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CENTRAL RECEIVER SOLAR THERMAL POWER SYSTEM PHASE 1

CDRL Item 2. Pilot Plant Preliminary Design Report

Volume 6. Electrical Power Generation and Master Control Subsystems and Balance of Plant

By
Raymon W. Hallet, Jr.
Robert L. Gervais

October 1977
Date Published

Work Performed Under Contract No. EY-76-C-03-1108

McDonnell Douglas Astronautics Company
Huntington Beach, California

U.S. Department of Energy

Solar Energy

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CENTRAL RECEIVER SOLAR THERMAL POWER SYSTEM PHASE 1

CDRL ITEM 2
Pilot Plant
Preliminary Design Report

VOLUME VI
Electrical Power Generation and Master Control Subsystems and Balance of Plant

Raymon W. Hallet, Jr. and Robert L. Gervais

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY
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PREFACE

This report is submitted by the McDonnell Douglas Astronautics Company to the Department of Energy under Contract EY-76-C-03-1108 as the final documentation of CDRL Item 2. This Preliminary Design Report summarizes the analyses, design, test, production, planning, and cost efforts performed between 1 July 1975 and 1 May 1977. The report is submitted in seven volumes, as follows:

Volume I, Executive Overview

Volume II, System Description and System Analysis

Volume III, Book 1, Collector Subsystem

Book 2, Collector Subsystem

Volume IV, Receiver Subsystem

Volume V, Thermal Storage Subsystem

Volume VI, Electrical Power Generation and Master Control Subsystems and Balance of Plant

Volume VII, Book 1, Pilot Plant Cost and Commercial Plant Cost and Performance

Book 2, Pilot Plant Cost and Commercial Plant Cost and Performance

Specific efforts performed by the members of the MDAC team were as follows:

- McDonnell Douglas Astronautics Company
  Commercial System Summary
  System Integration
  Collector Subsystem Analysis and Design
  Thermal Storage Subsystem Integration

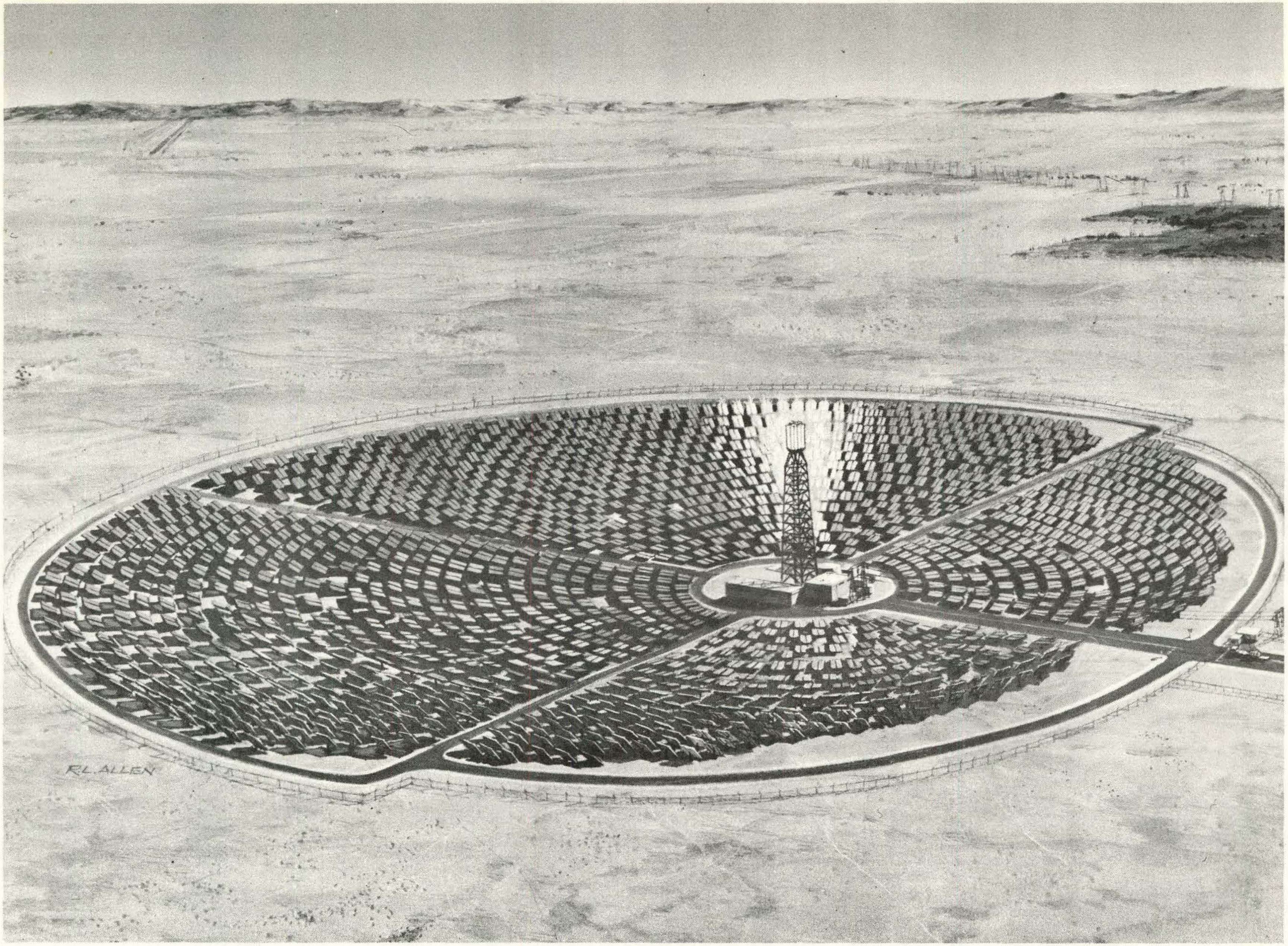
- Rocketdyne Division of Rockwell International
  Receiver Assembly Analysis and Design
  Thermal Storage Unit Analysis and Design

- Stearns Roger, Inc.
  Tower and Riser/Downcomer Analysis and Design
  Electrical Power Generation Subsystem Analysis and Design

- University of Houston
  Collector Field Optimization

- Sheldahl, Inc.
  Heliostat Reflective Surface Development

- West Associates
  Utility Consultation on Pilot Plant and Commercial System Concepts


R.L. ALLEN

CONTENTS

Section 1
INTRODUCTION AND SUMMARY

1.1 ELECTRICAL POWER GENERATION SUBSYSTEMS AND BALANCE OF PLANT

This section summarizes the requirements, performance, and subsystem configuration for both the Commercial and Pilot Plant electrical Power generation subsystems (EPGS) and balance of plants.

The EPGS for both the Commercial Plant and Pilot Plant make use of conventional, proven equipment consistent with good power plant design practice in order to minimize risk and maximize reliability.

The EPGS is designed to interface with other subsystems to satisfy the overall system requirements. Normal startup, power operations, mode changes, and shutdown will be coordinated through master control.

1.1.1 Commercial System

1.1.1.1 Requirements

Performance Requirements

Net Turbine Output (Power to Grid)	
Receiver Steam	100,000 kW at Equinox Noon (System Design Point)
Thermal Storage Steam (6-Hour Storage)	70,000 kW
Heat Rejection	Wet Cooling
Design Wet Bulb Temperature	23°C (73.4°F)
EPGS Availability	93.05%

Environmental Conditions

Wind Conditions
(At 10m [30 ft] Elevation)

Maximum Operational, with Gusts	16 m/s (36 mph)
Maximum Survival, with Gusts	40 m/s (90 mph)
Wind Velocity Profile	Varies Exponentially to 0.15 Power

Seismological

Seismic Zone	3
Response Spectrum	NRC Reg Guide 1.60
Operational Basis Earthquake	0.165g Horizontal
Safe Shutdown Earthquake	0.25g Horizontal
Soil Conditions	Barstow Soil Data Assumed

1.1.1.2 Basic EPGS Cycle

Refer to Figure 1-1 for the basic Commercial Plant EPGS cycle schematic.

A five-heater cycle has been selected. The Commercial Plant preliminary design uses a single automatic admission, tandem-compound double flow, extraction, condensing turbine.

1.1.1.3 Performance Summary

The summary of performance for the Commercial EPGS and overall plant when operating at the system design point and during extended operation on storage steam follows:

	Receiver Operation* Design Point (Equinox Noon)	Thermal Storage Operation
Generator Output, kWe	112,000	76,100
Plant Auxiliary Power, kWe	12,000	6,100
Net Generation, kWe	100,000	70,000
Gross Turbine Cycle Efficiency, %	37.6	26.81
Net Plant Efficiency, %	30.14	N/A
Turbine Exhaust Pressure, kPa (In. HgA)	8.46 (2.50)	8.46 (2.50)

*Note: No steam flow to thermal storage subsystem.

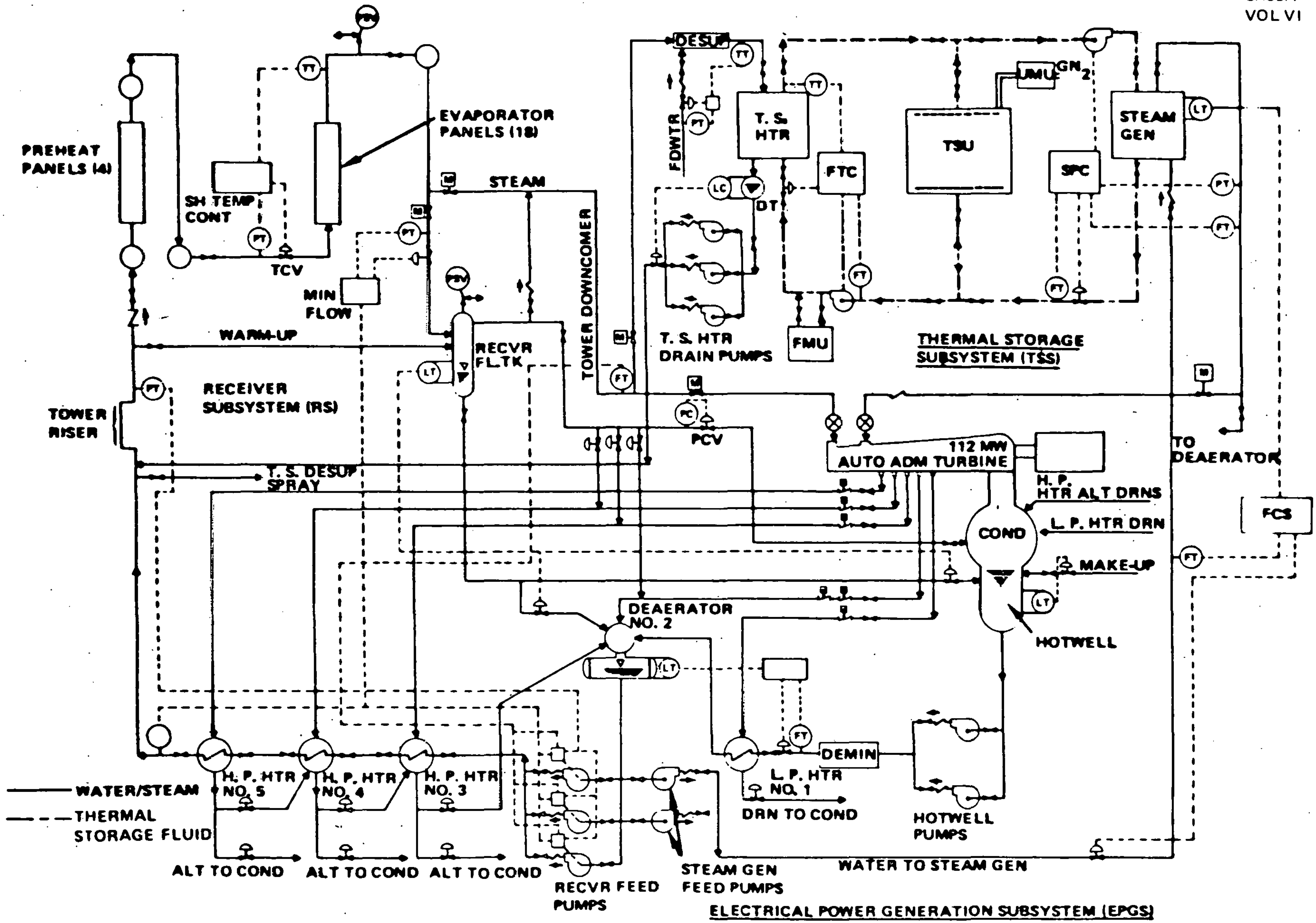


Figure 1-1. Overall Commercial System Schematic

1.1.1.4 Turbine-Generator

Turbine Type	Single Automatic Admission Tandem Compound Double Flow with 7.9 cm (20 in.) Last-Stage Blades (TCDF-20 LSB).
Turbine Rating	112,000 kW Generator Output at 8.46 kPa (2.5 In. HgA) Exhaust Pressure when Operating on 10.1 MPa (1465 psia), 510°C (950°F) Throttle Steam (Receiver Steam). 76,100 kW Generator Output at 8.46 kPa (2.5 In. HgA) Exhaust Pressure when Operating on 2.52 Mpa (365 psia) 296°C (565°F) Admission Steam (Storage Steam).
Generator Type	Hydrogen Cooled with Static Excitation System
Generator Rating	135,000 kVA, 0.90 Power Factor, 13,800V, 60 Hertz, 3,600 rpm.

1.1.1.5 Condenser

Type	Shell and Tube, Surface Condenser, 2-Pass
Surface	12,542m^2 (135,000 ft^2)
Tube Material	90-10 Copper Nickel
Tube Size	22.2 mm (0.875 In.) OD x 8.54m (28 ft) Effective Length
Condensing Pressure	8.46 kPa (2.5 In. HgA)
Condensing Temperature	42.6°C (108.7°F)

1.1.1.6 Cooling Tower

Type	Mechanical Draft, cross flow
Number of Cells	6
Fan Motor Size	150 kW (200 hp)

Wet Bulb Temperature	23°C (73.4°F)
Approach Temperature	8.1°C (14.6°F)
Range	7.8°C (14.0°F)
Heat Rejection	853.07 GJ/hr (808.6 x 10^6 Btu/hr)

1.1.1.7 Feedwater Heaters

One low-pressure heater, horizontal, stainless steel tubes, carbon steel shell, with drain cooler.

One deaerator heater, stainless steel trays and vent condenser, carbon steel shell. Horizontal condensate storage section, 75.7m^3 (20,000 gal) working capacity.

Three high-pressure heaters, carbon steel tubes, carbon steel shell with drain cooler.

1.1.1.8 Receiver Feed Pumps

Three half-capacity, electric motor-driven receiver feed pumps have been selected for the Commercial Plant. Each pump is of the double-case, barrel-type design; each is provided with a variable-speed hydraulic coupling for precise flow control, a speed-increaser gear, and an electric motor of 1,865 kW (2500 hp) 4,160V, and 3,560 rpm.

Receiver Pump Performance

Capacity, Each	4.07 m^3/min (1,125 gpm)
Head Developed	2,020m (6,625 ft)
Pumping Temperature	123.7°C (254.6°F)
Pump Efficiency	78%
Pump Brake Horsepower	1,690 kW (2,266 hp)
Pump Speed (Maximum)	6,300 rpm

1.1.1.9 Thermal Storage Feed Pumps

Two full-capacity, horizontal, electric motor-driven thermal storage feed pumps have been selected. Each pump is of the vertically or horizontally split case, multistage design and is directly connected to an electric motor drive of 597 kW (800 hp), 4,160V and 3,560 rpm.

Thermal Storage Feed Pump Performance

Capacity, Each	0.14m^3/min (2,200 gpm)
Head Developed	295.7m (970 ft)
Pumping Temperature	121.8°C (251.3°F)
Pump Efficiency	75%
Pump Brake Horsepower	503 kW (675 hp)

1.1.1.10 Thermal Storage Heater Drain Pumps

Receiver steam condensed in the thermal storage heaters is pumped as a subcooled liquid directly back to the receiver by the thermal storage heater drain pumps.

The alternative to pumping the drains is to allow the drains at high pressure and temperature, i.e., 9.65 MPa (1,400 psia) and 248.9°C (480°F), to flash to a lower pressure and temperature level in the turbine cycles. This would eliminate the requirement for heater drain pumps; however, impact of the heat added to the turbine cycle would adversely affect turbine design and performance (by requiring that the turbine operate nonextracting) and require oversizing of the condensor, pumps, and heaters in order to accommodate the increase in condensate flow.

A drain pump is provided for each of the five thermal storage heaters, and is sized for a minimum of 20% of the maximum charging steam rate.

1.1.1.11 Riser/Downcomer

The riser and downcomer piping supported from the receiver tower has been designed and analyzed in accordance with the requirements of ANSI B31.1 Power Piping Code, and a preliminary routing has been made.

	Riser	Downcomer
Fluid	Feedwater	Steam
Design Pressure	21.65 MPa (3,140 psia)	12.24 MPa (1,775 psia)
Design Temperature	260°C (500°F)	537.8°C (1,000°F)
Pipe Size	Nominal 30.5 cm (12 In.) Diameter Sch 160	34.3cm (13.5 In.) Min ID x 4.503 cm (1.773 In.) Nominal Wall
Pipe Material	Carbon Steel ASTM A106-C	Low Alloy Steel ASTM A335-P22 (2 1/4 CR-1Mo)
Unit Weight	238.5 kg/m (160.3 lb/ft)	440.4 kg/m 296 lb/ft)
Insulation	8.9 cm (3.5 In.) Calcium Silicate with Aluminum Jacket	14.0 cm (5.5 In.) Calcium Silicate with Aluminum Jacket

1.1.1.12 Main Electrical System

The generator will be connected by isolated phase bus to the unit auxiliary transformer, surge protection, voltage transformer cubicle, and the main transformer. The main power transformer will step up generator voltage to the voltage required by the power-transmission system. For the purpose of this report, the transmission system was assumed to be 115 kV. The main power transformer will be connected to the transmission system by an overhead or underground cable, oil circuit breaker, and disconnecting switches.

Main Power Transformer	
Rating	130 MVA, FOA
Voltage	115-13.2 kV

A startup transformer will be connected to the transmission system by either an overhead line or underground cable, and a circuit switcher.

1.1.1.13 Auxiliary Electrical Systems

Auxiliary power will normally be supplied by the unit auxiliary transformer, which will be rated 13,200 to 4,160V, 13.44/17.92/22.4 MVA, OA/FA/FA. The unit auxiliary transformer will be connected to the generator-isolated phase bus. The secondary of the transformer will feed two bus sections of metal-clad switchgear, operating at 4,160V. The connection to the 4,160V bus will be nonsegregated phase bus.

Startup power will be supplied from the transmission system by the startup transformer. The startup transformer will normally supply all auxiliary power when the generator is not operating (such as during startup and during the charging thermal storage only operating mode). In addition, the startup transformer will be available for emergency service and to supply auxiliary power if the unit auxiliary transformer is not available (due to failure). The startup transformer will be rated 115 kV to 4.16 kV, 13.44/17.92/22.4 MVA, OA/FA/FA.

1.1.1.14 Emergency Shutdown Power

Two 750-kW emergency diesel generators will be provided power for safe shutdown and emergency service (such as emergency slewing of heliostats on loss of electrical power).

Each generator will be rated 2,000 kVA, 80% power factor, 4,160 VAC. A generator will be connected to each of the two 4,160 V bus sections by power cable. The diesel engines will be automatic starting.

1.1.1.15 Heliostat Field Feeders

The heliostats will be served by eight 4,160V feeders. Pad-mounted transformers rated 4,160/240V will supply the heliostat field. The feeders will be direct-burial power cable, with concrete cover. The number, size, and location of transformers will be as required by the collector subsystem.

1.1.1.16 Feedwater Treatment

The use of a once-through-to-superheat receiver dictates that the dissolved or suspended solids present in the feedwater be held at an absolute minimum, so the solids do not deposit out on the boiler (receiver) surface or carry through and deposit in the turbine. Accordingly, a full-flow condensate polisher is essential to maintain feedwater total solids at the required level of 20 to 50 parts per billion (ppb).

A "volatile" feedwater treatment will be used to control pH and reduce dissolved oxygen in the feedwater.

Ammonia and hydrazine are added to the feedwater: the former to elevate the pH sufficiently (to approximately 9.5) to reduce corrosion to a practical minimum, the latter to remove any last trace of dissolved oxygen.

Demineralized water will be supplied for boiler makeup by two demineralizers, each rated at 0.37 m^3/min (100 gpm).

1.1.2 Pilot Plant System

1.1.2.1 Requirements

Performance Requirements

Net Turbine Output (Power to Grid)	
Receiver Steam Winter Solstice, 2 PM	10,000 kW at (System Design Point)
Thermal Storage Steam (3-Hour Storage)	7,000 kW
Heat Rejection	Wet Cooling
Design Wet Bulb Temperature	23°C (73.4°F)
EPGS Availability	93.05%

Environmental Conditions

Wind Conditions (at 10m [30 ft] elevation)	
Maximum Operational, with Gusts	16 m/s (36 mph)
Maximum Survival, with Gusts	40 m/s (90 mph)
Wind Velocity Profile	Varies Exponentially to 0.15 Power

Seismological

Seismic Zone	3
Response Spectrum	NRC Reg Guide 1.60
Operational Basis Earthquake	0.165g Horizontal
Safe Shutdown Earthquake	0.25g Horizontal
Soil Conditions	Barstow Soil Data

1.1.2.2 Basic EPGS Cycle

See Figure 1-2 for the basic Pilot Plant EPGS cycle schematic.

A four-heater cycle has been selected for the Pilot Plant preliminary design, using a single automatic admission, tandem-compound single flow, extraction, condensing turbine.

1.1.2.3 Performance Summary

The summary of performance for the Pilot Plant EPGS and overall plant when operating at the system design point and during extended operation on storage steam follows:

	Receiver Operation* Design Point Winter Solstice, 2 PM	Thermal Storage Operation
Generator Output, kWe	11,200	7,800
Plant Auxiliary Power, kWe	1,200	800
Net Generation, kWe	10,000	7,000
Gross Turbine Cycle Efficiency, %	34.5	24.3
Net Plant Efficiency, %	26.10	N/A
Turbine Exhaust Pressure, kPa (In. HgA)	8.46 (2.50)	8.46 (2.50)

*Note: No steam flow to thermal storage subsystem.

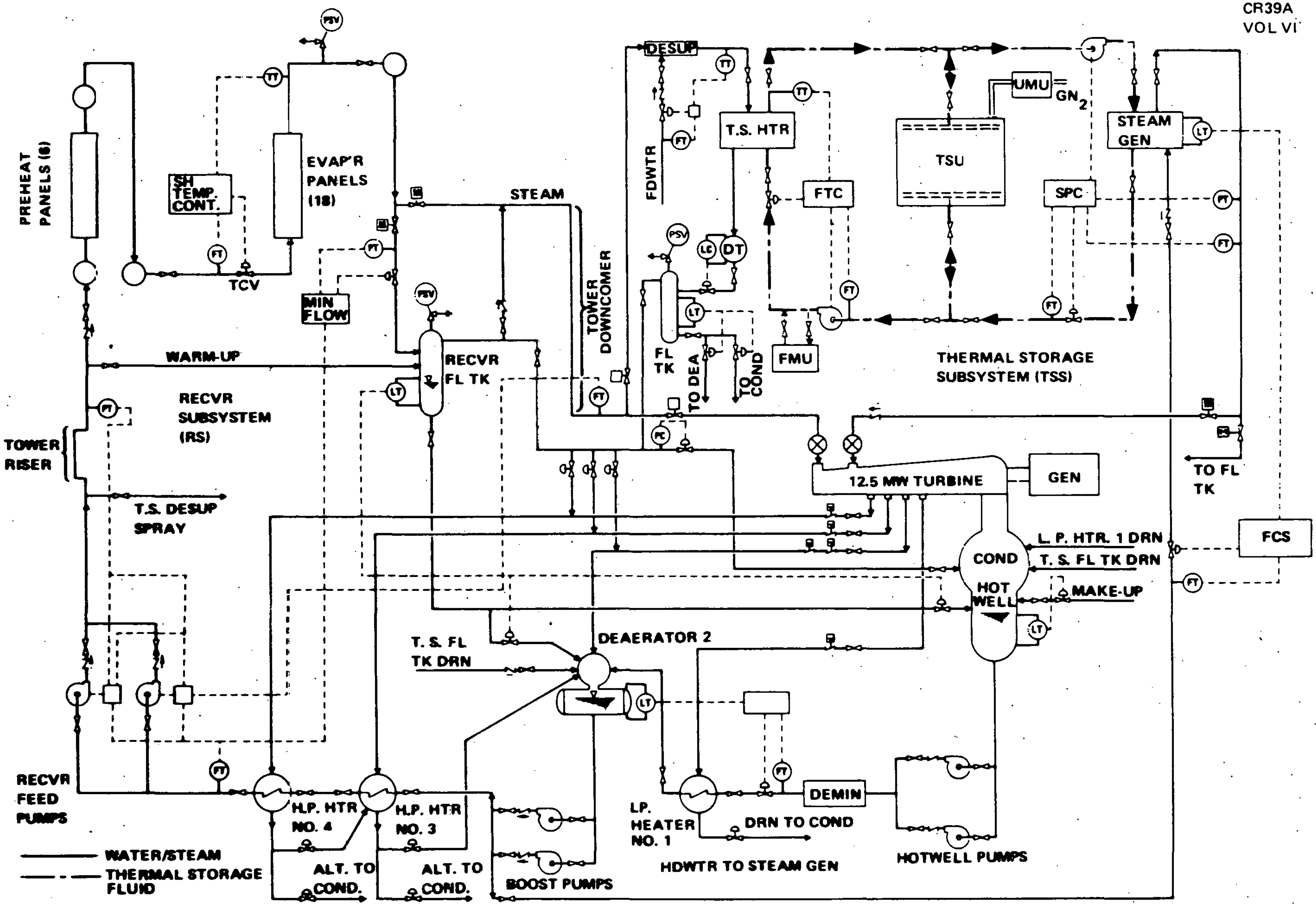


Figure 1-2. Overall Pilot Plant System Schematic

1.1.2.4 Turbine-Generator

Turbine Type	Single Automatic Admission Tandem-Compound Single Flow with 4.5 cm (11.4 In.) Last-Stage Blades (TCSF-11.4 LSB).
Turbine Rating	12,500-kW Generator Output at 8.46 kPA (2.5 In. HgA) Exhaust Pressure when Operating on 10.1 MPa (1,465 psia), 510°C (950°F) Throttle Steam (Receiver Steam). 7,800-kW Generator Output at 8.46 kPa (2.5 In. HgA) Exhaust Pressure when Operating on 2.65 MPa (385 psia), 274.4°C (525°F) Admission Steam (Storage Steam).
Generator Type	Air Cooled with Static Excitation System.
Generator Rating	16,000 kVA, 0.85 Power Factor, 13,800V, 60 Hertz, 3,600 rpm.

1.1.2.5 Condenser

Type	Shell and Tube, Surface Condenser, 2-Pass
Surface	1,115m² (16,000 ft²)
Tube Material	90-10 Copper Nickel
Tube Size	19.05 (0.750 In.) OD x 6.1m (20 ft) Effective Length
Condensing Pressure	8.46 kPa (2.5 In. HgA)
Condensing Temperature	42.6°C (108.7°F)

1.1.2.6 Cooling Tower

Type	Mechanical Draft, Cross Flow
Number of Cells	2

Fan Motor Size	75 kW (100 hp)
Wet Bulb Temperature	23°C (73.4°F)
Approach Temperature	6.4°C (11.6°F)
Range	7.8°C (14.0°F)
Heat Rejection	100 GJ/hr (95.0 x 10^6 Btu/hr)

1.1.2.7 Feedwater Heaters

One low-pressure heater, horizontal, stainless steel tubes, carbon steel shell, with drain cooler.

One deaerator heater, stainless steel trays and vent condenser, carbon steel shell. Horizontal condensate storage section, 18.92m^3 (5,000 gal) working capacity.

Three high-pressure heaters, carbon steel tubes, carbon steel shell with drain cooler.

1.1.2.8 Receiver Feed Pumps

Two full-capacity, electric motor-driven receiver feed pumps have been selected for the Pilot Plant. Each pump is of the double-case, barrel-type design and is provided with a variable-speed hydraulic coupling for precise flow control and 448 kW (600 hp), 2,400V, 3,560 rpm electric motor drive.

<u>Receiver Pump Performance</u>

Capacity, Each	1.32 m^3/min (350 gpm)
Head Developed	1,423.7m (4,670 ft)
Pumping Temperature	201.7°C (395°F)
Pump Efficiency	65%
Pump Brake Horsepower	407.4 kW (546 hp)
Pump Speed (Maximum Load)	3,465 rpm

1.1.2.9 Booster Pumps

Two full-capacity, horizontal, electric motor-driven booster pumps have been selected. Each pump is of the horizontally split case, multistage design, and is directly connected to a 186 kW (250 hp), 480V, 3560 rpm electric motor drive.

Thermal Storage Feed Pump Performance	
Capacity, Each	2.2 m^3/min (575 gpm)
Head Developed	355.5m (1,166 ft)
Pumping Temperature	121.1°C (250°F)
Pump Efficiency	75%
Pump Brake Horsepower	158 kW (212 hp)

1.1.2.10 Riser/Downcomer

The riser and downcomer piping supported from the receiver tower has been designed and analyzed in accordance with the requirements of ANSI B31.1 Power Piping Code, and a preliminary routing has been made.

	Riser	Downcomer
Fluid	Feedwater	Steam
Design Pressure	19.9 MPa (2,890 psia)	11.82 MPA (1,715 psia)
Design Temperature	232.2 (450°F)	537.8°C (1,000°F)
Pipe Size (Nominal Diameter)	10.2 cm. (4 In.)	15.24 cm (6 In.)
	Sch 160	Sch 160
Pipe Material	Carbon Steel ASTM A106-B	Low Alloy Steel ASTM A335-P22 (2-1/4 CR-1 Mo)
Unit Weight	33.5 kg/m (22.5 lb/ft)	67.4 kg/m (45.3 lb/ft)
Insulation	6.35 cm (2.5 In.) Calcium Silicate with Aluminum Jacket	12.7 cm (5.0 In.) Calcium Silicate with Aluminum Jacket

1.1.2.11 Main Electrical System

The generator will be connected to the main power transformer by a 15-kV circuit breaker (switchgear unit). Connections from the generator to the switchgear, and from the switchgear to the main power transformer, will be cable. Two unit auxiliary transformers will be connected to the main power transformer by cable. Surge protection will be provided for the generator.

The main power transformer will step up generator voltage to the voltage required by the transmission system. Voltage is expected to be 115 kV. The main power transformer will be rated 115-13.2 kV, 12/16 MVA, OA/FA, 55°C rise for a 50°C ambient. The 115-kV winding will be wye-grounded, and the 13.2-kV winding will be delta. The 115-kV winding will be provided with surge arresters.

The main power transformer will be connected to the transmission system by an overhead line, oil circuit breaker, and disconnecting switches. The oil circuit breaker and disconnecting switches will be rated 115 kV, 1,200 amperes. The switches will be mounted on a steel structure. The 115-kV switching equipment will be as required by the utility.

The startup transformer will not be required because auxiliaries can be supplied by the unit auxiliary transformers when the generator is shut down.

1.1.2.12 Auxiliary Electrical System

Auxiliary power will be supplied by two unit auxiliary transformers. Each transformer will be rated 13,200-2,400V, 1,500/1,750 kVA, OA/FA, 55°C rise for 50°C ambient. The primaries will be delta. The secondaries will be grounded wye. The unit auxiliary transformers will be supplied by the main power transformer. The secondary of each transformer will feed a section of 2,400V bus, with a bus tie circuit breaker between sections. The secondary connection will be cable or bus duct. The 2,400V bus will supply directly, 600-hp receiver feed pump motors, and 2,400-480v load center transformers.

The two unit auxiliary transformers provide redundant capacity based on their emergency short-time overload capacity.

Each load center transformer will be rated 2,400-480V, 750 kVA, OA, and will provide 100% redundant capacity. The 480V bus will feed motors of 100 hp and larger and motor control centers.

The motor control centers will be served from the 480V bus, one from each bus section; circuit breaker combination starters will be provided for motors. Molded-case circuit breakers will be provided for lighting transformers, battery charger, and miscellaneous service.

1.1.2.13 Emergency Shutdown Power

A 350-kW emergency power engine generator will provide power for safe shutdown and emergency service. The generator will be rated 1,000 kVA, 80% power factor, 2,400V. The generator will be connected to one of the two 2,400V switchgear bus sections. The diesel will be automatic starting.

1.1.2.14 Heliostat Field Feeders

The heliostats will be served by eight 2,400V feeders. Pad-mount, dry-type transformers rated 2,400-240V 22.5 kVA will supply the heliostat field. The feeders will be direct-burial cable, with concrete cover.

1.1.2.15 Feedwater Treatment

The use of a once-through-to-superheat receiver dictates that the dissolved or suspended solids in the feedwater be held at an absolute minimum, lest the solids deposit out on the boiler (receiver) surface of carry through and deposit in the turbine. Accordingly, a full-flow condensate polisher is essential to maintain feedwater total solids at the required 20 to 50 ppb level.

A "volatile" feedwater treatment will be used to control pH and reduce dissolved oxygen in the feedwater. Ammonia and hydrazine are added to the feedwater, the former to elevate the pH sufficiently (to approximately 9.5) to reduce corrosion to a practical minimum, and the latter to remove any last trace of dissolved oxygen.

Demineralized water will be supplied for boiler makeup by two demineralizers, each rated at 0.18 m^3/min (50 gpm).

1.1.2.16 Auxiliary Steam Boiler

An oil-fired auxiliary steam boiler will build heating and process steam requirements such as turbine seal steam, feedwater heater blanketing, and feedwater preheating and deaeration prior to a startup. Normally, the process steam requirements will be supplied from thermal storage when available.

The auxiliary steam boiler will be rated at 4,536 kg/hr (10,000 lb/hr) and 310.2 kPa (45 psia), oil-fired, and stamped with ASME code.

1.2 MASTER CONTROL

Master control consists of the control and display hardware and associated software necessary for coordination of subsystem processes, either automatically or manually under direction of the Pilot Plant operator.

Computer-automated techniques are designed into master control to benefit the following operations:

- To continuously compute the collector subsystem synthetic track during each solar day and correct the track, and subsequently the heliostat positions, using algorithms influenced by current meteorology and plant performance data.
- To continuously optimize plant heat and steam generation, and plant balance profiles at startup and during steady-state operation when immediate and temporary weather changes, with varying receiver and thermal storage heat input and output demands, present a situation crucial to maintaining the plant on-line.
- To provide on-time data reduction of voluminous plant operation and performance data to engineers during the development phase.
- To evaluate and develop the computer in a solar power-generation system as a controller for follow-on power generation control applications of the same type.

The master control architecture is modular in design to accommodate scaling to the Commercial Plant. The following design concepts facilitate the growth and expansion capabilities of master control.

A. The computer system memory and peripheral devices are interfaced to a common bus that is expandable and can accommodate a large number and variety of peripherals.

B. MDAC special-purpose devices (i. e., steering logic and collector subsystem interface) are modular and addressable by the computer, making it easy to add on.

C. Applications software is written in function-independent modular form sharing common tables, buffers, etc. This design minimizes program rewrite and redesign to accommodate changes and expansion.

D. Use of the MDAC combination analog and digital automatic control design simplifies the software and provides flexibility in implementing new control functions.

E. Patch panels and analog recording devices are of modular design and can be added or removed easily.

F. The MDAC design minimizes wiring and signal conditioning to support master control manual and automatic control using steering logic, buffered amplifiers, and patch panels. The feature permits economical add-ons and reduces maintenance.

Items in master control that require alterations to accommodate expansion are:

A. The control console, which will have to be enlarged and probably redesigned to accommodate the increased number of control and monitoring devices.

B. The uninterruptible power source, which will have to be sized to handle the increased power requirements of master control.

Section 2
DATA LISTS

2.1 COMMERCIAL PLANT EPGS

2.1.1 Design Characteristics

2.1.1.1 Turbine-Generator

The gross power output is 112,000 kW on throttle steam (76,100 kW gross on admission steam) at 8.46 kPa (2.5 in. HgA) backpressure, based on a single automatic admission, tandem compound, double flow, 20-in. LSB, extraction, condensing turbine. The generator is rated at 135,000 kVA, 0.90 power factor, 13,800V, 60 Hertz, and is hydrogen cooled with static excitation system. The maximum calculated capability on throttle steam is 122,080 kW gross.

2.1.1.2 Inlet Steam Conditions

Pressure	10.1 MPa (1,465 psia)
Temperature	510°C (950°F)
Enthalpy	3399 kJ/kg, (1,461.2 Btu/lb)

2.1.1.3 Admission Steam Conditions

Pressure	2.52 MPa (365 psia)
Temperature	296°C (565°F)
Enthalpy	3,000 kJ/kg (1.289.9 BTU/lb)

2.1.1.4 Feedwater Heater Extractions

Five feedwater heater extractions (one low-pressure heater, one deaerating heater, and three high-pressure heaters) are indicated in Figure 1-1.

2.1.1.5 Condenser Type and Configuration

Type	Surface Condenser, 2 Pass
Surface Area	12,542m^2 (135,000 ft^2)
Tube Material	90-10 Copper Nickel
Tube Diameter (OD)	22.2 mm (0.875 in.)
Tube Wall Thickness	0.89 mm (0.035 in.) 20 BWG
Tube Length (Effect)	8.54m (28 ft)
Condenser Pressure	8.46 kPa (2.5 in. HgA)
Heat Rejection	828 GJ/hr (785 x 10^6 Btu/hr)
Cooling Water Flow	7.1 m^3/s (112,100 gpm)
Water Velocity	2.13 m/s (7 fps)
Cooling Water In	31.1°C (88°F)
Cooling Water Out	40.0°C (102°F)
TTD	3.7°C (6.7°F)
Temperature Rise	7.8°C (14°F)

2.1.1.6 Feedwater Pumping Stages

One stage of feedwater pumping is provided on the Commercial EPGS. Feedwater is pumped from the deaerator heater through three high-pressure heaters to the receiver feedwater inlet as shown in Figure 1-1.

2.1.1.7 Turbine Seal Steam Requirements

Seal Steam Flow	591 kg/hr (1,300 lb/hr)
Pressure	138 kPa (20 psia)
Temperature	123°C (253°F) Minimum for Cold-Start Conditions

2.1.1.8 Auxiliary Steam Supply

Auxiliary steam requirements include:

- Turbine seal steam (startup and shutdown).
- High-pressure feedwater heater blanketing.
- Deaerator feedwater heater blanketing.
- Deaerator pressure "pegging".
- Startup requirements (deaeration and feedwater heating).
- Receiver freeze protection.

Auxiliary Steam Sources

Two independent steam sources will provide auxiliary steam for the EPGS, namely: (1) thermal storage subsystem, and (2) auxiliary oil-fired low pressure steam boiler. Except for the building heating requirements, the auxiliary boiler will act as a backup to the thermal storage steam generator, should this steam source not be available.

Auxiliary Steam Requirements

A summary of the auxiliary steam requirements for the Commercial EPGS is as follows:

	Nighttime Standby		Maximum Demand	
	kg/hr	(lb/hr)	kg/hr	(lb/hr)
Turbine Seal Steam	591	(1,300)	591	(1,300)
High-Pressure Heater Shell Blanketing (3 Heaters)	12	(27)	12	(27)
Deaerator Heater Blanketing	13	(28)	13	(28)
Deaerator Pressure (20 psia) "Pegging" (Low Load)	N/A	N/A	6,804	(15,000)
Startup Requirements (Deaeration and Feedwater Heating)	N/A	N/A	17,917	(39,500)
Receiver Freeze Protection (If Required)	9,548	(21,050)	9,548	(21,050)
Total	8,804	(19,405)	18,250	(40,827)*

*Note: Maximum demand total includes turbine seal steam, H-P heater blanketing, and startup requirements only. A more detailed discussion of the Commercial EPGS auxiliary steam requirements is in Section 3.2.4.

2.1.1.9 Startup and Shutdown Characteristics

The typical startup and loading characteristics for the Commercial turbine are shown in Table 2-1. Also refer to Section 3.2.3.2. After the unit has been synchronized and loaded in accordance with the above table, the load or throttle steam temperature may be increased or decreased in accordance with Figure 2-1.

Shutdown Characteristics

During normal shutdown, except in an emergency, the load must be removed gradually, with the normal rate of decrease not exceeding that indicated in Figure 2-1.

2.1.2 Design Discussion

2.1.2.1 Turbine-Generator Selection

The turbine selected for the Commercial Plant and Pilot Plant EPGS is a single automatic admission, condensing unit. A typical cross section of the type is shown in Figure 2-2. The turbine consists of high-pressure and low-pressure sections. The higher pressure steam (receiver steam) is supplied to the high-pressure turbine inlet valves; the lower pressure steam (from thermal storage) is supplied through the automatic admission port ahead of the low-pressure section. The admission pressure is regulated by an electro-hydraulic control system discussed in Section 3.3.1.3.

Table 2-1
TYPICAL STARTUP AND LOADING CHARACTERISTICS

Type of Start	Cold	Warm	Hot
Average Metal Temperature	-18° to 149°C (0° to 300°F)	149° to 371°C (301° to 700°F)	372° to 538°C (701° to 1,000°F)
Time to Roll (Minutes)	125	50	15
Time at Minimum Load (Minutes)	48	27	15
Time from Minimum Load to Full Load (Minutes)	112	83	35
Total Time (Minutes)	285	160	65

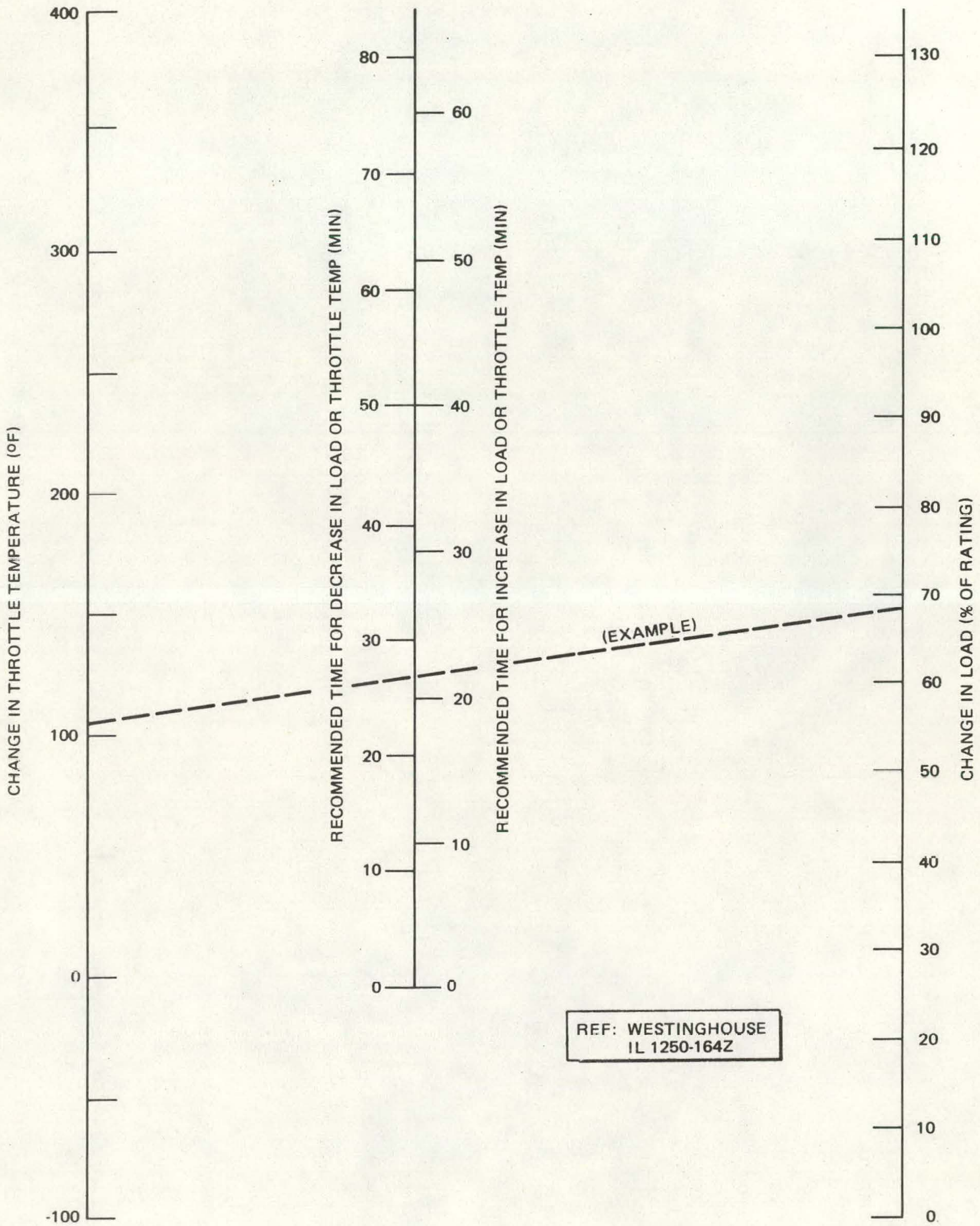
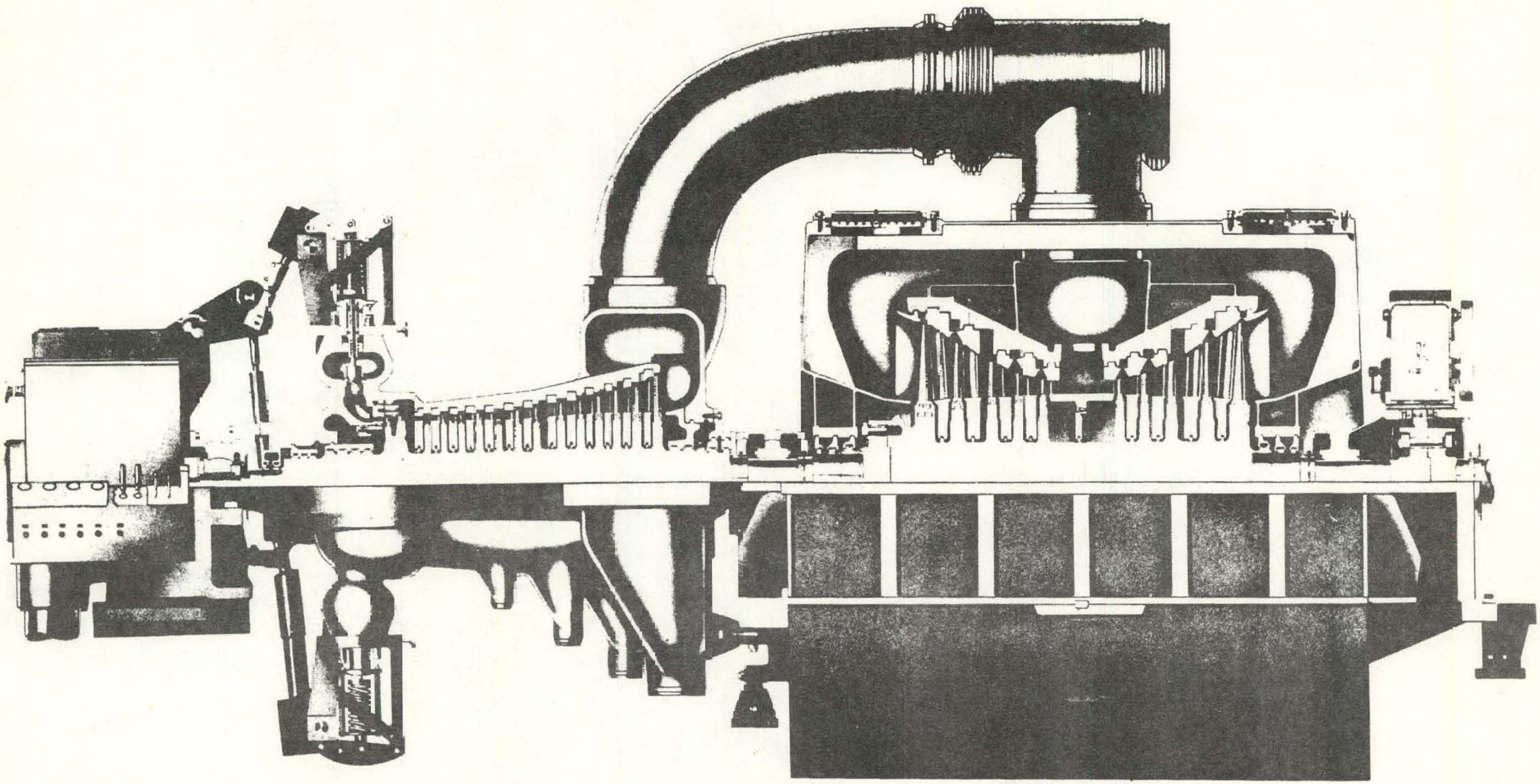


Figure 2-1. Recommended Minimum Time For Change in Load or Throttle Steam Temperature



COURTESY OF GENERAL ELECTRIC CO

Figure 2-2. Typical 100-MWe Commercial Turbine

This type of turbine (automatic extraction or admission design) is widely used in various industrial installations. It was selected over the conventional utility turbine for the EPGS because its dual-admission feature lends itself to two steam sources of different pressure and temperature characteristics.

From an operational standpoint, the single automatic-addmission turbine offers the following advantages over a conventional utility turbine:

- The changeover from receiver steam (high pressure) to thermal storage steam (low pressure) can be instantaneous, from a turbine standpoint, without limiting the cyclic life of the turbine due to temperature transients.
- The turbine is capable of operating on both receiver steam and thermal storage steam simultaneously to generate the required load.
- The automatic admission feature will permit turbine startup on relatively low-pressure, low-temperature thermal storage steam, if required.

The Commercial EPGS turbine-generator is sized to produce 112,000 kW electrical gross generation (100,000 kW net) when operating entirely from receiver steam (1,465 psia - 950°F) at equinox noon, which is the design point for the system. When operating from thermal storage steam (365 psia - 565°F) the turbine-generator will produce 76,100 kW net for 6 hr. The turbine backpressure for both the receiver steam and storage steam operating condition is 8.46 kPa (2.5 in. HgA).

2.1.2.2 Turbine Inlet/Admission Steam Conditions

Inlet (Receiver) Steam Conditions

The turbine inlet steam conditions selected for the Commerical and Pilot Plant turbines are 10.1 MPa (1,465 psia) and 510°C (950°F). The selection was based on the following considerations:

- Compatibility with thermal storage charging requirements.
- Compatibility with admission steam conditions.
- Moisture limitations at the exhaust end of the turbine.

- Standard commercial turbine throttle steam conditions.
- Turbine construction (single-shell vs double-shell high-pressure section).

