a function of wind velocity.

g) Optical - The optical efficiency factor includes all aperture spillage losses due to the size and shape of the reflected image. This optical efficiency (also referred to as aperture efficiency) varies as a function of time of day and time of year as shown in Figure III.B-5. The value for 2:00 PM summer is 0.973.

h) Tower Sway - The tower sway efficiency factor accounts for losses due to movement of the tower aperture. At the design point wind speed of 3.5 m/s (8 mph) there is virtually no tower movement and thus an efficiency factor of 1.00.

2) Receiver Subsystem - The overall receiver subsystem pilot plant design point efficiency is 0.932; which is made up of the following efficiency factors:

a) Radiation - The radiation efficiency factor for the receiver includes losses due to solar and infrared radiation. The loss varies as a function of power into the receiver cavity as shown in Figure III.B-6. The efficiency for the design point power level is 0.972.

b) Convection - The convection efficiency factor takes into account heat loss due to atmospheric air circulation in and out of the cavity. The convective loss varies as a function of ambient temperature and wind velocity as shown in Figure III.B-7. The loss at design point conditions represents an efficiency factor of 0.966.

c) Insulation - The insulation efficiency factor accounts for the heat loss through the insulated receiver exterior walls and varies as a function of ambient temperature as shown in Figure III.B-8. The loss at design point temperature represents an efficiency factor of 0.997.

d) Tower Riser - The tower riser loss is that loss of heat associated with transporting the feedwater from the electrical power generation subsystem to the receiver. The efficiency for the pilot plant is 0.998.

e) Tower Downcomer - The tower downcomer loss is that loss associated with transporting the superheated steam from the receiver to the turbine in the electrical power generation subsystem. The efficiency for the pilot plant is 0.998.

3) Electrical Power Generation Subsystem - The overall EPGS pilot plant design point efficiency is 0.3354 which is the efficiency equivalent of the gross cycle heat rate.

4) Plant Auxiliary Loads - The pilot plant auxiliary loads are those parasitic electrical loads required to operate the plant. The auxiliary loads vary as a function of steam flow rate, ambient temperature, wind velocity and operating mode. Table IV.B-1 shows the pilot plant auxiliary loads for the basic steady state operational modes. The load for "receiver operation only" is 798 KW which represents a design point efficiency of 0.926.

5) Thermal Storage Subsystem - Assessable thermal storage subsystem efficiency is a combination of the effects from the TSS and the reduced EPGS efficiency while operating

Table IV.B-1. Pilot Plant Auxiliarv Loads

AUXILIARY LOADS $-kW_e$

	OPERATIONAL MODES					
	RECEIVER OPERATION ONLY	RECEIVER OPERATION & CHARGE TSS	RECEIVER OPERATION & DISCHARGE TSS	CHARGE TSS AND DISCHARGE TSS	DISCHARGE TSS	CHARGE TSS
COLLECTOR	51	51	51	51	0	51
RECEIVER	2	2	2	2	0	2
THERMAL STORAGE	0	105	105	361	190	190
ELECTRICAL POWER GENERATION	739	812	651	587	397	674
CONTROLS	6	6	6	6	6	6
TOTAL	798	976	815	1007	593	923

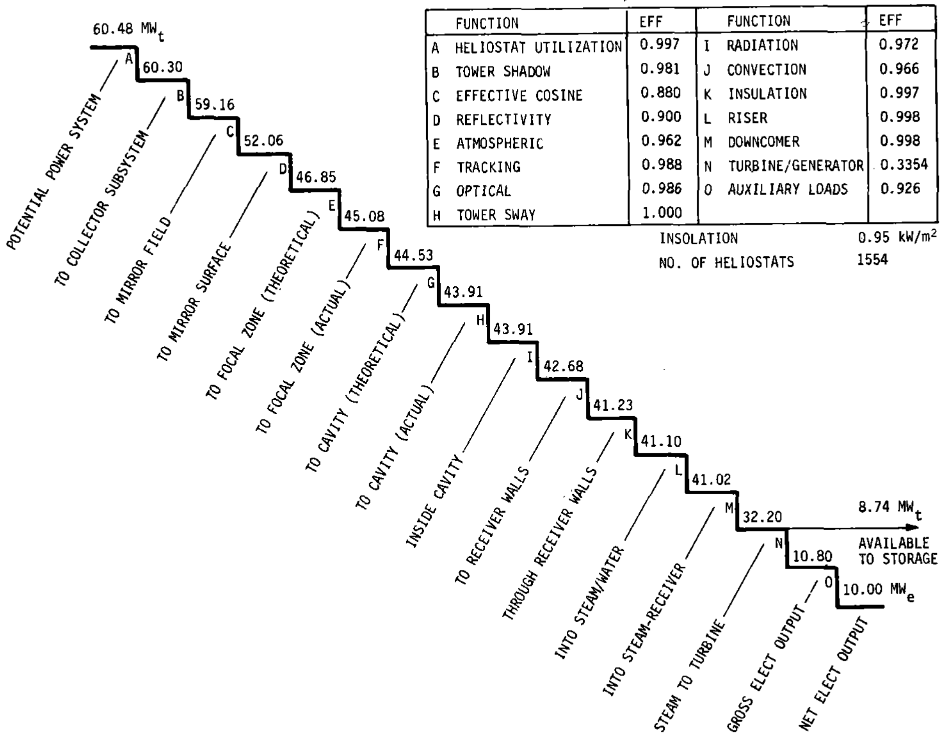
on storage steam. Effective storage efficiency is 0.910 (energy retrieved/charging energy supplied) multiplied by 0.829 (increased heat rate and auxiliaries fraction effect) for a net efficiency of 0.754. The effective storage efficiency of 0.91 for the pilot plant is less than the 0.96 discussed in the commercial section. This is caused by the ratio of surface area to energy stored being less for the commercial plant than for the pilot plant thermal storage. The commercial plant has six full and one empty oil tank where the pilot plant has one full and one empty oil tank.

3. Pilot Plant Yearly Performance

The pilot plant performance at the ERDA specified design point, as well as the plant performance over the summer solstice design point day, was discussed in the previous section. Of equal, or perhaps greater, importance is the pilot plant yearly performance, both in terms of total annual energy production and performance variations over the year. The commercial plant module, which forms the collector/receiver portion of the pilot plant, was designed to maximize annual energy production and minimize, to the extent possible, plant performance variations throughout the year.

a. Yearly Performance Variation - Six additional performance profile (stairstep) charts similar to those presented in Section IV.B.2, were prepared to illustrate the pilot plant yearly performance variation. These profiles, shown in Figures IV.B-4 through IV.B-9, show the plant performance at 2:00 PM for the 21st day of each month of the year. The profiles based upon an insolation of 0.95 kW/m^2, which were prepared on the basis of producing 10 MW_e net output at each point, show that the excess energy available at 2:00 PM for charging storage ranges from 5.56 MW_t in the summer to 9.69 MW_t in the winter. Another method to visualize plant performance as a function of time of the year is to calculate the potential net electrical output for various times of the year. Figure IV.B-10 shows the results of these calculations for both the 1554 commercial module pilot plant and the minimum size pilot plant of 1325 heliostats. The curves show the plant performance to be relatively flat throughout the year with a maximum variation of approximately 11%.

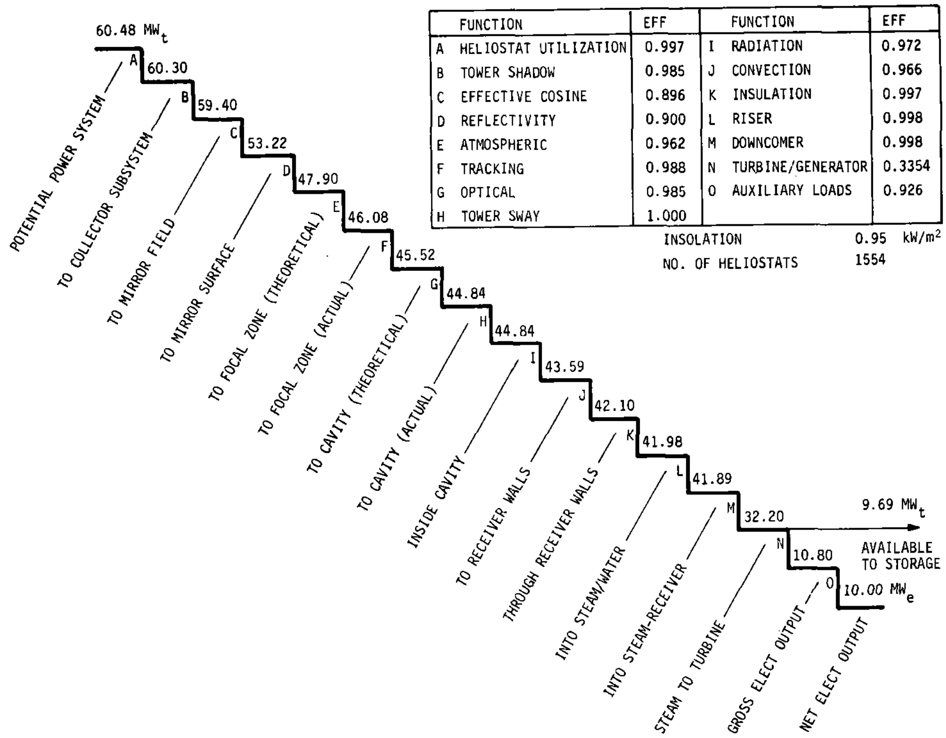
The daily plant performance for winter solstice and equinox, as well as summer solstice, is shown in Figure IV.B-11. These curves were again based upon insolation data normalized to 0.95 kW/m^2 at noon. The inset on the figure shows the total energy generated



	FUNCTION	EFF		FUNCTION	EFF
A	HELIOSTAT UTILIZATION	0.997	I	RADIATION	0.972
B	TOWER SHADOW	0.981	J	CONVECTION	0.966
C	EFFECTIVE COSINE	0.880	K	INSULATION	0.997
D	REFLECTIVITY	0.900	L	RISER	0.998
E	ATMOSPHERIC	0.962	M	DOWNCOMER	0.998
F	TRACKING	0.988	N	TURBINE/GENERATOR	0.3354
G	OPTICAL	0.986	O	AUXILIARY LOADS	0.926
H	TOWER SWAY	1.000			

INSOLATION 0.95 kW/m^2
NO. OF HELIOSTATS 1554

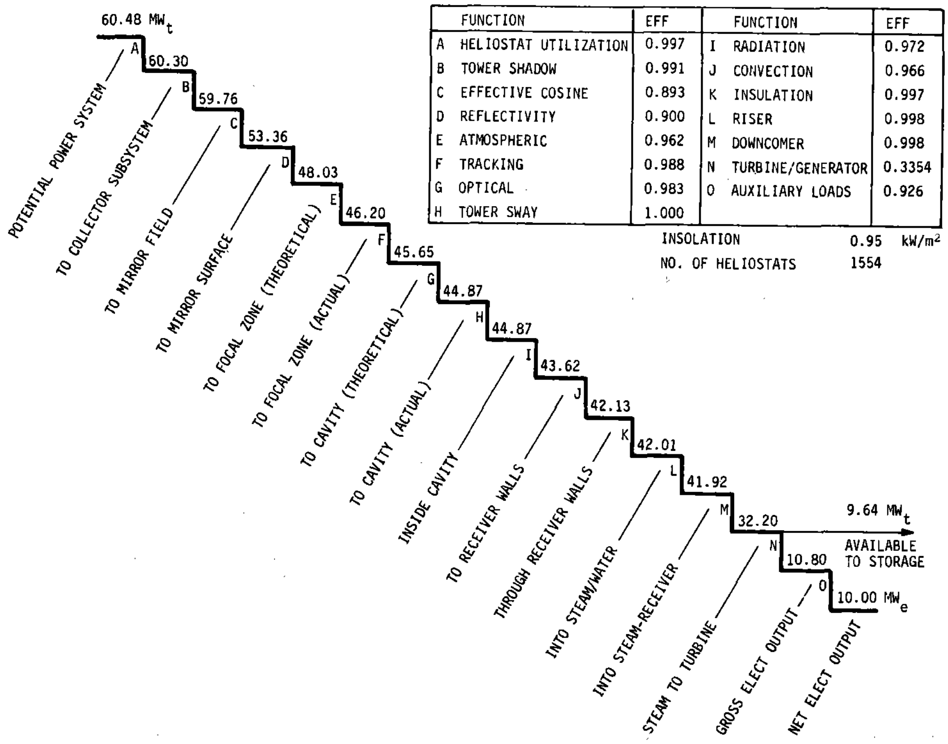
Figure IV.B-4. Pilot Plant Performance Profile - 2:00 PM, December 21



	FUNCTION	EFF		FUNCTION	EFF
A	HELIOSTAT UTILIZATION	0.997	I	RADIATION	0.972
B	TOWER SHADOW	0.985	J	CONVECTION	0.966
C	EFFECTIVE COSINE	0.896	K	INSULATION	0.997
D	REFLECTIVITY	0.900	L	RISER	0.998
E	ATMOSPHERIC	0.962	M	DOWNCOMER	0.998
F	TRACKING	0.988	N	TURBINE/GENERATOR	0.3354
G	OPTICAL	0.985	O	AUXILIARY LOADS	0.926
H	TOWER SWAY	1.000			

INSOLATION 0.95 kW/m^2
NO. OF HELIOSTATS 1554

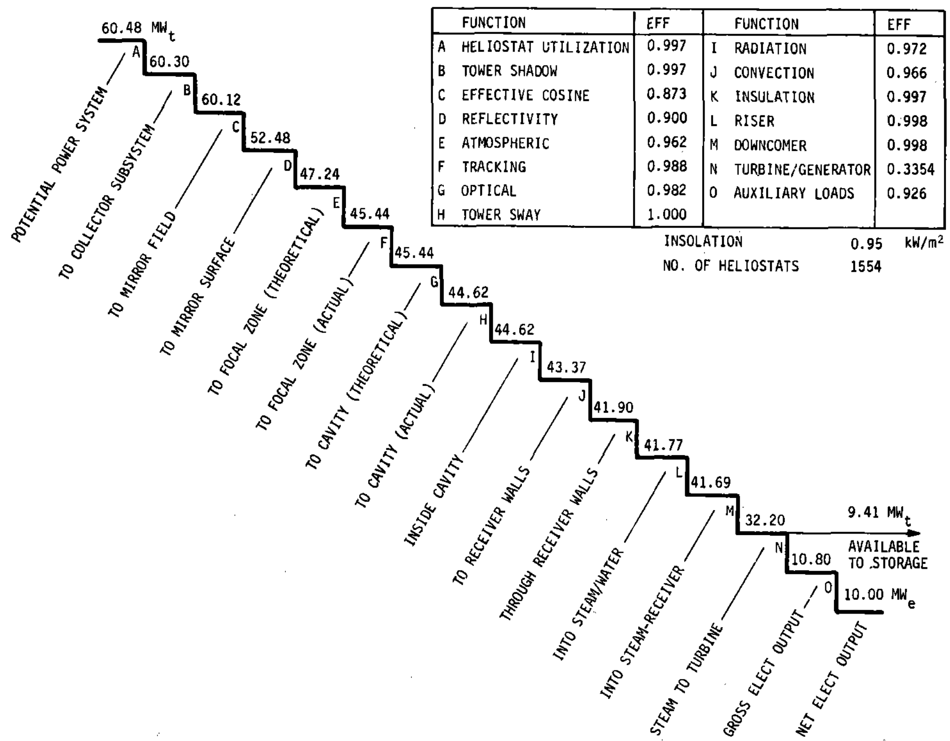
Figure IV.B-5. Pilot Plant Performance Profile - 2:00 PM, January 21 (November)



	FUNCTION	EFF		FUNCTION	EFF
A	HELIOSTAT UTILIZATION	0.997	I	RADIATION	0.972
B	TOWER SHADOW	0.991	J	CONVECTION	0.966
C	EFFECTIVE COSINE	0.893	K	INSULATION	0.997
D	REFLECTIVITY	0.900	L	RISER	0.998
E	ATMOSPHERIC	0.962	M	DOWNCOMER	0.998
F	TRACKING	0.988	N	TURBINE/GENERATOR	0.3354
G	OPTICAL	0.983	O	AUXILIARY LOADS	0.926
H	TOWER SWAY	1.000			

INSOLATION 0.95 kW/m²
NO. OF HELIOSTATS 1554

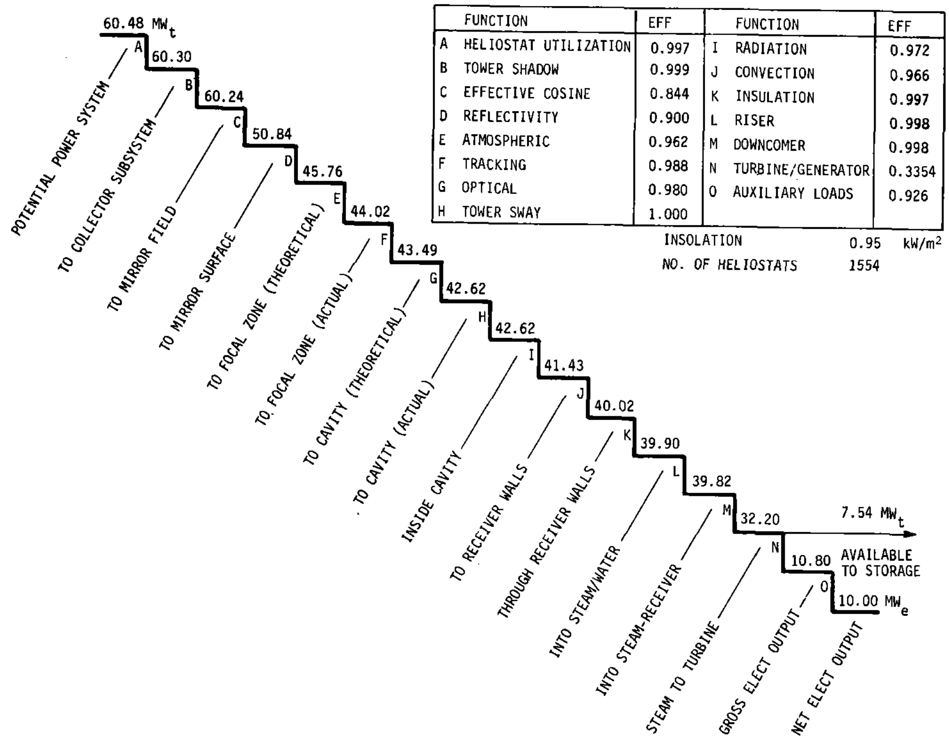
Figure IV.B-6. Pilot Plant Performance Profile - 2:00 PM, February 21 (October)



	FUNCTION	EFF		FUNCTION	EFF
A	HELIOSTAT UTILIZATION	0.997	I	RADIATION	0.972
B	TOWER SHADOW	0.997	J	CONVECTION	0.966
C	EFFECTIVE COSINE	0.873	K	INSULATION	0.997
D	REFLECTIVITY	0.900	L	RISER	0.998
E	ATMOSPHERIC	0.962	M	DOWNCOMER	0.998
F	TRACKING	0.988	N	TURBINE/GENERATOR	0.3354
G	OPTICAL	0.982	O	AUXILIARY LOADS	0.926
H	TOWER SWAY	1.000			

INSOLATION 0.95 kW/m²
NO. OF HELIOSTATS 1554

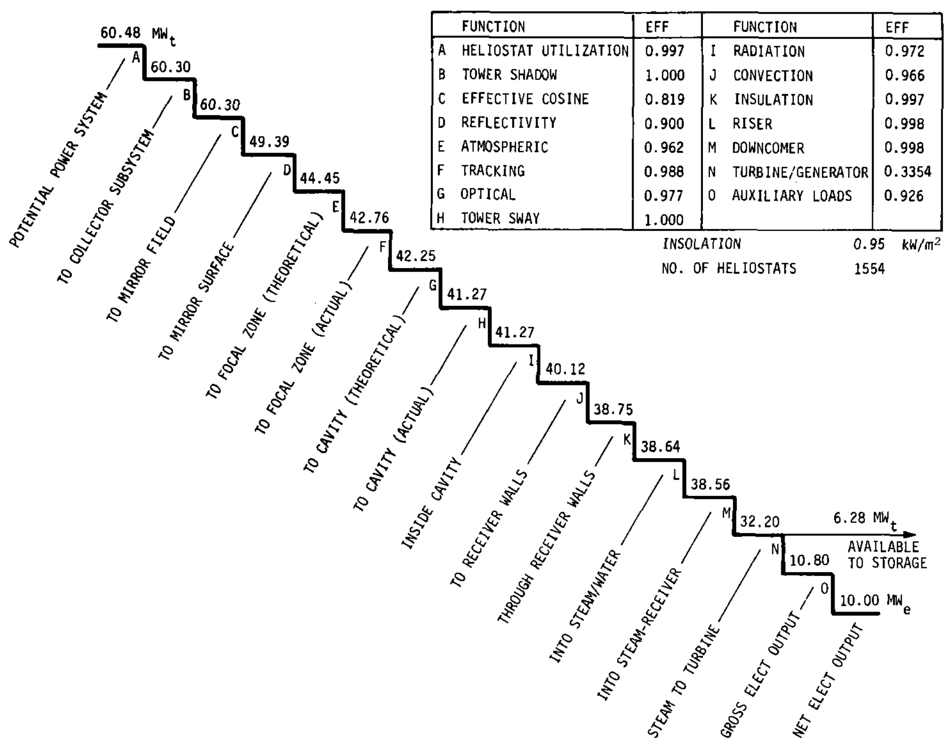
Figure IV.B-7. Pilot Plant Performance Profile - 2:00 PM, March 21 (September)



	FUNCTION	EFF		FUNCTION	EFF
A	HELIOSTAT UTILIZATION	0.997	I	RADIATION	0.972
B	TOWER SHADOW	0.999	J	CONVECTION	0.966
C	EFFECTIVE COSINE	0.844	K	INSULATION	0.997
D	REFLECTIVITY	0.900	L	RISER	0.998
E	ATMOSPHERIC	0.962	M	DOWNCOMER	0.998
F	TRACKING	0.988	N	TURBINE/GENERATOR	0.3354
G	OPTICAL	0.980	O	AUXILIARY LOADS	0.926
H	TOWER SWAY	1.000			

INSOLATION 0.95 kW/m²
NO. OF HELIOSTATS 1554

Figure IV.B-8. Pilot Plant Performance Profile - 2:00 PM, April 21 (August)



	FUNCTION	EFF		FUNCTION	EFF
A	HELIOSTAT UTILIZATION	0.997	I	RADIATION	0.972
B	TOWER SHADOW	1.000	J	CONVECTION	0.966
C	EFFECTIVE COSINE	0.819	K	INSULATION	0.997
D	REFLECTIVITY	0.900	L	RISER	0.998
E	ATMOSPHERIC	0.962	M	DOWNCOMER	0.998
F	TRACKING	0.988	N	TURBINE/GENERATOR	0.3354
G	OPTICAL	0.977	O	AUXILIARY LOADS	0.926
H	TOWER SWAY	1.000			

INSOLATION 0.95 kW/m²
NO. OF HELIOSTATS 1554

Figure IV.B-9. Pilot Plant Performance Profile - 2:00 PM, May 21 (July)

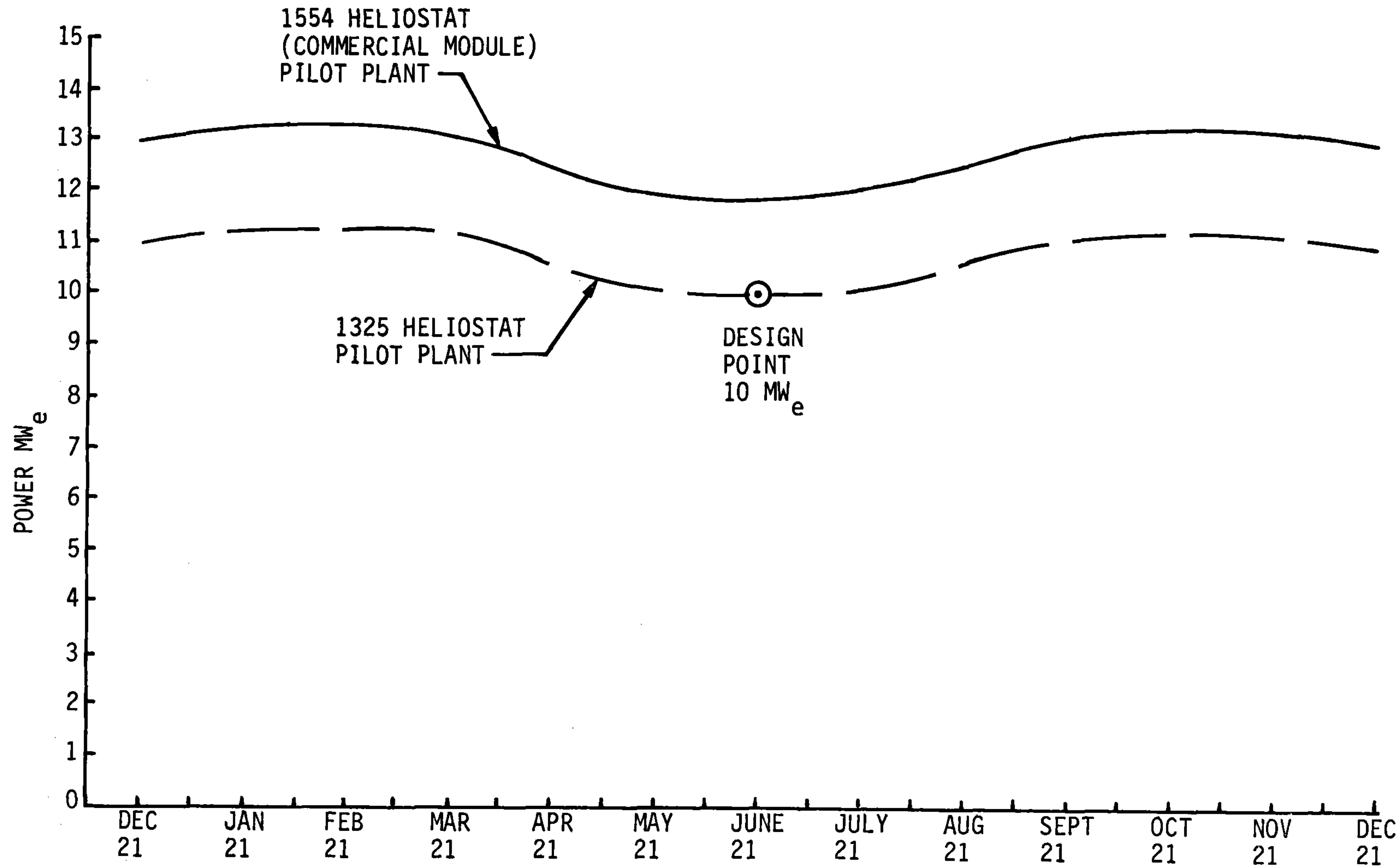


Figure IV.B-10 Annual Variation in Pilot Plant Output at 2 pm

	WINTER	SUMMER	EQUINOX
TOTAL ENERGY	327 MW_t-HR	419 MW_t-HR	396 MW_t-HR
ENERGY-TURBINE	269 MW_t-HR	380 MW_t-HR	331 MW_t-HR
ENERGY-TSS	58 MW_t-HR	39 MW_t-HR	65 MW_t-HR
HOURS OF STORAGE	2.1 HR	1.4 HR	2.4 HR
HOURS STORAGE (INCLUDING STARTUP)	1.9 HR	1.2 HR	2.2 HR

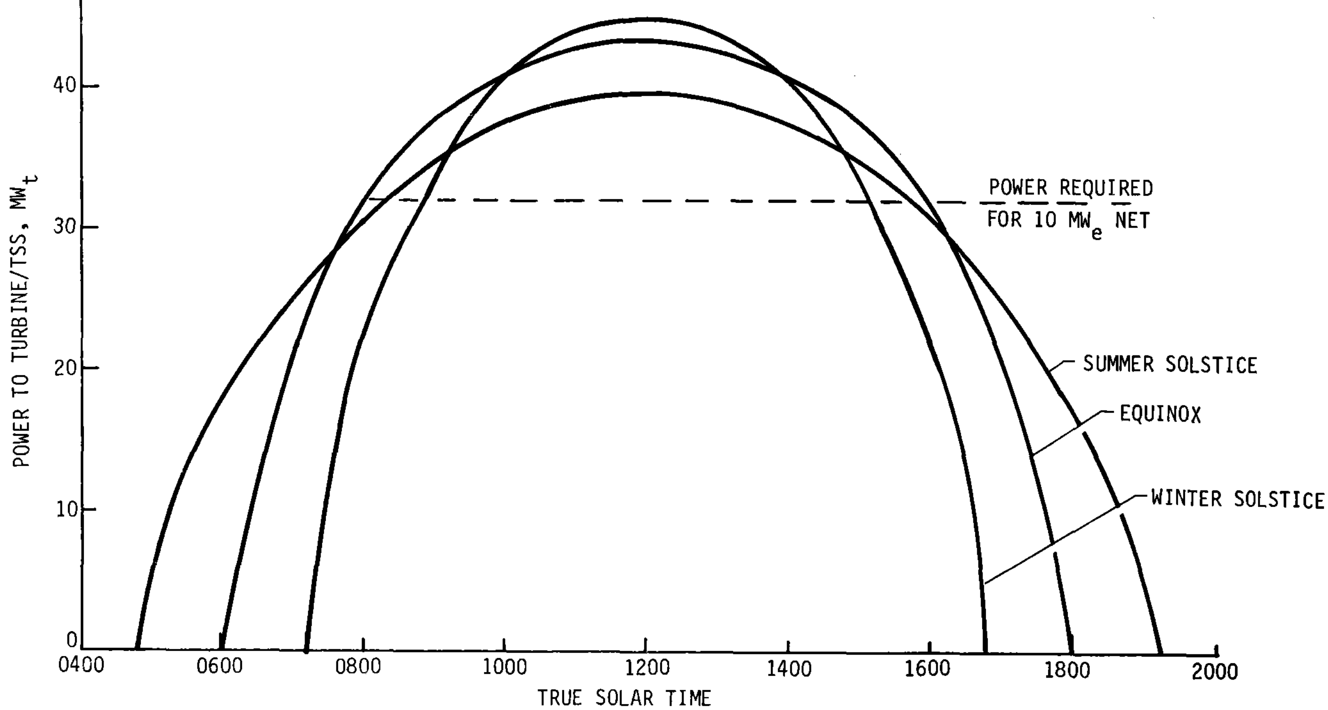


Figure IV.B-11 Pilot Plant Seasonal Performance, 1554 Heliostats on each day as well as the capability of the system to charge thermal storage. The overall performance balance of the plant is further illustrated by the fact that the plant peak power generation occurs in winter, the peak energy generation in summer and the peak storage capability at the equinox.

b. Pilot Plant Annual Energy (Inyokern) - In addition to examining pilot plant performance variations over the year, the total annual energy production must be considered in evaluating over-all plant performance. Therefore, the pilot plant total annual electrical output was calculated using the 1963 Inyokern, California insolation data base supplied by the Aerospace Corporation.

The annual energy was calculated using the efficiency factors discussed in Section IV.B.2.d, subsystem efficiencies. A power calculation was performed for each daylight hour using the Inyokern insolation data and the efficiency factors appropriate for the particular time of day and day of the year. The power was integrated over each day and then summed for the year. Losses due to receiver start-up and minimum receiver flowrate were also considered in the energy calculation.

The monthly and yearly energy production for the Pilot Plant, using the full commercial plant module of 1554 heliostats, is shown in Figure IV.B-12. The upper curve shows the potential energy to the system. This is the product of the mirror area and the insolation and therefore includes no system losses. The yearly total potential energy is 203,410 MW_t-hr or 3195 kW_t-hr per square meter of mirror area. The second curve is the reflected energy which includes losses due to heliostat utilization, tower shadow, field cosine, heliostat shading and blocking and mirror reflectivity. The yearly total reflected energy is 139,930 MW_t-hr or 2198 kW_t-hr per square meter of mirror area. The third curve, receiver output, is the energy available at the base of the tower. It takes into account tracking, optical and atmospheric absorption losses as well as tower sway, receiver radiation, convection and insulation, and riser and downcomer losses. The total receiver output is 117,920 MW_t-hr or 1852 kW_t-hr per square meter of mirror area. The lower curve is the pilot plant net electrical output and includes the turbine/generator efficiency and the plant auxiliary loads. The yearly total net electrical output is 35,916 MW_e-hr or 564 kW_e-hr per square meter of mirror area. It should be noted that the relatively small variation in electrical output over the year is the result inherent efficiency characteristics of the north collector field.

YEARLY TOTALS	TOTAL ENERGY	ENERGY PER M^2 OF MIRROR
POTENTIAL ENERGY TO SYSTEM	203,410 MW_t-HR	3195 kW_t-HR/m^2
REFLECTED ENERGY	139,930 MW_t-HR	2198 kW_t-HR/m^2
RECEIVER OUTPUT	117,920 MW_t-HR	1852 kW_t-HR/m^2
NET ELECTRICAL OUTPUT	35,916 MW_e-HR	564 kW_e-HR/m^2

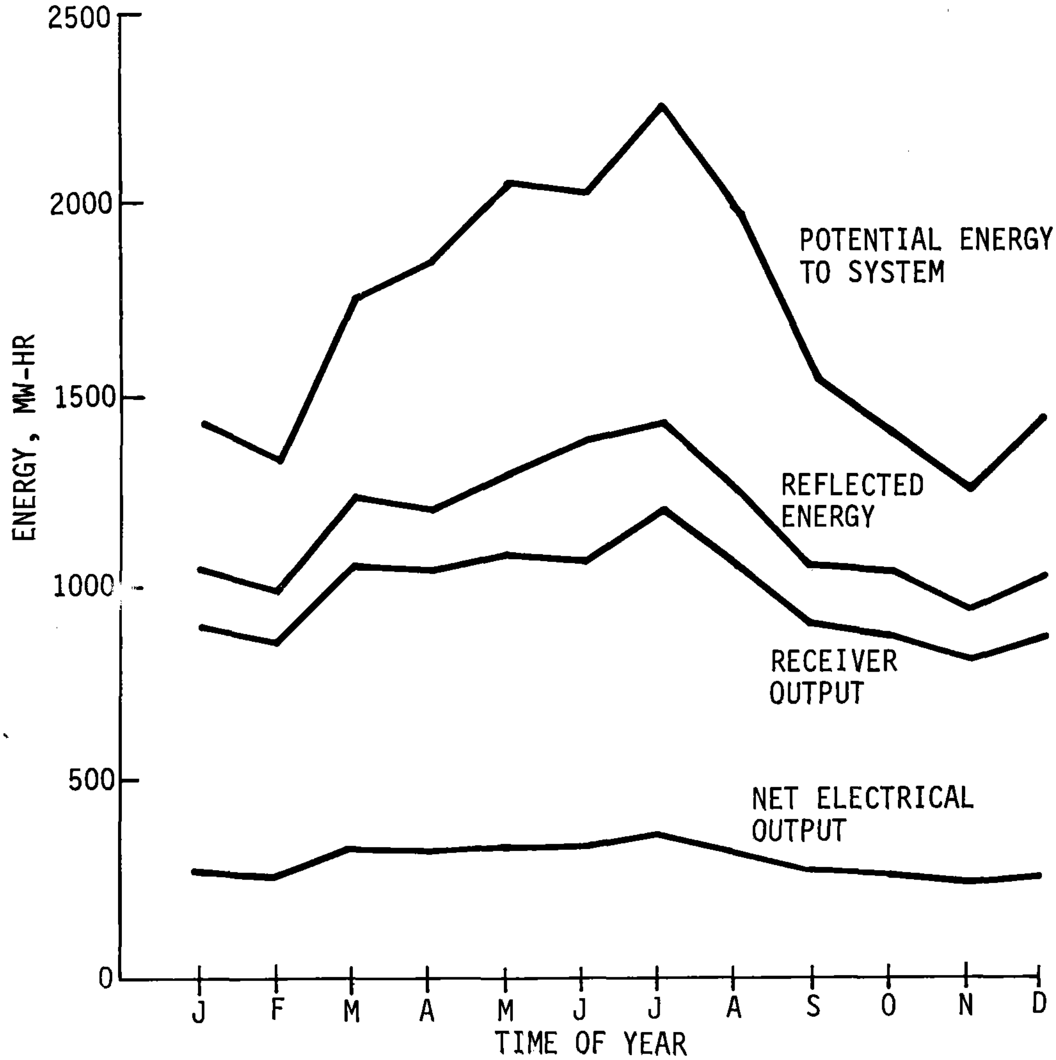


Figure IV.B-12 Pilot Plant Annual Energy

4. Subsystem Characteristics

This section summarizes in tabular form the salient operational characteristics of each Pilot Plant subsystem, including design point, maximum and minimum performance data. Note that data for the collector and receiver subsystems also apply to one module of the commercial plant.

a. Collector Subsystem

1) Heliostat Control Power Input

Operating Mode	Average Power Input (KWe) Module
Tracking	51
Slew	590
Emergency Shutdown	590

2) Potential and Delivered Power - The potential power is that amount available at the mirror surface if normal to the insolation. The delivered power is that amount that passes through the receiver aperture.

Potential Power (MWth)	Minimum (2:00 PM Summer Solstice, 0.95 KW/m^2)	Design Point (2:00 PM Summer Solstice, 0.95 KW/m^2)	Maximum (12:00 Winter Solstice, 1.02 KW/m^2)
Module	60.5	60.5	64.9
Delivered Power (MWth)			
Module	40.5	40.5	52.3

b. Receiver Subsystem

1) Power Into Receiver - The power into the receiver is the amount that passes through the aperture and into the cavity in MWth.

	Minimum (For Rated Steam)	Design Point (2:00 PM Summer Solstice, 0.95 KW/m^2)	Maximum (12:00 Winter Solstice, 1.02 KW/m^2
Module	8.5	40.5	52.3

2) Output Steam Properties

	Minimum Performance	Design Point Performance	Maximum Performance
Temperature, K(°F)	789 (960)	789 (960)	789 (960)
Pressure kPa(psig)	10,687 (1,550)	10,687 (1,550)	10,687 (1,550)
Flow kg/hr(lb/hr)	8,892 (19,600)	56,520 (124,600)	73,980 (163,100)

3) Feedwater Properties

	Minimum Performance	Design Point Performance	Maximum Performance
Temperature, K(°F)	466 (380)	503 (445)	522 (480)
Pressure kPa(psig)	10,890 (1,580)	12,550 (1,820)	13,450 (1,950)
Flow kg/hr(lb/hr)	8,964 (19,760)	57,060 (125,795)	74,735 (164,760)

c. Thermal Storage Subsystem

1) Storage Media Temperatures

	Charged	Discharged
Salt, K (°F)	755 (900)	544 (519)
Oil, K (°F)	568 (568)	511 (460)

2) Charging Steam Conditions

	Minimum Performance	Design Point Performance	Maximum Performance
Temperature, K (°F)	780 (945)	780 (945)	780 (945)
Pressure, kPa(psig)	8,860 (1,285)	8,860 (1,285)	8,860 (1,285)
Flow kg/hr(lb/hr)	10,600 (23,400)	45,750 (100,860)	53,200 (117,000)

3) Discharging Steam Conditions

	Minimum Performance	Design Point Performance	Maximum Performance
Temperature, K(°F)	701 (802)	701 (802)	701 (802)
Pressure kPa(psig)	2,999 (435)	2,999 (435)	2,999 (435)
Flow kg/hr(lb/hr)	8,580 (18,900)	41,960 (92,500)	42,900 (94,500)

4) Power Capability (MWth)

	Minimum Performance	Design Point Performance	Maximum Performance
Charge	7.0	30.0	34.8
Discharge	5.6	27.5	28.1

5) Total Stored Energy Capability 91.7 MWth-hr.

d. Electrical Power Generation Subsystem

1) Operating From Receiver Only (Main Steam)

	Design Point		Maximum	
Net Electrical Power Output (MWe)	10.0		11.6	
Gross Electrical Power Output (MWe)	10.8		12.5	
Turbine Cycle Gross Heat Rate, KJ/KWH (BTU/KWH)	10,735	(10,177)	10,548	(9,998)
Steam Inlet Conditions:				
Pressure, kPa (psig)	9,308	(1,350)	9,308	(1,350)
Temperature, K (°F)	783	(950)	783	(950)
Flow Rate, kg/hr(lb/hr)	46,490	(102,500)	53,525	(118,000)
Exhaust Pressure, kPa(in.Hg)	8.5	(2.5)	8.5	(2.5)

2) Operating From Thermal Storage Only (Admission Steam)

	Design Point		Maximum	
Net Electrical Power Output, MWe	7.0		8.4	
Gross Electrical Power Output, MWe	7.6		9.1	
Turbine Cycle Gross Heat Rate, KJ/KWH (BTU/KWH)	12,890	(12,220)	12,650	(11,990)
Steam Inlet Conditions:				
Pressure, kPa (psig)	2,758	(400)	2,758	(400)
Temperature, K (°F)	700	(800)	700	(800)
Flow Rate, kg/hr (lb/hr)	40,869	(90,100)	48,958	(107,900)
Exhaust Pressure, kPa(in.Hg)	8.5	(2.5)	8.5	(2.5)

C. PILOT PLANT OPERATION

1. Modes of Operation

The pilot plant is capable of performing all modes of operation required for the commercial plant as discussed in section III.C.1. The operational flexibility of the pilot plant will permit thorough testing of the total system and each subsystem to verify performance for all system configurations and modes of operation.

The pilot plant is capable of many operational configurations. These operational configurations result from alternate configurations at the subsystem level and transitions from one pilot plant configuration to another. At the system level there are six basic configurations or steady state modes for daily operation. These six basic modes of operation are described below.

There are many additional modes such as overnight standby, transitions such as startup, shutdown, and transition from one steady state mode to another. The more significant transition modes are discussed in the Transient Plant Operation section that follows. These transition modes combined with the basic steady state operating modes form the true flexibility of operation for the plant. An example of a very important subsystem configuration associated with the electrical power generation subsystem is the capability to bypass steam around the turbine and directly to the condenser. This capability is very important in transition and startup modes and provides additional capability for testing in the six basic steady state modes discussed below.

As with the commercial plant there can be several different scenarios for any given day using these basic modes of operation. The selected scenario for any given day will be determined by such things as; the state of charge of thermal storage and the desired state of charge at the end of the day; the desired load profile to be generated throughout the day; the insolation profile for the day; operational status of the plant, etc. Some examples of operational scenarios are shown in Section IV.C.2.b.

The six operational modes discussed below are by no means the only operational modes of the plant. They do encompass the major steady state operational modes and thus the capability to satisfy the performance requirements of the plant. Each of the six operational modes discussed below is accompanied by a separate schematic/flow diagram. The solid heavy line indicates the flow of the steam/water working fluid for the particular mode under discussion. The dashed heavy lines represent the flow of oil and salt line of thermal storage subsystem.

a. Receiver Operating Turbine Only - This mode of operation is normally used in the morning and afternoon or during periods of low insolation, when the desire is to generate and put on the grid all the receiver subsystem capability. The required net electrical output for the pilot plant in this mode of operation is 10 MWe. The pilot plant is capable of producing up to 11.6 MWe with the selected steam conditions, selected turbine and cycle arrangement in this mode of operation. If the collector and receiver subsystems can generate more than 11.6 MWe net, then portions of the collector will have to be turned down. For testing purposes it may be desirable to operate with steam from the receiver only and have the turbine at an intermediate load setting. This can be accomplished in this mode either by turning down some heliostats or utilizing the main steam bypass valve to route a portion of the steam around the turbine and through a desuperheater directly to the condenser.

As shown in Figure IV.C-1 the steam flow path is from the outlet of the receiver superheater to the turbine main steam throttle valve. Normally the selected control configuration for the electrical power generation subsystem will be the turbine following the output of the receiver on pressure control when the turbine is controlling the receiver operating pressure.

After the steam leaves the low pressure sections of the turbine and is condensed, the condensate is heated in the feedwater heaters and the feedwater is pumped directly back to the receiver subsystem. Recirculation lines from the output of the high and low pressure feedwater pumps to the condenser are provided for proper pump operation and flow balance as required. For this mode of operation the thermal storage subsystem is not operating either in charge or discharge. This mode of operation is similar to that for a conventional plant since there is only one source of steam and it is all being delivered to the turbine main steam throttle valve.

The flow path used for this mode of operation is also used for a normal morning startup from the receiver. For morning startup the receiver start up control logic regulates the build up of receiver output pressure, temperature and flowrate. The output of the receiver is diverted around the turbine to the condenser via PCV 2 until acceptable steam conditions for the turbine are generated. These startup conditions are discussed in Paragraph IV.C.2a.

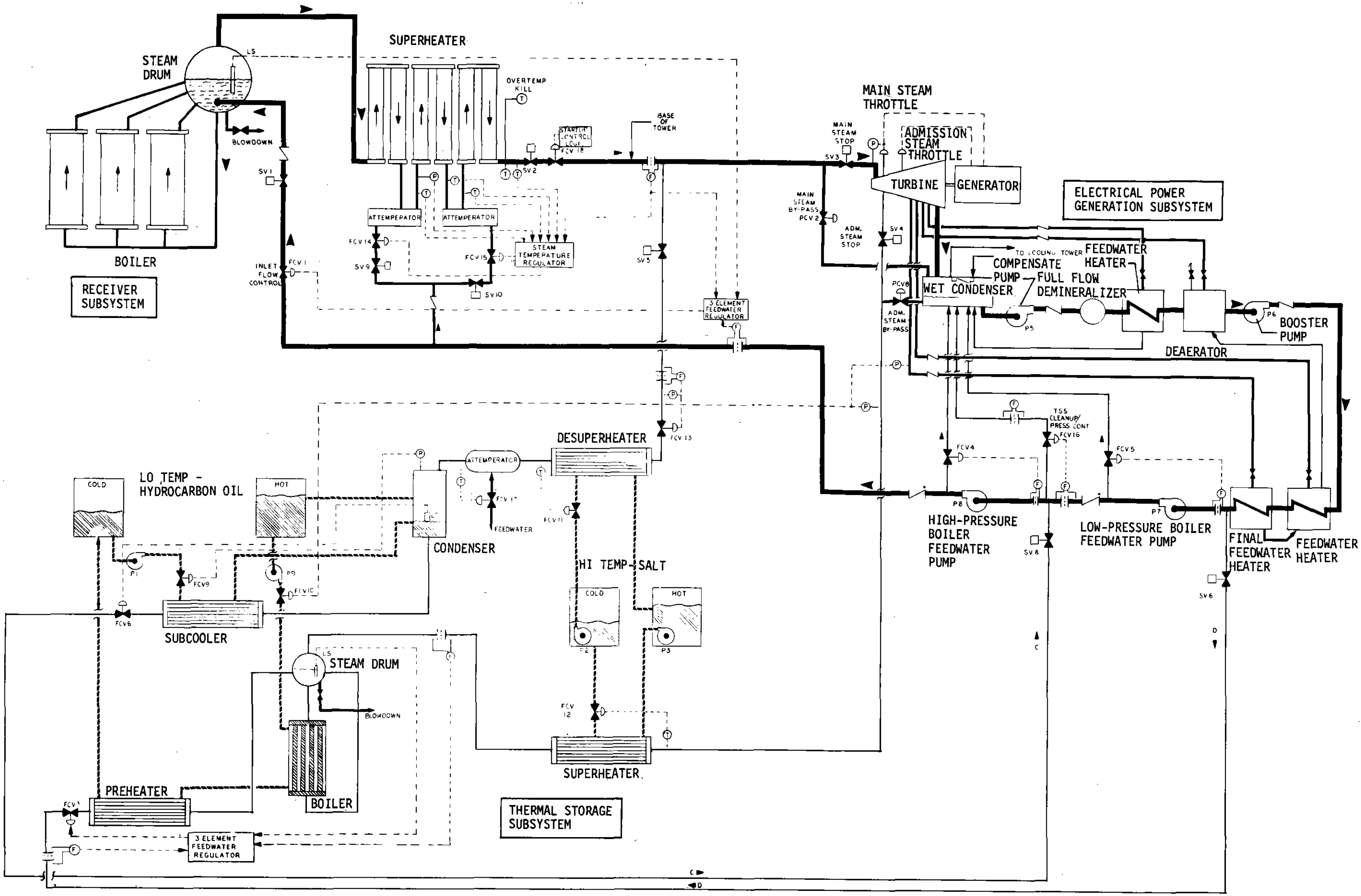


Figure IV.C-1 Receiver Operating Turbine Only

When the steam conditions are acceptable, the turbine is spun up and synchronized with the grid. Following synchronization the turbine load is increased using planned load time profiles as discussed in paragraph IV.C.2.a.

b. <u>Receiver Operating Turbine and Receiver Charging Thermal Storage-</u> This mode of operation will be the predominant mode of operation throughout the day on a sunny day. The receiver subsystem is capable of providing the desired electrical output plus providing additional steam for partially charging the thermal storage. Steam that is in excess of the turbine capability is diverted to the thermal storage for charging. For test purposes additional steam can be diverted to thermal storage by reducing that amount going to the turbine.

As shown in Figure IV.C-2 steam from the receiver is split and a portion sent to the turbine main steam throttle valve and a portion to the thermal storage for charging. There are two primary options for controlling this mode of operation. First the turbine can be set on a fixed load and all excess steam will be diverted to the thermal storage for charging. For this control option the turbine is controlling the flow to the main steam throttle valve to satisfy the load requirement. As excess steam becomes available the pressure will increase and pressure control will modulate FCV 13, to maintain turbine pressure, thus establishing the charge rate of thermal storage.

An alternate option for controlling this mode of operation is to select the desired charge rate for thermal storage and divert the remainder of the receiver output to the turbine. Thus providing a fixed charge rate and a variable electrical output. This is accomplished by controlling the flowrate to the thermal storage by flow control of FCV 13. The turbine main steam throttle valve would be on pressure control and accept that steam not required by thermal storage.

The condensate resulting from desuperheating, condensing, and subcooling the charge steam is joined with the feedwater from the turbine at a point between the low and high pressure feedwater pumps and is pumped back to the receiver. At the output of the high and low pressure feedwater pumps are the circulation lines back to the condenser. These lines provide the necessary buffering between the series pumps and the additional of the condensate from thermal storage. In addition a recirculation line is provided for water purity for the thermal storage charge operation. As shown the discharge portion of thermal storage is not operational for this mode.