Compatibility with Thermal Storage Charging

As discussed under the thermal storage subsystem design requirements in Volume V, the required steam pressure entering the thermal storage heater is 10.1 MPa (1,465 psia), which is the same as the selected turbine inlet pressure. If a lower turbine inlet pressure was selected, it would be necessary to throttle the steam supply pressure to the turbine, resulting in a thermodynamic loss.

Compatibility with Admission Steam Conditions

Considering the inlet pressure and temperature with respect to the admission (thermal storage) steam condition, it is desirable to minimize the temperature mismatch occurring at the admission port (high-pressure section exhaust) of the turbine during the various operating modes. Based on admission steam conditions of 2.52 MPa (365 psia) and 296°C (565°F), the inlet steam temperature of 510°C (950°F) at 10.1 MPa (1,465 psia) at the 112,000 kW load results in a high-pressure section exhaust temperature of 332°C (630°F), or 36°C (65°F) higher than the admission steam temperature (see Section 2.1.3.1). This temperature difference will increase slightly as inlet steam flow decreases. The General Electric Company has advised that temperature changes of this magnitude (<100°F) can be made instantaneously without adverse effect on turbine life.

Moisture Limitations

Moisture content of the steam entering the last row of turbine blades is an important consideration because of its effect on blade life due to erosion. This is particularly a problem on nonreheat-type turbines since reheating tends to lower the steam moisture content at the exhaust end of the low-pressure section. Generally, on nonreheat turbines, the higher the initial pressure the wetter the steam in the exhaust end of the turbine. The amount of moisture that can be permitted is a function of the blade tip velocity; thus, the Pilot Plant turbine, with 4.5 cm (11.4 in.) last-stage blades, can tolerate a higher moisture level than the Commercial Plant turbine with 7.9 cm (20 in.) last-stage blades, both turning at 3,600 rpm. For both turbines, the highest moisture content is experienced when operating on admission steam only. It was moisture limitations on the Commercial turbine that dictated the use of 7.9 cm (20 in.) last-stage blades over 9.1 cm (23 in.) blades.

For the Commercial Plant turbine at full load (112,000 kW), the moisture content at the expansion line point (low-pressure turbine exhaust) at 8.46 kPa (2.5 in. HgA) is 13.0% on inlet steam and 14.4% on admission steam. For the Pilot Plant turbine, these values are 10.3% and 14.6%, respectively. General Electric considers 15 to 16% moisture at the expansion line end point to be a maximum allowable. Actually, the important figure is the moisture content entering the last row of blades, and General Electric recommends a maximum of 10 to 12% moisture at this point. It can be said, therefore, that operation on inlet steam above 10.1 MPa (1,465 psia) or admission steam above 2.65 MPa (385 psia), without a corresponding increase in temperature, is not recommended. In general, the exhaust steam moisture content decreases as load decreases.

Standard Turbine Inlet Conditions

For nonreheat turbines in the 100-MW range, certain throttle pressure-temperature combinations are considered standard. Although steam conditions differing from the published values can be selected, it is desirable from a pricing and performance standpoint to use one of the following throttle or inlet steam conditions:

8.7 MPa (1,265 psia), 510°C (950°F)
10.1 MPa (1,465 psia), 510°C (950°F) or 538°C (1,000°F)
12.5 MPa (1,815 psia), 538°C (1,000°F)

Turbine Construction

For throttle pressures of 10.1 MPa (1,465 psia) and under on the Commercial turbine, a single-shell construction can be used for the high-pressure section of the turbine. For turbines designed for 12.5 MPa (1,815 psia), the next highest standard throttle pressure rating, a double-shell high-pressure section is required to contain the higher pressure at a considerably higher cost. Also, considerable turbine redesign would be required because double-shell construction is not standard on automatic admission/extraction turbines.

Admission Steam Conditions

Turbine admission steam conditions were determined by two requirements:

- Thermal storage oil temperature.
- Turbine requirements.

As discussed in Volume V, the maximum oil temperature available to the thermal storage steam generator is 316°C (600°F); thus, steam leaving the superheater section of the steam generator has an upper temperature limit of 288° to 296°C (550° to 565°F).

The turbine requirements are two-fold: (1) generate 70,000 kW net when operating entirely from thermal storage, and (2) admission steam conditions should be chosen to minimize the moisture level in the turbine exhaust steam. As previously discussed, the selection of 7.9 cm (20 in.) last-stage blades on the Commercial turbine was determined by the consideration of minimizing the moisture level at the rear end of the turbine when operating on admission steam only. The other consideration was the choice of admission steam conditions that will maximize the turbine performance, consistent with the capabilities of the steam generators in the thermal storage subsystem. A comparison of the economic leverage associated with the increased efficiency and electrical output vs the additional costs for the superheat section of the thermal storage steam generators caused the decision to increase the admission steam by 15°F, from 550° to 565°F, which is still within the thermodynamic pinch point constraints for steam generator operation. The resulting admission steam conditions measured at the turbine are 2.52 MPa (365 psia) and 296°C (565°F).

2.1.2.3 Cycle Analyses

Feedwater Heating Stages

A five-heater turbine cycle was selected for the Commercial EPGS. The feedwaters consist of one closed low-pressure heater, one open deaerating heater, and three closed high-pressure heaters. The deaerator placement was determined by the requirement for 121°C (250°F) maximum feedwater temperature leaving this heater for water makeup to the thermal storage steam generator. A final feedwater temperature leaving the last heater of 218°C (425°F) is provided to meet receiver requirements.

Unlike the Pilot Plant turbine cycle analysis, no trade studies were made for feedwater staging, i.e., four vs five heaters, on the Commercial plant. The five-heater cycle selected is similar to the 100-MW nonreheat ASME preferred standard configuration in both arrangement and performance, with minor changes due to the feedwater temperature constraints mentioned. It is estimated, however, that a four-heater cycle will result in a 42 to 53 kJ/kW-hr (40 to 50 Btu/kWhr) poorer gross turbine heat rate than a five-heater cycle.

Feedwater Pumping Stages

On the Commercial Plant (see Figure 1-1), the receiver feed pumps are located ahead of the three high-pressure heaters, taking suction from the deaerator. Unlike the Pilot Plant, no booster pumps are provided ahead of the receiver feed pumps. Instead of booster pumps which also serve as thermal storage feed pumps on the Pilot Plant, separate thermal storage feed pumps are provided on the Commercial Plant. This was done to improve the reliability of the pumping systems on the Commercial Plant and to minimize the possibility of flashing at the receiver feed pump inlet.

Three half-capacity receiver feed pumps are provided (including one spare half-capacity pump). The pumps are of the horizontal centrifugal double case, barrel-type with variable-speed hydraulic coupling driven by an electric motor. The variable speed control regulates the receiver feedwater inlet pressure to 15.5 MPa (2,250 psia). Feedwater flow is used as a feed-forward signal to the receiver feed pump speed control system to ensure rapid response to changes in receiver flow requirements.

The thermal storage feed pumps are each 100% capacity. The pumps are of the horizontal, multistage, split-case type, with direct electric motor drive.

Feedwater flow to the thermal storage steam generators is regulated at each unit by a throttling valve that is controlled by a three-element feedwater control system on each steam generator.

Thermal Storage Heater Drain System

As indicated in Figure 1-1, steam condensed in the thermal storage heaters during charging of the thermal storage unit is drained into a drain tank where a level is maintained by a heater drain pump that pumps the high-pressure condensate back into the feedwater line to the receiver. The heater drain pump is designed to operate singly or in parallel with the receiver feed pumps. A startup flash tank system also is provided to drain the thermal storage heater drains to the condenser for cleanup prior to normal operation.

Effects of Solar Multiple

Since the collector subsystem and receiver subsystem are designed for a solar multiple of 1.7 (70% more solar thermal energy collected and absorbed than required by the EPGS), there exists a considerable amount of "excess" heat to be disposed of in the form of high-pressure, high-temperature drains from the thermal storage heater. The heat content of these drains represents approximately 39% of the total heat required by the turbine cycle at equinox noon, and exceeds that required for feedwater heating normally supplied by turbine extraction steam. The only viable alternative to adding this heat to the turbine cycle appears to be to pump the drains from the thermal storage heater directly back to the receiver without interacting with the turbine cycle or rejecting heat to the condenser.

However, three apparent problem areas arise when using a closed system for thermal storage charging and occur during the charging thermal storage only or intermittent-cloud modes of operation.

The problem areas are:

A. Lack of in-line demineralizer for feedwater cleanup.
B. Lack of deaeration of feedwater.
C. Difficult pump duty.

Because of the high-purity feedwater required for systems using the once-through receiver, it is a requirement that the feedwater or condensate be continually "polished" with an in-line demineralizer to remove dissolved and suspended solids to minimize deposition of solids in the receiver or turbine. Generally, the maximum allowable operating temperature in the polishing demineralizer is 60°C (140°F), being limited by the demineralizer resin. Thus polishing demineralizers are always located near the condenser in the low-temperature, low-pressure condensate system. Since the condensate leaving the thermal storage heater is approximately 9.65 MPa (1,400 psia) and 249°C (480°F), a demineralizer cannot be used in this line. An alternative to the conventional resin-type demineralizer is the electromagnetic separator. An electromagnetic separator could be employed for the removal of corrosion products (chiefly iron oxides) from the water. An electromagnetic separator has been developed by Kraftwerk Union AG, Erlangen, Germany, and is in use at several power stations, both nuclear and fossil, in Europe. In principle, electromagnetic separators can be used up to about 350°C (660°F); however, the corresponding operating pressure does have a significant cost impact on the equipment.

Operation during the thermal charging only mode or intermittent-cloud mode results in the thermal storage heater drains bypassing the deaerator. However, if the feedwater is effectively deaerated during startup and an oxygen scavenger such as hydrazine is used, lack of deaeration should not be a real problem.

The thermal storage heater drain pump would probably be of the double-case barrel-type design similar to the receiver feed pump. However, the drain pump must be designed to handle very-high-pressure 9.65 MPa (1,400 psia), high-temperature 249°C (480°F) water and raise the pressure to approximately 17.6 MPa (2,560 psia) to meet the receiver requirements. Special consideration must be given to the pump seal design and NPSH requirements because of the high inlet pressure and temperature.

2.1.2.4 Heat-Rejection System

The baseline heat-rejection system for both the Commercial and Pilot Plants is wet evaporative cooling incorporating a steam surface condenser, mechanical draft cooling tower, and closed circulating water system. Also, for both plants, the admission steam only operating mode governed the size of the heat-rejection system.

A condenser design pressure of 8.46 KPa (2.5 in. HgA) was used based on a wet bulb temperature of 23°C (73.4°F) on both plants.

2.1.2.5 Auxiliary Power

Commercial Plant auxiliary power requirements for various operating modes are shown in Table 2-2.

As indicated in Table 2-2, the principal parasitic losses during daytime (equinox noon) when operating from receiver steam are the receiver feed pumps, thermal storage heater drain pump, cooling tower fans, circulating water pumps, heliostat drives, and thermal storage charging pumps. During the extended operating mode from thermal storage steam, the principal auxiliary power loads are the thermal storage feed pump, cooling tower fans, circulating water pumps, and thermal storage extraction pumps.

Emergency shutdown power amounting to 1,500 kW will be provided by two diesel-engine electric AC generator sets. As indicated in Table 2-2, the greatest emergency power requirement is for the heliostats during emergency slew. The estimated time required from loss of AC power to establishment of all full emergency power is 10 sec.

2.1.3 Commercial Plant Performance

2.1.3.1 Heat Balances and Performance Data

Figure 2-3; 112,000 kW at 8.46 kPa (2.5 in. HgA)
Equinox Noon (Design Point, Turbine Rating)

Table 2-2 (Page 1 of 2)

COMMERCIAL PLANT AUXILIARY POWER REQUIREMENTS

Component	Receiver Operation Equinox (Design) 100 MW Net kW	Thermal Storage Operation 70 MW Net kW	Night Standby kW	Emergency Power AC kW	Emergency Power DC kW
Receiver Feed Pump	3,492	-	-	-	-
Thermal Storage Drain Pump	2,235	-	-	-	-
Thermal Storage Feed Pump	-	500	-	-	-
Hotwell Pump	130	121	-	-	-
Condenser Vacuum Pump	41	41	41	-	-
Condensate Trans Pump	-	-	24	-	-
Service Air Compressor	60	-	-	-	-
Instrument Air Compressor	45	45	45	-	-
Cooling Tower Fans	886	886	-	-	-
Circ Water Pumps	2,313	2,313	-	-	-
Turbine AC Oil Pump	-	-	20	20	-
Turbine DC Oil Pump	-	-	-	-	20
Lube Oil Filter Pump	1	1	1	-	-
Chemical Pumps	5	5	-	-	-
Motor-Operated Valves	-	-	-	5	-
Raw Water Pump	90	70	40	-	-
Clarified Water Pump	70	60	30	-	-
Water Treating System	25	25	10	-	-

Table 2-2 (Page 2 of 2)

COMMERCIAL PLANT AUXILIARY POWER REQUIREMENTS

Component	Receiver Operation Equinox (Design) 100 MW Net kW	Thermal Storage Operation 70 MW Net kW	Night Standby kW	Emergency Power AC kW	Emergency Power DC kW
Jockey Pump (Fire Water)	5	5	5	-	-
Auxiliary Boiler	-	-	25	-	-
Turbine Turning Gear	-	-	5	5	-
Computer	15	15	7	15	-
Miscellaneous DC	-	-	-	-	20
Controls and Computer HVAC	50	50	30	30	-
Plant HVAC	440	300	300	-	-
Thermal Storage Charging Pump	750	-	-	-	-
Thermal Storage Extraction Pump	-	930	-	-	-
Sewage Treatment Plant	2	2	2	-	-
Potable Water Pump	5	5	-	-	-
Receiver Tower Elevator	-	-	-	30	-
Heliostats and Controllers	350	-	-	1,308	-
Lighting and Miscellaneous AC	990	726	100	30	-
TOTAL	12,000	6,100	685	1,443	40

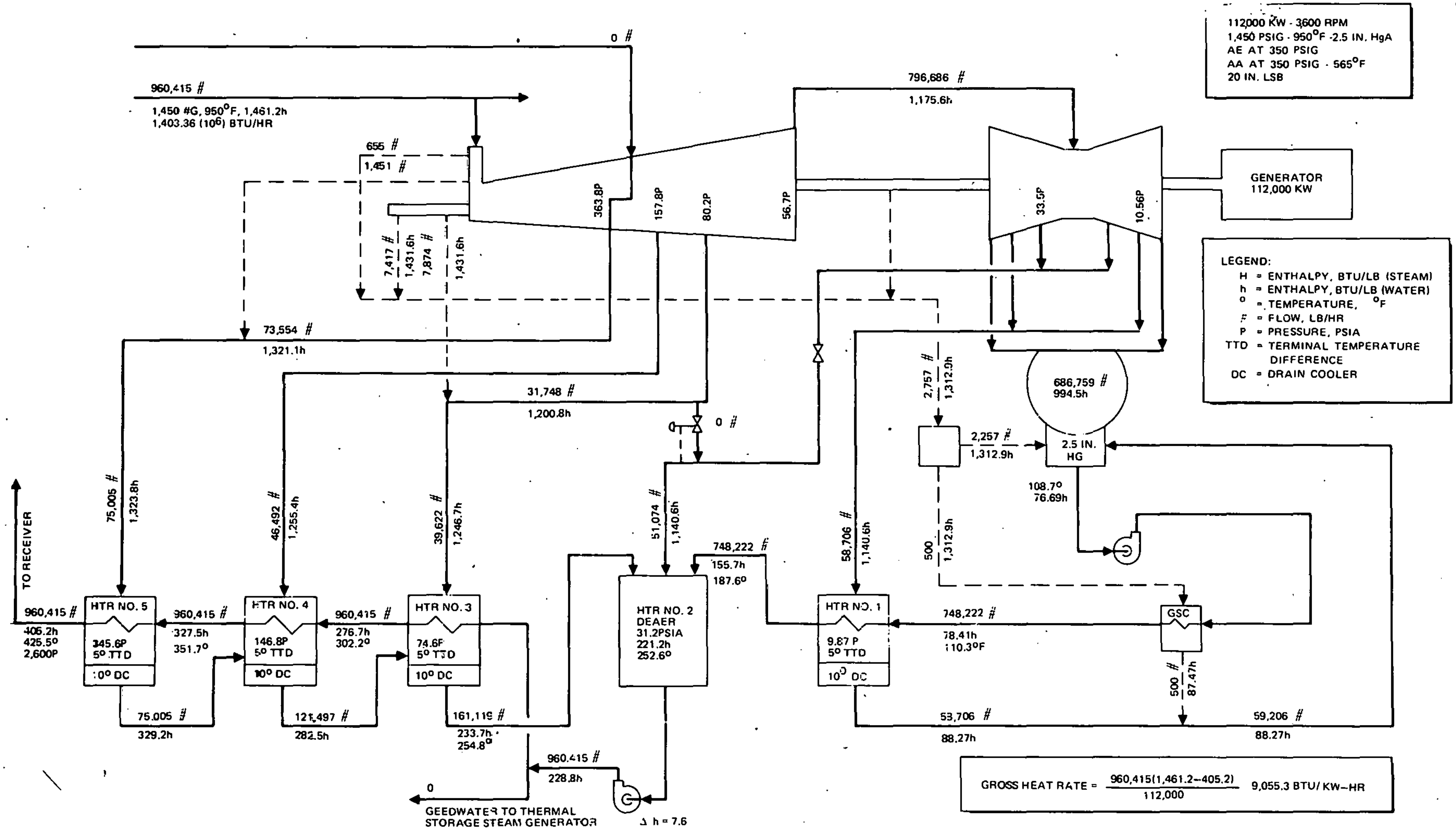


Figure 2-3. Commercial Plant Heat Balance (Design Point Operation at Turbine Rating)

Figure 2-4; 76,100 kW at 8.46 kPa (2.5 in. HgA)
Admission Steam Only

Figure 2-5; Curve, ΔkW
Vs Exhaust Pressure

Figure 2-6; Curve, Throttle
Flow and Admission Flow vs Generator Output

Figure 2-7; Mollier Chart
Turbine Expansion Lines 112,000 kW
Auto Admission, Extraction Turbine
1,450 psig - 950°FTT - 2.5 in. HgA
AA at 350 psig - 565°F

2.1.3.2 Summary of Performance

Table 2-3 shows the Commercial Plant performance summary for equinox noon (turbine rating), with the thermal storage subsystem out of service and for thermal storage only operating mode.

2.2 PILOT PLANT EPGS

2.2.1 Design Characteristics

2.2.1.1 Turbine-Generator

The gross power rating is 12,500 kW, at 8.46 kPa (2.5 in. HgA) backpressure, based on a single automatic admission, tandem-compound, single flow, extraction, condensing turbine. The generator is rated at 16,000 kVA, 0.85 power factor, 13,800V, 60 Hertz, and is air-cooled with static excitation system. The maximum calculated capability on throttle steam (valves wide open) is 13,625 kW gross.

2.2.1.2 Inlet Steam Conditions

Pressure	10.1 MPa (1,465 psia)
Temperature	274.4°C (950°F)
Enthalpy	3,399 kJ/kg (1,461.2 Btu/lb)

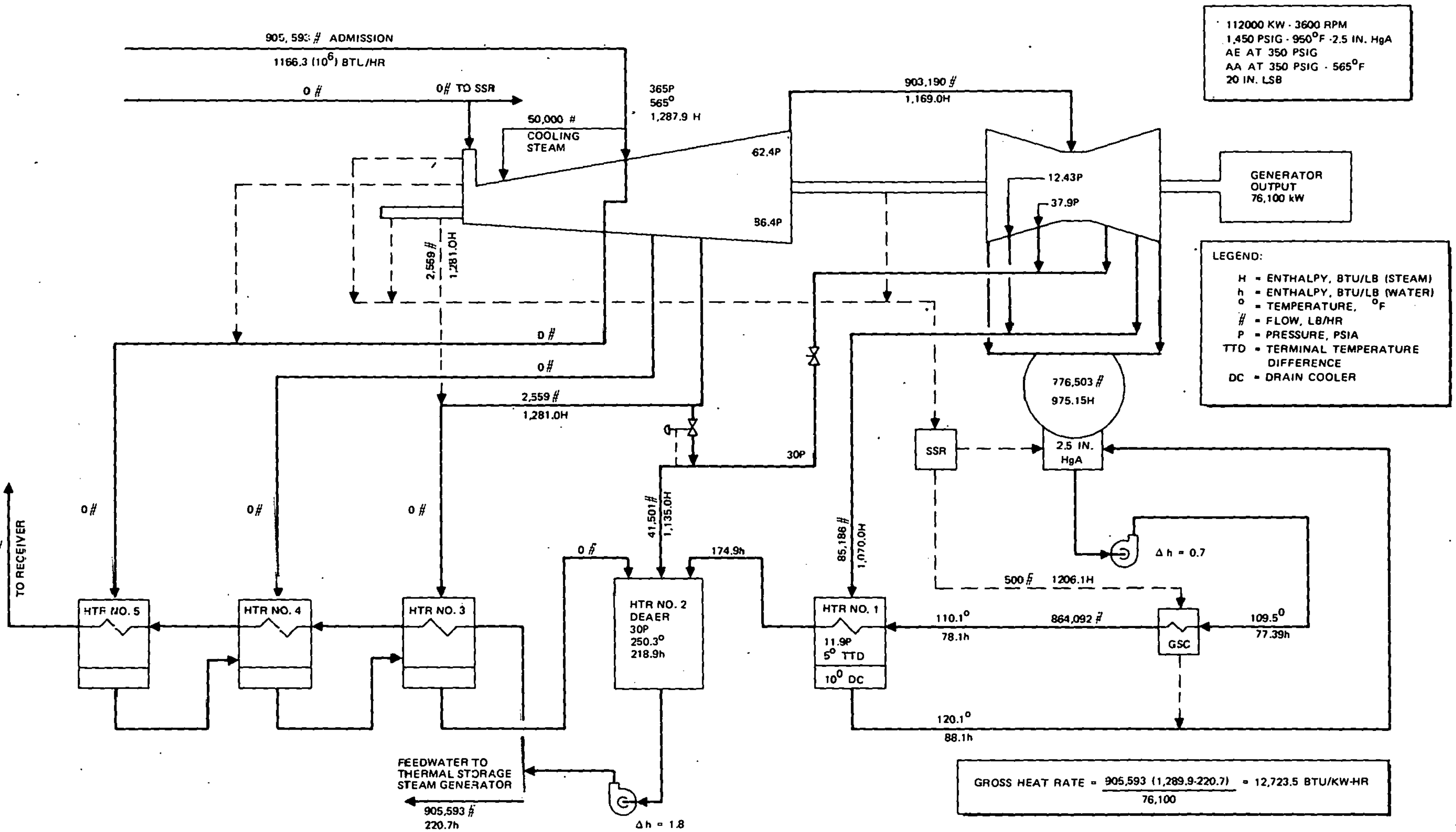


Figure 2-4. Commercial Plant Heat Balance (Admission Steam Only)

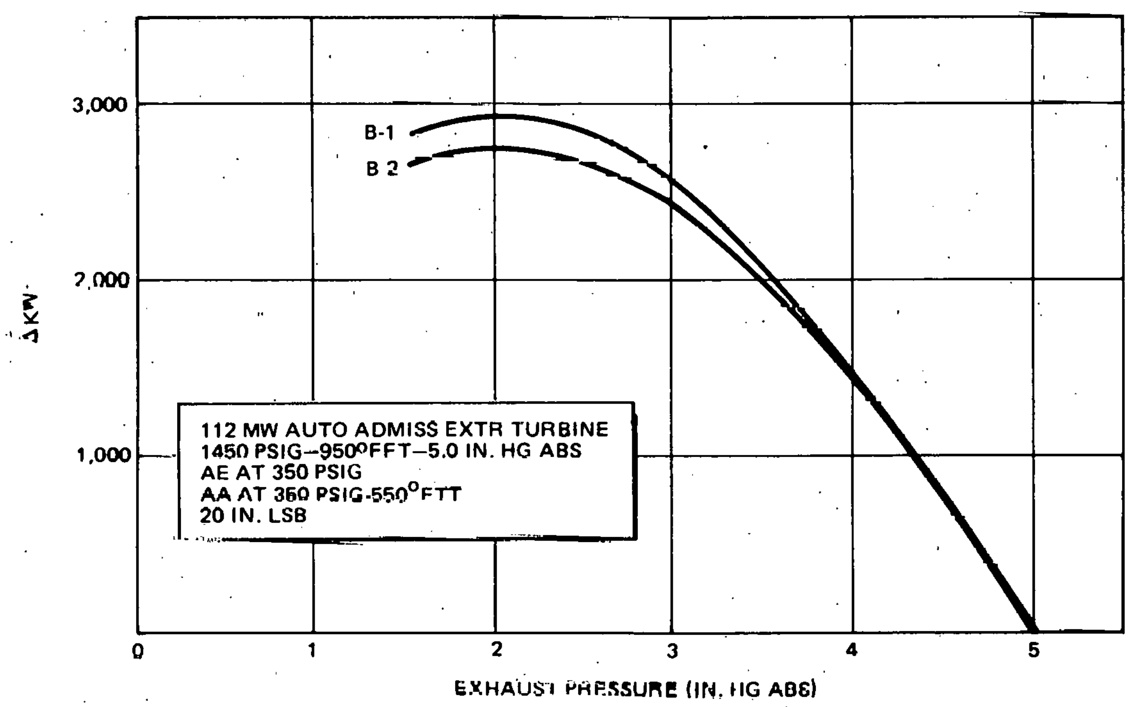


Figure 2-5. Commercial Turbine Back Pressure Correction Curve

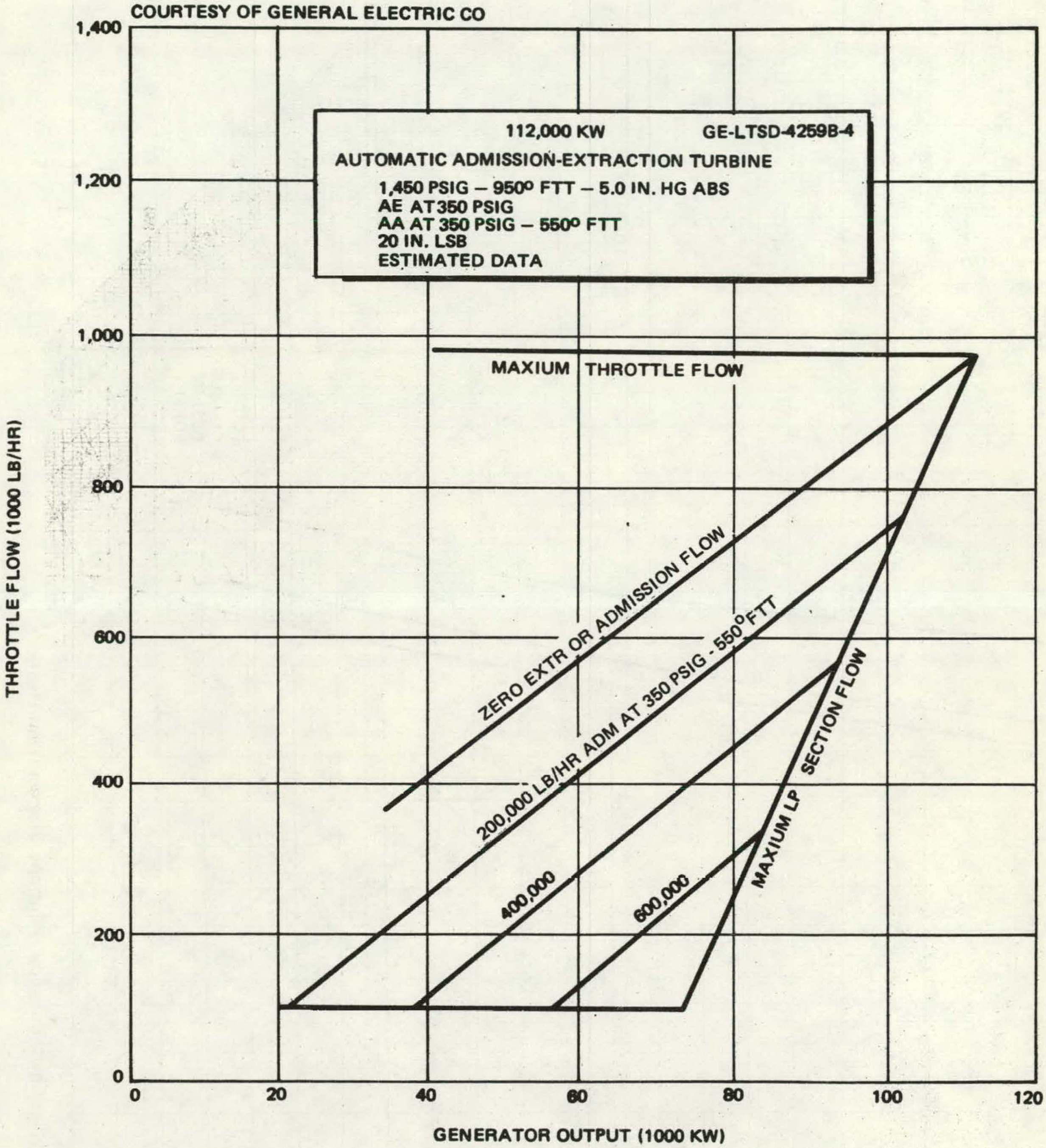


Figure 2-6. Commercial Turbine Performance Map

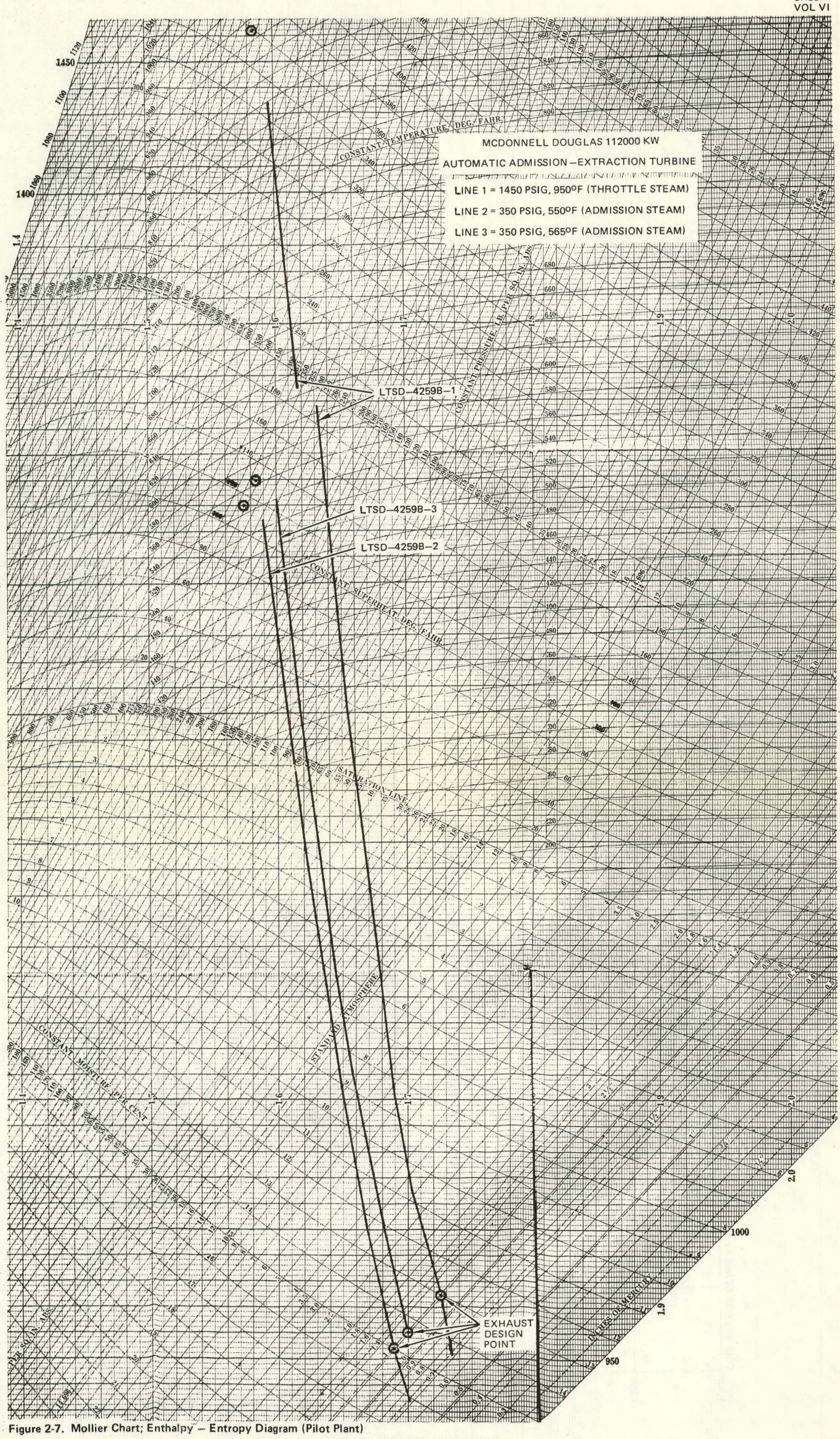


Figure 2-7. Mollier Chart; Enthalpy – Entropy Diagram (Pilot Plant)

Table 2-3

SUMMARY OF PERFORMANCE, 100-MWe COMMERCIAL PLANT

		Receiver Operation*	
		Design Point Equinox Noon (Turbine Rating)	Thermal Storage Operation
1.	Generator Output, kWe	112,000	76,100
2.	Total Auxiliary Power, kWe	12,000	6,100
3.	Net Generation, kWe	100,000	70,000
4.	Pump Work, kWe	3,622	621
5.	Heat Onto Receiver, kWt (Allocated to Turbine)	331,800	-
6.	Heat Input to Cycle, kWt	297,232	283,770
7.	Gross Turbine Cycle Efficiency (Item 1) ÷ (Item 6)	0.3768	0.2681
8.	Net Turbine Cycle Efficiency (Item 1 - Item 4) ÷ (Item 6)	0.3646	0.2659
9.	Net Plant Efficiency (Item 1 - Item 2) ÷ (Item 5)	0.3014	-
10.	Gross Cycle Heat Rate, kJ/kW-hr (Btu/kW-hr) (3,600 kJ/kW-hr) ÷ (Item 7)	9,554 (9,056)	13,428 (12,728)
11.	Net Cycle Heat Rate, kJ/kW-hr (Btu/kW-hr) (3,600 kJ/kW-hr)÷ (Item 8)	9,873 (9,358)	13,539 (12,833)
12.	Net Plant Heat Rate, kJ/kW-hr (Btu/kW-hr) (3,600 kJ/kW-hr)÷ (Item 9)	11,945 (11,321)	- -
13.	Turbine Exhaust Pressure, kPa (In. HgA)	8.46 (2.50)	8.46 (2.50)
14.	Feedwater Temperature, °C (°F)	218.6 (425.5)	121 (250)
15.	Steam Flow to Turbine, kg/s (lb/hr)	121.3 (960×10^3)	114.3 (905.6×10^3)

*Note: No steam sent to thermal storage subsystem.

2.2.1.3 Admission Steam Conditions

Pressure	2.65 MPa (385 psia)
Temperature	274.4°C (525°F)
Enthalpy	2,939 kJ/kg (1,263.4 Btu/lb)

2.2.1.4 Feedwater Heater Extractions

Four feedwater heater extractions (one low-pressure heater, one deaerating heater, and two high-pressure heaters) as indicated in Figure 1-2.

2.2.1.5 Condenser Type and Configuration

Type	Surface Condenser, 2 Pass
Surface Area	1,115 m^2 (12,000 ft^2)
Tube Material	90-10 Copper Nickel
Tube Diameter (OD)	19.05 mm (0.75 in.)
Tube Wall Thickness	0.89 mm (0.035 in.) 20 BWG
Tube Length (Effect)	6.1 m (20 ft)
Condenser Pressure	8.46 kPa (2.5 in. HgA)
Heat Rejection	94.95 GJ/hr (90 x 10^6 Btu/hr)
Cooling Water Flow	0.725 m^3/s (11,500 gpm)
Water Velocity	2.13 m/s (7.0 fps)
Cooling Water In	29.4°C (85.0°F)
Cooling Water Out	38.2°C (100.7°F)
TTD	4.4°C (8.0°F)
Temperature Rise	8.7°C (15.7°F)

2.2.1.6 Feedwater Pumping Stages

Two stages of feedwater pumping are provided on the Pilot Plant EPGS as indicated in Figure 1-2.

2.2.1.7 Turbine Seal Steam Requirements

Seal Steam Flow	445 kg/hr (1,000 lb/hr)
Pressure	124 kPa (18 psia)
Temperature	121°C (250°F) Minimum for Cold Start

2.2.1.8 Auxiliary Steam Supply

Auxiliary steam requirements for the Pilot Plant EPGS include:

- Turbine seal steam.
- High-pressure feedwater heater blanketing.
- Deaerator feedwater heater blanketing.
- Dearator pressure "pegging".
- Startup requirements (deaeration and feedwater heating).
- Receiver freeze protection.

Auxiliary Steam Sources

Two independent steam sources will provide auxiliary steam for the EPGS: (1) thermal storage subsystem, and (2) auxiliary oil-fired low-pressure steam boiler. Except for the building heating requirements, the auxiliary boiler will act as a backup to the thermal storage steam generator, should this steam source not be available.

Auxiliary Steam Requirements

Auxiliary steam requirements for the Pilot Plant EPGS are as follows:

	Nighttime Standby		Maximum Demand	
	kg/hr	(lb/hr)	kg/hr	(lb/hr)
Turbine Seal Steam	455	(1,000)	455	(1,000)
High-Pressure Heater Shell Blanketing (2 Heaters)	2	(5)	2	(5)
Deaerator Heater Blanketing	5	(12)	5	(12)
Dearator Pressure (20 psia) "Pegging" (Low Load)	N/A	N/A	544	(1,200)
Startup Requirements (Deaeration and Feedwater Heating)	N/A	N/A	2,041	(4,500)
Receiver Freeze Protection (If Required)	1,910	(4,210)	1,910	(4,210)
Total	2,372	(5,227)	2,498	(5,505)*

*Note: Maximum demand total includes turbine seal steam, HP heater blanketing, and startup requirements only. A more detailed discussion of Pilot Plant auxiliary steam requirements can be found in Section 4.2.4.

2.2.1.9 Startup and Shutdown Characteristics

Typical startup characteristics for the Pilot Plant turbine are shown in Table 2-4.

2.2.2 Design Discussion

2.2.2.1 Turbine-Generator

The turbine selection for the Pilot Plant is a single automatic-admission, condensing unit and is of the same type as described for the Commerical Plant turbine (Section 2.1.2.1). A typical cross section of the type is shown in Figure 2-8.

The turbine-generator is sized to produce 11,200 kW electrical gross generation (10,000 kW net) when operating entirely from receiver steam at Winter solstice, 2 PM, which is the design point for the system. The turbine is also capable of producing 12,500 kW gross (11,100 kW net) during Equinox noon, which corresponds to the maximum power collection time.

When operating entirely from storage steam, the turbine-generator will produce 7,800 kW gross (7,000 kW net) for 3 hr. The turbine backpressure for both the receiver steam and storage steam operating conditions is 8.46 kPa (2.5 in. HgA).

2.2.2.2 Turbine Inlet/Admission Steam Conditions

Inlet (Receiver) Steam Conditions

The turbine inlet steam conditions for both turbines are 10.1 MPa (1,465 psia) and 510°C) (950°F). The selection was made for the following reasons:

- Compatibility with thermal storage charging requirements.
- Compatibility with admission steam conditions.
- Moisture limitations at the exhaust end of the turbine.

As discussed in Volume V, the requirements for the outlet steam conditions leaving the steam generator are determined by the temperature of the thermal storage fluid entering, namely 302°C (575°F). The temperature and pressure

Table 2-4

PILOT PLANT TURBINE STARTING AND LOADING PROCEDURE*

Type of Start		Cold Start	Warm Start	Hot Start
Average Metal Temp		0° to 300°F	301° to 1,000°F	701° to 1,000°F
1.	Turning Gear	2 Hr Minimum Operation	3 Hr Minimum Operation	Minimum Time
2.	Establish Seals	Raise Vacuum to Maximum Obtainable Without Seals	2 psig	2 psig
3.	Raise Vacuum	Establish Seals 2 psig	--	--
4.	Roll Unit	At 25 in. Hg Vac	At 25 in. Hg Vac	At 25 in. Hg Vac
5.	Accelerate to 1,000 rpm	(250 rpm/Min) 4 Min	(500 rpm/Min) 2 Min	(500 rpm/Min) 2 Min
6.	Hold at 1,000 rpm	10 Min	10 Min	5 Min
7.	Accelerate to 3,550 rpm	(250 rpm/Min) 10 min	(500 rpm/Min) 5 Min	(500 rpm/Min) 5 Min
8.	Synchronize and Load Generator	(1/2%/Min) 200 Min	(1 1/2%/Min) 66 Min	(3%/Min) 33 Min
	Time After Start of Roll to Full Load	224 Min (3 Hr - 44 Min.)	83 Min (1 Hr. - 13 Min)	45 Min

*Per General Electric Co. Starting and Loading Instruction GEK-14402C

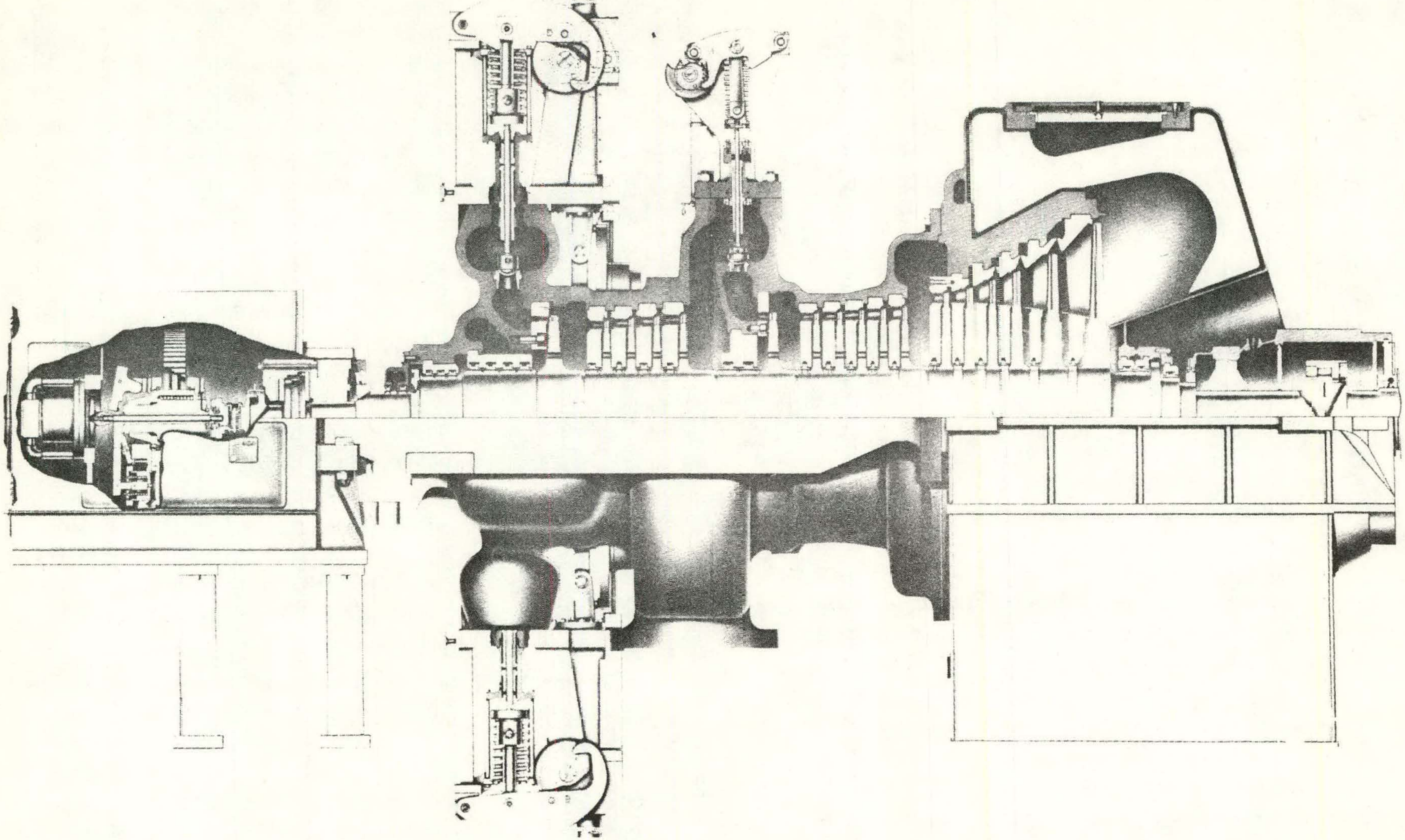


Figure 2-8. 10-MWe Industrial Turbine

of the steam at the steam generator outlet are 277°C (530°F) and 2.76 MPa (400 psia), thus providing approximately 47.8°C (86°F) superheat in the steam being supplied to the turbine. It is desirable from a turbine standpoint to keep the pressure at the admission port as low as practical within the thermal storage subsystem operating constraints in order to maximize the degree of superheat and minimize the moisture content of the steam entering the last stage of the turbine.

2.2.2.3 Cycle Analysis

Feedwater Heating Stages

The turbine cycle selected for the Pilot Plant EPGS is a four-heater regenerative cycle, consisting of one closed low-pressure heater, one open deaerator, and closed two-high pressure heaters. The heaters are arranged to provide 121°C (250°F) feedwater, leaving the deaerator for thermal storage steam generator makeup, and 204°C (400°F), leaving the receiver feed pump (final feedwater temperature) to meet receiver requirements.

The four-heater cycle was selected over the three-heater cycle, which was previously baselined in the Preliminary Design Baseline Report for the Pilot Plant, on the basis of an economic trade study, as follows:

	3 Heaters	4 Heaters
Gross Generation, kW	11,200	11,200
Gross Turbine Heat Rate J/kW hr (Btu/kw hr)	9,952	9,902
Energy-Collection System Costs $\$(10^6)$	32.6	32.43
Energy-Collection System Cost Over Base	$170,000	Base

(Concluded on next page)

	3 Heaters	4 Heaters
Estimatod Coot of Adding Additional Feedwater Heater		
1. Basic Heater		$25,000
2. Auxiliary Piping and Valves		27,750
3. Turbine Design Impact		73,500
4. Installation		15,750
5. Indirect and Miscellaneous Costs		22,250
6. Total	$170,000	$164,250
Cost Saving with 4 Heaters		$ 5,750

Feedwater Pumping Stages

Two stages of feedwater pumping were selected for the Pilot Plant. A booster pump takes suction from the elevated deaerator storage tank and pump through the high-pressure heaters to the receiver feed pump suction, or to the thermal storage steam generator feedwater inlet, bypassing the high-pressure heaters, separately or simultaneously as required by the mode of operation. When pumping to the receiver, the receiver feed pump raises the feedwater pressure to that required by the receiver. When operating from thermal storage only, assuming the receiver is out of service, it is only necessary to operate the relatively low-pressure (500 psia) booster pump. The booster pump will also be used to fill the receiver in addition to maintaining circulation through the riser and receiver when required at night to prevent freezing, or to facilitate cleaning up of the preboiler system prior to startup.

The two receiver feed pumps are each 100% capacity and are of the horizontal centrifugal double-case, barrel-type design with electric motor drive through a variable-speed hydraulic coupling. The variable-speed control regulates the receiver feedwater inlet pressure to 15.5 MPa (2,250 psia). Feedwater flow is used as a feed forward signal to the receiver feed pump speed control system to ensure rapid response to changes in receiver flow requirements.

The two booster pumps are each 100% capacity and are of the horizontal centrifugal, split-case design with direct electric motor drive. Feedwater flow to the thermal storage steam generator is regulated by a throttling valve, which is controlled by a three-element feedwater control system.

2.2.2.4 Heat-Rejection System

As described for the Commercial Plant, the heat-rejection system on the Pilot Plant uses a shell and tube, two-pass surface condenser for condensing turbine exhaust steam. The condenser heat load is rejected to the atmosphere by circulating condenser cooling water through a two-cell mechanical draft cooling tower.

Copper nickel condenser tubes were selected for the Pilot Plant and Commercial Plant condensers in lieu of stainless steel because of pitting failure problems that have occurred with stainless steel tubes in high-solids circulating water systems. Since a full-capacity in-line polishing demineralizer is located downstream of the condenser condensate pumps, copper carryover through the demineralizer should be minimal.

A condenser design pressure of 8.46 kPa (2.5 in. HgA) was used based on a 29.4°C (85°F) inlet water temperature and a 4.4°C (8.0°F) terminal temperature difference.

The cooling tower sizing is based on a 6.4°C (11.6°F) approach to a 23.0°C (73.4°C) wet bulb temperature, resulting in a cold water temperature of 29.4°C (85.0°F), and a temperature range of 8.4°C (15.2°F). The cooling tower duty of 95 x 10^6 Btu/hr includes an allowance of 5 x 10^6 Btu/hr for auxiliary plant equipment cooling loads.

2.2.2.5 Auxiliary Power

The Pilot Plant auxiliary power requirements for various operating modes are shown in Table 2-5. As indicated, the principal parasitic losses during daytime when operating off receiver steam are the receiver feed pump, booster pump, cooling tower fans, circulating water pumps, and thermal storage charging pump. During the extended or evening operating mode from thermal storage steam, the principal auxiliary power loads are the booster pump, cooling tower fans, circulating water pumps, and thermal storage extraction pump.