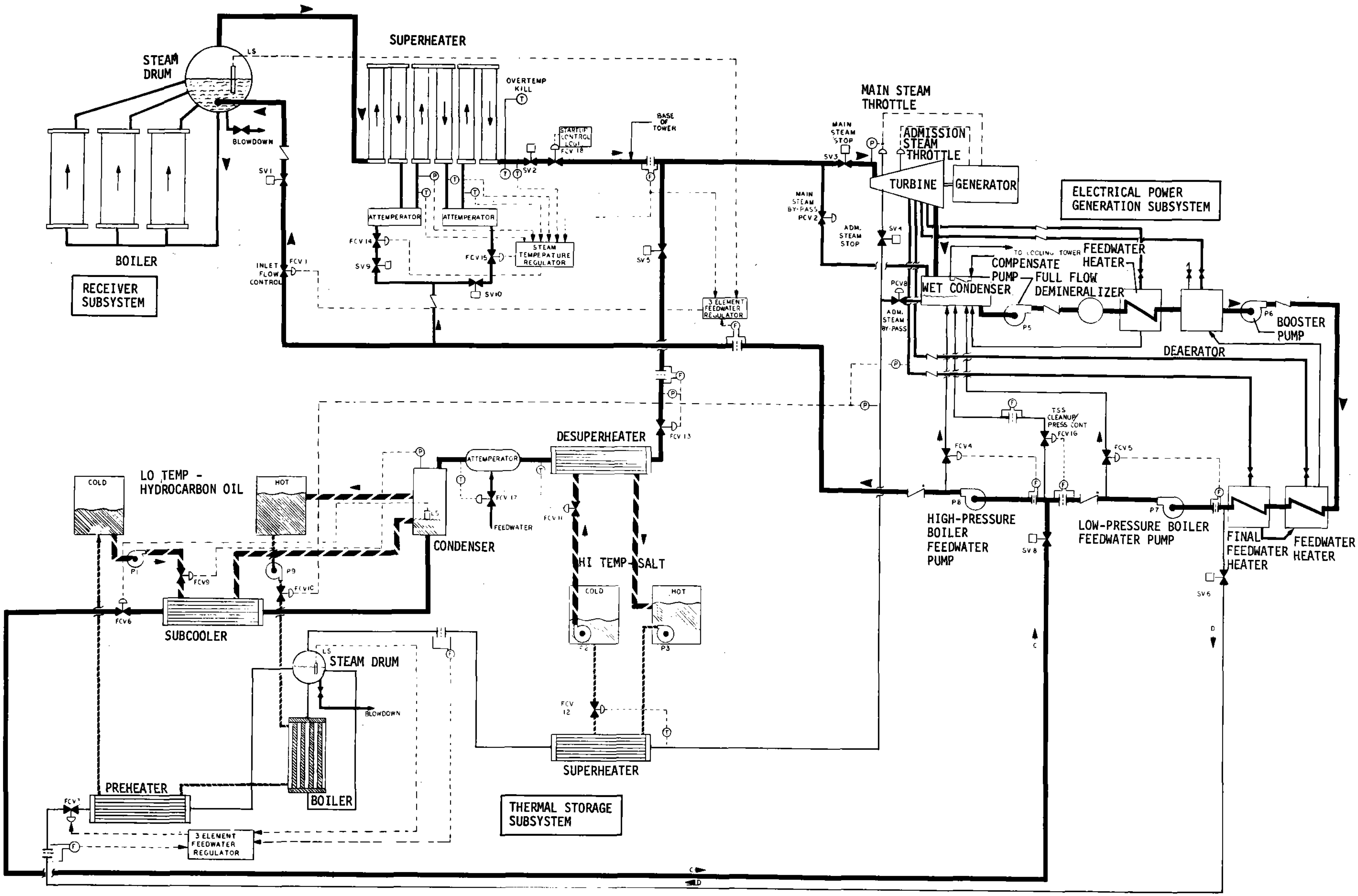


Figure IV.C-2 Receiver Operating Turbine and Charging Thermal Storage

c. Receiver and Thermal Storage Operating the Turbine - This mode of operation would normally be used if the desired load can not be satisfied by the output of the receiver alone. Such a situation may exist during a low insolation period in a day or at the end of the solar day. For this mode of operation the pilot plant is required to produce up to 7 MWe net electrical output for all combinations of receiver, and thermal storage output.

As shown in Figure IV.C-3 steam from the receiver is provided to the turbine main steam throttle valve simultaneously with steam going from the thermal storage to the turbine admission steam throttle valve. The normal control would be to set the turbine on load control requiring a fixed load. As steam from the receiver decreases the thermal storage steam will increase to maintain the fixed load requirement. Steam from both sources are simultaniously routed through the turbine, condensed and heated in the feedwater heaters. After leaving the final feedwater heater, the feedwater is split and a portion is delivered to the thermal storage for further generation of steam and the remainder is pumped to the receiver for further generation of steam. In this mode all subsystem components are operational except for the charge portion of thermal storage.

d. Receiver Charging Thermal Storage and Thermal Storage Operating the Turbine - This mode provides for simultaneous charging and discharging thermal storage. However, by simultaneous charging and discharging thermal storage, the electrical power is generated at the lower efficiency of the turbine admission point rather than the higher efficiency of the turbine main steam point. It is an alternate mode to operating back and forth between the modes in Figure IV.C-2 and IV.C-3. The main advantage of this configuration is to provide rapid transitions between these modes. Even though the mode configuration allows for accepting the full output of the receiver subsystem it would require increasing the size of the heat exchangers in the charge portion of the thermal storage which is not cost effective. The electrical output in this configuration is similar to the pilot plant capability when operating from thermal storage alone.

As shown in Figure IV.C-4, all of the steam from the receiver is provided to the thermal storage for charging and all of the steam provided to the turbine is from the thermal storage discharging. This combination provides essentially two isolated closed loops like the Receiver Charging Thermal Storage Only of Figure IV.C-5 and the Thermal Storage Operating Turbine Only of Figure IV.C-6.

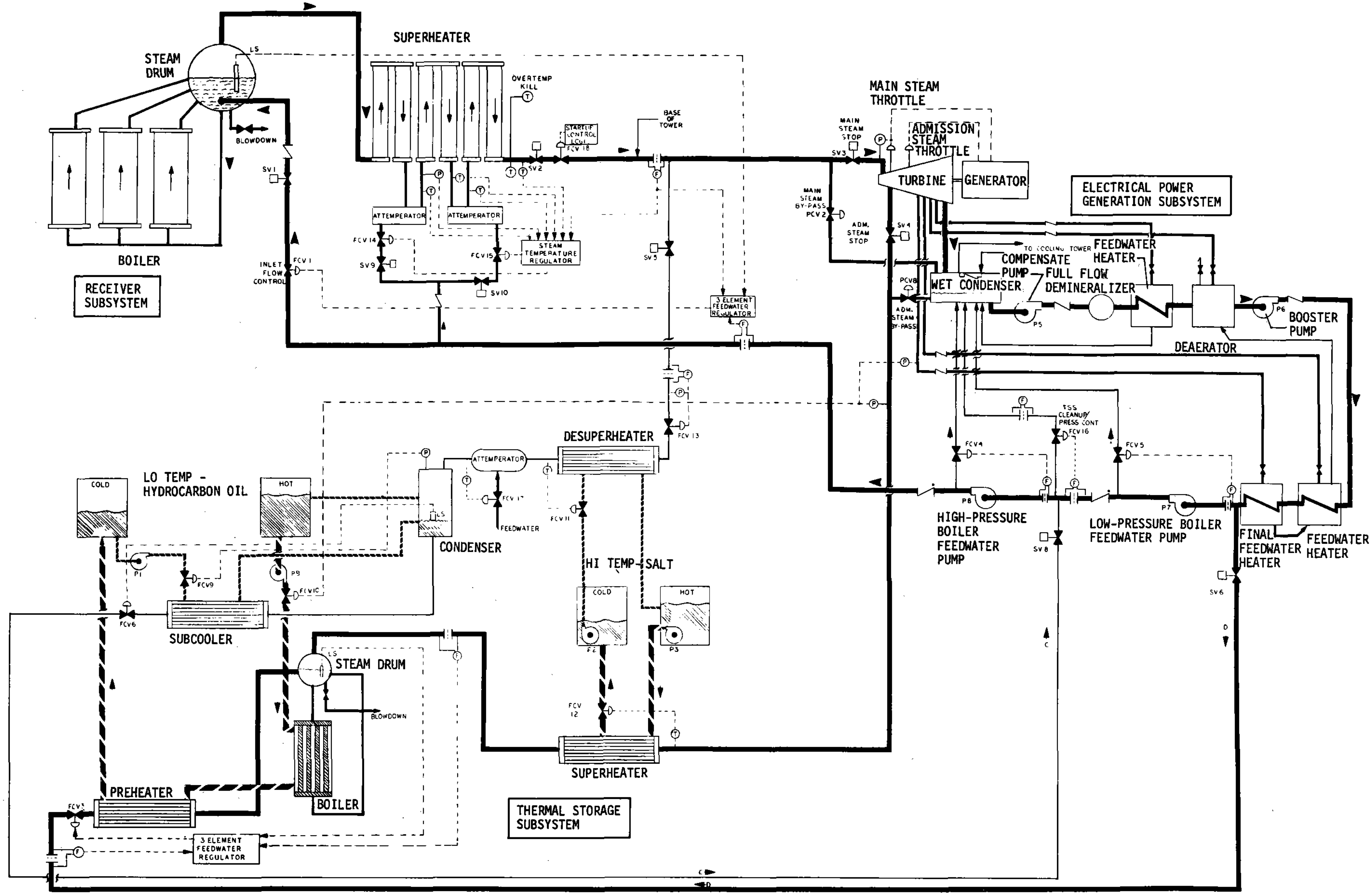


Figure IV.C-3 Receiver and Thermal Storage Operating the Turbine

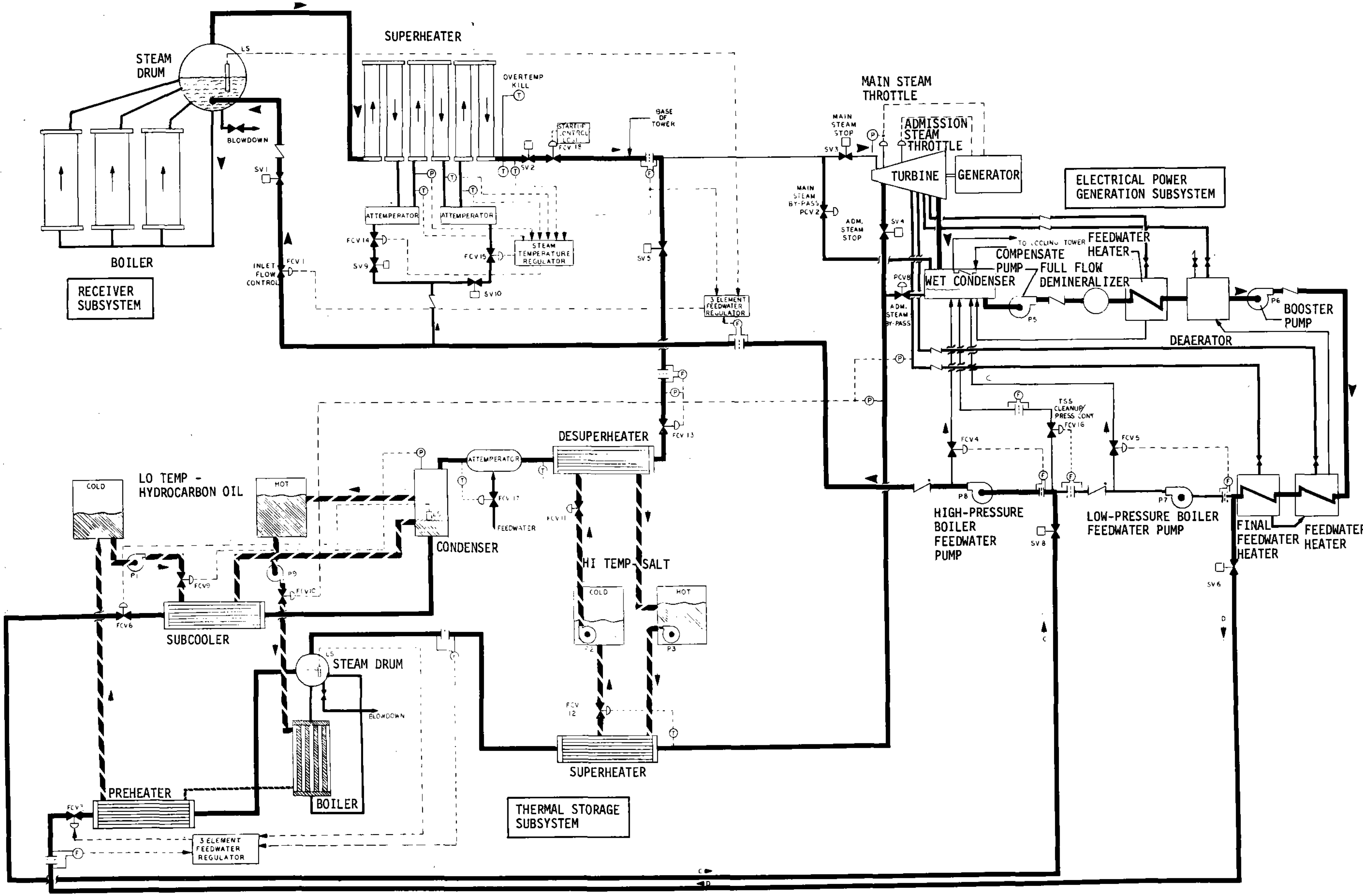


Figure IV.C-4 Receiver Charging Thermal Storage and Thermal Storage Operating the Turbine

As shown all subsystems are operating but note that the steam generated by the receiver for charging thermal storage is essentially in a closed loop separate from the steam generated by the thermal storage for operating the turbine.

e. Receiver Charging Thermal Storage Only - This mode of operation will normally be used when the operating strategy indicates that it is more advantageous to store energy for later use than to generate electrical power at the present time. No electrical power is being generated in this mode. In the pilot plant this mode may be used more in test situation to insure that thermal storage gets fully charged in a given day. This is particularly true since it is not required that the pilot plant be capable of operating at rated output and also fully charge thermal storage in a given day. However, the Martin Marietta Team design used one full commercial plant module and therefore has capability to provide charge to thermal storage in addition to generating the required 10 MWe net electrical power output.

As shown in Figure IV.C-5, the receiver is generating steam, all of which is being used to charge thermal storage. The steam enters the salt stage where superheat is removed and then passes to the oil stage where the steam is condensed and subcooled. After the condensate leaves the thermal storage it is pumped back to the receiver to continue steam generation. During this mode neither the discharge portion of thermal storage nor the EPGS turbine, condenser and feedwater heaters are operating. The high pressure feedwater pump (P8) is operating to pump the condensate back to the receiver.

f. Thermal Storage Operating Turbine Only - This mode of operation will normally be used in periods of no insolation. The required net electrical output of the pilot plant in this mode of operation is 7 MWe. This mode of operation can be used for testing the thermal storage at various discharge rates by operating the turbine at various load settings.

As shown in Figure IV.C-6 the thermal storage subsystem is generating steam and providing it to the turbine admission steam throttle valve. Feedwater is delivered to the discharge portion of the thermal storage where it is preheated and boiled by the oil stage and superheat is added by the salt stage. After the steam passes through the turbine and condenser, the condensate is heated by the feedwater heaters and is pumped back to thermal storage to continue the cycle. Neither the charge portion of the thermal storage nor the receiver is operating in this mode. This mode of operation is also similar to that of a conventional power plant in that only one steam generation source is being used.

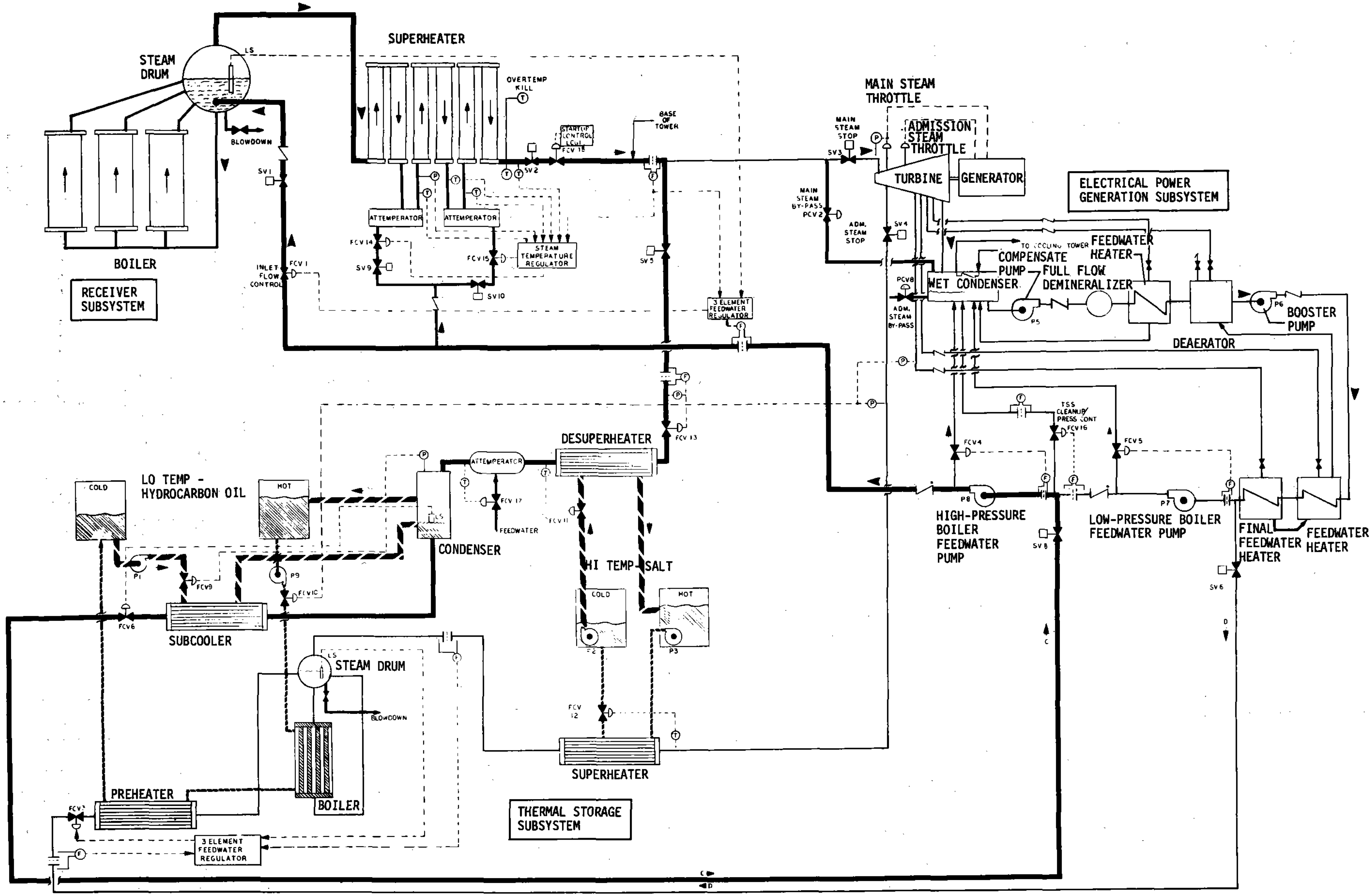


Figure IV.C-5 Receiver Charging Thermal Storage Only

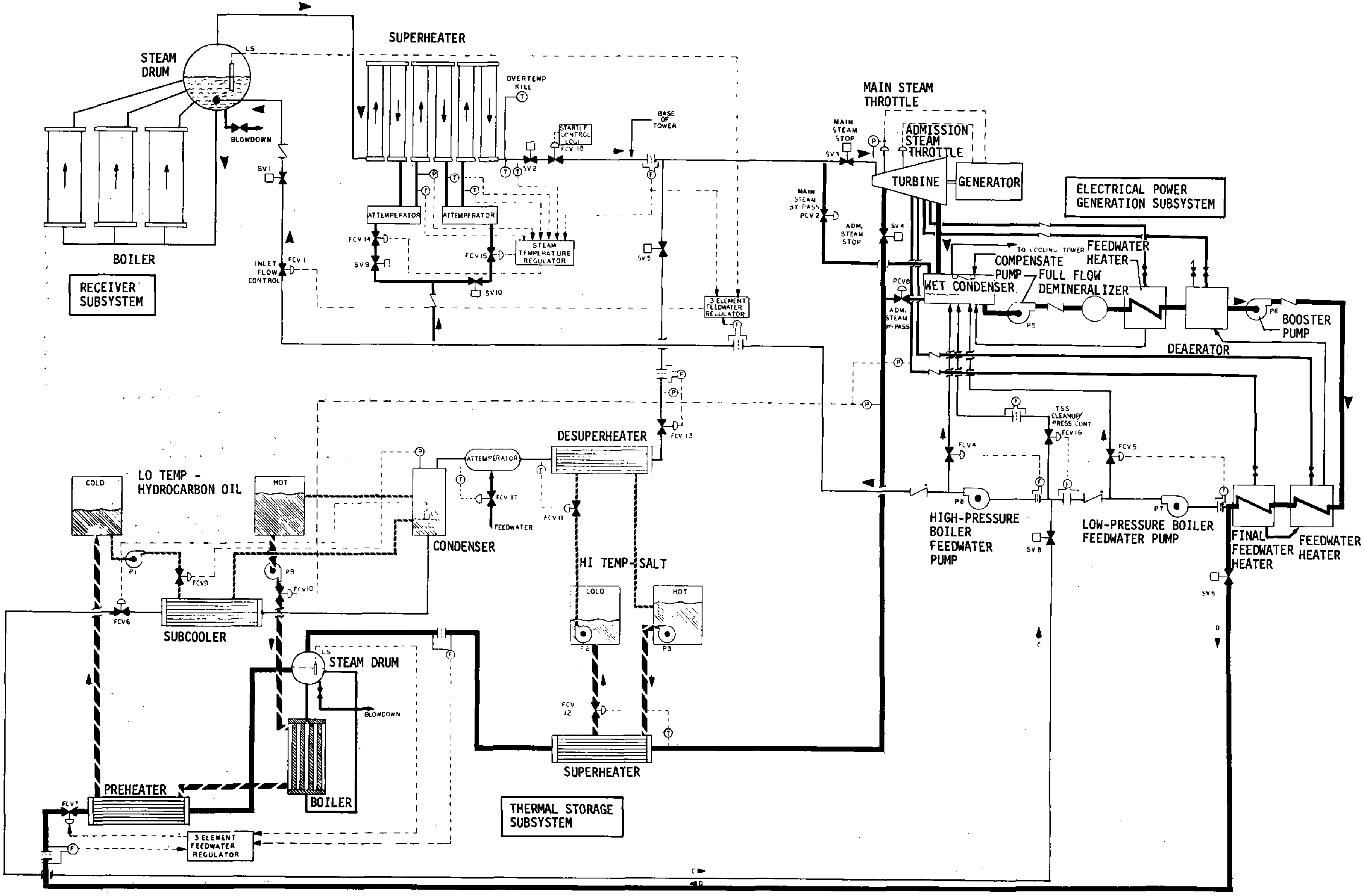


Figure IV.C-6 Thermal Storage Operating Turbine Only

The flow path shown for this mode of operation is also used for starting the turbine from thermal storage. Steam that may not be acceptable to the turbine at the beginning of startup can be diverted around the turbine to the condenser via the admission steam bypass valve PCV 8.

2. Transient Plant Operation

One of the most significant differences between a solar power plant and a conventional nuclear or fossil fueled plant is the plant operational profile. While a conventional plant operates in a basically steady state mode, the solar plant is subject to the variations inherent to it's fuel source, incident solar radiation. In addition to the obvious requirement to operate on a diurnal cycle, the plant must be capable of operating during periods of intermittent solar radiation due to cloud passage. The solar plant must be capable, with the aid of thermal storage, of meeting the required load while converting as much of the collectable solar energy as possible into usable electrical energy.

The ability of the pilot plant to operate under these conditions was analyzed and is presented in this section. The analysis includes plant startup and daily operational analysis.

a. Plant Startup - Analyses were performed for various types of pilot plant startup including receiver/turbine hot start, receiver/turbine cold start, receiver/thermal/storage hot start and thermal storage/turbine hot and warm starts. The approach, in all cases except the receiver/turbine cold start, was to start the system as fast as possible within the constraints of the subsystems involved and to calculate the start time and energy loss associated with each case. The primary receiver constraints for startup are to maintain acceptable superheater tube metal temperatures. These metal temperatures are a function of the flux on the cavity walls, the energy required to bring the steam drum temperatures up from the overnight conditions and the resultant flowrates in the tubes.

The primary startup constraints for the turbine are the rates of change of temperatures allowable on a daily basis and still provide the operational life required. Selected starting and loading curves are based on the average metal temperatures. As the shutdown period increases and the average metal temperatures decrease, the minimum allowable time to bring the turbine on line increases. The turbine is generally capable of a hot start when the shutdown time is less than 12 hours, a warm start for 12-72 hours and a cold start is usually required after 72 hours of shutdown. The predicted turbine starting and loading curves for a hot start are shown in Figure IV.C-7. These curves show the flowrates and

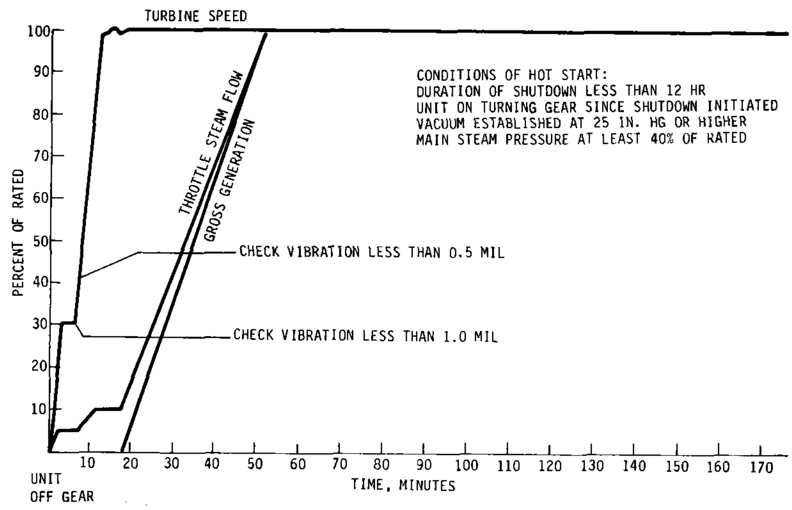


Figure IV.C-7. Turbine Starting and Loading Curve - Hot Start

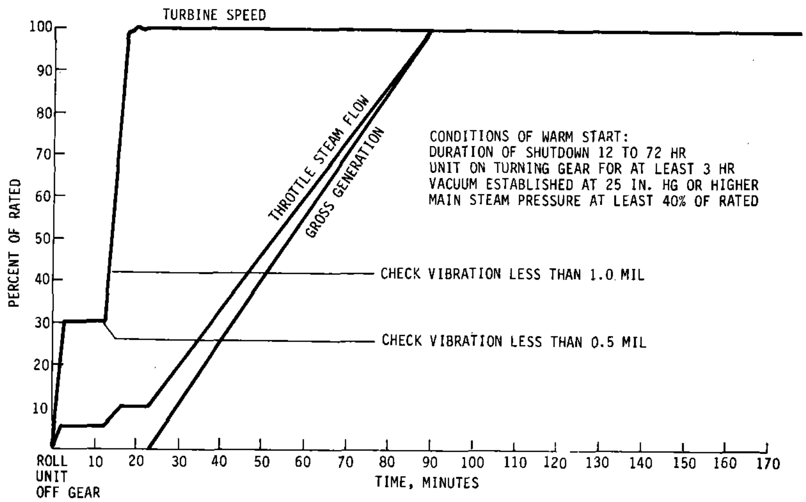


Figure IV.C-8. Turbine Starting and Loading Curve - Warm Start

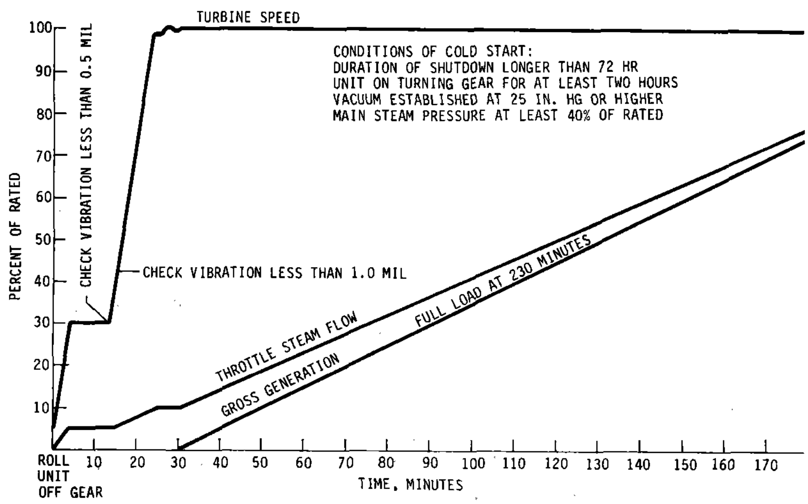


Figure IV.C-9. Turbine Starting and Loading Curve - Cold Start and time required to synchronize the turbine and the allowable rate of increase for loading the turbine. The initial steam conditions required for starting the turbine are 40% of rated pressure and 56 K (100°F) of superheat. Turbine startup characteristics for warm and cold starts are shown in Figures IV.C-8 and IV.C-9.

The constraints for the thermal storage subsystem center around the temperature and pressure of the input steam. The temperature of the charge steam entering the salt stage should be greater than 761 K (910°F) to prevent cooling of the heat exchanger. The steam entering the condensing stage has to be greater than 9412 kPa (1365 psia) in order to initiate the flow of oil. These conditions are set in order to insure adequate oil temperatures on the subsequent discharge cycle.

1) Receiver/Turbine Hot Start - This type of a start-up, considered to be a normal morning start, was analyzed to determine the maximum time required to bring the plant to "full power", where full power is defined as the point at which all available insolation is used in the generation of electrical power. Insolation data taken at Martin Marietta, together with field cosines, show that the worse case start up conditions (fastest rate of increase of power to receiver) occur at winter solstice. This power input profile was calculated and is shown, as the "solar power to the receiver" curve in Figure IV.C-10. The "Potential Power to Turbine" is the thermal power in megawatts that the receiver could generate and the turbine could accept if the receiver and turbine were operating under normal operating conditions. The "Actual Power to Turbine" is the thermal power in megawatts that the turbine has accepted for the morning start-up operation. The "Potential Electrical Output" is the electrical power that could be generated if the "Potential to Power to Turbine" were actually delivered to and accepted by the turbine. The "Actual Electrical Output" is that electrical power delivered during the morning startup operation. The startup losses shown inset in Figure IV.C-10 reflect the losses assigned to the startup operation if considered either as thermal or electrical. The losses include the energy required to heat up the receiver, turbine and riser downcomer piping. These losses are in addition to those that would occur if the plant were in a normal mode of operation. It should be pointed out that the losses are not to be combined, but are the same losses stated two different ways. This analysis showed that, for a normal morning start-up, the receiver can accept all the available solar energy and the plant can reach "full power" in approximately 45 minutes.

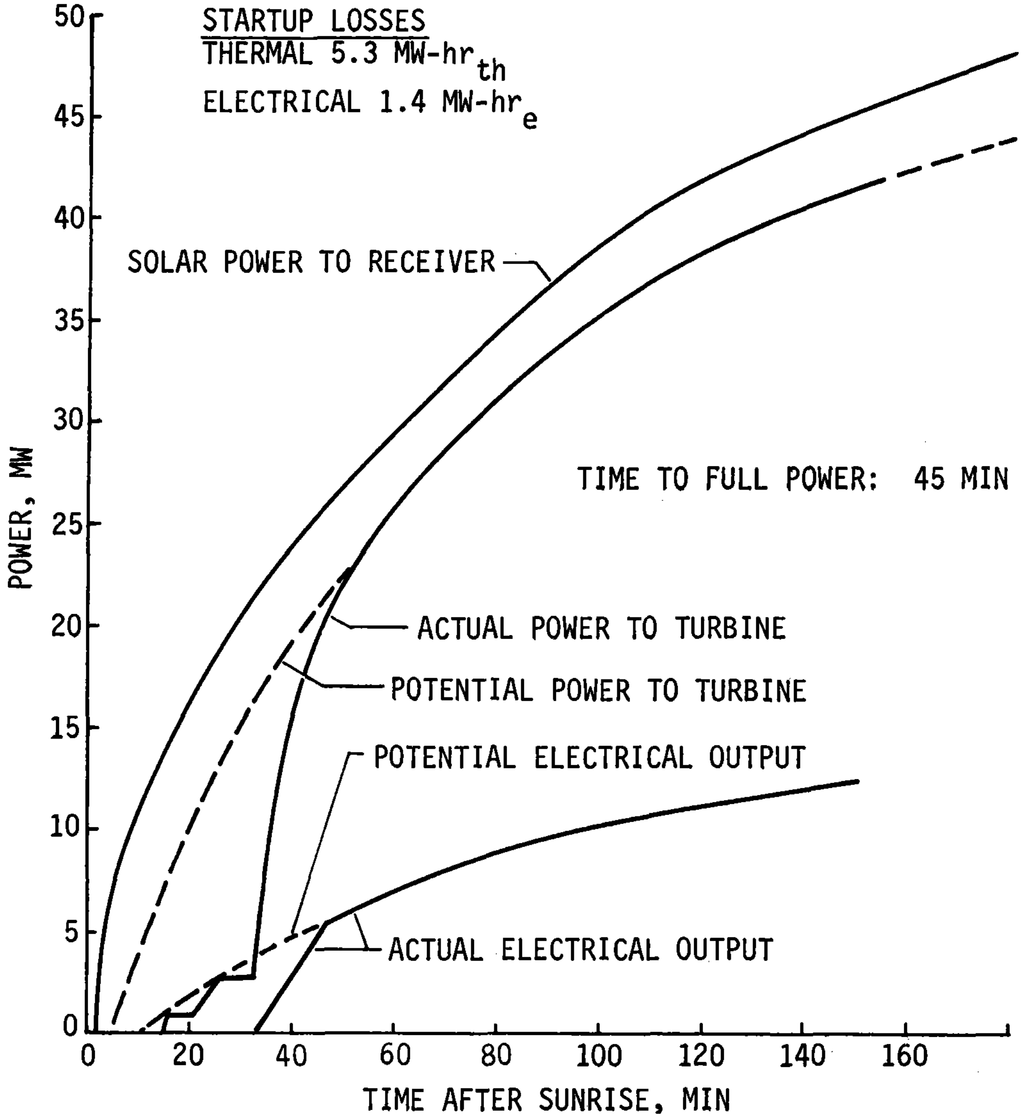


Figure IV.C-10 Hot Morning Startup - Receiver/EPGS

2) Receiver/Thermal Storage Hot Start - An alternative mode of operation to the morning startup with the turbine-generator, discussed above, is a morning startup operation of charging thermal storage only. This mode of operation is intended to provide additional capability from storage prior to starting the turbine-generator. This mode of operation also allows charging thermal storage when the output of the turbine-generator is not required for the first part of the day or for a given day.

   This startup power profile is shown in Figure IV.C-11. The "Solar Power to Receiver" is the same as previously shown in Figure IV.C-10. The "Potential Power to TSS" curve is the same as the "Potential Power to Turbine" curve of Figure IV.C-10. This is true since the collector and receiver performance is the same whether the steam is delivered to thermal storage of the turbine. However, there is an increased delay in the "Actual Power to TSS" as compared to the "Actual Power to Turbine" of Figure IV.C-10. This is due to the temperature and pressure constraints on steam to thermal storage. This delay reflects itself in increased losses, as shown in the inset of Figure IV.C-11, as compared to those of a Hot Receiver/ Turbine Start. The difference between the "Actual Power to TSS" and "Actual Stored Power" is the energy required to make up for the TSS overnight heat losses.

3) Receiver/Turbine Cold Start - The Pilot Plant cold start-up is a start after the receiver and turbine have cooled to ambient temperature. This analysis was also performed to determine the plant start time but differs from the hot start analysis in that the receiver is not attempting to follow an anticipated power input profile. In this case the receiver is dictating the power input profile which it can accept. Figure IV.C-12 summarizes a possible cold start-up and shows the turbine start-up profile as well as typical receiver characteristics as a function of time after start. Although the analysis shows a start-up time of approximately 7.8 hours, it should be noted that this does not necessarily represent the fastest receiver start-up time.

4) Thermal Storage/Turbine Hot and Warm Starts - This analysis was conducted to determine the time required to bring the plant to design point operating conditions for both a hot (0 to 12 hours) and warm (12 to 72 hours) start, and to identify the energy required for each. Start-up time was defined as beginning when the turbine rolls off turning gear and ending when the turbine generator gross output reaches 7.6 MWe. The resultant start-up curves, as well as a summary of the results, are shown

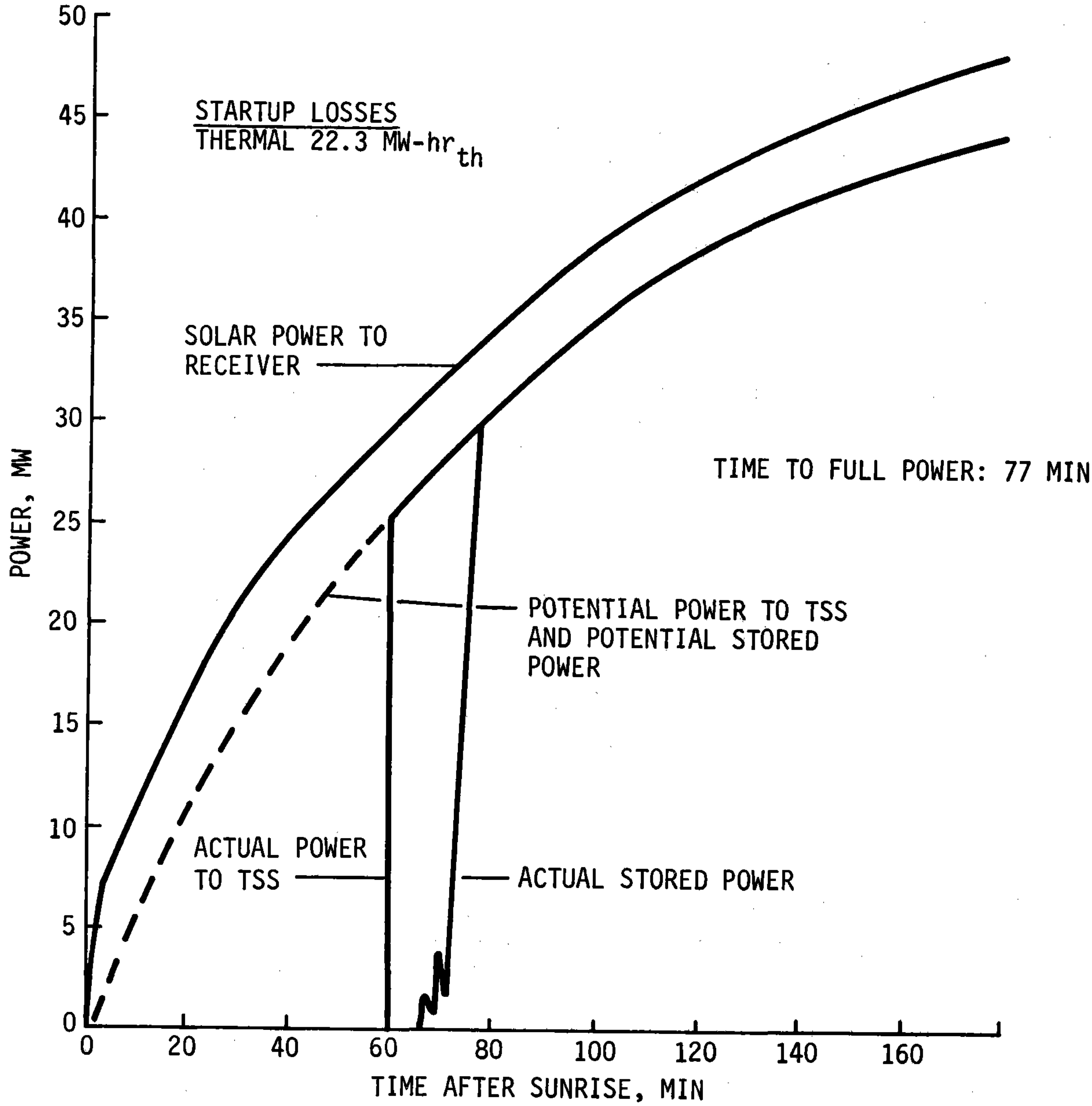


Figure IV.C-11 Hot Morning Startup - Receiver/TSS

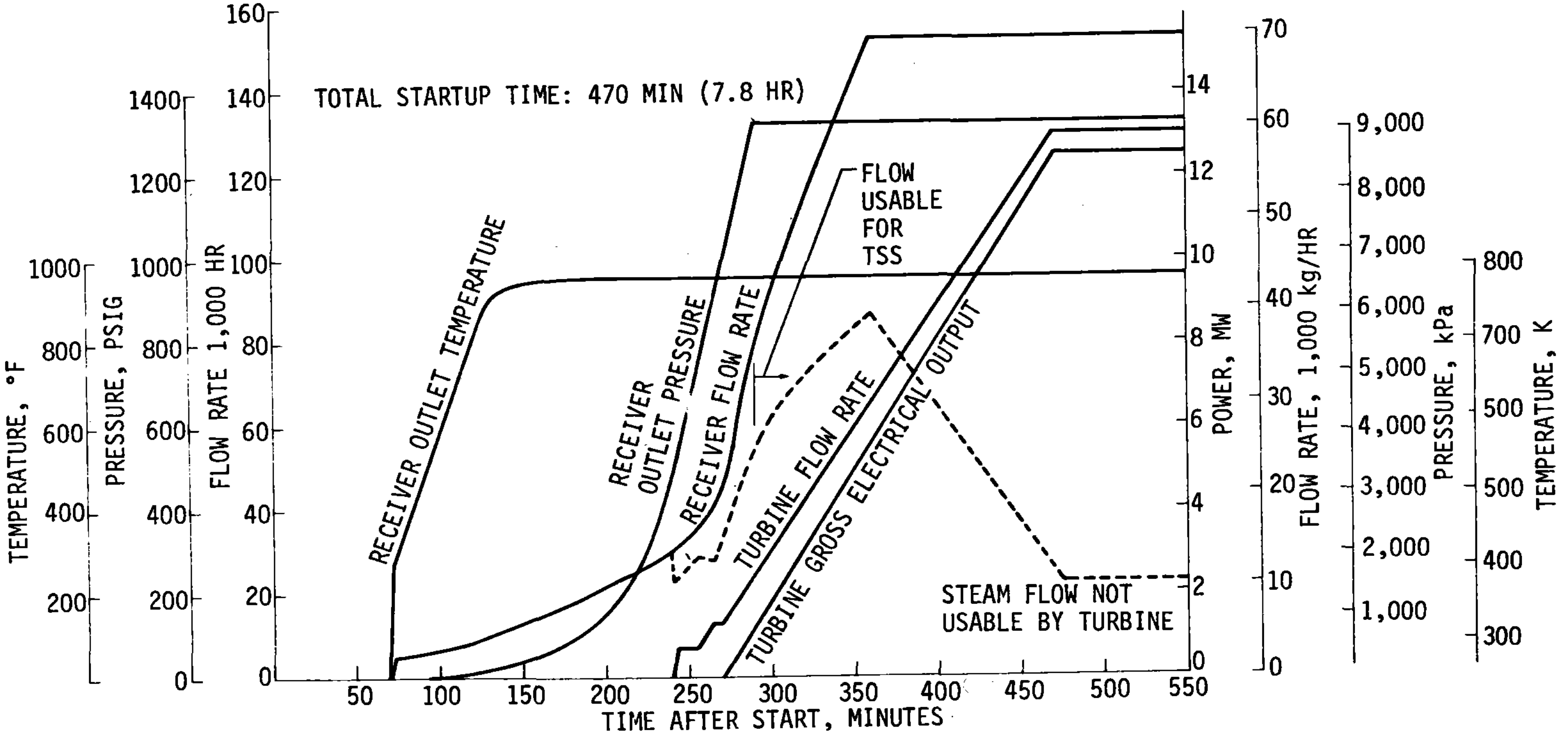
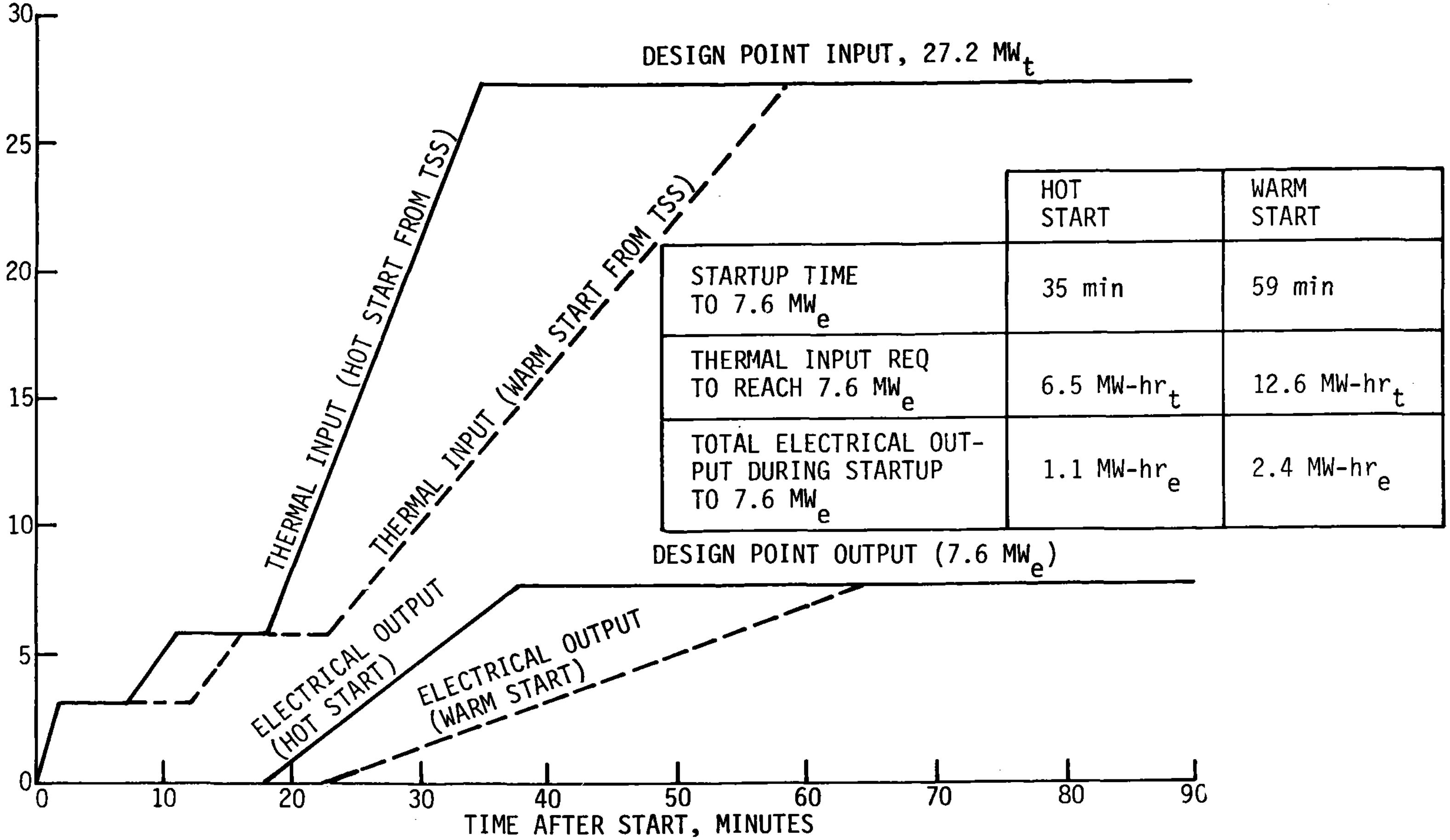


Figure IV.C-12 Receiver/Turbine Cold Start in Figure IV.C-13. The hot start from TSS required 35 minutes and required 6.5 $MW\text{-}hr_{th}$ and the warm start required 59 minutes and required 12.6 $MW\text{-}hr_{th}$

b. Daily Operational Analysis - In addition to the start-up modes discussed above, the plant must be capable of operating in various other modes of operation as well as making the transition from one mode to another as required by the load demand and insolation conditions. The overall plant efficiency depends not only upon the proper utilization of the various operating modes, but also upon the energy lost during mode transition, if any, and the response time of the subsystems.

In order to illustrate the operation of the pilot plant, and in response to a request from Sandia to analyze plant transient operation (Ref: letter from A. C. Skinrood to F. A. Blake, 02/25/77), pilot plant performance and operation has been analyzed for four complete days using the insolation profiles supplied by Sandia. The insolation profiles provided include a clear day (designated case A), a day with intermittant clouds in the afternoon (case B), a day with intermittant clouds and one cloud interruption in the morning (case C) and an intermittant day (case D). Pilot plant operation was analyzed for each of these days using the pilot plant computer simulation model assuming design point temperature and wind speed data. In each case the plant was started from a hot condition and thermal storage was assumed to be in a zero state of charge at sunrise. In all four cases receiver output steam is at rated conditions except during morning startup. The operational sequences selected for each case do not necessarily represent the most efficient nor the most typical. They were chosen to illustrate plant performance and represent one of many possible operational sequences for the type of day being analyzed.

1) Operational Analysis - Case A - A graphical summary of the analysis is shown in Figures IV.C-14 and IV.C-15. Frame A-1 of the figure shows the Sandia supplied insolation profile for April 13. With the exception of a slight dip at 0700, it is a clear day with sunrise at about 0640 and sunset at 1930. The operational sequence selected was to start the receiver and turbine with the sun and flow all available steam through the turbine for maximum power generation. When the steam flow exceeded the turbine maximum, the excess (and whatever additional was necessary to maintain minimum flow) was routed into thermal storage. As the insolation decreases in the afternoon the plant switches to load control to maintain a 7 MWe output. The plant operates at 7 MWe until thermal storage is depleted.