Table 2-5 (Page 1 of 2)

PILOT PLANT AUXILIARY POWER REQUIREMENTS

Component	Receiver Operation Equinox 11.3 MW Net kW	Receiver Operation Winter (Design) 10.0 MW Net kW	Evening Thermal Storage 7.0 MW Net kW	Night Standby kW	Emergency Power AC kW	Emergency Power DC kW
Receiver Feed Pump	325	282	-	-	-	-
Booster Pump	90	77	77	-	-	-
Hotwell Pump	20	18	18	-	-	-
Condenser Vacuum Pump	22	22	22	22	-	-
Condensate Trans Pump	-	-	-	7	-	-
Service Air Compressor	50	50	-	-	-	-
Instrument Air Compressor	28	28	28	28	28	-
Cooling Tower Fans	150	150	150	-	-	-
Circ Water Pumps	203	203	203	-	-	-
Gland Seal Vacuum Pumps	2	2	2	2	-	-
Bearing Cool Water Pump	15	15	5	5	15	-
Turbine AC Oil Pump	-	-	-	13	13	-
Turbine DC Oil Pump	-	-	-	-	-	13
Lube Oil Filter Pump	1	1	1	1	-	-
Chemical Pumps	3	3	3	-	-	-
Motor-Operated Valves	-	-	-	-	3	-
Raw Water Pump	20	18	18	12	-	-
Clarified Water Pump	12	10	10	5	-	-
Water Treating System	16	14	14	8	-	-

Table 2-5 (Page 2 of 2)

PILOT PLANT AUXILIARY POWER REQUIREMENTS

	Receiver Operation				Emergency Power	
Component	Equinox 11.3 MW Net kW	Winter (Design) 10.0 MW Net kW	Evening Thermal Storage 7.0 MW Net kW	Night Standby kW	AC kW	DC kW
Jockey Pump (Fire Water)	5	5	5	5	-	-
Auxiliary Boiler	-	-	-	10	-	-
Turbine Turning Gear	-	-	-	3	3	-
Computer	10	10	10	5	10	-
Miscellaneous DC	-	-	-	-	-	10
Controls and Computer HVAC	41	41	33	33	33	-
Plant HVAC	150	138	22	-	-	-
Thermal Storage Charging Pump	-	-	-	-	-	-
Thermal Storage Extraction Pump	-	-	104	-	-	-
Sewage Treat Plant	1	1	1	1	-	-
Potable Water Pump	4	4	4	-	-	-
Receiver Tower Elevator	-	-	-	-	15	-
Heliostats and Controllers	30	30	-	-	200	-
Lighting and Miscellaneous AC	202	78	70	50	10	-
TOTAL	1,400	1,200	800	210	330	23

Emergency shutdown power will be provided by a 350-kW diesel engine electric AC generator set. As indicated in the table, the greatest emergency power requirement is for the heliostats during emergency slew. The estimated time required from loss of AC power to establishment of full emergency power is 10 sec.

2.2.3 Pilot Plant Performance

2.2.3.1 Heat Balances and Performance Data

Figure 2-9; 12,500 kW at 2.5 in. HgA
Turbine Rating

Figure 2-10; 11,200 kW at 2.5 in. HgA
Winter 2 PM (System Design Point)

Figure 2-11; 7,800 kW at 2.5 in. HgA
Admission Steam Only

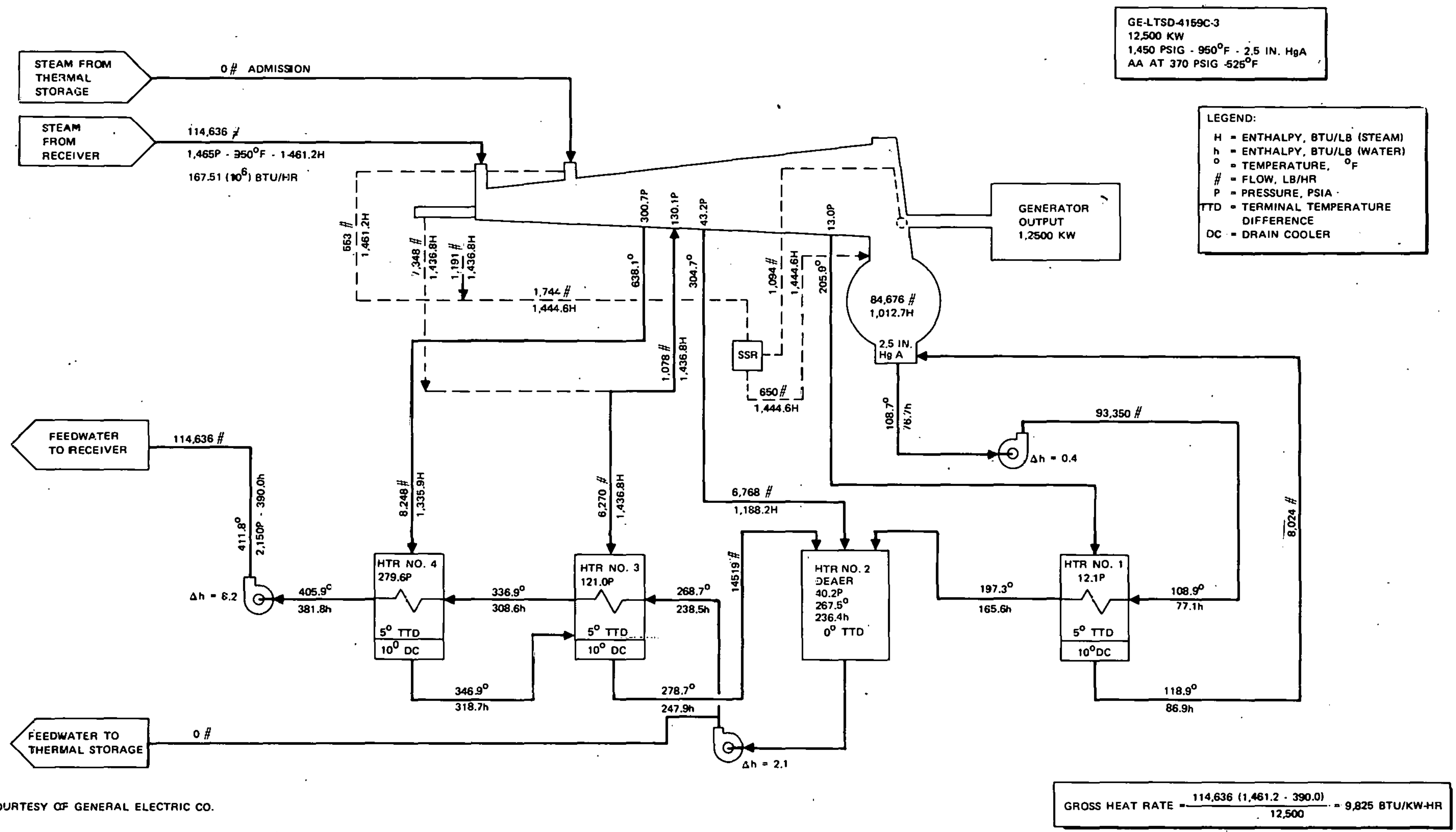
Figure 2-12; Curve-Throttle Flow and Admission Flow vs Generator Output

Figure 2-13; Curve-Throttle Flow vs Final Feedwater Temperature

Figure 2-14; Curve-Gross Turbine Heat Rate vs Steam Flow to Turbine

Figure 2-15; Curve-Exhaust Loss vs Annulus Velocity

Figure 2-16; Mollier Chart
Turbine Expansion Lines 12,500 kW SAXC 1,450 psig - 950°F - 2.5 in. HgA
A. A. at 370 psig - 525°F



COURTESY OF GENERAL ELECTRIC CO.

Figure 2-9. Pilot Plant Heat Balance - Receiver Steam Only - Equinox Noon, Maximum Guarantee Turbine Rating

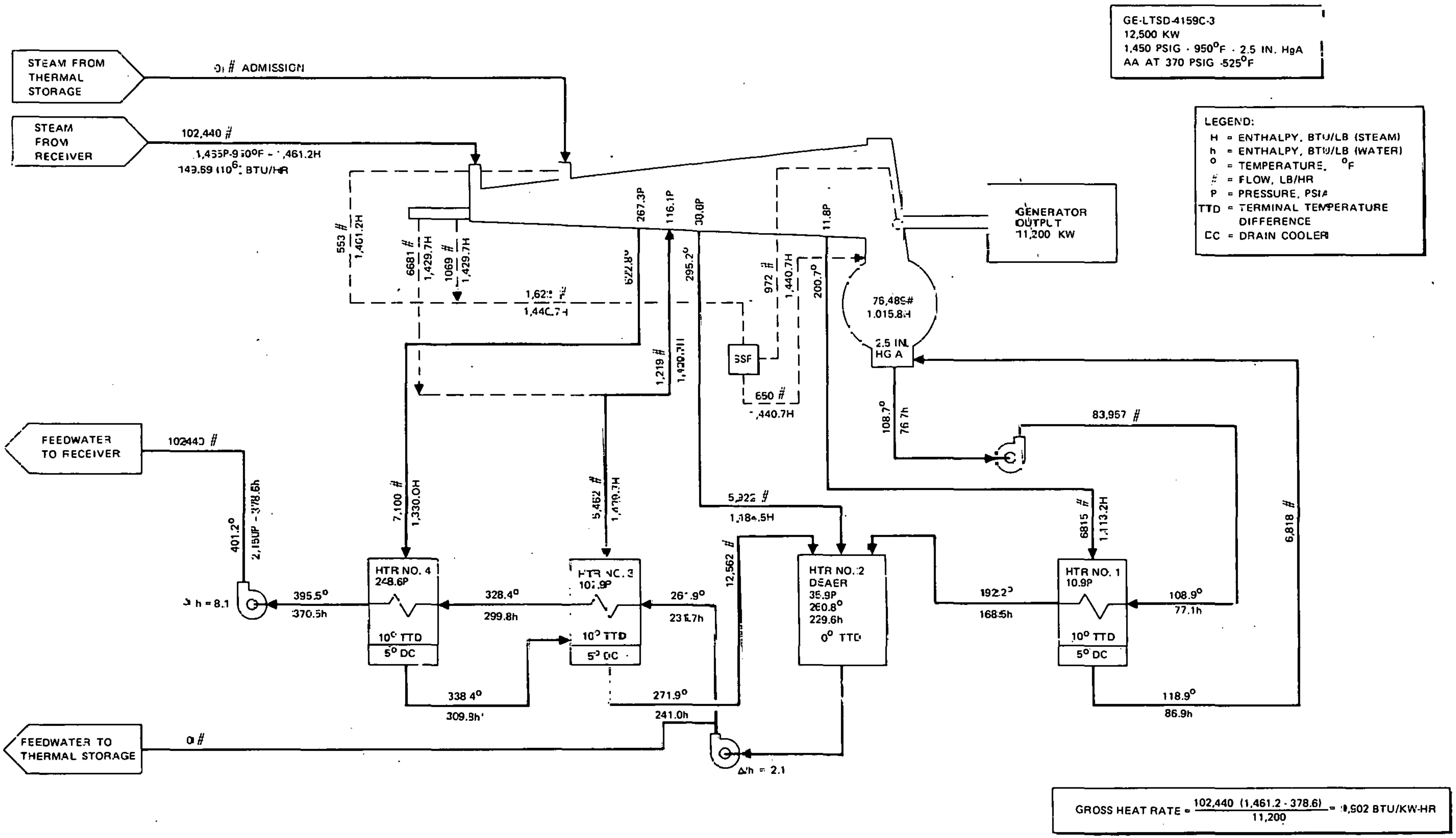


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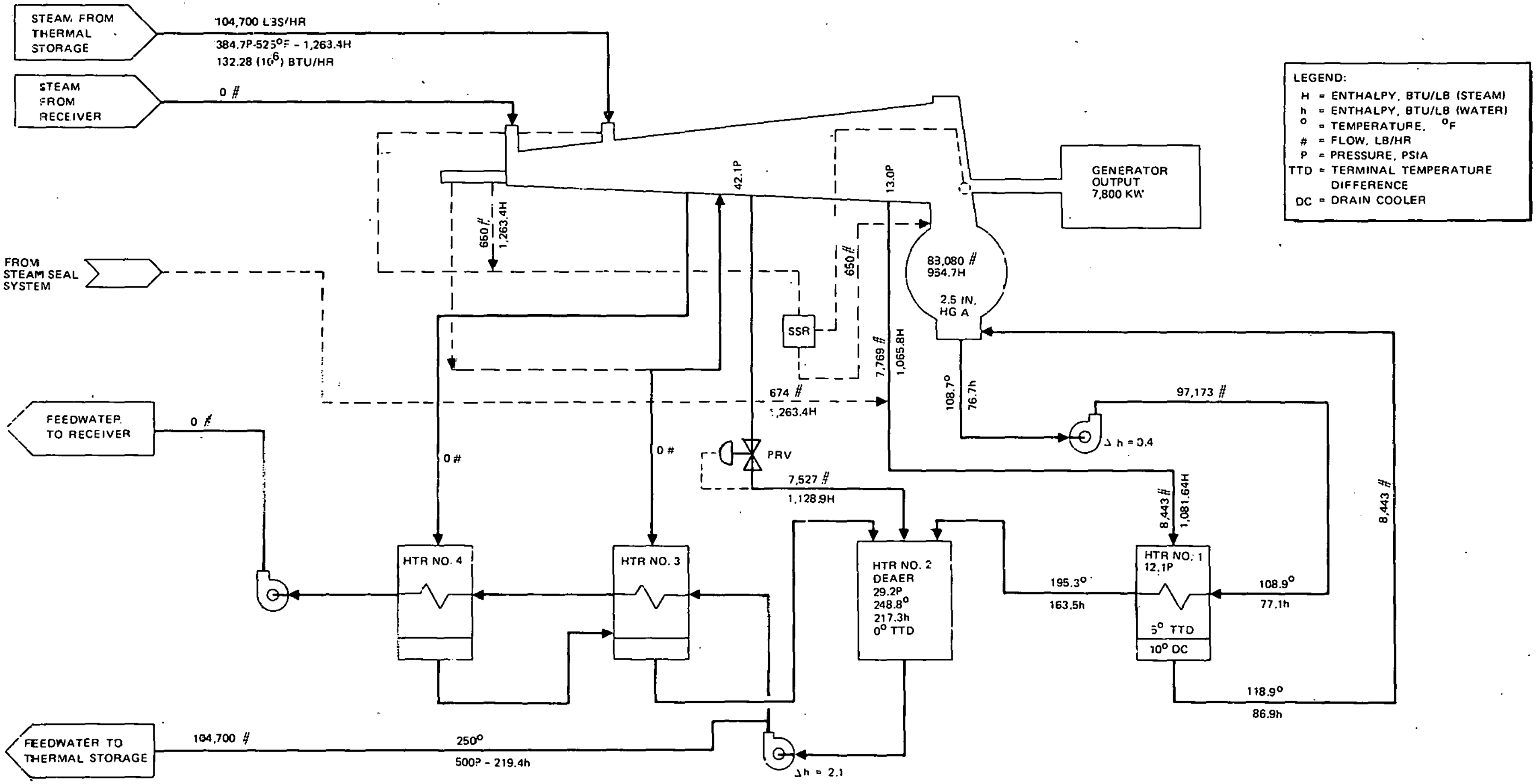
Figure 2-10. Pilot Plant Heat Balance - Receiver Steam Only - Winter Solstice, 2 PM System Design Point



$$\text{GROSS HEAT RATE} = \frac{104{,}700\ (1{,}263.4 - 219.4)}{7{,}800} = 14{,}014\ \text{BTU/KW-HR}$$

COURTESY OF GENERAL ELECTRIC COMPANY

Figure 2-11. Pilot Plant Heat Balance - Admission Steam Only (Thermal Storage Operation)

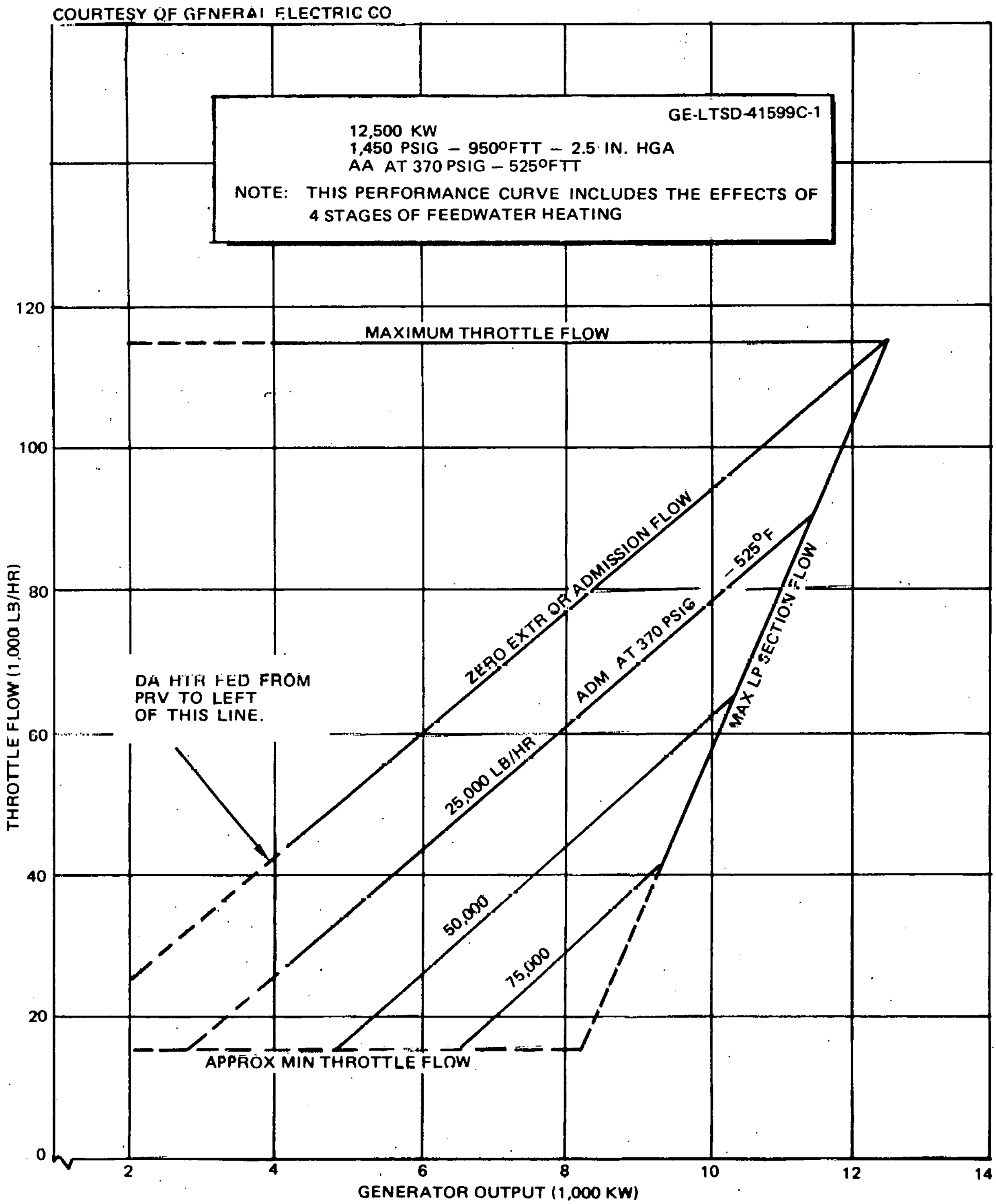


Figure 2-12. Pilot Plant Turbine Performance Map

COURTESY OF GENERAL ELECTRIC CO

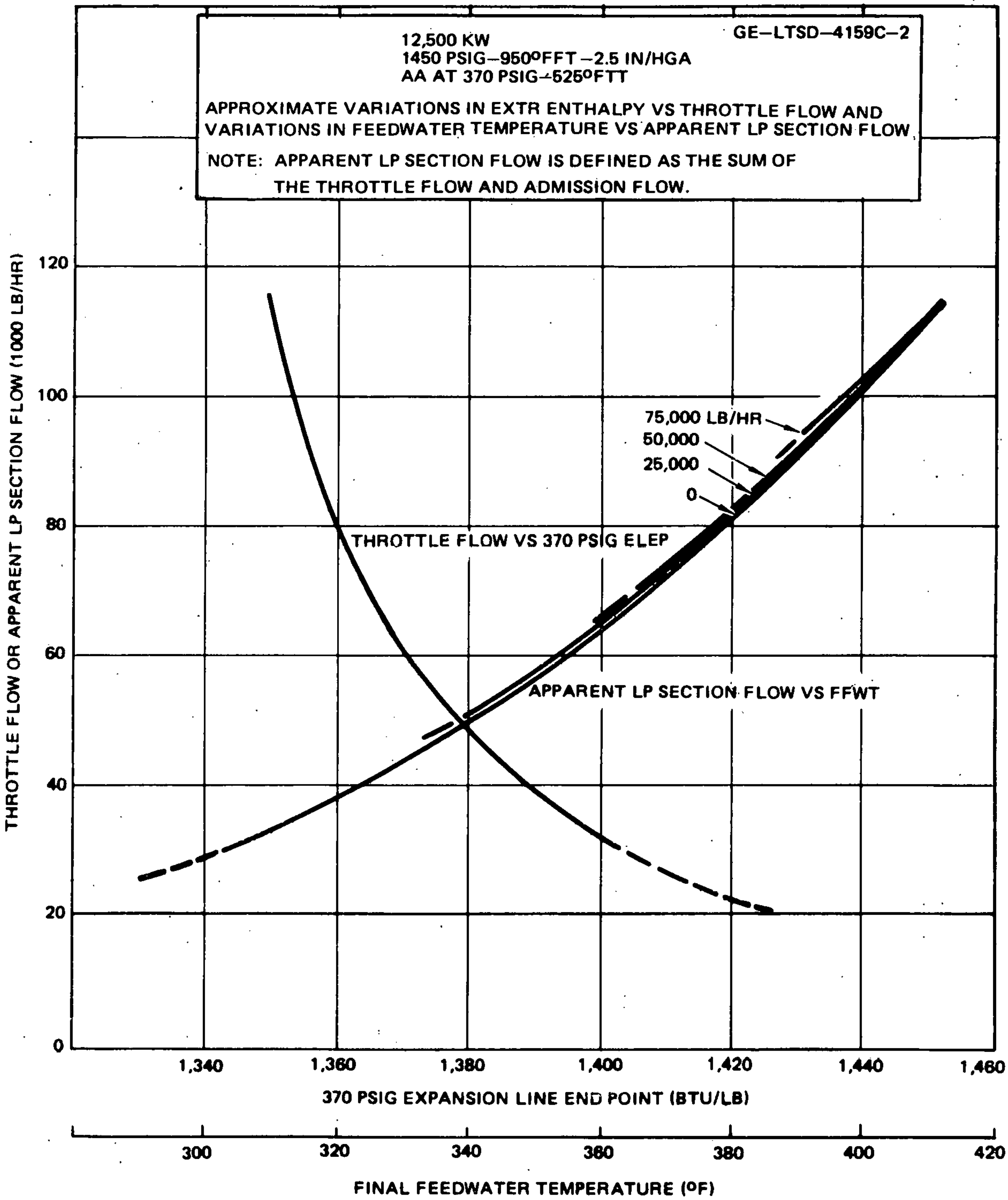


Figure 2-13. Pilot Plant Extraction Enthalpy and Feedwater Temperature Variations

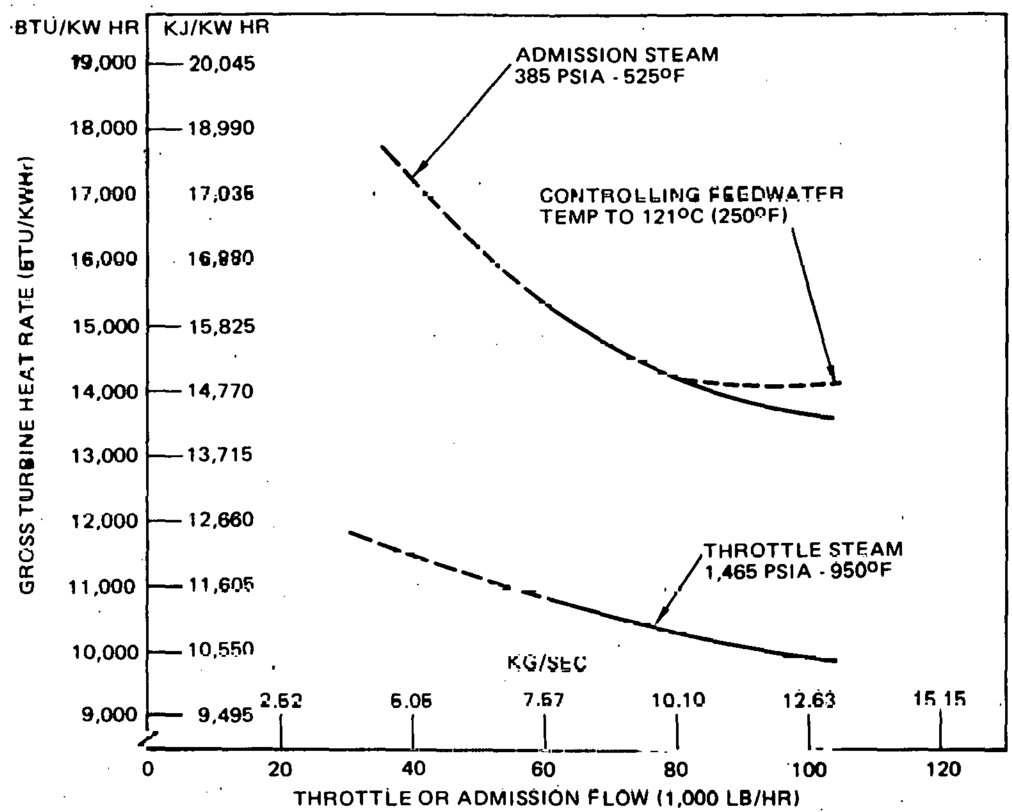


Figure 2-14. Pilot Plant Predicted Performance - 2.5 In. Hg Abs

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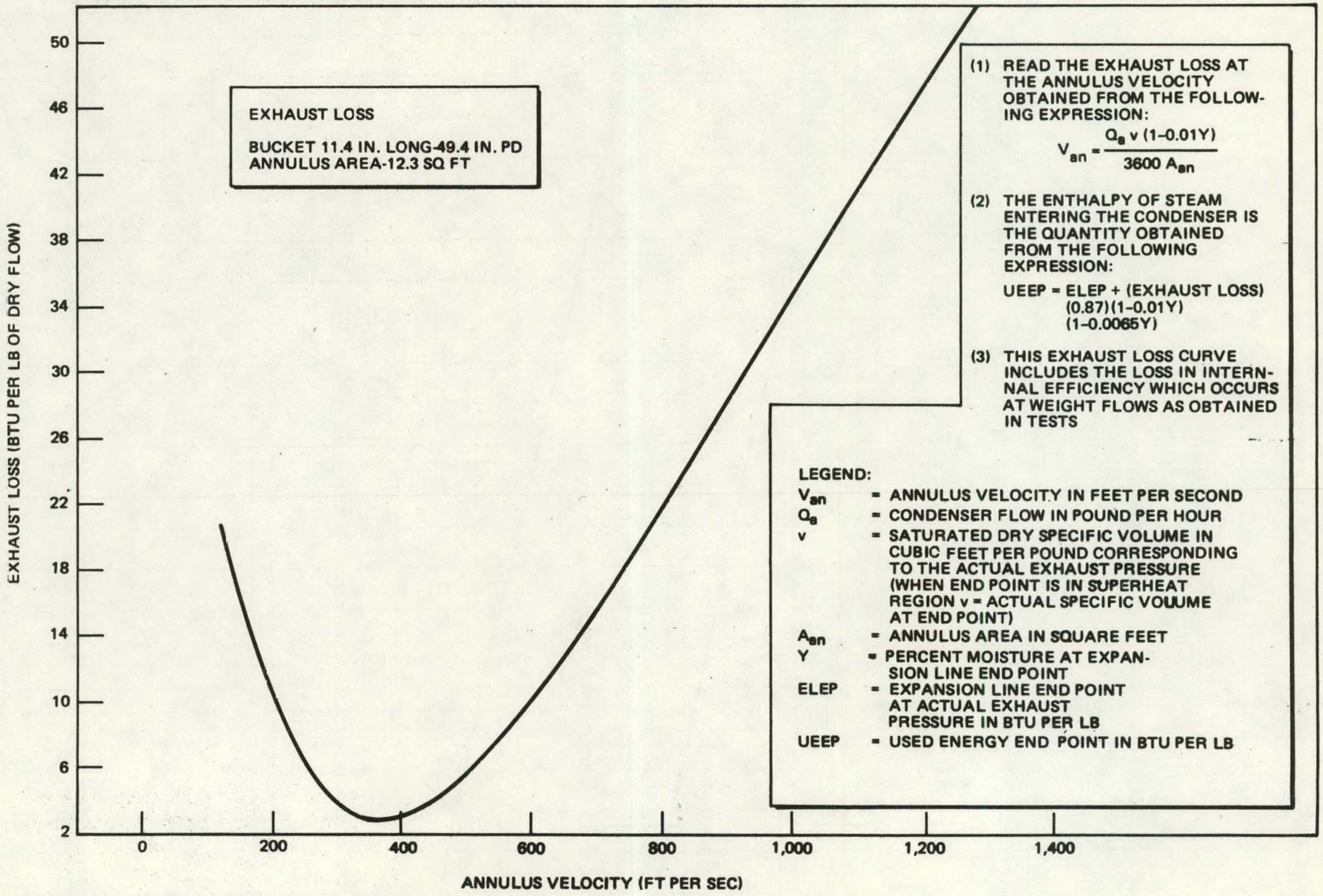


Figure 2-15. Pilot Plant Turbine Exhaust Losses

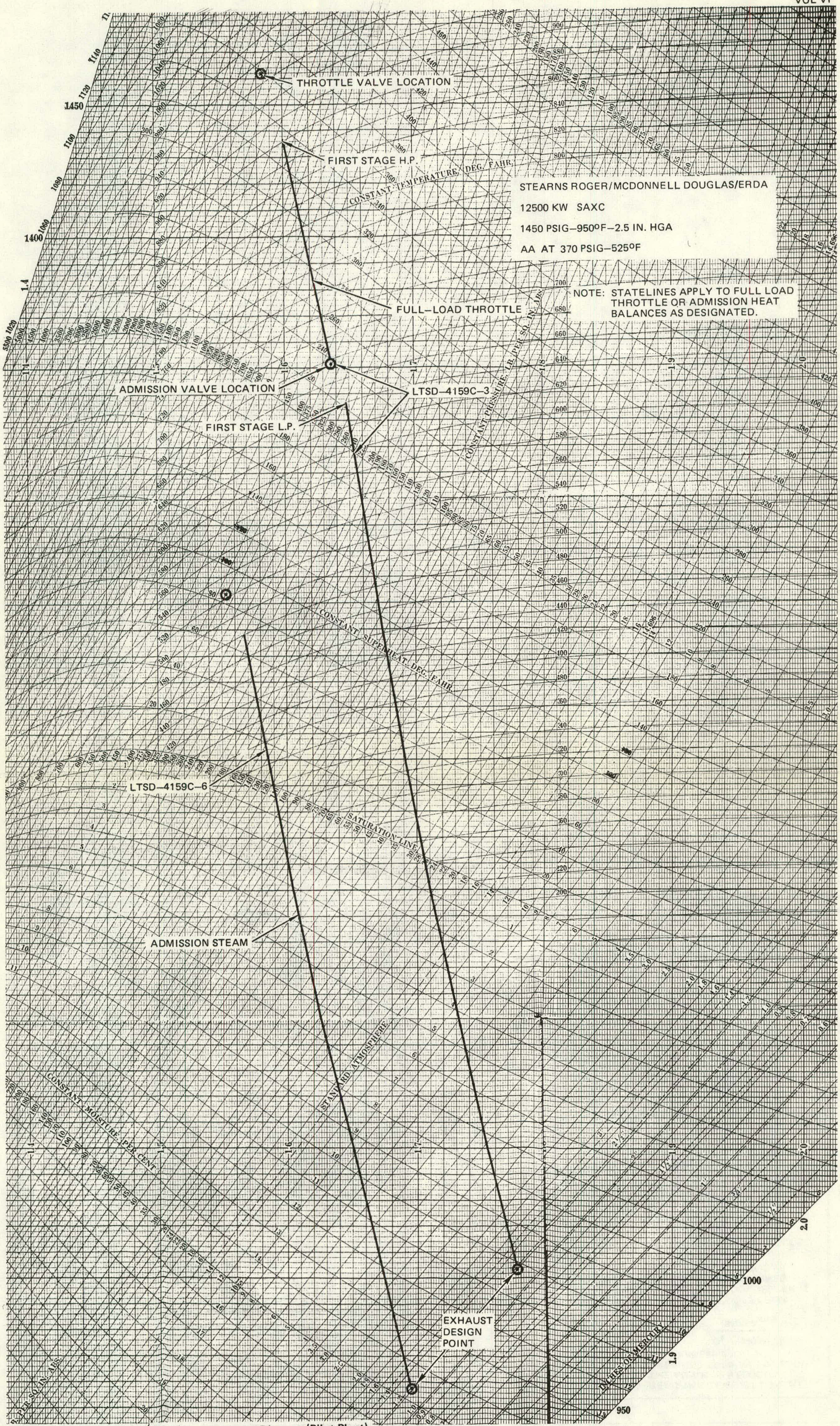


Figure 2-16. Mollier Chart; Enthalpy – Entropy Diagram (Pilot Plant)

2.2.3.2 Summary of Performance

Table 2-6 shows the Pilot Plant performance summary for the turbine rating, system design point (Winter solstice, 2 PM), and thermal storage operation only.

2.3 MASTER CONTROL

The rationale used in the choice of approach to master control is summarized here, in accordance with the Sandia-specified data list. More information and background on master control are in Section 6.

Master control is designed to operate in either automatic or manual mode. The design shares control and instrumentation wiring, from the central control room to the subsystem, by switching signal paths between the automatic central computer and the manual controls on the central control console. The control, instrumentation, and processing requirements for the Pilot Plant are tabulated in Table 2-7. A detailed description of these requirements is contained in Section 6.3.2.

The Pilot Plant operator has the control and display hardware and associated software necessary for automatic or manual coordination of all system and subsystem processes. When the operator selects the automatic mode, the master control central digital computer provides extensive capability, flexibility to accomodate charges, and plant operation efficiency as outlined in Table 2-8. Whether in the automatic or manual mode, the central computer can provide diagnostic software to aid in maintenance and troubleshooting functions. The solar power system operating concepts are described in detail in Section 6.6.

Table 2-6

SUMMARY OF PERFORMANCE FOR 10-MWe PILOT PLANT

		Receiver Operation*		
		Equinox Noon	Design Point Winter Solstice 2 PM	Thermal Storage Operation
1.	Generator Output, kWe	12,700	11,200	7,800
2.	Total Auxiliary Power, kWe	1,400	1,200	800
3.	Net Generation, kWe	11,300	10,000	7,000
4.	Pump Work, kWe	435	377	95
5.	Heat Onto Receiver, kWt	43,000	38,300	-
6.	Heat Input to Cycle, kWt	36,600	32,503	32,033
7.	Gross Turbine Cycle Efficiency (Item 1) ÷ (Item 6)	0.3473	0.3446	0.2435
8.	Net Turbine Cycle Efficiency (Item 1 - Item 4) ÷ (Item 6)	0.3352	0.3330	0.2405
9.	Net Plant Efficiency (Item 1 - Item 2) ÷ (Item 5)	0.263	0.2610	-
10.	Gross Cycle Heat Rate, kJ/kW-hr (Btu/kW-hr) (3,600 kJ/kW-hr) ÷ (Item 7)	10,366 (9,825)	10,447 (9,902)	14,784 (14,014)
11.	Net Cycle Heat Rate, kJ/kW-hr (Btu/kW-hr) (3,600 kJ/kW-hr) ÷ (Item 8)	10,739 (10,179)	10,811 (10,247)	14,969 (14,188)
12.	Net Plant Heat Rate, kJ/kW-hr (Btu/kW-hr) (3,600 kJ/kW-hr) ÷ (Item 9)	13,688 (12,975)	13,788 (13,068)	- -
13.	Turbine Exhaust Pressure, kPa (In. HgA)	8.46 (2.50)	8.46 (2.50)	8.46 (2.50)
14.	Feedwater Temperature, °C (°F)	211.0 (411.8)	205.1 (401.2)	121 (250)
15.	Steam Flow to Turbine, kg/s (lb/hr)	14.70 (116,500)	12.92 (102,440)	13.22 (104,700)

*Note: No steam sent to thermal storage subsystem.

Table 2-7

CONTROLLER PROCESSING REQUIREMENTS

	Input					Output		
	Control			Instrumentation		Control		
Subsystem	Digital	Discrete	Analog	Discrete	Analog	Digital	Discrete	Analog
Receiver		12	43	2	69		6	2
Thermal Storage		29	76	4	21		17	10
EPGS and BOP		25	28	2	49		18	14
Collector	74					74		
Subtotal	74	66	147	8	139	74	41	26
20% Contingency	-	13	29	2	28	-	8	5
Total	74	79	176	10	167	74	49	31

- **In addition, arithmetic calculations are required for collector field and likely for outer-loop closure, instrumentation, the subsystems, and data processing.**

Table 2-8
AUTOMATION CHOICES

- Digital interfacing and calculations are most efficiently done in digital computer
- Digital computer can efficiently perform
    - Logical decisions
    - Adaptive sequencing
    - Timing
    - Outer-loop control
    - Display interfacing
- Digital computer provides greatest flexibility
- Small (inner) loop control can be either digital or analog

Method	Advantages	Disadvantages
Central Computer	Possibly cost-effective in long-term after sufficient plant experience	Plant operation depends completely on 1 (or 2) computer
Individual Microprocessor	Possibly cost-effective in long-term after sufficient plant experience	Requires considerable development
Individual Analog	Completely developed conventional industrial control	Relatively expensive hardware for long term

Section 3

COMMERCIAL PLANT ELECTRICAL POWER GENERATION SUBSYSTEM AND BALANCE OF PLANT

3.1 REQUIREMENTS

3.1.1 Performance Requirements

3.1.1.1 Operating Requirements

The operating requirements for the Commercial EPGS are as follows:

		Requirement Source
Gross Turbine Output		
Daytime (Design-Equinox Noon)	112 MW_e	MDAC
Nighttime	76.1 MW_e	MDAC
Net Turbine Output		
Daytime	100 MW_e	DoE/Sandia
Nighttime	70 MW_e	DoE/Sandia
Turbine Inlet Conditions		
Daytime (Receiver Steam)		
Pressure	10.1 MPa (1,465 psia)	MDAC
Temperature	510°C (950°F)	MDAC
Throttle Flow	121.3 kg/sec (960,415 lb/hr)	MDAC
Nighttime		
Pressure	2.52 MPa (365 psia)	MDAC
Temperature	296°C (565°F)	MDAC
Admission Flow	114.3 kg/sec (905,593 lb/hr)	MDAC
Turbine Exhaust Pressure		
Daytime	8.46 kPa (2.5 in. HgA)	MDAC
Nighttime	8.46 kPa (2.5 In. HgA)	MDAC
Heat Rejection		
Method	Wet Cooling	DoE/Sandia
Wet Bulb Temperature	23°C (73.4°F)	DoE/Sandia
Generator Output		
Generator Rating	135,000 kVA	MDAC

		Requirement Source
Power Factor	0.90	MDAC
Voltage	13,800V	MDAC
Frequency	60 Hertz	MDAC
Main Transformer		
Rating	130,000 kVA	MDAC
Voltage	13.2/115 kV	MDAC
Feedwater Conditioning		
Dissolved Solids	20 to 50 ppb	MDAC
pH	9.5	MDAC

3.1.1.2 Functional Interface Requirements

The functional flows between the major elements of the EPGS and between the EPGS and other interfacing subsystems are indicated in Figure 3-1.

The EPGS is coordinated through the master control to provide normal startup, power operations, mode changes, and shutdown of the solar thermal power systems.

3.1.1.3 Availability Requirement

The Commercial Plant availability has been defined by DoE/Sandia at 0.90, exclusive of solar insolation conditions.

To meet the 90% availability requirement for the plant, the availability allocation for the EPGS is as follows:

Forced Outage	1.03%
Maintenance Outage	1.42
Planned Outage	4.50*
Total Unavailable	6.95%

The average percentage of the time the EPGS is unavailable 6.95%. The EPGS availability requirement is therefore 93.05%.

*This down time assumes some preventive maintenance performed simultaneously.

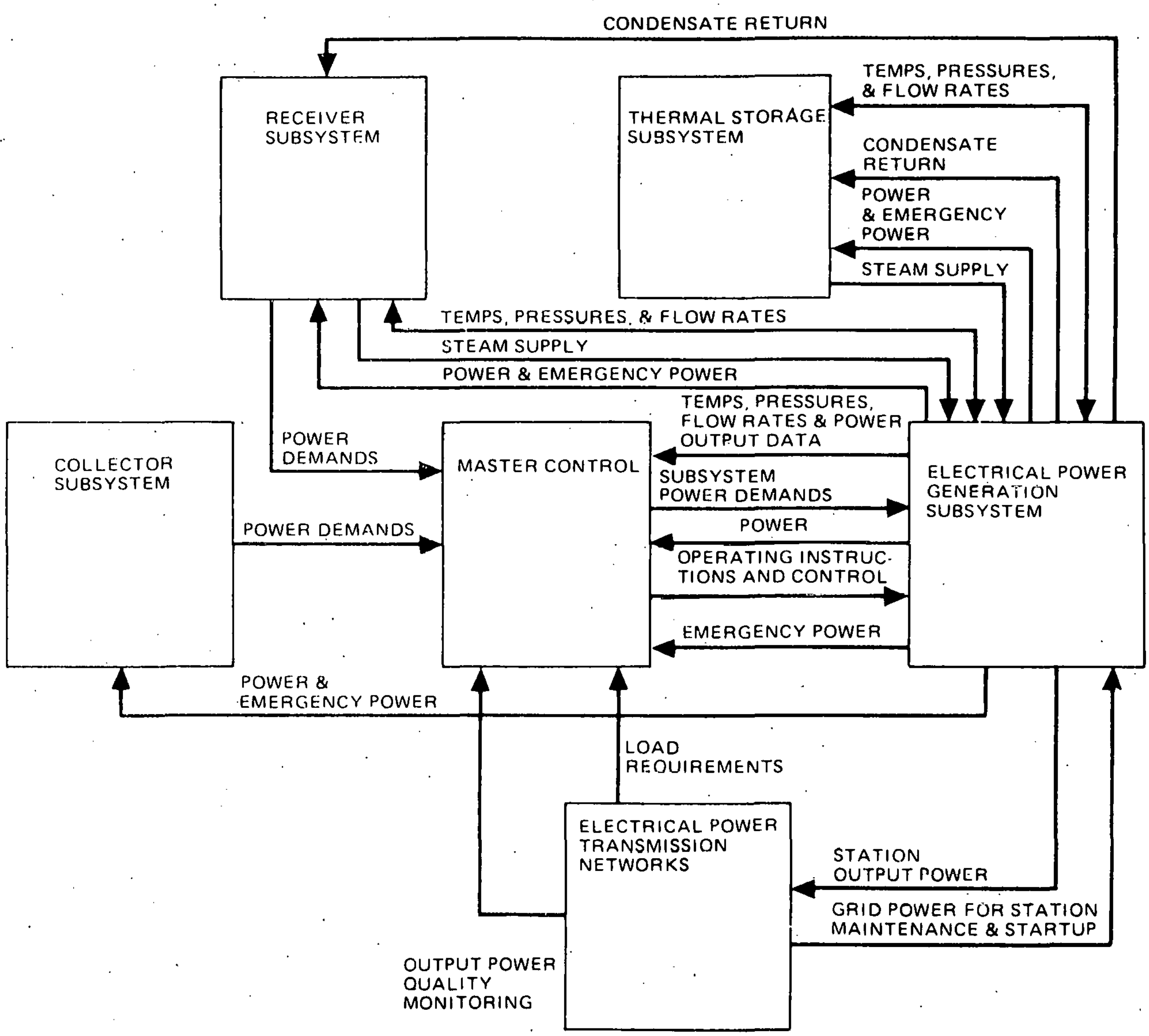


Figure 3-1. Functional Interfaces Between the Electrical Power Generation Subsystem and Other Operating Elements

3.1.2 Design Requirements

3.1.2.1 Physical Interface Requirements

Descriptions of the physical interfaces between the EPGS and other subsystems elements follow:

EPGS/Receiver Subsystem

Turbine Throttle/Downcomer/Receiver Interface -- The EPGS is designed to connect the primary high-pressure steam inlet to the receiver downcomer interface at the top of the receiver tower. The interface pressure and temperature are 11.1 MPa (1,615 psia) and 516°C (960°F) (rated conditions), to satisfy turbine inlet steam design requirements of 10.1 MPa (1,465 psia) and 510°C (950°F).

EPGS Feedwater Riser/Receiver Interface -- The EPGS is designed to provide feedwater at the riser/receiver interface at the top of the receiver tower at 15.51 MPa (2,250 psia) and 234°C (454°F), exclusive of thermal storage operation.

EPGS/Thermal Storage Subsystem

Automatic Admission Port/Steam Generator Interface -- The EPGS is designed to connect the automatic admission port of the turbine with the thermal storage steam generator outlet header and receive superheated steam at the rated conditions of 2.52 MPa (365 psia) 296°C (565°F) at the terminal connection with the steam generator outlet header.

EPGS Feedwater/Steam Generator Interface -- The EPGS is designed to connect the steam generator feed pump to the steam generator feedwater inlet, at a pressure and temperature of 2.90 MPa (420 psia) and 121°C (250°F) measured at the steam generator inlet.

EPGS/Collector Subsystem

The EPGS will include a power grid to deliver approximately 700 kVA electric power at 240V, 3-phase to operate the heliostat field during normal Commercial Plant operation. An emergency source of power will be provided to enable safe shutdown in the event of loss of power from the generator and grid.

EPGS/Master Control

The EPGS will be responsive to control signals from master control.

EPGS/Electrical Power Transmission Network

The EPGS will be designed to connect to an electrical power transmission network and deliver a nominal range from 700 to 110 MWe net of regulated 60 Hz electrical power at 115 kV (assumed) to the grid.

3.1.2.2 Code and Legal Requirements

The equipment, materials, design, and construction of the EPGS will comply with all Federal, state, local and user standards, regulations, codes, laws, and ordinances which are currently applicable for the selected site and using utility. These shall include but not be limited to the following:

A. Regulations of the Occupational Safety and Health Administration (OSHA).
B. Regulations of the California Occupational Safety and Health Administration (Cal/OSHA), if required.
C. ANSI B31.1 Pressure Piping Code.
D. IEEE, Switchgear and Transformers.
E. NEME Standards, Motor, Starters.
F. ASTM Standards.
G. Uniform Building Code.
H. ASME Boiler and Pressure Vessel Code, unfired pressure vessels.
I. American Institute of Steel Construction (AISC) Steel Construction Manual.
J. American Concrete Institute (ACI) Standards.
K. National Electric Code.
L. National Fire Protection Association (NFPA) Standards.

3.1.2.3 Environmental Conditions

The following environmental requirements have been defined for the Commercial Plant EPGS:

Environmental Factor		Requirement Source
Wind Conditions (at 10m [30 ft] Elevation)		
Maximum Operational, with Gusts	16 m/s (36 mph)	MDAC
Maximum Survival		
Sustained (Tower Only)	40 m/s (90 mph)	MDAC
With Gusts (Other Subsystems)	40 m/s (90 mph)	DoE/Sandia
Wind Velocity Profile (Relative to 10m Height)	Varies Exponentially to the 0.15 Power	DoE/Sandia
Seismological		
Seismic Zone	3	DoE/Sandia
Response Spectrum	NRC Reg Guide 1.60	DoE/Sandia
Operational Basis Earthquake (OBE)	0.165g (Horiz)	MDAC
Safe Shutdown Earthquake (SSE)	0.33g (Horiz) (Revised to 0.250g Horiz)	MDAC
Soil Conditions	Barstow	DoE/Sandia
Lightning Protection	Cost/Risk Basis	DoE/Sandia
Precipitation		
Rain		
Average Annual	100 mm (4 in.)	DoE/Sandia
Maximum 24-hr Rate	75 mm (3 in.)	MDAC
Snow (Design Snow Load)	250 Pa (5 psf)	DoE/Sandia
Sleet (Maximum Ice Buildup)	50 mm (2 in.)	DoE/Sandia
Hail	20 mm (3/4 in.) at 20 m/s (65 fps) Terminal Velocity	DoE/Sandia

3.2 SUBSYSTEM CYCLE AND OPERATION

3.2.1 Basic Subsystem Cycle

The basic commercial EPGS cycle is shown in Figure 1-1. The cycle selected for the commercial turbine is a five-heater regenerative cycle that uses a single automatic admission, condensing, tandem-compound double-flow turbine.

3.2.2 Subsystem Operating Modes

The Commercial Plant and Pilot Plant EPGS experience several different modes of operation which the subsystems must be designed for and operate stably in. The modes are:

- Normal Solar Operating Mode. During the normal solar operating mode, steam is generated in the receiver at rated conditions and directed to both the turbine inlet and thermal storage heater. Turbine inlet steam is then expanded through the turbine and condensed in the condenser. The resultant condensate is then pumped through a full-flow polishing demineralizer and low-pressure feed water heater to the deaerator. Then the feedwater is pumped through the high-pressure heaters and mixes with drains pumped from the thermal storage heater. The combination of turbine cycle feedwater and thermal storage heater drains then flows back to the receiver where the process is repeated. No heat is extracted from thermal storage during the normal solar operating mode.
- Low Solar Operating Mode. The low solar operating mode occurs during periods of low solar insolation levels and combines both the receiver or inlet steam with thermal storage or admission steam simultaneously to maintain the required electrical generation level. During this mode of operation, steam generated in the receiver at rated conditions passes through the turbine high-pressure section and mixes with admission steam generated in the thermal storage steam generator downstream of the low-pressure turbine admission valves. The combined steam sources then flow through the low-pressure section to the condenser. Condensate is then pumped from the condenser hotwell through the polishing demineralizer and low-pressure heater and into the deaerator. The feedwater is then divided and pumped both to the receiver, through the high-pressure heaters, and to the thermal storage steam generator where the process is repeated. No steam is sent to thermal storage during the low solar mode of operation.
- Intermittent-Cloud Operating Mode. In the intermittent-cloud case, the solar insolation incident on the receiver is insufficient to generate rated steam conditions; thus, all steam generated in the

receiver is sent to thermal storage. Heat is simultaneously extracted from thermal storage for turbine operation on storage steam only via the automatic admission port on the turbine, generating approximately 70% of rated load. Condensate formed in the condenser is pumped through the polishing demineralizer and low-pressure heater and into the deaerator. The feedwater leaving the deaerator is then pumped by the thermal storage feed pump back to the steam generator whence it came. Meanwhile, the condensate formed in the thermal storage heater is pumped by the thermal storage heater drain pump directly into the receiver feedwater line and into the receiver.

- Extended Operation. The extended-operating mode or admission-steam-only mode allows turbine operation during nighttime periods while operating solely on thermal storage steam. The receiver at this time is out of service. During the extended operation mode the turbine is capable of producing approximately 70% of rated load for 6 hr.
- Thermal Storage Charging Only. During the thermal storage charging only mode, the turbine is out of service and all steam generated in the receiver is delivered at derated steam conditions to thermal storage. Condensate formed in the thermal storage heater is then pumped directly back to the receiver.

3.2.3 Turbine Operating Scenarios

The Commercial Plant turbine, like the Pilot Plant turbine, is required to be started every morning, transferred to an alternate steam source during the evening, and shut down every night. During satisfactory weather conditions, the unit will generate 112,000 kW gross (100,000 kW net) at equinox noon while operating on 10.1 MPa (1,465 psia), 510°C (950°F), receiver steam. When the setting sun or cloud cover limits the receiver steam output, the unit will generate a minimum of 76,100 kW gross (70,000 kW net) by operating on 2.52 MPa (365 psia), 296°C (565°F) automatic admission steam from the thermal storage subsystem, either alone or in combination with the receiver steam.

Turbines are designed to essentially operate with steady-state throttle steam conditions. The allowable operating transients are primarily dependent on the mass of and the required life of the unit. Larger units, such as this Commercial unit, containing relatively massive components are more susceptible to large temperature gradients and the consequential cyclic fatigue than smaller, less massive units, such as the Pilot Plant turbine. Therefore, the allowable transients for smaller units are generally more liberal than for larger ones. The various turbine manufacturers normally indicate the allowable operating steam pressure and temperature variations that a turbine can be subjected to without unduly shortening its useful life.

The turbine type selected for the Commercial Plant is of the same type as selected for the Pilot Plant; namely, it is a tandem-compound, automatic admission, condensing, industrial turbine. This turbine is well-suited for the solar plant application because it permits introduction of the lower temperature and pressure thermal storage steam through an automatic admission port located downstream of the primary (receiver steam) high-pressure steam inlet, thus minimizing temperature gradients when switching from receiver steam to thermal storage steam operation.

3.2.3.1 Allowable Temperature Ramp Rate

The recommended temperature ramp rate vs temperature change for the Commercial Plant turbine is shown in Figure 3-2. The temperature change is measured using the first stage inner-shell thermocouple. The curve indicated is the operating curve for the Commercial turbine assuming a 10,000-cycle life expectancy. Once the temperature change is determined (the difference between the metal temperature before startup and the temperature once full operation is attained), the ramp rate is fixed so as to maintain the planned life expectancy. The steam inlet temperature can lead the metal temperature by 28° to 56°C (50° to 100°F). Figure 3-2 also shows that instantaneous temperature changes of 37.8°C (100°F) and ramp rates of 204.4°C (400°F) per hour and less will not have adverse effects on turbine life.

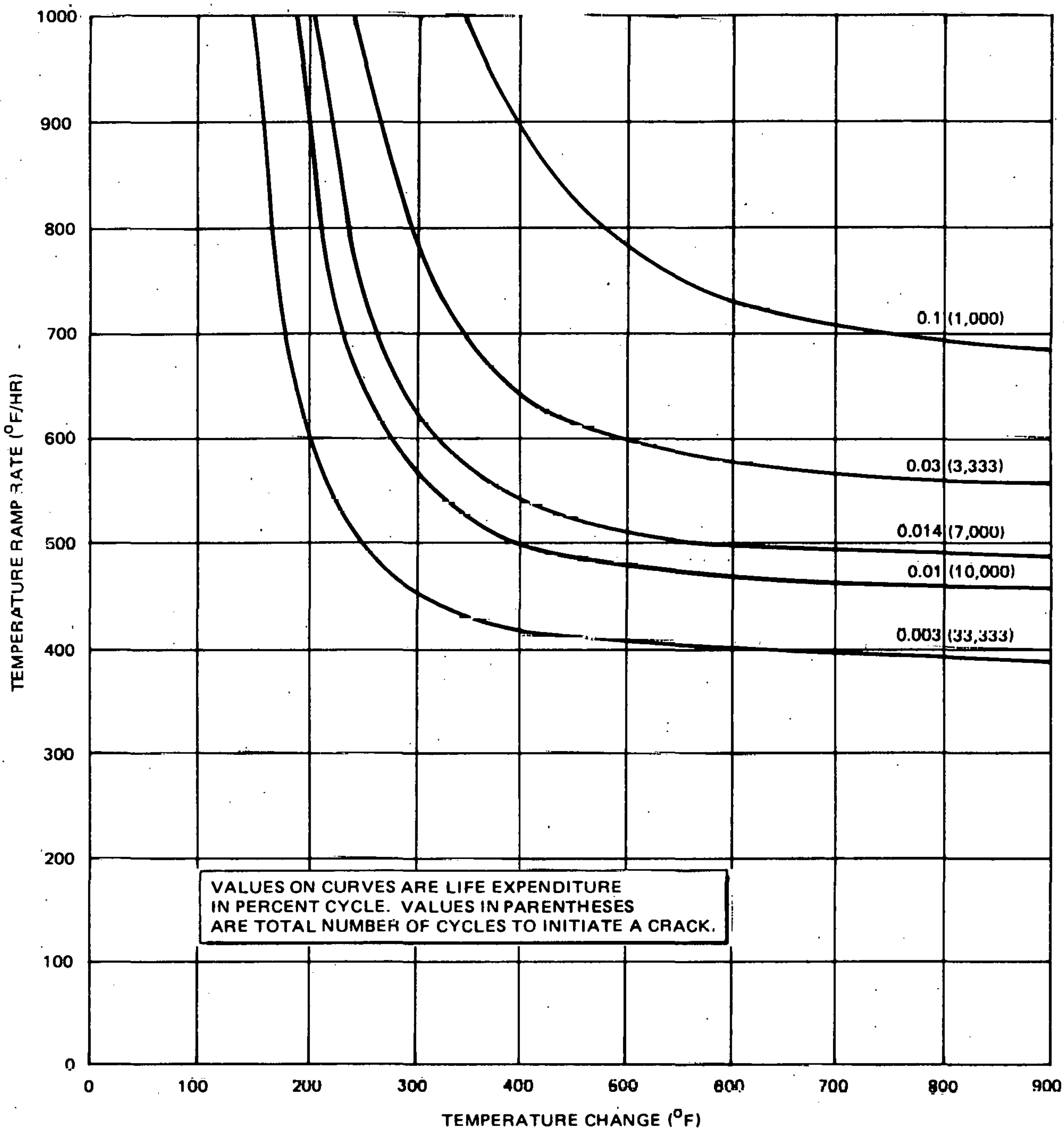


Figure 3-2. Recommended Commercial Turbine Temperature Ramp Rates

3.2.3.2 Turbine Startup and Shutdown

The type of start (cold, warm, or hot) will depend on the average temperature of the shell metal and will establish the rotor acceleration rate to rated speed. The average metal temperature can be established by actual thermocouple readings (if the turbine is equipped with controlled start thermoccouples) or by the duration of the previous shutdown.

To determine temperatures, the following rules apply to turbines with thermocouples:

A. Read the following temperatures:
   1. Steam chest, inner and outer surfaces.
   2. First valve port, inner and outer surfaces.
   3. Adjacent valve port, inner surface.
   4. First-stage shell, inner surface.

B. Average the six thermocouple readings to obtain the average shell metal temperature.

C. Select the type of start:
   1. Cold Start – average metal temperature is -18° to 149°C (0° to 300°F).
   2. Warm Start – average metal temperature is 149° to 371°C (301° to 700°F).
   3. Hot Start – average metal temperature is 372° to 538°C (701° to 1000°F).

For turbines without thermocouples, select the type of start from following data:

Duration of Previous Shutdown	Type of Start
Longer than 72 hours	Cold
12 to 72 hours	Warm
Less than 12 hours	Hot

A typical cool-down curve for a high-pressure turbine of single-shell design is shown in Figure 3-3.

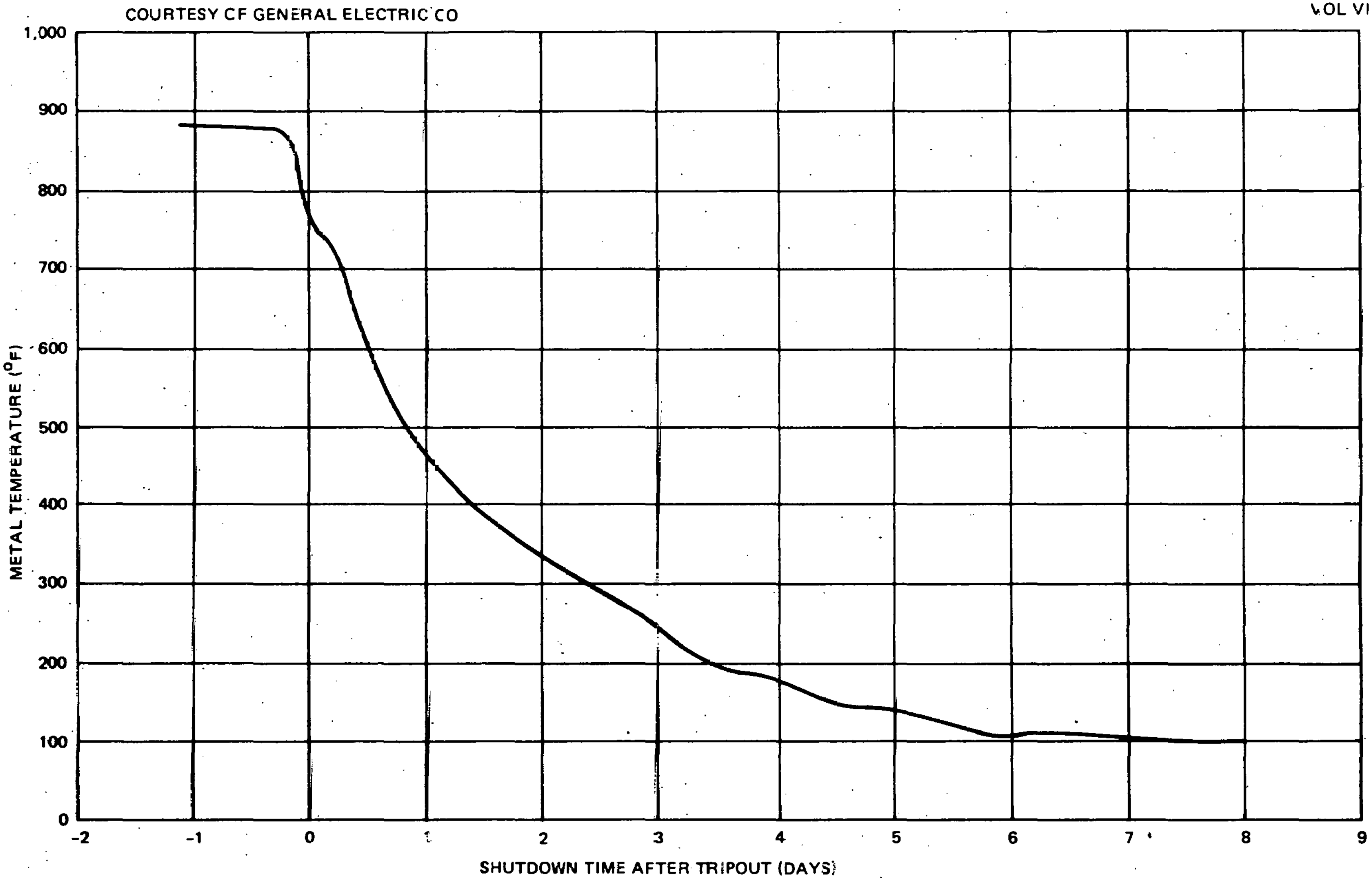


Figure 3-3. Typical Commercial Turbine Cooldown Curve

Figure 3-4 shows the typical rolling and loading time vs length of shutdown for controlled starting on single-wall cylinder with no flange heating for a typical 100-MW unit. The actual time requirements for the solar turbine, however, will depend on the specific turbine design, but the values can be considered representative.

The estimated startup characteristics for the Commercial turbine are shown in Table 3-1 based on values in Figure 3-4 for various time durations from previous shutdown.

After the unit has been synchronized and loaded, the load or throttle steam temperature may be increased or decreased in accordance with Figure 3-5.

Steam Conditions for Turbine Roll

With respect to the steam conditions necessary for a turbine roll, the General Electric Company recommends an initial pressure above 40% of design and a temperature at 41.6°C (75°F) to 55.5°C (100°F) above saturation. If the temperature drops below 41.6°C (75°F) superheat, attempts are to be made to increase it and if it drops to 13.9°C (25°F) superheat, the turbine is to be tripped. For the Commercial Plant, like the Pilot Plant, it is expected that the conditions can be met by first establishing circulation through the receiver, the receiver power will build and the steam quality will build until the desired

Table 3-1

STARTUP CHARACTERISTICS OF COMMERCIAL TURBINE

Type of Start	Hot	----	Warm	----	Cold
Duration of Previous Shutdown (Hr)	4	12	24	48	96
Time to Roll (Min)	15	19	30	60	168
Time at Minimum Load (Min)	15	18	20	30	58
Time from Minimum Load to Full Load (Min)	35	48	66	90	119
Total Time-Roll to Full Load (Min)	65	85	116	180	345
Total (Hr-Min)	(1-5)	(1-25)	(1-56)	(3-0)	(5-45)

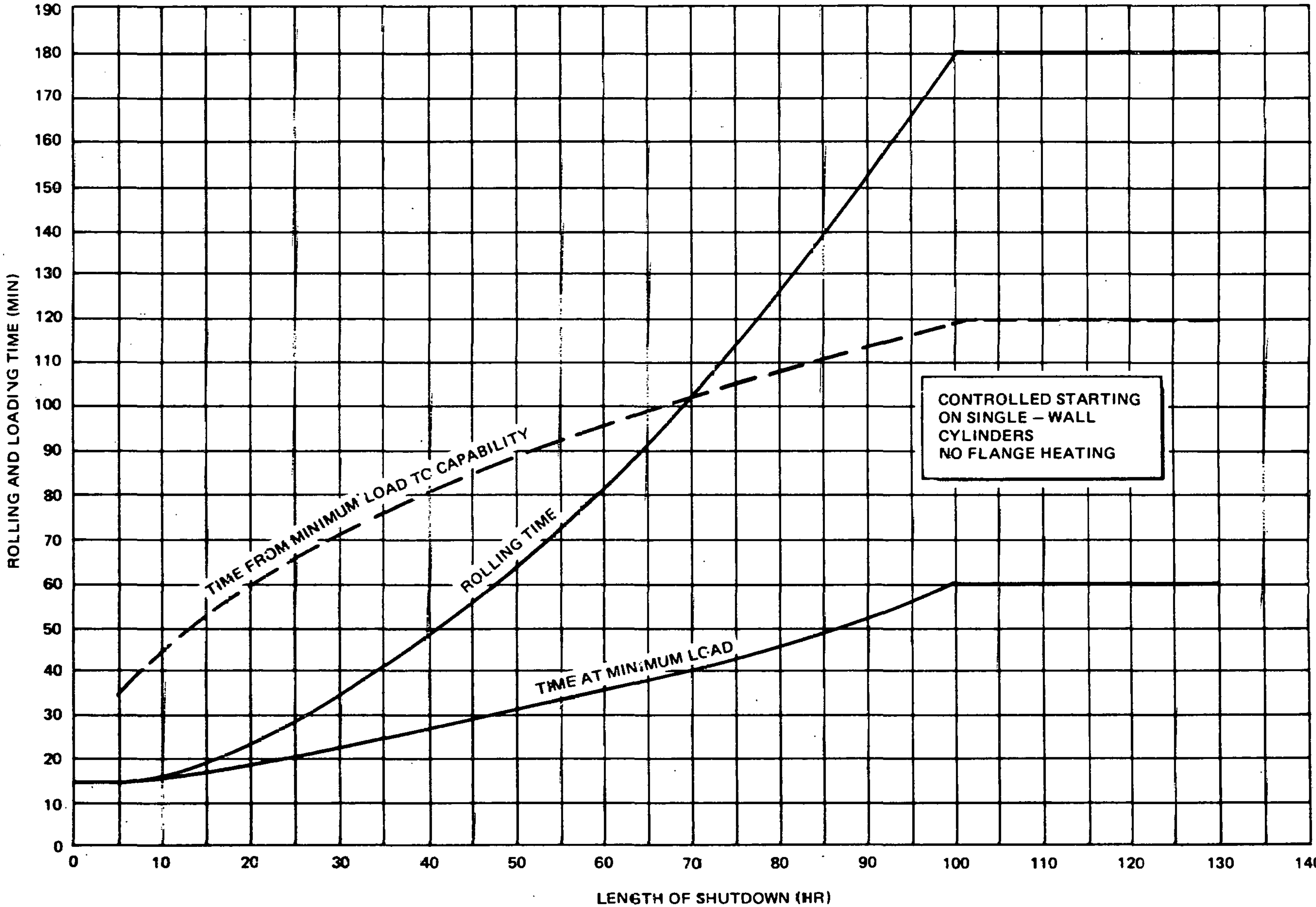


Figure 3-4. Typical Turbine Rolling and Loading Times

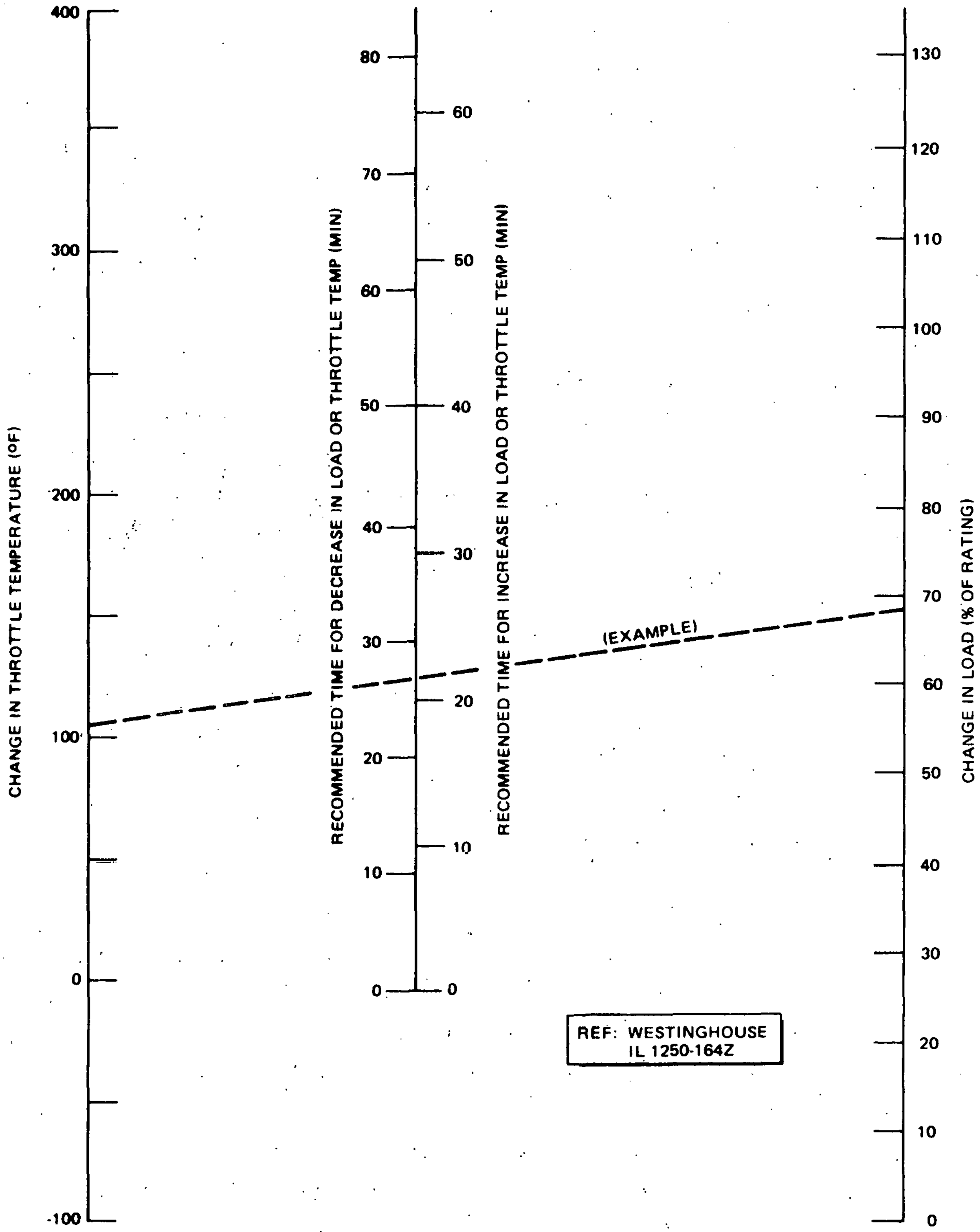


Figure 3-5. Recommended Minimum Time for Change in Load or Throttle Steam Temperature

conditions are achieved. The time required to obtain the turbine roll steam conditions will have to be determined through experimentation and using knowledge developed in the Pilot Plant program.

Transfer to Thermal Storage Steam

The transfer from receiver steam to thermal storage steam can be accomplished automatically or manually. As receiver steam conditions decay with the setting sun or intermittent-cloud cover, the transition from receiver steam to thermal storage steam will take place automatically; storage steam will be admitted through the automatic admission port while the primary steam inlet valve closes.

After the thermal storage steam supply has been exhausted, the turbine should be shut down in a manner that will leave the average turbine metal temperature in the 149°C (301°F) to 371°C (700°F) range. This can be done by assuring that the thermal storage steam temperature does not excessively decay before the unit is removed from service. It would also be helpful to unload and trip the turbine as rapidly as system conditions permit.

Startup with Thermal Storage Steam

If desired, the turbine can be rolled and loaded on thermal storage steam (admission steam) only, and the transition from admission steam to inlet steam from the receiver can be made when inlet steam conditions permit. The pressure and temperature requirements for turbine roll apply to admission steam starts as well as inlet steam.

Nighttime Standby

Throughout the night, when the unit is not generating, it is anticipated that the turbine steam seals will be supplied from the auxiliary steam boiler or thermal storage subsystem and condenser vacuum will be maintained. Also, the turbine will be placed on turning gear and blanketing steam will be applied to the high-pressure heaters and deaerator. These activities will keep the system warm and simplify the morning startup. This will also lessen the corrosion tendencies by preventing air from entering the condenser, deaerator, and high-pressure heaters. During the morning startup, the feedwater system will no doubt have to be cleaned up. To accomplish this, a recirculation line has been provided in the feedwater line following the last feedwater heater and is routed back to condenser. In addition, provisions are made for by bypassing the receiver with a feedwater warmup line routed to the receiver startup flash tank to facilitate feedwater system cleanup prior to startup and to maintain feedwater flow in the riser to prevent freezing.

3.2.4 Auxiliary Steam Supply

As summarized in Section 2.1.1.8, the Commercial Plant auxiliary steam requirements will be supplied from one of two sources, i.e., thermal storage subsystem or auxiliary oil-fired low-pressure steam boiler.

Auxiliary steam requirements are described in the following paragraphs:

3.2.4.1 Turbine Seal Steam

Turbine seal steam is required at the turbine shaft seals to prevent leakage of air into the turbine whenever a vacuum is established in the condenser. During normal turbine operation, the gland steam leakage from the turbine high-pressure section is sufficient to provide seal steam for the turbine requirement; consequently, no external source of seal steam is required during this period of operation. However, during a turbine startup or whenever vacuum is maintained on an idle turbine, an external source of seal steam is required. The seal steam requirement for the Commercial turbine is estimated at 591 kg/hr (1,300 lb/hr) at a pressure of 124-138 KPa (18 to 20 psia). The steam temperature preferably should be in the superheated range, providing at least 14°C (25°F) superheat on a cold start. During a warm or hot start, however, the temperature difference between the seal steam and turbine rotor surface in the gland zone should be kept to a minimum when starting or shutting down so as to minimize thermal stresses in the rotor.

3.2.4.2 High-Pressure Heater Shell Blanketing

Auxiliary steam is used for blanketing the shell side of the high-pressure heaters when they are out of service in order to prevent air leakage into the heater that could cause serious corrosion problems to the carbon steam tubes in the heater. The estimated steam consumption for this requirement is small, estimated at 12 kg/hr (27 lb/hr) for three high-pressure heaters.

3.2.4.3 Deaerator Heater Blanketing

The deaerator, including the storage tank section, is also blanketed with steam to minimize corrosion effects. In addition, the blanketing steam serves to maintain the condensate in the deaerator storage tank, approximately 75.7m^3 (20,000 gal) at about 108.9°C (228°F), corresponding to the 138 KPa (20 psia) steam saturation temperature, to facilitate morning startup. The amount of steam required for deaerator blanketing is 13 kg/hr (28 lb/hr).

3.2.4.4 Deaerator Pressure "Pegging"

To maintain efficient deaeration of feedwater at low loads when the deaerator extraction pressure is below atmospheric, auxiliary steam must be supplied to the deaerator so that a slight positive pressure is maintained inside the deaerator to facilitate venting to the atmosphere. The normal turbine extraction pressure to the deaerator goes subatmospheric at about 40% load. The next highest pressure turbine extraction is then used to peg the deaerator down to about 25% load. At about 25% load and less, auxiliary steam is automatically supplied at 138 Pa (20 psia). The amount of auxiliary steam required for deaerator pressure pegging is approximately 6,804 kg/hr (15,000 lb/hr).

3.2.4.5 Startup Requirements

The startup requirements for the auxiliary steam system are based on a cold startup when steam is required for initial deaeration and preheating of the feedwater, assuming a minimum flow of 25% of the turbine-rated throttle flow. The auxiliary steam required for the process is 17,917 kg/hr (39,500 lb/hr). A short time after the receiver startup system is in operation, steam from the receiver startup flash tank will supplement the auxiliary steam until turbine extraction steam is available for feedwater heating and deaeration.

3.2.4.6 Receiver Freeze Protection

The receiver must be protected from freeze during periods when the ambient air temperature is below freezing. Hot water will be circulated through the receiver, returning to the deaerator through the receiver startup flash tank. The estimated receiver heat loss, based on -17.8°C (0°F) air and 18.3 m/s (40 mph) wind velocity, is 21,000 MJ/Hr (20 x 10^6 Btu/hr), requiring about 9,548 kg/hr (21,050 lb/hr) auxiliary steam, which is added to the deaerator.

3.2.5 Receiver Startup Flash Tank

3.2.5.1 Requirements

The function of the receiver startup flash tank system is to provide a means of establishing flow through the receiver during the cleanup mode prior to startup, and during the startup mode prior to generation of rated steam conditions. The receiver startup flash tank system schematic is shown in Figure 3-6.

The operational characteristics during the receiver prestart and startup modes are discussed in Section 3.4 of Volume IV.

For the Commercial Plant, the receiver flash tank will be sized for 52.80 kg/s (418,250 lb/hr), which corresponds to the minimum flow for stable receiver operations. The figure corresponds to approximately 25% of the maximum receiver flow at equinox noon.

The flash tank design and construction will conform to ASME Section VIII, Unfired Pressure Vessel Code.

3.2.5.2 Sizing Conditions

Receiver Flow Rate	52.80 kg/s (418,250 lb/hr)
Receiver Outlet Pressure	11.1 MPa (1,615 psia)
Receiver Outlet Temperature	349°C (660°F)
Flash Tank Operating Pressure	2.17 MPa (315 psia)
Flash Tank Design Pressure	2.51 MPa (365 psia)

$$\text{Percent Flash} = \frac{h_{f1} - h_{f2}}{h_{fg2}}$$

h_{f1} = 625.9 Btu/lb

h_{f2} = 398.9 Btu/lb

h_{fg2} = 804.4 Btu/lb

$$\text{Percent Flash} = \frac{625.9 - 398.9}{804.4} = 0.282 \text{ or } 28.2\%$$

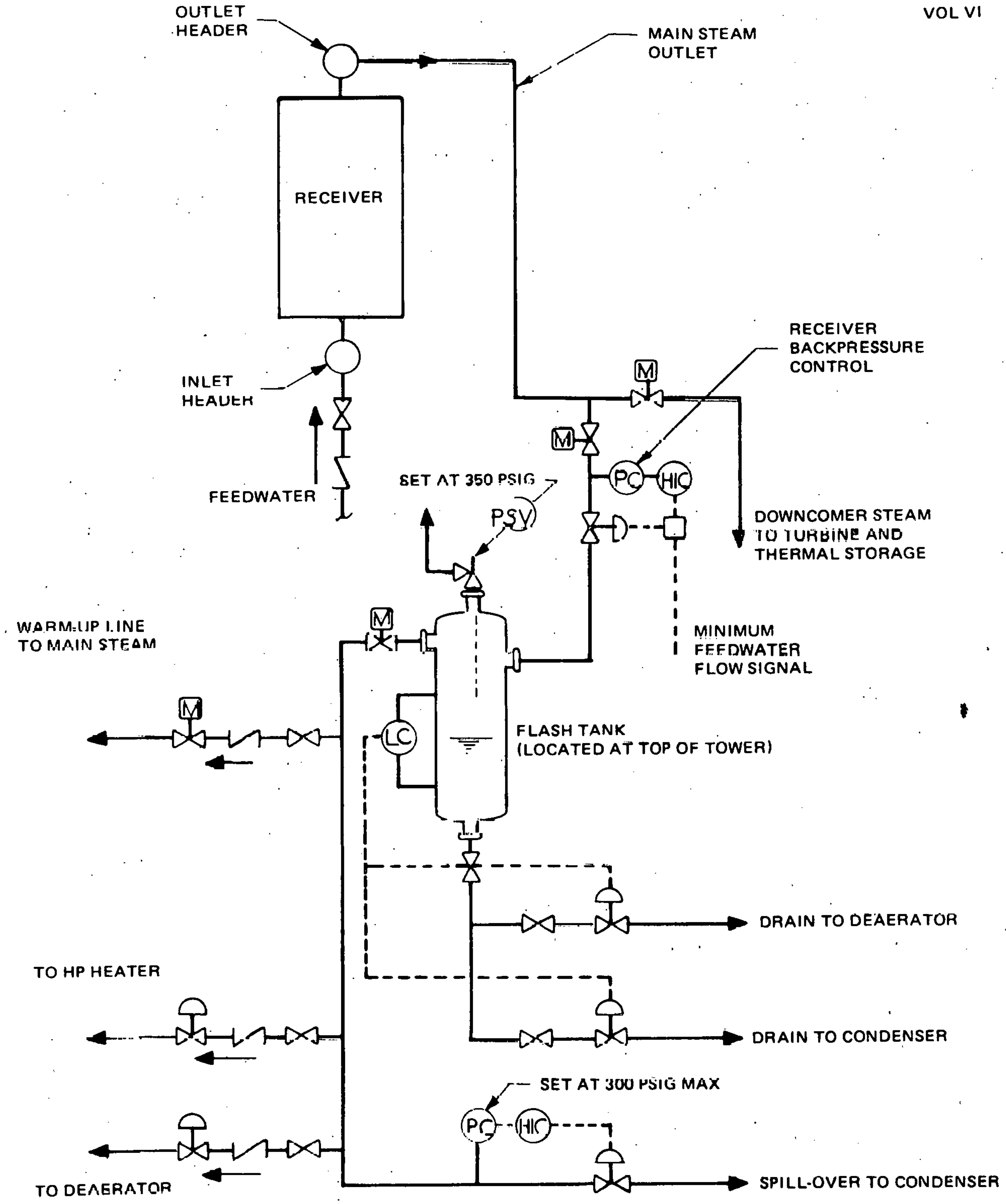


Figure 3-6. Receiver Startup Flash Tank Schematic

Flash Steam = 0.282 (52.8) = 14.90 kg/s (117,950 lb/hr)

Condensate = 52.8 - 14.9 = 37.9 kg/s (300,300 lb/hr)

3.2.5.3 Sizing

Design flash tank for maximum of 1.22 m/s (4 fps) vapor velocity in tank

$$A = Q/V$$

$$Q = \frac{117,950 \text{ lb/hr}}{3,600} \times 1.47 \text{ ft}^3/\text{lb} - 48.16 \text{ ft}^3/\text{sec}$$

$$A = \frac{48.16}{4.0} = 12.0 \text{ ft}^2$$

$d = 3.91$ ft say 1.22m (4.0 ft) flash tank diameter

Commercial receiver flash tank dimensions are 1.22m (4.0 ft) diameter by 2.13m (7.0 ft) long. See Figure 3-7 for the flash tank configuration.

3.2.6 Thermal Storage Heater Drain System

Steam condensed in each thermal storage heater is drained to a drain tank where a level is maintained. From there, the condensate is pumped into the riser downstream of the receiver feed pumps and on to the receiver. A separate drain tank and pump is provided for each of five thermal storage heaters. A level-control valve at each drain pump discharge is modulated by the corresponding drain tank level controller to maintain the level setpoint under all operating conditions. During startup conditions at low load, however, each thermal storage heater is drained through an alternate drain to a flash tank, where flashed steam is used for feedwater heating and deaeration, and condensate is drained to the condenser for cleanup in the polishing demineralizer prior to being pumped by the receiver feedwater pump to the receiver. A schematic of the thermal storage heater drain system is shown in Figure 3-8.

3.3 EPGS EQUIPMENT AND BALANCE OF PLANT CHARACTERISTICS

3.3.1 Turbine-Generator

3.3.1.1 Selection

The turbine-generator selected for the Commercial Plant is a tandem-compound, double-flow, automatic admission, condensing unit rated at

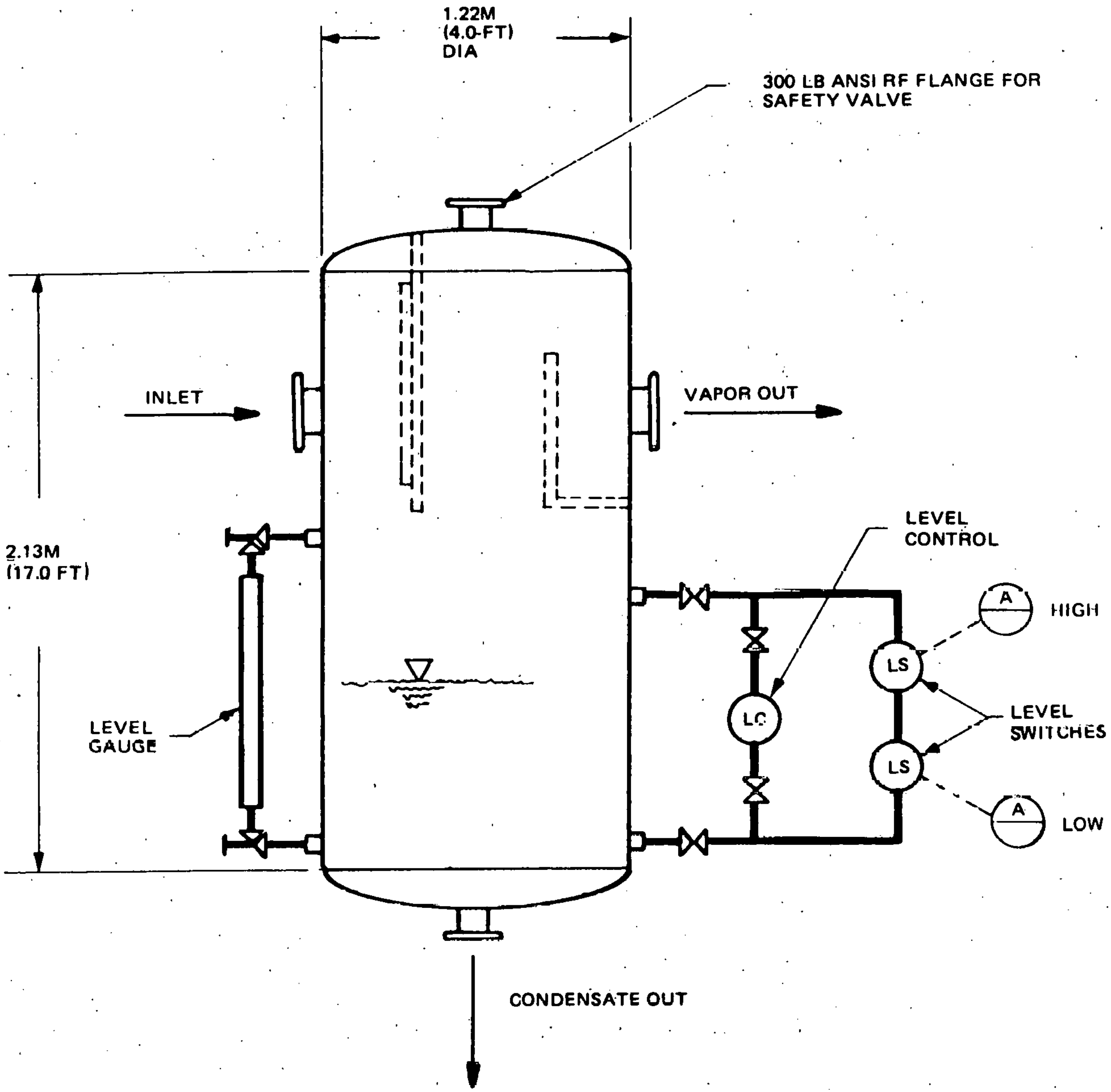


Figure 3-7. Receiver Startup Flash Tank

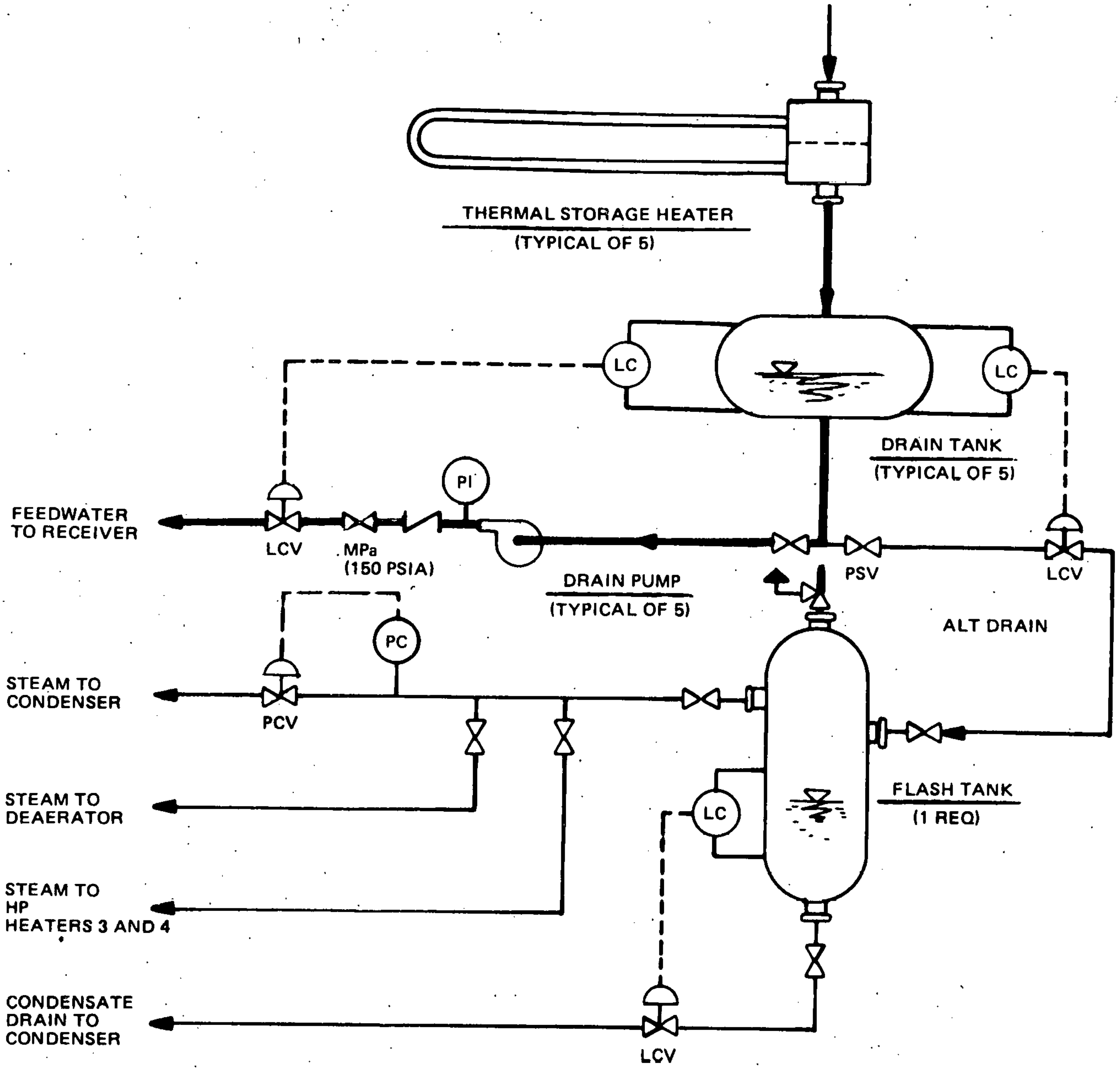


Figure 3-8. Thermal Storage Heater Drain System (Commercial Plant)

112,000 kW at 8.46 KPa (2.5 in HgA) backpressure when operating with inlet steam conditions of 10.1 MPa (1,465 psia) and 510°C (950°F). When operating on admission steam at 2.52 MPa (365 psia) and 296°C (565°F), the turbine will generate 76,100 kW at 8.46 KPa (2.5 in HgA) backpressure.

The generator is rated at 135,000 kVA, 0.90 power factor, 13,800V, 60 Hz and is hydrogen-cooled, with static excitation system.

Turbine accessories are:

- Generator hydrogen coolers.
- Lube oil coolers.
- Lube oil reservoir.
- AC auxiliary oil pump.
- DC auxiliary oil pump.
- Generator vapor extractor.
- Gland steam condenser with exhauster.
- Electrohydraulic control system.

The rationale for the selection of the admission-type turbine, in addition to inlet and admission steam conditions and cycle analysis, is discussed in Section 2.1.2.

3.3.1.2 Turbine Performance

The predicted performance for the Commercial Plant turbine is as follows:

	Equinox Noon (Design Point) Receiver Steam	Admission Only (Extended Operation) Thermal Storage Steam
Gross Generation, kW	112,000	76,100
Net Generation, kW	100,000	70,000
Gross Turbine Heat Rate, kJ/kW hr (Btu/kW hr)	9,554 (9,055)	13,428 (12,724)
Steam Flow, kg/s (lb/hr)	121.3 (960,415)	114.3 (905,593)
Turbine Backpressure, KPa (In. HgA)	8.46 (2.5)	8.26 (2.5)

Turbine Partial Load Performance

The predicted turbine performance for both receiver steam and thermal storage steam as a function of throttle or admission steam flow is shown in Figure 3-9.

Turbine Maximum Capability

The maximum expected turbine throttle steam flow while operating at rated inlet steam conditions is 10% above the rated steam flow of 121.3 kg/s (960,415 lb/hr), or 133.4 kg/s (1,056,528 lb/hr). This maximum throttle flow will result in an increase of generation of approximately 9%, or 122,080 kW maximum expected capability.

Note: In order to pass an additional 10% flow through the admission valve gear, it will be necessary to increase the admission point pressure 10% above rated admission steam pressure.

The maximum admission steam flow is equal to the rated steam flow 114.3 kg/s (905,593 lb/hr) at rated admission steam conditions, ie., 2.52MPa (365 psia and 296°C (565°F) because of flow limitations in the admission valve gear. An additional 10% admission steam flow is possible, however, if admission pressure is increased 10%, from 2.52 MPa (365 psia) to 2.77 MPa (401 psia). The maximum expected generation at 10% overpressure on admission steam only is approximately 82,949 kW.

3.3.1.3 Turbine Operating Modes

The single automatic extraction/admission turbine selected for both the Commercial and Pilot Plants is designed to operate in three basic operating modes:

- Total admission mode.
- Initial pressure and speed/load control.
- Initial pressure and admission pressure control.

Operation on Admission Steam Only

During the total admission mode, the turbine is operated entirely on the 2.52 MPa (365 psia) steam admitted into the stage shell ahead of the admission valves. In this case, the turbine operates in the speed/load control mode, and the turbine will accept and reject load automatically.

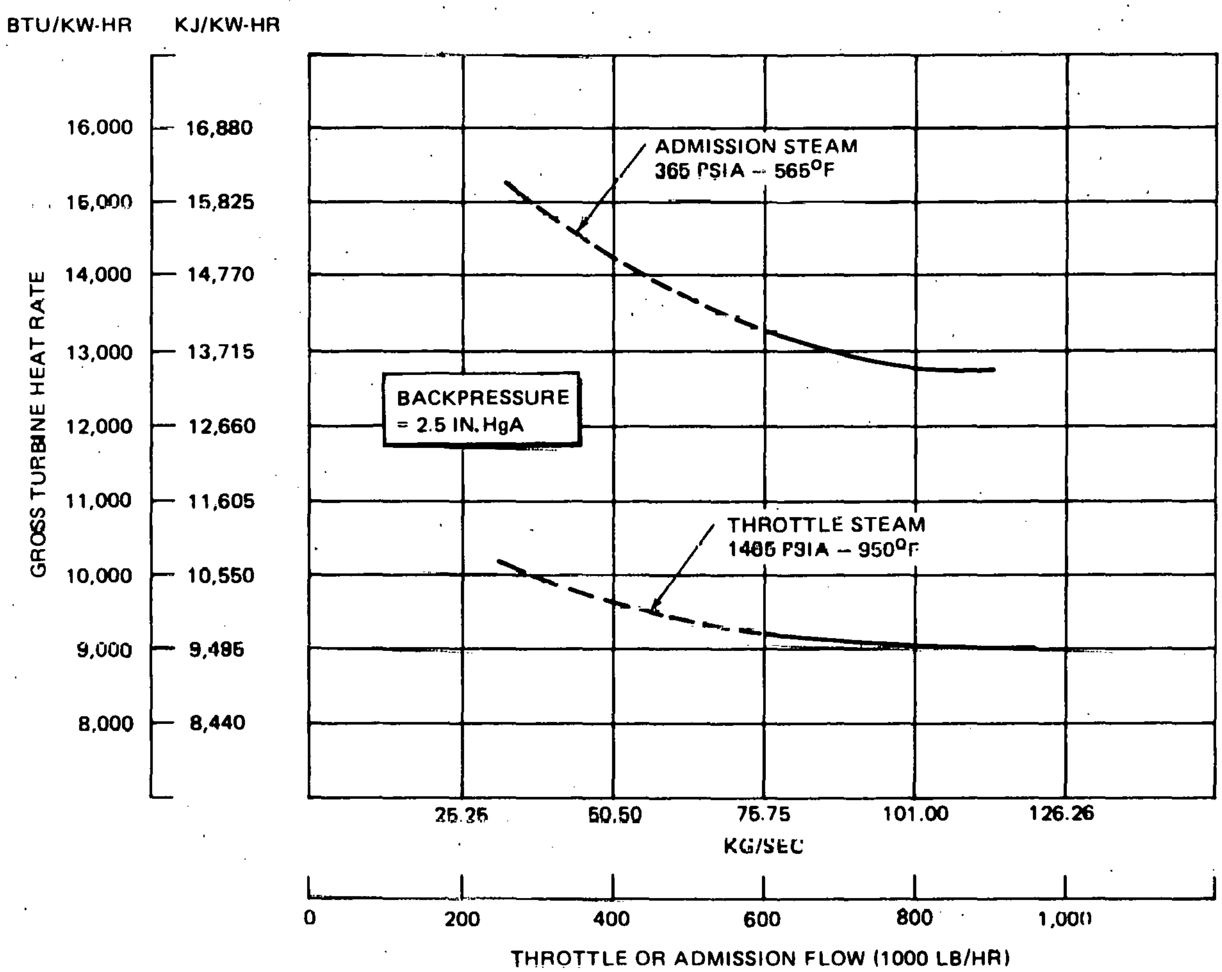


Figure 3-9. Commercial Plant Predicted Performance

A cooling steam line that runs from the first-stage shell to the admission head is necessary on this type of unit to provide a path for circulating admission steam through the high-pressure section in order to carry away excess heat generated there during total admission operation. Circulation is accomplished by the pumping action of the high-pressure section buckets that pump steam downstream from the first-stage shell to the admission point.

Operation on Initial Pressure and Speed/Load Control (Low Solar Power Operating Mode)

When all subsystems are placed in service except for the admission pressure control subsystem, the turbine will accept and reject load without significantly affecting inlet flow. In this mode, the inlet control valves are positioned to control initial pressure (receiver pressure), and the admission control valves are positioned to control speed/load.

Operation on Initial Pressure and Admission Pressure Control (Normal Solar Operating Mode)

The third operating mode is one in which initial pressure and extraction pressure are controlled by the turbine. In this mode, it will be necessary to tie the turbine to a stiff electrical system to maintain the rated frequency. During operation in this mode, the generation will be determined by, and will vary with, the available steam supply. Since in the solar plant there is little control of the heat absorbed in the receiver, the turbine will control initial pressure (receiver pressure) and accept receiver steam up to its limits, unless steam is diverted to thermal storage.

3.3.2 Condenser and Air-Removal Equipment

3.3.2.1 Performance Requirements

The condenser selected for the commercial turbine is of the shell and tube-type using cooling tower circulating water for heat rejection. The condenser is sized for the highest heat-rejection load that can be expected during the various plant operating modes.

The air-removal equipment is required to remove air and other noncondensible gases form the steam side of the condenser.

The type of air-removal equipment selected is mechanical vacuum pumps with electric motor drive.

All condenser design and performance characteristics are in accordance with Heat Exchange Institute Standards for Steam Surface Condensers, 6th Edition.

3.3.2.2 Condenser Heat Loads

Heat-rejection loads that govern the condenser sizing follow for two operating conditions:

	Receiver Operation Equinox Noon 112,000 kW	Admission Steam Only Extended Operation 76,100 kW
Turbine Exhaust Flow	86.5 kg/s (686,759 lb/hr)	97.8 kg/s (776,503 lb/hr)
Condenser Pressure	8.46 kPa (2.5 In. HgA)	8.46 kPa (2.5 In. HgA)
Heat Rejection GJ/hr (Btu/hr)		
Turbine Exhaust Steam	664.90 (630.24 [10^6])	735.95 (697.58 [10^6])
No. 1 Heater and GSC Drains	0.72 (0.68 [10^6])	1.03 (0.98 [10^6])
Steam Seal Regulator	2.94 (2.79 [10^6])	2.27 (2.15 [10^6])
Subtotal	668.56 (633.71 [10^6])	739.25 (700.71 [10^6])
Margin for Miscellaneous Drains	80.22 (76.04 [10^6])	88.71 (84.09 [10^6])
Total Condenser Duty	748.78 (709.75 [10^6])	827.96 (784.80 [10^6])
Difference	Base	+10.57% (Design)

3.3.2.3 Condenser Design Parameters

Surface Area	12,542m^2 (135,000 ft^2)
Tube Materials	90-10 copper nickel
Tube Diamter (OD)	22.2 mm (0.875 in.)
Tube Wall Thickness	0.89 mm (0.035 in.) 20 BWG
Tube Length (Effective)	8.5m (28 ft)
Condenser Pressure	8.46 kPa (2.5 In. HgA)
Heat Rejection	828 GJ/hr (785 x 10^6 Btu/hr)

Cooling Water Flow	7.1 m^3/s (112,100 gpm)
Water Velocity	2.13 m/s (7 fps)
Cooling Water In	31.1°C (88.0°F)
Cooling Water Out	38.9°C (102.0°F)
Temperature Rise	7.8°C (14.0°F)
TTD	3.7°C (6.7°F)
Tube Cleanliness	85%

3.3.2.4 Condenser Material Selection

The materials of construction selected for the Commercial Plant condenser have been based on previous experience with many utility condensers. Of particular concern, however, is the tube material selection. From the standpoint of the receiver, it is preferred that no copper alloy materials be used on systems incorporating once-through boilers because of possible copper pickup in the condensate that results in copper deposition on the boiler heat-transfer surfaces or on the turbine blades. For this reason, stainless steel would seem a good choice for condenser tube material. However, stainless steel is subject to pitting failure due to circulating water impurities, particularly when high concentrations of solids are maintained in the circulating water system to minimize blowdown requirements. Also, pitting failure in stainless steel is accelerated in systems which have frequency shutdowns. Since it is planned to operate the solar plant in a cyclic manner (startup every day), it is imperative to keep a circulating water pump operating at all times when stainless steel condenser tubes are employed. In view of the apparent problems with stainless steel, it has been decided to use 90-10 copper-nickel tubes in the condenser. Since full-capacity in-line polishing demineralizers are located downstream of the condenser condensate pumps, the possibility of copper carryover through the demineralizer units is considered minimal.