	HOT START	WARM START
STARTUP TIME TO 7.6 MW_e	35 min	59 min
THERMAL INPUT REQ TO REACH 7.6 MW_e	6.5 MW-hr_t	12.6 MW-hr_t
TOTAL ELECTRICAL OUTPUT DURING STARTUP TO 7.6 MW_e	1.1 MW-hr_e	2.4 MW-hr_e

Figure IV.C-13 Thermal Storage/Turbine Hot and Warm Start

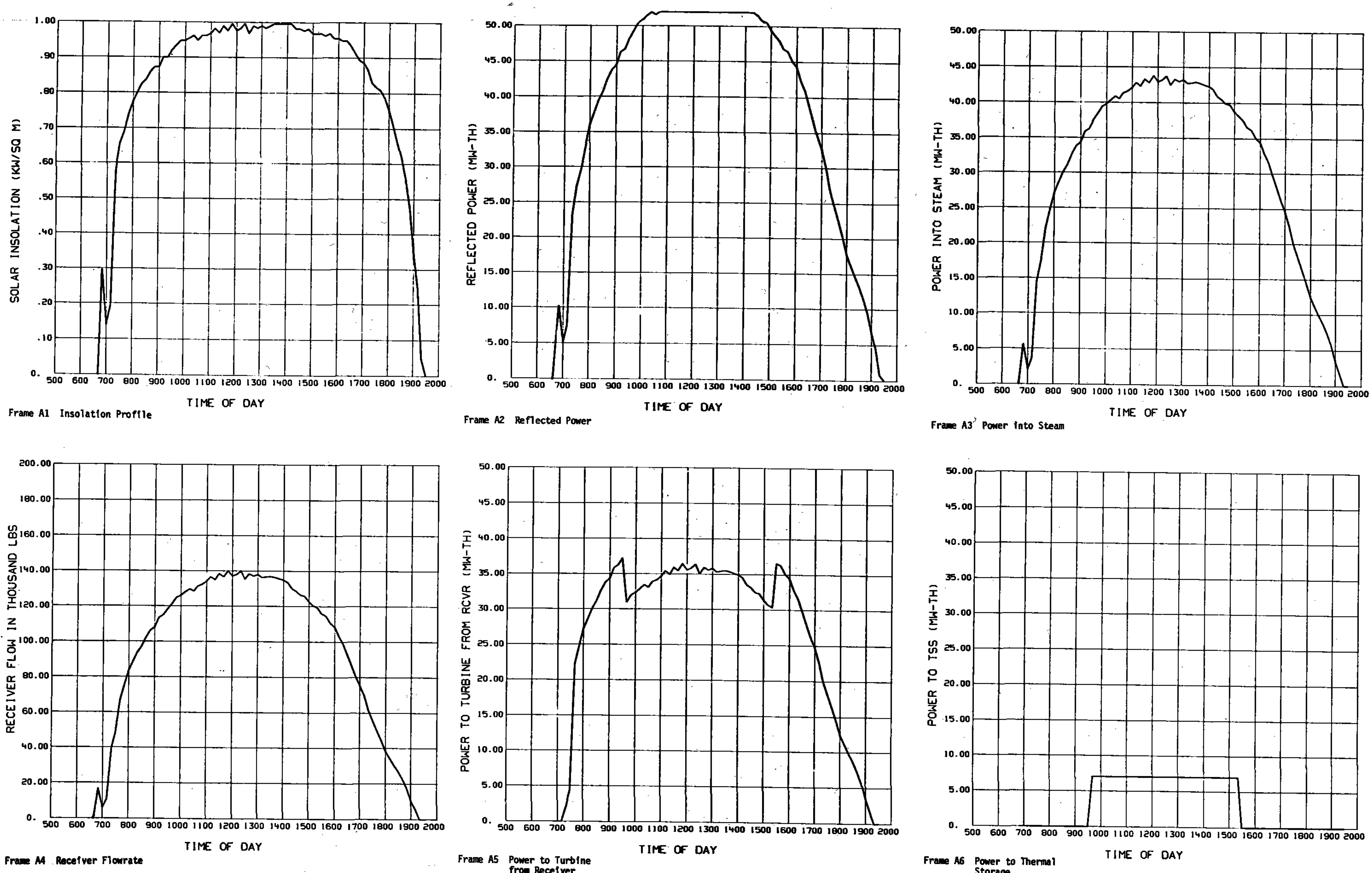
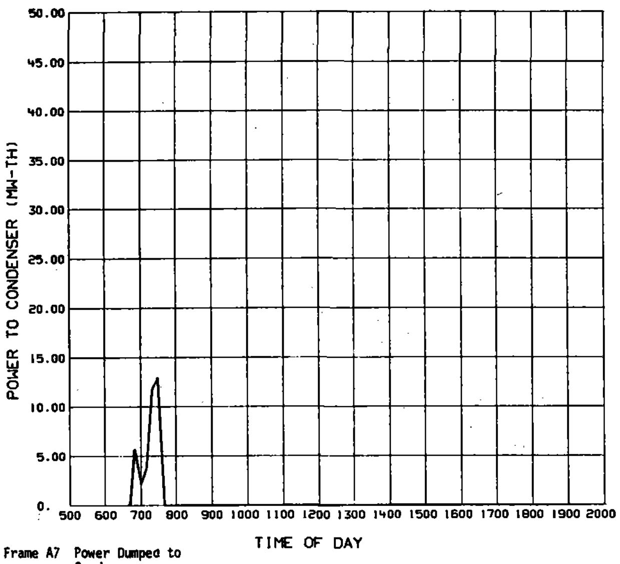
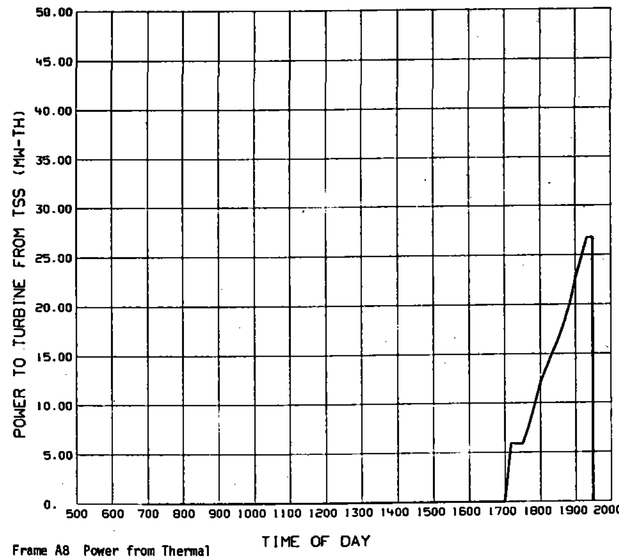


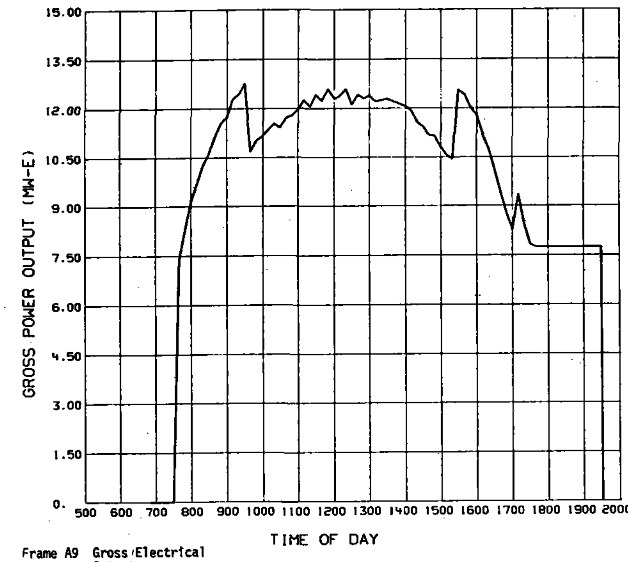
Figure IV.C-14.. Operational Analysis - Case A



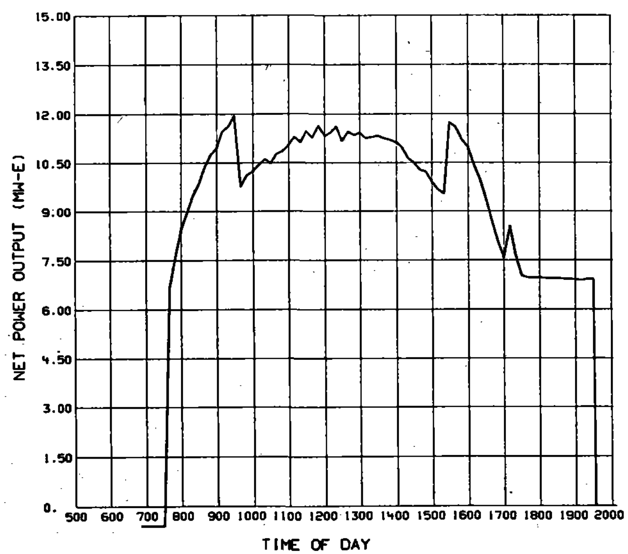
Frame A7 Power Dumped to Condenser



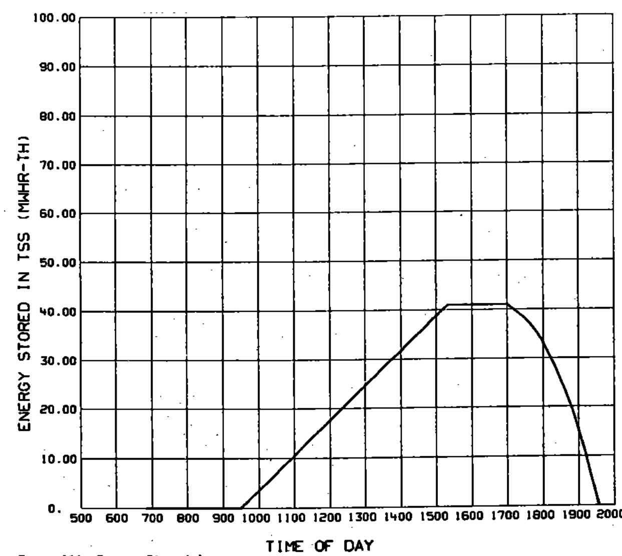
Frame A8 Power from Thermal Storage to Turbine



Frame A9 Gross Electrical Output



Frame A10 Net Electrical Output



Frame A11 Energy Stored in Thermal Storage

INYOKERN, CALIFORNIA

PILOT PLANT OPERATIONAL ANALYSIS CASE A

04/13/76

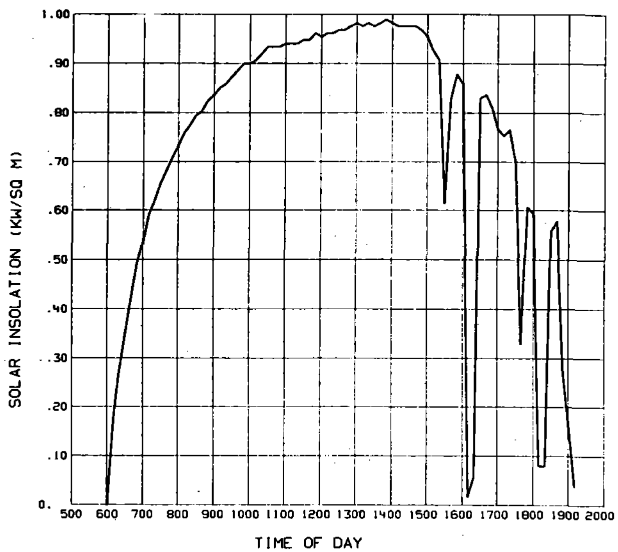
POTENTIAL ENERGY TO SYSTEM (MWHR-TH)	678.307
REFLECTED ENERGY (MWHR-TH)	505.954
ENERGY TO RCVR APERTURE (MWHR-TH)	428.642
ENERGY INTO STEAM (MWHR-TH)	389.760
ENERGY TO TURBINE FROM RCVR (MWHR-TH)	340.595
ENERGY TO TSS (MWHR-TH)	41.003
ENERGY TO TURBINE FROM TSS (MWHR-TH)	38.462
ENERGY DMPD TO CONDENSER (MWHR-TH)	6.039
NET ELECTRICAL OUTPUT (MWHR-E)	116.878
GROSS ELECTRICAL OUTPUT (MWHR-E)	127.667
FINAL TSS STATE OF CHARGE (PERCENT)	2.007
ENERGY REMAINING IN TSS (MWHR-TH)	1.829
NET CHANGE IN TSS ENERGY (MWHR-TH)	1.829
NET PLANT EFFICIENCY (PERCENT)	17.231
GROSS PLANT EFFICIENCY (PERCENT)	18.821

Summary Table

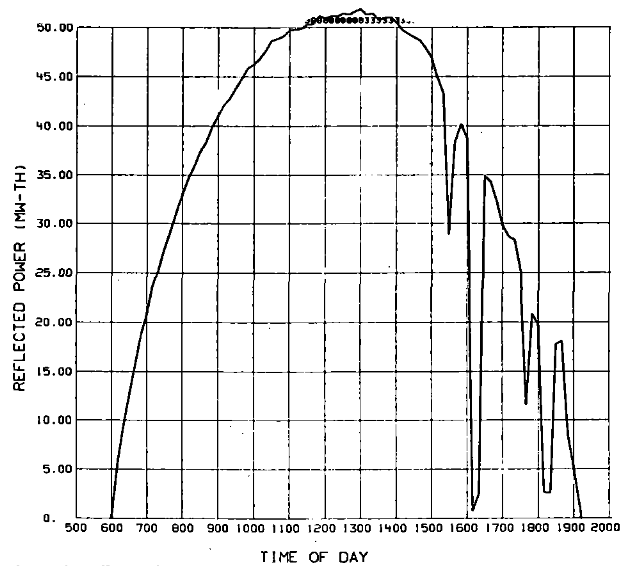
Figure IV.C-15. Operational Analysis - Case A (cont)

The receiver begins to accept power from the collector subsystem, Frame A-2, at 0640 and begins startup. The steam produced, Frames A-3 and A-4, from 0640 until about 0710 is unacceptable to the turbine and is dumped to the condenser, Frame A-7. The turbine begins accepting some of the steam at about 0710, Frame A-5, with the remainder being dumped to the condenser. Plant startup is complete at 0740, at which time the receiver steam is at rated conditions and the turbine is accepting all the receiver output. From 0740 the turbine accepts the final receiver output until the turbine maximum is exceeded at about 0940. At this time the minimum flow is routed to thermal storage, Frame A-6, with the balance continuing to the turbine. This transition is seen as a sharp dip in at about 0940 in Frames A-5, A-9 and A-10. Plant operation continues in this manner until about 1520 when the receiver flow falls below the maximum turbine flow; at this time thermal storage charging is stopped and the full receiver flow is again routed through the turbine. The energy stored in thermal storage during this period was approximately 41 MWt-hr as shown in Frame A-11. At about 1710 the plant switches to a load control mode to maintain a plant output of 7 MWe during the late afternoon. This mode transition causes a spike in the output at 1710 which is the result of the minimum thermal storage discharge flowrate, Frame A-8. The plant operates from receiver and thermal storage steam until the receiver output goes to zero at 1910. The turbine continues to operate on thermal storage steam until thermal storage is depleted and the turbine is shut down at 1930. The summary table in Figure IV.C-15 shows the net electrical output for the day was 116.9 MWe-hr with a daily net plant efficiency of 17.2%. The net plant efficiency is defined as the daily net electrical output divided by the potential energy to the system.

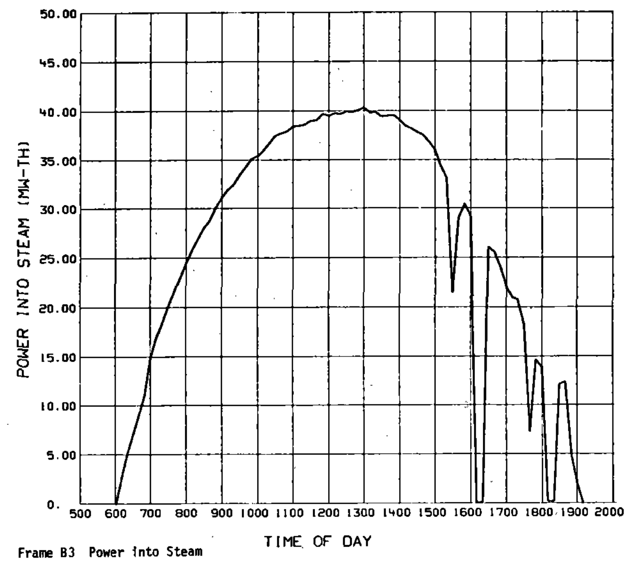
2) Operational Analysis - Case B - Figure IV.C-16 and IV.C-17 shows the graphical analysis of Case B. Frame B-1 shows the insolation profile for June 10. The day is clear until about 1500 and partly cloudy thereafter with sunrise at 0600 and sunset at 1910. The operational sequence selected for this day again started the receiver and turbine with the sun. After startup the plant output was maintained at 10 MWe (where possible), with the excess charging thermal storage until about 1300. At that time the load was reduced to 7 MWe and the mode changed to one of charging and discharging thermal storage. This mode was maintained for the duration of the day.



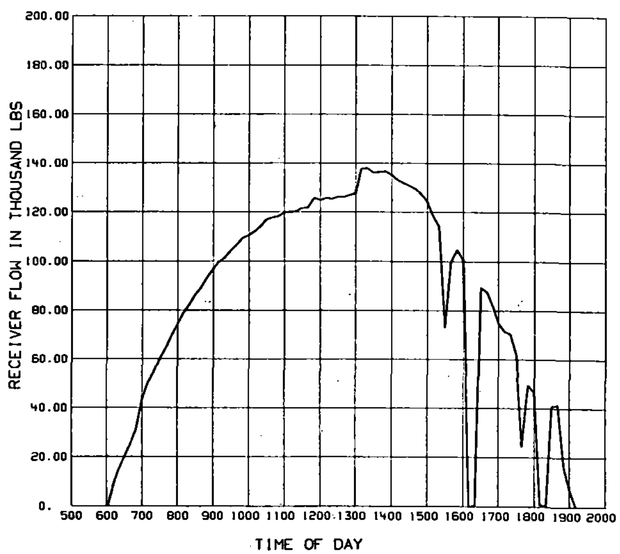
Frame B1 Insolation Profile



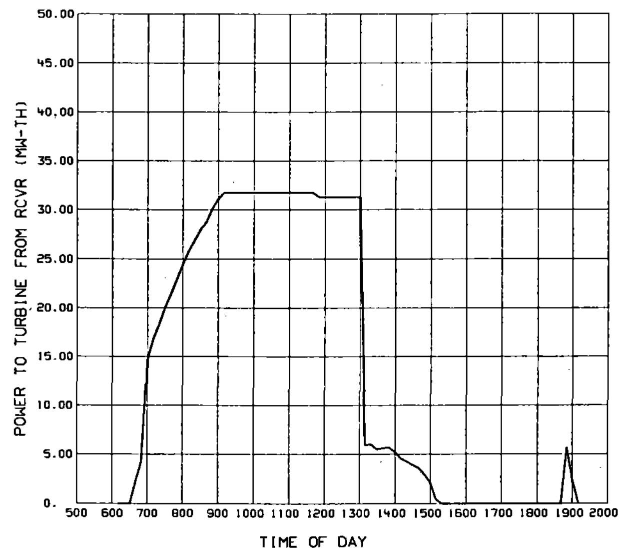
Frame B2 Reflected Power



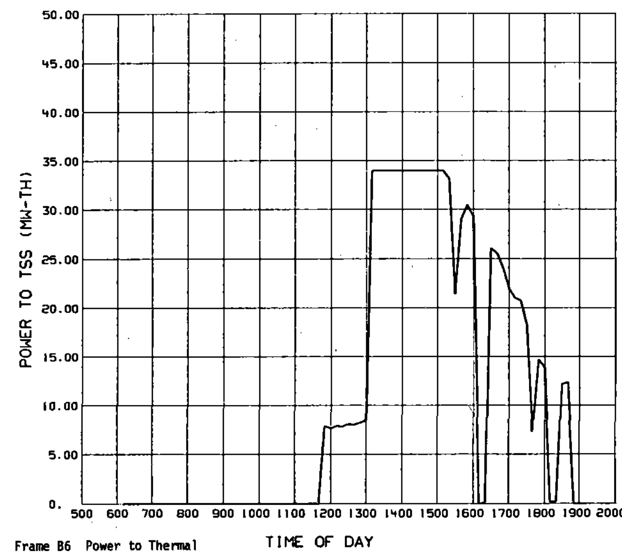
Frame B3 Power into Steam



Frame B4 Receiver Flowrate

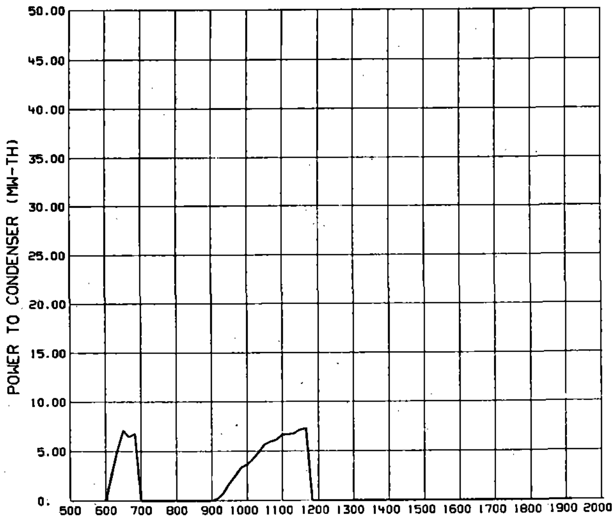


Frame B5 Power to Turbine from Receiver

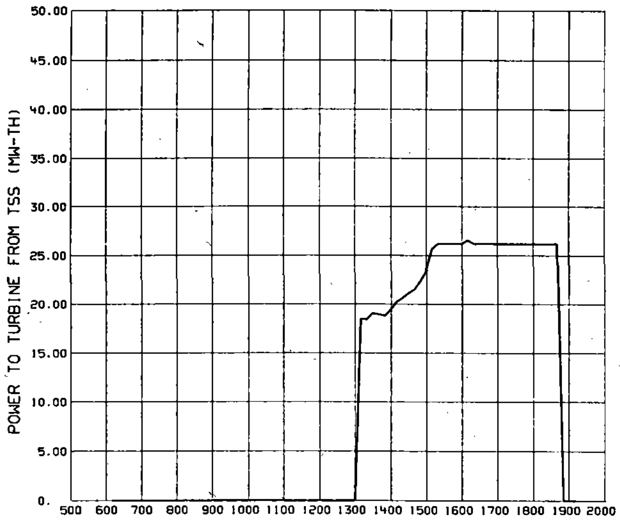


Frame B6 Power to Thermal Storage

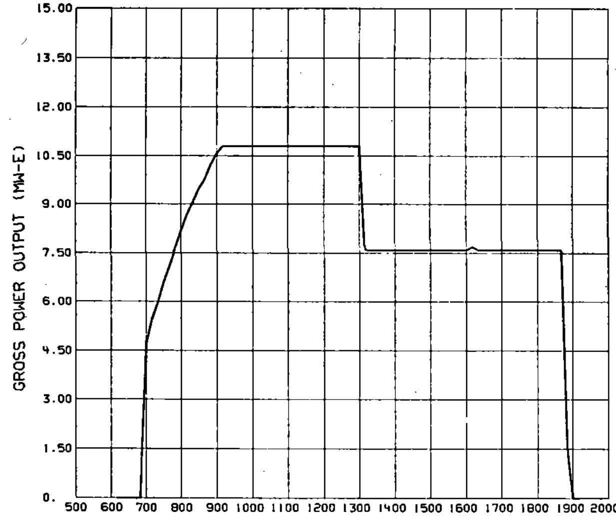
Figure IV.C-16. Operational Analysis - Case B



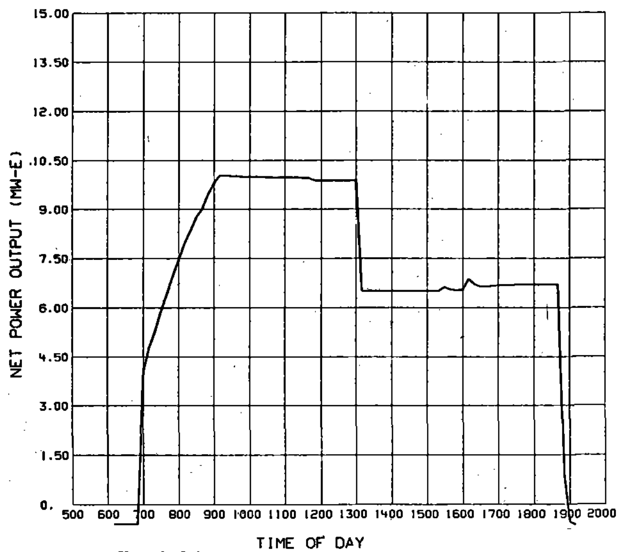
Frame B7 Power Dumped to Condenser



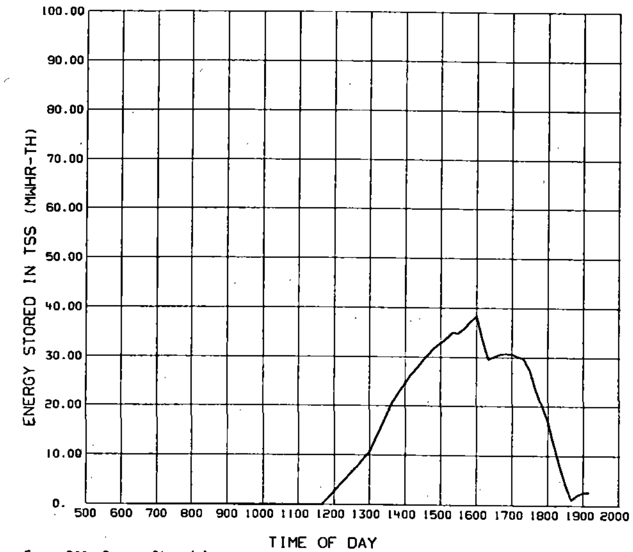
Frame B8 Power from Thermal Storage to Turbine



Frame B9 Gross Electrical Output



Frame B10 Net Electrical Output



Frame B11 Energy Stored in Thermal Storage

INYOKERN, CALIFORNIA

PILOT PLANT OPERATIONAL ANALYSIS CASE B

08/10/76

POTENTIAL ENERGY TO SYSTEM (MWHR-TH)	625.389
REFLECTED ENERGY (MWHR-TH)	467.548
ENERGY TO RCVR APERTURE (MWHR-TH)	396.105
ENERGY INTO STEAM (MWHR-TH)	351.421
ENERGY TO TURBINE FROM RCVR (MWHR-TH)	189.627
ENERGY TO TSS (MWHR-TH)	144.530
ENERGY TO TURBINE FROM TSS (MWHR-TH)	136.545
ENERGY DMPD TO CONDENSER (MWHR-TH)	16.932
NET ELECTRICAL OUTPUT (MWHR-E)	92.396
GROSS ELECTRICAL OUTPUT (MWHR-E)	103.742
FINAL TSS STATE OF CHARGE (PERCENT)	2.875
ENERGY REMAINING IN TSS (MWHR-TH)	2.621
NET CHANGE IN TSS ENERGY (MWHR-TH)	2.621
NET PLANT EFFICIENCY (PERCENT)	14.774
GROSS PLANT EFFICIENCY (PERCENT)	16.588

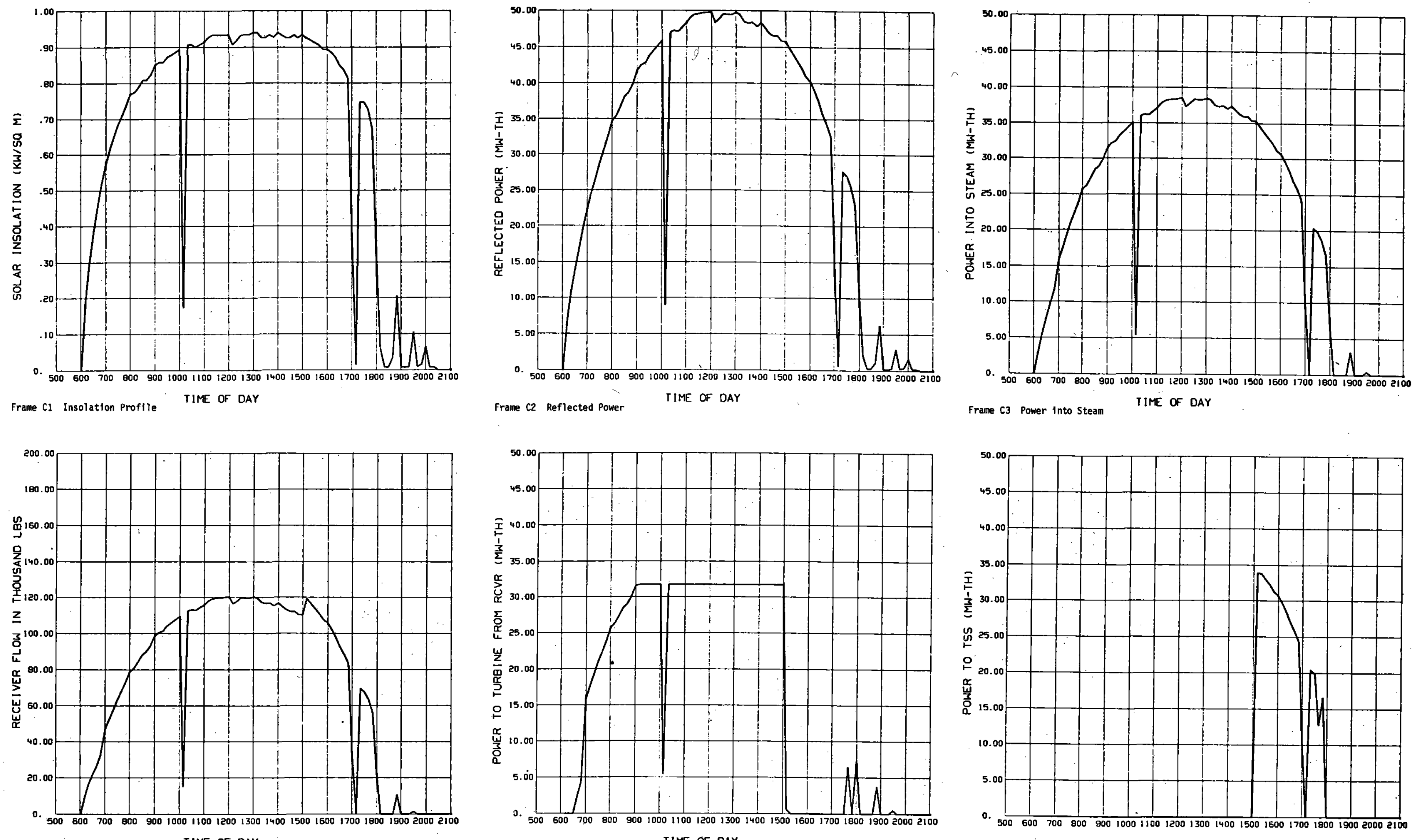
Summary Table

Figure IV.C-17. Operational Analysis - Case B (cont)

The startup sequence is essentially the same as Case A with startup beginning at 0600, turbine start at 0630 and startup complete at 0700. From 0700 until 0910 the turbine accepts the full receiver output. At 0910 the requested load of 10 MWe is reached and maintained. From 0910 until 1150 10 MWe is maintained and the excess receiver output is dumped to the condenser, Frame B-7, due to the fact that it is less than the minimum acceptable flow for thermal storage. At 1150 the excess flow reaches the thermal storage minimum and charging begins. At 1300, in anticipation of the cloudy afternoon, the system switches to the thermal storage charge/discharge mode and the load is reduced to 7 MWe. In this mode storage is charged with the receiver output steam up to the maximum charge rate, with the excess going to the turbine. The remainder of the turbine requirement is supplied by admission steam from thermal storage. Operation continues in this mode until 1910, at which time thermal storage is depleated. It should be noted that the electrical output remains stable throughout the afternoon in spite of the transient insolation. The summary table in Figure IV.C-17 shows the net electrical output for the day was 92.4 MWe-hr and the net plant efficiency 14.8%.

3) <u>Operational Analysis - Case C</u> - The analysis for Case C is shown in Figures IV.C-18 and IV.C-19. The June 20 insolation profile provided is shown in Frame C-1. The day is similar to Case B with the addition of an isolated dip in insolation at mid-morning. Sunrise is at 0600 and sunset at 2100. The operational sequence selected was the same as for Case B with the exception that the 10 MWe load was maintained until about 1500 instead of 1300 as in Case B.

The startup sequence is the same as A and B with startup beginning at 0600, turbine start at 0630 and startup complete at 0700. From 0700 until 0900 the turbine accepts the full receiver output. At 0900 the requested load of 10 MWe is reached and maintained, with the excess flow dumped to the condenser. A cloud passage from 1000 to 1020 causes a drop in receiver output. Since there is no stored energy in thermal storage at this time the plant output also dips, Frames C9 and C10. Following the cloud passage the receiver output and plant output recovers and operation at 10 MWe continues to 1500.



Frame C1 Insolation Profile

Frame C2 Reflected Power

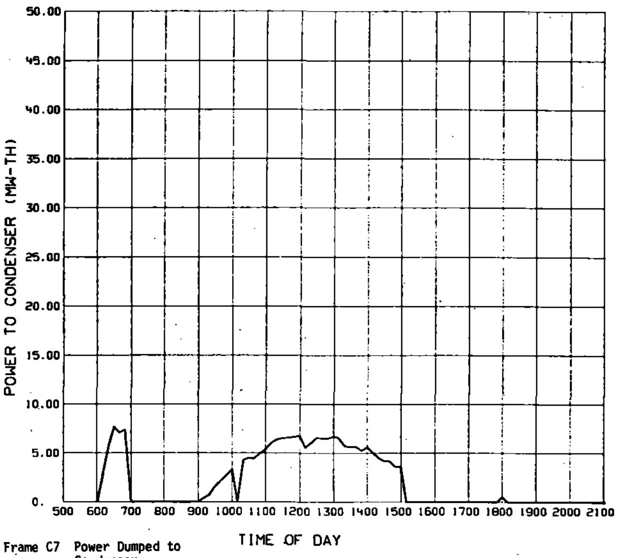
Frame C3 Power into Steam

Frame C4 Receiver Flowrate

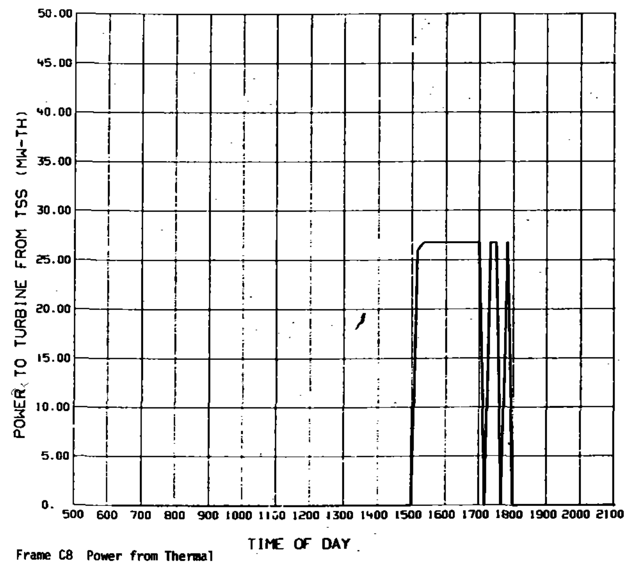
Frame C5 Power to Turbine from Receiver

Frame C6 Power to Thermal Storage

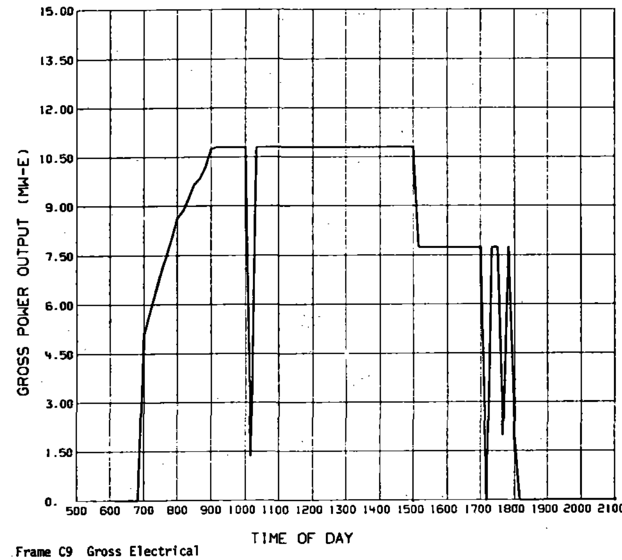
Figure IV.C-18. Operational Analysis - Case C



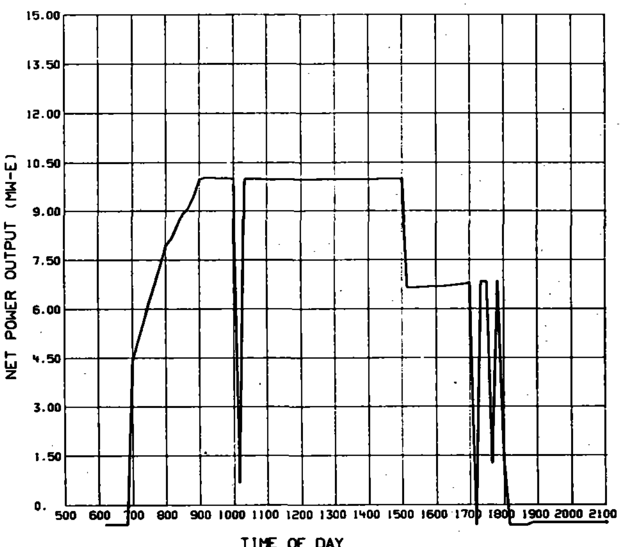
Frame C7 Power Dumped to Condenser



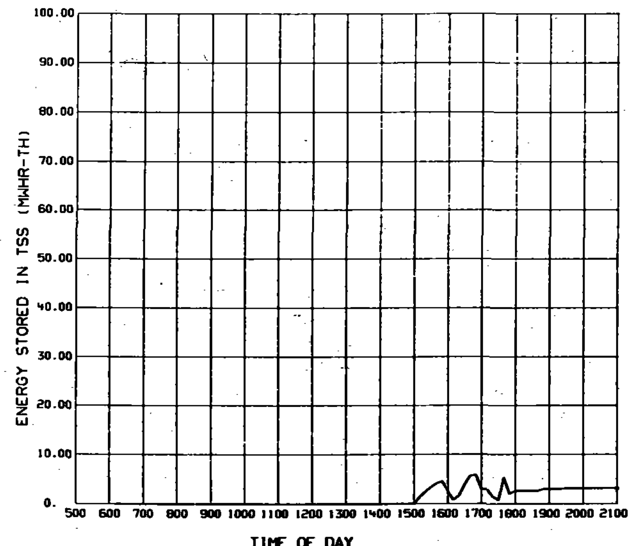
Frame C8 Power from Thermal Storage to Turbine



Frame C9 Gross Electrical Output



Frame C10 Net Electrical Output



Frame C11 Energy Stored in Thermal Storage

DAILY SUMMARY

INYOKERN, CALIFORNIA

PILOT PLANT OPERATIONAL ANALYSIS CASE C

06/20/76

POTENTIAL ENERGY TO SYSTEM (MWHR-TH)	610.832
REFLECTED ENERGY (MWHR-TH)	458.344
ENERGY TO RCVR APERTURE (MWHR-TH)	388.307
ENERGY INTO STEAM (MWHR-TH)	344.721
ENERGY TO TURBINE FROM RCVR (MWHR-TH)	243.105
ENERGY TO TSS (MWHR-TH)	68.373
ENERGY TO TURBINE FROM TSS (MWHR-TH)	66.750
ENERGY DMPD TO CONDENSER (MWHR-TH)	33.690
NET ELECTRICAL OUTPUT (MWHR-E)	89.271
GROSS ELECTRICAL OUTPUT (MWHR-E)	101.002
FINAL TSS STATE OF CHARGE (PERCENT)	3.400
ENERGY REMAINING IN TSS (MWHR-TH)	3.098
NET CHANGE IN TSS ENERGY (MWHR-TH)	3.098
NET PLANT EFFICIENCY (PERCENT)	14.615
GROSS PLANT EFFICIENCY (PERCENT)	16.535

Summary Table

Figure IV.C-19. Operational Analysis - Case C (cont)

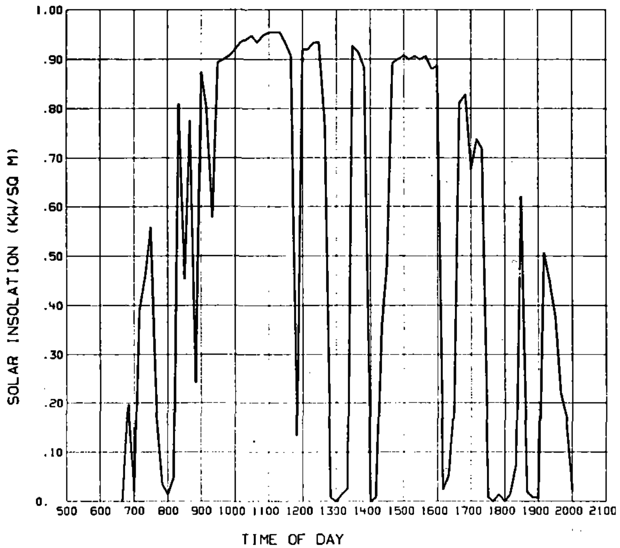
It should be noted that the excess receiver flow never reached the thermal storage minimum causing the excess to be dumped to the condenser. At 1500, in anticipation of the cloudy afternoon, the system switched to the thermal storage charge/discharge mode and the load was reduced to 7 MWe. However, at 1710, with the arrival of the first afternoon cloud, a turbine shutdown occurred due to lack of stored energy. The turbine was put back on line at 1720, was reduced to minimum load at 1740, returned to full load at 1750, minimum load at 1800 and final shutdown at 1810. It is clear that this is not a desireable way to operate the turbine and in actual operation the plant probably would have been shut down after the first turbine shutdown at 1710. This problem could have been avoided by altering the operating profile to allow some charging of thermal storage earlier in the day. The summary table in Figure IV.C-19 shows the net electrical for the day was 89.3 MWe-hr and the net plant efficiency 14.6%.

4) Operational Analysis - Case D - The analysis for Case D is shown in Figure IV.C-20 and IV.C-21. The July 13 insolation curve is shown in Frame D-1. The entire day is partly cloudy with sunrise at approximately 0620 and sunset at 2000. The selected operational sequence consisted of a delayed morning startup with operation for the remainder of the day in the thermal storage charge/discharge mode at reduced load.

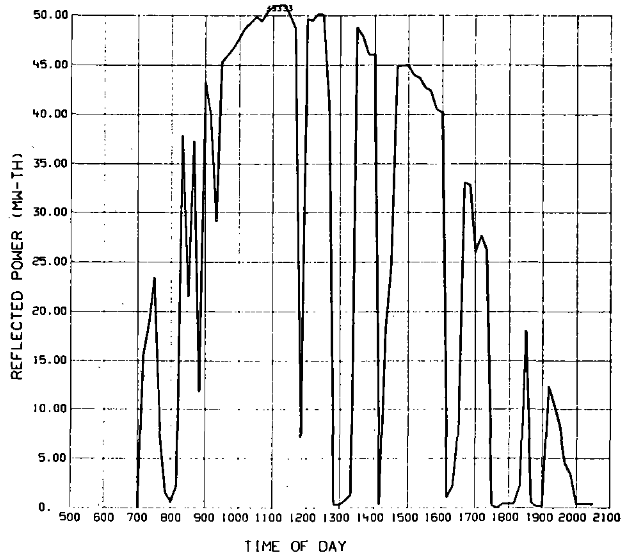
Startup was delayed until 0700 due to the intermittant insolation conditions. Turbine startup began at 0720 on the receiver and the requested load of approximately 4.5 MWe was attained at 0820 after the transition to thermal storage steam. The plant operated in the thermal storage charge/discharge mode for the remainder of the day maintaining a relatively stable output of approximately 4.5 MWe. Turbine shutdown occurred at about 2030 when thermal storage had been depleated. The summary table in Figure IV.C-21 shows the net electrical output for the day was 56.3 MWe-hr and the net plant efficiency 12.6%. This analysis shows that the pilot plant is capable of operating even under the highly intermittant conditions shown in Frame D1.

3. Emergency Operation

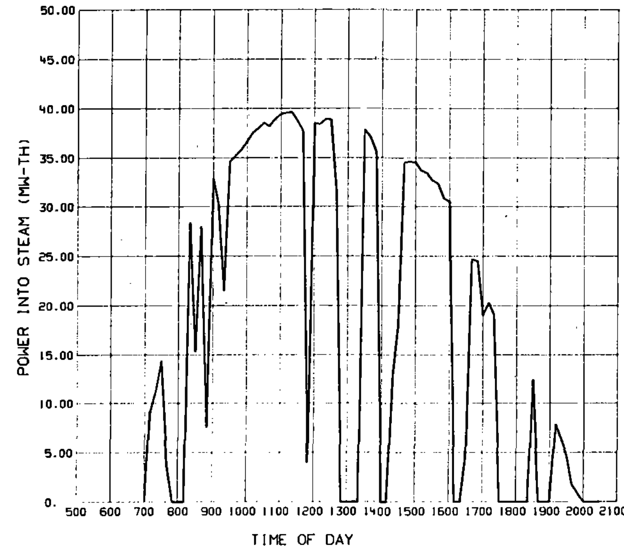
In addition to the normal steady state modes of operation and the transient and transition operation, there are also emergency conditions that the plant design must be capable of. Each subsystem is designed to react to out of limit fault conditions and provide for a safe shutdown. The safe shutdown of a particular subsystem



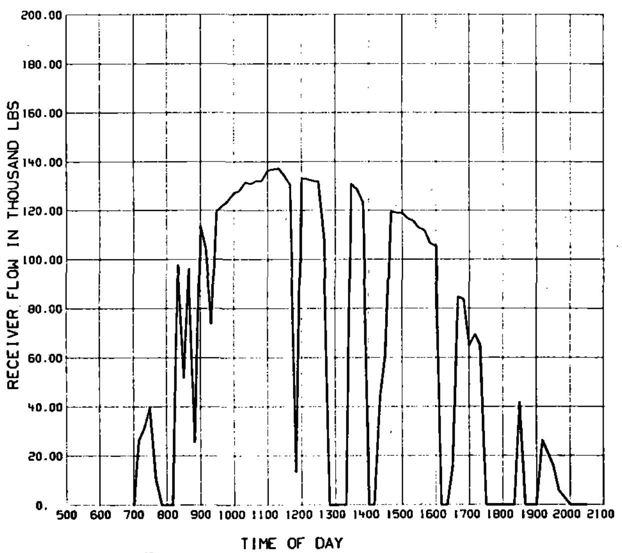
Frame D1 Insolation Profile



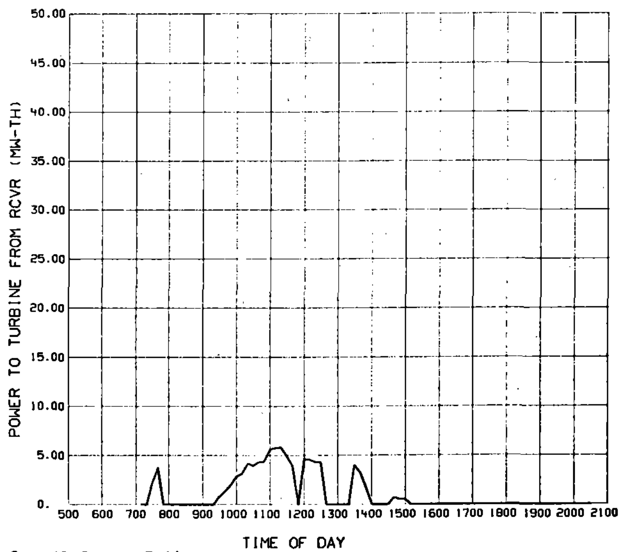
Frame D2 Reflected Power



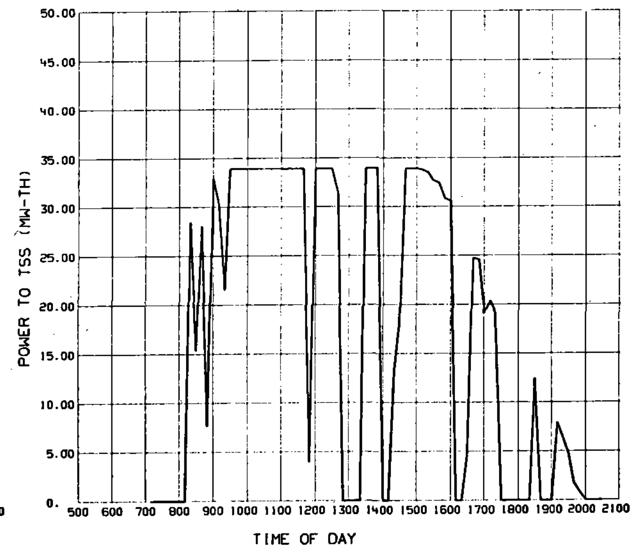
Frame D3 Power into Steam



Frame D4 Receiver Flowrate

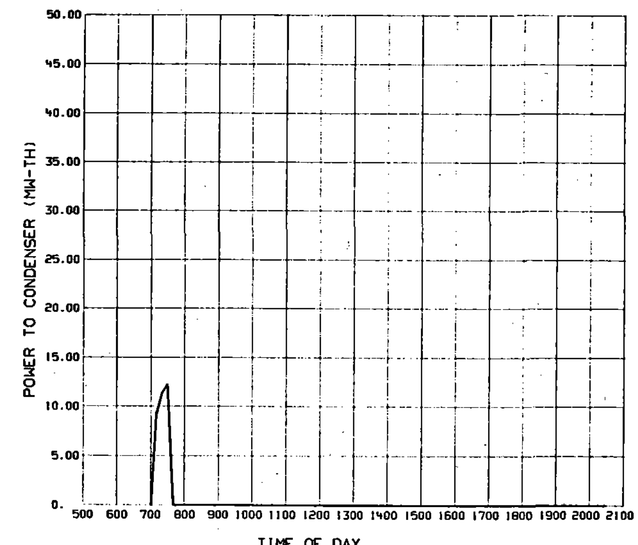


Frame D5 Power to Turbine from Receiver

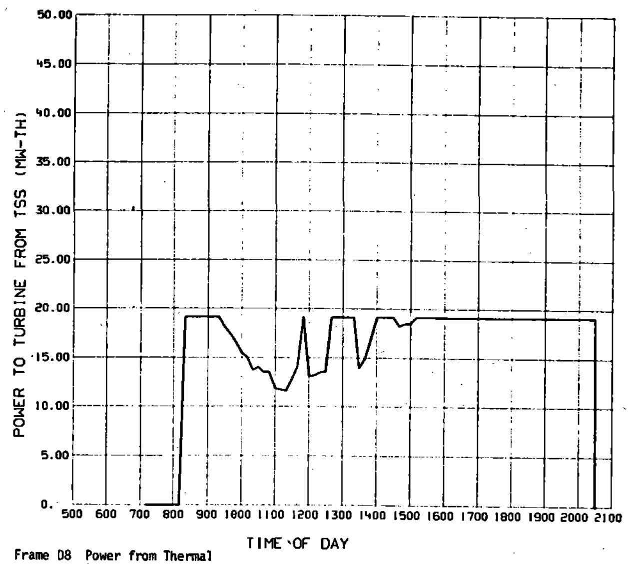


Frame D6 Power to Thermal Storage

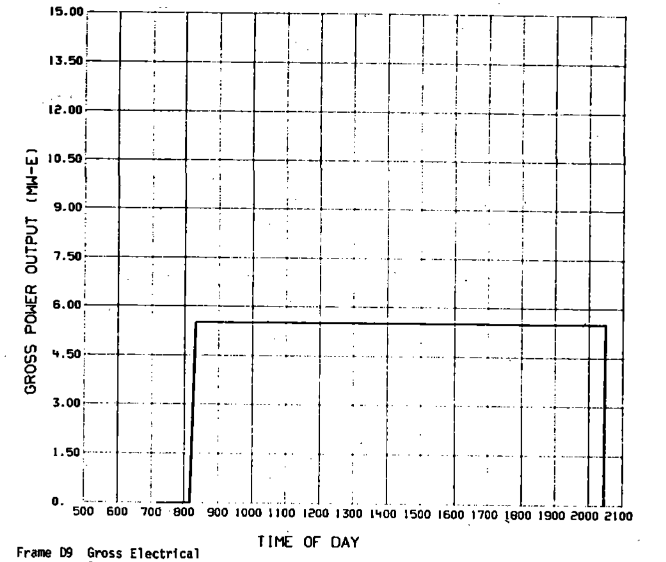
Figure IV.C-20. Operational Analysis - Case D



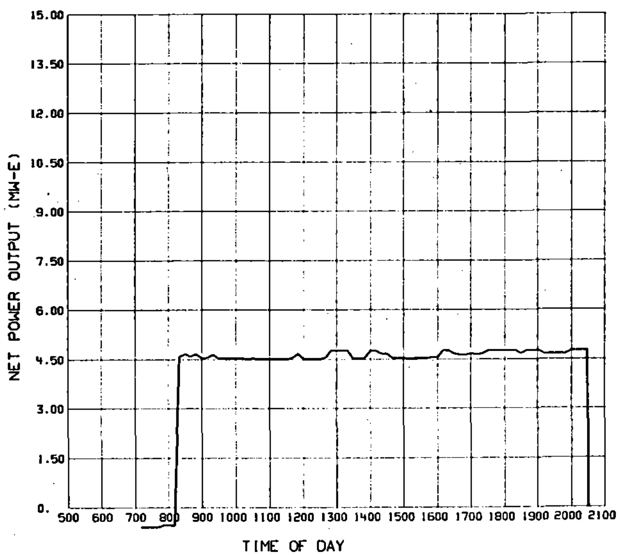
Frame D7 Power Dumped to Condenser



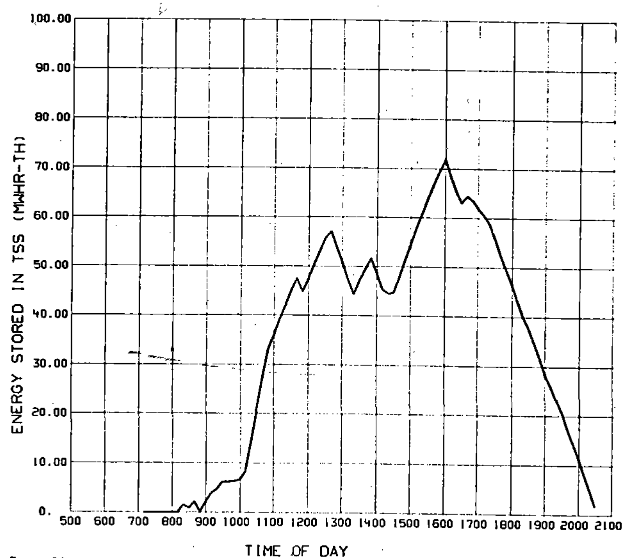
Frame D8 Power from Thermal Storage to Turbine



Frame D9 Gross Electrical Output



Frame D10 Net Electrical Output



Frame D11 Energy Stored in Thermal Storage

INYOKERN, CALIFORNIA
PILOT PLANT OPERATIONAL ANALYSIS CASE D
07/13/76

POTENTIAL ENERGY TO SYSTEM (MWHR-TH)	446.662
REFLECTED ENERGY (MWHR-TH)	344.560
ENERGY TO RCVR APERTURE (MWHR-TH)	285.122
ENERGY INTO STEAM (MWHR-TH)	250.949
ENERGY TO TURBINE FROM RCVR (MWHR-TH)	14.558
ENERGY TO TSS (MWHR-TH)	230.902
ENERGY TO TURBINE FROM TSS (MWHR-TH)	218.195
ENERGY DMPD TO CONDENSER (MWHR-TH)	5.458
NET ELECTRICAL OUTPUT (MWHR-E)	56.344
GROSS ELECTRICAL OUTPUT (MWHR-E)	67.823
FINAL TSS STATE OF CHARGE (PERCENT)	1.866
ENERGY REMAINING IN TSS (MWHR-TH)	1.700
NET CHANGE IN TSS ENERGY (MWHR-TH)	1.700
NET PLANT EFFICIENCY (PERCENT)	12.614
GROSS PLANT EFFICIENCY (PERCENT)	15.184

Summary Table

Figure IV.C-21. Operational Analysis - Case D (cont) may or may not effect another subsystem. If necessary, depending on the mode of operation and status of the plant, a shutdown of the total plant may result. The emergency condition resulting from the loss of the utility grid in combination with fault conditions that trip out the EPGS is discussed below.