Materials of Construction

Waterboxes	Steel, ASTM A-285 Grade C, Epoxy Coated on Interior, with Sacrificial Anodes
Steel Plate	Steel, ASTM A-285 Grace C

Tube Sheets	Muntz Metal, ASTM B-171, Alloy 365, or 90-10 Copper-Nickel ASTM B-171, Alloy 706
Tubes	Copper-Nickel, ASTM B-111, Alloy 706
Tube Support Plates	Steel, ASTM A-285 Grade C

3.3.2.5 Condenser Air-Removal Equipment

The type of condenser air-removal equipment selected for the Commercial Plant is the mechanical vacuum pump. The mechanical vacuum pump was selected over steam jet air ejectors because of its fast start capability and because it is not dependent on high-pressure auxiliary steam supply for operation. Also, it is planned to maintain condenser vacuum throughout the night when drive steam would not be available.

Two full-capacity vacuum pumps are provided, each sized in accordance with the Heat Exchange Institute Standards for Surface Condensers. Each pump is rated at 12.5 scfm dry air at 3.38 kPa (1 in. HgA) suction pressure. The pumps are of the centrifugal, liquid-ring type, powered by a 37.5 kW (50 hp), 700 rpm, electric motor drive.

3.3.3 <u>Heat Rejection</u>

The method of condenser heat rejection selected for the Commercial and Pilot Plants is the mechanical draft, wet cooling tower. A six cell, cross-flow tower has been selected for the Commercial plant.

The cooling tower heat load equals the condenser design heat rejection plus an assumed 3% for auxiliary plant equipment cooling. A design wet bulb temperature of 23°C (73.4°F) was used in accordance with the design requirements previously set forth.

3.3.3.1 Cooling Tower

Quantity	One
Type	Mechanical Induced Draft, Cross Flow
Number of Cells	Six
Number of Fans	Six
Fan Motor Size	150 kW (200 hp)

Overall Dimensions (LxWxH)	66x21x18m (217x69x59 ft)
Heat Rejection	853.07 GJ/hr (808.6x10^6 Btu/hr)
Design Wet Bulb Temperature	23°C (73.4°F)
Cold Water Temperature	31.1°C (88°F)
Temperature Range	7.8°C (14°F)
Circ Water Flow	7.28 m^3/s (115,500 gpm)
Structure	Redwood or Treated Fir
Fill Material	Wood or PVC
Basin	Concrete

3.3.3.2 Cooling Tower Makeup Water Requirements

The cooling tower makeup water requirement is the sum of the cooling tower evaporation rate, drift rate, and blowdown rate. The blowdown rate is a function of the evaporation rate, drift rate, and number of cycles of concentrations to be maintained in the tower circulating water, or in equation form:

$$\text{Blowdown, } BD = \frac{E + D(1 - C)}{C - 1}$$

where

E = Evaporation rate

D = Drift rate

C = Number of cycles concentration

BD = Blowdown rate

The tower evaporation rate can be assumed to be equal to approximately three-fourths of 1% of the circulating water flow for every 5.6°C (10°F) of cooling range. Thus for a 7.1°C (14°F) cooling range and a circulating water flow of 7.28 m^3/s (115,500 gpm), the evaporation rate is approximately 0.0766 m^3/s (1,213 gpm).

Drift loss can be assumed to be 0.01% of the circulating water flow, or 7.3 x 10^{-4} m^3/s (12 gpm).

The cooling tower makeup and blowdown requirements, as a function of cycle concentration, are shown in Figure 3-10. The number of cycle concentrations that can be maintained will depend on the makeup water quality, as discussed in Section 3.3.10.2.

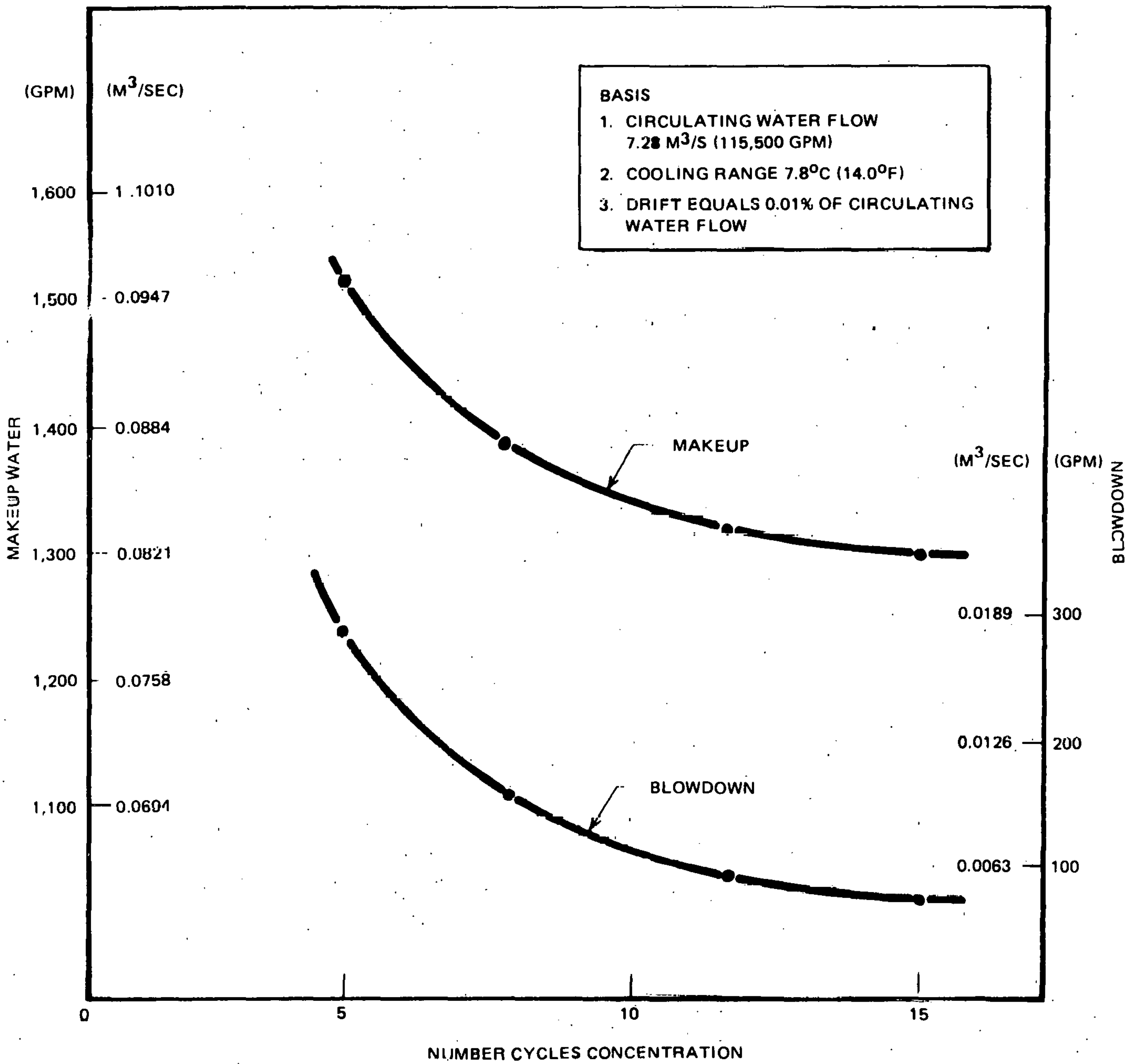


Figure 3-10. Commercial System Cooling Tower Makeup Water and Blowdown

3.3.3.3 Circulating Water Pumps

Condenser/cooling tower water circulation is accomplished by two half-capacity circulating water pumps which take suction from the cooling tower basin. Each pump is of the vertical mixed flow type with electric motor drive. Each pump is rated at 3.64 m^3/s (57,750 gpm) at 23.2m (76.0 ft), requiring 1,033.5 kW (1,385.4 Bhp) and using a 1,119 kW (1,500 hp) motor.

3.3.4 <u>Feedwater Heaters</u>

As previously mentioned, a five-heater cycle was selected for the Commercial Plant: one closed, horizontal low-pressure heater; three closed, horizontal high-pressure heaters; and one open deaerating heater with a horizontal condensate storage section.

3.3.4.1 Low-Pressure Heater (Located in Condenser Neck)

Sheel Material	Carbon Steel, ASTM A-285-C
Tube Material	Stainless Steel, ASTM A249
Tube Design Pressure	2.17 MPa (315 psia)

Horizontal Heater with Drain Cooler Section

ASME Code, Section VIII Design

3.3.4.2 High-Pressure Heaters

Shell Material	Carbon Steel, ASTM A285-C
Tube Material	Carbon Steel, ASTM A210-C
Tube Design Pressure	24.9 MPa (3,615 psia)

Horizontal Heater with Drain Cooler Section

ASME Code, Section VIII Design

3.3.4.3 Deaerator

Sheel Material	Carbon Steel, ASTM A285-C
Tray Material	Stainless Steel Type 430
Vent Condenser Material	Stainless Steel Type 304
Design Pressure	448 kPa (65 psia)
Guar Oxygen in Effluent	Less than 0.055 cc/l
Condensate Storage Capacity	75.7m^3 (20,000 gal)

ASME Code, Section VIII Design

Carbon steel tube material was selected for the high-pressure heaters to maintain a copper-free system downstream of the polishing demineralizers, thus minimizing copper pickup in the feedwater system. Stainless steel tubes were considered on the high-pressure heaters; however, several stress-corrosion cracking failures of stainless steel high-pressure feedwater heater tubes have been reported, indicating that stainless steel may not be a good choice without further study. Carbon steel tubes, however, experience corrosion problems when exposed to air; therefore, an inert gas or steam blanket is required when the heater is out of service. The problem is aggravated on a cyclic operating plant such as the solar plant.

3.3.5 Receiver Feed Pumps

The receiver feed pumps take suction from the deaerator condensate storage section and pump through the three high-pressure heaters to the inlet of the receiver. Three half-capacity pumps are provided, one pump being a spare. Each pump is of the double-case, centrifugal barrel-type with seven stages as indicated in the typical pump configuration in Figure 3-11. Each pump has a variable-speed hydraulic coupling and speed-increaser gear.

The pump speed is automatically controlled through the variable-speed drive to maintain a constant receiver inlet pressure. Feedwater flow is also sensed and used as a feed-forward signal into the feedwater pressure control system to anticipate load changes.

The pump materials of construction include a forged carbon steel outer barrel, cast chrome steel inner casing and impellers, and a chrome steel pump shaft.

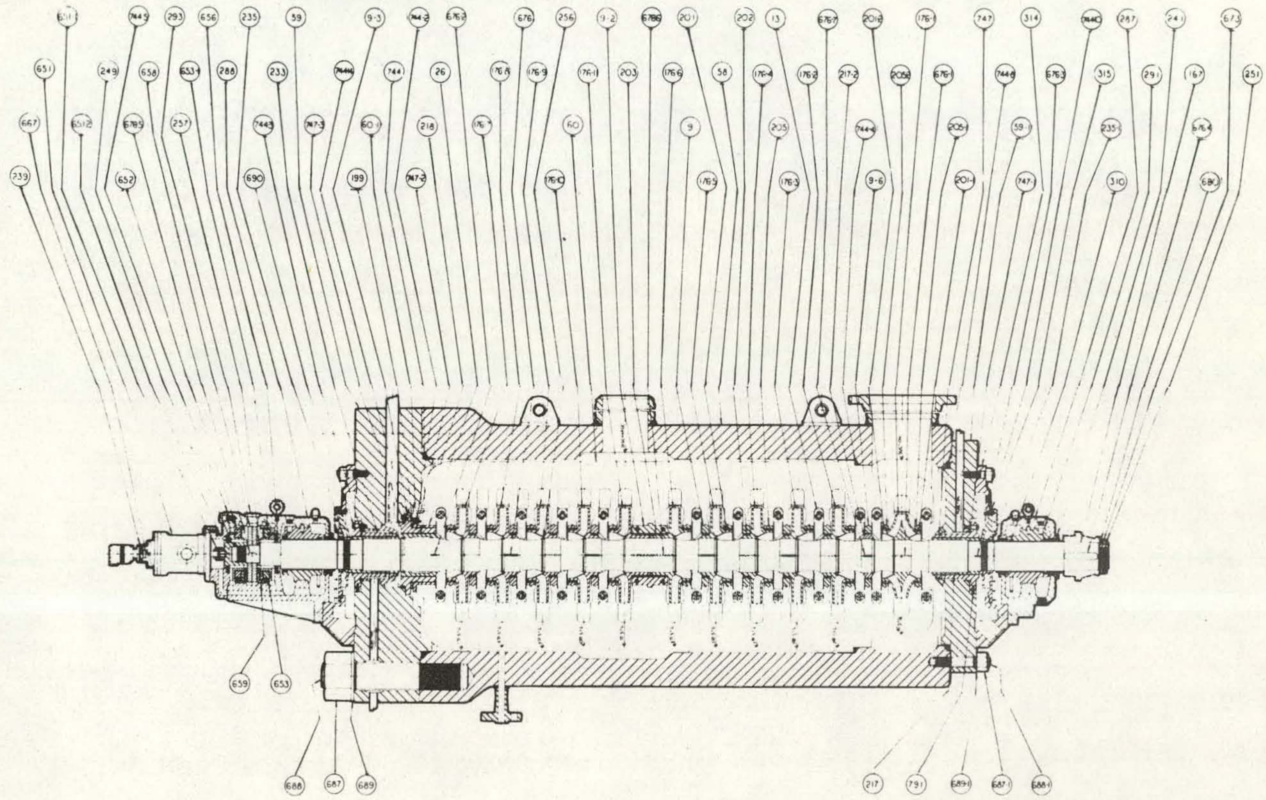
Pump design characteristics are summarized in Table 3-2.

3.3.6 Thermal Storage Drain Pumps

The characteristics of the pumps required to transfer high-energy water from the thermal storage heater drain tanks back into the receiver feedwater loop are summarized in Table 3-3.

HIGH PRESSURE • DOUBLE CASE • BOILER FEED PUMPS

SECTIONAL DRAWING — 11 STAGE — TYPE HDB



REF. NO.	NAME OF PART
9	STAGE PIECE–SERIES
9-2	STAGE PIECE–CENTER–SPLIT
9-3	COVER ADAPTER–BALANCE SLEEVE
9-6	STAGE PIECE–1ST STAGE SLEEVE
13	SPLITTER
26	BUSHING–VOLUTE
58	BARREL–OUTER
59	COVER–OUTER BARREL
59-1	COVER–SUCTION END
60	VOLUTE CASE–IN HALVES
60-1	LOCK PIN–VOLUTE CASE
167	SHAFT
176-1 TO 176-11	IMPELLER–STAGES 1 THRU 11
199	VOLUTE LOCATING RING
201	WEAR RING–IMPELLER–SERIES
201-1	WEAR RING–IMPELLER–S.D.
201-2	WEAR RING–IMPELLER–L.D.
202	WEAR RING–IMPELLER–HUB
203	WEAR RING–CENTER–HUB
205	WEAR RING–CASE–SERIES
205-1	WEAR RING–CASE–S.D.
205-2	WEAR RING–CASE–L.D.
217	SHAFT SLEEVE
217-2	SHAFT SLEEVE–1ST STAGE
218	BALANCE SLEEVE
233	BUSHING–STUFFING BOX
235	SLEEVE NUT–COVER END

REF. NO.	NAME OF PART
235-1	SLEEVE NUT–SUCTION END
239	TACHOMETER BRACKET
241	DEFLECTOR
249	OIL PUMP DRIVE
251	LOCK NUT–COUPLING
256	SPLIT RING
257	LOCATING RING–SHAFT
287	HOUSING–RADIAL BEARING–IN HALVES
288	HOUSING THRUST BEARING IN HALVES
291	SLEEVE BEARING–IN HALVES
293	OIL SIGHT COVER
310	OIL RING
314	BEARING BRACKET
315	COVER–BEARING BRACKET
651	OIL PUMP
651-1	COUPLING ASSEMBLY–OIL PUMP
651-2	BRACKET–OIL PUMP
652	HOUSING RING
653	LEVELING PLATE (12 PER SET)
653-1	ROCKER PLATE (12 PER SET)
656	OIL SEAL
658	THRUST DISC
659	THRUST SHOE ASSEMBLY (12 PER SET)
667	TACHOMETER COUPLING
673	LOCKWASHER–COUPLING
676	KEY–IMPELLER–SERIES
676-1	KEY–IMPELLER–1ST STAGE

REF. NO.	NAME OF PART
676-2	KEY–BALANCE SLEEVE
676-3	KEY–SHAFT SLEEVE
676-4	KEY–COUPLING
676-5	KEY–THRUST DISC
676-6	KEY–IMPELLER–CENTER
676-7	KEY–1ST STAGE SHAFT SLEEVE
680	SPACER NUT–COUPLING
687	NUT–COVER TO BARREL
687-1	NUT SUCTION COVER TO BARREL
688	STUD–COVER TO BARREL
688-1	STUD–SUCTION COVER TO BARREL
689	WASHER–COVER TO BARREL
689-1	WASHER–SUCTION COVER TO BARREL
690	LOCKING LUG
744	GASKET–COVER TO BARREL
744-2	GASKET–VOLUTE BUSHING
744-3	GASKET–SHAFT SLEEVE
744-4	GASKET–VOLUTE TO BARREL
744-5	GASKET–BRACKET TO HOUSING
744-8	GASKET–SUCTION COVER TO BARREL
744-10	GASKET–BEARING BRACKET COVERS TO BEARING BRACKET
744-14	GASKET–COVER ADAPTER BALANCE SLEEVE TO COVER
747	O-RING STUFFING BOX BUSHING INSIDE
747-1	O-RING–STUFFING BOX BUSHING–FLANGE
747-2	O-RING–COVER ADAPTER BALANCE SLEEVE TO VOLUTE
747-3	O-RING–COVER ADAPTER BALANCE SLEEVE TO COVER
791	ADJUSTING SCREW–STUFFING BOX BUSHING

Courtesy of Byron Jackson

Figure 3-11. Typical Receiver Feed Pump Configuration

Table 3-2

RECEIVER PUMP DESIGN CHARACTERISTICS OF COMMERCIAL SYSTEM

Quantity	3, half-capacity
Type	Double-case, barrel-type, 7-stage, 6,300 rpm
Drive	Speed increaser and variable-speed hydraulic coupling
Motor	1,865 kW (2,500 hp), 4,160V
Capacity, Each	4.07 m^3/min (1,125 gpm)
Head	2,020m (6,625 ft)
Fluid Temperature	123.7°C (254.6°F
Efficiency	78%
Brake Horsepower	1,690 kW (2266 HP)

Each thermal storage heater will have a drain tank and a pump for moving the high-temperature water to the feedwater loop; hence, the total requirements are for five pumps.

3.3.7 Thermal Storage Feed Pumps

The thermal storage feed pumps take suction from the deaerator and pump to the inlet of the thermal storage steam generators. When the thermal storage steam generators are not in operation, the thermal storage feed pump would be inoperative.

Table 3-3

THERMAL STORAGE DRAIN PUMP DESIGN CHARACTERISTICS OF COMMERCIAL SYSTEM

Quantity	5, full capacity
Type	Horizontal, centrifugal, double case, barrel-type, 5-stage, 3,550 rpm
Motor	746 kW (1,000 hp), 4160V, 3-phase
Capacity, Each	2.27 m^3/min (600 gpm)
Head	1,183m (3,880 ft)
Inlet Fluid Conditions	9.75 MPa (1,400 psig) 249°C (480°F)

The thermal storage feed pump operates at constant speed and its capacity is controlled by a throttling to maintain the desired water level in each thermal storage steam generator. Two pumps are provided in the design.

Each pump is full-capacity, is of the horizontally or radially split, multi-stage design of steel construction, and is directly connected to an electric motor drive.

Each pump is sized as follows:

Capacity	8.3 m^3/min (2,200 gpm)
Head	295.7m (970 ft)
Efficiency (Estimated)	75%
Brake Horsepower	503 kW (675 hp)
Motor Size	597 kW (800 hp), 3,550 rpm

3.3.8 Plant Piping

The Commercial Plant EPGS piping systems are discussed herein, with particular attention given to the riser/downcomer piping configuration and analysis in the unique central receiver concept. Piping design characteristics are also given for the thermal storage subsystem/EPGS steam and feedwater systems.

3.3.8.1 Riser/Downcomer

The downcomer is defined as that portion of the piping system which conveys high-pressure, high-temperature steam from the receiver superheater outlet header(s), running down the receiver tower structure, and includes the horizontal run of piping to the turbine building limits, and to the thermal storage subsystem limits.

The function of the riser is to convey high-pressure feedwater from the turbine building limits, up the receiver tower structure to the stop-check valves at the receiver inlet. The design requirements and characteristics are presented for the riser and downcomer in Tables 3-4 through 3-7.

Table 3-4

RISER DESIGN REQUIREMENTS

Applicable Code	ANSI B31.1 Power Piping Code
Pressure Required at Tower/Receiver Interface	15.51 MPa (2,250 psia)
Design Flow to Receiver (Equinox Noon)	
From Turbine Building	121.3 kg/s (0.960 x 10^6 lb/hr)
From Thermal Storage Heaters	90.2 kg/s (0.714 x 10^6 lb/hr)
Total	213.0 kg/s (1.687 x 10^6 lb/hr)
Seismic Accelerations (Survival)	
Horizontal Ground Acceleration	0.33g (Revised to 0.25g)
Vertical Ground Acceleration	0.22g
Tower Height	242m (794 ft)

Routing Considerations

The main steam system is routed with consideration for:

A. Thermal expansion.

B. Ease of support.

C. Horizontal and vertical seismic accelerations.

D. Accessibility.

E. Maintenance.

F. Economy.

Table 3-5

DOWNCOMER DESIGN REQUIREMENTS

Applicable Code	ANSI B31.1 Power Piping Code
Design Pressure	12.24 MPa (1775 psia)
Design Temperature	537.6°C (1,000°F)
Maximum Allowable Pressure Drop (Receiver/Tower Interface to Turbine and/or Thermal Storage Heaters)	1.03 MPa (150 psi)
Seismic Accelerations (Survival)	
Horizontal Ground Acceleration	0.33g (Revised to 0.25g)
Vertical Ground Acceleration	0.22g
Tower Height	242m (794 ft)

Table 3-6

RISER DESIGN CHARACTERISTICS

	Turbine Branch	Thermal Storage Branch	Receiver Tower
Design Pressure	22.55 MPa (3,270 psia)	21.65 MPa (3,140 psia)	21.65 MPa (3,140 psia)
Design Temperature	232^oC (450^oF)	260^oC (500^oF)	260^oC (500^oF)
Pipe Size (Nominal)	25.4 cm (10 in.) Sch 160	30.5 cm (12 in.) Sch 160	30.5 cm (12 in.) Sch 160
Pipe Material	Carbon Steel ASTM A106 Grade C	Carbon Steel ASTM A106 Grade C	Carbon Steel ASTM A106 Grade C
Unit Weight	172.2 kg/m (115.7 lb/ft)	238.5 kg/m (160.3 lb/ft)	238.5 kg/m (160.3 lb/ft)
Insulation	8.9 cm (3.5 in.) Calcium Silicate with Aluminum Jacket	8.9 cm (3.5 in.) Calcium Silicate with Aluminum Jacket	8.9 cm (3.5 in.) Calcium Silicate with Aluminum Jacket

Thermal Expansion -- There is approximately 274m (900 ft) of vertical drop from the top of the receiver to the base of the tower. With an average thermal expansion of 21.5 cm/30.5m (8.46 in./100 ft) of pipe, more than 1.83m (6 ft) of vertical movement must be absorbed by the pipe flexiblity. This can be done by either of the following two methods:

A. Provide horizontal expansion loops at various elevations in the tower and use long pipe risers. (See Figure 3-12).

B. Provide a step routing using as many rigid supports as possible. (See Figure 3-13).

Pipe Support -- On horizontal pipe runs, pipe supports should be located on a 32-ft spacing. The resulting dead weight pipe stress will be less than 1,500 psi and the sag between supports will be less than 0.25 cm (0.1 in.)

Table 3-7

DOWNCOMER DESIGN CHARACTERISTICS

	Receiver Tower	Turbine Branch	Thermal Storage Branch	
			(Before Desuperheater)	(After Desuperheater)
Design Pressure	12.24 MPa (1,775 psia)	12.24 MPa (1,775 psia)	12.24 MPa (1,775 psia)	12.24 MPa (1,775 psia)
Design Temperature	537.8°C (1,000°F)	537.8°C (1,000°F)	537.8°C (1,000°F)	371.1°C (700°F)
Pipe Size	34.3 cm (13.5 in.) Minimum IDX 4.503 cm (1.773 in.) Nominal Wall	26.7 cm (10.5 in.) Minimum IDX 3.512 cm (1.383 in.) Nominal Wall	25.4 cm (10.0 in.) Minimum IDX 3.345 cm (1.317 in.) Nominal Wall	30.48 cm (12 in.) Nominal Sch. 120
Pipe Material	Low Alloy Steel ASTM A335 Grade P22 (2-1/4 CR-1 Mo)	Low Alloy Steel ASTM A335 Grade P22 (2-1/4 CR-1 Mo)	Low Alloy Steel ASTM A335 Grade P22 (2-1/4 CR-1 Mo)	Carbon Steel ASTM A106 Grade B
Unit Weight	440.4 kg/m (296 lb/ft)	263.4 kg/m (177 lb/ft)	238.1 kg/m (160 lb/ft)	186.7 kg/m (125.5 lb/ft)
Insulation	14.0 cm (5.5 in.) Calcium Silicate with Aluminum Jacket	12.7 cm (5.0 in.) Calcium Silicate with Aluminum Jacket	12.7 cm (5.0 in.) Calcium Silicate with Aluminum Jacket	10.2 cm (4.0 in.) Calcium Silicate with Aluminum Jacket

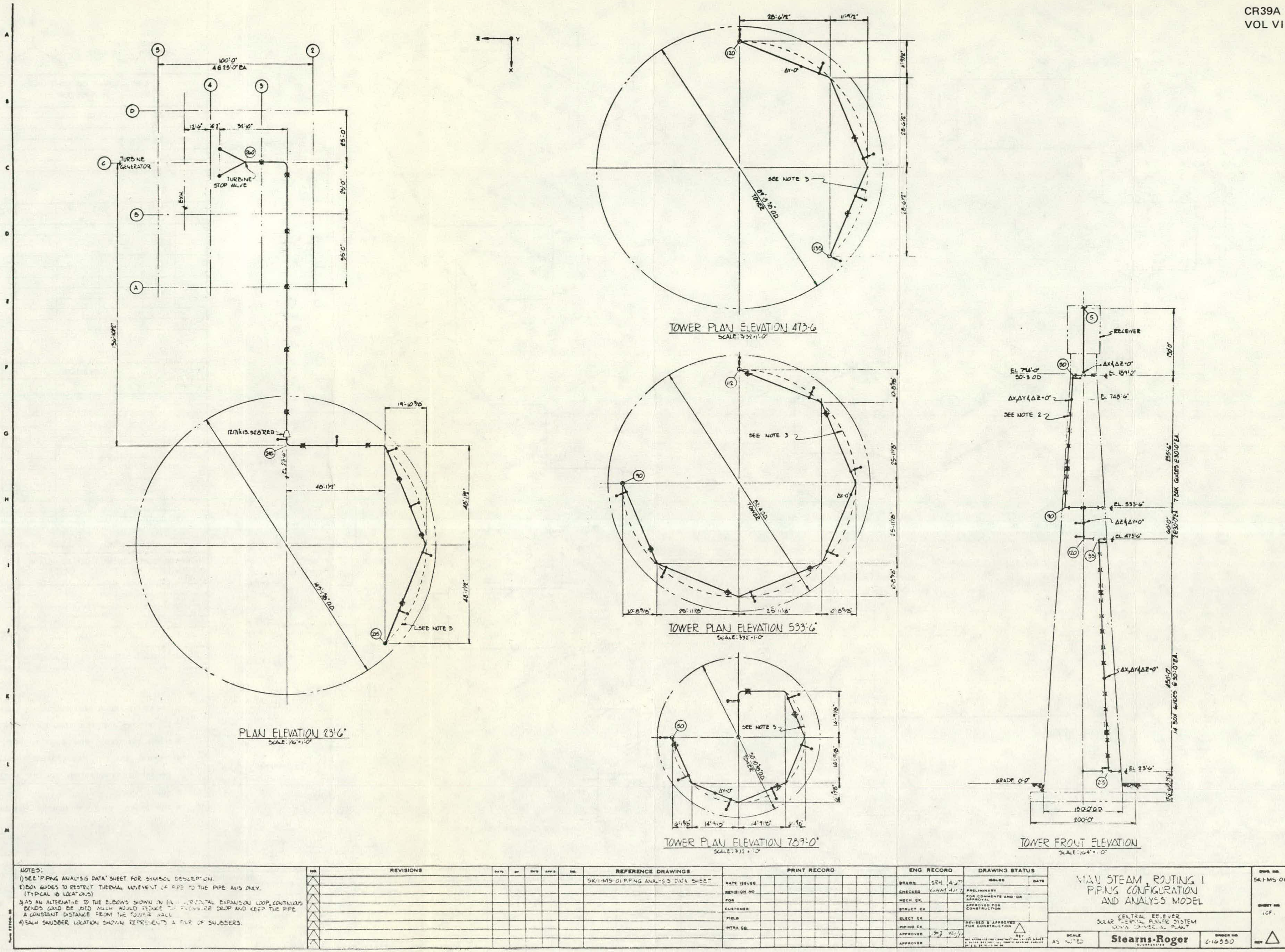
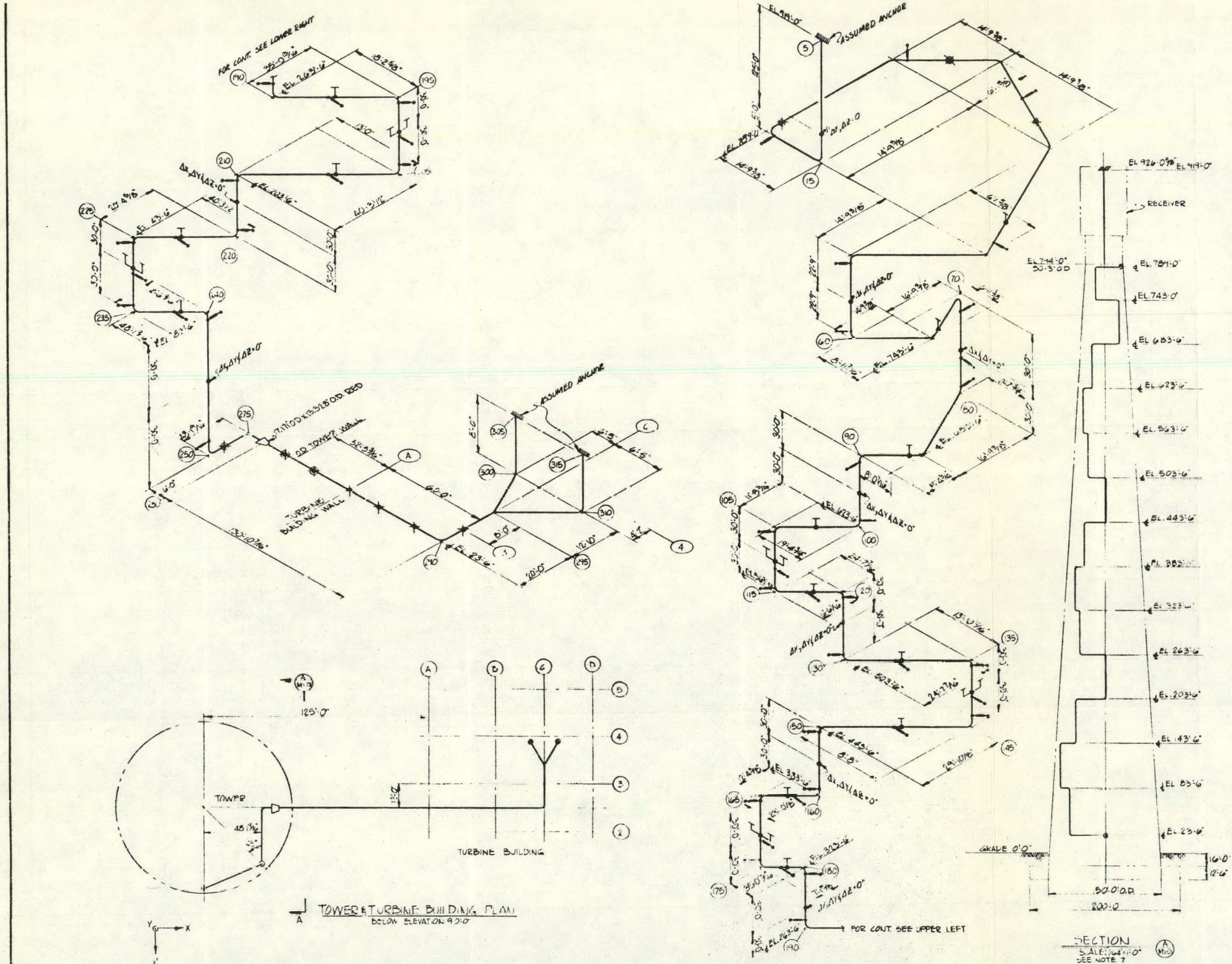


Figure 3-12. Main Steam, Routing 1, Piping Configuration and Analysis Model, 100-MW Commercial Plant



RIGHT-HAND CARTESIAN COORDINATE SYSTEM (Y, Z, X)

PIPE MATL.	LINE SPEC.	LINEAR EXP. COEFF. (IN./100 FT.) @ REF. TEMP. (°F)	DESIGN PRESS (PSIG) / TEMP (°F)	MOD. OF ELAS. (10^6 P.S.I.) E_H	E_C
A335 P22			1500 PSIG/1000°F		[illegible]

DATA POINTS FROM	TO	PIPE SIZE (IN.) O.D.	W.T.	WEIGHT LBS/LINEAR FT PIPE	FLUID	INSULATION	INS. THK
[illegible]	[illegible]	17.71	[illegible]	302.5	N/A	21.0	5"
[illegible]	315	[illegible]	[illegible]	130.1	N/A	24.0	5"

ANCHOR &/OR TERM. POINTS	COORDINATE X	Y	Z	OPERATING CONDITIONS TEMP (°F)	PRESSURE (P.S.I.G.)	CASE
5	0	0	0	[illegible]°F	[illegible]	
305	[illegible]	[illegible]	[illegible]			
315	[illegible]	[illegible]	[illegible]			

ANCHOR OR RESTRAINT NO.	DISPLACEMENT (COLD TO HOT) IN. X	Y	Z
5	0	[illegible]	[illegible]
305	[illegible]	[illegible]	[illegible]
315	[illegible]	[illegible]	[illegible]

NOTES:

1) DIMENSIONS ARE IN FEET AND INCHES UNLESS NOTED OTHERWISE.
2) ALL ELBOWS ARE ASA LONG RADIUS UNLESS NOTED OTHERWISE.
3) PIPING ANALYZED FROM COLD TO HOT.
4) THERMAL ANALYSIS TEMPERATURE RANGE IS FROM 70° F TO OPERATING TEMPERATURE UNLESS NOTED OTHERWISE.
5) SCALE NONE.
6) THIS DRAWING USED FOR ANALYSIS PURPOSES ONLY.
7) ALL TOWER RISERS BELOW ELEVATION 751-0" ARE LOCATED ON THE X-AXIS OR Z-AXIS OR 45° FROM THE X-AXIS.
8) EACH SNUBBER LOCATION SHOWN REPRESENTS A PAIR OF SNUBBERS.

MODELING SYMBOLS: POINT OF INTEREST; DATA POINT NO.; MASS POINT OR CENTER OF GRAVITY

PIPING SYMBOLS: ELBOW; BEND; VALVES (ASSUMED RIGID); REDUCER OR INCREASER; EQUIPMENT NOZZLE

PIPE SUPPORT SYMBOLS: CONSTANT SUPPORT; VARIABLE SPRING SUPPORT; RIGID ROD OR STRUT; HYDRAULIC SNUBBER; RIGID GUIDE; ANCHOR

BRANCH CONNECTION SYMBOLS: UNREINFORCED PIPE-PIPE INTERSECTION; REINFORCED PIPE-PIPE INTERSECTION; ASA TEE; WELDOLET; SWEEPOLET

NO.	ANALYSIS CODES
A	T-6880-MS 0-5-5

NO.	REFERENCES

NO.	REVISIONS	DATE	BY	CH'D	APP'D

PIPING ANALYSIS ISOMETRIC

Stearns-Roger INCORPORATED

MAIN STEAM, ROUTING 2
PIPING CONFIGURATION
AND ANALYSIS MODEL

DRAWN: [illegible]	DATE:	ANAL. BY: [illegible]	DATE: [illegible]
CHECKED: [illegible]	DATE:	APPD. BY: [illegible]	DATE: [illegible]
JOB NO. [illegible]	SYSTEM NO. [illegible]		SHEET OF

Figure 3-13. Main Steam, Routing 2, Piping Configuration and Analysis Model, 100-MW Commercial Plant

On vertical risers, at least one pipe support is required but more may be used to reduce the load on any single support.

Rigid supports are used wherever possible instead of variable spring or constant support hangers for three reasons:

A. Initial cost is lower.

B. Adjustments are not usually required during startup.

C. Maintenance is not required.

Seismic Accelerations -- It has been assumed that the major portion of the tower's seismic accelerations exist at frequencies less than 12 cps. Thus, if the pipe is supported such that its lowest natural frequency is greater than 12 cps, the pipe's natural frequencies should not be highly excited by the tower accelerations.

If the pipe is assumed to be simply supported at two ends, the maximum span between supports that will yield a pipe natural frequency of 12 cps can be calculated by:

$$L_{crit} = \sqrt{\frac{a^2}{f_n^2} \frac{EI}{W_y}}$$

where

L_{crit} = Maximum distance between supports, ft

a = Constant for simply supported beam, 0.743

f_n = Minimum desired pipe natural frequency, 12 cps

E = Modulus of elasticity at temperature, 23.6×10^6 psi

I = Moment of inertia, 2,608 $in.^4$

W_y = Weight of pipe and insulation, 325 lb/ft

L_{crit} = 29.2 ft

Thus at every 8.84 to 9.15m (29 to 30 ft) a rigid guide or mechanical or hydraulic snubber is required to resist the seismic accelerations and keep the pipe natural frequencies above 12 cps. Rigid guides are preferred to snubbers because of lower initial cost and because they require no maintenance. Snubbers are used only where thermal expansion requirements govern.

Accessibility and Maintenance -- The pipe is routed inside the tower within a few feet of the concrete tower walls. Pipe supports can be attached to the tower with a minimum amount of steel embeddments. Any platforms required for maintenance need only be cantilevered from the wall a few feet to provide access to spring pipe supports and snubbers. The rigid vertical and horizontal restraints usually require no maintenance and therefore access platforms are usually not provided at these locations.

Economy -- The basic concept is to route the pipe from the receiver to the turbine with the least amount of pipe. This reduces the cost of pipe, pipe supports, structure, and access platforms. The use of rigid restraints, such as rods, box guides, stanchion supports, etc, are preferred to the more complicated and expensive spring supports and snubbers and are used wherever practicable.

Routing Details

The two selected routings are designated:

- Routing 1. Horizontal Expansion Loops Routing (see Figure 3-12)
  - A. The minimum amount of bends or fittings.
  - B. The maximum amount of box guides instead of mechanical or hydraulic snubbers for horizontal seismic accelerations.
  - C. Rigid vertical supports wherever possible.

The pipe is routed from the receiver immediately into an expansion loop at elevation 240. 55m (789 ft). This loop proceeds 270^{o} around the tower and then drops into a 77. 9m (255 ft 6 in.) long riser. At this elevation, 162. 65m (533 ft 6 in.), another 270^{o} expansion loop is provided and the pipe drops into a 18. 29m (60 ft) riser. At this elevation a 135^{o} expansion loop is included.

Finally, the pipe drops 137. 2m (450 ft) to elevation 7. 16m (23 ft 6 in.) where the pipe is run nearly directly to the turbine. Note that even on the risers, the pipe is kept within a few feet of the inside edge of the tower wall. One quadrant of the tower is left completely open for elevator and ladder access.

The length of each riser is determined by the maximum allowable distance between the rigid vertical restraints on each riser. Specifically, the rigid vertical support at elevation 228.2m (748 ft 6 in.) is located as far down the tower as possible from the top of the receiver, given the expansion loop at elevation 240.55m (789 ft). Below this support a 62.02m (210 ft) riser is used, maintaining vertical expansion to less than 50.8 cm (20 in.). This is a maximum practical travel limit for constant support hangers. The same philosophy is used in sizing the riser from elevation 144.36m (474 ft 6 in.) to 7.16m (23 ft 6 in.). The 18.29m (60 ft) riser between elevations 162.65m (533 ft 6 in.) and 144.35m (473 ft 6 in.) provides capability for lateral thermal expansion.

The weight of each riser is supported by rigid supports with some additional help from constant support hangers on the two long risers. Each horizontal expansion loop can be supported to one rigid hanger and several constant support hangers.

Horizontal seismic accelerations on the risers are resisted by rigid box guides located every 9.15m (30 ft) on the pipe. The vertical seismic accelerations on the risers are resisted by the rigid vertical supports. Due to the pipe's thermal growth, both the horizontal and vertical seismic accelerations must be resisted by mechanical or hydraulic snubbers on the horizontal pipe runs.

The thermal expansion analysis shows that the pipe routing is satisfactory. The maximum thermal expansion stress between the top of the receiver and the turbine stop valve is 12,320 psi compared to an allowable stress of 21,300 psi (ANSI-B31.1-1973). The forces and moments on the receiver and turbine are shown in Table 3-8. There should be no serious design problems with these loads. The rigid box guides have a maximum thermal load of 5,682 kg (12,500 lb), although most loads are less than 909 kg (2,000 lb).

A slight variation of Routing 1 is shown as a dashed line on Figure 3-12. It consists of using large-radius continuous bends on each horizontal expansion loop instead of several long-radius elbows. This may be useful in limiting pressure drop and the number of snubbers for seismic support.

Table 3-8

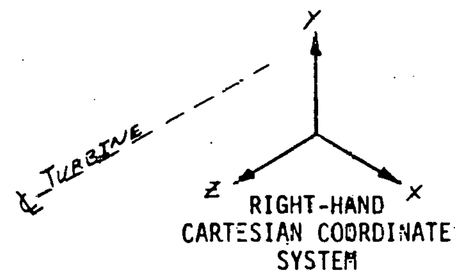
STEARNS-ROGER SUMMARY OF FORCES AND MOMENTS

CUSTOMER:	
PROJECT:	100MW Solar Commercial Plant
JOB NO:	C-16880, X31012
BY: May	DATE: 4/4/77
REF. DWGS:	SK-1-MS-01
ANALYSIS CODE:	T-16880-MS-01-A-8

SUMMARY OF FORCES & MOMENTS ON SYSTEM TERMINAL EQUIPMENT

(SYSTEM)

MAIN STEAM, ROUTING 1



THE REPORTED REACTIONS BASED ON A THERMAL EXPANSION ANALYSIS FROM 70° F to 960°F USING E_c, THE COLD MOD. OF ELASTICITY, AND ZERO% COLD SPRING.

NOTE: THERMAL LOADS ONLY!

EQUIPMENT CONNECTIONS	FORCES (LBS)					MOMENTS (FT.-LBS)			
	LOC. NO.	X	Y	Z	RESULTANT	X	Y	Z	RESULTANT
Top of Receiver, El.919 0"	5	-263	12190	414	12200	-17250	13050	-10970	24250
Turbine Connection	270	12130	-3350	-8500	15180	36900	-50890	85160	105850
Turbine Connection	260	-18630	3025	10190	21450	-62950	60030	-120900	149000

DIVISION USAGE: MM | P | PP | SH | FI | SP

APPROVALS

Div. Sec.

Sec. Supv.

Div.

Stearns-Roger INCORPORATED

ENGINEERING STANDARD

SUMMARY OF FORCES & MOMENTS PER. ANSI B31.1-1973 PWR. PIPING CODE

STANDARD NUMBER EE 16.01.7

PAGE 1 OF 1

ISSUED 2/28/74

REVISED

- Routing 2. Step Routing (see Figure 3-13)
  - A. Uses virtually all rigid vertical supports in the tower.
  - B. Uses pipe expansion loops designed in 36.6m (120 ft) modules.
  - C. Keeps all thermal movements to a minimum.

The pipe is routed from the receiver into a 225° horizontal expansion loop at elevation 240.55m (789 ft). The pipe is then routed through a series of 18.29m (60 ft) risers with horizontal legs at the bottom of each riser. This continues until the pipe reaches elevation 7.16m (23 ft 6 in.) where the pipe is run nearly directly to the turbine. The horizontal runs provide the flexibility for thermal expansion while keeping the pipe close to the tower wall.

Except for the horizontal expansion loop at the top of the riser and the horizontal pipe run to the turbine building, all supports are rigid rods. The remainder are shown as constant support or variable spring hangers, although refined analysis may show that some of the supports between the tower and turbine may be rigid.

Horizontal seismic accelerations are resisted by rigid box guides only at the middle of every alternate 18.29m (60 ft) riser; otherwise, snubbers must be used. All vertical seismic accelerations are resisted by the rigid rod supports. For Routing 2, it would be advantageous to use more rigid supports to resist seismic accelerations. However, due to thermal expansion stresses, the only convenient locations for rigid supports are those shown on Figure 3-13.

The thermal expansion analysis shows that the pipe routing is satisfactory. The maximum thermal expansion stress between the receiver and the turbine stop valve is 12,790 psi, compared with an allowable stress of 21,300 psi (ANSI-B31.1-1973). The forces and moments on the receiver and turbine are shown in Table 3-9. The loads should not cause any serious design problems. The maximum load on any box guide restraint is 1,981.7 kg (6,500 lb), which should be a satisfactory load in the tower design.

Table 3-9

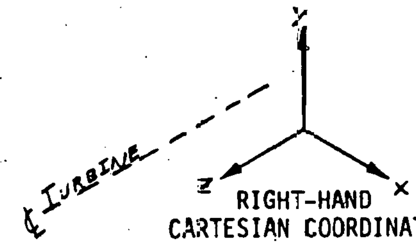
STEARNS-ROGER SUMMARY OF FORCES AND MOMENTS

CUSTOMER:	
PROJECT:	100MW Solar Commercial Plant
JOB NO:	C-16880, X-31012
BY: MAY	DATE: 4/4/77
REF. DWGS:	SK-2-MS-01
ANALYSIS CODE:	T-16830-MS-01-B-3

SUMMARY OF FORCES & MOMENTS ON SYSTEM TERMINAL EQUIPMENT

(SYSTEM)

MAIN STEAM, ROUTING 2



RIGHT-HAND CARTESIAN COORDINATE SYSTEM

THE REPORTED REACTIONS BASED ON A THERMAL EXPANSION ANALYSIS FROM 70°F to 960°F USING E_o, THE COLD MOD. OF ELASTICITY, AND ZERO% COLD SPRING.

NOTE: THERMAL LOADS ONLY!

EQUIPMENT CONNECTIONS		FORCES (LBS)				MOMENTS (FT.-LBS)			
	LOC. NO.	X	Y	Z	RESULTANT	X	Y	Z	RESULTANT
Top of Receiver, El. 919'0"	5	-329	14250	960	14290	-39760	15640	-13710	45240
Turbine Connection	305	-13940	-920	1370	14040	-4500	-53550	-93700	108000
Turbine Connection	315	16720	830	-2720	16960	16000	57500	110900	126000

DIVISION USAGE: MM | P | PP | SH | FI | SP

APPROVALS: Dsn. Sec. / Sect. Supv. / Div.

Stearns-Roger INCORPORATED

ENGINEERING STANDARD

SUMMARY OF FORCES & MOMENTS

PER. ANSI B31.1-1973 PWR. PIPING CODE

STANDARD NUMBER: EE 16.01.7

PAGE 1 OF 1

ISSUED 2/28/74

REVISED

Routing Comparison

Table 3-10 shows a comparison of the amount of pipe and support components which are required for the two routings. The length of pipe for the routings is nearly identical. Routing 2 requires more snubbers and more fittings; Routing 1 requires more constant support hangers. Routing 1 requires maintenance platforms for snubbers and constant support hangers at eight elevations; Routing 2 requires platforms at 20 elevations.

The only strong advantage for Routing 2 over Routing 1 is the number of constant support hangers. Routing 1 is clearly desirable in almost all other categories, including maintenance. Routing 1 is recommended.

Other Piping Systems

Three other piping systems must be routed down the tower. They are:

1. Receiver feedwater (riser).
2. Flash tank vapor.
3. Flash tank condensate.

Each line can be routed using the same design philosophy as either routing of the main steam line. This will minimize platform and steel requirements.

3.3.8.2 Admission Steam Piping

The admission steam piping defined herein includes that piping from the thermal storage steam generator interface to the turbine admission steam inlet.

Requirements	
Applicable Code	ANSI B31.1 Power Piping
Pressure Required at Turbine Inlet	2.52 MPa (365 psia)
Temperature Required at Turbine Inlet	296°C (565°F)
Maximum Allowable Pressure Drop	103.4 kPa (15 psi)
Design Admission Flow	114.3 kg/s (905,593 lb/hr)

Design Characteristics	
Design Pressure	3.21 MPa (465 psia)
Design Temperature	301.7°C (575°F)

Table 3-10

STEARNS-ROGER COMPARISON OF ROUTINGS 1 AND 2

Stearns-Roger

COMPARISON OF ROUTINGS 1 AND 2

COMPONENT		ROUTING 1	ROUTING 2
Length of Pipe Including Fittings		1441 ft.	1469 ft.
Number of Constant Support Hangers		25	6
Number of Variable Spring Hangers		0	4
Number of Rigid Vertical Supports		6	26
Number of Box Guides		21	7
Number of Snubbers		53	87
Number of Fittings			
	90°	10	30
	67°	2	1
	54°	0	2
	45°	12	3
	TOTAL	24*	36

Note: All components are measured from the bottom of the receiver to the turbine stop valve with the exception of the "number of snubbers". The snubbers are not tabulated from the tower to the turbine because seismic response of the turbine building and pipe racks have not been calculated.