In the event of loss of the normal source of power to the auxiliary electrical equipment in the power plant, harm to personnel and/or damage to equipment could occur unless backup power sources are provided. Two sources of backup power are provided to preclude this danger. A standby diesel generator is provided to prevent either harm to personnel or damage to equipment if power is lost. In addition, an emergency battery is provided to preclude harm to personnel during the startup period of the diesel generator or if there is a malfunction in the diesel generator. During normal operation, power is provided to the electrical equipment by the power plant itself or the utility grid, depending on the mode of operation.

a. Auxiliary, Standby, and Emergency Loads - The electrical power requirements of the power plant can be categorized into auxiliary, standby, or emergency loads for purposes of defining the requirements of the backup power sources. The auxiliary loads are all power plant loads, including the standby and emergency loads. The auxiliary loads vary depending on the operating mode of the plant. These loads are made up of power requirements from the collector, receiver, thermal storage, electrical power generation and controls subsystems. Standby loads are those required to place and maintain equipment in a safe condition. These loads are a part of the auxiliary loads and may be supplied by a standby diesel generator when power to the plant is lost. Emergency loads are required for personnel safety and critical plant loads that require continuous power. These loads are a portion of standby loads and are supplied by an emergency battery in parallel with, but isolated from, the normal sources of power for the auxiliary loads and the standby diesel generator.

b. Normal and Emergency Power Operation

1) Normal Daily Operation - During normal daily operation, the power plant supplies power required for auxiliary loads and the net power generated is supplied to the utility grid. The utility grid supplies power to the plant auxiliary equipment for morning startup, evening shutdown, overnight operations and other periods when the main generator is not

operating. This power is drawn from the utility grid through the main transformer and circuit breaker as shown in Figure IV.C-22. The 13,8 kV switchgear than distributes the power to the two load center units where it is stepped down to 480 V and distributed to the required auxiliary loads.

During morning startup, the main generator is brought up to rated voltage and speed. After it is synchronized with the 13.8 kV main bus, the generator circuit breaker is closed, thereby paralleling the unit with the utility power grid. The generator is then controlled to supply the pilot plant auxiliary loads and transmit net power to the utility grid.

2) Emergency Condition - Abnormal occurrences which cause automatic starting of the diesel generator are divided into three categories, as follows:

- o Loss of all normal power supply (i.e., main generator and offsite utility supply)
- o Load rejection
- o Loss of main generator

Several possible causes for loss of all normal power supply are storm, earthquake, fire, or main turbine generator trip due to instability following a load rejection. Immediately upon loss of the 13.8 kV switchgear bus voltage, sensing circuitry detects the power loss, and within 0.5 seconds, signals operate the compressed air line solenoid to start the standby diesel generator, and open the normally closed essential load bus tie breaker. During the diesel generator startup period of about ten seconds, or if the diesel fails to start, the emergency battery will supply all loads on the 125 Vdc bus, for periods of up to one hour. As the output of the battery charger fails due to the loss of power, the battery immediately takes over and continues an uninterrupted supply of power to the emergency DC loads. Additionally, power to the uninterruptable power source (UPS) inverter serving the plant computer and emergency AC loads will be supplied by the battery. As soon as the diesel generator is up to speed and ready to accept the load, the normally open diesel generator breaker closes, supplying power to all loads required for an orderly plant shutdown, and recharging the battery.

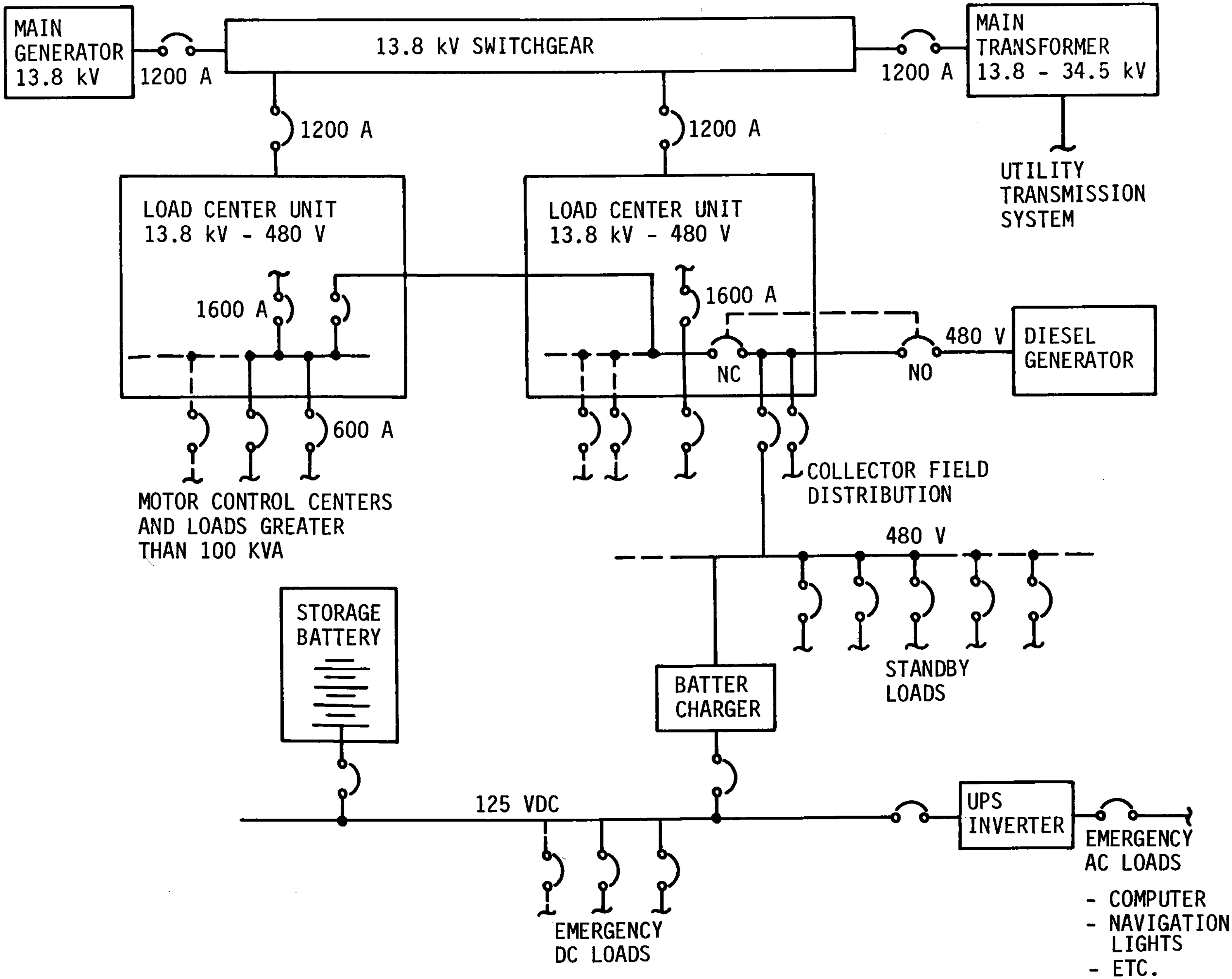


Figure IV.C-22 Electrical System Block Diagram

In the event of a load rejection or turbine-generator trip, the diesel generator will be automatically started as described above, and will remain in a standby mode, should it be required.

Once the diesel generator has started and has been brought on line, it will supply loads up to 250 kV for up to 48 hours. If it is determined that a longer run time will be required, additional fuel will need to be trucked in. Upon resumption of the utility grid power tie, it will be necessary to manually shutdown the diesel generator and reset the 1600 A load center main circuit breakers and the 600 A essential load bus tie breaker, thereby restoring normally supplied power.

After the standby diesel generator has come up to speed and assumes its standby loads, plant safing actions will begin. If this occurs during normal daytime operating conditions, the turbine-generator, condenser, and feedwater pumps will stop. Using the residual water in the boiler drum, steam will continue to be generated until the heliostats are removed from the receiver cavity. This steam will be vented to the atmosphere since the condenser is not operating, therefore, the initial sequence to be performed on standby power includes defocusing the heliostats off the receiver aperture and stowing, sealing off the thermal storage subsystem, closing the receiver doors, and sealing off the receiver subsystem. Appropriate computer routines control the collector field to limit the maximum demand to 100 kVA during an emergency stow operation.

4. Plant Control System

As in a conventional power plant, operation of the 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. Volume VI defines the master control system (MCS), its requirements, functions, and interfaces with other elements of the plant. In our design of the controls, we have developed a system which is simple, is user oriented, and a system which employs state of the art hardwired control logic to the degree possible. As we have defined the master control system, it is comprised of the independent control elements for each of the four subsystems, an integrating element, the plant control system (PCS), and a data handling system (DHS).

The receiver subsystem, thermal storage subsystem, and electrical power generation subsystem are all controlled with conventional hardwired logic and controllers. The heliostats are controlled by a digital computer, and that control represents the only computer controlled element of the pilot plant. Because of the critical nature of heliostat control, the collector subsystem (CS) control computer is backed-up by the data handling system computer. In the event of a CS control computer anomaly, the CS 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. Each individual heliostat will maintain control in the event of loss of control commands from the computer, and the heliostat will automatically stow itself. The rationale for the general design of the master control system stems from the character of the pilot plant itself and its operating characteristics. By industry standards, the plant is small (10 MW), and elaborate controls are not required. As we have said, control of the heliostats is sufficiently complicated to require computer control. However, by design, the remaining controls are simple enough to be easily implemented with conventional hardwired logic control devices. This approach results in an overall system which is simpler than one which is controlled exclusively by a computer; it is more reliable; and it is a lower cost system.

a. General Requirements - To assist the control operators in their operation of the plant, the MCS will:

a. provide the capability to the control operators to safely control the entire plant operations for all modes and for transitions between modes;

b. detect, alarm, and respond to emergency conditions;

c. acquire, process, store and retrieve, and output data for all plant elements. Processing includes production of logs, summaries, and performance calculations.

The MCS, then, encompasses all control elements of the plant as well as the data handling and data logging functions. We should emphasize that the data handling system has been designed to be completely independent of the controls. That is, if the DHS were removed, the plant control activities would continue unaltered.

b. MCS Definition - Figure IV.C-23 is a simplified schematic of the major elements of the pilot plant. In this figure, "boxes" represent functional elements of the plant; for example, "TSS" represents the entire thermal storage field hardware, and "TSS controls" represents the TSS control logic which resides predominantly in the control building. The arrows (and "bubbles")

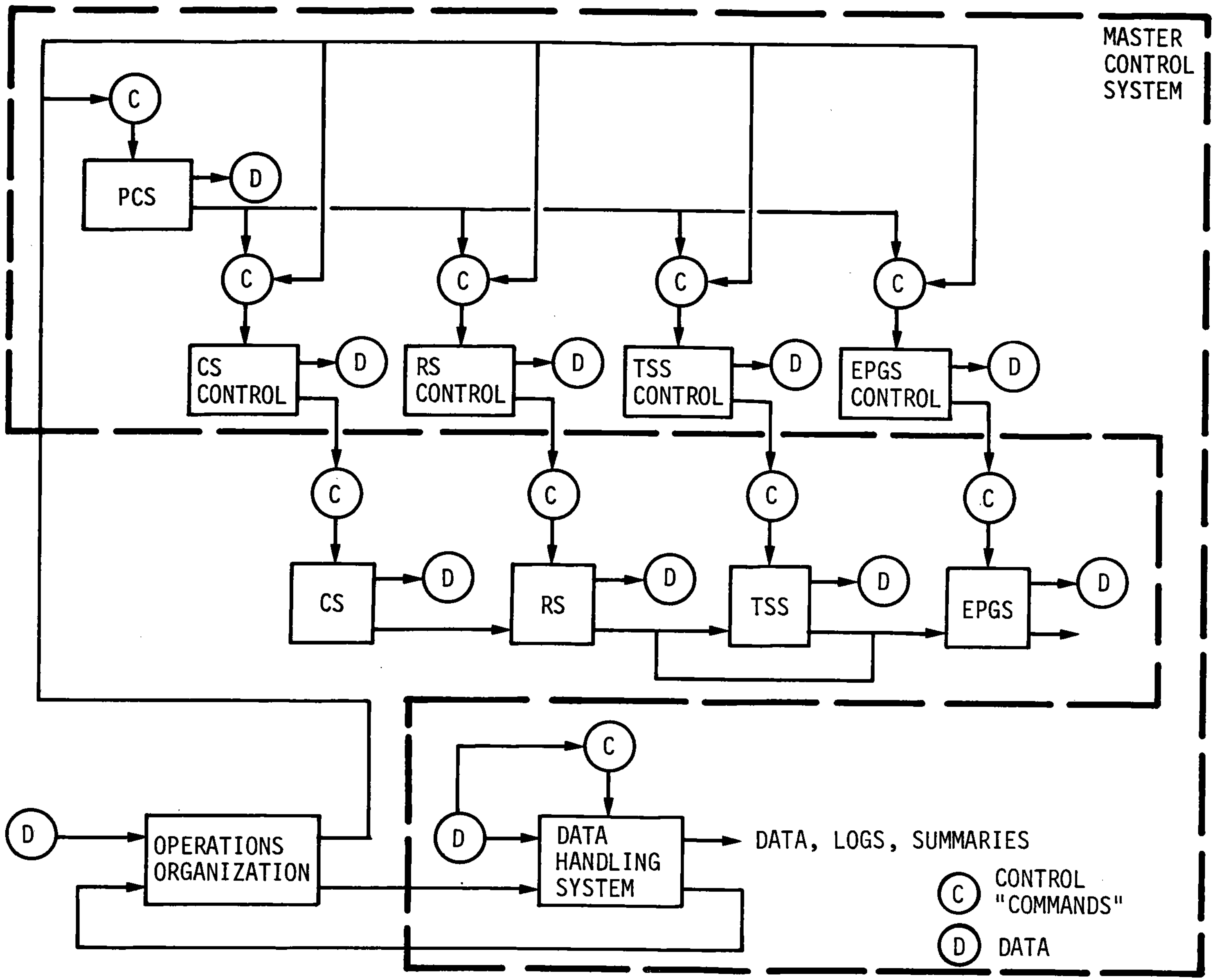


Figure IV.C-23 Pilot Plant Schematic Defining Master Control System represent interfaces between the functional elements. The basic flow of the plant--from sunlight to electrical power--is represented by the arrows proceeding from the collector subsystem (CS), to receiver subsystem (RS), to thermal storage subsystem (TSS) and/or the electrical power generation subsystem (EPGS). The source of control of each functional element is indicated by the interface arrow pointing to the top of each box. The master control system is defined to be all of the plant elements contained within the heavy dashed lines of Figure IV.C-23.

A few notable features are implied by Figure IV.C-23. Each of the subsystems is controlled exclusively by its own control element. These four control elements are, in turn, controlled--"orchestrated" would be a more appropriate term--by the plant control system. The 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 PCS serves the functions of system level coordination, sequencing, and system level response to emergency conditions such as a turbine trip. The concept of maximizing controls within the subsystem control elements is consistent with the pilot plant design and construction philosohpy in which each subsystem and its controls derive from separate contractors. Integration of the subsystems' controls is accomplished, then, by the PCS.

Another significant feature shown by the figure is the operations organization; that is the control operators. Each control element in the MCS is directly under manual control of the control operators. In all senses, the operators run the plant assisted by the MCS.

c. Pilot Plant Master Control System Features - Based on considerations of the pilot plants operational cycle and the functions which each subsystem's controls and the PCS must perform, the following six features of the MCS were established:

1. The Master Control System provides a capability enabling the pilot plant control operators to safely control plant operations.

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

3. The Master Control System 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 (by the PCS).

4. The Master Control System provides a capability to orchestrate system level operations by control through subsystem control elements.

5. Integrated pilot plant operations are accomplished by manually implementing written procedures which define operational profiles and sequences for steady state mode control and for transitions between modes.

6. The collector subsystem control computer is backed up by the redundant Data Handling System computer.

These features have guided the design process for the pilot plant controls--the master control system.

5. Safety Considerations

The Pilot Plant presents hazards that are unique to Solar Thermal Power applications and they have been evaluated for hazard reduction and/or control during our design selection processes. The most significant Pilot Plant hazards which have required specific design attention are related to concentrated solar beams and addressing beam movement, system control, structural damage, operating personnel injury, and elimination of general public exposure hazards. Hazards considered typical or common to similar industrial facilities which are covered by federal, state and local regulations or codes are not discussed as their elimination on control by specific requirements are mandatory. Pilot Plant hazards associated with Solar Thermal Power are summarized as follows:

a. Solar Beam Movement and Control - The inherent potential to damage unprotected structures and cause serious injury to personnel has been and will continue to be evaluated for safe beam control and personnel protective applications for the Pilot Plant. The safe beam control design options that were evaluated for use during the control system selection are as follows:

(1) Heliostat vertical positioning for beam blocking
(2) Structural fence/wall/target surface
(3) Controlled Beam Movement Corridor (PATH)
(4) Land Acquisition - No positive beam control
(5) Heliostat shutters/covers
(6) Physical defocus/diffuse
(7) Eliminate/turn-off sun during maneuvers

The control system selected is based upon option (3) using full-time control of beams with their movement held to a prescribed beam corridor during stow or acquisition maneuvers. By using option (3) as the basic control method and obtaining some effective beam blocking (option 1) by selective heliostat stow/acquisition commands, overall heliostat beam control is maintained. Option 2 is not used at this time but can be added for additional protection of the facility area and operating personnel if required, Options (4) through (7) were not considered necessary based upon the positive system control and fail-safe capabilities incorporated into the selected computer control system.

The control system provides full-time positive control of beams to and from the receiver for all operating modes and stow position. During all normal power mode operations the beams are moved on and off the receiver, as required, to an azimuth offset standby position. The standby position movement off of the receiver is the first command to all heliostats, for receiver protection, in a stow sequence. From the standby position selected heliostat groups are then moved within the established beam corridor to a safe beam position (beam on the ground) using both azimuth and elevation movements to a final stow position. Acquisition is accomplished by reversing the stow maneuvers outlined above.

The proposed layout of the Pilot Plant facility has determined our initial selection of beam corridors but these will be adjusted during final design to optimize position and control of the beams. The final selected stow maneuvers command sequence will be evaluated to ensure that the progressive blocking effect by the front rows of the far rows provides additional protective capability. The collector field stow maneuvers controlled by this selected method will not allow: (1) beam movement up or down the tower; (2) movement through normally occupied areas; or (3) concentrated ground reflections in excess of the defined perimeter of the Pilot Plant facility. By use of this control system we have assumed the plant area and all property external to the site will be considered beam protected areas.

b. <u>Beam Control Failure Modes</u> - Potential failure modes that may occur during Pilot Plant operations effecting beam control and safety are as follows:

(1) Loss of normal power (main generator or offset utility supply)
(2) Loss of Computer Control
(3) Individual Heliostat Component Failure

All of these failure modes have been evaluated and adequate design precautions have been taken to eliminate any safety hazards from their occurrence. Loss of normal power to the facility has no effect on safety. Its only effect is an operational constraint based upon the standby diesel generator load capability which requires a longer time internal to perform a collector field stow maneuver. Computer control is not lost during this mode and the system safe status is maintained.

Loss of master computer control to any individual heliostat or the entire field due to failures for any reason initiates a fail-safe capability at the individual heliostat control microprocessor. The microprocessor, upon loss of a control signal, will initiate a controlled stow maneuver to its heliostat in the same manner as a normal stow maneuver command. Therefore, loss of control initiates stow the same as issuance of a descrete command to stow and a hazardous beam condition should not occur due to this failure mode. The only difference between a control signal loss initiated stow maneuver and a directed stow maneuver is the orderly selection of heliostats during the maneuver is not controlled. The occurrence of a total field loss of control should be low with the loss potential occurring in groups or at individual heliostats as the more likely failure mode. None of these failure modes should present a serious safety hazard.

Failure of an individual heliostat component will be indicated at the master control area as a heliostat non-response and corrective action by operating personnel can then be initiated. Total failure of an individual heliostat is not considered a serious safety problem as personnel can repair/replace components or manually stow a heliostat to eliminate random pointing of the beam.

c. Receiver/Tower Hazards - The Receiver/Tower has three directly related hazards as a result of being illuminated by concentrated solar beams.

Illumination of the receiver surfaces produces a strong re-radiated light source which will be visible at the aperture when viewed from the north of the tower.

The illuminated surfaces are not viewing hazards to the general public who are outside of the field perimeter. It is a viewing hazard to operating personnel near the tower if they fix upon the source for extended periods without eye protection. This hazard is considered to be a normal solar plant operating hazard and will be controlled by use of eye protective equipment and personnel training.

Exposure of personnel working in the vicinity of the receiver to strong illuminated surfaces by concentrated solar beams is a potential hazard that will be controlled by tower access interlocks and personnel access controls. The remaining receiver/tower hazard is the potential of damage to the receiver and/or tower surfaces by spot concentrations of solar flux which could cause damage to structures or personnel from falling material. This hazard will be operationally controlled by the master control system interfaces between the receiver and the collector system controls and personnel access controls during operations.

d. Personnel Exposures to Beams - Exposures of personnel to concentrated solar beams within the plant area will not occur due to the beam controls discussed in Section a. Personnel working in the collector field boundaries may be exposed to hazardous beam concentrations. Operational access procedural controls, personnel protective equipment, caution and warning systems, and personnel training will be implemented to reduce or avoid this hazard during the operational phase.

6. Reliability

Most of the reliability features of the pilot plant are identical with those of the commercial plant, because of the modular identity described earlier. Refer to Section III.C.4 for collector, receiver, thermal storage and EPGS subsystem discussions which also apply to the pilot plant with the exceptions discussed below. It should also be noted that pilot plant reliability is particularly enhanced over the two to five year test program span time, by designing to the specified 30 year life span requirement.

a. Heliostat Control Reliability - In addition to redundant computer capability in the central control subsystem, multiple data bus lines are routed to the heliostat field. Each data bus line will control one fourth of the heliostat field, independently of the rest of the field.

This effectively circumvents an identified single point failure mode and will assure continued operation (on approximately three-fourths energy level input) in the event of the loss of a single data bus line.

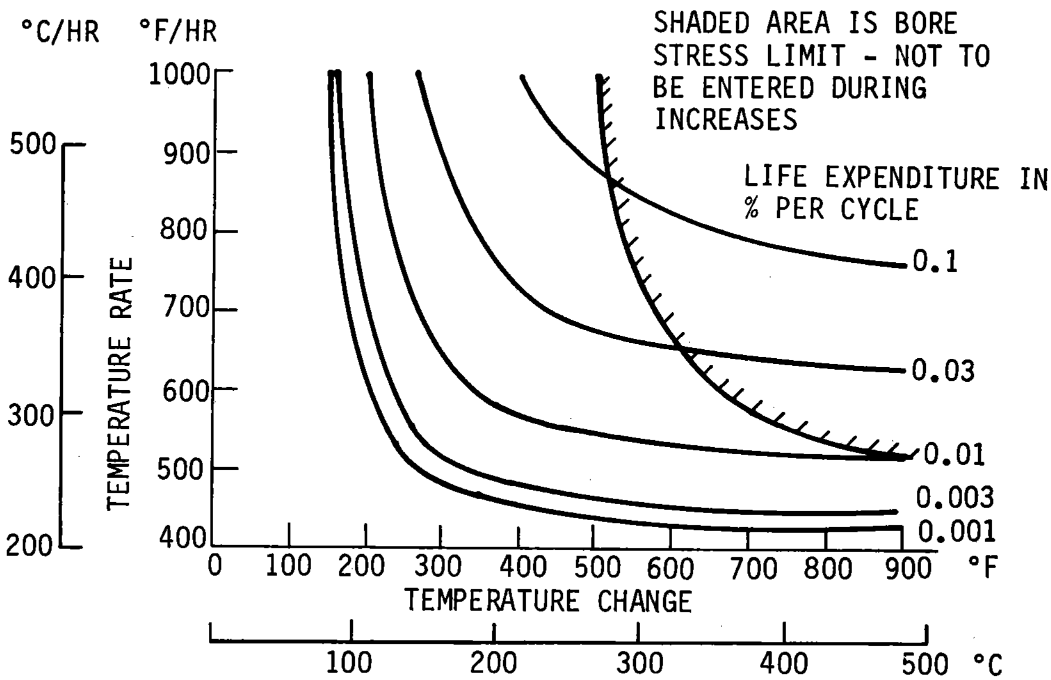


Figure IV.C-24 Pilot Plant Turbine Cyclic Life Expenditure Curve

b. <u>Turbine Thermal Cycling</u> - Unlike the larger commercial turbines, units of the size used for the pilot plant incorporate thinner casings and other features to accommodate the thermal cycling associated with power peaking applications, which is their main usage. These smaller units are thus better suited to the diurnal thermal cycling service of solar applications. It was estimated that the pilot plant turbine will experience a total of 13,000 hot or warm starts, and 1300 starts from an initial cold condition for the 30 year life requirement. Figure IV.C-24 presents life expenditure vs. temperature excursions and rates for a turbine of the size and configuration selected.

This data shows that step temperature changes of up to 83°C (150°F) and rates of up to 222°C/hr (400°F/hr) can be endured indefinitely without adverse effects. An overnight temperature drop of 167°C (300°F) is expected. Using a realistic morning start-up time of 50 minutes (to bring turbine to speed and stabilize transient effects) it can be concluded from the data presented that diurnal cycling falls outside the area contributing to life expenditure. It was also concluded that the infrequent cold starts can readily be controlled procedurally to avoid unacceptable accumulation of time/cycle-related life expenditure. Like all equipment of its type, the turbine will require periodic inspection and maintenance within its projected 30 year life.

D. PILOT PLANT COLLECTOR SUBSYSTEM DESCRIPTION

1. Collector Subsystem Layout

The Pilot Plant collector subsystem, consisting of a field of 1554 heliostats, is identical with one collector subsystem module of the commercial plant, discussed in Section III.E. This identity extends to heliostat configuration and operating modes, heliostat placement geometry in the field, and to the total land surface area required for heliostat deployment. The pilot plant, requiring a single heliostat field, needs a total land area commitment extending 737 m, (2412 ft.) wide and 659 m, (2162 ft.) deep (from receiver aperture), including the required access roadways on the east and west parimeters, and the surrounding security fence.

Figure IV.D-1 shows the heliostat placement locations for the west half of the symmetrical field, and shows a north field boundry limit for a smaller field of 1325 heliostats that would meet ERDA specified minimum performance requirements for the Pilot Plant. The 1325 heliostat field would be just capable of producing 10 MWe net under design point conditions, at 2:00 p.m. on summer solstice. This would also result in sufficient excess capability, on the design point day, to permit thermal storage sufficient for 0.2 hour operation at 7 MWe net output.

Our recommended baseline retains a one-for-one identity with the commercial plant module, which results in a pilot plant capability in excess of specified minimum requirements. This will allow direct correlation of solar-peculiar characteristics of the pilot plant with a commercial plant module without scaling or extrapolation. Receiver flux patterns, net power output, power to thermal storage, and all operating modes can be directly verified on a module basis, reducing technological risks in proceeding to the first commercial sized plant. Our recommended 1554 heliostat field has the capability of producing in excess of 10 MWe net at 2:00 p.m. on each day of the year, and permits thermal storage sufficient for 1.4 hour operation at 7 MWe net output on a design point day.

The minimum field (1325 heliostat) configuration does, of course, provide an option of interest should continued development of the pilot plant hinge on the cost delta of 229 heliostats.

2. Heliostat Configuration

The heliostat assembly for the pilot plant is identifical with that described for the commercial plant in Section III.E. The foundation

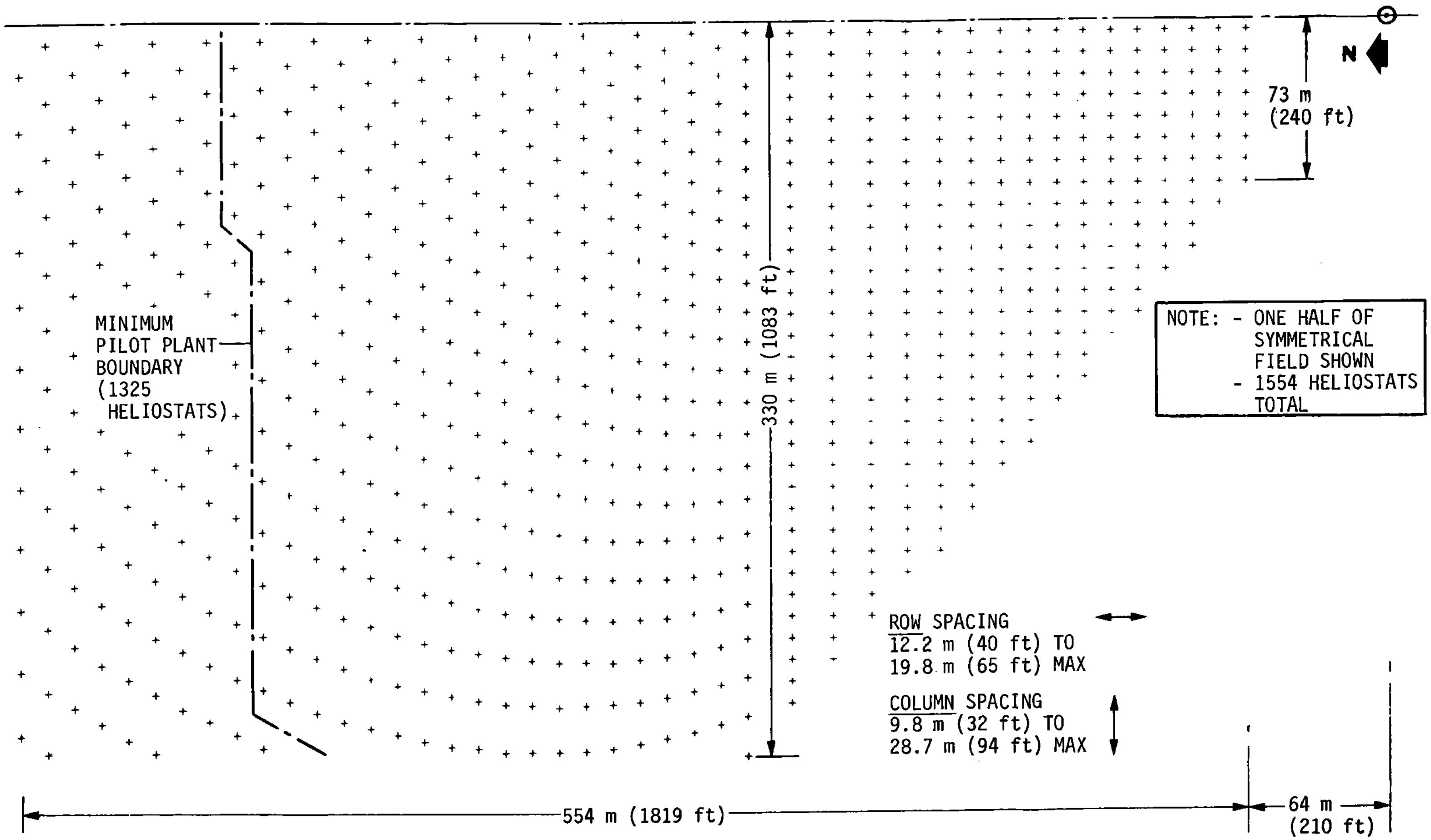


Figure IV.D-1 Collector Subsystem Configuration/Dimensions for use at Barstow, California is shown in Figure III.E-3. Foundation depth will vary up to a maximum of 5.6 m (18.5 ft.).

E. PILOT PLANT RECEIVER SUBSYSTEM DESCRIPTION

1. Receiver Subsystem Configuration

The Pilot Plant receiver subsystem, including the receiver (boiler) assembly, the supporting tower and related piping and controls, is identical with the receiver subsystem in one module of the commercial plant, which was described in Section III.F of this volume. All operating conditions, dimensions and tower height rationale also apply to the Pilot Plant.

Summary of Receiver Subsystem Dimensions

Tower Overall Height	113 m (370 ft.)
Height of Receiver Aperture (c/l)	90 m (295 ft.)
Aperture Size (square)	7.5 m (24.6 ft.)
Approximate Receiver Overall Dimensions	19.2 m (63 ft.) high
	15.2 m (50 ft.) wide
	9.8 m (32 ft.) deep

F. PILOT PLANT THERMAL STORAGE SUBSYSTEM DESCRIPTION

1. Thermal Storage Subsystem General Arrangement

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 IV.F-1 through IV.F-4 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, 17.6 m (57.8 ft.) in diameter, with an overall height above ground level of 20 m (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 236 m (775 ft.) east of the tanks.

The two salt storage tanks are cylindrical in section, with hemispherical top and bottom domes. Tank diamter is 5.8 m (19 ft.), height is 8.1 m (26.5 ft.), and they contain a total of 151 m^3 (5,350 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.

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. The functions of the heat exchangers and other components of the subsystem are the same as described for the Commercial Plant TSS, Section III.G. The salt and oil storage media and their operating

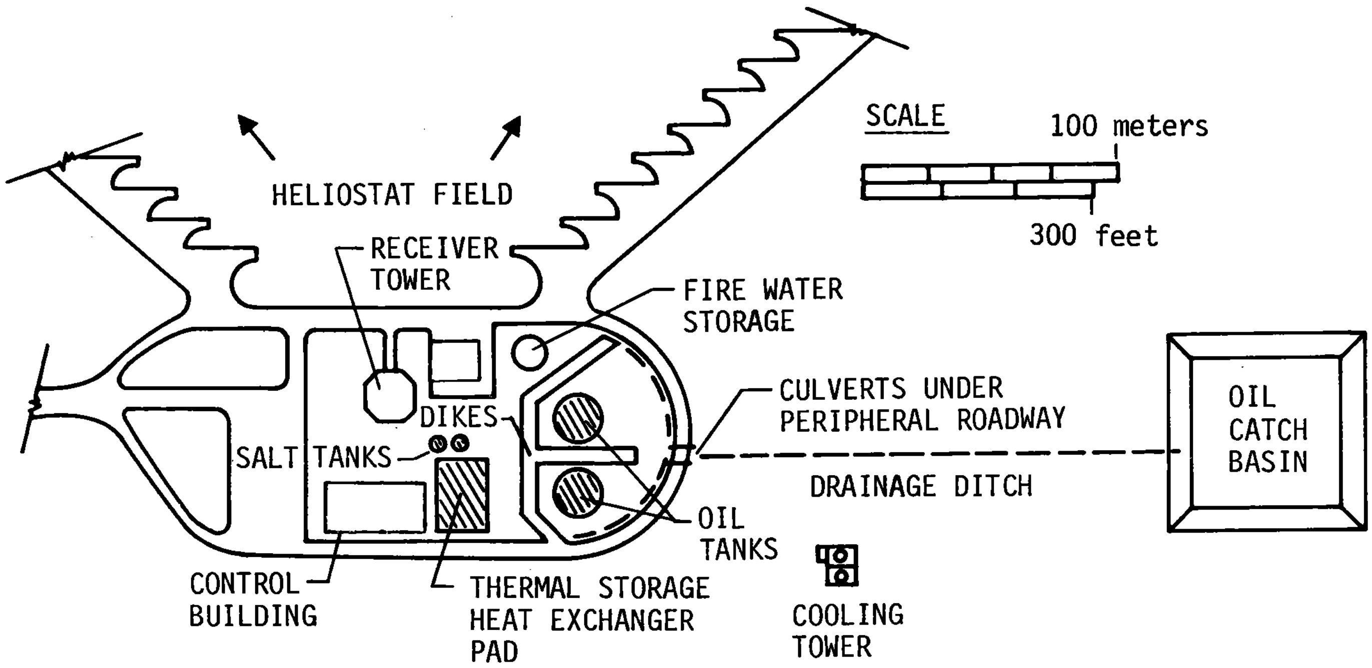


Figure IV.F-1 Thermal Storage Subsystem, General Arrangement

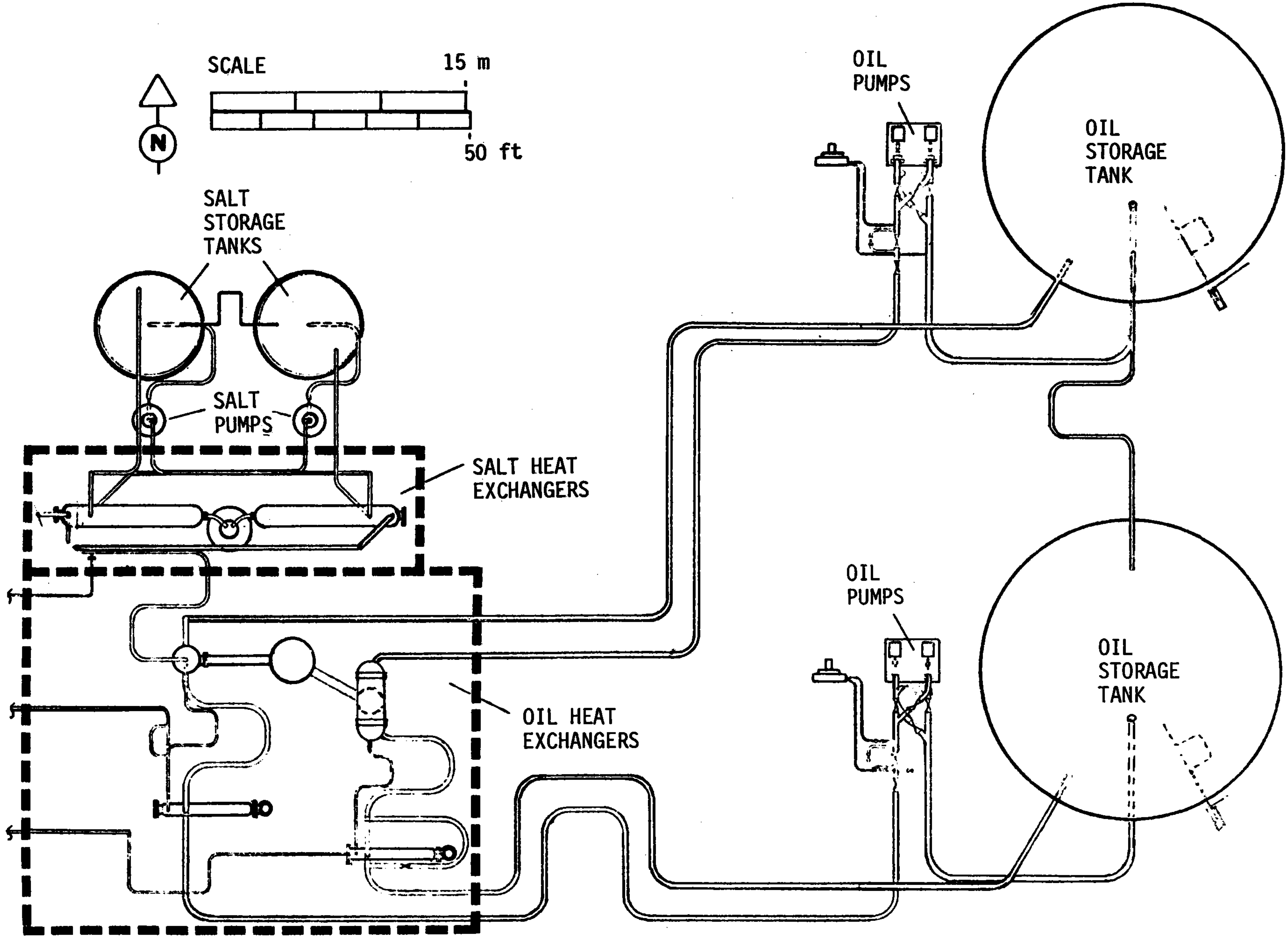


Figure IV.F-2 Thermal Storage Subsystem - Plan View of Components

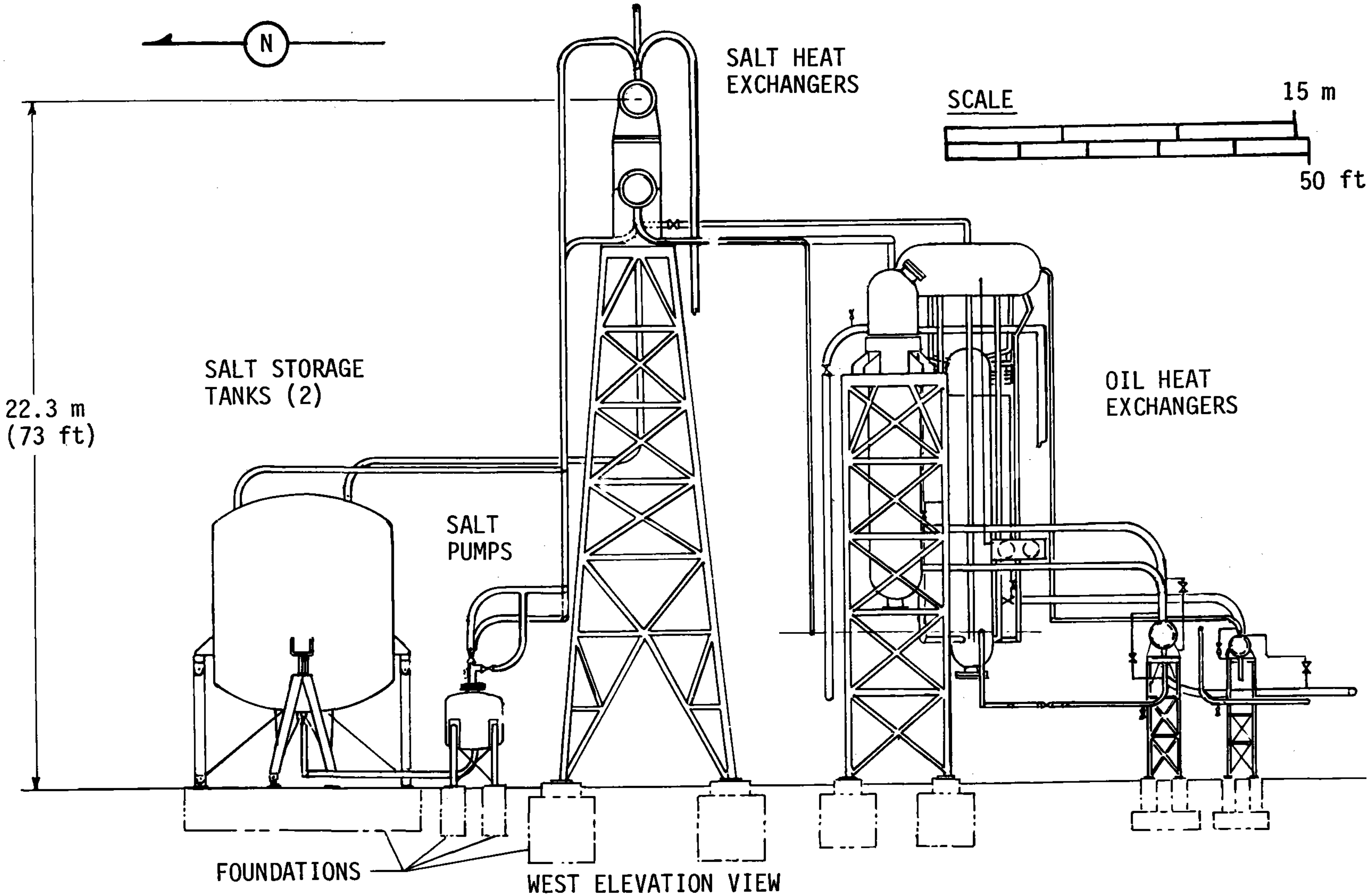
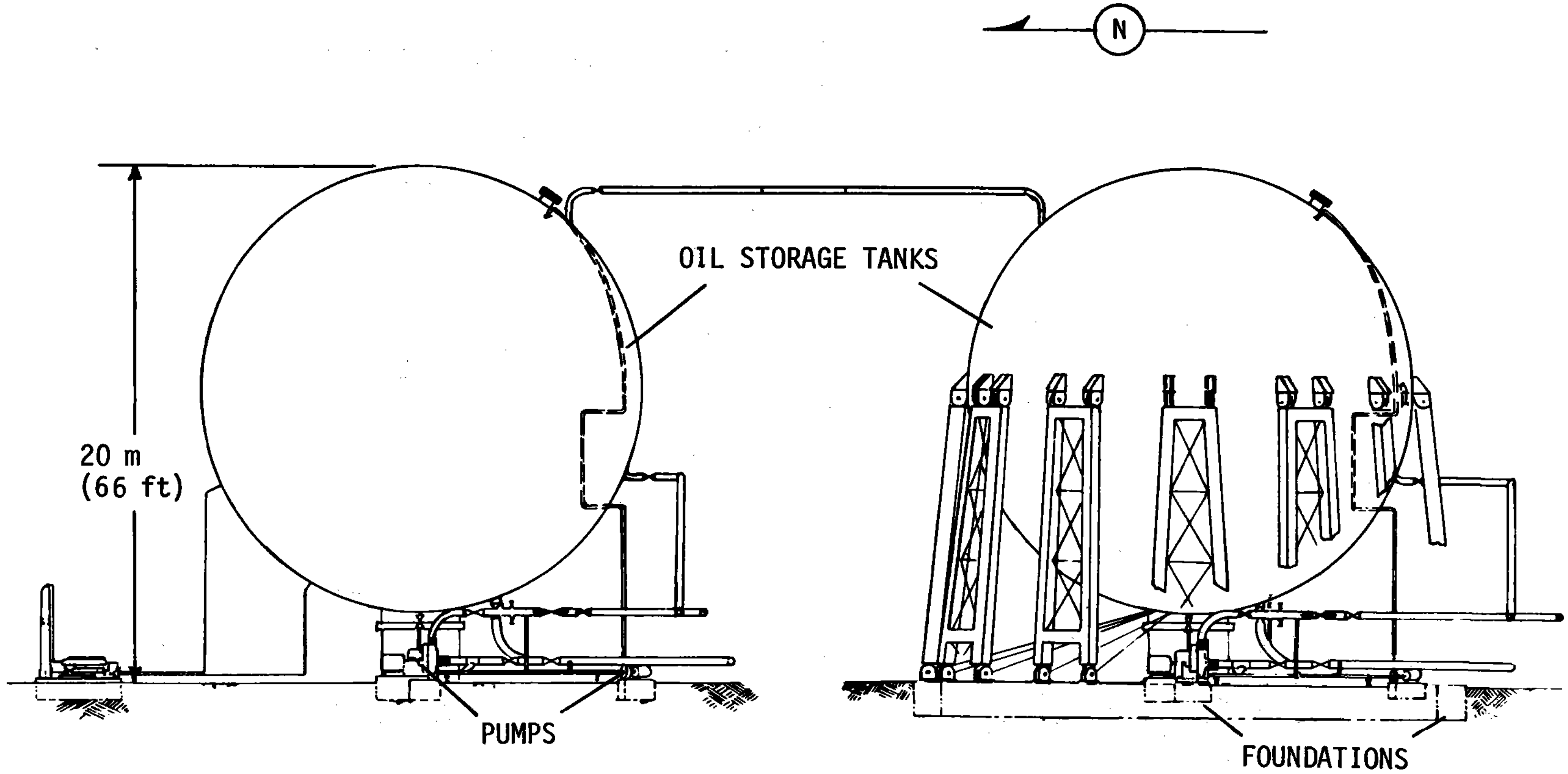


Figure IV.F-3 TSS Salt Storage and Heat Exchangers



WEST ELEVATION VIEW

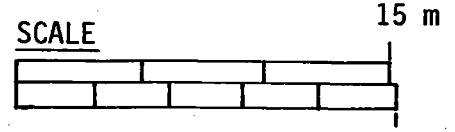


Figure IV.F-4 TSS Oil Storage Tanks

conditions are also identical with those used for the Commercial Plant, except for the smaller quantities used. 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 (Dupont HITEC), 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.