* See note 3, "Main Steam, Routing 1, Piping Configuration and Analysis Model".

Pipe Size, OD	45.7 cm (18 in.) Standard Weight 0.95 cm (0.375 in.) Wall
Pipe Material	Carbon Steel, ASTM A106 Gr B
Unit Weight	105.0 kg/m (70.6 lb/ft)
Insulation	10.2 cm (4.0 in.) Calcium Silicate with Aluminum Jacket

3.3.8.3 Thermal Storage Feedwater Piping

The feedwater piping described herein includes that piping from the thermal storage feed pump to the thermal storage steam generator interface.

Requirements	
Applicable Code	ANSI B31.1 Power Piping
Pressure Required at Thermal Storage Heater Inlet	2.76 MPa (400 psia)
Temperature Required at Thermal Storage Subsystem Interface (Maximum)	121°C (250°F)
Design Feedwater Flow	114.3 kg/s (905,593 lb/hr)
Design Characteristics	
Design Pressure	4.48 MPa (650 psia)
Design Temperature	138.9°C (275°F)
Pipe Size (Nominal)	20.3 cm (8 in.) Sch 40
Pipe Material	Carbon Steel, ASTM A106 Grade B
Unit Weight	42.6 kg/m (28.6 lb/ft)
Insulation	6.35 cm (2.5 in.) Calcium Silicate with Aluminum Jacket

3.3.8.4 Balance of Commercial EPGS Piping

The balance of the Commercial Plant EPGS piping lying within the scope of the subsystem, including turbine extraction, condensate and feedwater piping, and miscellaneous piping systems, will be designed in accordance with the required turbine cycle performance requirements, using ANSI B31.1 Power Piping Code when applicable, in accordance with accepted power plant design practice.

3.3.9 Electric Plant Systems

3.3.9.1 Main Electrical System

The generator will be connected by isolated phase bus to the unit auxiliary transformer, surge protection, and voltage transformer cubicle, and the main power transformer, as shown in Figure 3-14, which is the electrical one-line diagram for the Commercial Plant.

The main power transformer will step up generator voltage to the voltage required by the power-transmission system. For the purpose of this report, the transmission system was assumed to be 115 kV. The main power transformer will be rated 115-13.2 kV; 130 MVA, FOA. Transformer temperature rise will be reduced based on ambient temperature if ambient temperature exceeds 40°C. The 115 kV winding will be wye-grounded; the 13.2 kV winding will be delta.

The main power transformer will be connected to the transmission system by an overhead line or underground cable, oil circuit breaker, and disconnecting switches. The oil circuit breaker would be rated 115 kV, 1,200 amperes. The disconnecting switches will be 115 kV, 1,200 ampere, 3-pole gang operated. The switches will be mounted on a steel structure. The 115-kV switching equipment will be as required by the utility.

The startup transformer will be connected to the transmission system by either an overhead line or underground cable, and a circuit switcher. The circuit switcher will be rated 115 kV, 1,200 amperes. The startup transformer supply and switching equipment will be as required by the utility.

3.3.9.2 Auxiliary Systems

Auxiliary power will normally be supplied by the unit auxiliary transformer which will be rated 13,200-4,160V, 13.44/17.92/22.4 MVA, OA/FA/FA. Transformer temperature rise will be reduced based on ambient temperature if ambient exceeds 40°C. The primary will be connected delta. The secondary will be wye resistance-grounded. The unit auxiliary transformer will be connected to the generator isolated phase bus. The secondary of the

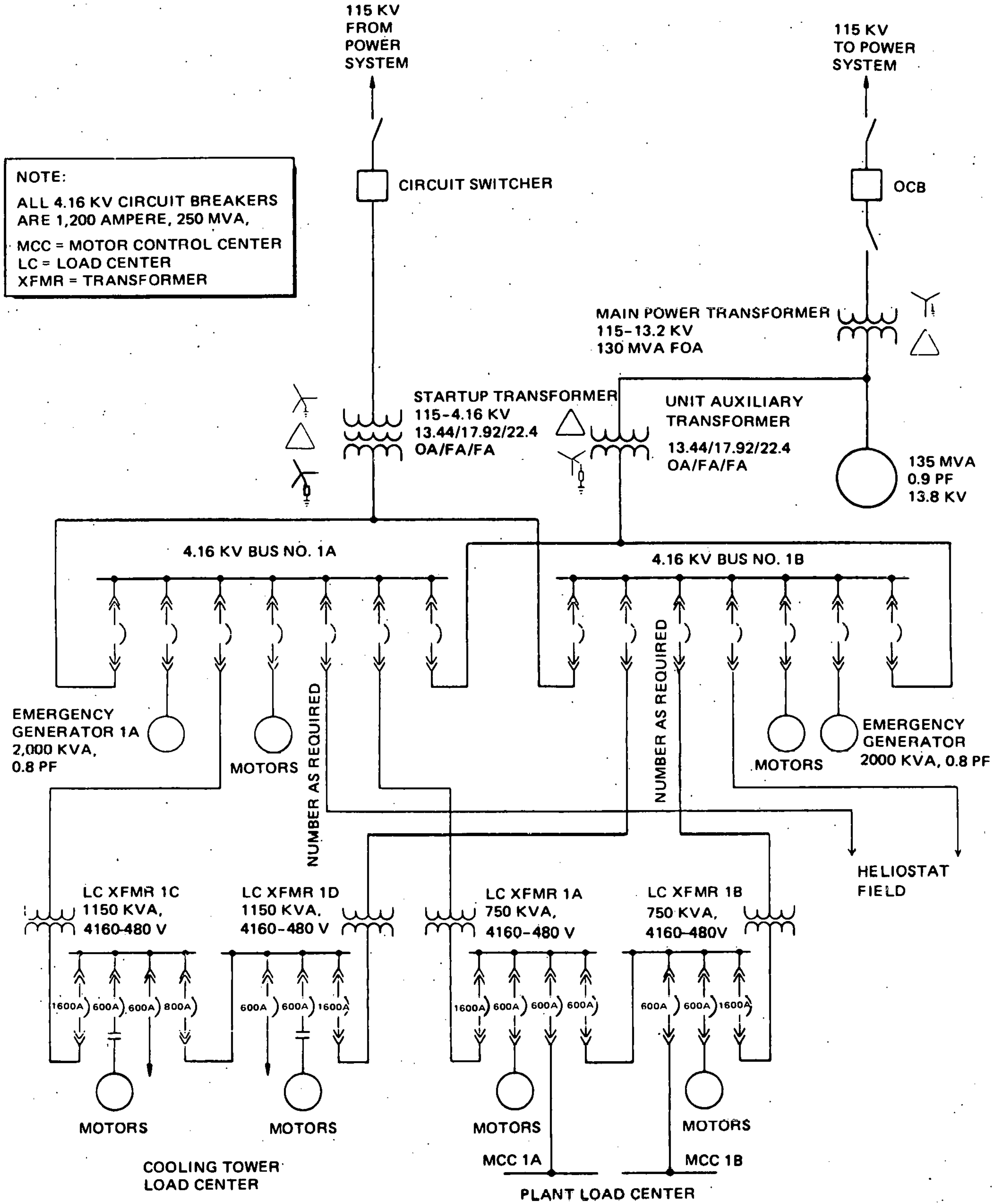


Figure 3-14. Commercial Plant Electrical One Line Diagram

transformer will feed two bus sections of metal-clad switchgear, operating at 4,160V. The connection to the 4,160V bus will be nonsegregated phase bus.

Startup power will be supplied from the transmission system by the startup transformer. The transformer will normally supply all auxiliary power when the generator is not operating. In addition, the transformer will be available, for emergency service, and to supply auxiliary power if the unit auxiliary transformer is not available (due to failure). The startup transformer will be rated 115 kV, 4.16 kV, 13.44/17.92/22.4 MVA, OA/FA/FA. The primary will be grounded wye, the secondary resistance-grounded wye. The transformer will have a tertiary. The final primary voltage will be determined by available transmission voltages. The transformer will be 550 kV BIL, and will be provided with surge arresters. Transformer temperature rise will be reduced based on ambient temperature if ambient exceeds 40°C.

Two bus sections of 4,160V switchgear were selected to obtain greater reliability and substantially the same cost as a single bus section. The larger breaker required for a single bus section cost about twice as much as the smaller breakers required for two bus sections.

All motors larger than 200 hp will be served directly from the 4,160V buses. Motors larger than 100 hp up to 200 hp will be served from load center circuit breakers. Where reversing motors are required, these will be served by motor control center. Motors of 100 hp and less will be served by motor control centers.

The plant load center (1A and 1B) will be double ended with two 4,160-480V, three phase, 750 kVA silicone oil-filled or dry-type transformers. The secondary main breakers will be 600V, 1,600-ampere drawout power circuit breakers. A 600V, 800-ampere drawout circuit breaker will be provided for the bus tie. Feeder circuit breakers will be 600V, 600-ampere drawout power circuit breakers. The plant load center will be located indoors.

The cooling tower load center will be double-ended with two 4, 160-480V, three phase, 1, 150 kVA oil-filled transformers. The secondary main breakers will be 600V, 1,600-ampere, drawout power circuit breakers. A 600V, 800 ampere drawout power circuit breaker will be provided for the bus tie. The feeder assembly will be a motor control center. The starters for cooling tower fans will be circuit-breaker combination, reversing (if reversing is required). Molded case breakers will supply lighting transformers and miscellaneous services. The cooling tower load center transformers will be located outdoors. The switchgear and motor control centers will be located indoors.

Two motor control centers will be served by the plant load centers, one from each bus section. Circuit-breaker combination starters will be provided for motors. Molded case breakers will be provided for lighting transformers, battery chargers, and miscellaneous service.

3.3.9.3 Emergency Generator

Two 750-kW emergency power diesel engine generators will provide power for safe shutdown and emergency service. The generators will each be rated 2,000 kVA, 80% power factor, 4, 160V. Each generator will be connected to one of the 4, 160V bus sections by power cable. The diesels will be automatic starting.

3.3.9.4 Heliostat Field Feeders

The heliostat fields will be served by eight 4, 160V feeders. The feeders will form a loop. Pad-mount transformers rated 4, 160/240V will supply the heliostat field. The feeders will be direct-burial power cable, with concrete cover. The number, size, and location of transformers will be defined under the collector subsystem.

3.3.9.5 DC System

The DC system for the Commercial Plant will consist of a battery, two battery chargers, distribution panels, and two inverters. The battery will be a 60-cell lead acid, 400 ampere-hour, pasted plate type. The battery chargers will be automatically regulated, 125 VDC float, 140 VDC-equalizing charge, 460 VAC supply. A main distribution panel will supply all loads over 100 amperes. There will be two small distribution panels. The small distribution panels will supply all loads of less than 100 amperes. All distribution panels will use switches and fuses. Two 15-kVA inverters will provide supply critical control requiring 120 or 208 VAC.

3.3.10 Auxiliary Power

The Commercial Plant auxiliary power requirements for various operating modes are shown in Table 3-11.

The maximum auxiliary power requirements occur at equinox noon when concurrently charging thermal storage and generating rated power. As seen from the table, the major auxiliary power requirements are for the receiver feed pumps, thermal storage drain pumps, cooling tower fans, circulating water pumps, plant HVAC, heliostats and controllers, and thermal storage charging pumps.

During evening operation on thermal storage steam, the major auxiliary power users are the thermal storage feed pump, cooling tower fans, circulating water pumps, and thermal storage extraction pumps.

During nighttime standby, auxiliary power is required for the water-treatment facilities, condensate transfer pump, auxiliary steam boiler, condenser vacuum pumps, plant HVAC, lighting, and miscellaneous services.

AC power for emergency shutdown is provided by two 750-kW diesel engine-generator sets. Emergency power is provided for the heliostat field, instrument air compressor, turbine AC oil pump, receiver tower elevator, emergency lighting, and miscellaneous services such as computer, control and computer HVAC, motor-operated valves, and turbine turning gear.

The heliostat field for the Commercial system requires approximately 10,460 kW when operating all drive motors simultaneously, such as could occur during an emergency slew condition. However, it is not practical to

Table 3-11 (Page 1 of 2)

COMMERCIAL PLANT AUXILIARY POWER REQUIREMENTS

Component	Receiver Operation Equinox (Design) 100 MW Net kW	Thermal Storage Operation 70 MW Net kW	Night Standby kW	Emergency Power AC kW	Emergency Power DC kW
Receiver Feed Pump	3,492	-	-	-	-
Thermal Storage Drain Pump	2,235	-	-	-	-
Thermal Storage Feed Pump	-	500	-	-	-
Hotwell Pump	130	121	-	-	-
Condenser Vacuum Pump	41	41	41	-	-
Condensate Trans Pump	-	-	24	-	-
Service Air Compressor	60	-	-	-	-
Instrument Air Compressor	45	45	45		
Cooling Tower Fans	886	886	-	-	-
Circ Water Pumps	2,313	2,313	-	-	-
Turbine AC Oil Pump	-	-	20	20	-
Turbine DC Oil Pump	-	-	-	-	20
Lube Oil Filter Pump	1	1	1	-	-
Chemical Pumps	5	5	-	-	-
Motor-Operated Valves	-	-	-	5	-
Raw Water Pump	90	70	40	-	-
Clarified Water Pump	70	60	30	-	-
Water Treating System	25	25	10	-	-

Table 3-11 (Page 2 of 2)

COMMERCIAL PLANT AUXILIARY POWER REQUIREMENTS

Component	Receiver Operation Equinox (Design) 100 MW Net kW	Thermal Storage Operation 70 MW Net kW	Night Standby kW	Emergency Power AC kW	Emergency Power DC kW
Jockey Pump (Fire Water)	5	5	5	-	-
Auxiliary Boiler	-	-	25	-	-
Turbine Turning Gear	-	-	5	5	-
Computer	15	15	7	15	
Miscellaneous DC	-	-	-	-	20
Controls and Computer HVAC	50	50	30	30	-
Plant HVAC	440	300	300		-
Thermal Storage Charging Pump	750	-	-	-	-
Thermal Storage Extraction Pump	-	930	-	-	-
Sewage Treatment Plant	2	2	2	-	-
Potable Water Pump	5	5	-	-	-
Receiver Tower Elevator	-	-	-	30	-
Heliostats and Controllers	350	-	-	1,308	-
Lighting and Miscellaneous AC	990	726	100	30	-
TOTAL	12,000	6,100	685	1,443	40

size the emergency AC power supply for this load. The rationale used, then, for sizing the emergency power supply was to provide power to one-fourth the field at a time and then only to the elevation drive motors. This will reduce the emergency power demand for the heliostats to about 1,307 kW, which, in addition to the other emergency AC power requirements, can be supplied by the two 750-kW engine-generators provided.

3.3.11 Water Treatment

3.3.11.1 Pretreatment

With surface waters, pretreatment is required upstream of the treatment process used for the production of electric utility system steam generator makeup water. The principal purpose of such pretreatment is to remove suspended material and reduce turbidity. Without pretreatment, physical fouling of the ion exchange resins, membranes, or cartridge filters preceding membrane processes could result. In addition, some colloidal material will not be removed by ion exchange processes. If it is not removed, it would pass through an ion exchange demineralizer and result in deposit formation in the steam generator (receiver) and turbine. Colloidal silica, in particular, has been a source of such difficulties. Pretreatment can also be used to remove organic materials such as humic and fulvic acids. These materials, the result of decaying vegetable matter, can foul anion exchange resins. Pretreatment to remove suspended solids is usually accomplished by adding various flocculating materials and coagulant aids to promote coalescence of particles. The larger particles can then settle out of the water at a reasonably rapid rate. The equipment used for this purpose provides for adequate mixing of the various chemicals and weighting agents with the water, followed by a relatively quiescent zone for settling. The process, called clarification, is usually followed by filtration. The filters remove that small quantity of suspended material which inevitably fails to be removed by the clarification step. If the water has an unusually high content of suspended solids, presettling may be required to avoid overloading the clarifier. In some cases, the clarification step is omitted, and direct filtration is used. Coagulants are added upstream of the filter to promote particle growth and attract suspended material to the filter media.

If the surface water contains substantial concentrations of calcium and bicarbonate ions, lime softening is frequently carried out during the clarification step. Sufficient lime is added to precipitate most of the calcium and bicarbonate as the sparingly soluble calcium carbonate. This is a relatively inexpensive means of reducing hardness, alkalinity, and total dissolved solids, thus reducing the load on the boiler makeup water treatment facilities.

The suspended solids content of well waters is usually low, and clarification or filtration is not generally needed to remove same. However, well waters can contain significant quantities of dissolved iron, manganese, hydrogen sulfide, carbon dioxide, hardness, alkalinity, and colloidal silica. The appropriate pretreatment approach depends on the concentration and combination of these constituents in the water. Aeration can remove carbon dioxide and, depending on the pH, much of the hydrogen sulfide. Depending on the nature of the water in which the iron and manganese is present, aeration can also oxidize the materials from their soluble divalent forms to their insoluble trivalent forms. They then precipitate as the ferric hydroxide and manganic hydroxide and can be removed by settling and filtration, or occasionally filtration alone. Chlorine is occasionally used as an oxidant to supplement the aeration step, or to eliminate it. Chlorine will also oxidize hydrogen sulfide to sulfuric acid. It is used to remove small quantities of hydrogen sulfide remaining after aeration, or in place of aeration if the concentration of hydrogen sulfide is relatively low and aeration is not required for other purposes. Ozone is another effective oxidizing agent, and might be used in place of chlorine.

Ferric and manganic hydroxides may be removed in a clarifier, in which case lime softening may again be carried out.

Chlorination or ozonation of the effluent water from a pretreatment process is usually adequate to produce water for potable purposes.

3.3.11.2 Circulating Water Treatment

Pretreatment is occasionally required to reduce the concentrations of suspended solids, iron, manganese, phosphate, calcium, magnesium, alkalinity, silica, and/or other constituents of the cooling tower makeup water.

Evaporation from the cooling tower system will result in concentration of the various materials introduced into the system with the makeup water. The degree of concentration must be limited to prevent precipitation of various materials such as calcium carbonate, calcium sulfate, silica (as quartz or amorphous silica), and magnesium silicate, which would interfere with heat transfer at the condenser. In addition, over-concentration of suspended solids in the circulating water must be avoided to prevent physical fouling of the system.

Internal treatment in the system would normally consist of the introduction of sulfuric acid to prevent excessive buildup of carbonate alkalinity, supplemented by addition of a commercial-scale inhibitor. Such inhibitors are usually organophosphonates or phosphate-based polyol esters. Use of these materials will usually permit reasonably high cycles of concentration without the formation of calcium carbonate scale. Use of the scale inhibitor permits higher alkalinity concentrations, thus reducing sulfuric acid requirements. This is beneficial since the potential for corrosion in the system is lower at higher alkalinity levels. Further, since fewer sulfate ions will be present in the circulating water, higher calcium concentrations may be carried without formation of calcium sulfate scale.

Cycles of concentration within the system are maintained at the appropriate level by cooling tower blowdown. One of the goals of the circulating water treatment will be to permit reasonably high cycles of concentration to limit the quantity of blowdown. Since no waste water is to be discharged from the plant, limiting the blowdown quantity will reduce the size of the evaporation pond to be used for its final disposition.

If the suspended solids content of the circulating water appears to be a limiting factor with respect to cycles of concentration, sidestream filters can be employed. These are sand and/or anthracite units usually designed to filter 1 to 3% of the total circulating water flow, thereby effecting a significant reduction in the suspended solids concentration. The backwash water from such filters is settled and reclaimed.

In some instances, the silica concentration of the makeup water is a limiting factor, and is sufficiently high that removal by pretreatment is uneconomical, impractical, or both. In such a situation, removal by lime softening a sidestream from the circulating water system might prove advantageous. The higher temperature and higher silica concentration of the sidestream as compared to the makeup water lend themselves to more efficient silica removal. Hardness and alkalinity would also be reduced with a sidestream lime softener, although not usually more efficiently than with a makeup lime softener.

Biological activity (growth of algae and bacterial slimes) within the cooling tower system must be controlled to avoid fouling, and in some cases, corrosion. This is usually accomplished with intermittent chlorination of the circulating water for 15 to 30 min, 1 to 3 times daily. Chlorination must occasionally be supplemented with intermittent addition of other commercially available biocidal materials.

3.3.11.3 Final Treatment

Demineralization or evaporation is required for production of boiler makeup water. The most widely used demineralization process for this purpose is ion exchange. In certain situations, high dissolved solids concentrations, high chemical costs, and/or relatively low water requirements have resulted in reverse osmosis demineralization proving to be a more economical approach. Reverse osmosis does not produce a water sufficiently low in dissolved solids for high-pressure boiler makeup purposes. Its effluent must be further treated by ion exchange. Demineralized or evaporated water would also be the most suitable water in the facility for mirror washing.

Although there are a number of reasons why evaporators are no longer in general use in large steam-generating stations, they could be the only practical alternative for the production of boiler makeup water if the raw water has an extremely high concentration of dissolved solids (approaching sea water). Daily startup and shutdown of an evaporator would be an inconvenience.

The ion exchange demineralizer configuration is subject to many variations. The quality of the water to be treated will determine the most appropriate one.

Regardless of whether reverse osmosis or ion exchange demineralization is used, the final ion exchange vessel would be a mixed bed polisher. This uses a mixture of strongly acidic cation exchange resin and strongly basic anion exchange resin. It functions in much the same way as would an infinite number of alternating cation and anion exchange units, and produces water of consistently high quality. Water of similar quality could be produced with a sufficient number of alternating individual ion exchange units and/or the appropriate use of counter-current regeneration (in which the direction of regenerant flow is opposite from the service flow), but usually not as consistently or as readily.

In some situations, intermediate treatment is required upstream of an ion exchange demineralizer to remove organic materials, which might foul the ion exchange resin, and which have not been wholly removed by the pre-treatment process. Unfortunately, unless the organic content of the raw water is very high, it is not always possible to predict in advance whether or not organic fouling will be a problem. In many cases, organic removal facilities have had to be added after the fact. Activated carbon filters have been used with some success to remove organics with fouling potential. "Organic traps" have also been used. These are anion exchange resins capable of efficient removal of organics from the water and from which sorbed organics can be readily eluted upon regeneration. They are operated in the chloride cycle and regenerated with a sodium chloride solution. Organic fouling can frequently be ameliorated by a judicious selection of the ion exchange resins to be used in the demineralizer.

3.3.11.4 Condensate Polishing

With a once-through steam generator, any dissolved or suspended solids present in the feedwater will either be deposited on the boiler (receiver) surface as the carrier water evaporates, or will carry through and deposit in the turbine. Recommended limits for solids and pH in feedwater for once-through boilers are shown in Table 3-12. The presence of such materials in the feedwater is inevitable because of corrosion in the condensate feedwater cycle. Even though corrosion is reduced to a very low level by deaeration and pH control, it cannot be completely eliminated. A unit subject to daily startups and shutdowns is even more susceptible to corrosion than a continuously operated unit. Accordingly, a full-flow condensate

Table 3-12

RECOMMENDED LIMITS FOR SOLIDS AND pH IN FEEDWATER FOR ONCE-THROUGH BOILERS

Factor	Recommended Maximum Limit	Typical Concentrations
Total Solids	0.050 ppm	0.020 ppm
Silica as SiO_2	0.020 ppm	0.002 ppm
Iron as Fe	0.010 ppm	0.003 ppm
Copper as Cu	0.002 ppm	0.001 ppm
Oxygen as O_2	0.007 ppm	0.002 ppm
Hardness	0.0 ppm	0.0 ppm
Carbon Dioxide	0.0 ppm	not measured
Organic	0.0 ppm	0.002 ppm
Lead	0.0 ppm	---
pH	9.3 - 9.5	9.45

*Steam, Its Generation and Use. Babcock and Wilcox, 38th edition (1972).

polisher is essential to maintain feedwater total solids at the required 20 to 50 ppb level. This is an ion exchange unit of sufficient capacity to treat the entire plant condensate stream. Two basic types of polisher are available, deep bed and powdered resin. The deep bed unit uses bead-form strongly acidic cation exchange resins and strongly basic anion exchange resins in a mixed-bed configuration to remove impurities from the water by ion exchange and filtration. The resins are regenerated as required with acid and sodium hydroxide. In some cases, in order to reduce chemical consumption, an ultrasonic cleaning device has been used to treat the resins when they are physically fouled with suspended material, but still retain considerable ion exchange capacity. The powdered resin unit employs a thin layer of powdered resin deposited on a nylon or stainless steel septum. It also removes impurities by ion exchange and filtration. When the pressure drop across the unit exceeds a predetermined value, the unit is taken out of service, the resin is removed by backflushing, and fresh resin is applied. There is no regeneration.

The powdered resin unit is less expensive initially because no regeneration facilities need be purchased, and the initial resin inventory is low. It may or may not be more costly on a long-term basis, depending upon how frequently replacement resin is required. It is somewhat more effective as a filter than the deep-bed polisher; however, it has very little reserve ion exchange capacity. In the event of a small condenser leak, operation could not be continued for any significant period of time with a powdered resin unit.

The condensate suspended solids loading is considerably greater after a startup than during normal operation. Accordingly, with daily startups, it is anticipated that use of a powdered resin unit would result in an extremely high resin consumption.

Because of the anticipated high suspended solids loading and the possibility of a condenser leak, a deep-bed polisher would appear to be the appropriate selection for this facility.

3.3.11.5 Impact of Water Quality Requirements on Water-Treatment Costs
Given a once-through steam generator configuration and intermittent operation, the above discussion, with respect to pretreatment, final treatment, and condensate polishing, is valid. A relaxation of makeup water quality requirements could conceivably indicate that no mixed-bed polisher was necessary on the makeup demineralizer, or that lower regenerant dosages could be used; however, this act would be a false economy for several reasons. First, a greater load would be placed on the condensate polisher. Since regeneration of such unit is usually accomplished externally by transporting the resin from these units to other vessels, a greater amount of resin loss through attrition occurs than in a makeup demineralizer bed polish. Thus, resin replacement costs would increase. Further, using the polisher to remove materials that should have been removed by the makeup system reduces its availability for condensate cleanup. Also, the makeup demineralizer mixed-bed polisher provides a backup for faulty operation of the primary demineralizer.

Elimination of the need for condensate polishers of the type described above would require a relaxation of the feedwater quality requirements to the point at which excessive steam generator and turbine deposition would be inevitable. In addition, as indicated above, condensate polishing is needed to protect against potential condenser leaks and the inevitable high concentration of corrosion products and miscellaneous suspended matter found in the feedwater whenever a unit is started up.

Any increase in the makeup and feedwater quality requirements would be unrealistic because experience has indicated that the use of treatment facilities of the type described has resulted in satisfactory power plant operation, and that more elaborate facilities are either not required or would produce water of no higher quality.

The plant raw water quality will have a considerable impact on water-treatment costs.

3.3.11.6 Feedwater Treatment

"Volatile" treatment has been well established as the appropriate method of treating feedwater for once-through steam generators. With this approach, no solid chemicals (such as phosphate or caustic soda) are added to either the boiler or preboiler cycle. Ammonia and hydrazine are added to the feedwater; the former, to elevate the pH sufficiently to reduce corrosion to a practical minimum, and the latter, to remove any last traces of dissolved oxygen. The reaction between hydrazine and dissolved oxygen is as follows:

$$N_2H_4 + O_2 \longrightarrow N_2 + H_2O$$

In addition, hydrazine will decompose at elevated temperature and pressure as follows:

$$3N_2H_4 \longrightarrow N_2 + 4NH_3$$

Thus, in addition to being volatile itself, hydrazine's reaction products are also volatile.

Ammonia feed to the system is reduced to the extent that ammonia resulting from the decomposition of hydrazine is formed.

Neutralizing amines are used in some systems (primarily those with drum-type boilers) in place of ammonia for pH adjustment. Their chief advantage is that, unlike ammonia, they do not contribute to the corrosion of copper-bearing alloys. Ammonia is considerably less expensive than neutralizing amines, and since a condensate polisher will remove at least some of the pH adjusting chemical, amines become a significant consideration in systems using such equipment.

3.3.11.7 Water Treatment Equipment

Pretreatment Equipment

One - Lime softener, rated capacity 11.35 m^3/min (3,000 gpm), 19.8 m (65 ft) diameter.

Lot - Clarifier chemical feed equipment (polymer/coagulant/Alum feed equipment).

Two - Lime feeder, 454 kg/hr (1,000 lb/hr).

Two - Lime slaker, 454 kg/hr (1,000 lb/hr).

One - Lime silo, 113m^3 (4,000 ft^3).

Circulating Water Treatment Equipment

One - Cooling tower acid tank 22.7m^3 (6,000 gal).

Two - Cooling tower acid feed pumps (1 spare) 11.3 ℓ/hr (3 gph), 3/4 hp, DC motor.

One - Cooling tower chemical feed tank, 0.19m^3 (50 gal), Type 304 stainless steel.

Two - Cooling tower chemical feed pumps (1 spare), 7.6 ℓ/hr (2 gph), 1/4 hp, DC motor.

One - Cooling tower chlorinator, 22.7 m^3/day (6,000 gpd), V-hatch chlorinator with evaporator.

Final Water Treatment Equipment

Two - Makeup water demineralizers, full-size, three bed trains. Rating 0.38 m^3min (100 gpm) per train.
Effluent quality:

Total dissolved solids	50 ppb maximum
Silica	10 ppb maximum

Two - Makeup demineralizer sand filters, each full size, 0.38 m^3/min. (100 gpm) each, 1.98m (6.5 ft) diameter.

One - Demineralizer acid tank, 22.7m^3 (6,000 gal).

Two - Demineralizer acid pump (1 spare), 0.56 m^3/hr (200 gph), 1 hp, 460 VAC motor.

One - Demineralizer caustic tank, 22.7m^3 (6,000 gal).

Two - Demineralizer caustic pump (1 spare), 0.45 m^3/hr (120 gph), 3/4 hp, 460 VAC motor.

Condensate Polishing

Two - Full-size, mixed-bed units, 6.81 m^3/min (1,800 gpm) per vessel. Effluent quality 30 to 40 ppb total dissolved solids, 90% suspended solids removal. With regeneration tanks and controls.

Feedwater Treatment

Two - Feedwater chemical feed tank, 0.19 m^3 (50 gal).

Three - Feedwater chemical feed pumps (1 spare), 5.6 ℓ/hr (2 gph), 1/4 hp, 460 VAC motor.

3.3.12 Miscellaneous Plant Equipment

Descriptions for the Commercial EPGS and balance of plant miscellaneous equipment not covered under the previous sections can be found in Appendix C.

3.3.13 Buildings

3.3.13.1 Power House

The power house contains the equipment required for operation of the EPGS. The building will be approximately 26m x 46m x 24m (85 ft x 150 ft x 80 ft) with two main floors and three partial floors. The building will be designed and fabricated to withstand all environmental loads of the specific site in accordance with the uniform building code.

A service elevator will be provided for access to all operating levels, including the roof. Stairs using structural steel and grating will be provided at each end of the building to provide access to all levels. All structural steel will be fabricated in accordance with the American Institute of Steel Construction (AISC). Appropriate platforms, railings, and other safety features will be provided.

Corrugated, prepainted panels of proper thickness and configuration to provide the load-carrying capabilities required will be provided for exterior siding. Panels will be of the interlocking type with proper sealant as required to provide a weather-tight enclosure. Walls will have an insulation coefficient (U value) of 0.20, and installed as part of the building. Noise or fire protection required for safety purposes will be provided.

The ground and operating main floors will be finished concrete of minimum compressive strength of 3,000 psi at 28 days with steel reinforcement. Proper expansion joints and floor joint sealant will be supplied as required. All materials will conform to applicable industrial or federal specifications. The HVAC floor will be fabricated of structural steel in accordance with the AISC standards with steel grating floor. Personnel doors will be heavy-duty industrial-type hollow metal with panic hardware. Doors and frames will conform to the current issue of US Department of Commerce Standard CS 211. A steel slat, roll-up, motor-operated service door will be provided for maintaining equipment and large items in the power house.

The roof will be steel roof deck, 18 gage, with 1-1/2 in. rigid insulation and builtup roof with gravel surface, and of such configuration to provide the necessary load-carrying capabilities and requirements. Proper sealant will be provided for a weather-tight enclosure. Roof insulation with maximum heat transfer coefficient (U value) of 0.16 will be provided.

A 40-ton overhead bridge crane with 10-ton auxiliary hook will be provided for maintenance of the turbine-generator. Supports for the crane will be independent from the building superstructure.

The power house will be heated by steam in the operating areas. Evaporative cooling will be provided in operating areas. The operating and ground floor computer and control rooms will be environmentally controlled by the use of localized air-conditioning/heating units with appropriate humidity control for computer room as required by the installed electronic equipment.

Operating areas within the power house will be protected from fire by the use of local fire hose reels and fire extinguishers at critical points throughout the building. Automatic sprinkler systems will be provided for turbine lube oil reservoir and storage tank, and oil piping inside the building, and main power transformer, auxiliary transformer, and startup transformer outside the building. All equipment will be specified and designed to comply with all NFPA and OSHA regulations. Computer and control rooms will be protected from fire by a Halon 1301 fire-suppression system or acceptable alternate. The system will be capable of extinguishing fires involving ordinary combustible materials, flammable liquids, gases, greases, etc, and also fires associated with energized electrical equipment. The system will not reduce oxygen level below that required for support of human life in normal extinguishing concentrations.

3.3.13.2 Technical and Administration Building

The technical and administration building will contain area and facilities for plant management, visitor control, and technical support for the solar thermal power system. The building will be approximately 18m x 27m x 7m (60 ft x 90 ft x 22 ft) with two stories. The superstructures will be a beam and column structural steel frame, pre-engineered, prefabricated design conforming to the standards of the Metal Building Manufacturer's Association and the Uniform Building Code. Stairs will provide access to all levels. Corrugated, prepainted panels will be provided for exterior siding with architectural facing on the main entrance side. Panel construction and insulation will be the same as described for the power house. Interior walls will be standard commercial steel stud with gyp-board siding. Standard acoustical drop ceilings will be provided.

Floors will be provided with standard, economic office coverings.

Doors will be standard office-type with lock hardware and panic hardware for emergency exits.

The roof will be steel roof panels, galvanized or aluminum coated on both sides by continuous hot-dip method. Roof panels will be of standard interlocking design of minimum 20-gage material and of such configuration to provide the necessary load-carrying capabilities and requirements. Roof insulation with a maximum heat-transfer coefficient (U value) of 0.16 will be provided and installed as part of the building.

The administration building will include a guard-controlled entrance area for visitor control. An appropriate intercom system will be installed for contact with all sections of the plant to assist management and security in controlling the area. Proper visitor waiting areas will be provided.

The administration building will be steam-heated with an absorption chilling system for air-conditioning. Master control computer area will be environmentally controlled with separate air-conditioning/heating unit and appropriate humidity control equipment.

The administration building will have a commercial water sprinkler system for fire protection with accessible fire hydrants outside the building. Sprinkler spray nozzles will be temperature-controlled on-off type in lieu of fusible-link type. The master control room will have a Halon-type fire suppression system as described for the power house control rooms.

3.3.13.3 Water-Treatment Building

The water-treatment building will house all equipment for treatment and distribution of process water. The building will be approximately 27m x 18m x 8m (50 ft x 60ft x 25 ft) with one story. The superstructure will be a structural steel frame. Appropriate catwalks and service platforms will be provided at critical equipment operating and service areas. Roof and siding construction, including insulation, will be the same as the power house.

The floor will be finished concrete and steel reinforcement, with the requirements described for the power house. All service platforms, catwalks, and stairs will be fabricated of structural steel in accordance with the AISC.

Personnel doors and overhead roll-up door will be provided as described for the power house.

The water-treatment building will be steam-heated with no air-conditioning provided.

Local fire hydrants and extinguishers and emergency showers will be provided at critical areas for fire and personnel protection in accordance with NFPA and OSHA regulations.

3.3.13.4 Warehouse and Assembly Building

The warehouse and assembly building will contain equipment required for shipping, receiving, and assembly operations as well as sufficient bin and floor storage area for assembly parts. The building will be approximately 27m x 46m x 6m (90 ft x 150ft x 20 ft) with one floor. A raised dock will be provided for truck loading and unloading operations. In addition to the raised dock, a drive-in area will be provided to allow warehouse access for small vehicles and maintenance equipment. The superstructure will be a truss-type structural steel frame of pre-engineered, prefabricated design.

Exterior wall and roof panels, including insulation, will be the same as described for the administration building.

The floor will be finished concrete with structural steel reinforcement with the requirements described for the power house. Personnel doors will be the same as described for the power house. Roll-up doors will be provided for dock and drive-in areas. The doors will be the same as described for the power house.

A 20-ton overhead bridge-type crane with 5-ton auxiliary hook will be provided to assist in assembly operations. Supports for the crane will be integrated into the building superstructure.

The warehouse-assembly building will be heated by steam. No air-conditioning will be provided.

Areas within the warehouse-assembly building will be protected from fire by the use of local fire hydrants and fire extinguishers at critical areas in accordance with NFPA and OSHA regulations.

3.3.14 Yardwork

Yardwork as described in this section is limited to localized development or excavation within the plant operating area. Areas will be cleared of any items that would interfere with construction operations. Any depressions will be filled with suitable material and compacted unless further excavation is required. Excavation will be performed as required dependent upon the terrain of the specific site. Excavation will include building foundations, trenching for utility systems including underground pipeways, and excavation for paved areas. Unsatisfactory material encountered or anticipated from soils data at normal grades for installed foundations will be removed and replaced with satisfactory material and compacted as required. Grading will be performed so that the area of the site and areas affecting operations at the site will be continually and effectively drained.

Compaction requirements for grading and excavation operations cannot be determined until appropriate soils data are available. Compaction requirements will be identified and the soil moistened or aerated to obtain the specified compaction.

Backfill of satisfactory material and compacted as required will be used to bring areas up to finish grade. Caution will be observed when using heavy compaction equipment around building foundations and over utility trenches. No landscaping is anticipated except for dust control or environmental conditions as warranted by the local site conditions.

3.4 DRAWINGS AND SCHEMATICS

The following drawings have been developed for the Commercial Plant EPGS preliminary design and are included in this section.

	Drawing Number	Revision	Title
	Plot Plan		
Figure 3-15	L-22755 SK-Y11	P	Plot Plan
	General Arrangements		
Figure 3-16	L-22755 SK-G11	P	Ground Floor Plan
Figure 3-17	L-22755 SK-G12	P	Mezzanine Floor
Figure 3-18	L-22755 SK-G13	P	Operating Floor
Figure 3-19	L-22755 SK-G14	P	HVAC Floor
Figure 3-20	L-22755 SK-G16	P	Elevation
	Flow Diagrams		
Figure 3-21	L-22755 SK-P11	P	Steam and Condensate
Figure 3-22	L-22755 SK-P12	P	Composite Flow Diagram (Simplified)

3.5 EPGS SCHEDULE

A preliminary schedule for the activities and equipment associated with a 100-MWe Commercial EPGS has been defined and is shown in Figure 3-23. The overall schedule for implementation of a first Commercial central receiver solar thermal power plant has been estimated to take 5-1/2 yr from go-ahead to initial commercial operational capability, as indicated on the figure. The EPGS activities are compatible with this total time span, with the turbine-generator being the equipment item with the longest lead time. A 4-mo period for preparation of the specification is shown, which would use the information derived from the completion of the preliminary design effort. Following a 2-mo period for advertise and award activities, a total of 26 mo is the period estimated to be required for fabrication and delivery of the turbine-generator set to the site. An additional 18 mo are allocated for installation and checkout of the equipment prior to the initial plant startup milestone.

The other major equipment items shown are the receiver feed pumps, the switchgear, e.g., main and auxiliary power transformers, and auxiliary equipment, e.g., feedwater heaters. The times required for other plant items would all fall within this framework. The time spans shown here

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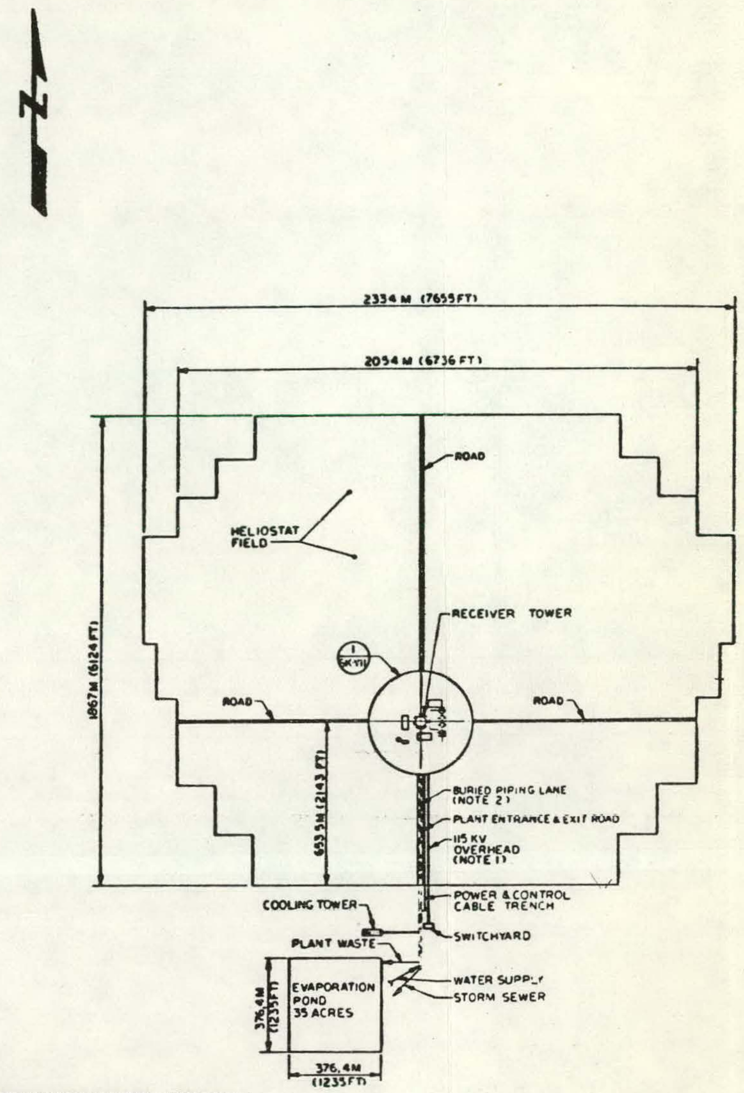
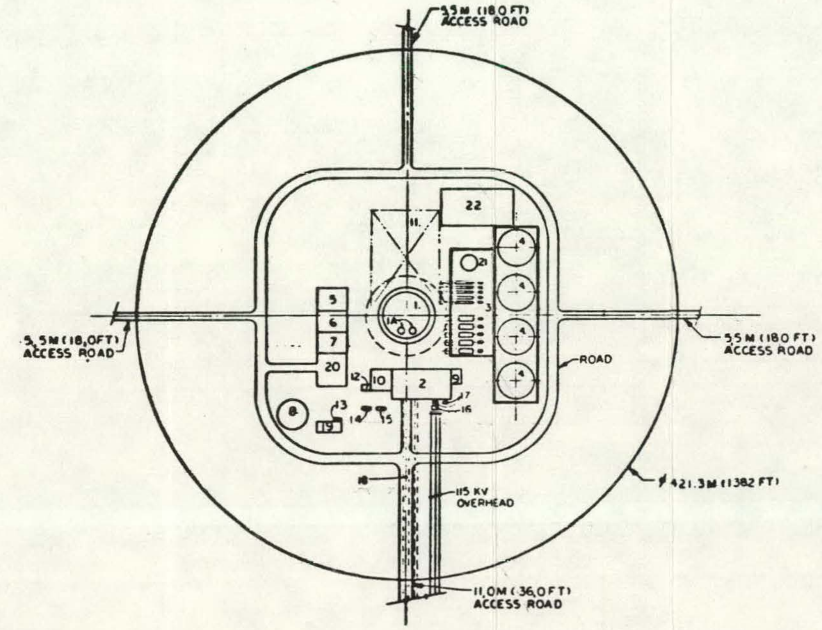


NOTES

1. OVERHEAD 115KV TRANSMISSION PREFERRED IF IT DOES NOT INTERFERE WITH HELIOSTATS AND IF IT DOES NOT OVERHEAT LOW POINT OF LINES APPROX 15.3 M (50 FT) ABOVE GRADE
2. LOCATION AND USE OF ONLY ONE PIPING LANE IS TENTATIVE AND COULD VARY WITH SITE SELECTION
3. LOCATION OF COOLING TOWER IS TENTATIVE AND WOULD VARY WITH SITE SELECTION AND PREVAILING WINDS.

PLOT PLAN
SCALE: 1:10 000M (METRIC)



1 RECEIVER TOWER AND FOUNDATION
1A CONDENSATE STORAGE TANKS
2 POWER HOUSE
3 THERMAL STORAGE HEAT EXCHANGERS
4 THERMAL STORAGE TANKS
5 ASSEMBLY
6 WAREHOUSE
7 ADMINISTRATION BUILDING
8 LIME SOFTENER
9 DIESEL GENERATOR
10 WATER TREATMENT BLDG
11 RECEIVER PANELS LAYDOWN AREA
12 SEWAGE PLANT
13 TREATED WATER & FIRE PUMPS
14 NaOH
15 H_2SO_4
16 MAIN TRANSFORMER
17 AUX & START-UP TRANSFORMER
18 BURIED PIPING LANE
19 CLEARWELL (COVERED)
20 PARKING AREA
21 FLUID MAKE UP VESSEL
22 ROCKFILLED CATCH BASIN

DETAIL (1 / SK-Y II) POWER HOUSE AND AUXILIARIES
SCALE: 1:2000 M (METRIC)

PRELIMINARY DESIGN

PLOT PLAN
CENTRAL RECEIVER SOLAR THERMAL POWER SYSTEM
100 MW COMMERCIAL PLANT

MC DONNELL DOUGLAS ASTRONAUTICS COMPANY

Stearns-Roger

DWG. NO. L-22755
SHEET NO. SK-Y II
SCALE: AS NOTED

Figure 3-15. Plot Plan of 100-MW Commercial Plant

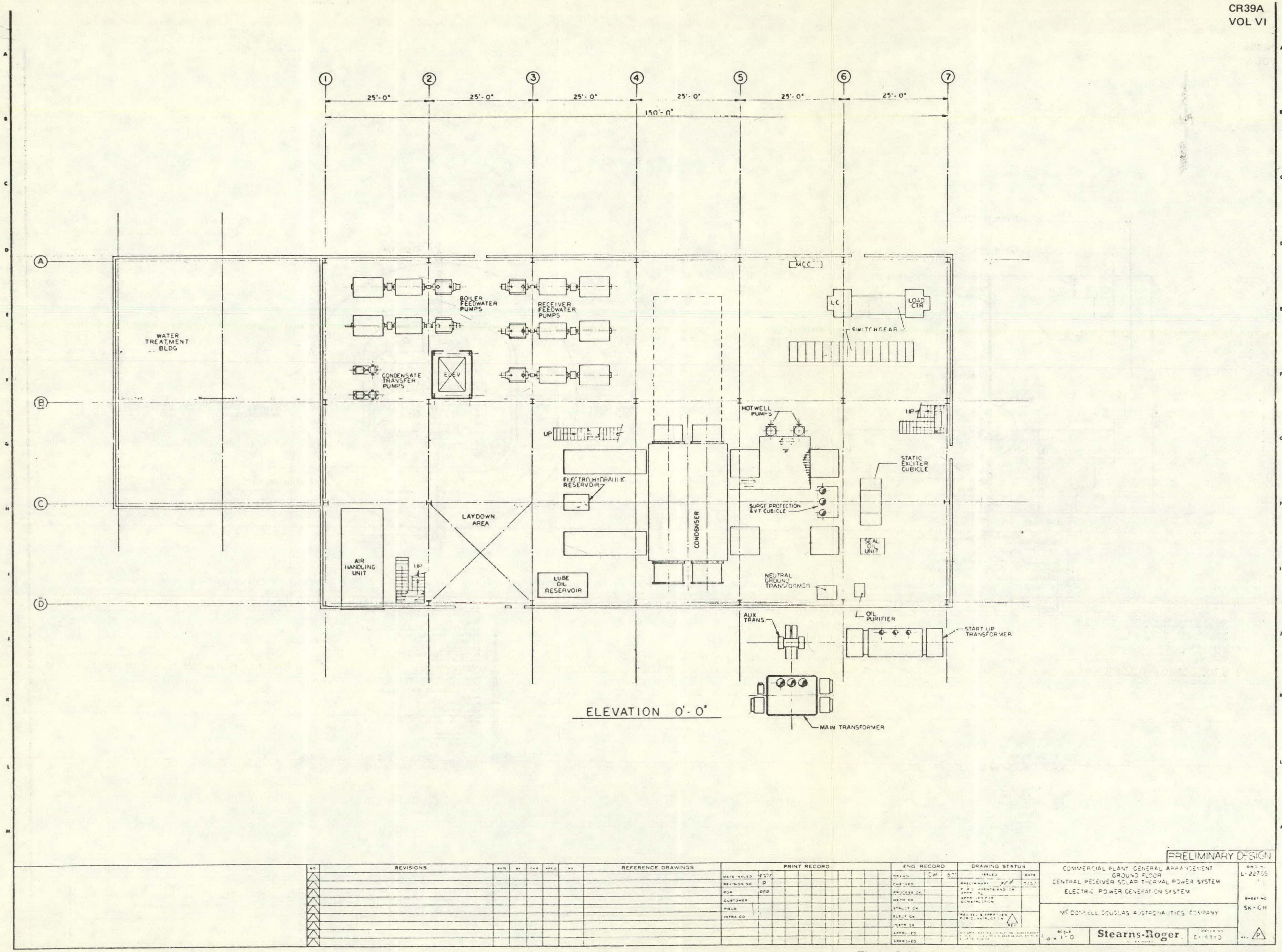


Figure 3-16. Commercial Plant General Arrangement -- Ground Floor, EPGS

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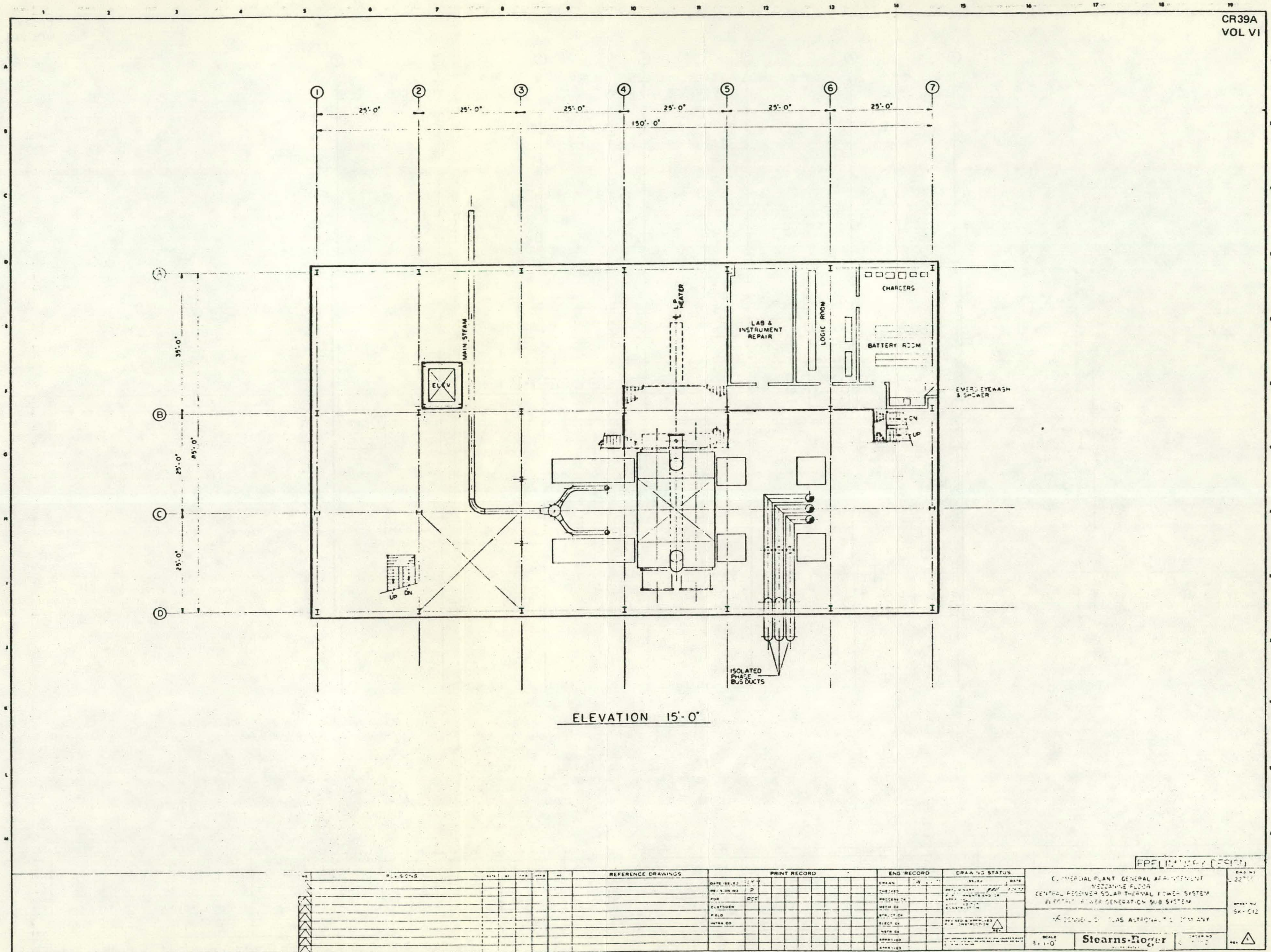

Figure 3-17. Commercial Plant General Arrangement -- Mezzanine Floor, EPGS

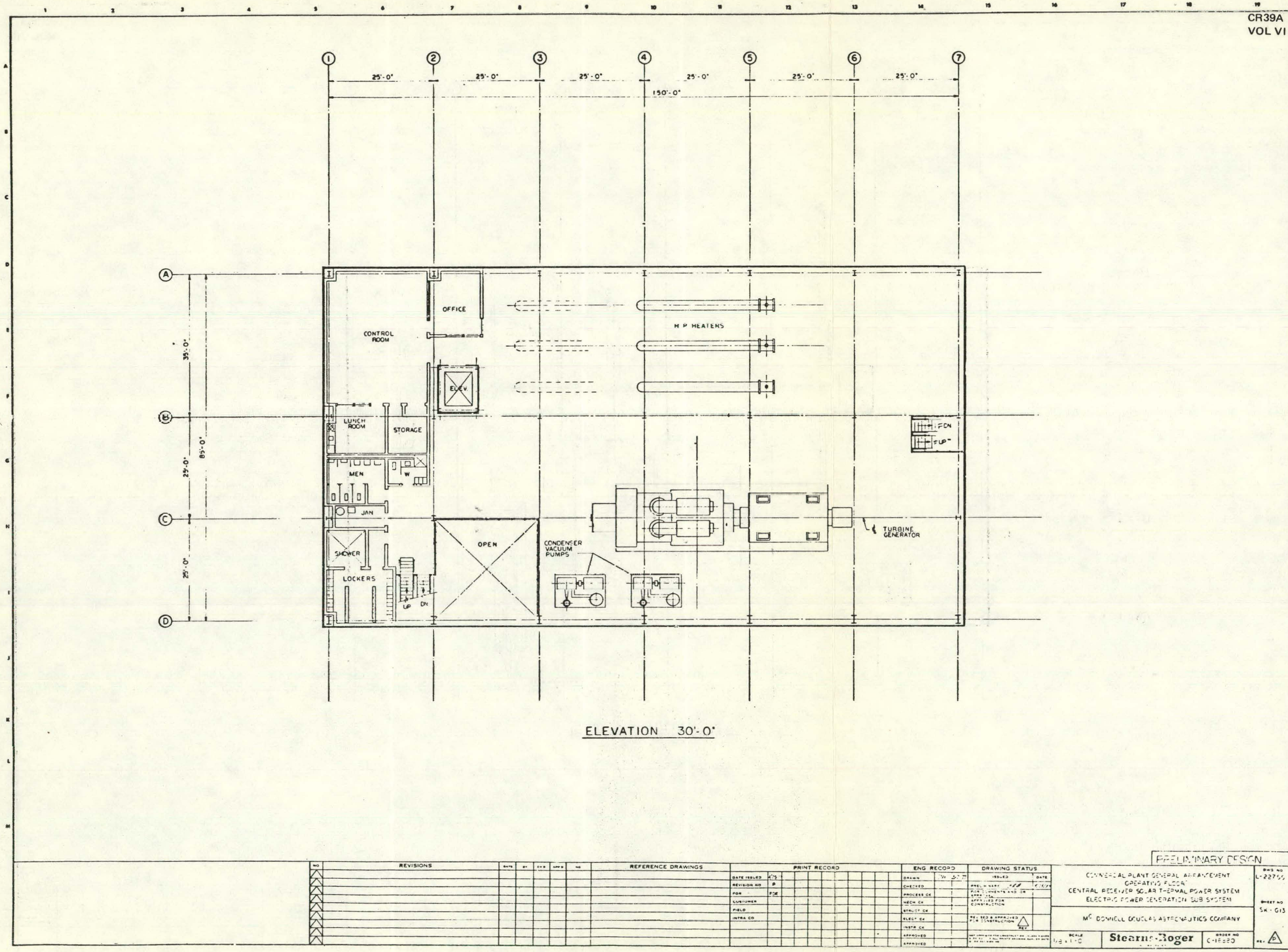

Figure 3-18. Commercial Plant General Arrangement -- Operating Floor, EPGS

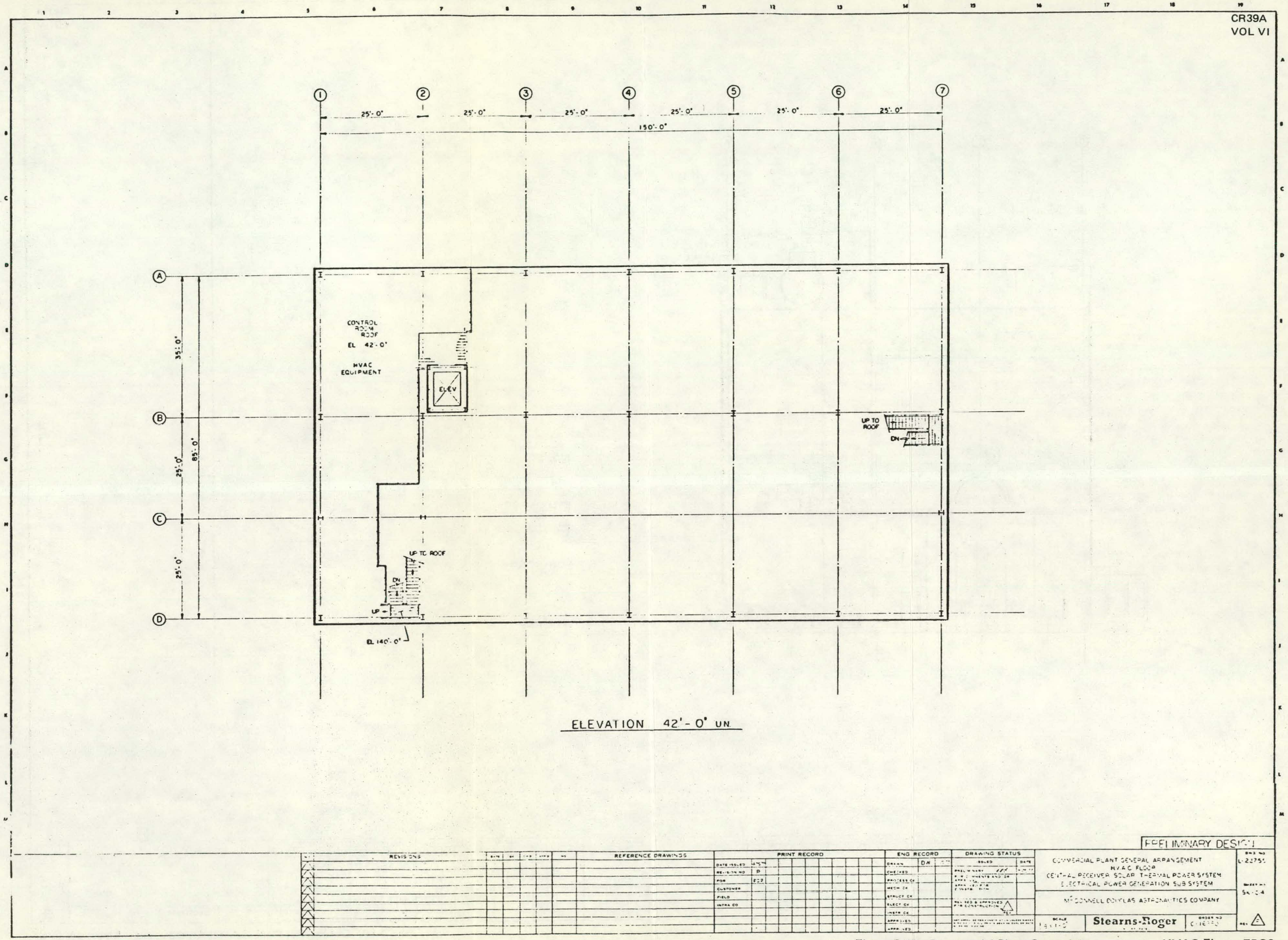

Figure 3-19. Commercial Plant General Arrangement -- HVAC Floor, EPGS

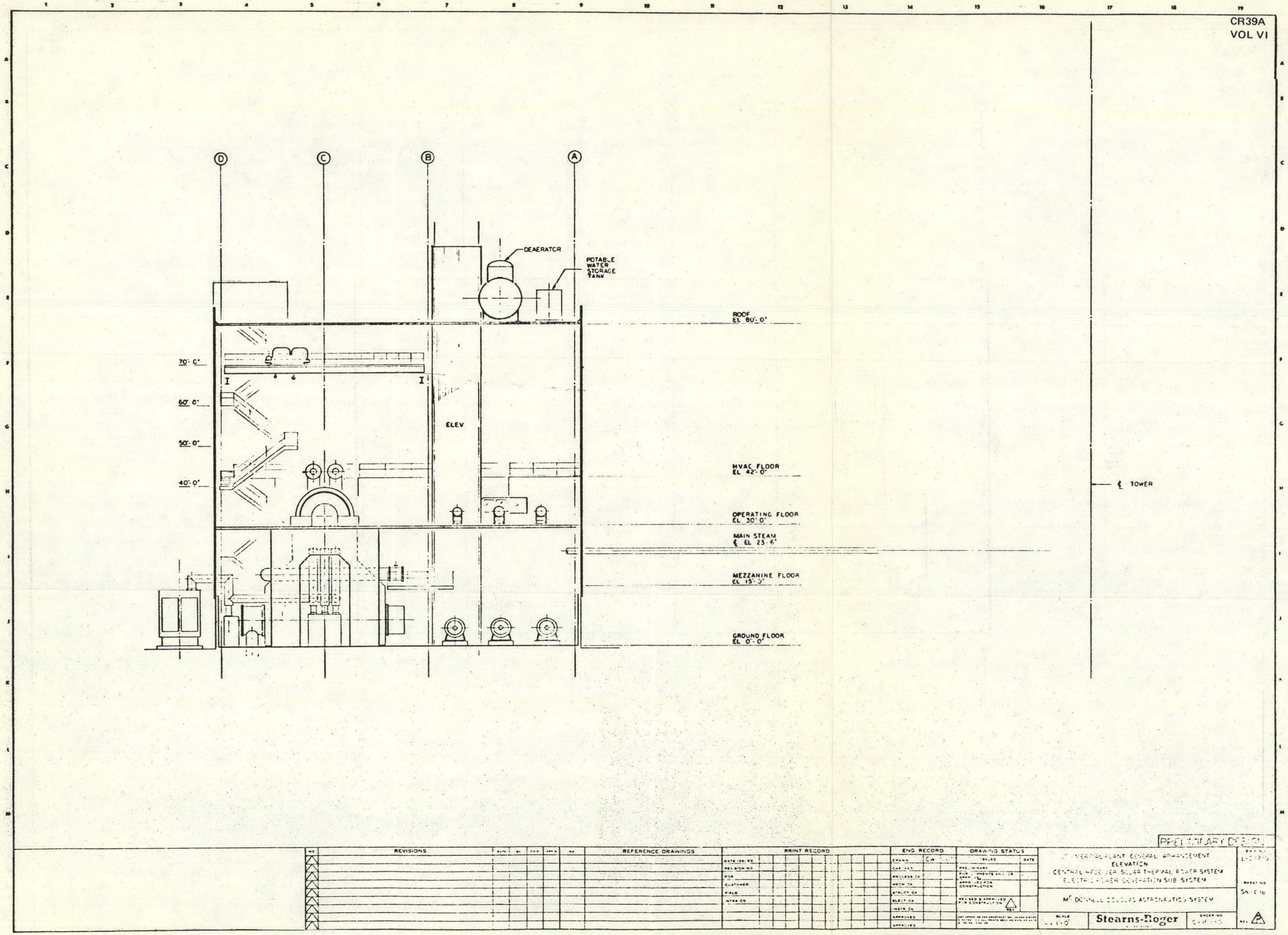

Figure 3-20. Commercial Plant General Arrangement -- Elevation, EPGS

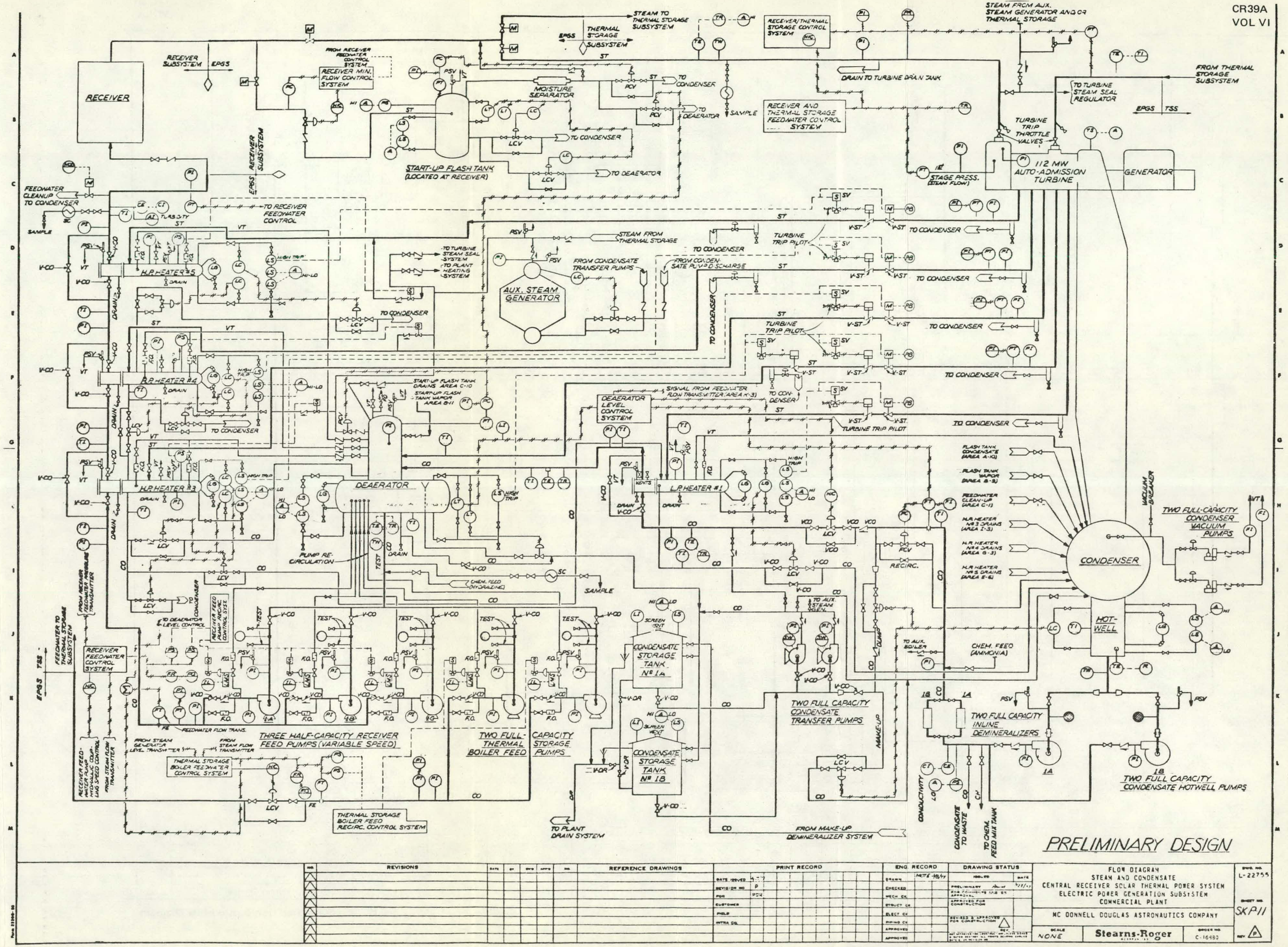

Figure 3-21. Flow Diagram -- Steam and Condensate, Commercial Plant EPGS

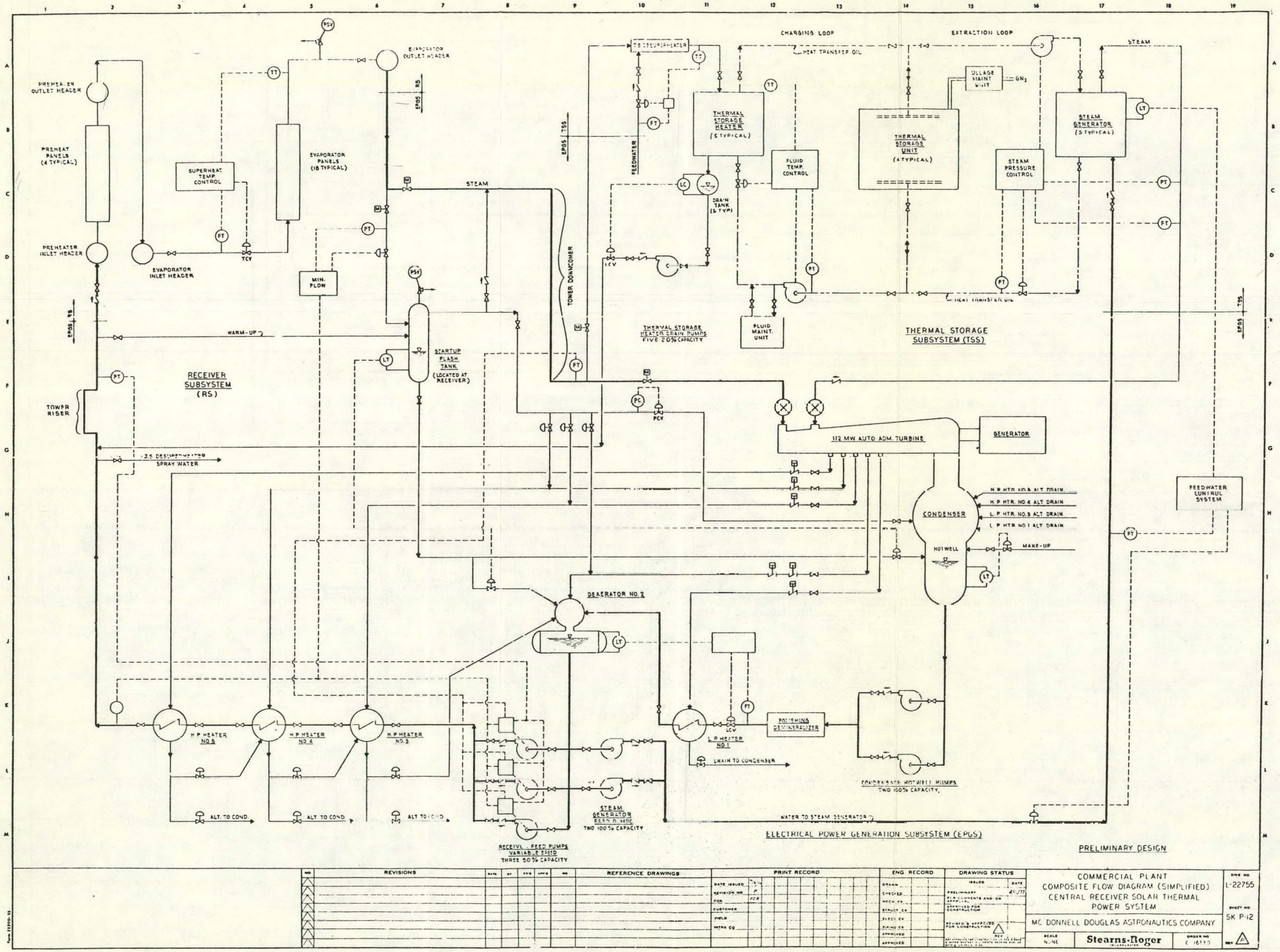

Figure 3-22. Commercial Plant -- Simplified Composite Flow Diagram

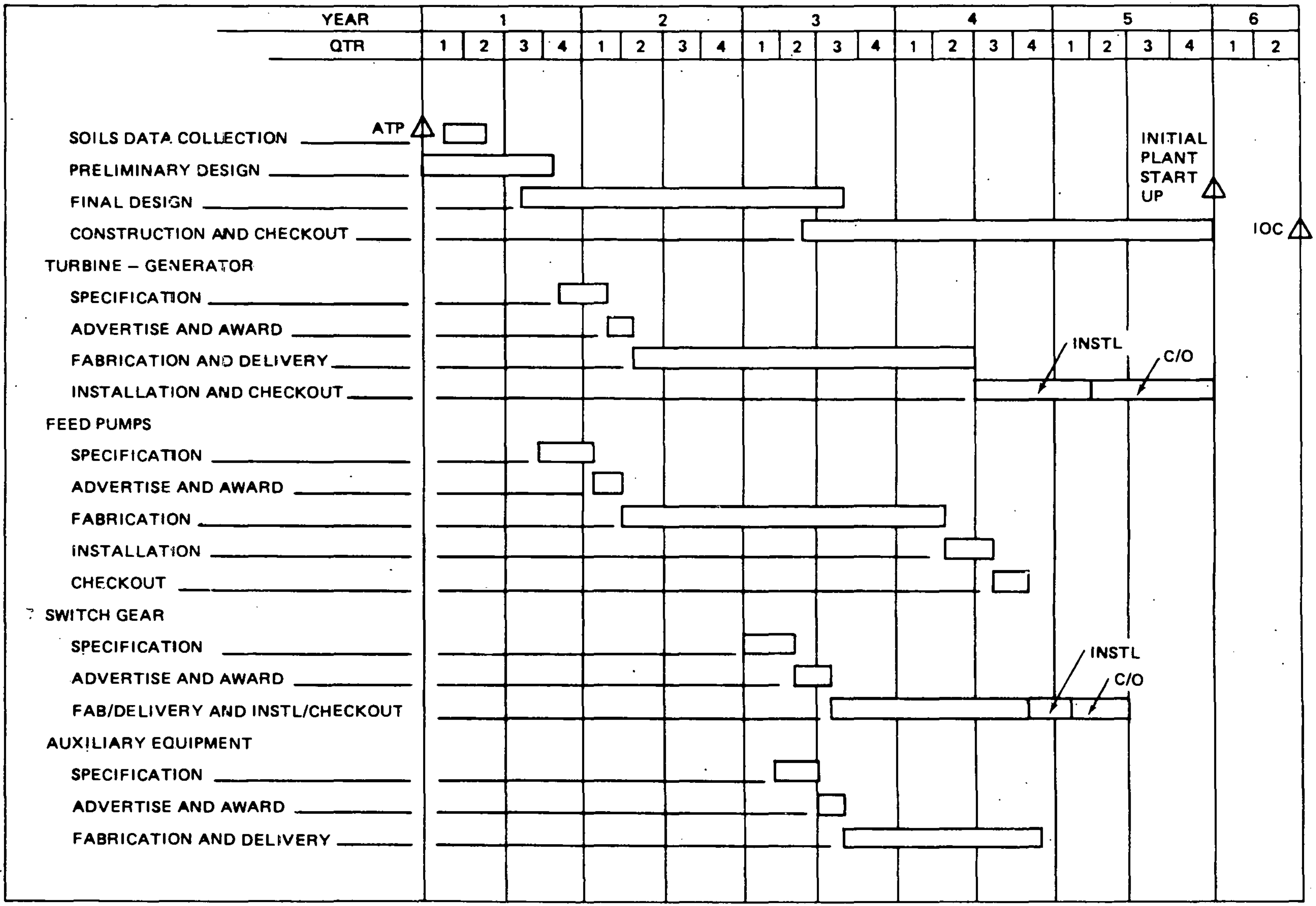

Figure 3-23. Commercial EPGS Schedule

were developed by Stearns-Roger, based upon past operating experience and current lead-time projections on major equipment.

3.6 COMMERCIAL EPGS AND BALANCE OF PLANT DESIGN SUMMARY

The Commercial Plant EPGS and balance of plant configuration and design conditions are presented here as a summary of Section 3.3:

Overall

Power output	112,000 kW_e gross 100,000 kW_e net	Equinox Noon (Turbine Rating)
	76,100 kW_e gross 70,000 kW_e net	Nighttime

Output Voltage

Generator	13,800V
Main Power Transformer	115,000V (Assumed)
Output Frequency	60 Hz Nominal

Turbine

Single automatic admission, tandem-compound, double-flow (TCDF-20 in. LSB) extraction, condensing turbine. Turbine rating 112,000 kW at 8.46 kPa (2.5 in. HgA).

Five extraction points for low-pressure heater, deaerator heater, and three high-pressure heaters.

Inlet Steam Conditions (from Receiver):

Pressure	10.1 MPa (1,465 psia)
Temperature	510°C (950°F)
Enthalpy	3.339 kJ/kg (1,461.2 Btu/lb)

Admission Steam Conditions (from Thermal Storage)

Pressure	2.52 MPa (365 psia)
Temperature	296°C (565°F)
Enthalpy	3,000 kJ/kg (1,289.9 Btu/lb)
Throttle Flow	121.3 kg/sec (960,415 lb/hr)
Admission Flow	114.3 kg/sec (905,593 lb/hr)

Turbine Exhaust Pressure	8.46 kPa (2.5 in. HgA)
Shaft Speed	3,600 rpm

<u>Generator</u>

Generator Rating	130,000 kVA
Power Factor	0.9
Output Voltage	13,800V
Frequency	60 Hz
Cooling	Hydrogen Cooled
Exciter	Static Excitation System
Shaft Speed	3,600 rpm

<u>Condenser</u>

Type	Shell and Tube, 2-Pass
Surface	12,542m^2 (135,000 ft^2)
Tube Material	90-10 Copper Nickel
Tube Diameter (OD)	22.2 mm (0.875 in)
Tube Wall Thickness	0.89 mm (0.035 in) 20 BWG
Tube Length (Effective)	8.54 m (28 ft)
Condenser Pressure	8.46 kPa (2.5 in. HgA)
Heat Rejection	828 GJ/hr. (785 x 10^6 Btu/hr)
Cooling Water Flow	7.1 m^3/s (112,100 gpm)
Water Velocity	2.13 m/s (7.0 fps)
Cooling Water In	31.1^{o}C (88.0^{o}F)
Cooling Water Out	40.0^{o}C (102.0^{o}F)
Condenser Air Removal	Mechanical Vacuum Pump (2-full capacity)

<u>Cooling Tower</u>

Quantity	One
Type	Mechanical Draft, Cross Flow
Number of Cells	6
Fan Motor Size	6-150 kW (200 hp)
Design Wet Bulb Temperature	23^{o}C (73.4^{o}F)
Cold Water Temperature	31.1^{o}C (88.0^{o}F)
Hot Water Temperature	38.9C (102.0^{o}F)

Circulating Water Flow	7.28 m^3/s (115,500 gpm)
Heat Rejection	853.07 GJ/hr. (808.6 x 10^6 Btu/hr)

Circulating Water Pumps

Quantity	Two, Half Capacity
Type	Vertical Mixed Flow
Capacity, Each	3.64 m^3/s (57,750 gpm)
Head	23.2m (76 ft)
Efficiency	80%
Brake Horsepower	1,033.5 kW (1,385.4 Bhp)
Motor Size	1,119 kW (1,500 hp)

Feedwater Heaters

One low-pressure heater, horizontal, stainless-steel tubes, carbon steel shell with drain cooler.

One direct contact deaerating heater, stainless-steel trays and vent condenser, carbon steel shell. Horizontal condensate storage section carbon steel, 75.7 m^3 (20,000 gal) working capacity; 0.005 cc/l max. oxygen in effluent.

Three high-pressure heaters, horizontal, carbon steel tubes, carbon steel shell with drain cooler.

Receiver Feed Pump

Quantity	Three, Half Capacity
Type	Double Case, Barrel-Type, Horizontal, Centrifugal, 7 Stage, 6,300 rpm
Drive	Speed Increaser and Variable-Speed Hydraulic Coupling connected to 1,865 kW (2,500 hp), 3,650 rpm, 4.160V Electric Motor
Capacity, Each	4.07m^3/min (1,125 gpm)
Head	2,020m (6,625 ft)
Fluid Temperature	123.8°C (254.8°F)
Efficiency (Pump)	78%
Brake Horsepower	1,690 kW (2,266 hp)

Thermal Storage Feed Pump

Quantity	Two, Full Capacity
Type	Vertical Split Case, Horizontal, Centrifugal, 4-Stage, 3,560 rpm
Drive	Direct Connected to 448 kW (600 hp) 4,160V, 3,550 rpm Motor
Capacity, Each	7.95 m^3/min. (2,100 gpm)
Head	295.7m (970 ft)
Fluid Temperature	121.8°C (251°F)
Efficiency	75%
Brake Horsepower	503 kW (675 hp)

Main Power Transformer

Quantity	One
Rating	130 MVA, FOA
Voltage	115-13.2 kV

Auxiliary Power Transformer

Quantity	One
Rating	13.44/17.92/22.4, OA/FA/FA
Voltage	13.2 - 4.16 kV

Startup Transformer

Quantity	One
Rating	13.44/17.92/22.4, OA/FA/FA
Voltage	115-4.16 kV

Emergency Shutdown Power

Diesel-Generator	Two 750 kW, 2,000 kVA, 0.8 PF, 4, 160V

Feedwater Treatment

Demineralized Water Makeup

Two Demineralizers - Each rated 0.37 m^3/min (100 gpm)

Normal Requirement - Approximately 0.15% of rated receiver steam flow.

Maximum Capability - Approximately 3% of rated receiver steam flow.

In-line Polishing Demineralizers

Two Full-Capacity Demineralizers - Each rated 6.81 m^3/min (1,800 gpm)

Feedwater Purity Levels

Solid content-controlled to 20 to 50 ppb dissolved solids, pH maintained at 9.5 to meet receiver requirements.

Feedwater Treatment Chemicals

Ammonia (pH control) and hydrazine (oxygen scavenger).

Feedwater Piping/Riser

Feedwater Leaving Turbine Building

Design Pressure	22.55 MPa (3270 psia)
Design Temperature	232°C (450°F)
Pipe Size (Nominal)	25.4 cm (10 in) Sch 160
Pipe Material	Carbon Steel, ASTM A-106 Grade C
Unit Weight	172.2 kg/m (115.7 lb/ft)
Code	ANSI B31.1 Power Piping
Insulation	8.9 cm (3.5 in.) Calcium Silicate with Aluminum Jacket

Feedwater Leaving Thermal Storage Heaters

Design Pressure	21.65 MPa (3,140 psia)
Design Temperature	260°C (500°F)
Pipe Size (Nominal)	30.5 cm (12 in.) Sch 160
Pipe Material	Carbon Steel, ASTM A-106 Grade C
Unit Weight	238.5 kg/m (160.3 lb/ft)
Code	ANSI B31.1 Power Piping
Insulation	8.9 cm (3.5 in.) Calcium Silicate with Aluminum Jacket

Feedwater Riser to Receiver

Design Pressure	21.65 MPa (3,140 psia)
Design Temperature	260°C (500°F)
Pipe Size (Nominal)	30.5 cm (12 in) Sch 160
Pipe Material	Carbon Steel, ASTM A-106 Grace C
Unit Weight	238.5 kg/m (160.3 lb/ft)
Code	ANSI B31.1 Power Piping
Insulation	8.9 cm (3.5 in.) Calcium Silicate with Aluminum Jacket

Feedwater to Thermal Storage Steam Generator

Design Pressure	4.48 MPa (650 psia)
Design Temperature	138.9°C (275°F)
Pipe Size (Nominal)	20.3 cm (8 in.) Sch 40 Grade B
Pipe Material	Carbon Steel, ASTM A106
Unit Weight	42.6 kg/m (28.6 lb/ft)
Code	ANSI B31.1 Power Piping
Insulation	6.35 cm (2.5 in.) Calcium Silicate with Aluminum Jacket

Steam Piping/Downcomer

Steam Leaving Receiver (Downcomer)

Design Pressure	12.24 MPa (1,775 psia)
Design Temperature	537.8°C (1,000°F)
Pipe Size	34.3 cm (13.5 in) Minimum ID x 4.503 cm (1.773 in.) Nominal Wall Thickness.
Pipe Material	Low Alloy Steel, ASTM A-335 Grade P22 (2 1/4 CR-1 MO)
Unit Weight	440.4 kg/m (296 lb/ft)
Code	ANSI B31.1 Power Piping
Insulation	14.0 cm (5.5 in.) double layer Calcium Silicate with Aluminum Jacket.

Main Steam to Turbine

Design Pressure	12.42 MPa (1,775 psia)
Design Temperature	537.8°C (1,000°F)
Pipe Size	26.7 cm (10.5 in.) Minimum ID x 3.512 cm (1.383 in.) Nominal Wall Thickness
Pipe Material	Low Alloy Steel, ASTM A335 Grade P22 (2 1/4 CR-1 MO)
Unit Weight	263.4 kg/m (177 lb/ft)
Code	ANSI B31.1 Power Piping
Insulation	12.7 cm (5.0 in.) double-layer Calcium Silicate with Aluminum Jacket

Steam to Thermal Storage Heaters

	Before Desuperheater	After Desuperheater
Design Pressure	12.24 MPa (1,775 psia)	12.24 MPa (1,775 psia)
Design Temperature	537.8°C (1,000°F)	371.1°C (700°F)
Pipe Size	25.4 cm (10 in.) Min ID x 3.345 cm. (1.317 in.) Nominal Wall	30.48 cm (12 in.) Nominal Sch 120
Pipe Material	Low Alloy Steel ASTM A335 Grade P22 (2 1/4 CR-1MO)	Carbon Steel, ASTM A106 Grade B
Unit Weight	238.1 kg/m (160 lb/ft)	186.7 kg/ft (125.5 lb/ft)
Code	ANSI B31.1 Pressure Piping	ANSI B31.1 Power Piping
Insulation	12.7 cm (5.0 in.) double layer Calcium Silicate with Aluminum Jacket	10.2 cm (4.0 in.) double layer Calcium Silicate with Aluminum Jacket

Admission Steam to Turbine (from Thermal Storage)

Design Pressure	3.21 MPa (465 psia)
Design Temperature	301.7° (575°F)
Pipe Size, OD	45.7 cm (18 in.) Standard Weight 0.95 cm (0.375 in.) Wall
Pipe Material	Carbon Steel, ASTM A106 Grade B
Unit Weight	105.0 kg/m (70.6 lb/ft)
Code	ANSI B31.1 Power Piping
Insulation	10.2 cm (4.0 in.) Calcium Silicate with Aluminum Jacket

Auxiliary Steam Boiler

Type	Scotch Marine
Capacity	22,680 kg/hr (50,000 lb/hr)
Pressure	310.2 kPa (45 psia)
Fuel	Light Oil (No. 2)
Code	ASME

Buildings

Power House (Turbine Building): 26m x 46m x 24 m (85 ft x 150 ft x 80 ft).

Technical and Administration Building: 18m x 27m x 7m (60 ft 90 ft x 22 ft); Two Stories.

Water Treatment Building: 27m x 18m x 8m (50 ft x 60 ft x 25 ft); Single Story.

Warehouse and Assembly Building: 27m x 46m x 6m (90 ft x 150 ft x 20 ft); Single Story.

Section 4

PILOT PLANT ELECTRICAL POWER GENERATION SUBSYSTEM AND BALANCE OF PLANT

4.1 REQUIREMENTS

4.1.1 Performance Requirements

4.1.1.1 Operating Requirements

Operating requirements for the Pilot Plant EPGS are as follows:

		Source
Gross Turbine Output	$11.2\ MW_e$	MDAC
Daytime (Design-Winter Solstice, 2 PM)		
Nighttime	7.8 MWe	MDAC
Net Turbine Output		
Daytime	$10.0\ MW_e$	DoE/Sandia
Nighttime	7.0	DoE/Sandia
Turbine Inlet Conditions		
Daytime (Receiver Steam)		
Pressure	10.1 MPa (1,465 psia)	MDAC
Temperature	510^oC (950^oD)	MDAC
Throttle Flow	12.93 Kg 1/sec (102,440 lb/hr)	MDAC
Nightime		
Pressure	2.65 MPa (385 psia)	MDAC
Temperature	274.4^oC (525^oF)	MDAC

Turbine Inlet Conditions		
Nightime (continued)		
Admission Flow	13.21 Kg/sec (104,700 lb/hr)	MDAC
Turbine Exhaust Pressure		
Daytime	8.46 kPa (2.5 in. HgA)	MDAC
Nighttime	8.46 kPa (2.5 in. HgA)	MDAC
Heat Rejection		
Method	Wet Cooling	DoE/Sandia
Wet Bulb Temperature	23°C (73.4°F)	DoE/Sandia
Generator Output		
Generator Rating	16,000 kVA	MDAC
Power Factor	0.85	MDAC
Voltage	13,800V	MDAC
Frequency	60 Hertz	MDAC
Main Transformer		
Rating	12/16 MVA OA/FA	MDAC
Voltage	13.2/115 kV	MDAC
Feedwater Conditioning		
Dissolved Solids	20 to 50 ppb	MDAC
pH	9.5	MDAC

4.1.1.2 Functional Interface Requirements

The functional flows between the major elements of the EPGS and between the EPGS and other interfacing subsystems are indicated in Figure 3-1.

The EPGS is coordinated through master control to provide normal startup, power operations, mode changes, and shutdown of the solar thermal power system.

4.1.1.3 Availability Requirement

The Commercial Plant availability has been defined by DoE/Sandia at 0.90, exclusive of solar insolation conditions.

To meet the 90% availability requirement for the plant, the availability allocation for the EPGS is as follows:

Forced Outage	1.03%
Maintenance Outage	1.42%
Planned Outage	4.50*
Total Unavailable	6.95%

The average percentage of the time the EPGS is unavailable is 6.95%. The EPGS availability requirement is therefore 93.05%.

4.1.2 Design Requirements

4.1.2.1 Physical Interface Requirements

Descriptions of the physical interfaces between the EPGS and other subsystems or elements follow:

EPGS/Receiver Subsystem

Turbine Throttle/Downcomer/Receiver Interface--The EPGS is designed to connect the primary high-pressure steam inlet to the receiver downcomer interface at the top of the receiver tower. The interface pressure and temperature are 10.45 MPa (1,515 psia) and 516°C (960°F) (rated conditions) to satisfy turbine inlet steam design requirements of 10.1 MPa (1,465 psia) and 510°C (950°F).

EPGS Feedwater Riser/Receiver Interface--The EPGS is designed to provide feedwater at the riser/receiver interface at the top of the receiver tower at 13.79 MPa (2,000 psia) and 205°C (401°F).

*This down time assumes some preventive maintenance is performed simultaneously.

EPGS/Thermal Storage Subsystem

Automatic Admission Port/Steam Generator Interface--The EPGS is designed to connect the automatic admission port of the turbine with the thermal storage steam generator outlet header and receive superheated steam at the rated conditions of 2.76 MPa (400 psia) 277°C (530°F) at the terminal connection with the steam generator outlet header.

EPGS Feedwater/Steam Generator Interface--The EPGS is designed to connect the steam generator feed pump to the steam generator feedwater inlet, at a pressure and temperature of 3.45 MPa (500 psia) and 121°C (250°F) measured at the booster pump outlet.

EPGS/Collector Subsystem

The EPGS will include a power grid to deliver approximately 60 kVA electric power at 240V, 3-phase to operate the heliostat field during normal Pilot Plant operation. An emergency source of power will provide safe shutdown in the event of loss of power from the generator and grid.

EPGS/Master Control

The EPGS will be responsive to control signals from master control.

EPGS/Electrical Power Transmission Network

The EPGS will be designed to connect to an electrical power transmission network and deliver a nominal range from 7 to 11 MWe net of regulated 60 Hz electrical power at 115 kV (assumed) to the grid.

4.1.2.2 Code and Legal Requirements

The equipment, materials, design, and construction of the EPGS will comply with all Federal, state, local and user standards, regulations, codes, laws, and ordinances which are applicable for the selected site and using utility. These shall include but not be limited to the following:

A. Regulations of the Occupational Safety and Health Administration (OSHA).

B. Regulations of the California Occupational Safety and Health Administration (Cal/OSHA), if required.

C. ANSI B31.1 Power Piping Code.
D. IEEE - Switchgear and Transformers.
E. NEME Standards - Motor, Starters.
F. ASTM Standards.
G. Uniform Building Code.
H. ASME Boiler and Pressure Vessel Code-Unfired Pressure Vessels.
I. American Institute of Steel Construction (AISC) Steel Construction Manual
J. American Concrete Institute (ACI) Standards
K. National Electric Code.
L. National Fire Protection Association (NFPA) Standards.

4.1.2.3 Environmental Conditions

The following environmental requirements have been defined for the Pilot Plant EPGS:

Environmental Factor		Source
Wind Conditions		
(at 10m (30 ft.) Elevation)		
Maximum Operational, with Gusts	16 m/s (36 mph)	MDAC
Maximum Survival		
Sustained (Tower Only)	40 (90 mph)	MDAC
With Gusts (Other Subsystems)	40 m/s (90 mph)	DoE/Sandia
Wind Velocity Profile		
(Relative to 10m Height)	Varies Exponentially to the 0.15 Power	DoE/Sandia
Seismological		
Seismic Zone	3	DoE/Sandia
Response Spectrum	NRC Reg Guide 1.60	DoE/Sandia

Environmental Factor		
Seismological (Continued)		
Operational Basis Earthquake (OBE)	0.165g (Horizontal)	MDAC
Safe Shutdown Earthquake (SSE)	0.250g (Horizontal)	MDAC
Soil Conditions	Barstow	DoE/Sandia
Lightning Protection	Cost/Risk Basis	DoE/Sandia
Precipitation		
Rain		
Average Annual	100 mm (4 in.)	DoE/Sandia
Maximum 24-Hr Rate	75 mm (3 in.)	MDAC
Snow (Design Snow Load)	250 Pa (5psf)	DoE/Sandia
Sleet (Maximum Ice Buildup)	50 mm (2 in.)	DoE/Sandia
Hail	20 mm (3/4 in.) at 20 m/s (65 fps) Terminal Velocity	DoE/Sandia

4.2 SUBSYSTEM CYCLE AND OPERATION

4.2.1 Basic Subsystem Cycle

The basic Pilot Plan EPGS cycle is shown in Figure 1-2. The cycle selected for the Pilot Plant turbine is a four-heater regenerative cycle using a single automatic admission, condensing, tandem-compound single-flow turbine.

4.2.2 Subsystem Operating Modes

Both the Commercial Plant and Pilot Plant EPGS experience several modes of operation which the subsystems must be designed for and operate stably in. The modes are:

- Normal Solar Operating Mode. During the normal solar operating mode, steam is generated in the receiver at rated conditions and directed to both the turbine inlet and thermal storage heater. Turbine inlet steam is then expanded through the turbine and is condensed in the condenser. The resultant condensate is then pumped through a full-flow polishing demineralizer and low-pressure feedwater heater to the deaerator. After the deaerator, the feedwater is pumped through the high-pressure heaters and mixes with drains pumped from the thermal storage heater. The combination of turbine cycle feedwater and thermal storage heater drains flows back to the receiver where the process is repeated. Normally, no heat is extracted from thermal storage during the normal solar operating mode.

- Low Solar Operating Mode. The low solar operating mode occurs during periods of low solar isolation levels and combines both the receiver or inlet steam with thermal storage or admission steam simultaneously to maintain the required electrical generation level. During this mode, steam generated in the receiver at rated conditions passes through the turbine high-pressure section and mixes with admission steam generated in the thermal storage steam generator. The total steam flow then passes through the low-pressure turbine admission valves, thence through the low-pressure section to the condenser. Condensate is then pumped from the condenser hotwell through the polishing demineralizer, low-pressure heater, and into the deaerator. After the deaerator, the feedwater is divided and pumped both to the receiver, through the high-pressure heaters, and to the thermal storage steam generator where the process is repeated. Normally, during the low solar mode of operation, no steam is sent to thermal storage unless rated receiver steam conditions cannot be safely maintained.

- Intermittent-Cloud Operating Mode. In the intermittent-cloud case, the solar insolation incident on the receiver is insufficient to generate rated steam conditions, so all steam generated in the receiver is sent to thermal storage. Heat is simultaneously extracted from thermal storage for turbine operation on storage steam only via the automatic admission port on the turbine, generating approximately 70% of rated load. Condensate formed in the condenser is pumped through the polishing demineralizer, low-pressure heater, and into the deaerator. The feedwater leaving the deaerator is then pumped by the booster pump back to the steam generator whence it came. Meanwhile, the condensate formed in the thermal storage heater is discharged to a flash tank where the resultant flashed steam and drains are used for feedwater heater.

- Extended Operation. The extended operating mode or admission steam only mode allows turbine operation during nighttime periods while operation is solely on thermal storage steam. The receiver at this time is out of service. During the extended-operation mode, the turbine is capable of producing approximately 70% of rated load for 3 hr.

- Thermal Storage Charging Only. During the thermal storage charging only mode the turbine is out of service and all steam generated in the receiver is delivered at derated steam conditions to thermal storage. Condensate formed in the thermal storage heater is then rejected to the turbine feedwater system where feedwater is heated and deaerated before it is returned to the receiver.

4.2.3 Turbine Operating Scenarios

The Pilot Plant turbine is required to be started every morning, transferred to an alternate steam source during the evening, and shut down every night. During satisfactory weather conditions, the unit will generate 11,200 kW gross (10,000 kW net) at Winter solstice, 2 PM, while operating on 10.1 MPa (1,465 psia), 510°C (950°F) receiver steam. When the setting sun or cloud cover limits the receiver steam output, the unit will generate a minimum of 7,800 kW gross (7,000 kW net) by operating on 2.65 MPa (385 psia), 274.4°C (525°F) automatic admission steam from the thermal storage subsystem, either alone or in combination with the receiver steam.

Turbines are designed to essentially operate with steady-state throttle steam conditions. The allowable operating transients are primarily dependent on the mass of and the required life of the unit. Larger units, such as this commercial unit that contains relatively massive components, are more susceptible to large temperature gradients and the consequential cyclic fatigue than smaller, less massive units, such as the Pilot Plant turbine. Therefore, the allowable transients for smaller units are generally more liberal than for larger ones. The various turbine manufacturers normally indicate the allowable operating steam pressure and temperature variations that a turbine can be subjected to without unduly shortening its useful life.

The turbine type selected for the Pilot Plant is of the same type as selected for the Commercial Plant; namely, it is a tandem-compound, automatic-admission, condensing, industrial turbine. This turbine is well-suited for the solar plant application. It permits introduction of the lower temperature and pressure thermal storage steam through an automatic admission port located downstream of the primary (receiver steam) high-pressure steam inlet, thus minimizing temperature gradients when switching from receiver steam to thermal storage steam operation.

4.2.3.1 Allowable Temperature Ramp Rate

The recommended temperature ramp rate vs temperature change for the Commercial Plant turbine is shown in Figure 3-2. The temperature change is measured using the first-stage inner-shell thermocouple. The curve indicated is the operating curve for the Commercial turbine assuming a 10,000-cycle life expectancy. Once the temperature change is determined (the difference between the metal temperature before startup and the temperature once full operation is attained), the ramp rate is fixed in order to maintain the planned life expectancy. The steam inlet temperature can lead the metal temperature by 28°-$56^{\circ}C$ (50°-$100^{\circ}F$). Figure 3-2 also shows that instantaneous temperature changes of $37.8^{\circ}C$ ($100^{\circ}F$) and ramp rates of $204.4^{\circ}C$ ($400^{\circ}F$) per hour and less will not have any adverse effects on turbine life.

Allowable temperature ramp rates for the Pilot Plant turbine will be basically the same as shown for the Commercial turbine.