A fluid maintenance unit (side-stream processor) is included in the oil system to remove products of decomposition which will accumulate over long periods of use. This unit is functionally identical to the side-stream processor of the commercial plant, described in Section III G.

G. PILOT PLANT ELECTRICAL POWER GENERATION SUBSYSTEM (EPGS) DESCRIPTION

1. EPGS General Arrangement

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 IV.G-1 shows the general locations of the EPGS major components. An elevation detail of the EPGS building is shown in Figure IV.G-2. 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 pre-finished protective surface.

Cooling water for the condenser (Figure IV.G-3) is piped to and from a two unit wet (evaporative) cooling tower, located approximately 180 m (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 by cardinal position. Fallout deposition during unusual wind conditions is minimized by cooling tower design (to reduce water droplets in the plume), and by the 168 m (550 ft.) separation distance to the nearest heliostat. The cooling tower location is also acceptable when considering the adverse shadowing effects on heliostats during cold weather conditions, when a visible plume could significantly attenuate insolation.

2. EPGS Turbine

The turbine selected for the Pilot Plant application is a General Electric admission type unit, rated at 12.5 MWe output, and commercially available with only minor modifications required to the basic design. Figure IV.G-4 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 MWe standard size closely matches that required to supply the specified 10 MWe net, plus the plant auxiliary loads. The admission port improves operating efficiency at reduced loads from thermal storage steam. Under these lower temperature/pressure con-

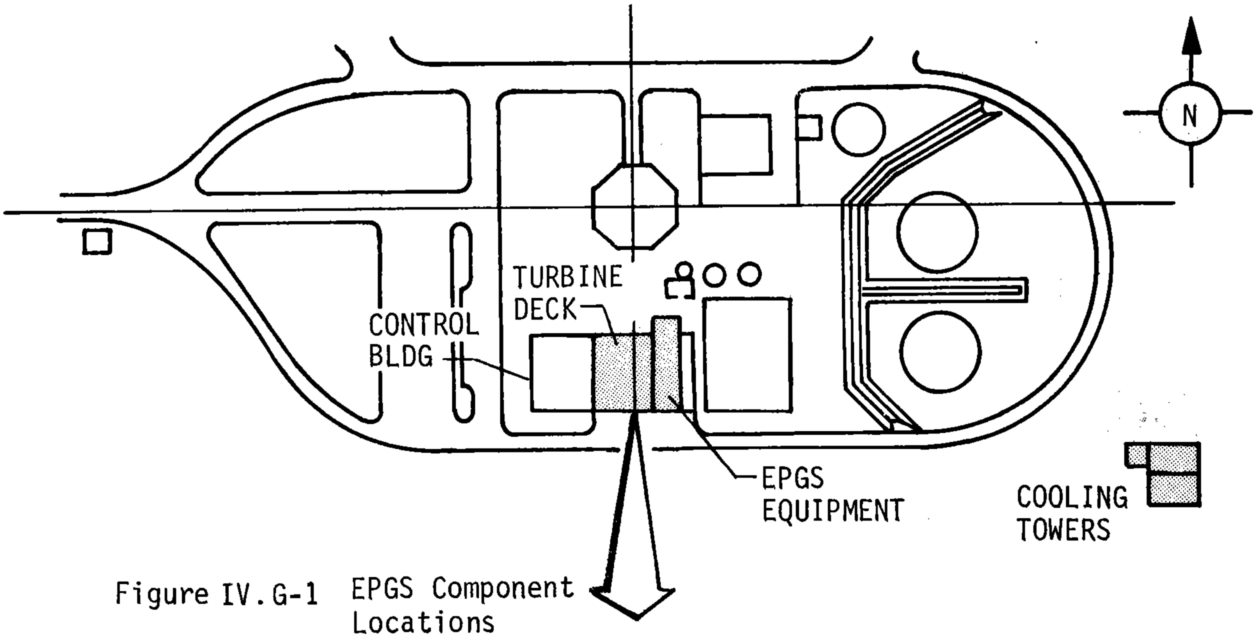


Figure IV.G-1 EPGS Component Locations

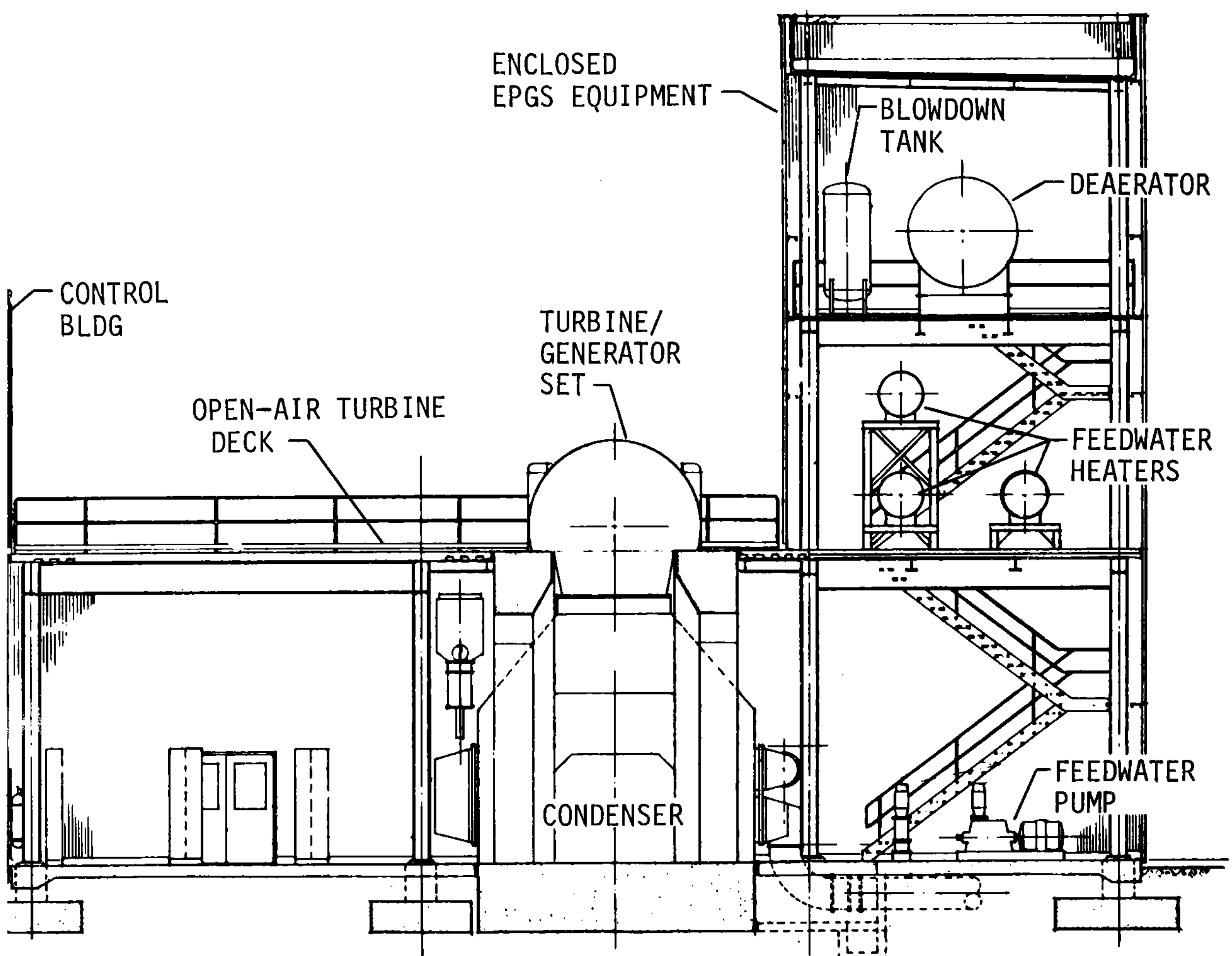


Figure IV.G-2 EPGS Building, South Elevation

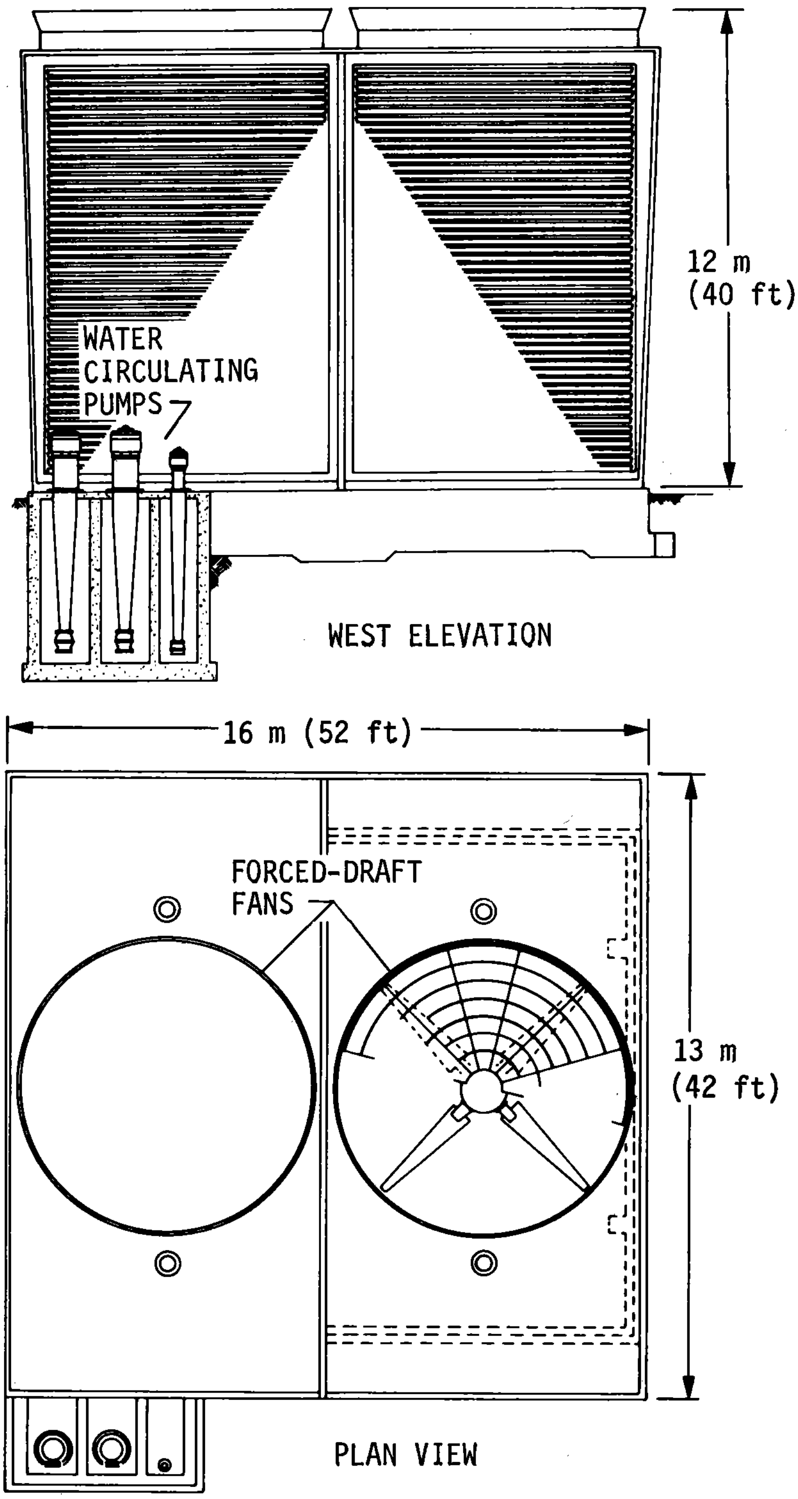


Figure IV.G-3 Pilot Plant Cooling Tower

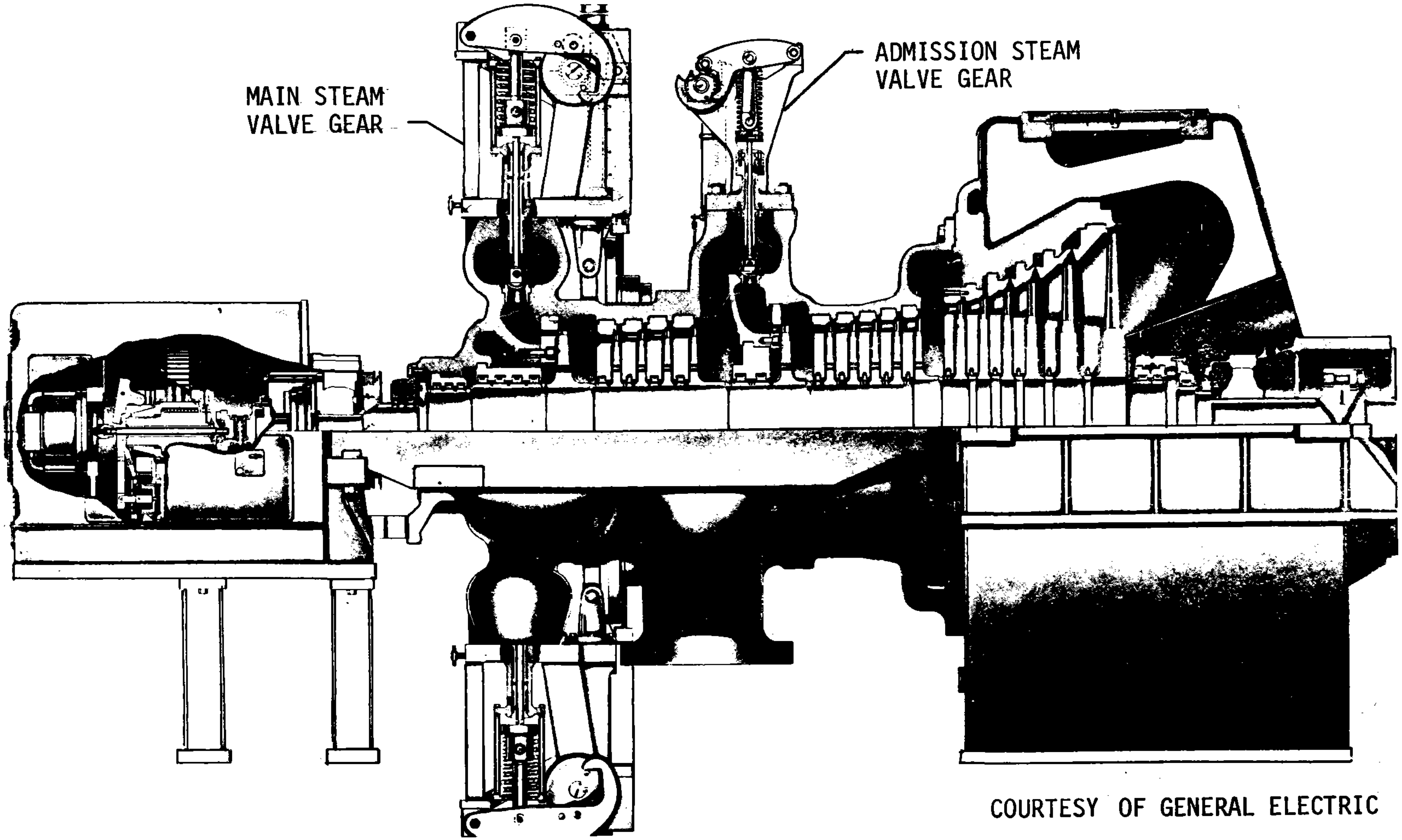


Figure IV.G-4 12.5 MW Pilot Plant Turbine ditions, steam is admitted four stages downstream of the main steam admission point.

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.

V. SYSTEM REQUIREMENTS

A. COMMERCIAL PLANT REQUIREMENTS

1.0 System Requirements

*1.1 General

Provide a Solar Central Receiver power plant that is sized for either:

a) 100 MW_e peak net output while operating on receiver steam, including all auxiliary losses, and assuming weather conditions that occur at the design point, or

b) A more cost effective peak net output (minimum 100 MW_e) assuming the same conditions stated above.

*1.2 Design Point

Site: Inyokern, California

Direct Normal Insolation: 950 watts/square meter

Sun Angle: That which occurs at the time of the year when peak thermal power from the receiver at the turbine generator building is at a maximum, assuming the insolation specified above (i.e., the best sun angle).

Wind Speed: 3.5 meters/second (8 mph) at a height of 10 meters, varying with height to the 0.15 power.

Wet Bulb Temperature: 23°C (74°F)

Dry Bulb Temperature: 28°C (82.6°F)

1.3 Commercial Plant Output

1.3.1 Peak Net Electrical Power - The peak net electrical power output shall be 150 MW_e.

* ERDA Requirements

*1.3.2 The plant shall be capable of providing the peak net electrical power when operating from the receiver subsystem only and providing the auxiliary load required if thermal storage is charging.

*1.3.3 The plant shall be capable of providing 70% of the peak net electrical power when operating from the thermal storage subsystem only for a period of 3 hours assuming thermal storage is fully charged and including the thermal power required for startup and shutdown when operating from storage.

2.0 Collector Subsystem Requirements

The collector subsystem shall use focused heliostats to track and redirect maximum solar energy into the aperture of the receiver subsystem.

2.1 Size - The collector subsystem shall consist of 15 north field modules as shown in Figure III.E-1. Each module shall contain 1554 heliostats.

2.2 Control - The heliostats shall be controlled by computer for all modes of operation.

2.3 Stowage - The heliostats shall be capable of being stowed with the reflective surface down during all non-operating modes.

2.4 Power reflected at the design point to Receiver Aperture: 49.9 MW_t.

3.0 Receiver Subsystem Requirements

The receiver subsystem shall consist of a natural circulation boiler, mounted on a tower such that the boiler tubes and the superheater tubes line the walls of an enclosed cavity. The aperture of the cavity shall face north to capture the reflected beams from the collector subsystem. An insulated closure door shall be provided to close the aperture during periods of receiver inactivity.

3.1 Aperture Height - The receiver shall be mounted on the tower such that the aperture centerline height is 90 meters (295 ft).

* ERDA Requirements

3.2 Aperture Size: 7.5 x 7.5m (24.6 x 24.6 ft.)

3.3 Orientation: The receiver shall be oriented to place the planes of the rear wall and aperture vertical.

3.4 Output Steam Conditions
Temperature, K (°F): 789 (960)
Pressure, kPa (psig): 10,687 (1550)

3.5 Feedwater Input Conditions
Temperature, K (°F): 503 (446)
Pressure, kPa (psig): 12,550 (1820)

3.6 Design Point Power Rating

45.6 MW_t

4.0 Thermal Storage Subsystem (TSS) Requirements

The TSS shall store thermal energy in the form of sensible heat, using molten salt and hydrocarbon oil as the storage media. The TSS shall be capable of simultaneous charge and discharge.

*4.1 Capacity - When fully charged the TSS shall be capable of starting and loading the turbine, from a hot start condition, followed by operating the turbine at 70% of rating for 3 hours and then shutting the turbine down.

4.2 Charging Steam Conditions (from receiver)

Temperature, K (°F): 780 (945)
Pressure, kPa (psia): 8860 (1285)

4.3 Admission Steam Conditions (from TSS)

Temperature K (°F): 701 (802)
Pressure, kPa (psia): 2999 (435)

4.4 Total Stored Energy Capability:

1189 MWH_t

* ERDA Requirements

5.0 Electrical Power Generation Subsystem (EPGS)

The EPGS shall consist of a tandem compound four flow non-reheat turbine with an automatic extraction point being used in the admission mode. Heat rejection will be wet cooling. There will be 5 feedwater heaters.

5.1 Gross Turbine Rating: 160 MW_e

5.2 Net Electrical Power Output: 150 MW_e

5.3 Inlet Steam Conditions (Receiver Steam, Design Point)

Pressure, kPa (psig): 9308 (1350)
Temperature, K (°F): 783 (950)

B. Pilot Plant Requirements

1. System Requirements

*1.1 Net Power Output

The electrical power generation subsystem shall provide The means for transforming the thermal output of the working fluid from the receiver into 60 cycles electrical power at 10,000 kW_e net at 13.8 KV and transform the thermal output of the working fluid from storage or combinations of thermal output from storage and receiver into 60 cycles electrical power of at least 7000 kW_e net.

*1.2 Design Point

Site: Inyokern, California (For performance calculations). The Pilot Plant shall be sized to deliver 10 MW_e busbar electricity at 2:00 p.m. solar time on the day of least favorable collector cosine. An insolation value of 0.95 kW/m^2 shall be assumed. The Pilot Plant shall be sized to allow for all appropriate energy losses including all thermal storage subsystem energy losses and still deliver at least 7 MW_e net busbar power for a period of three hours while operating solely from the storage subsystem. Wet cooling shall be comployed.

Wet Bulb Temperature: 23°C (74°F)

Dry Bulb Temperature: 28°C (82.6°F)

Wind Speed: 3.5 meters/second (8 mph) at a height of 10 meters, varying with height to the 0.15 power.

*1.3 Maximum Survival Wind Speed (without damage): 40 meters/second (90 mph).

*1.4 Seismic - Survive 0.25g vertical and horizontal ground accelerations.

*1.5 Soil Properties - Bearing Capacity:

Depth (Ft.)	Load (psf)
2	1,500
5	5,000
10	10,000

*ERDA Requirements

*1.6 Dynamic Performance

The time for diurnal startup should be minimized but should be consistent with present day turbine characteristics. Loss of energy during startup and shutdown must be included in the total yearly energy calculations.

*1.7 Endurance Capability

The hardware shall be designed to have a 30 year operational lifetime to withstand the specified environmental conditions. During this 30-year period the performance of the pilot plant shall remain within the design specification requirements with normal plant maintenance.

*1.8 Electrical Transients

The Pilot Plant should be designed with sufficient lightning protection to be effective on a cost-risk-basis. Some damage is allowable.

2.0 Collector Subsystem Requirements

The collector subsystem shall use focused heliostats to track and redirect maximum solar energy into the aperture of the receiver subsystem.

2.1 Size - The collector subsystem shall consist of a north field including 1554 heliostats.

2.2 Stowage - The heliostats shall be capable of being stowed with the reflective surface down during all nonoperating modes.

2.3 Mirror Configuration - Each heliostat shall have nine (9) mirrors having a total reflecting area of 41 m^2 (441 ft^2).

2.4 Mirror Reflectivity - 91%, minimum.

2.5 Motor Drive Configuration - Two electric (AC) motors for each axis, one for tracking, another for slew.

2.6 Control - Open Loop control by local microprocessor.

*ERDA Requirements

2.7 Rotational Limits - ± 110° Azimuth
180° (total) elevation

2.8 Power to Heliostat - 115 ± 5 vac, single phase.

*2.9 Survival Wind Conditions - 1) Angle of attack of ± 10° during maximum survival winds, (Paragraph 1.3), without damage; 2) Maximum winds, including gusts of 24 m/s (50 mph) from any direction, in any heliostat position without damage.

*2.10 Maximum Wind Rise Rate - .01 m/s^2 (1.3 mph/min).

*2.11 Stowage Initiation - Stowage shall be initiated at a maximum speed of 13.4 m/s (30 mph).

*2.12 Temperature - The heliostat and control subsystem shall be able to operate over the ambient temperature range of -30°C (-20°F) to +50°C (120°F). Reduced performance is permitted to meet this range.

*2.13 Precipitation - Average annual: 100 mm (4 in)
Maximum 24 hour rate: 75 mm (3 in)
Design Snow Load: 250 Pa (5 psf)
Maximum Ice Accumulation: 50 mm(2 in)
Hail: 1) 20 mm (3/4 in) maximum at 20 m/s (65 fps) without damage in any heliostat position, and 2) 25 mm (1 in) maximum at 23 m/s (75) fps) in stowed position.

2.14 Power Reflected at the Design Point to Receiver Aperture: 43.8 MW_t.

3.0 Receiver Subsystem Requirements

The receiver subsystem shall consist of a natural circulation boiler, mounted on a tower such that the boiler tubes and the superheater tubes line the walls of an enclosed cavity. The aperture of the cavity shall face north to capture the reflected beams from the collector subsystem. An insulated closure door shall be provided to close the aperture during periods of receiver inactivity.

*ERDA Requirements

3.1 Aperture Height - The receiver shall be mounted on the tower such that the aperture centerline height is 90 meters (295 ft).

3.2 Aperture Size: 7.5 x 7.5m (24.6 x 24.6 ft).

3.3 Orientation: The receiver shall be oriented to place the planes of the rear wall and aperture vertical.

3.4 Output Steam Conditions

Temperature, k (^oF): 789 (960)
Pressure, kPa (psig): 10,687 (1550)

3.5 Feedwater Input Conditions

Temperature, k (^oF): 503 (446)
Pressure, kPa (psig): 12,550 (1820)

3.6 Design Point Power Rating: 40.5 MW_t.

4.0 Thermal Storage Subsystem (TSS) Requirements

The TSS shall store thermal energy in the form of sensible heat, using molten salt and hydrocarbon oil as the storage media. The TSS shall be capable of simultaneous charge and discharge.

*4.1 Capacity - When fully charged, and after a 20 hour hold time, the TSS shall be capable of starting and loading the turbine, from a hot start condition, followed by operating the turbine at 70% of rating for 3 hours and then shutting the turbine down.

4.2 Quantity of thermal storage media tanks - The TSS shall store molten salt in two tanks and oil in two tanks.

4.3 Charging Steam Conditions (from receiver)

Temperature, K (^oF): 780 (945)
Pressure, kPa (psia): 8860 (1285)

4.4 Admission Steam Conditions (from TSS)

Temperature, K (^oF): 701 (802)
Pressure, kPa (psia): 2999 (435)

4.5 Total Stored Energy Capability: 97.1 MWH_t.

* ERDA Requirements

APPENDIX A

CENTRAL RECEIVER SOLAR THERMAL PILOT PLANT

ENGINEERING DATA FOR USE IN ENVIRONMENTAL ASSESSMENT

MARCH 30, 1977

INTRODUCTION

Data contained herein describe solar peculiar pilot plant features of the Martin Marietta Central Receiver Solar Thermal Pilot Plant design concept that need to be evaluated in conjunction with specific site data to establish environmental impacts of the plant construction and operation at Barstow, California.

The engineering factual data are supplemented with comments and additional information which will be of value in performing the impact assessments and in establishing approaches to mitigation measures. The data reflect the Martin Marietta concept at the end of the concept definition phase; quantitative refinements can be expected in the detail design phase.

(Due to the earlier submittal date, certain details, e.g., receiver tower top configuration, differ from body of report.)

CONTENTS

GLOSSARY OF TERMS

Aesthetics - Pertaining to the subjective impressions of the appearance (of solar power plant features). Those features relating to perception of beauty, i.e., size, shape, color, setting, or other factors that can be appealing to, or irritating to the senses.

Aperture - The opening through which solar flux passes in a cavity type receiver; the boiler "window."

Berm - Dike; raised narrow ledge; e.g., surrounding a fuel storage tank for containment in case of spills.

Blowdown - An operation to purge a system (boiler) of accumulated contaminants. A portion of normal water/steam flow through the boiler is released, carrying with it solids, dissolved solids, parasitic gases and other contaminants not wanted in the system.

Catastrophic Failure - A failure having features of suddenness and substantial adverse consequences, e.g., rupture of a pressure vessel.

Cavity - The receiver or boiler internal volume which provides the interface between focused solar flux and water/steam heat exchanger tubes; comparable to a boiler firebox.

Collector - The total assemblage of heliostats (mirrors) and related control elements that intercept incident solar flux, and redirect it in a concentrated beam to the receiver. This is accomplished by reflecting solar radiation from a large area, aiming the reflected energy onto a relatively much smaller area, and maintaining a tracking function that keeps individual mirrors in motion to compensate for the collector subsystem's changing position with respect to the sun.

Conduction (Thermal) - Transmission of heat through a solid or between solids, e.g., receiver heat lost through supports to tower structure.

Convection (Thermal) - Transmission of heat by means of air motion across surface.

Cooling Tower (Wet) - A component of the solar power plant that rejects waste heat to the atmosphere, mainly by utilizing the heat of vaporization of water. Turbine exhaust steam is cooled and condensed to water by cooling circuit water which is, in turn, cooled by distribution over large surface areas of the cooling tower. Forced air draft is employed in the cooling tower to increase evaporation rate of cooling water.

Design Point - The conditions under which rated power output is required for the solar pilot plant, i.e., insolation of 950 watts/m^2, dry bulb temp = 28°C, wet bulb temp = 23°C, wind speed = 3.5 m/sec at 10 m elevation, and at 2:00 PM on summer solstice.

Diurnal - Daily

Ecology - Biology dealing with interactions of organisms and their environment.

Effluents - That which is discharged as a by-product of a main process. Effluents of the solar power plant include boiler blowdown products and cooling tower exhaust plumes.

Evaporation Ponds - Catch basins for containment of contaminated industrial liquid wastes. Water is evaporated by natural processes; contaminants are concentrated and contained in basin to preclude release to the general environment.

Failure Mode - The manner in which failure has (or can) occur; e.g., seal leakage, pipe blockage, pipe rupture.

Feedwater - Water introduced to a boiler for making steam, usually processed to a high degree of purity in interests of system efficiency and durability. Makeup feedwater is that introduced to replace water lost through seals, blowdown and other factors.

Features - Characteristics of the solar power plant (that may be important in an environmental assessment). Static features are those fixed characteristics, e.g., buildings, tower, roads; dynamic features are those in motion, e.g., heliostat mirror motion, cooling tower plume.

Flash Point - The temperature at which vapors from a flammable liquid will flash in air and in the presence of an ignition source.

Flux (Solar)	- The rate of flow of energy across or through a surface; e.g., the radiant energy transmitted in a beam reflected by a collector mirror to the receiver. Expressed quantitatively as watts (or kilowatts) per square meter (or square foot). The notation (W_{th}) indicates that the power is in the form of heat flow as distinguished from (W_e) which indicates the power is in the form of the equivalent electrical flow.
Heliostat	- A mirror mounted on gimbals or axes and moved by control devices to steadily reflect sunlight onto a small area (receiver).
Insolation	- Direct solar radiation on the earth, expressed quantitatively as watts per square meter (square foot).
Irreversible Topographic Modifications	- Those changes to ground configuration that would leave scars precluding reversion of the surface to the pristine state in the foreseeable future.
Latent Heat	- Nonsensible thermal energy associated with changes in state of a medium, e.g., evaporation, freezing or melting of water (ice) at constant temperature.
Microclimate	- Very localized climate, e.g., the air motion, temperature, humidity at one side of a building.
Mitigation	- Relating to those actions or design changes that could alleviate, reduce, or eliminate the adverse effects of the solar pilot plant on the environment.
Natural Environment	- Those physical conditions imposed on a system by ambient natural phenomena, e.g., wind, rain, seismic accelerations.
Pristine	- Primitive; natural state.
Radiation (Thermal)	- Transmission of heat by rays (like light); not dependent on an atmosphere.
Receiver	- That portion of the solar power plant that receives solar (heat) energy and transfers it to the steam cycle working media (water); comparable to a boiler in a conventional fossil fueled power plant.

Receiver Tower - Structure to place receiver (boiler) in elevated position. The elevated position permits concentration of solar flux beams onto the receiver from a large number of heliostats mounted on ground surface.

Sealing Steam - Low pressure steam supplied to inactive steam circuit components to prevent entry of air and other contaminants into the system, e.g., past shaft seals of rotating machinery.

Seismic Acceleration - Movement of the earth by an earthquake.

Self-induced Environment - Those physical conditions imposed on a system which are due to system operation, e.g., steam pressure and temperature effects on components of a power plant.

Sensible Heat - Thermal energy which can be measured as a function of temperature or temperature changes.

Slew - Operational mode of heliostats when they are moved at maximum rate in angular position, as in transitioning from a stowed to a tracking mode, or vice versa.

Solar Peculiar - Those portions of the solar power plant that constitute technological departure from a conventional fossil fueled steam cycle plant, i.e., the solar collector components, the solar heated receiver (boiler), and the thermal storage subsystem.

Solstice - That point in the year when the sun is farthest from the equator north (summer solstice, June 21/22) or south (winter solstice, December 21/22).

Steam Circuit - Those parts of the power plant that constitute the main, power conversion, water/steam cycle; i.e., receiver (boiler), turbine, condenser, feedwater pumps, and related piping.

Stow (Unstow) - To place collector subsystem heliostats (mirrors) in a safe, face down position for system inactivity.

Thermal Flux Hazard - A condition caused by interception with, or intrusion into a concentrated beam of solar energy which can cause elevated temperatures, resulting in pain or injury to persons, birds, or other animals.

Thermal Storage Subsystem (TSS) - Those elements of a solar power plant that receive thermal energy from receiver steam, and store/convert it for use at a later time. Major elements include heat exchangers (into and out of storage), containers of heat storage media (for sensible, latent or other forms of thermal storage), and pumps to circulate the storage media.

Topography - Configuration of the ground surface, including soil, drainage, plant life, and elevation profile.

Tracking Mode - Operational condition of heliostats when they are being continually adjusted in position to keep the reflected solar radiation on the receiver.

RECEIVER SUBSYSTEM

ENVIRONMENTAL IMPACT DATA SHEET

A. System Concept ___MMC___

B. Subsystem ___Receiver___

C. Design Feature ___Aperture and Boiler Cavity___

D. Environmental Factors Impacted:

- o Bird/Insect Hazard - Lethal heat flux is present in and adjacent to boiler cavity while plant is operating on collector energy.
- o Meteorology - Waste heat is transmitted to atmosphere external to and in the vicinity of the receiver aperture.
- o Aesthetics - The aperture/boiler cavity area will appear as a bright area, or glow, to observers north of the receiver tower.

E. Design Feature Descriptive Data:

1. Aperture: (See Figure 1 for Receiver Configuration)

   Size - 7.5 x 7.5 m. (24.6 x 24.6 ft)

   Location - Centerline 90 m. (295 ft) above ground level, facing north

   Energy Crossing Aperture Plane: 52.3 MW_{th} (max.)

2. Waste Heat Loss to atmosphere: 3.1 MW_{th} (Typical)

3. When Flux is Present: During daylight hours, when plant is operating on collector energy; estimated total of 4,200 hours per year.

4. Additional Comments:

   These data are primarily of interest in assessing solar flux effects in the vicinity of the receiver tower that would be damaging to intruding birds or insects in flight. Other considerations required to complete the assessment include injury threshold levels for the various species and flight habits. Note that this pilot plant concept presents no thermal hazards for periods when the collector system is stowed. During these periods (e.g., immediately following operation on solar energy and for overnight periods) flight into a residually hot boiler cavity is denied by the insulated aperture closure. This same closure will preclude entry of nesting birds into the receiver cavity during periods of inactivity.

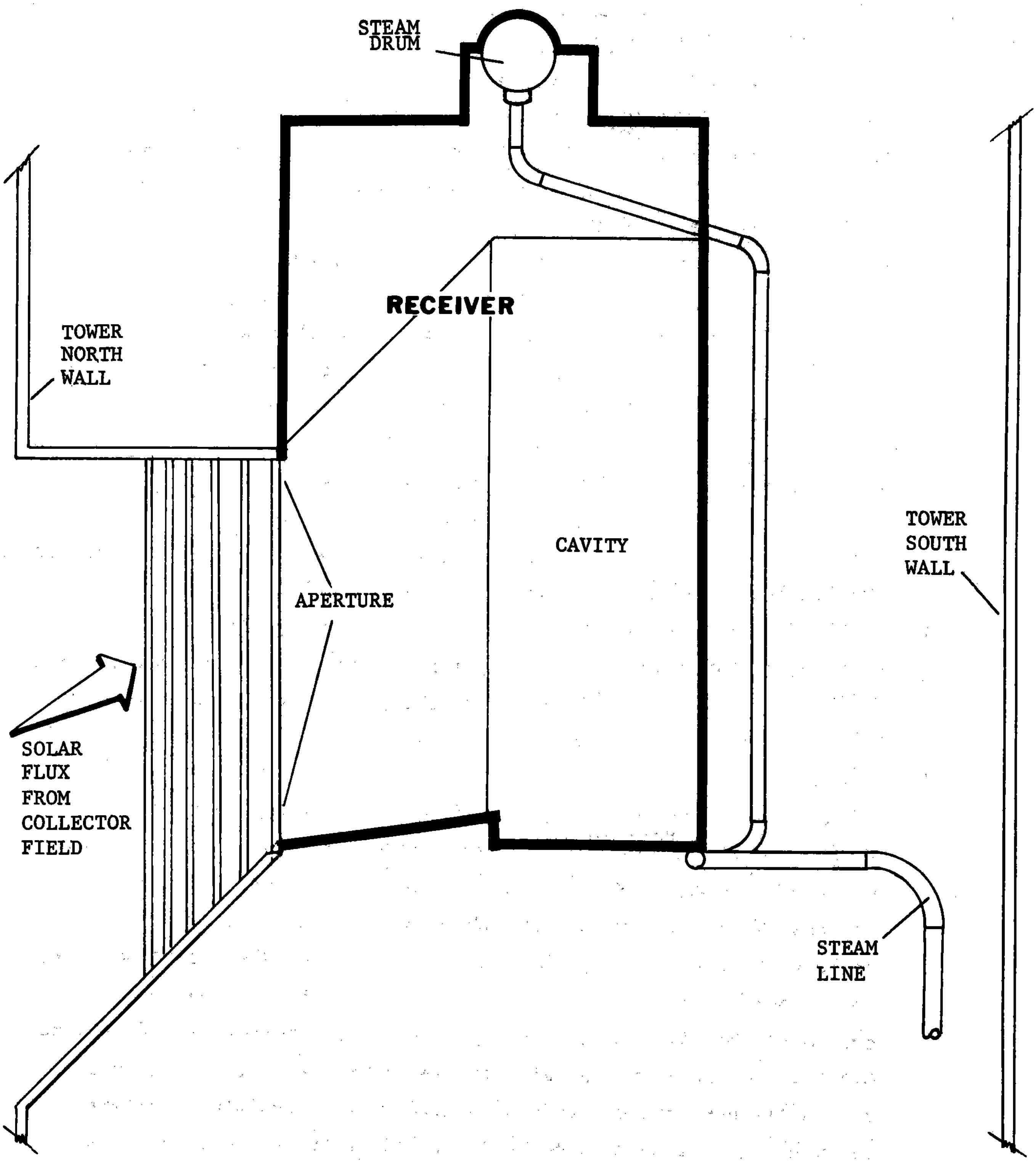


Figure 1 Receiver Configuration

E. Design Feature Descriptive Data (Continued)

It is expected that there will be additional localized volumes of the atmosphere close to the collector field/receiver tower that will experience elevated, and perhaps lethal flux levels during daylight stowing/unstowing operations. This can be caused by the random (or programmed) dynamic coincidences of multiple heliostat beams as they are moved off the receiver aperture. It is expected that regions of high flux levels will be small and durations transitory.

Waste heat from the receiver could have minor effects on very localized meteorology. This waste heat is transmitted to the atmosphere in the vicinity of the receiver aperture by means of convection, radiation, and, to a much lesser extent, by conduction. Whereas the radiated heat losses are relatively constant while operating on collector energy, the convection losses will be dependent on wind velocity and direction. Heat transmitted to the atmosphere with the receiver closure in place (i.e., to retain heat in boiler overnight) will be minimal and should be considered insignificant with respect to the local meteorology.

The visible glow associated with receiver operation constitutes a feature of interest which will be observable from vantage points north of the field. This will not constitute a direct hazard and is not expected to be so prominent as to be aesthetically objectionable.

5. Mitigation Considerations

- o High concentrated flux levels for significant areas outside the receiver cannot be avoided in this concept, which utilizes a conventional steam cycle.
- o Birds in flight could conceivably be denied access to lethal regions by physical screening surrounding the high flux zones. This is considered impractical on bases of cost, maintenance and adverse environmental and plant operating effects.

E. Design Feature Descriptive Data (Continued)

- Birds in flight could be discouraged from entering high flux zones via aural or visual devices[1] placed and operated in the vicinity of the upper part of the receiver tower.
- The only source of experience data applicable in assessing this potential problem is the French Solar Furnace Research Facility.[2] It has been reported that there is no indication that birds are attracted to or are adversely affected by the focused solar flux beam of that facility, and that birds have been observed to divert their flight paths to avoid the beam. Although operation of the French facility has resulted in no known injuries to birds in the flux beam, there have been fatal bird collisions with the building, itself. Consumption of flying insects in the flux beam does occur regularly. The insects seem to be attracted to the beam.

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[1]Noise Generators, "Windmill" Devices and other measures have been employed to discourage birds from buildings, airports and agricultural crops, with limited success.

[2]Centre National de la Recherche Scientific Laboratoire de l'Energie Solaire.

ENVIRONMENTAL IMPACT DATA SHEET

A. System Concept MMC

B. Subsystem Receiver

C. Design Feature Tower Height, Geometry, Appearance

D. Environmental Factors Impacted:

- o Aesthetics - Tower height, geometry, color, and surface finish will affect the distance this most prominent static feature will be observed, and are major contributing factors to the short range appearance of the overall pilot plant installations.
- o Flight Obstruction - The tower represents a flight obstruction to low altitude air navigation and requires marking and location reporting to FAA. It also represents a collision hazard to birds in flight.
- o Meteorology - The tower may have minor impacts on microclimate due to its shadowing effects on ground surface and will modify wind patterns locally.

E. Design Feature Descriptive Data:

1. Dimensions:

   Height: 113 m (370 ft)

   Diameter: 21 m (69 ft)

2. Geometry: Octagonal cross section, constant section dimensions top to bottom (Figure 2).

3. Exterior Surface Treatment: Vertical exterior surfaces will be clad with a commercial, corrugated sheeting[1] of galvanized steel, approximately 20 gauge, with 10 cm (4 in) corrugations running vertically. The panels are precoated with a .04 cm (15 mil) asbestos/polymeric coating. The exterior coating

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[1]Robertson "Galbestos"; Sea Foam Color Selection; Reference Robertson Technical Data Sheets R-41-74 and R-18-75.

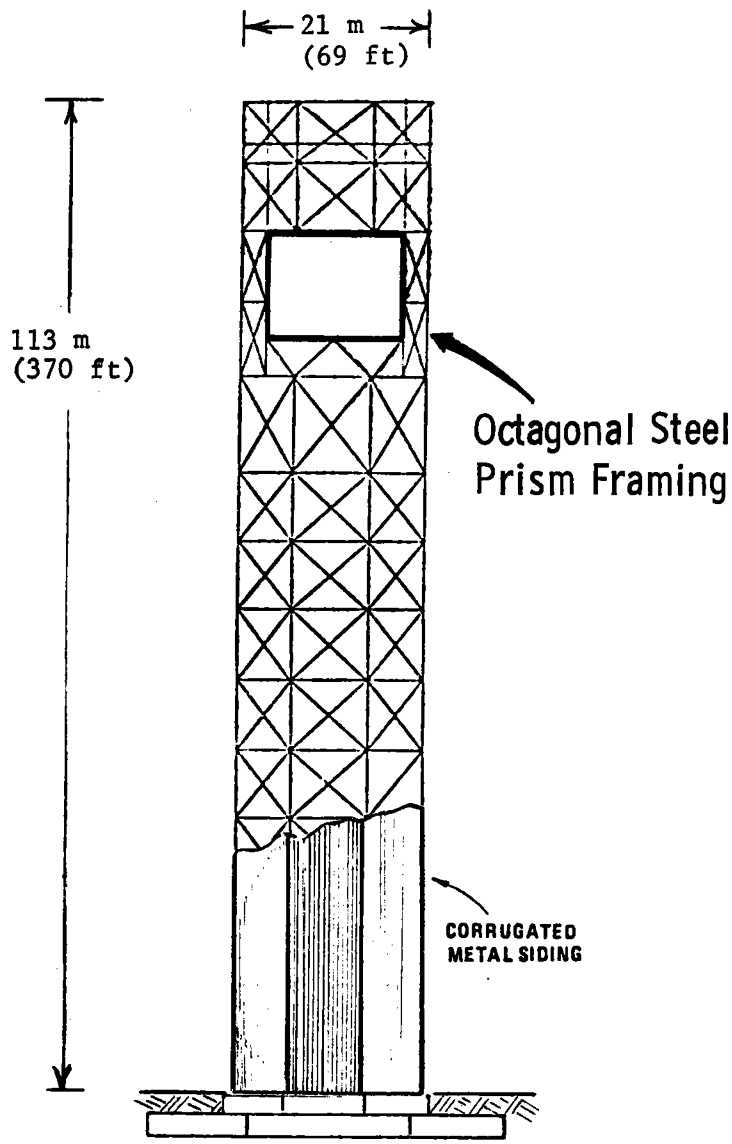


Figure 2 Receiver Tower Configuration

is nonreflective, textured and buff (off-white) in color. The top of the tower is closed with a flat roof.

4. Marking for Air Navigation: Red incandescent flashing clearance lights will be mounted at the top of the tower (and at an intermediate level, if required); installation and operation will be in compliance with FAA requirements.

5. Additional Comments:

Areas immediately adjacent to the receiver aperture will incorporate thermal protective materials which can withstand flux spillover from the aperture, and transient flux levels associated with stowing/unstowing operations. External surfaces of these protected areas will be sheet stainless steel.

6. Mitigation Considerations:

The tower will be configured and finished to present pleasing close range appearance in conjunction with other plant architectural features. The octagonal shape, nonreflective surface finish and color will all contribute to a blending, nonintrusive appearance when viewed from a distance against the natural surroundings background. Note that this tower will be located on a site adjacent to an existing fossil fuel power plant having two stacks, each 76 m (250 ft) above ground level.

The elevated location of the receiver aperture is a basic design requirement for the pilot plant concept. Reduction of tower height could be made to mitigate any adverse environmental factors found to be a function of this feature, but at the expense of severely compromising plant efficiency.

ENVIRONMENTAL IMPACT DATA SHEET

A. System Concept MMC

B. Subsystem Receiver

C. Design Feature Tower Foundation

D. Environmental Factors Impacted:

o Topography - Tower foundation represents a contribution to the irreversible topographic modifications required by plant site installations.

E. Design Feature Descriptive Data

1. Foundation Size and Geometry (Refer to Figure 3)

Configuration: Octagonal concrete tower pedestal atop an octagonal concrete footing.

Size: Pedestal - 24.4 m (80 ft) diameter
2.13 m (7 ft) thick

Footing - 39.62 m (130 ft) diameter
2.13 m (7 ft) thick

Location with Respect to Ground Level: Pedestal top surface is 0.15m (6 inches) above ground level.

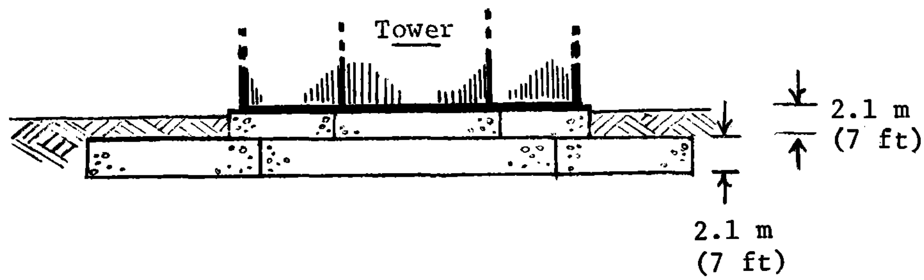
Approx. Ground Area Graded/Excavated to Construct Foundation: 1500 m^2 (16,146 ft^2)

2. Additional Comments

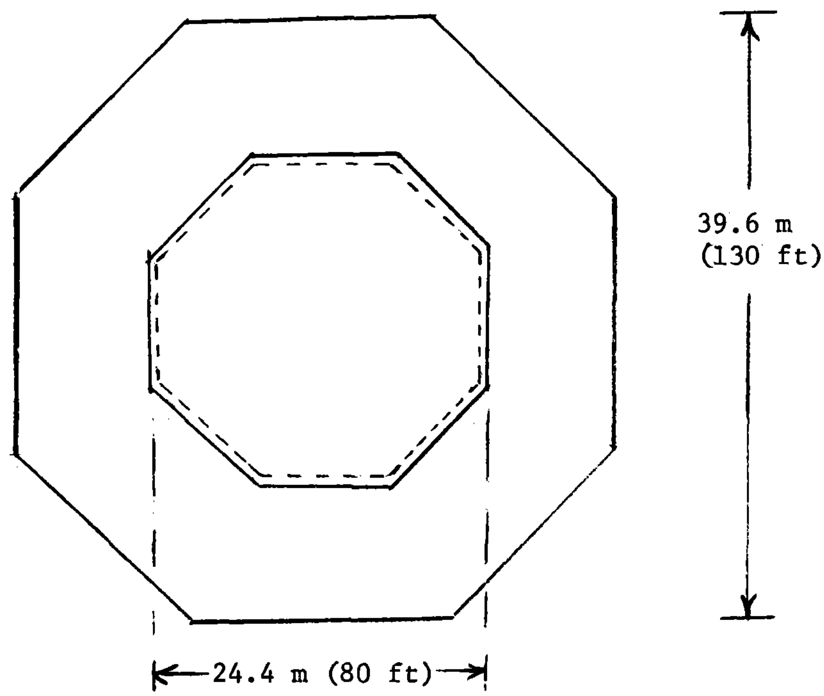
Excavated soil will be removed from the vicinity of the receiver tower site. After construction is completed the disrupted terrain will be graded and landscaped to blend with other pilot plant installations and the natural surroundings.

3. Mitigation Considerations

The requirement for an elevated receiver, the considerable mass of the receiver and its related installations, and the environmental criteria imposed on the design, all contribute to the need for a foundation of the size and configuration described. If there were compelling environmental pressures to reduce the area of disrupted topography, a smaller diameter, but deeper foundation could be employed, which would depart from a minimum cost baseline.



Elevation View



Plan View

Figure 3 Receiver Tower Foundation Configuration

ENVIRONMENTAL IMPACT DATA SI ET

A. System Concept MMC

B. Subsystem Receiver

C. Design Feature-Boiler Blowdown Operations

D. Environmental Factors Impacted:

- o Soil/Water Quality - Boiler must be blown down to purge accumulated solids and contaminants from system. Effluents may impact environment, depending on disposal/ disposition procedures.
- o Contribution to total water required for plant operation.

E. Design Feature Descriptive Data:

1. Blowdown Frequency: Constant while operating on collector flux.
2. Effluent Quantity: 2,268 Kg (5,000 lb)/hr, max.
3. Solids Content:

	Silica	1 ppm*(max.)
	Total dissolved solids	75 ppm (max.)
	Phosphate	5-10 ppm (range)

4. Disposition: Blowdown water, with dissolved solids, will be piped to the existing Coolwater lined evaporation ponds for evaporation and containment of solids.
5. Additional Comments: Blowdown requirements and the content of effluents are expected to be similar to those for a conventional fossil fuel plant of comparable size. There are no solar-peculiar differences evident.
6. Mitigation Considerations:
   - o See E.4 above for baseline disposition of blowdown products.
   - o Blowdown products could be processed in a closed system to recycle waste water as feedwater makeup. This is not considered practical for the small quantities involved, and in view of an adequate water supply and existing disposal means.

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* ppm - Parts per Million

ENVIRONMENTAL IMPACT DATA SHEET

A. System Concept: MMC

B. Subsystem: Receiver

C. Design Feature: Accident Potential

D. Environmental Factors Impacted:

- o Catastrophic failure of boiler, piping or support structure could endanger life in vicinity of Receiver Tower.

E. Design Feature Descriptive Data:

1. Data relating to potential energy in boiler and related piping at operating design point:
   - o Total weight of receiver (wet): 272,158 kg (600,000 lbs)
   - o Total quantity and properties of hot water:

Location	Quantity	Temperature	Pressure
Receiver	7212 Kg (15,900 lbs)	597 K (615°F)	11,790 kPa (1710 lbs/in^2)
Riser	635 Kg (1400 lbs)	500 K (440°F)	13,460 kPa (1952 lbs/in^2)

   - o Total quantity and properties of steam:

Location	Quantity	Temperature	Pressure
Receiver	544 Kg (1200 lbs) (Receiver and Downcomer combined)	789 K (960°F)	10,687 kPa (1550 lbs/in^2)
Downcomer		$\simeq$ 789 K (960°F)	10,687 kPa (1550 lbs/in^2)

2. Data relating to natural environment integrity of receiver and tower piping.
   - o Receiver/tower wind loads capability - 40 m/sec (90 mph)*
   - o Receiver/tower seismic loads capability - 0.25 g (horizontal and vertical)
3. Data relating to induced environmental integrity of receiver and related plumbing.
   - o Capability of tower to sustain uncontrolled, focused flux from collector - 157 KW_{th}/m^2-hr (50,000 Btu/ft^2-hr), for regions adjacent to receiver aperture.
   - o Capability of receiver to sustain loss of feedwater - receiver can accept full (design point) collector output for one minute without failure, under worst case conditions.

*At reference height of 10 m; varying with height to the 0.15 power.

4. Additional Comments:

Failure of the steam circuit pressure vessels (including piping) or failures that secondarily could cause rupture of pressure vessels have the potential of releasing scalding water and steam and, conceivably, (for a worst case accident) propelling steam circuit and structural parts from the point of rupture. It is expected that the consequences of a rupture of the steam circuit would be a fairly orderly release of steam (or water) and that the effects would be confined to internal regions of the tower and to the external area immediately surrounding the tower. Sheet metal cladding, if released, could be carried some distance from the tower. Panels are 0.67 m (26.5 in.) wide by 7.6 m (25 ft) long and relatively lightweight (typically 50 to 75 kg, 110 to 166 lbs) which should confine hazard potential to exposed personnel. Release of water and steam would create a hazard only to unprotected personnel in the immediate vicinity; rupture of the receiver is not expected to present a steam/hot water hazard to exposed personnel at ground level.

The tower/receiver will be structurally designed to withstand natural environments in excess of those expected to occur at the Barstow location, i.e., winds up to 40 m/sec (90 mph)* and seismic accelerations of 0.25 g will be sustained without incurring catastrophic damage.

The integrity of the pressure systems of the receiver and piping will be assured during normal operation by designing to the requirements of industry codes as they apply to power plant design. In this respect, and with respect to operating procedures for the non-solar elements of the pilot plant, this installation will present no greater risk of catastrophic failure than presented by a fossil fuel plant of contemporary design.

The elevated postion of the boiler and related piping, and the solar-peculiar failure modes present the significant differences from conventional designs that warrant special attention.

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*At reference height of 10 m; varying with height to the 0.15 power.

Solar-peculiar failure modes that could cause rupture of pressure vessels include those system failures and procedural errors that will cause solar energy to be focused onto receiver or tower areas at such flux levels and for such durations as to exceed structural design limits. Following is a tabulation of possible failure modes and the design features incorporated into the pilot plant design to preclude these occurrences or to avoid propogation to a catastrophic event.

- Loss of Tracking Control Data (Sun Position) to Heliostats; Heliostats in Static Positions, Focused on Receiver Aperture - The continuous change in sun position would cause the focused flux to move across the aperture edge and onto tower structure. This occurrence is prevented by incorporating into each heliostat the logic that will cause it to automatically perform a preprogrammed, safe, stow sequence upon loss of data communication.

- Failure of Collector Field Control System Which Causes Collector System (or a Significant Portion of It) to Focus on a Target Area Other Than Receiver Aperture - Sustained flux levels associated with multiple, focused, heliostat beams could exceed the design limits of the tower structure outside the receiver aperture area. This failure mode is considered improbable due to a number of coincidental events required to direct damaging flux levels to susceptible structure. The following system features will prevent its occurrence:

  - Collector field computer logic incorporating "reasonableness" self-checks to prevent transmittal of grossly inaccurate sun position data;
  - Redundant computer and other critical control elements, with appropriate switching logic;
  - Control room instrumentation monitoring receiver and aperture edge temperatures, with alarms to indicate the onset of hazardous conditions. Manual override can initiate a safe stow command.

- <u>Loss of Receiver Feedwater Supply</u> - The receiver can withstand operating design point flux levels for one minute (worst case conditions) after a complete loss of feedwater supply. This failure mode will be prevented by:

  - Completely redundant feedwater pump capability;
  - Receiver overtemperature alarms which will allow manual initiation of collector field stow sequence, moving focused flux from aperture before damaging temperatures are reached.

ENVIRONMENTAL IMPACT DATA SHEET

A. System Concept ______ MMC ______

B. Subsystem ______ Collector ______

C. Design Feature ___ Collector Field Area ___

D. Environmental Factors Impacted:

o Land Committment - Removes land from other uses.

E. Design Feature Descriptive Data:

1. Geometry and dimensions of land area required for heliostat field: 610 m (2000 ft) long by 732 m (2400 ft) wide* (see Figure 4).

2. Additional Comments:

The collector field is the most land intensive feature of the pilot plant. The area occupied by the heliostats, peripheral paved maintenance roadways and outer boundary protective fence constitutes the bulk of the area committed for the plant site, which is removed from other uses.

3. Mitigation Considerations:

The area identified for heliostat deployment is an integral feature of the pilot plant concept being developed; reduction of this area can only be made at the expense of net power output and/or greater initial and operating costs.

* Including peripheral roadway and security fencing.

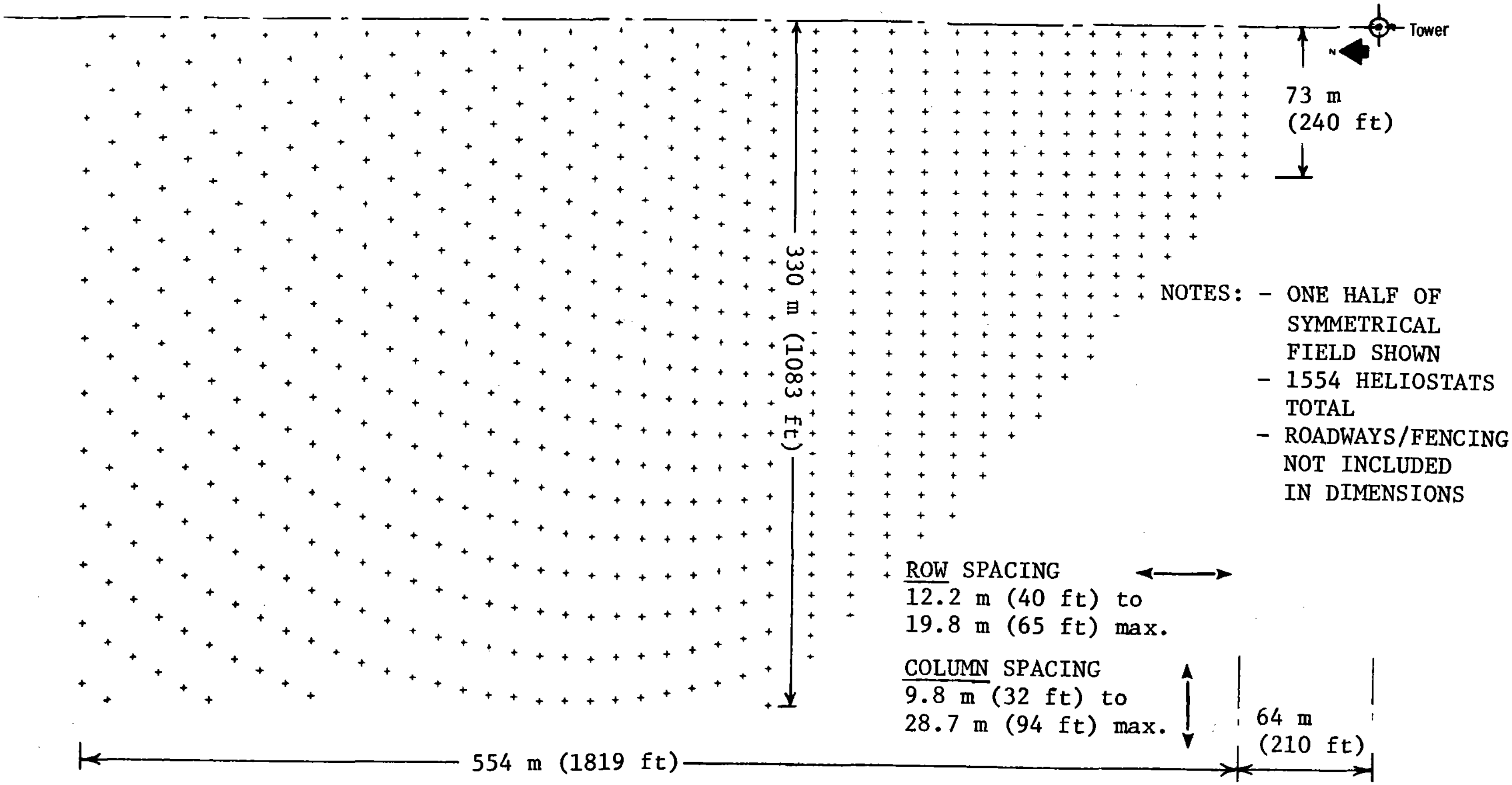


Figure 4 Collector Subsystem Configuration/Dimensions

ENVIRONMENTAL IMPACT DATA SHEET

A. System Concept MMC

B. Subsystem Collector

C. Design Feature Topographic Modifications

D. Environmental Factors Impacted:

- o Topography, Biology, Meteorology - Grading, foundations, paving, trenching and fencing contribute to irreversible modification of the pristine desert topography, affecting drainage patterns, plant and animal life, and modifying local meteorological factors.

E. Design Feature Descriptive Data:

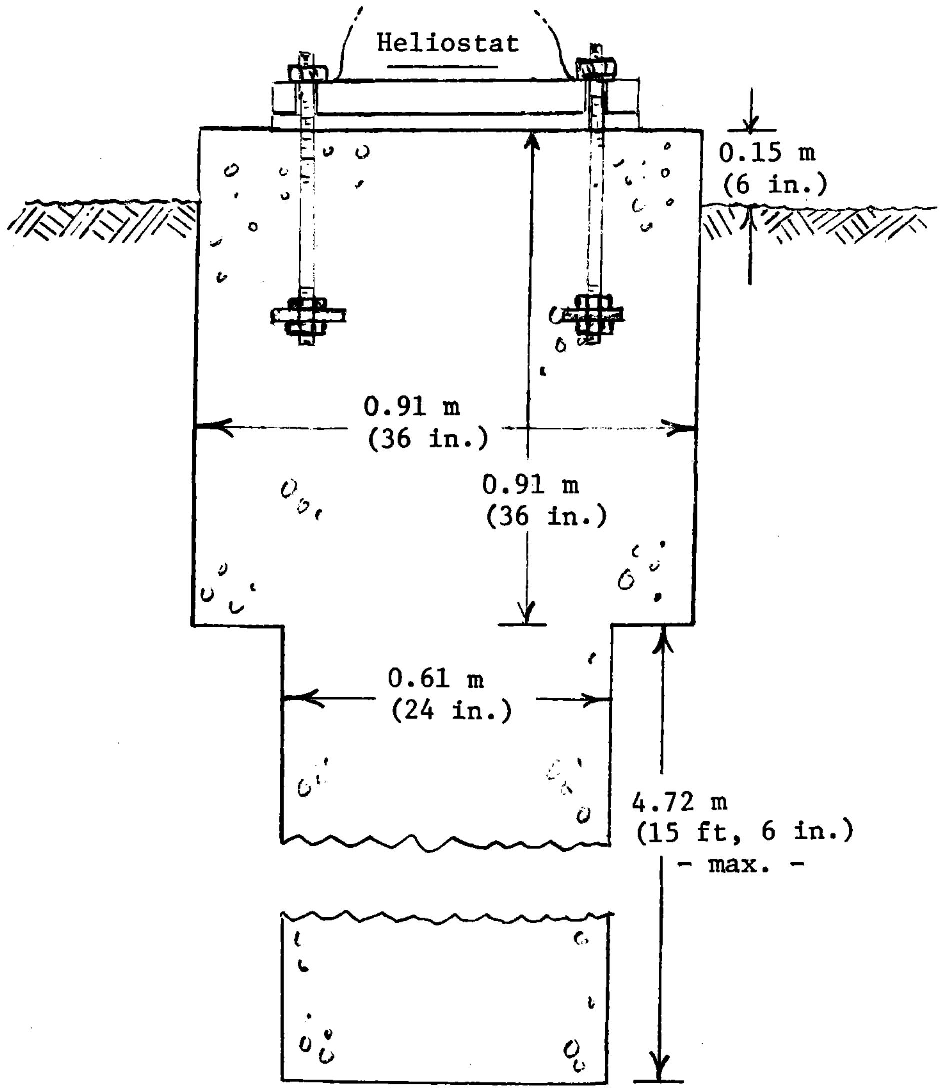
1. Quantity of Heliostat Installations: 1554
2. Heliostat Foundation Dimensions: (Figure 5) 0.91 m (36 in) diameter by 5.6 m (18.5 ft) deep (max)

   Net Excavated Volume: 2 m^3 (70 ft^3)
3. Power Transformer Installations: 16 Transformers, similar in size to residential distribution units, requiring surface slab concrete foundations (typically) 1.5 m (5 ft) square and 10 cm (4 in) thick, which may be precast.
4. Paving: Access/maintenance roadway along E and W edges of heliostat field and connecting with roadway in tower/control center area, including paved turn-around and row access areas (Figure 6).

   Total Paved Area: 32,400 m^2 (38,700 yd^2), including Macadam shoulders

   Total Disturbed Area: 40,700 m^2 (48,700 yd^2) including drainage grading

   Pavement Description (Figure 7A): Pavement consists of a 0.15 m (6 in) thick base of soil cement, mixed in place, topped with a 3.8 cm (1.5 in)



NOTE: Foundation is Circular in Plan View

Figure 5 Heliostat Foundation

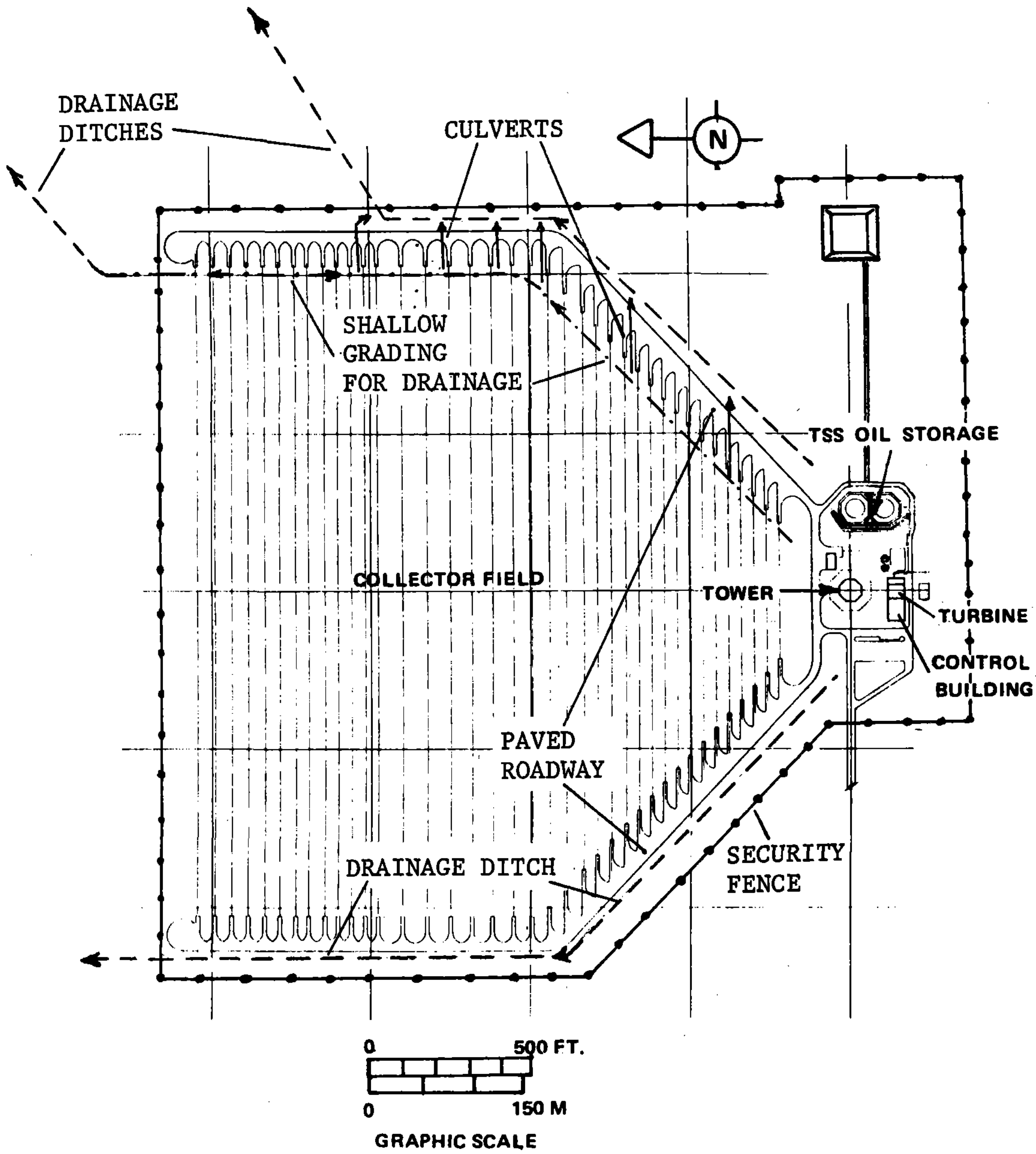


Figure 6 Collector Field Paving/Fencing/Drainage

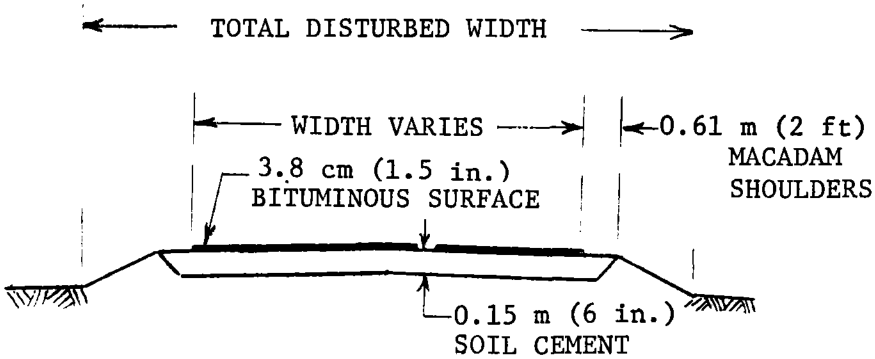


FIGURE 7 A, PAVEMENT

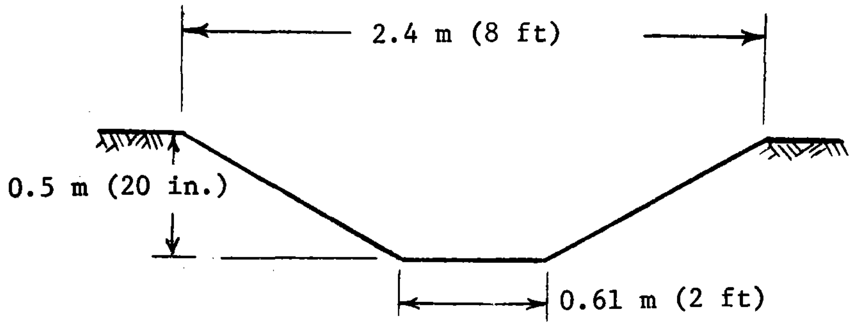


FIGURE 7 B, DRAINAGE TRENCH, (TYPICAL)

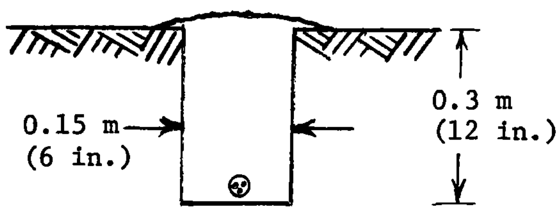


FIGURE 7 C, CABLE TRENCH, (TYPICAL)

thick bituminous surface. A 0.61 m (2 ft) wide shoulder of Macadam is provided on all edges. The roadbed is crowned and edge areas are graded as required to provide drainage.

5. Field Drainage: Drainage ditches similar to that shown in Figure 7B will be constructed along the E and W sides of the heliostat field, draining to the N and NE, respectively. Additional, shallower ditching will be required inside the heliostat field, along the E roadway draining the heliostat field. Culverts under the roadway will be provided to complete the drainage paths. Figure 6 shows the general routing of the drainage paths.

Total Area Disturbed by Drainage Ditches: 5727 m^2 (6850 yd^2) (approximate)

6. Buried Cabling: All cabling will be direct buried and covered via trenching equipment; no conduits will be employed (Figure 7C).

Power Distribution: Commercial (net) power will be distributed to the primaries of 16 transformers dispersed through the heliostat field. Secondaries of these transformers will supply power to each heliostat.

Total Length of Buried Cable: 27,240 m (92,100 ft)

Trench Width: 0.15 m (6 in)

Trench Depth: 0.15 to 0.45 m (6 to 18 in)

Command Control: Control cabling will consist of shielded, twisted pairs, distributed the length of the heliostat field from the control room to junction boxes, and across the widths of each heliostat row.

Total Length of Buried Cable: 28,237 m (82,645 ft)

Trench Width: 0.15 m (6 in)

Trench Depth: 0.15 to 0.45 m (6 to 18 in)

Lightning Protection/Grounding: The grounding net will consist of five No. 4/0 bare copper conductors fanned out through the length of the field, starting near the receiver tower, and connecting with lateral runs of No. 2 bare copper across each heliostat row.

Total Length of Buried Conductors: 29,163 m (95,685 ft)

Trench Width: 0.15 m (6 in)

Trench Depth: 0.15 to 0.6 m (6 to 24 in)

7. Fencing:

Total Length: 2987 m (9800 ft), total for plant site

Height: 2.3 m (7.5 ft)

Type: 1.8 m (6 ft high) chainlink fence fabric, topped by 3 strands of barbed wire; 5 cm (2 in) diameter line posts, spaced on 3 m (10 ft) centers.

8. Grading: General grading of heliostat field will not be required; heliostat foundations will be installed at existing grade levels.

9. Total Area of Surface Alterations (estimated):

Foundations:	1,057 m^2	(1,265 yd^2)
Paving:	40,700 m^2	(48,700 yd^2)
Drainage:	5,727 m^2	(6,850 yd^2)
Trenching:	9,548 m^2	(11,420 yd^2)
Fencing:	18 m^2	(22 yd^2)
Total	57,050 m^2	(68,257 yd^2)

10. Additional Comments:

The area of the heliostat field expected to be significantly disturbed by primary construction constitutes approximately 17% of the total heliostat field. Displaced soil from foundations will be collected and used to construct containment basin dikes. Vehicles used in the collector field during the construction phase will be equipped with low footprint pressure tires to further reduce construction scars. Access to all heliostats by motorized equipment will be necessary for periodic maintenance during the plant operation phase. These vehicles will also be equipped with low pressure tires, obviating the need for extensive paving throughout the heliostat field. Paving will be provided on the more heavily travelled periphery of the field and at row ends where turns would otherwise cause scuff erosion.

Drainage trench area estimated above includes only that required by the heliostat field and does not include the necessary extensions of the ditches away from the field to lower ground.

Although much of the heliostat field will remain visibly unaltered with respect to surface features and plant life, the overall effects of the installations, modifications and operations associated with this area will be to alter the habitat of local flora and fauna (denying access to larger ground animals because of the fence) and to modify drainage patterns. Air current modifications due to changes in surface reflectance/absorptance characteristics are expected to be only a minor contributor to the more significant shading effects of the heliostats (discussed separately).

11. Mitigation Considerations:

Cable emplacement lengths and areas have been estimated on a worst case basis of dedicated trenches for each cable type; total disrupted area may be less than that indicated, depending on further evaluation of common trenching (e.g., for power and ground net cabling).

Total disrupted area could be reduced by routing power distribution and command/control cabling on the ground surface to reduce the total trenching required. This could result in increased maintenance and system down-time.

Fencing could be replaced by active patrol of the plant perimeter. This would increase operating cost.

ENVIRONMENTAL IMPACT DATA SE T

A. System Concept MMC

B. Subsystem Collector

C. Design Feature Heliostat Shading

D. Environmental Factors Impacted:

o Biology, Meteorology: Heliostats will shade a significant portion of the collector field ground surface and adjacent areas, affecting local ecology and microclimate.

E. Design Feature Descriptive Data:

1. Total Area shaded by heliostats and supporting structures:
   Figure 8 presents estimated total shaded areas for stowed and tracking modes, for summer and winter solstice, as a function of time-of-day.

2. Total Thermal Energy intercepted and reflected by the collector subsystem: 49.55 MW_t (At pilot plant design point, 2:00 p.m., Summer Solstice).

3. Additional Comments:

   Shading of the ground surface may impact local ecology by affecting soil moisture retention/evaporation, local air currents, attracting flora and fauna favoring shading, and discouraging flora and fauna favoring direct insolation.

   Note that shadowing due to heliostats (and receiver tower) is not confined within collector field boundaries in early morning and late afternoon, and in fact extends far beyond plant boundaries at sunrise and sunset.

4. Mitigation Considerations:

   Shading of large surface areas is implicit in solar concentrator technology; solar flux reflected to and focused upon the pilot plant receiver must necessarily be removed from the collector field. As a practical design consideration this flux must be gathered from as concentrated an area as technically feasible to reduce losses related to transmission distances. The only practicable mitigation approach (i.e., spreading heliostats to distribute shading over larger area) would reduce plant output and efficiency.

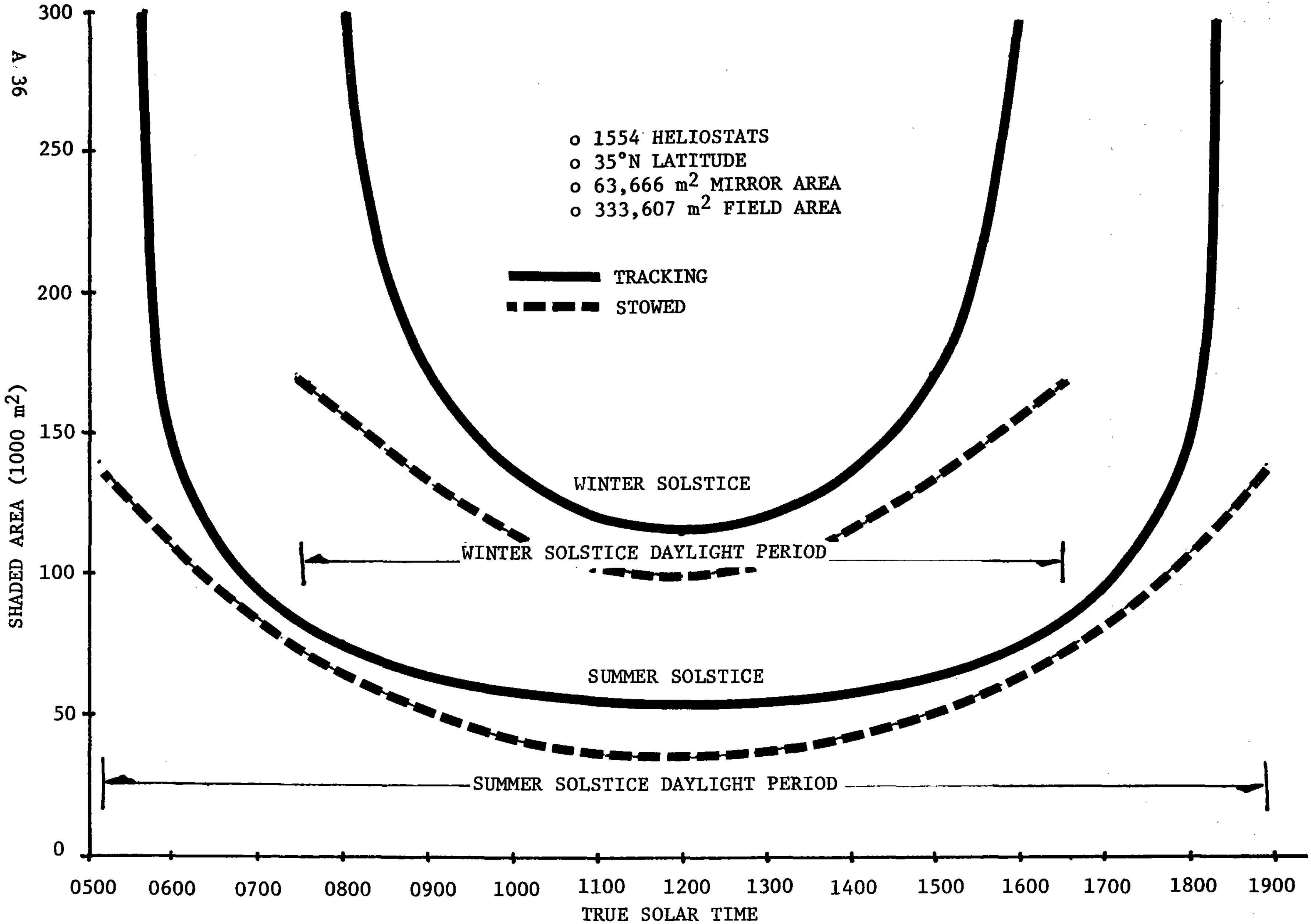


Figure 8 Total Area Shaded by Heliostats

E. Design Feature Descriptive Data (Continued)

Note that in terms of the total heat balance of the local meteorological area, approximately 70% of the heat flux removed from the collector field by the heliostats is rejected to the atmosphere as sensible and latent heat at the evaporative cooling tower.

ENVIRONMENTAL IMPACT DATA SHEET

A. System Concept ___MMC___

B. Subsystem ___Collector___

C. Design Feature ___Mirror Washing___

D. Environmental Factors Impacted:

- Biology, water consumption: Periodic mirror washing contributes to total quantity of water used by pilot plant, provides added moisture to soil at localized areas, and contributes to vehicular traffic over otherwise undisturbed areas of pilot plant site.

E. Design Feature Descriptive Data:

1. Mirror Washing Frequency: Once per month.
2. Quantity Cleaning Solution Used: 102 liters (27 gal)/heliostat.
3. Constituents of Cleaning Solution: Demineralized Water
4. Wash water disposition: Dispersed at Heliostat.
5. Additional Comments:

   Mirrors are washed with hot water sprayed from a vehicular mounted washer. The sprayer delivers 34 liters (9 gal)/minute and each heliostat is washed in 3 minutes. Heliostats are washed on a 5-minute cycle. The washer vehicle is equipped with low ground pressure tires to minimize effects on existing vegetation. Engine exhaust products include those from the transporting vehicle--a two-ton truck with gasoline engine of 6 liter (366 in^3) displacement, operated at near idle; and from a small gasoline engine (approximately 24 HP) used to heat and spray water. The cleaning vehicle will be operating in the morning and evening hours, for a total of approximately 160 hours per month.

6. Mitigation Considerations:

   Mirror washing processes and procedures could be modified to alleviate any unacceptable environmental impacts. Use of propane powered vehicles and pumps, and reduced cleaning frequency are examples of mitigation measures that have practical potential but may have adverse plant performance or operating cost impacts.

ENVIRONMENTAL IMPACT DATA SHEET

A. System Concept ______ MMC ______

B. Subsystem ______ Collector ______

C. Design Feature ______ Spurious Reflections/Solar Beams

D. Environmental Factors Impacted:

- o Safety Hazard, Aesthetics: During daylight stowing/unstowing operations distracting flashes may be visible for long distances from plant site. This feature may be objectionable to those working, living, or traveling within visual range of the phenomenon, and may constitute a hazard under certain conditions.

E. Design Feature Descriptive Data:

1. When Distractions May Occur:

Solar reflections will be projected beyond the area limits of the pilot plant facility. These flashes will occur during any movement of the collector field when the sun is visible in the sky and all beams are not aligned within the receiver aperture. This phenomenon will occur during all operations which move mirrors onto or off the aperture (e.g., stowing and unstowing operations).

These solar flux projections may only be objectionable and a curosity at long distances but may pose a hazard to the public if close proximity access to the field is allowed. Solar reflections will also be projected to higher elevations during normal tracking as well as stowing/unstowing operations. These may cause distractions/hazards to aircraft occupants depending upon their altitude, speed, and approach direction.

2. Angular Visibility, Duration and Intensities:

Quantitative analysis of these effects is the subject of a separate study for ERDA. Results, including eye threshold hazard levels and requirements to provide exclusion zones to the public domain, will be reported in the System Safety Design Criteria, which is currently in process.

3. Additional Comments:

Although the mirror field could be the source of objectionable reflections of the surroundings visible to nearby residents, the

E. Design Feature Descriptive Data:

only effects expected to be significant are the more prominent, long range reflections of the sun to surface points and aircraft in flight. These flashes could constitute direct or indirect hazards. They may occur when heliostats are slewed onto or off the aperture during sunlight conditions, e.g., when stowing or unstowing. These direct solar reflections are expected to constitute the primary concern for aesthetic acceptability and safety. Solar flux projections within the plant boundaries could be particularly intense, requiring absolute control for personnel protection and safety.

4. Mitigation Considerations:

Circumvention techniques that could reduce or eliminate unacceptable impacts include:

- o Provide shielding "wings" or flux tracks surrounding aperture and/or down tower to ground level.
- o Provide positive control of mirror movement operations to minimize or eliminate objectionable paths.
- o Maintain heliostats on aperture until after sunset; establish heliostats on aperture prior to sunrise. This approach would be ineffective for abnormal operations, e.g., receiver failure requiring mirror stowage midday.
- o Select and orient plant site and/or establish access boundaries to minimize effects of reflections.

THERMAL STORAGE SUBSYSTEM (TSS)

ENVIRONMENTAL IMPACT DATA SHEET

A. System Concept MMC

B. Subsystem Thermal Storage

C. Design Feature Size, Geometry, Appearance

D. Environmental Factors Impacted:

Aesthetics - Tank and heat exchanger dimensions, surface finish, color and locations all contribute to the short and medium range appearance of the overall pilot plant installations.

E. Design Feature Descriptive Data

1. Tank Quantities and Dimensions (See Figures 9 thru 12):

	Salt	Oil
No. of Tanks:	2	2
Configuration:	Cylindrical with Elliptical Domes, Top and Bottom	Spherical
Height:	8.1 m (26.5 ft)	18.3 m (60 ft)
Diameter:	6.4 m (21 ft)	18.3 m (60 ft)
Installed Height (AGL):	10.5 m (34.5 ft)	21.0 m (69 ft)

2. Surface Finish, Color

Salt Tanks: Unfinished, sheet aluminum over insulation on cylindrical section; aluminized PVC coating on domes.

Oil Tanks: Aluminized PVC coating over tank insulation.

Pipes: Unfinished, sheet aluminum over insulation.

3. Additional Comments:

The four thermal storage media tanks and their respective heat exchangers constitute the major visual elements of the Thermal Storage Subsystem. The salt heat exchanger is the highest feature, extending approximately 24.4 m (80 ft) above ground level. All components are located within a rectangular plot 55 by 73 m (180 by 240 ft) SE of the receiver tower. Another prominent close range feature of the subsystem is the containment dike or berm

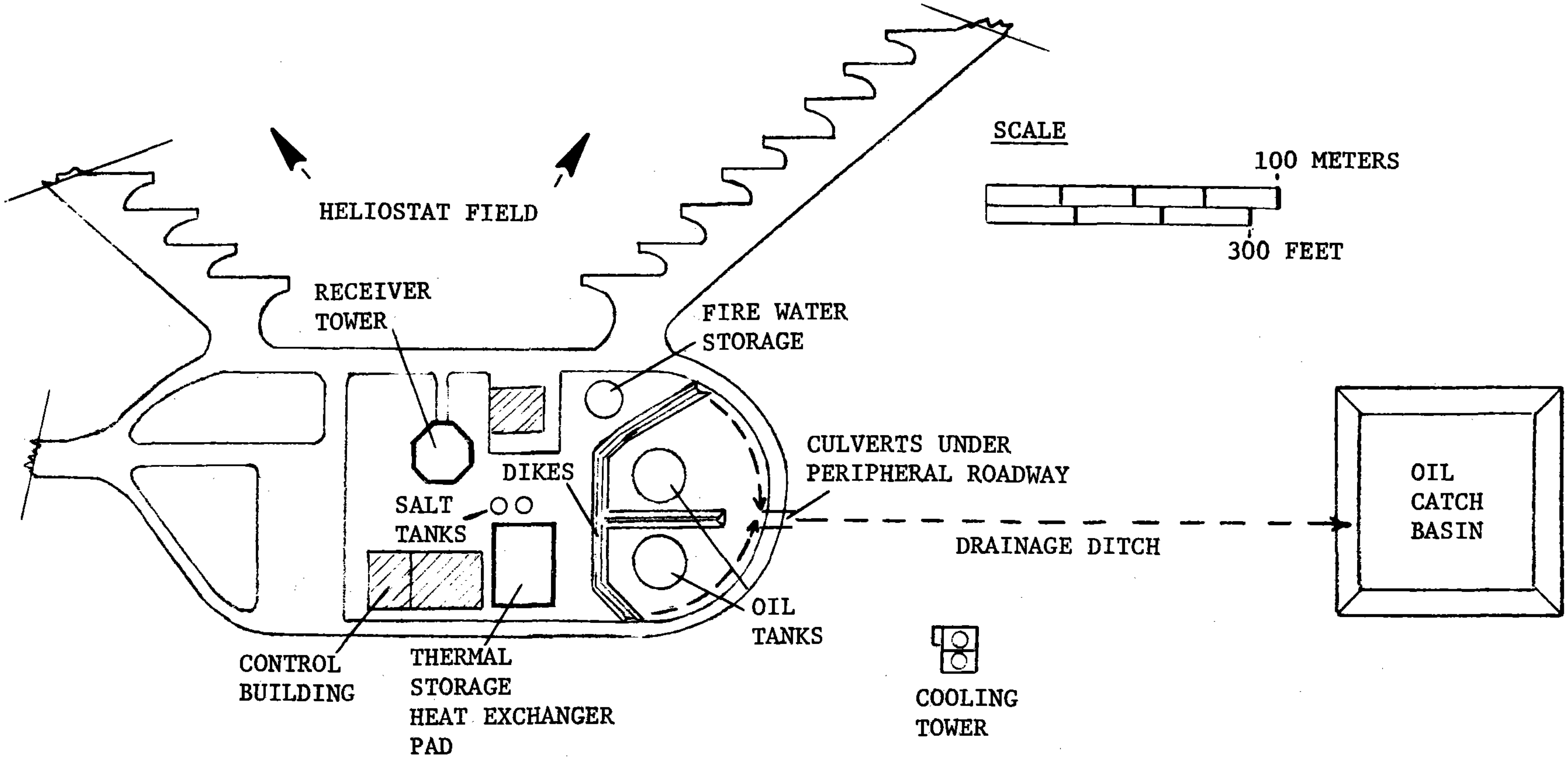


Figure 9 Thermal Storage Subsystem - General Arrangement

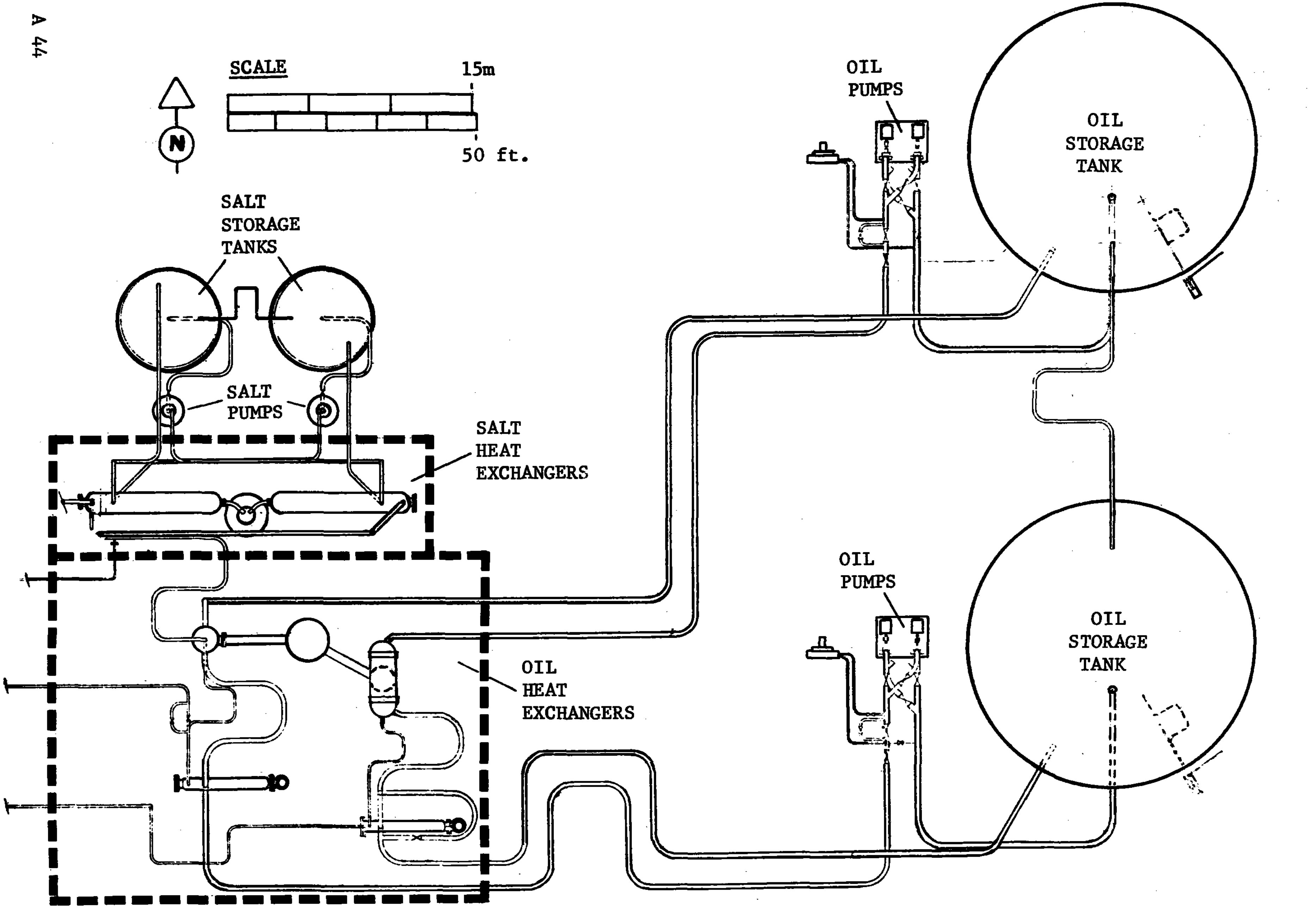


Figure 10 THERMAL STORAGE SUBSYSTEM - PLAN VIEW OF COMPONENTS

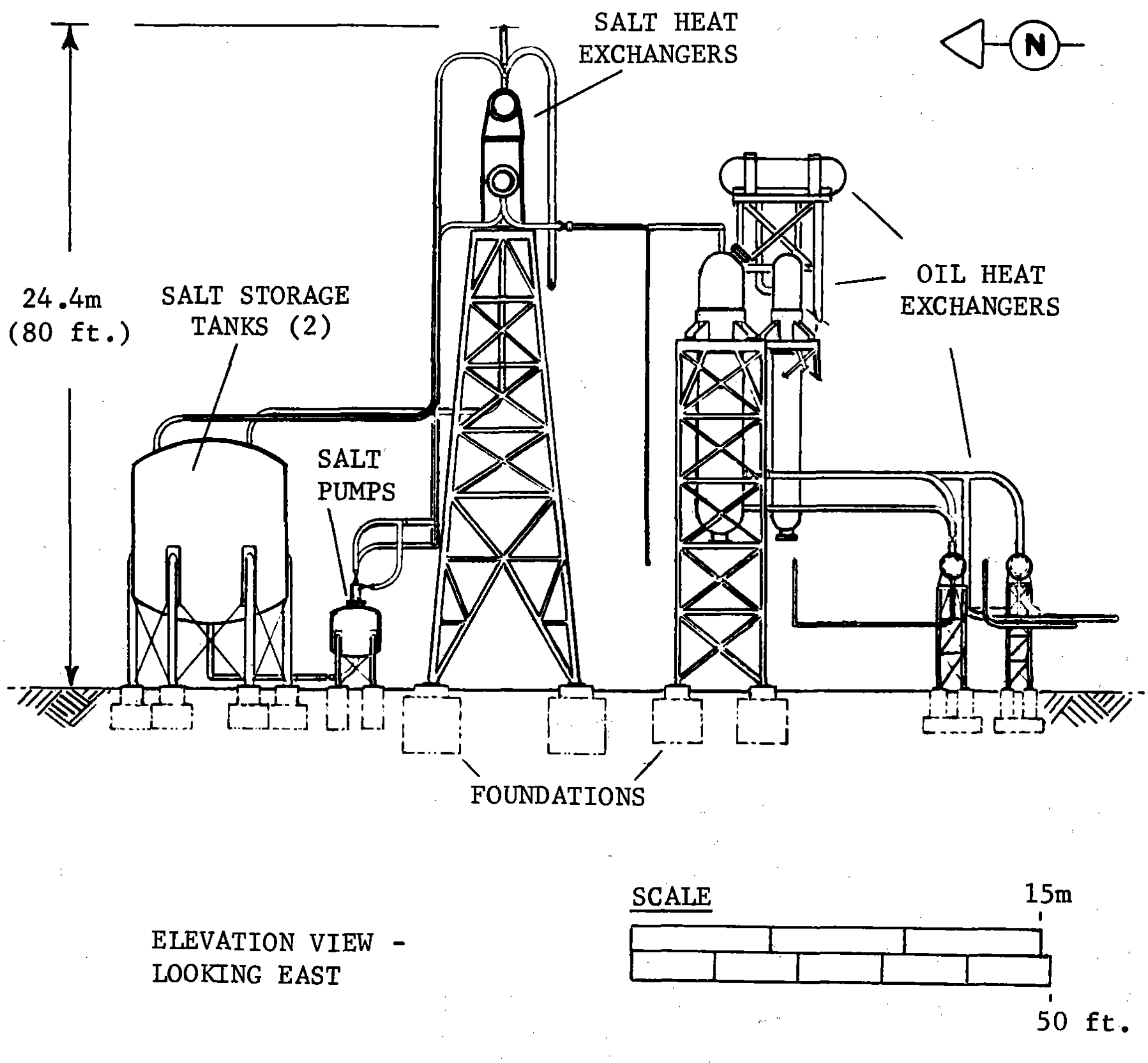


Figure 11 TSS SALT STORAGE AND HEAT EXCHANGERS

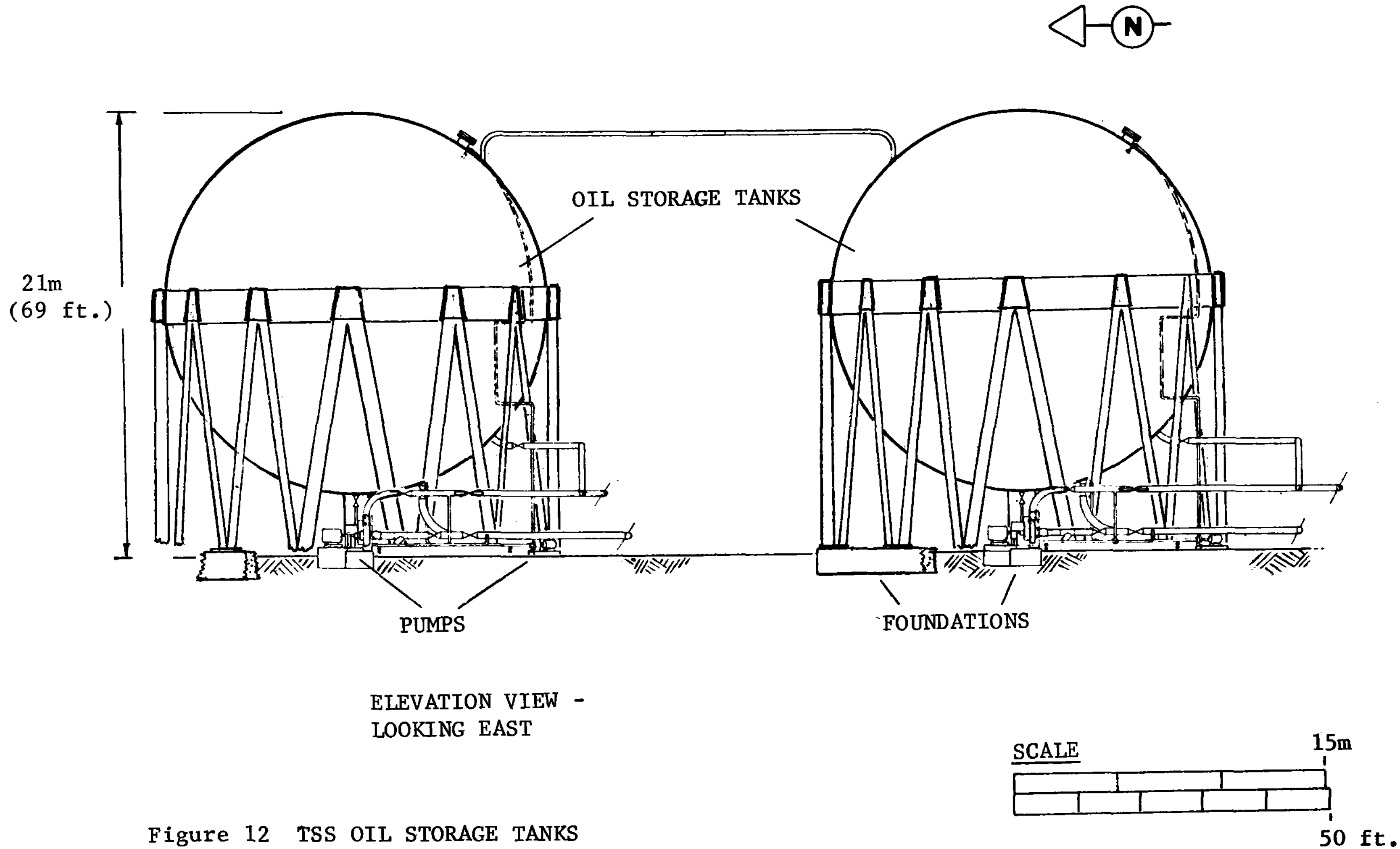


Figure 12 TSS OIL STORAGE TANKS

system surrounding the tank installations, which is further described on pages A 48 and A 49. There are no unusual or attracting visual features or emissions associated with these tanks that would distinguish them from typical industrial storage units for liquid combustibles.

4. Mitigation Considerations:

These tanks (and the related piping) could be placed underground to reduce their visual impact. This would result in higher installation and maintenance costs.

Thermal storage could be deleted from the Pilot Plant entirely, which would result in power interruptions during transient cloud conditions, preclude power generation after sunset, and would severely limit test goals relating to commercial plant feasibility/verification.

ENVIRONMENTAL IMPACT DATA SHEET

A. System Concept MMC

B. Subsystem Thermal Storage

C. Design Feature Tank and Dike Installations

D. Environmental Factors Impacted:

- Land Commitment/ Topography - Tank foundations, catch basin and dike construction contribute to the irreversible topographic modifications required by plant installations.
- Surface Drainage - The catch basin, ditching and dikes will modify local surface drainage patterns.

E. Design Feature Descriptive Data:

1. Excavation Requirements for Foundations:
   Maximum Depth - 3 m (10 ft)
   Total Area Excavated - 182 m^2 (1962 ft^2)
2. Paving (for Heat Exchanger Pad): 622 m^2 (6700 ft^2)
3. Oil Tank Dikes (Figure 9):
   Height (above local ground level): 1.1 m (3.5 ft)
   Dike Width - Top: 1.2 m (4 ft)
   - Base: 4.9 m (16 ft)
   Total Length: 152 m (500 ft)
4. Catch Basin:
   Total Area: 6280 m^2 (67,600 ft^2)
   Depth (below local ground level): 1.7 m (5.5 ft)
5. Ditch (to Catch Basin):
   Width - Top: 2.4 m (8 ft), typical
   Base: 0.6 m (2 ft)
   Length: 305 m (1000 ft)
6. Additional Comments:

   Oil spill confinement areas are formed around the oil storage tanks by earthen dikes between the tanks, and generally west and north of the tanks for separation from the remainder of the plant installations. This area is drained to a remote catch basin located 236 m (775 ft) east of the tanks, by means of an interconnecting drainage ditch.

The basins, ditch and dikes are of earthen construction. Soil removed from pilot plant installations foundations and the catch basin will be used to form the dikes. Most of the existing vegetation over the entire area of the containment basins, catch basin, dikes and ditch will be removed as an unavoidable consequence of the required grading.

Soil surfaces (particularly the dike) may require spray application of a suitable stabilizing agent to reduce blowing dust during construction and to control environmental erosion during the operating phase. Distillate has been successfully used for this purpose in the general area; other commercially available soil stabilizing agents will also be considered.

Due to the relatively small area associated with this modification, surface drainage patterns of the general area are not expected to be significantly impacted.

7. Mitigation Considerations:

Thermal storage could be deleted from the pilot plant (see page A 47).

Disturbed soil (basins and dikes) could be replanted to control erosion. This would increase construction and maintenance costs and would require irrigation for the most effective types of ground cover.

ENVIRONMENTAL IMPACT DATA SHEET

A. System Concept MMC

B. Subsystem Thermal Storage

C. Design Feature Heat Loss to Atmosphere

D. Environmental Factors Impacted:

- Meteorology, Microclimate - External surfaces of thermally charged tanks will be warmer than ambient, contributing to redistribution of thermal energy from collector field.

E. Design Feature Descriptive Data:

1. Total External Surface Areas of Storage Tanks, Piping and Other Subsystem Components:

Subsystem	Surface Area
Oil Subsystem	3015 m^2 (32,450 ft^2)
Salt Subsystem	907 m^2 (9,760 ft^2)
Superheated Steam	99 m^2 (1070 ft^2)
Saturated Steam	65 m^2 (700 ft^2)
Water	101 m^2 (1090 ft^2)

2. Mean Temperatures of Exposed Surfaces:

   Conditions - Fully charged system.
   - No wind.
   - Ambient temp. of 28°C (82°F)

Salt Tanks	34°C (92°F)
Oil Tanks	34°C (92°F)

3. Total Thermal Energy Losses to Atmosphere: (continuous)

   0.37 MW_{th} (1,262,810 BTU/Hr)

4. Period at Elevated Temperatures:

   Estimated hours per year: 8760 hours

5. Additional Comments:

   A portion of the thermal energy collected by the heliostat field will be stored as sensible heat in the storage media within the salt and oil tanks. Although most of this thermal energy is subsequently delivered to the steam generating cycle, losses through the insulated tank walls will occur. This heat loss energy is not only transported in distance (from collector field to thermal storage tank locations), but is also delayed in time, releasing some of this collected energy to the atmosphere after sunset. Although this feature, along with the other electric power generating components, tends to reduce diurnal temperature excursions, the total effects are expected to be insignificant for all but very localized areas.

6. Mitigation Considerations:

Increased insulation (at increased cost) could be added to tank and line external surfaces to further reduce heat losses to atmosphere.

Tanks and lines could be installed underground at significant increases to installation and maintenance costs.

ENVIRONMENTAL IMPACT DATA SHEET

A. System Concept MMC

B. Subsystem Thermal Storage

C. Design Feature Heat Exchanger Blowdown

D. Environmental Factors Impacted:

- o Soil/Water Quality - Heat exchanger (thermal storage subsystem boiler) must be blowndown to purge accumulated solids and contaminants from system. Effluents may impact environment, depending on disposal/disposition procedures.
- o Contribution to total water required for plant operation.

E. Design Feature Descriptive Data:

1. Blowdown Frequency - Constant while operating on TSS stored thermal energy.
2. Effluent Quantity - 2268 Kg (5,000 lb) per hour, max.
3. Contaminant Content-

Silica	1 ppm*(max.)
Total dissolved solids	75 ppm (max.)
Phosphate	5-10 ppm (range)

4. Disposition - Blowdown water with concentrated contaminants will be piped to existing Coolwater lined evaporating ponds.
5. Additional Comments:

   Blowdown requirements and the content of effluents are expected to be similar to those for a small conventional fossil fuel plant of comparable size. There are no solar peculiar differences evident.

6. Mitigation Considerations:
   - o See E.4, above for baseline disposition of blowdown products.
   - o Blowdown products could be processed in a closed system to recycle waste water as feedwater make-up. This is not considered economically practicable due to the small quantities involved and in view of existing disposal means.

*ppm - Parts per Million

ENVIRONMENTAL IMPACT DATA SHEET

A. System Concept MMC

B. Subsystem Thermal Storage

C. Design Feature Accident Potential

D. Environmental Factors Impacted:

- o Catastrophic Failure of Heat Exchangers, Oil or Salt Storage Tanks, or Piping could endanger life of persons on the plant site and could adversely affect local biology and water and air quality.

E. Design Feature Descriptive Data:

1. Figure 10 presents the general arrangement of pressure vessels, piping and storage tanks, constituting the thermal storage subsystem.

2. Data relating to potential energy in pressure vessels and related piping:

   - o Total quantities and properties of hot water and steam contained in subsystem (worst case operating conditions):

	Volume, m^3 (ft^3)	Temp, °C (°F)	Press, kPa (psig)
Water	12.7 (450)	232 (450)	2965 (430)
	0.3 (10)	216 (420)	5309 (770)
	5.7 (200)	299 (570)	8481 (1230)
	0.8 (30)	260 (500)	8481 (1230)
Steam	1.3 (45)	427 (800)	2965 (430)
	1.4 (50)	379 (715)	2965 (430)
	1.4 (50)	288 (550)	2965 (430)
	4.5 (160)	238 (460)	2965 (430)
	1.4 (50)	468 (875)	8619 (1250)
	1.4 (50)	382 (720)	8619 (1250)
	2.3 (80)	299 (570)	8619 (1250)

- o Total Quantities Nitrogen (blanket gas) contained in Subsystem:

  Liquid Nitrogen (Storage) - 396 liters (1500 gal)

  Gaseous Nitrogen (Ullage) - 3087 m^3 (109,000 ft^3) at 69 kPa (10 psig)

3. Thermal Storage Media Descriptions, Quantities, and Properties

<u>Salt</u> Quantity used (in two tanks) - 151 m^3 (5,350 ft^3)

Max. Storage Temperature - 294°C (562°F)

Properties - The thermal storage salt is an inorganic compound consisting of a Eutectic mixture of $NaNO_2$, $NaNO_3$ and KNO_3, with a melting point of 415 K (288°F). The salt is variously called HITEC, Dupont's tradename for the mixture, and Heat Transfer Salt (HTS) the generic name for the same salt mixture. Heat Transfer Salt has a density of 1746 kg/m^3 (109 lb/ft^3) and a specific heat of 1562 J/kg K (0.373 Btu/lb-°F). HTS has been used in industrial applications since the 1930's, and its physical and chemical properties are well documented. The salt has been operated at temperatures of up to 727 K (850°F) in low carbon steel systems and up to 810 K (1000°F) in stainless steel process equipment.

The salt is maintained in a molten state at all times in the thermal storage subsystem. A nitrogen gas blanket is used to fill all internal voids, preventing degradation of salt properties. The salt is nonflammable but could ignite combustibles on contact if the self-ignition temperature of the combustible is at or below the salt temperature. A molten salt spill flow will be limited by solidification which will occur at 415 K (288°F).

<u>Oil</u> Quantity Used (in two tanks) - 2339 m^3 (82,650 ft^3)

Max. Storage Temperature - 482°C (900°F)

Properties - The thermal storage oil is a commercial heat transfer fluid identified as CALORIA HT 43, as manufactured by Exxon Corporation.[1] 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 will burn, like petroleum products in

[1]Refer to Exxon Brochure <u>Lubetext DG-2G</u> for more detailed description and properties.

general, under conditions of high temperature and in the presence of oxygen and an ignition source. It exhibits a Viscosity Index of 115, a Specific Heat of 0.60 Btu/lb/^{o}F at 300^{o}F, a Flash Point of 420^{o}F, and a Pour Point of +15^{o}F.

4. Separation/Containment Features:

Salt and oil storage tanks, pumps and heat exchangers have been designed and located to minimize propagation of a hazardous condition caused by a rupture/spill incident. Both the oil and the salt heat exchangers are provided with permanent, metallic spill tanks and burst disc discharge lines to the tanks. In the event of steam line rupture within the heat exchangers, the hot storage media will be forced into the spill tanks, which are sized to safely contain the total quantities of oil or salt in their respective heat exchangers.

The closest distance between salt and oil tanks is 35 m (115 ft) and the minimum distance between oil storage and a heat exchanger is 33 m (106 ft). No combustible materials are located in the vicinity of either salt or oil storage tanks.

Oil tanks are located in an earthen spill basin formed by earthen dikes separating the two oil tanks and preventing the flow of an oil spill toward the pilot plant equipment installations. This basin is connected via drainage ditches to a remote earthen catch basin located 236 m (775 ft) E of the oil storage tanks. The catch basin will hold the total quantity of oil in storage.

5. Code Compliance:

The entire thermal storage system, including pressure vessels, piping and media storage tanks, is designed to comply with all local and national safety/building codes without deviations. The oil storage medium is classified basically as Class IIIB, which would require no containment measures. But since it is stored above flash point temperature it must be considered as Class II, which requires external spill containment.

6. Additional Comments:

Failures of the thermal storage subsystem that could result in major spills are mainly controlled (with respect to self-induced environmental factors) by conservative design and compliance with applicable construction codes. Although the thermal storage concept represents new technology at the subsystem level, all elements of the subsystem, including the storage media, involve materials and processes that are tried and proven in industrial applications. Additional experience has been gained on the overall subsystem concept by successfully constructing and operating a scale model of the entire subsystem using identical storage media under identical state conditions [1].

Damage caused by external factors (e.g., earthquake of unexpected severity) could result in major spills of storage media. The containment basins and locations of components are designed to confine fluids or consequential fire to localized areas, precluding propagation of a hazardous condition to other areas of the pilot plant.

The containment basins also assure that any spilled thermal storage oil will adversely affect only a limited area of the soil, and will facilitate recovery.

7. Mitigation Considerations

- Tanks, heat exchangers, piping and related components could be located underground at significant increases in installation and maintenance costs.
- Thermal storage could be deleted from pilot plant (see Page A 47).
- Separation and containment measures could be extended, including:
  - Increasing distance of subsystem from balance of plant;
  - Increasing distances between tanks (and other subsystem components);
  - Providing lined (e.g., concrete) spill areas and catch basins;

[1] Ref. Martin Marietta Research Experiment Project at Georgia Tech during Phase I.

- Providing active fire control installations (e.g., fog systems, water sprays).

These measures would provide additional hazard effects insurance at increased installation and maintenance costs.

ENVIRONMENTAL IMPACT DATA SHEET

A. System Concept MMC

B. Subsystem Collector, Receiver, Thermal Storage

C. Design Feature Emergency Power

D. Environmental Factors Impacted:

Air Quality, Ambient
Noise Level, Accident
Potential - Emergency electrical power is required to provide an orderly, safe means of pilot plant shutdown in the event of loss of main net power. This is provided by a standby diesel generator unit which will contribute to ambient noise levels and atmospheric pollution while operating. Stored fuel for the diesel engine is a potential accidental fire source.

E. Design Feature Descriptive Data:

1. The collector, receiver, and thermal storage subsystems each have contributory emergency power requirements which constitute inputs to sizing the emergency power supply and the required amount of stored fuel.

Subsystem	Power Required	Duration To Effect Plant Shutdown
Collector	90.0 kW_E	150 minutes
Receiver	27.0 kW_E	1 minute
Thermal Storage	None	

2. Additional Comments:

If main electrical net power is interrupted to the pilot plant it may become necessary to use the emergency power supply to move all heliostats to the stowed (safe) condition and to operate electrical equipment in other subsystems to effect an orderly plant shutdown. The operation of the emergency power supply will normally not be required except during such an emergency, reducing the related impacts to those short, infrequent periods when it will be needed.

Exceptions will be scheduled periodic operating cycles to verify performance, and possibly for more extended periods during early pilot plant checkout and activation.

3. Mitigation Considerations:

   - o A storage battery supply could be provided to supply the total electrical load required to secure the pilot plant in case of an emergency. This would necessarily be a large installation and would significantly increase installation and maintenance costs.

APPENDIX B

PRELIMINARY

CENTRAL RECEIVER SOLAR THERMAL POWER

PILOT PLANT SOLAR

PECULIAR SUBSYSTEMS

INSTALLATION AND CHECKOUT

TEST PLAN

APRIL 1977

CONTENTS

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I. INTRODUCTION

A. SCOPE

The Pilot Plant Installation and Checkout test plan establishes and documents the approach to testing and checkout of components (as required), subassemblies, subsystems and systems of the solar portion of the central receiver solar thermal power system pilot plant. The checkouts and tests described in this plan will be performed to assure proper functional operation of the collector, receiver, thermal storage and master control subsystems prior to marriage with the nonsolar portion of the operational pilot plant. However, there will exist the requirement to interface with certain portions of the power plant to accomplish subsystem testing. These interfaces will include such things as the feedwater and condenser systems.

The requirements of this plan will be effective for all hardware and software activities starting with receipt of hardware/software at the pilot plant site and continuing through final solar portion system testing which demonstrates delivery of properly conditioned steam at the interface to the power plant.

The general testing philosophy incorporated in this plan is to accomplish test/checkout activities at the highest level of assembly as is deemed practicable. This approach to testing will minimize the number of testing activities while maximizing the assurance of an operational capability of the various subsystems.

B. TEST PROGRAM CONTROLS

This section delineates the test program controls that will be implemented by the contractor test integration personnel during conduct of the pilot plant installation and checkout test program. These test program controls will provide a standardized testing approach to all testing activities associated with the various subsystems and system level test tasks. In addition, Section VII of this plan further delineates test method and test documentation requirements.

1. Customer Contact

Test integration will be the single point contact between the contractor and the customer for all activities associated with planning, statusing, and approval of installation and checkout testing.

2. Test Planning

Test integration will perform the following activities in establishing the various test plans.

a. Analyze the subsystem and system hardware/software and develop a detailed test plan for providing assurance of demonstration of critical performance criteria.

b. Determine test schedule and sequences for all testing activities.

c. Determine margin test requirements (if required) to establish assurance of performance capability for the various subsystems.

3. Test Procedures

All testing will be performed in accordance with written test procedures appropriate to the type of testing being performed. Test integration personnel will review and approve all test procedures to ensure that they accurately reflect all contractual test requirements. In addition, program safety personnel will review and approve all test procedures which involve operation which would be potentially hazardous to personnel or equipment. Quality personnel will review and approve all test procedures. Test integration will be the single point contact and will negotiate customer approval as required.

4. Test Surveillance

Test integration will implement all test surveillance activities to assure that proper testing is accomplished and does comply with the overall program standards and requirements. Test surveillance will encompass all activities related to test including procedure review, test conduct and control, data recording and report review from initial test planning to final program acceptance. Quality Control will witness test and certify the test was performed in accordance with the approved test procedure.

5. Test Reporting

All nonconformances (anomalies of failures) identified during testing activities will be documented in the approved discrepancy reporting system. The results obtained during all testing activities will be documented in the approved test procedure or associated data sheets and certified by Quality Control.

All test reports as required by the contractual requirements will be prepared by the test operations personnel and approved by the test integration personnel.

6. Test Summary

Test Integration personnel will prepare summaries of all testing activities. This summary will be the documentation used to show compliance to the hardware test requirements. This summary (as required) will also be used as a basis for customer concurrence to acceptability of the hardware of subsystem as applicable.

II. COLLECTOR SUBSYSTEM INSTALLATION AND CHECKOUT

This section delineates the test requirements, objectives and methods which will be used during the Collector Subsystem (CSS) installation and checkout for the 10 MWe Pilot Plant. Figure II-1 provides an overview of the hardware flow which illustrates the general approach for accomplishing CSS installation and checkout. Hardware items are shown in rectangles and tests/checkouts are identified by circles. This section also defines the various installation activities necessary to identify the in-process testing requirements, from receipt of hardware through subsystem checkout. Table II-1 summarizes the hardware level, test location, test type and general objectives for each test increment from the component level through the final subsystem checkout.

A. HELIOSTAT CONTROL ASSEMBLY

This assembly consists of the heliostat control unit, internal heliostat harness and azimuth and elevation drive mechanisms. The drive mechanisms contain their respective slew motors, limit switches, gear box and encoder. Figure II-2 provides the definitive installation and checkout flow associated with the heliostat control assembly from receipt of component parts through assembly level testing prior to installation in the heliostat array.

1. Elevation Drive Encoder and Limit Switch Test

a. Objective - The primary objective of this test is to align the encoder and establish set points for the limit switches.

b. Test Method - The encoder alignment will be accomplished using optical techniques and to check out general functional operations; its accuracy operation will be verified during the heliostat control assembly functional performance test. The limit switches will be installed on the drive mechanism and adjusted for proper activation. Circuit interruption for both the primary and backup functions will be verified with continuity checks.

2. Azimuth Drive Encoder and Limit Switch Test

a. Objective - The primary objective of this test is to align the encoder and establish set points for the limit switches.

b. Test Method - The encoder alignment will be accomplished using optical techniques and to check out general functional operations; its accuracy operation will be verified during

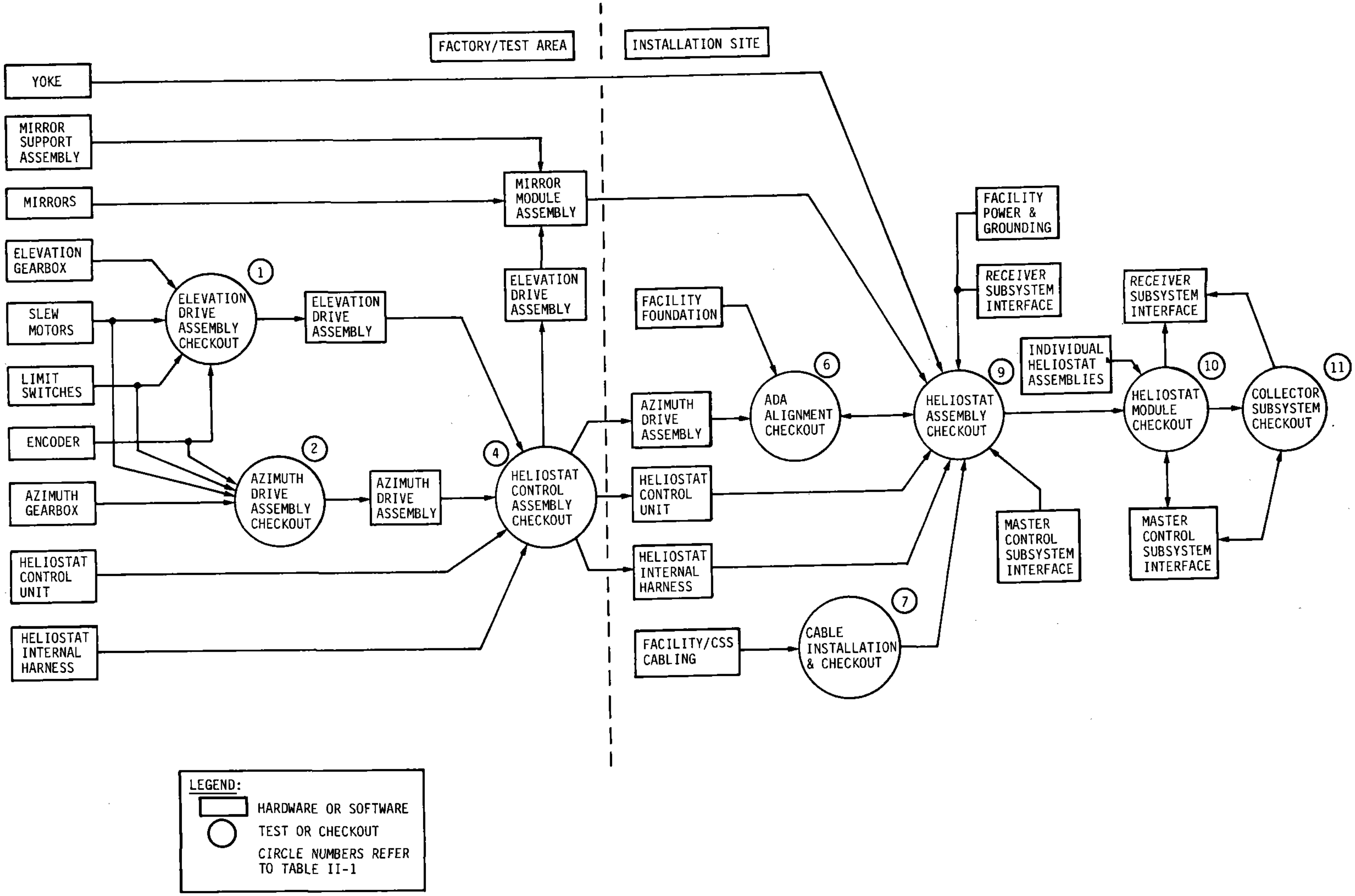


Figure II-1 Collector Subsystem Installation and Checkout Flow Plan

TABLE II-1 COLLECTOR SUBSYSTEM TEST SUMMARY

TEST NO.	HARDWARE	TEST LOCATION	TEST IDENTIFICATION	TEST OBJECTIVE	REF.
1	Elevation Drive Assembly	Test Area	Limit Switch Alignment Checkout	Verify proper limit switch actuation points and settings. Verify power interrupt capability	II-A.1
			Encoder Alignment Checkout	Verify proper encoder alignment and operation.	
2	Azimuth Drive Assembly	Test Area	Limit Switch Alignment Checkout	Verify proper limit switch actuation points and settings. Verify power interrupt capability.	II-A.2
			Encoder Alignment Checkout	Verify proper encoder alignment and operation.	
3	Heliostat Control Assembly	Test Area	Heliostat Control Assembly Alignment Checkout	Verify gimbal single accuracies. Verify proper encoder stimulus/ response characteristics.	II-A.3
4	Heliostat Control Assembly	Test Area	Heliostat Control Assembly Functional Checkout	Functional performance of the Heliostat Control electronics, azimuth drive, elevation drive and wiring harness as an integral system prior to installation. Verify Heliostat Control modes of operation (stimulus/response characteristics).	II-A.4

TABLE II-1 COLLECTOR SUBSYSTEM TEST SUMMARY (Continued)

TEST NO.	HARDWARE	TEST LOCATION	TEST IDENTIFICATION	TEST OBJECTIVE	REF.
5	Heliostat Mirror Module	Test Area	Facet 2-2 Alignment	Proper positioning of facet 2-2 which will be used as reference during heliostat alignment.	II-B.1
			Mirror Leveling	Establish an initial position of the remaining mirrors prior to Heliostat alignment.	II-B.2
6	Azimuth Drive Assembly	Pilot Plant Site	Azimuth Drive Assembly Alignment Checkout	Verify azimuth drive assembly is leveled prior to Heliostat assembly.	II-C.1
7	Facility Cabling	Pilot Plant Site	Facility Power Checkout	Verify cable wiring Verify voltage and phasing Verify interface requirements	II-C.2
			Facility Grounding Checkout	Verify proper grounding capability at each Heliostat	
8	Collector Subsystem Cabling	Pilot Plant Site	Cable Continuity Insulation resistance measurement	Verify proper fabrication Verify wiring integrity	II-C.3

TABLE II-1 COLLECTOR SUBSYSTEM TEST SUMMARY (continued)

TEST NO.	HARDWARE	TEST LOCATION	TEST IDENTIFICATION	TEST OBJECTIVE	REF.
9	Individual Heliostat Assembly	Pilot Plant Site	Mirror Alignment	Align each Heliostat mirror for proper interface with the receiver subsystem.	II-C.4
			Heliostat Control Modes Course & Fine Acquisition Fine Tracking (AZ. & Elevation) Synthetic Track Slew (Azimuth & Elevation) Stowage Limit Stops Emergency Standby	Verify Heliostat Control operations. Verify master control subsystem interface functions. Verify overall Heliostat operational performance.	II-C.5
10	Heliostat Module	Pilot Plant Site	Heliostat Module System Checkout. Multiple Heliostat Control Modes	Demonstrate collector/master control subsystem interface functions using multiple Heliostats. Demonstrate hardware/software interface functions.	II-D.1

TABLE II-1 COLLECTOR SUBSYSTEM TEST SUMMARY (continued)

TEST NO.	HARDWARE	TEST LOCATION	TEST IDENTIFICATION	TEST OBJECTIVE	
11	Collector Subsystem	Pilot Plant Site	Collector Subsystem Interface Verification.	Demonstrate collector subsystem capability to deliver adequate solar thermal energy to receiver subsystems for charging thermal storage subsystems and developing adequate steam characteristics for the EPGS. Demonstrate master control subsystem interface control operations.	II-E

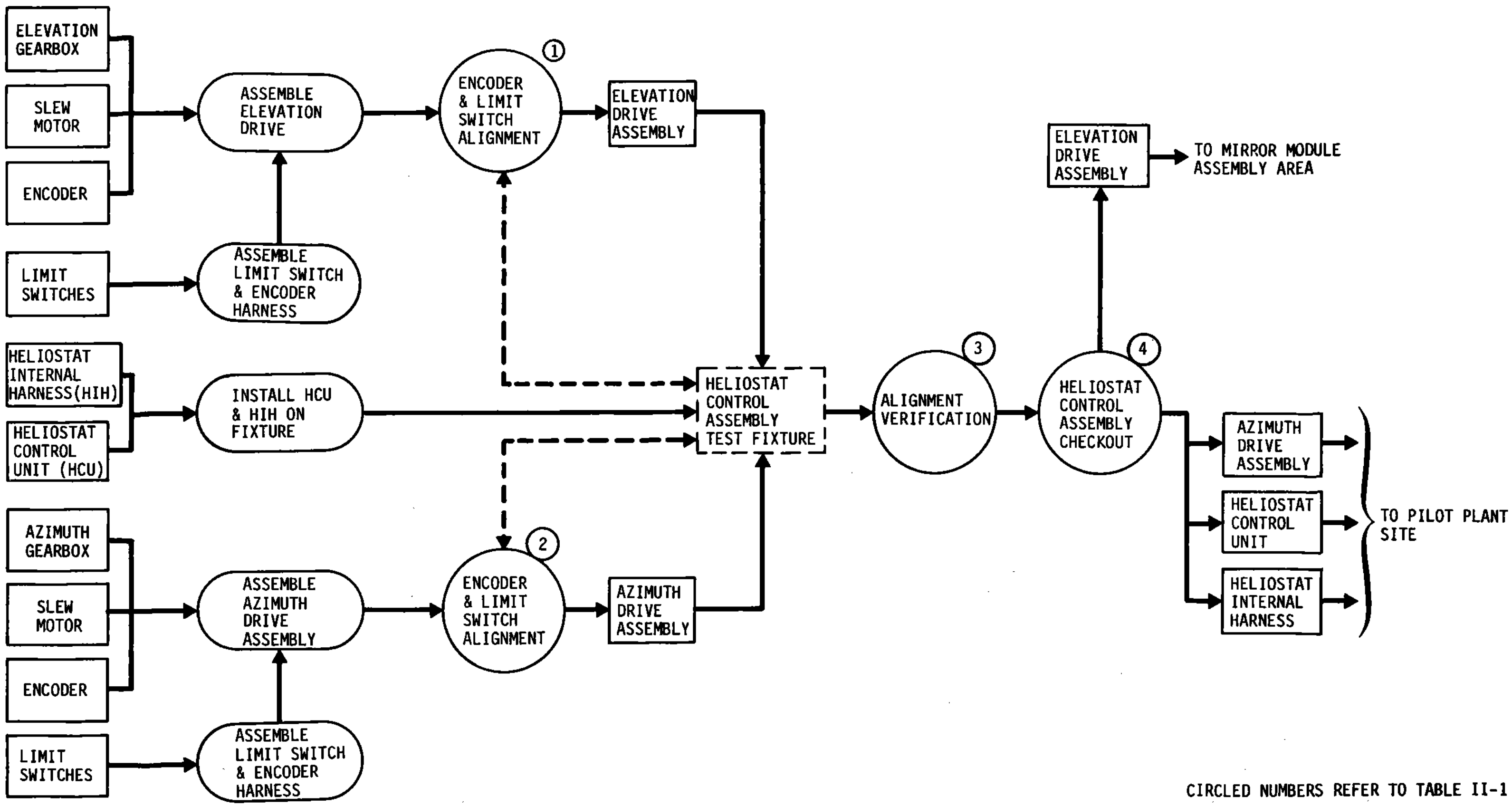


Figure II-2 Heliostat Control Assembly Checkout Flow the heliostat control assembly functional performance test. The limit switches will be installed on the drive mechanism and adjusted for proper activation. Circuit interruption for both the primary and backup functions will be verified with continuity checks.

3. Alignment Verification Test

a. Test Objective - The objective of this test is to verify gimbal angle accuracies as a function of encoder output.

b. Test Method - The gimbal angle accuracies will be verified using optical and electronic techniques and encoder response characteristics. The testing will consist of establishing sample gimbal angles using optical alignment equipment, and reading out encoder gimbal angle data of electronic measuring devices.

4. Functional Performance

a. Objective - The objective of this test is to verify proper functional operation of the heliostat control assembly. The testing will include limit switch, encoder, heliostat control unit and internal harness functional operations verification.

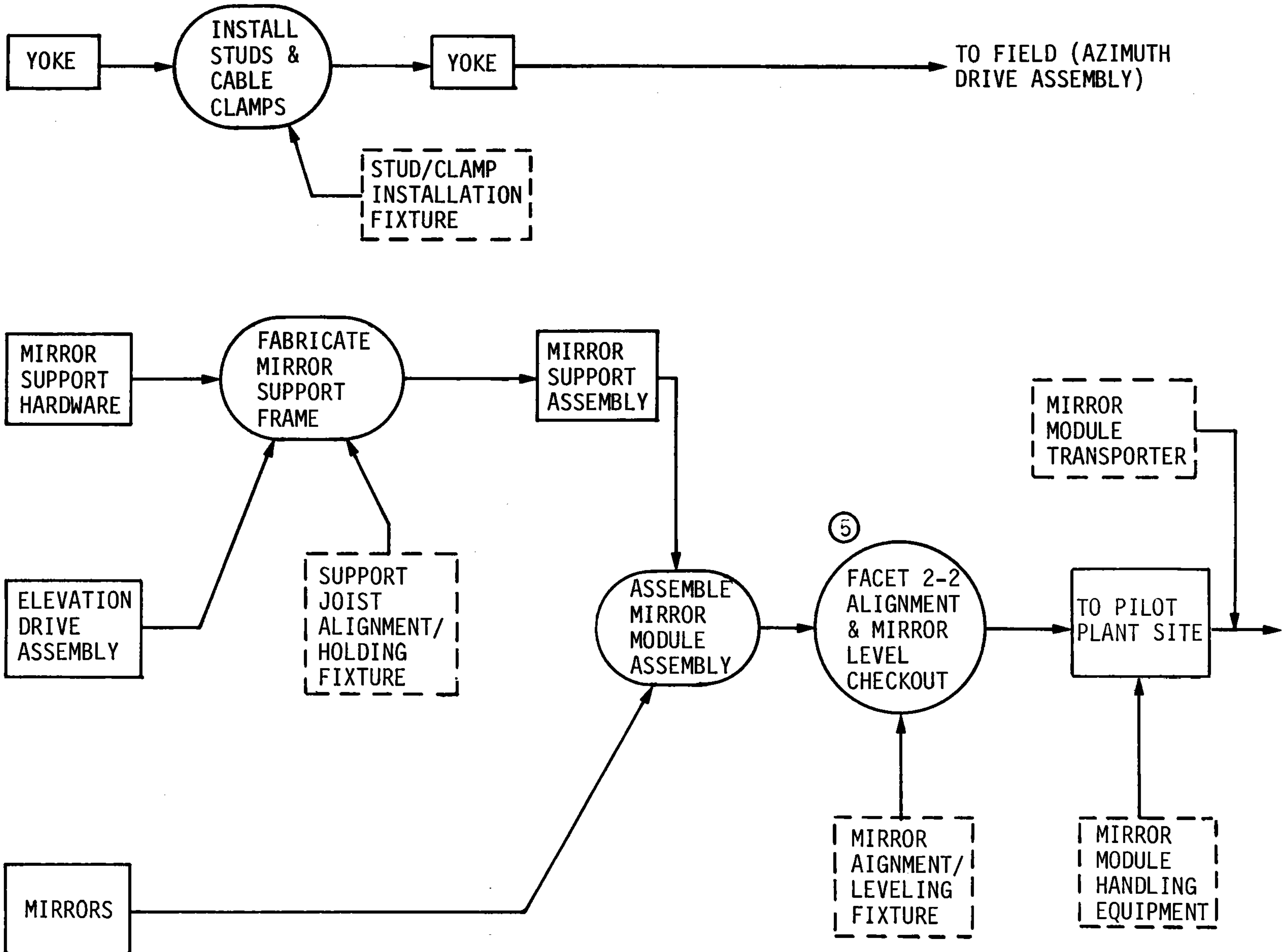
b. Test Method - The heliostat control subassemblies will be installed/connected to a test fixture capable of initiating control stimuli to the heliostat control assembly. A series of control functions will be issued to effect azimuth and elevation drives and the encoder responses verified on a readout device. Commands to initiate heliostat drive to the limit stops in both azimuth and elevation will be issued and proper responses verified.

B. MIRROR MODULE ASSEMBLY

This assembly consists of the mirror support structure, mirrors, and elevation drive mechanism. Figure II-3 provides the definitive installation and checkout flow associated with the mirror module assembly from receipt of component part through assembly level testing prior to installation in the heliostat array.

1. Reference Mirror Alignment Test

a. Objective - The primary objective of this test is to establish a reference for the heliostat mirror alignment which will be conducted at the pilot plant site.



CIRCLED NUMBERS REFER TO TABLE II-1

Figure II-3 Mirror Module Assembly Checkout and Flow

B. TEST METHOD

The center mirror (facet 2-2) will be installed onto the mirror support structure and aligned optically to establish the reference plane from which heliostat alignment will be accomplished. This testing will utilize the primary alignment fixture used during mirror support frame fabrication.

2. Mirror Leveling Test

a. Objective - The objective of this test is to position all subsequent mirrors of the mirror module in a nominal plane in preparation for alignment at the pilot plant site.

b. Test Method - Each heliostat mirror will be mounted on the mirror module structure and mechanically adjusted to effect a planar condition.

C. HELIOSTAT ASSEMBLY

The heliostat assembly testing will verify functional operation and interface functions of individual heliostats. This series of tests will marry together the previously verified subassemblies, software control and facility interfaces in demonstrating the heliostat's functional capabilities. This testing will be conducted on an individual heliostat basis. Figure II-4 provides the definitive installation and checkout activities associated with the installation and checkout of the individual heliostats within the collector subsystem. This series of tests brings the heliostat from selected component parts and subassemblies to the completed heliostat assembly which will be in a ready state for module and/or subsystem level of testing.

1. Azimuth Drive Installation Test

a. Objective - The objective of this test is to establish proper alignment and leveling of the azimuth drive assembly prior to installation of the heliostat yoke.

b. Test Method - The azimuth drive assembly will be installed on the pilot plant facility foundation and will be leveled and aligned using a collimator or precision bubble leveling device.

2. Facility Power and Grounding Checkout

a. Objective - The primary objective of this test is to verify proper facility power and grounding are available at each heliostat location.

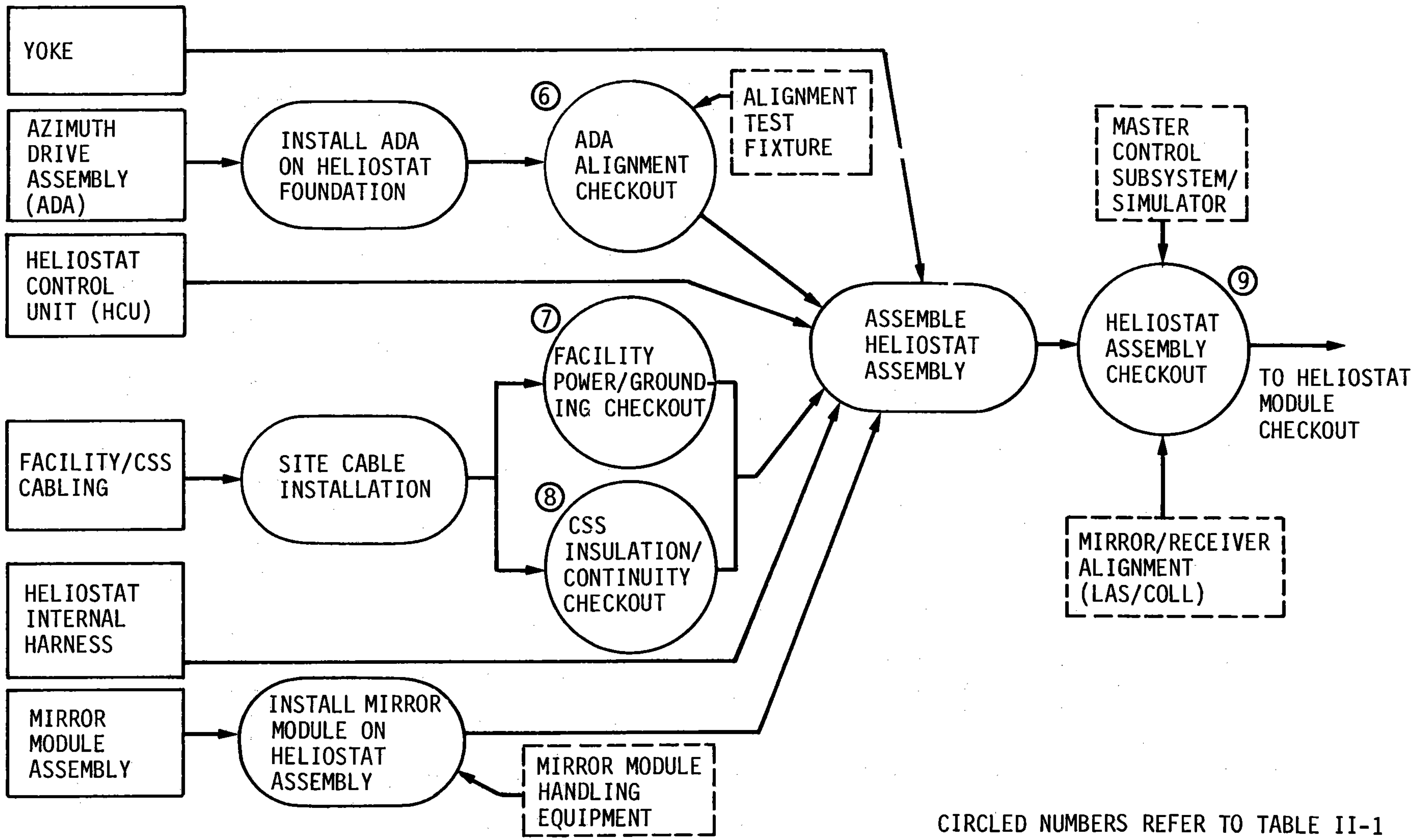


Figure II-4 Heliostat Assembly Checkout Flow

b. Test Method - The test method used during this testing will be standard continuity and insulation resistance verification of all facility cabling as well as conventional grounding test techniques. Power measurements will be verified to be within design requirements of the individual heliostat.

3. Collector Subsystem Cabling Checkout

a. Objective - The primary objective of this test is to verify proper configuration and connection of CSS interface cabling.

b. Test Method - The test method used during this testing will be standard continuity and insulation resistance verification of all CSS interface cables prior to connecting to the heliostat assembly. Continuity testing will be accomplished to show compliance with site engineering.

4. Mirror Alignment

a. Objective - The primary objective of the mirror alignment is to provide the best available solar image at the center of the receiver.

b. Test Method - Mirror alignment will be accomplished using a laser/collimator assembly in conjunction with a television and computerized readout system. During this testing, each mirror will be aligned sequentially with the heliostat positioned in a precalculated position for each facet. The laser source and target will be located on the receiver tower in close proximity to the receiver location.

5. Control Modes Checkout

a. Objective - The objective of these tests will be to verify heliostat functional operations in the various control modes using both manual and automatic control functions.

b. Method - The test method to be used during these demonstrations will be to initiate the various functions using a Master Control Subsystem simulator (or master control subsystem if available) and visually and electronically observing the heliostat responses. These tests include course and fine acquisition, fine tracking, synthetic track, slew, stowage, limit stops, emergency and standby functions.

D. HELIOSTAT MODULE CHECKOUT

The heliostat module checkout will be performed using multiple heliostats under single control.

1. Control Modes Checkout

a. Objective - The objective of these tests will be to demonstrate multiple heliostat operation in the various control modes using automatic control functions.

b. Method - The test method to be used during these demonstrations will be to initiate the various control functions using a master control subsystem simulator (or master control subsystem if available) and visually and electronically observing the multiple heliostat responses. These tests include course fine acquisition, fine tracking, synthetic track, slew, stowage, limit stops, emergency and standby functions. Further, this testing operation will be used to support Receiver Subsystem and Thermal Storage Subsystem operations.

E. COLLECTOR SUBSYSTEM CHECKOUT

This testing will consist of groups of heliostat modules which will be operated by the master control subsystem in various control modes using automatic control functions. Portions of this testing will be used for receiver subsystem and thermal storage subsystem testing as applicable. The CSS interface functions with the receiver, thermal storage and master control subsystems will be demonstrated in a combined systems test just prior to pilot plant operational status.

III. RECEIVER SUBSYSTEM INSTALLATION AND CHECKOUT

This section identifies the tests, objectives methods of test and hardware which will be used during the Receiver Subsystem installation and checkout for the 10 MW_e Pilot Plant. Figure III-1 identifies the major hardware subassembly flow plan for the receiver buildup and checkout. Hardware items are shown in rectangles and tests/checkouts are identified by circles.

Receiver subsystem installation and checkout at the Pilot Plant will primarily consist of on-site assembly of the hardware. Therefore, much of the instrumentation will be installed and checked out during the receiver buildup since some will become inaccessible as the buildup progresses. Table III-1 summarizes the hardware, type of tests and primary objectives of the major tests conducted on the receiver subsystem during installation at the Pilot Plant.

A. BOILER/STEAM DRUM ASSEMBLY CHECKOUT

This assembly contains all feeders, downcomers, valves and associated hardware required during the buildup process. Instrumentation for measuring temperature, pressure and liquid flow will be installed at appropriate times during the buildup.

1. Cavity Coating Checkout

a. Objective - The primary objective of this test is to verify the thickness of the coating material on the inner surface of the cavity not lined with boiler tubes.

b. Test Method - The thickness of the surface coating material will be determined magnetically using an adequate measuring device.

2. Instrumentation Checkout

a. Objective - The objectives of this checkout are to verify instrumentation hookup and operation and automatic valve operations.

b. Test Method - End-to end checkout of signal transducers will be accomplished using standard techniques that simulate the expected range of signals. Remotely operated values will be conditioned with appropriate signals and proper operation verified.

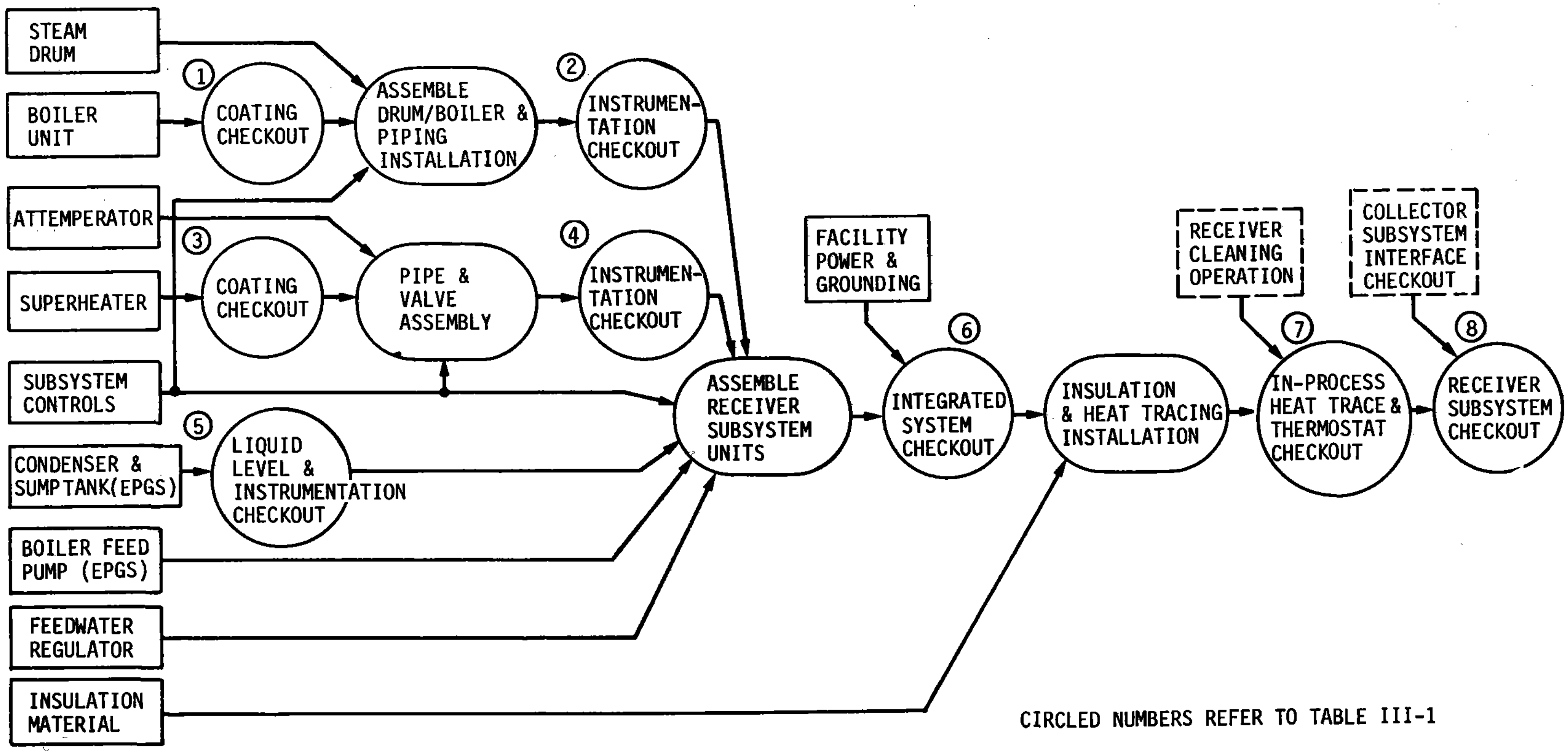


Figure III-1 Receiver Subsystem Installation and Checkout Flow Plan

TABLE III-1 RECEIVER SUBSYSTEM TEST SUMMARY

TEST NO.	HARDWARE	TEST LOCATION	TEST IDENTIFICATION	TEST OBJECTIVE	REF.
1	Boiler Unit	Pilot Plant Site	Cavity Coating Checkout	Verify cavity coating thickness meets requirements.	III-A.1
2	Boiler/ Steam Drum Assembly	Pilot Plant Site	Instrumentation Checkout	Verify proper location and connection of Instrumentation Units (Thermocouples, strain gages and flux meters).	III-A.2
3	Superheater	Pilot Plant Site	Panel Coating Checkout	Verify panel coating thickness meets requirements.	III-B.1
4	Superheater/ Attemperator Assembly	Pilot Plant Site	Instrumentation Checkout	Verify proper location and connection of instrumentation units.	III-B.2
5	Condenser/ Sump Tank (EPGS)	Pilot Plant Site	Liquid Level and Instrumentation Checkout.	Verify proper location and connection of instrumentation units.	III-C.1
6	Receiver Subsystem	Pilot Plant Site	Integrated System Checkout Hydrostat Subsystem Leak Feedwater Regulator Subsystem Flow Meter Pressure Transmitters	Verify proper operation of subsystem valves. Establish required gain, interval and rate adjustments for automatic valve functions. Verify subsystem control functions. Verify integrity of piping and tubing.	III-D

TABLE III-1 RECEIVER SUBSYSTEM TEST SUMMARY (Continued)

TEST NO.	HARDWARE	TEST LOCATION	TEST IDENTIFICATION	TEST OBJECTIVE	REF.
7	Receiver Subsystem	Pilot Plant Site	In-process Heat Trace and Thermocouple Checkout	Verify heat trace instrumentation. Obtain additional T/C verification during subsystem cleaning operations.	III-E
8	Receiver Subsystem	Pilot Plant Site	Receiver Subsystem Checkout Low Temperature and Pressure Test Run.	Check Boiler circulation and superheater steam flow distribution. Operator familiarization. Evaluate operational procedures.	III-F.1
			High Temperature and Pressure Test Run.	Demonstrate full load operation of the receiver from an ambient condition.	III-F.2
			Cold Start	Demonstrate the receiver cold start performance.	III-F.3
			Hot Start	Demonstrate diurnal startup requirements.	III-F.4
			Restart after cloud passage.	Demonstrate receiver restart after a simulated cloud condition has interrupted the incident radiation.	III-F.5
			Steady State Flow Tests	Demonstrate receiver operation at reduced steam flow rates for full temperature and pressure.	III-F.6

B. SUPERHEATER/ATTEMPERATOR ASSEMBLY CHECKOUT

This assembly contains all tubes, expansion loops, spacers and associated hardware required during the buildup process. Required flow meters, temperature and pressure measurement devices will be installed during subassembly buildup.

1. <u>Superheater Panel Coating Checkout</u>

a. <u>Objective</u> - The primary objective of this test is to verify the thickness of the coating material on the superheater panels.

b. <u>Test Method</u> - The thickness of the surface coating material will be determined magnetically using an adequate measuring device.

2. <u>Instrumentation Checkout</u>

a. <u>Objective</u> - The objectives of this checkout are to verify instrumentation hookup and operation and automatic valve operations.

b. <u>Test Method</u> - End-to-end checkout of signal transducers will be accomplished using standard techniques that simulate the expected range of signals. Remotely operated valves will be conditioned with proper signals and proper operation verified.

C. CONDENSER/SUMP TANK ASSEMBLY CHECKOUT

This assembly containes all tubing, valves and associated hardware required during the buildup process.

1. <u>Liquid Level Instrumentation Checkout</u>

a. <u>Objective</u> - The objective of this test is to verify proper operation of the sump tank liquid sensors.

b. <u>Test Method</u>- Each liquid level sensor will receive an end-to-end checkout using standard techniques that simulate the expected range of signals.

D. INTEGRATED SUBASSEMBLY CHECKOUT

Upon completion of the assembly of the receiver subsystem units, the subsystem will be prepared for hydrostatic testing. The objective of this testing is to obtain a preliminary check of flow orifices, pressure transmitters and valve open-close functions, and, will also help to identify subsystem problem areas. These tests will be performed in accordance with the ASME code.

E. IN-PROCESS HEAT TRACE CHECKOUT

During insulation installation, required heat tracing will be verified for proper hookup and thermostat operation using standard techniques that simulate the expected range of signals.

F. RECEIVER SUBSYSTEM CHECKOUT

The receiver subsystem checkout will consist of the following test modes to verify subsystem operation:

1. Low Temperature and Pressure Trial Runs

For this test the boiler will be operated at low pressure and temperature to check boiler circulation and superheater steam flow distribution and also to minimize adverse consequences of operating errors. These tests will also serve to evaluate test procedures and familiarize operators with subsystem controls.

2. High Temperature and Pressure Trial Run

This test will involve attaining a full load operating condition by starting the receiver from a cold state and stepping the heat input up in small increments until the receiver is producing steam at its rated condition. The boiler will be operated at steady state each time the power is increased and all the data measurements will be checked to determine if the unit is operating correctly before the power level is increased. No heat will be supplied to the superheater tubes until the boiler generates steam.

3. Cold Startup

This test will involve receiver startup from the cold state. The required heat-up time for the steam generator to deliver its rated steam flow will be as required in the RSS specification.

4. Hot Restart

In these tests the steam generator will be started from a predetermined steam drum pressure and brought to a full load condition. The optimum restart time will be as required in the RSS specification.

5. Restart After Cloud Passage

This test consists of simulating a condition where the energy input is cut off due to cloud cover and the receiver must be restarted shortly thereafter.

6. Steady State Reduced Flow Runs

The steam generator will be operated at the design point heat flux for a period of at least 4 hours. The unit will also be operated simulating the heat flux patterns occurring during a prescribed day of the year over a period of sunrise to sunset. The unit will be tested at partial loads (75%, 50%, and 25% of the rated steam flow rate at full temperature and pressure) by reducing the incident heat flux.

IV. THERMAL STORAGE SUBSYSTEM INSTALLATION AND CHECKOUT PLAN

This test plan delineates the test requirements, objectives, methods, and hardware which will be used during the Thermal Storage Subsystem (TSS) installation and checkout for the Pilot Plant. Figure IV-1 is a representation of the anticipated hardware/software flows as a general approach toward accomplishing the TSS installation and checkout. Hardware items are shown as rectangles and tests are shown as circles. The TSS testing is summarized in Table IV-1.

A. COMMON TESTS

These tests consist of those operations which are to be accomplished on identical hardware/circuitry for each stage, but which may be performed at different points in time, due to the necessity of performing checks or tests as soon as possible during the build cycle.

1. Temperature Sensors/Circuitry

a. Objective - The primary objective of this test is to verify the sensor and circuit functional capability from its point of installation to its control or readout panel in the control room.

b. Test Method - Locate a calibrated temperature readout device close to the installed sensor, apply an input from a heat source, and verify that the sensor readout in the control room agrees with the calibrated readout. Also, control functions will be verified at the same time either by the actual input from the sensor or by known voltage inputs at the sensor input to the control circuitry.

2. Flow Transducers/Circuitry

a. Objective - The primary objective of this test is to verify that the sensor and circuit are intact and properly wired into the control room. The functional capability of the sensor will have been previously verified prior to installation.

b. Test Method - The sensor wiring verification will be accomplished by continuity checks only. The circuit checks will be conducted by impressing known input signals on the control/readout circuitry and verifying proper response.

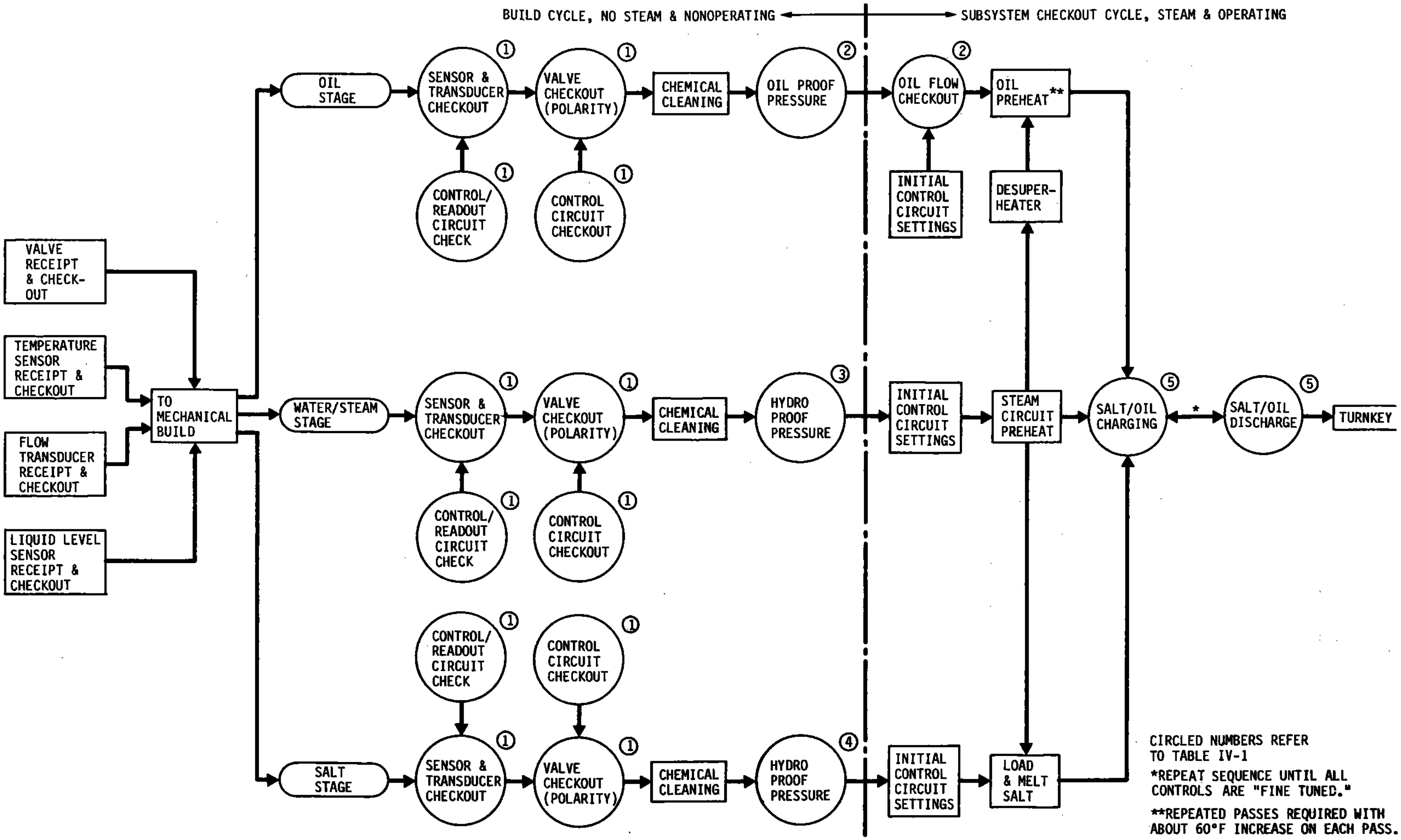


Figure IV-1 Thermal Storage Subsystem Installation and Checkout Flow Plan

TABLE IV-1 THERMAL STORAGE SUBSYSTEM TEST SUMMARY

TEST NO.	HARDWARE	TEST LOCATION	TEST IDENTIFICATION	TEST OBJECTIVE	REF.
1	TSSS Oil, Water/ steam & Salt Stages	Pilot Plant Site	Temperature Sensor/Circuit Checkout	Verify proper sensor operation and circuit connections.	IV-A.1
			Flow Transducer/Circuit Checkout	Verify proper location and connections of Flow Sensors.	IV-A.2
			Liquid Level Sensor/Circuit Checkout	Verify proper location and connections of level sensors. Verify sensor set points.	IV-A.3
			Valve/Control Circuit Checkout	Verify control connections and proper operation.	IV-A.4
2	TSSS Oil Stage	Pilot Plant Site	Proof Pressure Test	Verify structural integrity of mechanical section of the oil stage.	IV-B
3	TSSS Water/Steam Stage	Pilot Plant Site	Proof Pressure Test	Verify structural integrity of mechanical section of the water/steam stage.	IV-C
4	TSSS Salt Stage	Pilot Plant Site	Proof Pressure Test	Verify structural integrity of mechanical section of the salt stage.	IV-D
5	TSSS	Pilot Plant Site	Thermal Storage Subsystem Checkout Initial start up and control circuit checkout.	Verify: . Control circuit responses and set points. . Subsystem valve/controller operations. . Heat exchanger operation. . Three-element feedwater controller.	IV-E.1

TABLE IV-1 THERMAL STORAGE SUBSYSTEM TEST SUMMARY (continued)

TEST NO.	HARDWARE	TEST LOCATION	TEST IDENTIFICATION	TEST OBJECTIVE	REF.
			Constant Rate Charging & Discharging Test.	Demonstrate charging and discharging capability of the liquid storage media at the required temperatures, pressures and rates.	IV-E.2
			Transient Charging and Discharging Test	Demonstrate subsystem control functions during transients associated with switching from one operating mode to another, and fast start up or shutdown.	IV-E.3

3. Liquid Level Sensors/Circuitry

a. Objective - The primary objective of this test is to verify that the sensor and circuit are intact and properly wired into the control room. The functional capability of the sensor will have been previously verified prior to installation. Operation will be checked to verify that the controls respond in the proper direction and that actuation occurs at the desired set points.

b. Test Method - The sensor wiring verification will be accomplished by continuity checks only. The circuit checks will be conducted by impressing known input signals on the control readout circuitry and verifying proper response.

4. Valve/Control Circuit Polarity

a. Objective - The primary objective of this test is to verify that the valve(s) are properly wired into the control room. Correct response; i.e., open,,close, throttle, etc.

b. Test Method - The valve/control circuit verification will consist of operating the valve through its normal switching circuit and determining that the desired response, i.e., open close, throttle, etc, has occurred. Operation will be checked to verify that the controls respond in the proper direction and that actuation occurs at the desired set points.

B. OIL STAGE PROOF PRESSURE TEST

This test will be performed before and after cleaning of the oil stage and is peculiar to the oil stage only. Preliminary pressure tests will be performed pneumatically with low pressure helium prior to cleaning operations.

1. Objective

The primary objective of the proof pressure test after cleaning is to verify the structural integrity of the mechanical piping* portion of the stage. The test will be performed in such a manner as to meet the requirements of ANSI B31.1 Power Piping code.

2. Test Method

The proof pressure test of the oil stage shall be performed in two steps as follows:

a. Low Temperature Tank and All Piping - With all valving open (except two), the oil stage shall be filled with an amount of

* - Heat exchanges are designed, constructed and tested in accordance with ASME Sec. VIII, unfired pressure vessels prior to delivery.

oil sufficient to fill the circuit, excluding the storage tanks. The pressure shall be hydrostatically increased to the value required by the ANSI B31.1 Power Piping code and held for a period of time sufficient to verify all mechanical joints and piping. Leak checks shall be made using an appropriate bubble foaming coating.

b. High Temperature Tank - The portion of the stage not tested previously shall be separately tested with water or pneumatic (low pressure helium) and tested in the same manner as in a. above.

C. WATER/STEAM STAGE

This test will be performed before and after cleaning of the water/steam stage. Preliminary pressure tests will be performed pneumatically with low pressure helium prior to cleaning.

1. Objective

The primary objective of the proof pressure test after cleaning is to verify the structural integrity of the mechanical piping portion of the stage. The tests shall be performed in such a manner as to meet the requirements of ANSI B31.1 Power Piping code.

2. Test Method

With all valving opened, the water/steam stage shall be filled with water. The pressure will be hydrostatically increased to the value required by ANSI B31.1 and held for a period of time sufficient to verify all mechanical joints and piping. After successful completion of the proof pressure test, the water shall be removed.

D. SALT STAGE

This test will be performed before and after cleaning of the salt stage.

1. Objective

The primary objective of the proof pressure test is to verify the structural integrity of the mechanical piping portion of the stage. The test shall be performed in such a manner as to meet the requirements of ANSI B31.1 Power Piping code.

2. Test Method

With all valving opened, the salt stage encluding the storage tanks, shall be filled with low pressure helium. The pressure will be increased to the value specified by the ANSI B31.1 Power Piping code and held for a period of time sufficient to verify all mechanical joints and piping.

E. SUBSYSTEM TESTS

These tests will be performed to verify operational status culminating in "turn-key." They will consist of as many charging-discharging cycles as necessary to fine tune all control circuits and automatic operations.

1. Initial Subsystem Startup and Control Circuit Checkout

The oil stage will be initially charged and operated without the salt stage. The run sequence will include:

a. Preheating of the steam circuit, including piping and heat exchangers. This procedure will verify operation of:

(1) Steam admission valve and controller,

(2) The spray desuperheater and its controller,

(3) The feedwater exit valve to the EPGS.

b. Initial charging of the oil stage, including raising of the oil temperature to design operating level. The oil will be heated to its operating temperature of 500°F by passing it through the oil heat exchangers approximately seven times. Each pass, the oil temperature will be raised approximately 60°F. The steam will be spray desuperheated down to a temperature that is appropriate for each of the heating passes. These runs will verify the operation of:

(1) Oil flow throttling valve and controller in the charging mode,

(2) The functioning of HE2 as a condenser,

(3) The functioning of HE3 as a subcooler, and

(4) The operation of the liquid level control system.

c. Initial discharging of oil stage at approximetely 50 per cent of the maximum design rate. This test will verify the operation of:

(1) The feedwater admission valve and controller,

(2) The steam exit valve to the EPGS and its controller,

(3) The oil flow throttling valve and controller in the discharging mode,

(4) The operation of DHE2 as an evaporator,

(5) The operation of DHE3 as a preheater, and

(6) The operation of the three-element feedwater controller.

d. Initial charging of the molten salt stage, including raising of the salt temperature to design operating level. The heat transfer salt will already have been loaded into the two salt storage tanks and melted by the steam coils in these tanks. The oil stage will be operated during the salt charging process in order to condense the steam discharged from the salt stage. This test will verify the operation of the molten salt flow control valve and its controller in the charging mode.

e. Initial discharging of the Thermal Storage Subsystem. The entire subsystem will be operated in the discharging mode at approximately 50 per cent of the maximum discharging rate. This test will verify the operation of the molten salt flow control valves and its controller in the discharging mode.

2. Constant Rate Charging and Discharging Tests

These tests will be conducted in the following sequence:

a. The charging steam flowrate will be slowly brought from 20% to 50% of full flow on a linear ramp. The subsystem will be allowed to charge at this rate for a length of time such that after the flowrate has been reduced from 50% of full charging flow to 20% flow on a slow linear ramp, the subsystem will be fully charged.

b. The discharge steam flowrate will be increased from 20% to 50% of full discharge flowrate on a slow linear ramp. The subsystem will be allowed to discharge at this rate for a length of time such that after the flowrate has been reduced from 50% of full discharging flow to 20% flow on a slow linear ramp the subsystem will be fully discharged.

c. The charging steam flowrate will be brought from 20% to full flow on a linear ramp that is typical of normal pilot plant operation. The subsystem will be allowed to charge at full rate for a length of time such that after the flowrate has been reduced from full flowrate to 20% flowrate on a linear ramp that is typical for normal pilot plant operation, the subsystem will be fully charged.

d. The discharge steam flowrate will be increased from 20% to full flowrate on a linear ramp; this ramp rate will be consistent with normal pilot plant ramp rates. The subsystem will be allowed to discharge at this rate for a length of time such that after the flowrate has been reduced from full discharging flowrate to 20% flow on a linear ramp (the ramp consistent with normal pilot plant rates), the subsystem will be fully discharged.

e. The charging steam flowrate will be brought from zero to 20% flow. The subsystem will be allowed to charge at this rate for a length of time such that the subsystem will be fully charged.

f. The discharge steam flowrate will be increased to 20% flow and will be allowed to discharge at this rate for a length of time such that the subsystem will be fully discharged.

3. <u>Transient Charging and Discharging Test</u>

These tests will be conducted in the following order:

a. Charge steam flowrate will be ramped from 20% flow on a linear rate to 100% of full flow. The subsystem will then be allowed to come to steady state temperatures and pressures. After steady state has been achieved, the steam flow rate will be ramped down to 50% of full flow. The ramp down flowrate will be at the maximum expected for the pilot plant. The subsystem will be maintained at 50% of maximum charging rate until the charge is complete.

b. Discharge steam flowrate will be ramped from 20% on a linear rate to 100% of full flow. The subsystem will then be allowed to come to steady temperatures and pressures. After steady state has been achieved, the steam flowrate will be ramped down to 50% of full flow. The ramp down flowrate will be at the maximum expected for the pilot plant. The subsystem will be maintained at 50% maximum discharging rate until the discharge is complete.

c. Charge following a typical sun-up receiver steam generation flowrate from 20% up to full flow; terminate the charge with a typical receiver evening shutdown.

d. Immediately following the charging shutdown under c, the sequence for fast turn-around from charge to discharge will be demonstrated. The discharge flowrate will come up from 20% flow following a typical turbine startup flowrate. The discharge flowrate shutdown will follow a typical turbine shutdown from storage.

e. Immediately following the discharge shutdown under d, the sequence for fast turn-around from discharge to charge will be demonstrated. The charge flowrate will be taken to full flow then reduced to 20% flow without fully charging the storage system.

f. The tests under c, d, and e will be repeated (this test will demonstrate the repeatability of the system).

g. The subsystem will be put into a charging mode at 100% of design flow. The flow will come up on maximum expected pilot plant ramp rate. The flow will ramp down in a manner simulating the flowrate decay caused by a cloud covering the heliostat field.

h. Immediately following the charging shutdown under g, a fast charging to discharging turn-around will be demonstrated. The system will be ramped up to maximum discharging flowrate on a ramp that represents maximum expected pilot plant ramps. Then the discharging flow will be terminated simulating a turbine trip. Successful completion of these tests will accomplish all of the objectives of the subsystem test program.

V. MASTER CONTROL SUBSYSTEM INSTALLATION AND CHECKOUT PLAN

The Master Control Subsystem (MCS) will consist of the Plant Control Subsystem (PCS), and the four subsystems (collector, receiver, thermal storage and EPGE) controls. The major pilot plant system control functions will be accomplished by each of the four subsystems whereas the plant control subsystem will control critical interface parameters by commanding through the subsystems controls. The PCS will also include an emergency control capability to override the other four subsystems controls. Only the control functions which cannot be assigned to the four subsystems will be considered a a part of the plant control subsystem. Figure V-1 represents the anticipated hardware flow and testing which will be accomplished on the master control subsystem during installation and checkout at the 10 MWe Pilot Plant. Table V-1 summarizes the hardware level, test locations, test type and general objectives for the major MCS checkouts at the plant site.

A. SUBASSEMBLY INSTALLATION

The MCS control consoles and data handling hardware (i.e., line printer, magnetic tape units, disc, etc.) will be installed at the Pilot Plant site by the respective vendors. It is assumed these hardware items are pre-fabricated and subassembly interconnections will be accomplished by the vendors. Facility interface checkout will be required.

1. Facility Power and Grounding Checkout

a. Objective - The primary objective of this test is to verify proper facility power and grounding are available at the required MCS interfaces.

b. Test Method - The test method used during testing will be standard continuity and insulation resistance verification of all facility cabling as well as conventional grounding techniques. Power measurements will be verified to be within design requirements of the MCS.

B. DATA HANDLING CHECKOUT

Upon completion of installation and facility interface checkout of the MCS hardware, a series of self-test diagnostic checks will be accomplished on the central processor units (CPSs). These checks will be followed by CPU to peripheral hardware items using diagnostic programs provided by the vendor. These tests will be conducted by the MCS vendor.

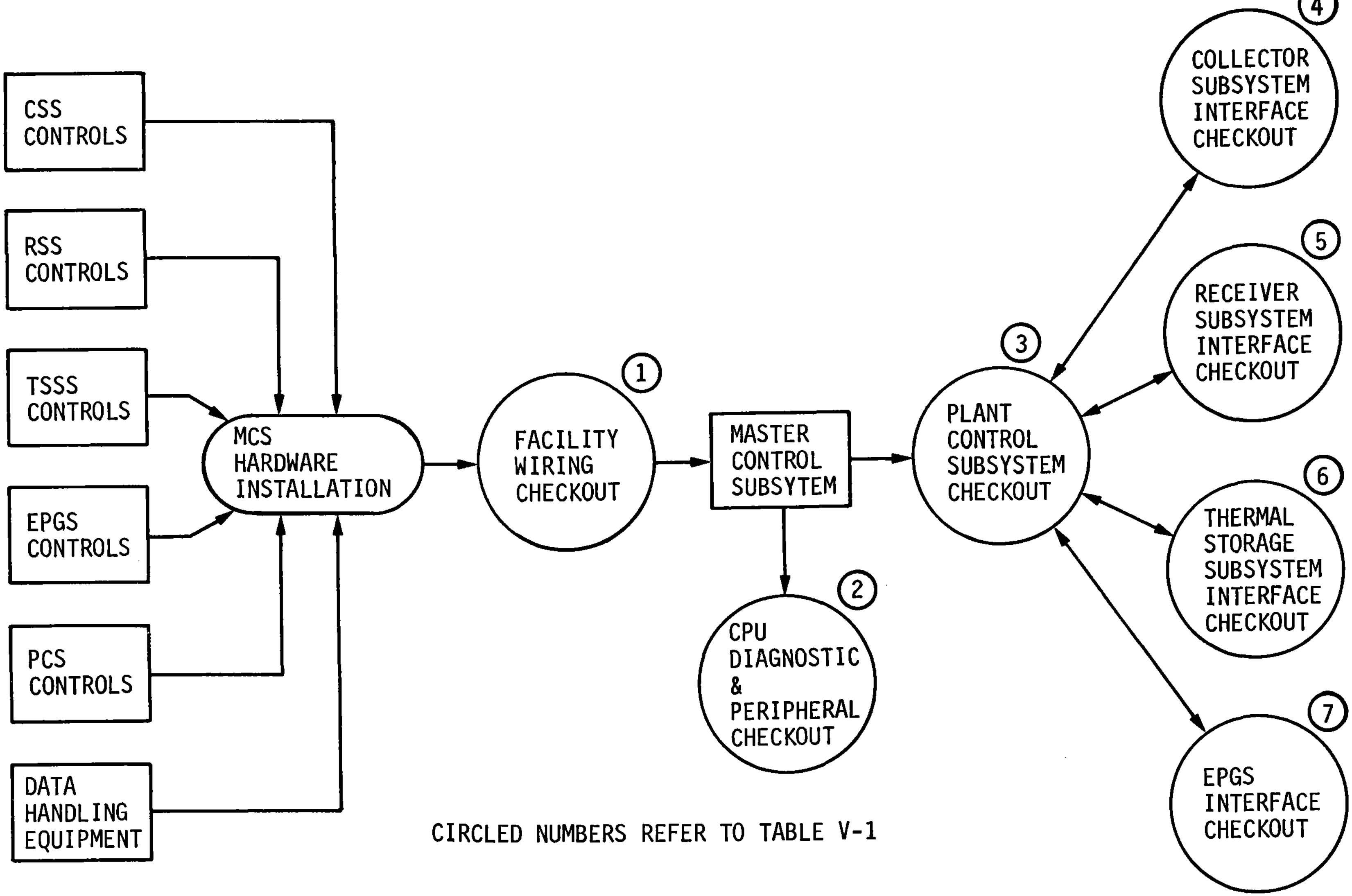


Figure V-1 Master Control Subsystem Installation and Checkout Flow Plan, Installation Site

TABLE V-2 MASTER CONTROL SUBSYSTEM TEST SUMMARY

TEST NO.	HARDWARE	TEST LOCATION	TEST IDENTIFICATION	TEST OBJECTIVE	REF.
1	Facility Cabling	Pilot Plant Site	Power and Grounding Checkout	Verify cable wiring Verify voltage and phasing Verify interface requirements Verify proper grounding	V-A.1
2	Data Handling Equipment	Pilot Plant Site	CPU/Peripheral Diagnostic Checkout	Verify computer memory, central processor, controller and I/O functions.	V-B.1
3-7	Master Control Subsystem	Pilot Plant Site	Control Circuit Checkout	Verify PCS/subsystems interface wiring.	V-C.1
3-7	Master Control Subsystem	Pilot Plant Site	Control Command Checkout	Verify PCS Interface commands to the other subsystems.	V-C.2

1. <u>CPU/Peripheral Units Diagnostic Checkout</u>

a. <u>Objective</u> - The objective of these checkouts is to verify correct functioning of the computer memory, central processor, controller and input/output devices as defined by the supplier.

b. <u>Test Method</u> - The tests will be accomplished using vendor supplied diagnostic software as required by the vendor. Diagnostic routines will be run and results of each run will be evaluated by appropriate personnel. Hardware failures, as determined by the diagnostic routines, will be recorded and corrective action implemented.

C. SUBSYSTEMS INTERFACE CHECKOUT

The PCS interfaces with the other Pilot Plant subsystems by monitoring and controlling critical parameters of the pilot plant operation. PCS control capability will be accomplished in conjunction with the individual subsystems controls through commanded inputs. The PCS control functions will also include an emergency override of subsystem controls in order to maintain stable and safe Pilot Plant operation. Figure V-2 illustrates the interrelationship of the PCS to CSS, RSS, TSSS and EPGS interface controls which require verification.

1. <u>Control Circuitry Checkout</u>

a. <u>Objective</u> - The objective of this testing is to verify signal and monitor circuits from the PCS to the other subsystems (CSS, RSS, TSSS and EPGS) are in tact and properly wired.

b. <u>Test Method</u> - The control circuitry checkout will be accomplished using standard techniques that simulate the expected range of signals and verifying responses.

2. <u>Control Command Checkout</u>

a. <u>Objective</u> - The primary objective of this test is to verify PCS control commands to the various subsystems.

b. <u>Test Method</u> - Control commands, which will be utilized for Pilot Plant operations by the various subsystems, will be initiated at the MCS console and responses verified using an adequate readout device at the subsystem interface. Both operational and emergency override commands anticipated during Pilot Plant operations will be verified.

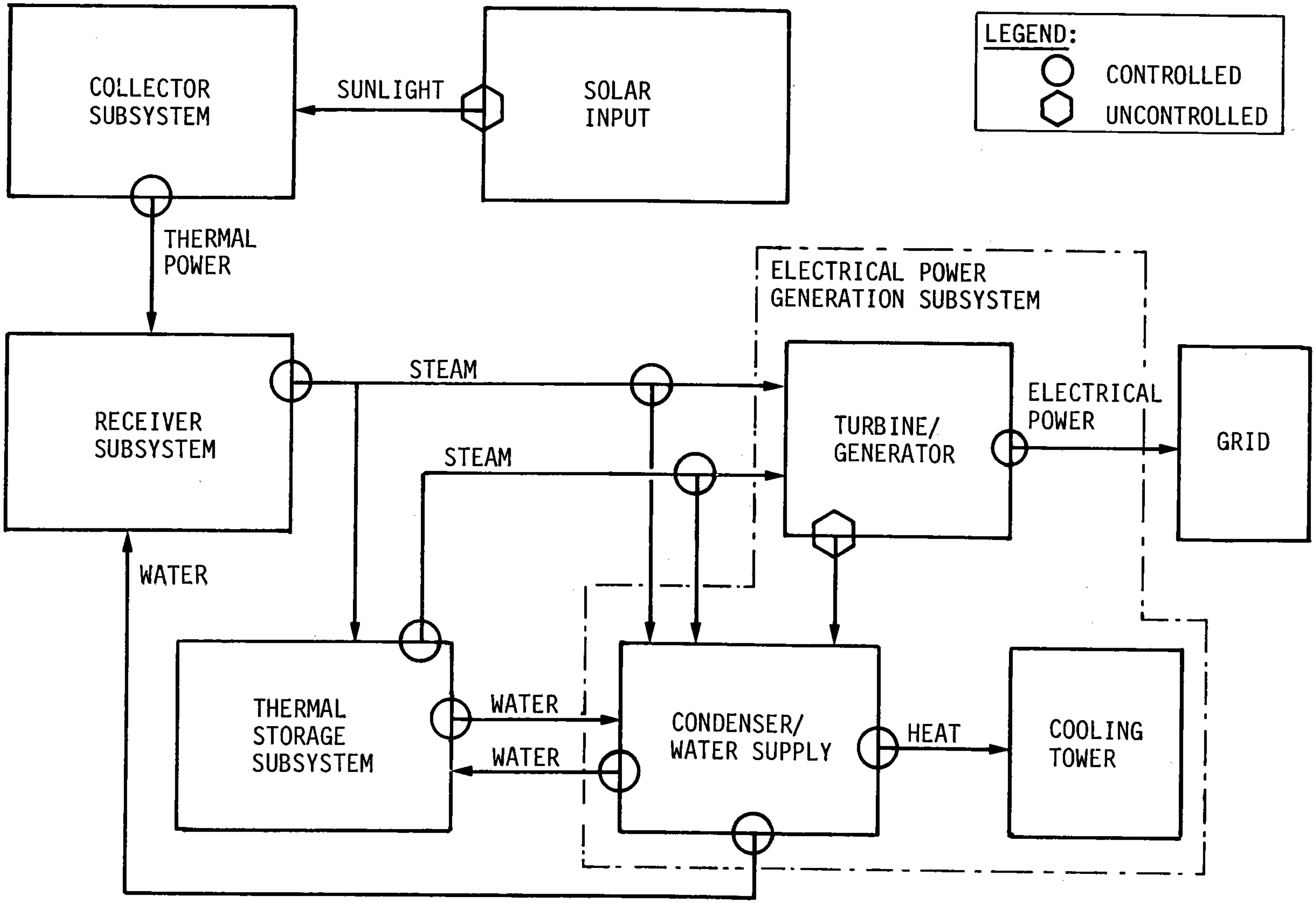


Figure V-2 Simplified System Schematic of MCS Interface Controls

VI. PILOT PLANT SYSTEM CHECKOUT

The system level testing associated with the solar portion of the Central Receiver Solar Thermal Power System Pilot Plant will consist initially of subsystem integration testing and will culminate with generation of properly conditioned steam at the power plant interface. These integration tests are being conducted in a sequence such that the step by step integration and testing of each system will lead to a totally integrated system. The sequence of the subsystem integration tests will be accomplished in the following order:

Master Control Subsystem (MCS) to Collector Subsystem (CSS)

MCS/CSS to Receiver Subsystem (RSS)

MCS/CSS/RSS to Thermal Storate Subsystem (TSS)

MCS/CSS/RSS/TSS to Electrical Power Generation Subsystem (EPGS)

After completion of solar portion subsystem marriage testing a system functional operation test will be conducted. The following paragraphs will delineate the objectives and methods associated with each of the above mentioned testing increments.

A. MASTER CONTROL TO COLLECTOR SUBSYSTEM INTEGRATION TEST

1. Objective

The primary objective of this test will be to demonstrate the compatibility between MCS hardware and the CSS Control functions in the various modes of CSS operations.

2. Methods

The initial tests consist of exercising the positioning controls and response for selected individual and groups of heliostats. The following capabilities will be tested:

a. The capability to drive the heliostat(s) in azimuth at a rate required in the CSS specification.

b. The capability to drive the heliostat(s) in elevation at a rate required in the CSS specification.

c. The capability to drive the heliostat(s) in both control axes simultaneously at a rate required in the CSS specification.

d. Checkout the proper heliostat(s) responses to all other MCS generated commands, including the ability to control selected portions of the heliostat array.

After completion of the MCS fundamental commands checkout, the automatic tracking capabilities will be tested using a selected number of heliostats. These activities will include the following test:

e. The capability of the fine tracking mode to acquire and command the heliostats to the proper position.

f. The capability of the fine tracking mode to maintain the tracking accuracy required in the CSS specification.

g. The capability to maintain the tracking function when in an emergency offset mode.

B. MCS/CSS TO RECEIVER SUBSYSTEM MARRIAGE TEST

1. Objective

The primary objective of this test will be to demonstrate the compatibility between the MCS hardware and the RSS control functions, and the thermal performance interface between the CSS and the RSS.

2. Methods

The initial tests consist of checkout of the MCS/Receiver interface to assure that all control and response activities associated with this interface including emergency actions are functionally operational. After completion of the aforementioned interface checkout the CSS will be integrated into the testing activities, also at this time the initial vacuum will be obtained in the condenser during the initial steam cycle. The EPGS equipment associated with condensate, feedwater, and heat rejection will have to be available for the remainder of this integration testing.

The CSS will be used to incrementally increase the heat flux to the receiver cavity up to full availability with the steam flow rates, pressures, and temperatures being monitored at the various selected flux levels. A series of tests will be conducted using the steam in varying amounts to simulate transient conditions for evaluation of the capabilities of the receiver and collector subsystems. The following capabilities of the subsystem will be tested:

a. The capability to control heat flux as a function of positioning the heliostats.

b. The capability of receiver startup from a cold condition in the time period required by the RSS specification.

c. The capability of receiver startup from hot standby condition in the time period required by the RSS specification.

d. The capability to accept feedwater at the rates required by the RSS specification.

e. The capability to generate steam at the various flow rates as required by the RSS specification.

f. The capability of limiting the saturation temperature drop to a maximum required in the RSS specification, at the required ambient temperature and wind conditions.

C. MCS/CSS/RSS TO THERMAL STORAGE SUBSYSTEM INTEGRATION TEST

1. Objective

The primary objective of this test will be to demonstrate the compatibility between the MCS hardware and the TSS control functions, and the thermal performance interface between the CSS, RSS and the TSS.

2. Method

The initial tests consist of checkout of the MCS/TSS interface to assure that all control and response activities associated with this interface including emergency actions are functionally operational. After completion of the aforementioned checkout, steam will be supplied to the TSS via the CSS and RSS with the flow rate being incrementally increased until the maximum rate as required in the TSS specification is reached. A series of TSS charge/discharge tests will be performed under varying steam conditions to evaluate TSS performance and transient operations. The following subsystem capabilities will be tested:

a. The capability to accept steam at flow rates required in the TSS specification.

b. The capability to supply properly conditioned steam at flow rates, pressure and temperature as required by the TSS specification for a period of six hours.

c. The capability to supply properly conditioned saturated steam of flow rates, temperature and pressure as required by the TSS specification for a period of 24 hours.

d. The capability to go from a charge to discharge mode, and a discharge to charge mode in the time period as required by the TSS specification.

e. The capability to fully charge the TSS in the time period as required by the TSS specification.

D. MCS/CSS/RSS/TSS TO ELECTRICAL POWER GENERATION SUBSYSTEM INTEGRATION TEST

1. Objective

The primary objective of this test activity is to establish the functional operating capability of the integrated Pilot Plant system including both the solar portion and the electrical power generation subsystem.

2. Method

This test activity will start with the initial roll of the turbine generator using receiver supplied steam in a bypass mode to the condenser. After performance checkout of the turbine generator, initial connection to a load simulator will be accomplished. A procedure similar to that of a conventional power plant checkout will be used to accomplish this task. A series of tests will be performed on the turbine generator at different load levels, increasing increments of approximately 1 MWe. Heat balance calculations will be made and the system tuned for operation in this mode. System response to load transients and other load-following capabilities will be tested by using simulated load profiles and by making changes to the set point of the turbine generator controller. System responses to emergency shutdown at various load conditions will also be evaluated. The following operational modes will be tested during this activity:

a. Cold Start - The initial tests are anticipated to take longer than the six hour requirements, inasmuch as, at each step the instrumentation will be evaluated to assure the system is operating normally and that no adverse stresses exist.

b. Hot Start - The initial hot start test will probably exceed 45 minutes for the same reasons as stated above.

c. Operation from RSS alone.

d. Operation from the RSS while charging the TSS.

e. Operation from the RSS and TSS.

f. Operation from the TSS alone.

g. Transient operations, including mode switching.

h. Shutdown.

E. SYSTEM LEVEL TESTS

1. Objective

The primary objective of the system level tests will be to demonstrate that the hardware/software is designed and constructed in such a manner as to provide the operational capability as required by the various subsystem and system specifications.

2. Method

The following tests will be conducted in order to demonstrate the Central Receiver Solar Thermal Power System Pilot Plant operational capabilities:

a. The capability to deliver 10 MW net electrical power operating from the receiver at 2 p.m. on winter solstice with a minimum insolation of 0.950 kW/m^2. Due to the uncertainty in plant construction schedule, this requirement may be fulfilled by extrapolating the input/output data from the test days to winter solstice.

b. The capability to deliver 7 MW net electrical power for a minimum of 3 hours while operating from a fully charged thermal storage system.

c. The capability to deliver 7 MW net electrical power operating from both the receiver and thermal storage subsystems. This requirement will be verified at a minimum of three receiver/thermal storage power ratios.

d. The capability to deliver 10 MW net in six hours after startup from a cold condition and in 45 minutes after startup from the hot standby configuration.

e. The capability to demonstrate shutdown within specification limits under normal and emergency conditions. Shutdown under normal conditions will be verified by test. Shutdowns under emergency will be verified by analysis except in the cases where emergency shutdown is required to safe the pilot plant. Real or simulated malfunctions will not be inserted into the system for the sole purpose of verifying emergency shutdown procedures.

VII. TEST CONTROLS AND DOCUMENTATION

This section delineates the requirements associated with conducting of various testing modes and the preparation of test documentation.

A. TEST METHODS AND CONTROLS

The test methods and control established herein document the general requirements associated with the conduct of testing and measurement requirements. The requirements identified in the subsequent paragraph will apply to all testing activities. Any variation or exception to these requirements will have to be approved by test integration personnel prior to start of the testing activity.

1.0 Instrumentation Requirements

Instrumentation required for all testing activities shall meet the following requirements:

1.1 Measurement Accuracies

Measurement accuracies shall be certifiable through secondary standard calibration traceable to National Bureau of Standards. This accuracy shall be stated as per cent of full scale, and shall be within 3% unless otherwise required by the subsystems design criteria.

1.2 Measurement System Accuracies

The requirements of measurement accuracies shall apply to measurement systems consisting of one or more items and sensing element, signal condition, and recorder. Inherent system accuracy that will not meet the above requirements shall be improved by the use of the following system calibration techniques.

1.2.1 Calibrate the system end-to-end by supplying a standard signal that simulates the expected range of signals in three or more steps. The standard signal error shall be not greater than one-third the measurement tolerance.

1.2.2 Such calibration of 1.2.1 above shall be used before and after measurement runs requiring high accuracy.

1.3 Measurement System Stability - System drift shall be less than 1/3 of the system error for a period of three times the expected test duration. If the system stability cannot be certified to these requirements, pretest and post-test system calibrations shall be required.

1.4 Measurement Response Requirements

Recording and signal conditioning system frequency response shall be flat within ±1.0 dB over the frequency range to be measured. If the frequency response is uncertified or unknown, a technique similar to that of paragraph 1.2.2 shall be used.

1.5 Visual Records

All visual record (direct writing) traces shall have a minimum of 1 inch deflection for full-scale measurement. The number of traces per record shall be limited to prevent overlap unless time correlation and phasing is of prime importance. If multiple recordings are used, correlation with time identification is required on each chart.

1.6 Chart Speed

Chart speed shall be such as to permit resolution of pertinent data. Chart speed and time intervals may be identified in the test procedure. External timing shall be required for time resolution greater than 0.01 sec.

1.7 Scale Suppression

In cases where the resolution required exceeds that which the recording system can provide, the technique of dc scale suppression shall be used. The suppression device shall be certified as required in paragraph 1.2.2.

1.8 Special Annotation

Records taken for special purposes that are not calibrated in both dimensions (i.e., traces to identify frequency without valid amplitude calibration) shall be so annotated.

1.9 Signal-to-Noise Ratio

Signal-to-noise ratios shall not be less than 20 dB.

1.10 Specialized Measurement Equipment or Test Tools

The use of specialized test tools or measurement equipment requires prior test integration approval. Details of such equipment shall be supplied with the test procedure and certifiable calibration data shall be available for review. Test tools shall also be validated to assure compatibility with the unit under test.

2.0 Functional Equipment and Media Requirements

Unless otherwise specified in the test unit design specification, the following equipment and media requirements shall apply to all functional tests.

2.1 Fluid Media Tests

2.1.1 Filtration

Filtration of 10 microns or less shall be maintained on all fluid media unless otherwise specified in the subsystems design criteria.

2.1.2 Flow

Capability shall exist to provide flows up to 120% of that specified for the operation of the test unit. Flow rates shall be continuously recorded whenever flow is a specified performance parameter.

2.1.3 Pressure

Capability shall exist to provide pressures up to 110% of that specified for the operation of the test unit. Inlet and outlet pressures shall be continuously recorded whenever these pressures are specified performance parameters. Pressure relief shall be provided to relieve at 110% of pressure desired on the item under test.

2.2 Gaseous Media Tests

Unless otherwise specified, the above requirements for fluid media tests shall apply except that flow shall be straight and undisturbed for a distance of at least 30 diameters upstream and 20 diameters downstream of any static pressure taps.

3.0 Electrical Power Requirements

3.1 DC Power - Unless otherwise specified, the power supply voltage range used for testing shall be from 24.0 to 37.0 v. A verification of noise plus ripple shall be made during periodic equipment calibration and shall not exceed a 200 mv peak. Ripple frequency restraints shall be as specified in the subsystems design criteria.

3.2 AC Power - When ac power is used to operate test instrumentation or equipment, it shall be regulated and isolated so it does not produce transients or generate inputs causing out-of-tolerance test results.

B. TEST DOCUMENTATION

These paragraphs provide the minimum requirements for Test Procedures and Test Reports for the Pilot Plant testing. Content and sequence shall be as shown in Table VII-1, or to an established test agency format which contains the minimum as defined herein. Guidelines for each required item are delineated in the following paragraphs.

1.0 Title Page

The procedure/report title page shall display the following information:

a. Document title.

b. Program designation.

c. Document number.

d. Test nomenclature.

e. Issue date of procedure/report.

f. Author and approval signatures.

2.0 Table of Contents

The table of contents provides the reader with a basic outline for the procedure/report and a guide for locating major sections. Generally, only the first major headings and subheadings will be listed. These headings shall be identical to those appearing in the procedure/report. Lists of figures, tables, data sheets, and nonconformance reports shall follow the test contents listing.

3.0 Administrative Data and Approvals

This page(s) shall document:

a. Test agency.

b. Document/test number.

c. Test nomenclature.

d. Applicable documents and references.

e. Program approval signatures (Test Integration Engineers).

TABLE I-1 TEST PROCEDURE/REPORT CONTENT REQUIREMENTS

Item	Reference Para.	Test Procedure	Test Report
Title	1.0	X	X
ontents	2.0	X	X
Administrative Data	3.0	X	X
Revision Record	4.0	X	X
Narrative Summary	5.0		X
Chronological Summary	6.0		X
Scope	7.0	X	X
Pretest Requirements	8.0	Requirements	Certification
Test Setup	9.0	X	X
Test Method	10.0	X	X
Data Requirements	11.0	X	X
Success Criteria	12.0	X	X
Test Equipment List	13.0	X	X
Data Sheets	14.0	X	
Test Results*	15.0		X
Safety Requirements	16.0	X	
Notes	17.0	X	X

Note: *To include completed Data Sheets.

4.0 Revision Record

This page shall display, in tabular form, the following data for each incorporated revision to the document. The page and table form shall be incorporated in the original issue of the procedure/report.

a. Revision number.

b. Page number.

c. Paragraph affected.

d. Change description and reason.

e. Approval and date.

5.0 Narrative Summary

This section shall present the program test results. The summary should highlight significant test events, test failures, failure analyses, and resolutions to permit test unit evaluation and compliance with program requirements.

6.0 Chronological Summary

This section of the test report shall include, for each test in chronological sequence:

a. Date of each test.

b. Type of test (e.g., initial, functional).

c. Serial number of the test unit (as applicable).

d. Results (e.g., passed, test stopped, failed, etc).

7.0 Scope

State, clearly and concisely, the extent or range of technical content covered by the document, special considerations, and meaningful information required for the conduct of the test. Emphasis shall be given to the following, as applicable:

a. Special test sequence.

b. Definition of function of the unit(s) under test.

c. Success criteria definition (general).

8.0 Pretest Requirements

The test procedure shall provide for methods to verify that the test unit is ready for the test program, that all the test instrumentation is within calibration (as applicable, and that the test facility/test tools have been validated. The test report shall certify that all the pretest verification requirements were complied with prior to start of test.

9.0 Test Setup

A detailed description of the setup for the test shall be presented. A schematic defining all controls, instrumentation, measuring devices, test equipment, etc, shall be shown when applicable.

10.0 Test Method

A written detailed (as required) step-by-step procedure shall be presented for accomplishing each operation of the test.

11.0 Data Requirements

A brief description of data requirements shall be shown.

12.0 Success Criteria

For each test, the criteria for success (i.e., "passes," in the summary sheet) shall be defined in sufficient detail to permit an objective confirmation of success.

13.0 Test Equipment List

A listing of all major instruments, test devices, test tools, etc, to be used shall be presented in the test procedure. The equipment list shall be repeated in the report.

14.0 Data Sheets

The test procedure shall include data sheet formats for each functional and performance test in the sequence in which the tests are to be performed and in the sequence in which the data are to be recorded. All data sheets shall include the following:

a. Test title.

b. Test item nomenclature.

c. Test date.

d. Performance criteria parameters.

e. Measured values.

f. Operating time/cycles (when applicable).

g. Remarks (nonconformance data and other pertinent information not otherwise provided).

h. Test conductor.

i. Test witnesses.

j. Pass/fail block.

15.0 Test Results

Completed data sheets shall be included in the test report together with additional details of any of the following, as applicable:

a. Nonconformance reports.

b. Development of marginal conditions.

c. Deviation from the previously established test method defined in the test procedure.

15.1 Photographs

Photographs may be used where theycontribute to the reader's understanding, e.g., test setups, failures, etc.

16.0 Safety Requirements

The test procedure shall include CAUTION notes and safety practices when tests are to be conducted under hazardous conditions, when the test may pose hazard to personnel or equipment, or when an overtest condition is possible to the unit under test.

17.0 Notes

Each test procedure/report shall contain a final section entitled "Notes." This section is a catchall and should contain such paragraphs as "References," "Abbreviations," "Definitions," and other general or explanatory information. If there are no notes, the heading shall still be used with the section left blank.

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