4.2.3.2 Turbine Startup and Shutdown

The type of start (defined as Cold, Warm, or Hot) will depend on the average temperature of the shell metal and will establish the rotor acceleration rate to rated speed. The average metal temperature can be established by actual thermocouple readings (if the turbine is equipped with controlled start thermocouples) or by the duration of the previous shutdown.

For turbines with thermocouples, the following apply:

A. Read the following temperatures:
   1. Steam chest, inner and outer surfaces.
   2. First valve port, inner and outer surfaces.
   3. Adjacent valve port, inner surface.
   4. First-stage shell, inner surface.

B. Average these six thermocouple readings to obtain the average shell metal temperature.

C. Select the type of start:
   1. Cold Start - average metal temperature is -18° to $149^\circ C$ (0°-$300^\circ F$)
   2. Warm Start - average metal temperature is 149°-$371^\circ C$ (301°-$700^\circ F$)
   3. Hot Start - average metal temperature is 372°-$538^\circ C$ (701°-$1000^\circ F$)

For turbines without thermocouples, select the type of start from the following data:

Duration of Previous Shutdown	Type of Start
Longer than 72 hours	Cold
12 to 72 hours	Warm
Less than 12 hours	Hot

A typical cool-down curve for a high-pressure single-shell design turbine is shown in Figure 3-3.

The estimated startup and loading characteristics for the Pilot Plant turbine are shown in Table 4-1.

Steam Conditions for Turbine Roll

With respect to the steam conditions necessary for a turbine roll, the General Electric Company recommends an initial pressure above 40% of design and a temperature at 41.6°C (75°F) to 55.5°C (100°F) above saturation. If the temperature drops below 41.6°C (75°F) superheat, attempts are to be made to increase it; if it drops to 13.9°C (25°F) superheat, the turbine is to be tripped. For the Commercial Plant, like the Pilot Plant, it is expected that the conditions can be met by first establishing circulation through the receiver, the receiver startup flash tank, and back to the condenser. As the solar insolation increases, the receiver power and steam quality will build until the desired conditions are achieved. The time required to obtain the turbine roll steam conditions will have to be determined through experimentation.

Startup with Thermal Storage Steam

If desired, the turbine can be rolled and loaded on thermal storage steam (admission steam) only, and the transition from admission steam to inlet steam from the receiver can be made when inlet steam conditions permit. The minimum pressure and temperature requirements for turbine roll apply to admission steam starts as well as inlet steam, as does the allowable temperature ramp rate shown in Figure 3-2.

Nighttime Standby

Through the night, when the unit is not generating, it is anticipated that the turbine steam seals from the auxiliary steam boiler or thermal storage subsystem and condenser vacuum will be maintained. Also, the turbine will be placed on turning gear and blanketing steam will be applied to the high-pressure heaters and deaerator. These activities will keep the system warm and simplify the morning startup. This will also lessen the corrosion tendencies by preventing air from entering the condenser, deaerator, and high-pressure heaters. During the morning startup, the feedwater system will no

Table 4-1

PILOT PLANT TURBINE STARTING AND LOADING PROCEDURE*

Type of Start	Cold Start	Warm Start	Hot Start
Average Metal Temperature	0° to 300°F	301° to 700°F	701° to 1,000°F
1. Turning Gear	2 Hr Minimum Operation	3 Hr Minimum Operation	Minimum Time
2. Establish Seals	Raise Vacuum to Maximum Obtainable without Seals	2 psig	2 psig
3. Raise Vacuum	Establish Seals 2 psig	--	--
4. Roll Unit	At 25 in. Hg Vac	At 25 in. Hg Vac	At 25 in. Hg Vac
5. Accelerate to 1,000 rpm	(250 rpm/Min) 4 Min	(500 rpm/Min) 2 Min	(500 rpm/Min) 2 Min
6. Hold at 1,000 rpm	10 Min	10 Min	5 Min
7. Accelerate to 3,550 rpm	(250 rpm/Min) 10 Min	(500 rpm/Min) 5 Min	(500 rpm/Min) 5 Min
8. Synchronize and Load Generator	(1/2%/Min) 200 Min	(1 1/2%/Min) 66 Min	(3%/Min) 33 Min
Time After Start of Roll to Full Load	224 Min (3 Hr - 44 Min)	83 Min (1 Hr - 23 Min)	45 Min

*Per General Electric Company Starting and Loading Instruction GEK-14402C doubt have to be cleaned up. To accomplish this, a recirculation line has been provided in the feedwater line at the receiver feed pump inlet and is routed back to the condenser. In addition, provisions are made for bypassing the receiver with a feedwater warmup line routed to the receiver startup flash tank to facilitate feedwater system cleanup prior to startup and to maintain feedwater flow in the riser to prevent freezing.

4.2.4 Auxiliary Steam Supply

As summarized in Section 2.1.1.8, the Commercial Plant auxiliary steam requirements will be supplied from one of two sources, i.e., thermal storage subsystem or auxiliary oil-fired low-pressure steam boiler.

The auxiliary steam requirements are described in the following paragraphs:

4.2.4.1 Turbine Seal Steam

Turbine seal steam is required at the turbine shaft seals to prevent the leakage of air into the turbine whenever a vacuum is established in the condenser. During normal turbine operation, the gland steam leakage from the turbine high-pressure section is sufficient to provide seal steam for the turbine requirements; consequently, no external source of seal steam is required during this period of operation. However, during a turbine startup or whenever vacuum is maintained on an idle turbine, an external source of seal steam is required. The seal steam requirements for the Pilot Plant turbine are estimated at 454 kg/hr (1,000 lb/hr) at a pressure of 124 to 138 kPa (18 to 20 psia). The steam temperature preferably should be in the superheated range, providing at least 14°C (25°F) superheat on a cold start. During a warm or hot start, however, the temperature difference between the seal steam and turbine rotor surface in the gland zone should be kept to a minimum when starting or shutting down so as to minimize thermal stresses in the rotor.

4.2.4.2 High-Pressure Heater Shell Blanketing

Auxiliary steam is used to blanket the shell side of the high-pressure heaters when they are out of service, to prevent air leakage into the heater which could cause serious corrosion problems to the carbon steam tubes in the heater. The estimated steam consumption for the requirement is small, estimated at 2.3 kg/hour (5 lb/hr) for two high-pressure heaters.

4.2.4.3 Deaerator Heater Blanketing

The deaerator, including the storage tank section, is also blanketed with steam to minimize corrosion effects; in addition, the blanketing steam serves to maintain the condensate in the deaerator storage tank, approximately 11.35m^3 (3,000 gal), at about 108.9°C (228°F), corresponding to the 138 kPa (20 psia) steam saturation temperature, to facilitate morning startup. The amount of steam required for deaerator blanketing is 5.4 kg/hr (12 lb/hr).

4.2.4.4 Deaerator Pressure "Pegging"

To maintain efficient deaeration of feedwater at low loads when the deaerator extraction pressure is below atmospheric, auxiliary steam must be supplied to the deaerator to maintain a slight positive pressure inside the deaerator to facilitate venting to the atmosphere. The normal turbine extraction pressure to the deaerator goes subatmospheric at about 40% load. The next highest pressure turbine extraction is then used to peg the deaerator down to about 25% load. At about 25% load and less auxiliary steam is automatically supplied at 138 Pa (20 psia). The amount of auxiliary steam required for deaerator pressure pegging is approximately 544 kg/hr (1,200 lb/hr).

4.2.4.5 Startup Requirements

The startup requirements for the auxiliary steam system are based on a cold startup when steam is required for initial deaeration and preheating of the feedwater, assuming a minimum flow of 25% of the turbine rated throttle flow. The auxiliary steam required for this process is 2,041 kg/hr (4,500 lb/hr). Shortly after the receiver startup system is in operation, steam from the receiver startup flash tank will supplement the auxiliary steam until turbine extraction steam is available for feedwater heating and deaeration.

4.2.4.6 Receiver Freeze Protection

The receiver must be protected from freeze during nighttime periods when the ambient air temperature is below freezing. Hot water will be circulated through the receiver, returning to the deaerator through the receiver startup flash tank. The estimated receiver heat loss based on -17.8°C (0°F) air and 18.3 m/s (40 mph) wind velocity is 4,220 MJ/hour (4 x 10^6 Btu/hr), requiring about 1,910 kg/hour (4,202 lb/hr) of auxiliary steam to be added in the deaerator.

4.2.5 Receiver Startup Flash Tank

4.2.5.1 Requirements

The function of the receiver startup flash tank system is to provide a means of establishing flow through the receiver during the cleanup mode before startup, and during startup mode before generation of rated steam conditions. The receiver startup flash tank system schematic is shown in Figure 3-6.

The operational characteristics during the Pilot Plant receiver prestart and startup modes are described in Section 4.4 of Volume IV.

For the Pilot Plant, the receiver flash tank will be sized for 3.16 kg/s (25,000 lb/hr), which corresponds to minimum flow for stable receiver operation. This corresponds to approximately 21.5% of maximum receiver flow at equinox noon.

The flash tank design and construction will conform to ASME Section VIII, Unfired Pressure Vessel Code.

4.2.5.2 Sizing Conditions

Receiver Flow Rate	3.16 kg/s (25,000 lb/hr)
Receiver Outlet Pressure	10.34 MPa (1,515 psia)
Receiver Outlet Temperature	343°C (650°F)
Flash Tank Operating Pressure	2.17 MPa (315 psia)
Flash Tank Design Pressure	2.51 MPa (365 psia)

$$\text{Percent Flash} = \frac{h_{f1} - h_{f2}}{h_{fg2}}$$

h_{f1} = 613.4 Btu/lb (saturated liquid at 1,515 psia)

h_{f2} = 398.9 Btu/lb (saturated liquid at 315 psia)

h_{fg2} = 804.4 Btu/lb (heat of evaporation at 315 psia)

$$\text{Percent Flash} = \frac{613.4 - 398.9}{804.4} = 0.266 \text{ or } 26.6\%$$

$$\text{Flash Steam} = 0.266\ (3.16) = 0.84 \text{ kg/s } (6,650 \text{ lb/hr})$$

$$\text{Condensate} = 3.16 - 0.84 = 2.32 \text{ kg/s } (18,350 \text{ lb/hr})$$

4.2.5.3 Tank Sizing

Design flash tank for maximum of 0.91 m/s (3 fps) vapor velocity in tank.

$$A = Q/V$$

$$Q = \frac{6,650 \text{ lb/hr} \times 1.47 \text{ ft}^3\text{/lb}}{3,600} = 2.71 \text{ ft}^3\text{/sec}$$

$$V = 3.0 \text{ fps}$$

$$A = 2.71/3.0 = 0.903 \text{ ft}^2 \text{ minimum}$$

$$I_{min} = 1.07 \text{ ft}$$

Use 0.6m (2 ft) flash tank diameter

The receiver flash tank for the Pilot Plant is a shell with a 0.60m (2 ft.) diameter and a 1.82m (6 ft) length. The configuration is depicted in Figure 4-1.

4.2.6 Thermal Storage Heater Drain System

Steam condensed in each thermal storage heater is drained to a drain tank where a level is maintained. From each drain tank the condensate is drained through a level control valve to a common flash tank. Flashed steam from the flash tank is used for feedwater heating and deaeration. Condensate from the flash tank is either drained to the deaerator or to the condenser for cleanup in the polishing demineralizer. Flash tank pressure will be maintained at 1.03 MPa (150 psia) maximum by a backpressure control valve in the vapor outlet line. Excess steam will be sent to the condenser. A schematic of the thermal storage heater drain system is shown in Figure 4-2.

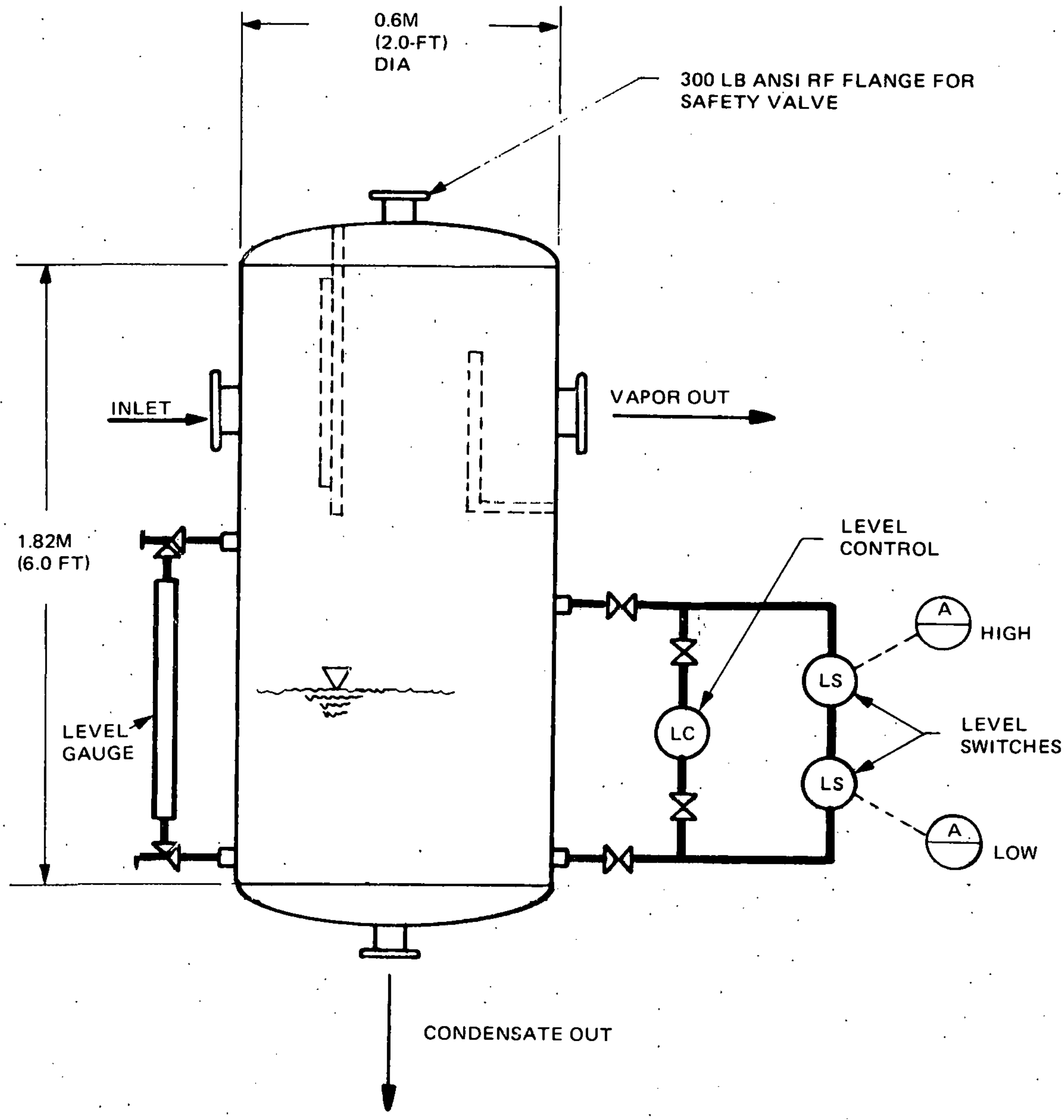

Figure 4-1. Receiver Startup Flash Tank

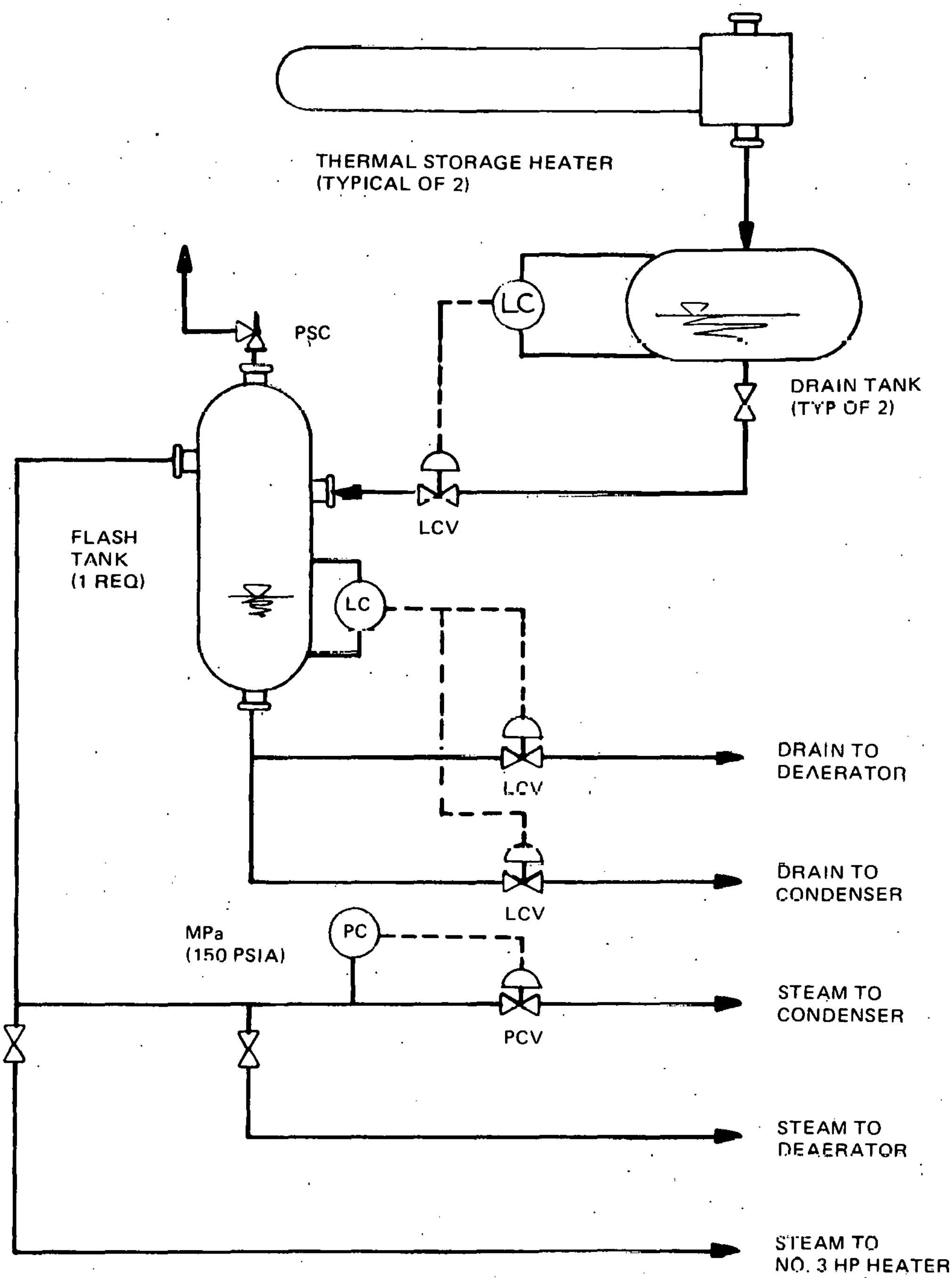

Figure 4-2. Thermal Storage Heater Drain System (Pilot Plant)

4.3 EPGS EQUIPMENT AND BALANCE OF PLANT CHARACTERISTICS

4.3.1 Turbine-Generator

4.3.1.1 Selection

The turbine-generator selected for the Pilot Plant is a tandem-compound, single-flow, automatic admission, condensing unit rated at 12,500 kW at 8.46 kPa (2.5 in. HgA) backpressure when operating with inlet steam conditions of 10.1 MPa (1,465 psia) and 510°C (950°F). When operating on admission steam at 2.65 MPa (385 psia) and 274.4°C (525°F), the turbine will generate 7,800 kW at 8.46 kPa (2.5 in. HgA) backpressure.

The generator is rated at 16,000 kVA, 0.85 power factor, 13,800V, 60 Hz and is air-cooled, with static excitation system.

Turbine accessories are:

- Generator air coolers.
- Lube oil coolers.
- Lube oil reservoir.
- AC auxiliary oil pump.
- DC auxiliary oil pump.
- Electrohydraulic control system.

The rationale for the selection of the admission-type turbine, in addition to inlet and admission steam conditions and cycle analysis, is discussed in Section 2.1.2.

4.3.1.2 Turbine Performance

The predicted performance for the Pilot Plant turbine is as follows:

	Winter Solstice (Design Point) Receiver Steam	Equinox Noon Receiver Steam*	Admission Only (Extended Op) TS Steam
Gross Generation, kW	11,200	12,700	7,800
Net Generation, kW	10,000	11,300	7,000
Gross Turbine Heat Rate	10,447	10,377	14,363
kJ/kW hr (Btu/kW hr)	(9,902)	9,836	(13,614)
Steam Flow, kg/s (lb/hr)	12.93 (102,440)	14.84 (117,568)	13.21 (104,700)
Turbine Backpressure, kPa (in. HgA)	8.46 (2.5)	8.46 (2.5)	8.46 (2.5)

*Maximum Capability, All Steam Flow to Turbine

Turbine Partial Load Performance

The predicted turbine performance for both receiver steam and thermal storage steam as a function of throttle or admission steam flow is shown in Figure 2-14.

Turbine Maximum Capability

The maximum expected turbine throttle steam flow while operating at rated inlet steam conditions is 10% above the rated steam flow at 12.5 MW gross of 14.47 kg/s (114,636 lb/hr), or 15.92 kg/s (126,100 lb/hr). This maximum throttle flow will result in an increase in generation of approximately 9%, or 13,625 kW maximum expected capability. NOTE: To pass an additional 10% flow through the admission valve gear, it will be necessary to increase the admission point pressure 10% above rated admission steam pressure.

The maximum admission steam flow is equal to the rated steam flow 13.21 kg/s (104,700 lb/hr) at rated admission steam conditions; i.e., 2.65 MPa (385 psia) and 274.4°C (525°F) because of flow limitations in the admission valve gear. An additional 10% admission steam flow is possible; however, if admission pressure is increased 10%, from 2.65 MPa (385 psia) to 2.91 MPa (423 psia).

The maximum expected generation at 10% overpressure on admission steam only is approximately 8,502 kW.

4.3.1.3 Turbine Operating Modes

The single automatic extraction/admission turbine selected for both the Commercial and Pilot Plants is designed to operate in three basic operating modes.

Operation on Admission Steam Only

During the total admission mode, the turbine is operated entirely on the 2.65 MPa (385 psia) steam admitted into the stage shell ahead of the admission valves. In this case, the turbine operates in the speed/load control mode, and the turbine will accept and reject load automatically.

A cooling steam line which runs from the first-stage shell to the admission header is necessary on this type of unit to provide a path for circulating admission steam through the high-pressure section to carry away excess heat generated there during total admission operation. Circulation is accomplished by the pumping action of the high-pressure section buckets that pump steam downstream from the first-stage shell to the admission point.

Operation on Initial Pressure and Speed/Load Control (Low Solar Power Operating Mode)

When all subsystems are placed in service except for the admission pressure control subsystem, the turbine will accept and reject load without significantly affecting inlet flow. In this mode, the inlet control valves are positioned to control initial pressure (receiver pressure), and the admission control valves are positioned to control speed/load.

Operation on Initial Pressure and Admission Pressure Control (Normal Solar Operating Mode)

The third operating mode is one in which initial pressure and extraction pressure are controlled by the turbine. In this mode, it will be necessary to tie the turbine to a stiff electrical system to maintain the rate frequency. In this mode, the generation will be determined by, and will vary with, the available steam supply. Since in the solar plant there is little control of the heat absorbed in the receiver, the turbine will control initial pressure (receiver pressure) and accept receiver steam up to its limits, unless steam is diverted to thermal storage.

4.3.2 Condenser and Air-Removal Equipment

4.3.2.1 Performance Requirements

The condenser selected for the Pilot Plant turbine is of the shell and tube type using cooling tower circulating water for heat rejection. The condenser is sized for the highest heat-rejection load that can be expected during plant operating modes.

The air-removal equipment is required to remove air and other noncondensable gases from the steam side of the condenser.

The air-removal equipment selected is mechanical vacuum pumps with electric-motor drive. Two full-capacity vacuum pumps are provided.

All condenser design and performance characteristics and air-venting requirements are in accordance with Heat Exchanger Institute Standards for Steam Surface Condensers, 6th Edition.

4.3.2.2 Condenser Heat Loads

The heat-rejection loads governing the condenser sizing follow for two operating conditions:

	Turbine Rating 12,500 kW	Admission Steam Only Extended Operation 7,800 kW
Turbine Exhaust Flow	10.69 kg/s (84,675 lb/hr)	10.12 kg/s (88,080 lb/hr)
Condenser Pressure	8.46 kPa (2.5 in. HgA)	8.46 kPa (2.5 in. HgA)
Heat Rejection, GJ/hr (Btu/hr)		
Turbine Exhaust Steam	83.620 (79.27×10^6)	80.950 (76.73×10^6)
No. 1 Heater Drains	0.086 (0.816×10^5)	0.092 (0.871×10^5)
Steam Seal Regulator	0.938 (0.889×10^6)	0.813 (0.771×10^6)
Subtotal	84.644 (80.24×10^6)	81.855 (77.588×10^6)
Margin for Misc Drains	5.275 (5.00×10^6)	13.095 (12.412×10^6)
Total Condenser Duty	89.919 (85.24×10^6)	94.950 (90.00×10^6)
Difference	Base	+5.58% (Design)

4.3.2.3 Condenser Design Parameters

Surface Area	1,115m^2 (12,000 ft^2)
Tube Material	90-10 Copper Nickel
Tube Diameter (OD)	19.05 mm (0.750 in.)
Tube Wall Thickness	0.89 mm (0.035 in.) 20 BWG
Tube Length (Effective)	6.1m (20 ft.)
Condenser Pressure	8.46 kPa (2.5 in. HgA)
Heat Rejection	94.945 GJ/hr (90.0 x 10^6 Btu/hr)
Cooling Water Flow	0.725 m^3/s (11,500 gpm)
Water Velocity	2.13 m/s (7.0 fps)
Cooling Water In	29.4°C (85.0°F)
Cooling Water Out	38.2°C (100.7°F)
Temperature Rise	8.7°C (15.7°F)
TTD	4.4°C (8.0°F)
Tube Cleanliness	85%

4.3.2.4 Condenser Material Selection

The construction materials selected for the Commercial Plant condenser have been based on experience with many utility condensers. Of particular concern, however, is the tube material. From the standpoint of the receiver, it is preferred that no copper alloy materials be used on systems incorporating once-through boilers because of possible copper pickup in the condensate, resulting in copper deposition on the boiler heat transfer surfaces or on the turbine blades. For this reason, stainless steel would seem a good choice for condenser tube material. However, stainless steel is subject to pitting failure due to circulating water impurities, particularly when high solids concentrations are maintained in the circulating water system to minimize blowdown requirements. Also, pitting failure in stainless steel is accelerated in systems that have frequent shutdowns. Since it is planned to operate the solar plant in a cyclic manner (startup every day), it is imperative to keep a circulating water pump operating at all times when stainless-steel condenser tubes are employed. In view of the apparent problems with stainless steel, it has been decided to use 90-10 copper-nickel tubes in the condenser. Since full-capacity in-line polishing demineralizers are located downstream of the condenser condensate pumps, the possibility of copper carryover through the demineralizer units is considered minimal.

Materials of Construction

Waterboxes	Steel, ASTM A-285 Grade C, Epoxy Coated on Interior, with Sacrificial Anodes
Shell Plate	Steel, ASTM A-285 Grade C
Tube Sheets	Muntz Metal, ASTM B-171, Alloy 365, or 90-10 Copper-Nickel ASTM B-171, Alloy 706
Tubes	Copper-Nickel, ASTM B-111, Alloy 706
Tube Support Plates	Steel, ASTM A-285 Grade C

4.3.2.5 Condenser Air-Removal Equipment

The type of condenser air-removal equipment selected for the Pilot Plant is the mechanical vacuum pump. The mechanical vacuum pump was selected for the reasons outlined in Section 3.3.2.5 for the Commercial Plant. Two full-capacity pumps are provided, each rated at 7.5 scfm dry air at 3.38 kPa (1 in. HgA) suction pressure. The pumps are of the centrifugal, liquid type, with 22.4 kW (30 hp), 900-rpm motors.

4.3.3 Heat Rejection

The method of condenser heat rejection selected for the Pilot Plant is the mechanical draft, wet cooling tower. A two cell, cross-flow tower has been selected.

The cooling tower heat load equals the condenser heat rejection plus an assumed 5.28 MJ/hr (5.0 x 10^6 Btu/hr) allowance for auxiliary plant equipment cooling. A design wet bulb temperature of 23°C (73.4°F) was used in accordance with the design requirements previously set forth.

4.3.3.1 Cooling Tower

Quantity	One
Type	Mechanical Induced Draft, Cross-flow
Number of Cells	2
Number of Fans	2
Fan Motor Size	75 kW (100 hp)
Overall Dimensions	(L X W X H)
	17.1 x 18.6 x 88.8m (56 x 61 x 29 ft)
Heat Rejection	100 GJ/hr (95 x 10^6 Btu/hr)
Design Wet Bulb Temperature	23°C (73.4°F)
Cold Water Temperature	29.4°C (85.0°F)
Hot Water Temperature	37.9°C (100.2°F)
Temperature Range	8.5°C (15.2°F)
Circ Water Flow	47.3m^3/min (12,500 gpm)

4.3.3.2 Cooling Tower Makeup Water Requirements

The cooling tower makeup water requirement is the sum of the cooling tower evaporation rate, drift rate, and blowdown rate. The tower blowdown rate is a function of the evaporation rate, drift rate, and number of cycles of concentrations to be maintained in the tower circulating water. The equation form is:

$$\text{Blowdown, BD} = \frac{E + D(1 - C)}{C - 1}$$

where

E = Evaporation rate

D = Drift rate

C = Number of cycles concentration

BD = Blowdown rate

The tower evaporation can be assumed to be equal to approximately three-fourths of 1% of the circulating water flow for every 5.6°C (10°F) of cooling range. Thus, for a 8.5°C (15.2°F) cooling range and a circulating water flow of 47.3m^3/min (12,500 gpm), the evaporation rate is approximately 0.54m^3/min (143 gpm).

Drift loss can be assumed to be 0.01% of the circulating water flow rate, or 4.0 liter/min (1.3 gpm).

The number of cycles that can be maintained will depend on the makeup water quality, as discussed in Section 3.3.11.2.

4.3.4 Feedwater Heaters

As previously mentioned, a four-heater cycle was selected for the Pilot Plant. These heaters consist of one closed, horizontal low-pressure heater; two closed, horizontal high-pressure heaters; and one open deaerating heater with a horizontal condensate storage section.

4.3.4.1 Low-Pressure Heater

Shell Material	Carbon Steel, ASTM A2855-C
Tube Material	Stainless Steel, ASTM A249
Tube Design Pressure	1.14 MPa (165 psia)

Horizontal Heater with Drain Cooler Section ASME Code, Section VIII Design

4.3.4.2 High-Pressure Heaters

Shell Material	Carbon Steel, ASTM A2855-C
Tube Material	Carbon Steel, ASTM A2855-C
Tube Design Pressure	5.27 MPa 765 psia)

Horizontal Heater with Drain Cooler Section ASME Code, Section VIII Design

4.3.4.3 Deaerator

Shell Material	Carbon Steel, ASTM A285 C
Tray Material	Stainless-Steel Type 430
Vent Condenser Material	Stainless-Steel Type 304
Design Pressure	0.45 kPa (65 psia)
Guar Oxygen in Effluent	Less than 0.005 cc/liter
Condensate Storage Capacity	18.9m^3 (5,000 gal)

ASME Code, Section VIII Design

4.3.5 Booster Pumps

The booster pumps take suction from the deaerator and pump both to the receiver feed pump inlet and to the thermal storage steam generators. During normal operation on receiver steam, the booster pumps deliver feedwater through the two high-pressure heaters to the receiver feed pump inlet where the feedwater pressure is increased to meet receiver requirements. During operation on thermal storage steam only, the booster pumps provide feedwater at the required pressure at the thermal storage steam generator inlet. At this time, the receiver feed pump would be out of service. During periods of intermittent-cloud operation, the booster pumps would deliver feed water to the receiver feed pump and thermal storage steam generator simultaneously.

Each booster pump is designed to handle 100% of the required capacity. Each pump is of the horizontal, multistage design with constant-speed motor drive. Each pump is designed for the following conditions:

Capacity	2.2 m/min (575 gpm)
Head	355.5m (1,166 ft)
Efficiency (Est)	75%
Brake Horsepower	158 kW (212 hp)
Motor Size	186.5 kW (250 hp)

4.3.6 Receiver Feed Pumps

Two full-capacity receiver feed pumps are provided, each with variable speed hydraulic coupling for speed control. Pump speed will be automatically controlled to maintain a set pressure at the inlet to the receiver. Each pump is of the double-case, barrel-type design, rotating at approximately 3,465 rpm at full load.

The pump materials of construction include a forged carbon steel outer barrel, cast chrome steel inner casing and impellers, and a chrome steel pump shaft.

The pump design characteristics are as follows:

Capacity, Each	1.32 m^3/min (350 gpm)
Inlet Pressure	310 MPa (450 psia)
Developed Head	1,423,7m (4,670 ft)

Efficiency (Est)	65%
Brake Horsepower	407.4 kW (546 hp)
Motor Size	448 kW (600 hp)

4.3.7 Plant Piping

The Pilot Plant EPGS piping systems are discussed in the following paragraphs, with particular attention given to the riser/downcomer configuration and analysis in the unique central receiver concept. Piping design characteristics are also given for the thermal storage subsystem/EPGS steam and feedwater systems.

4.3.7.1 Riser/Downcomer

The downcomer is defined as that portion of the piping system which conveys high-pressure, high-temperature steam from the receiver superheater outlet header(s), running down the receiver tower structure, and includes the horizontal run of piping to the turbine building limits, and to the thermal storage subsystem limits.

The function of the riser to convey high-pressure feedwater from the turbine building limits, up the receiver tower to the stop-check valves at the receiver inlet.

Riser Design Requirements

Applicable Code	ANSI B31.1 Power Piping Code
Pressure Require, at Tower/ Receiver Interface	20.69 MPa (3,000 psia)
Design Flow to Receiver	
Winter Solstice, 2 PM	12.93 kg/s (102,440 lb/hr)
Equinox Noon	14.84 kg/s (117,568 lb/hr)
Seismic Accelerations (Survival)	
Horizontal Ground Acceleration	0.33g (Revised to 0.25g)
Vertical Ground Acceleration	0.22g (Revised to 0.25g)
Tower Height	65m (213 ft)

Downcomer Design Requirements

Applicable Code	ANSI B31.1 Power Piping Code
Design Pressure	11.82 MPa (1715 psia)
Design Temperature	537.8°C (1,000°F)
Maximum Allowable Pressure Drop (Receiver/Tower Interface to Turbine and/or Thermal Storage Heater	0.34 MPa (50 psi)
Seismic Accelerations (Survival)	
Horizontal Ground Acceleration	0.33g (Revised to 0.25g)
Vertical Ground Acceleration	0.22g (Revised to 0.167g)
Tower Height	65 (213 ft)

Riser Design Characteristics

Design Pressure	19.93 MPa (2,890 psia)
Design Temperature	232.2°C (450°F)
Pipe Size (Nominal)	10.2 cm (4 in.) Sch 160
Pipe Material	Carbon Steel ASTM A106 Grade B
Unit Weight	33.5 kg/m (22.5 lb/ft)
Insulation	6.35 cm (2.5 in.) Calcium Silicate with Aluminum Jacket

Downcomer Design Characteristics

	Receiver Tower	Turbine Branch	Thermal Storage Branch: Before Desuper-heater	Thermal Storage Branch: After Desuper-heater
Design Pressure	11.82 MPA (1,715 psia)	11.82 MPa (1,715 psia)	11.82 MPa (1,715 psia)	11.82 MPa (1,715 psia)
Design Temperature	537.8°C (1,000°F)	537.8°C (1,000°F)	537.8°C (1,000°F)	357.2°C (675°F)
Pipe Size (Nominal)	6 in. Sch 160	6 in. Sch 160	(6 in.) Sch 160	(6 in.) Sch 120
Pipe Material	Low Alloy Steel ASTM A335 Grade P22 (2-1/4 CR-1 mo)	Low Alloy Steel ASTM A335 Grade P22 (2-1/4 CR-mo)	Low Alloy Steel ASTM A335 Grade P22 (2-1/4 CR-1 mo)	Carbon Steel ASTM A106 Grade B
Unit Weight	67.4 kg/m (45.3 lb/ft)	67.4 kg/m (45.3 lb/ft)	67.4 kg/m (45.3 lb/ft)	54.2 kg/m (36.4 lb/ft)
Insulation	12.7 cm (5 in.) Calcium Silicate with Aluminum Jacket	12.7 cm (5 in.) Calcium Silicate with Aluminum Jacket	12.7 cm (5 in.) Calcium Silicate with Aluminum Jacket	8.9 cm (3.5 in.) Calcium Silicate with Aluminum Jacket

Major Tower Piping Systems

In addition to the riser piping (FW-1) and downcomer piping (MS-1), the following additional tower piping was included in the analysis:

CO-1	Flash Tank Condensate
MS-2	Flash Tank Vapor
MS-3	Receiver Steam to Flash Tank

All systems are routed with consideration for:

1. Thermal expansion.
2. Ease of support.
3. Horizontal and vertical seismic accelerations.

4. Accessibility.
5. Economy.
6. Maintenance.

For accessibility, it is desirable to run the tower piping as close to each other as possible. This limits the amount of additional steel for supports. Each is routed nearly directly down the tower on the same side as the elevator. Jogs in the pipe are included to keep the pipe within about 8 to 9 ft of the outside of the tower. This allows access around the elevator without interference from the pipes, while keeping the pipes close enough to the elevator that only small platforms must be supplied for access to the pipe and supports.

The pipe jogs also supply convenient locations to attach elbow lugs for the riser hangers.

Practically all of the thermal expansion is accommodated in expansion loops at the base of the tower. The pipes are supported outside the tower by braced cantilever beams from the tower. This limits any possible interference problems at the lower elevations. Also, the pipe is high enough to provide clearance underneath for trucks. Two support structures are required for pipe supports between the tower and turbine building.

In most locations, seismic accelerations are resisted by rigid supports, i.e., horizontal runs. At locations where seismic restraints are required and which must accommodate large thermal displacements, mechanical or hydraulic snubbers must be used.

All five pipelines are analyzed for dead weight, pressure, and seismic loads. Pipelines MS-1 and MS-3 are combined into one analysis system for the thermal expansion and dead weight analyses. MS-2, C0-1, and FW-1 are routed similarly to MS-1. Since these three systems are more flexible than MS-1 and operate at lower temperatures than MS-1, no separate thermal analyses were performed. Satisfactory thermal results for MS-1 indicate MS-2, C0-1, and FW-1 are also satisfactory.

Thermal Expansion--Pipelines MS-1 and MS-3 were analyzed for two separate cases shown on Figure 4-3:

Case A. Steam from receiver to turbine, thermal storage heater and flash tank (Analysis T-16880-MS-01-A-3).

Case B. Steam from receiver to turbine only (Analysis T-16880-MS-01-B-2).

All rigid restraints are included in the analyses.

Maximum pipe stresses are shown in Table 4-2. Equipment reactions for the three thermal cases are shown in Tables 4-3 and 4-4. All results are satisfactory.

Table 4-2

SUMMARY OF PIPE STRESSES, PIPELINES MS-1 AND MS-3

Loading Condition	Maximum Stress (psi)	At Location	Allowable Stress (psi)
1. Dead Weight	2,560	215	N/A
2. Internal Pressure	2,700	215	N/A
3. Primary Stress (Item 1 + 2)	5,260	215	10,360
4. Seismic Primary Stress	1,180	125	N/A
5. Occasional Stress (Item 3 + 4)	6,440	125	12,430
6. Thermal Case A	16,960	515	21,340
7. Thermal Case B	15,220	515	21,340
8. Seismic Secondary Stress	870	515	N/A
9. Occasional Secondary Stress (Item 8 + maximum of Item 6 and 7)	17,830	515	21,340
10. Total Loads (Item 3 + 9)	23,090	515	31,700

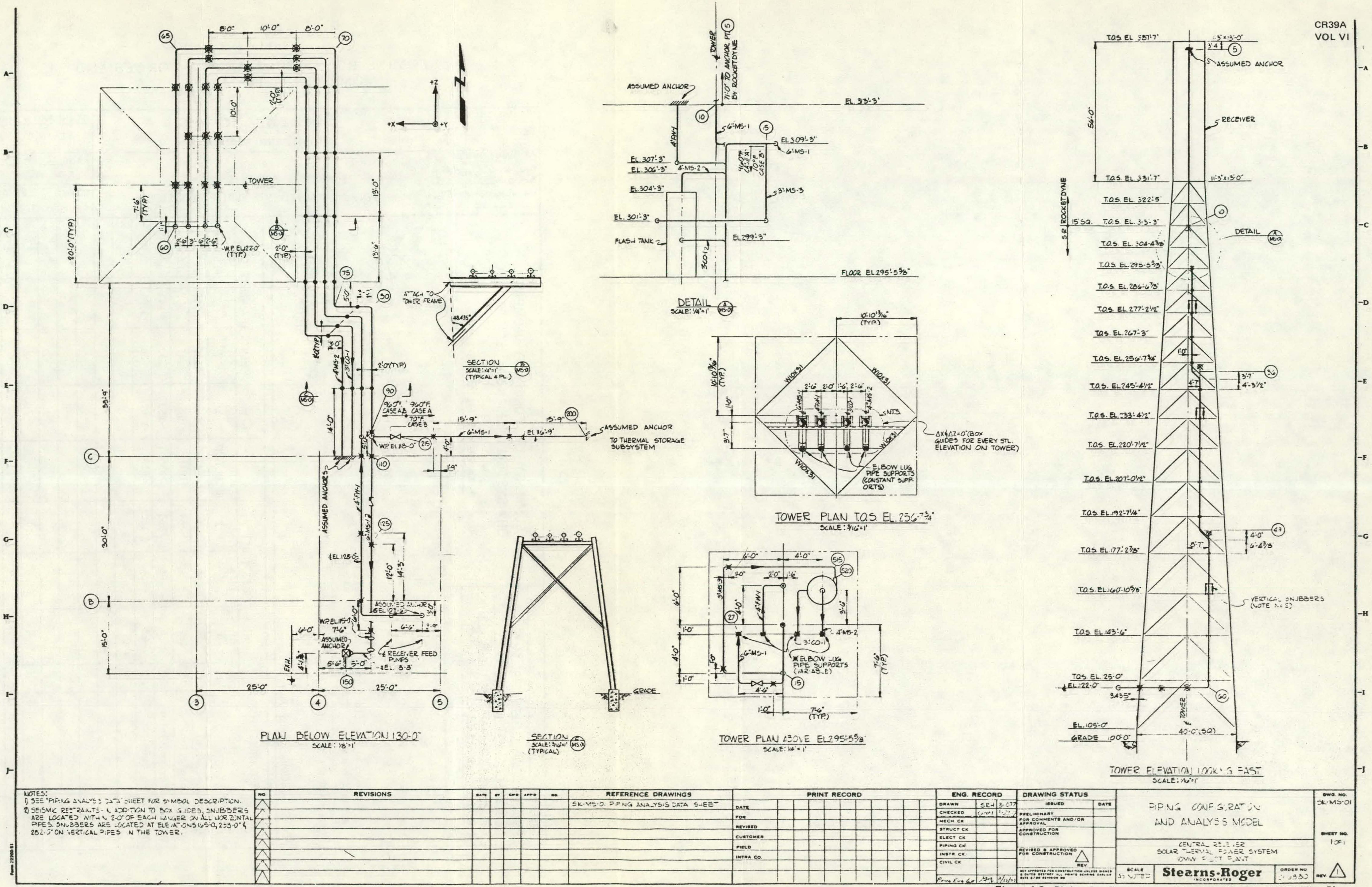

Figure 4-3. Piping Configuration and Analysis Model, 10-MW Pilot Plant

Table 4-3
STEARNS-ROGER SUMMARY OF FORCES AND MOMENTS, THERMAL CASE A

Stearns-Roger INCORPORATED
ENGINEERING STANDARD

SUMMARY OF FORCES & MOMENTS
PER. ANSI B31.1-1973 PWR. PIPING CODE

DIVISION USAGE: MM | P | PP | SH | FI | SP

APPROVALS
Des. Sect.
Sect. Supv.
Div.

STANDARD NUMBER
EE 16.01.7
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ISSUED 2/28/74
REVISED 3/28/77

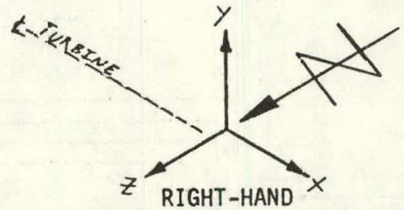
CUSTOMER:	
PROJECT:	Solar 10MW Pilot Plant
JOB NO:	C-16880, X-31002
BY: May	DATE: March 28, 1977
REF. DWGS:	SK-MS-01 1
ANALYSIS CODE:	T-16880-MS-01-A-3

Thermal Case A

SUMMARY OF FORCES & MOMENTS ON SYSTEM TERMINAL EQUIPMENT

(SYSTEM)

MAIN STEAM PIPELINES MS-1, MS-3



RIGHT-HAND CARTESIAN COORDINATE SYSTEM

The reported reactions based on a thermal expansion analysis from 70°F to 960°F using E_c, the cold modulus of elasticity, and 0% cold spring.

NOTE: THERMAL LOADS ONLY!

EQUIPMENT CONNECTIONS		FORCES (LBS)				MOMENTS (FT.-LBS)			
	LOC. NO.	X	Y	Z	RESULTANT	X	Y	Z	RESULTANT
Top of Receiver, El. 384.25'	5	29	868	7	868	164	107	688	716
Turbine Connection	150	469	4	-544	761	1600	6247	902	6512
Thermal Storage Heater	200	-564	-84	463	735	-153	-11050	-441	11060
Inlet Flash Tank	520	-42	-434	152	461	-1362	-960	-3304	3701

Table 4-4

STEARNS-ROGER SUMMARY OF FORCES AND MOMENTS, THERMAL CASE B

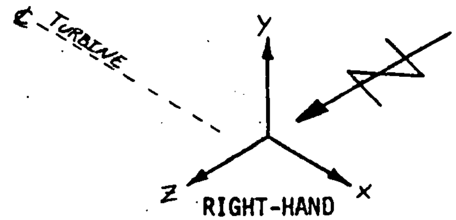
CUSTOMER:	
PROJECT:	Solar 10MW Pilot Plant
JOB NO:	C-16880, X-31002
BY:	May DATE: 3/28/77
REF. DWGS:	SK-MS-01 1
ANALYSIS CODE:	T-16880-MS-01-B2

SUMMARY OF FORCES & MOMENTS ON SYSTEM TERMINAL EQUIPMENT

(SYSTEM)

MAIN STEAM PIPELINES MS-1,MS-3

Thermal Case B



RIGHT-HAND CARTESIAN COORDINATE SYSTEM

The reported reactions based on a thermal expansion analysis from 70°F to 960°F using E_c, the cold modulus of elasticity, and 0% cold spring.

NOTE: THERMAL LOADS ONLY!

EQUIPMENT CONNECTIONS	LOC. NO.	FORCES (LBS) X	FORCES (LBS) Y	FORCES (LBS) Z	FORCES (LBS) RESULTANT	MOMENTS (FT.-LBS) X	MOMENTS (FT.-LBS) Y	MOMENTS (FT.-LBS) Z	MOMENTS (FT.-LBS) RESULTANT
Top of Receiver, El. 384.25'	5	31	823	1	824	-30	143	730	744
Turbine Connection	150	212	2	-482	527	1284	1027	119	1648
Thermal Storage Heater	200	-256	-84	355	445	-126	-9295	-442	9306
Inlet Flash Tank	520	-2	-389	47	392	-1299	-334	-2998	3284

DIVISION USAGE: MM | P | PP | SH | FI | SP

APPROVALS: Dept. Sec. / Sect. Supv. / Div.

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ENGINEERING STANDARD

SUMMARY OF FORCES & MOMENTS PER. ANSI B31.1-1973 PWR. PIPING CODE

STANDARD NUMBER EE 16.01.7

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ISSUED 2/28/74

REVISED 3/28/77

Dead Weight--A simple calculator program was run for each pipe system to determine the maximum spacing between pipe supports on horizontal pipe runs to maintain the stress less than 1,500 psi and the sag between supports to less than 25 cm (0.10 in.).

The stress and sag criteria are recommendations by ANSI B31.1-1973. Overspanning can be done if the primary stress allowable is met and if the slope in the line overcomes the sag to allow complete drainage. For economical use of support steel and pipe supports, overspanning is used as the pipes run outside the tower at elevation 37.2m (122 ft). (See Figure 4-3.)

System	Recommended Spacing (ANSI B31.1-1973)
MS-1	5.79m (19 ft 0 in.)
MS-2	4.67m (15 ft 4 in.)
MS-3	4.32m (14 ft 2 in.)
CO-1	3.91m (12 ft 10 in.)
FW-1	4.62m (15 ft 2 in.)

Internal Pressure--The longitudinal pressure stress,

$$S_{LP} = \frac{Pd^2}{D_o^2 - d^2}$$

Where:

P = Design pressure, psig

D_o = Outside pipe diameter, inches

d = Inside pipe diameter, inches

as defined in ANSI B31.1-1973, Section 102.3.2

System	S_{LP} (psi)
MS-1	2,700
MS-2	1,400
MS-3	2,190
CO-1	1,160
FW-1	3,930

The pressure stress for pipelines MS-1 and MS-3 is added to the dead weight stress (Analysis W-16880-MS-01-A-3) to obtain the normal operation primary stress. (See Table 4-2, Load No. 3).

Seismic Accelerations--Seismic loads create a primary and secondary stress on the pipe. The primary stress results from the pipe vibrating between its supports (rigid guides or snubbers). The secondary stress results from the movement of the structure applied at the supports.

Two analyses were performed to obtain the structural response to the tower for two accelerations:

A. An 0.33g horizontal ground motion.

B. An 0.22g vertical ground motion.

The structural response is plotted versus frequency for several elevations of the tower. The horizontal response is shown in Figure 4-4 and the vertical response in Figure 4-5. In Figure 4-4, an envelope curve of all the responses is constructed. The maximum horizontal structural response is at 5.3 cps. By examination, the lowest natural frequency that the pipe should be allowed to have is 12 cps. Thus, the lowest pipe natural frequencies are separated from the structure's high response natural frequencies.

The maximum distance between supports is set by the minimum pipe frequency allowed, in this case, 12 cps. If it is assumed the pipe acts as a simply supported structure between supports, it can be shown that,

$$L_{crit} = \left[\frac{\alpha^2}{f_n^2} \frac{EI}{W_y} \right]^{0.25}$$

Where,

L_{crit} = Maximum span between seismic supports

α = Constant = 0.743 for simply supported beam

f_n = Minimum desired pipe natural frequency, cps

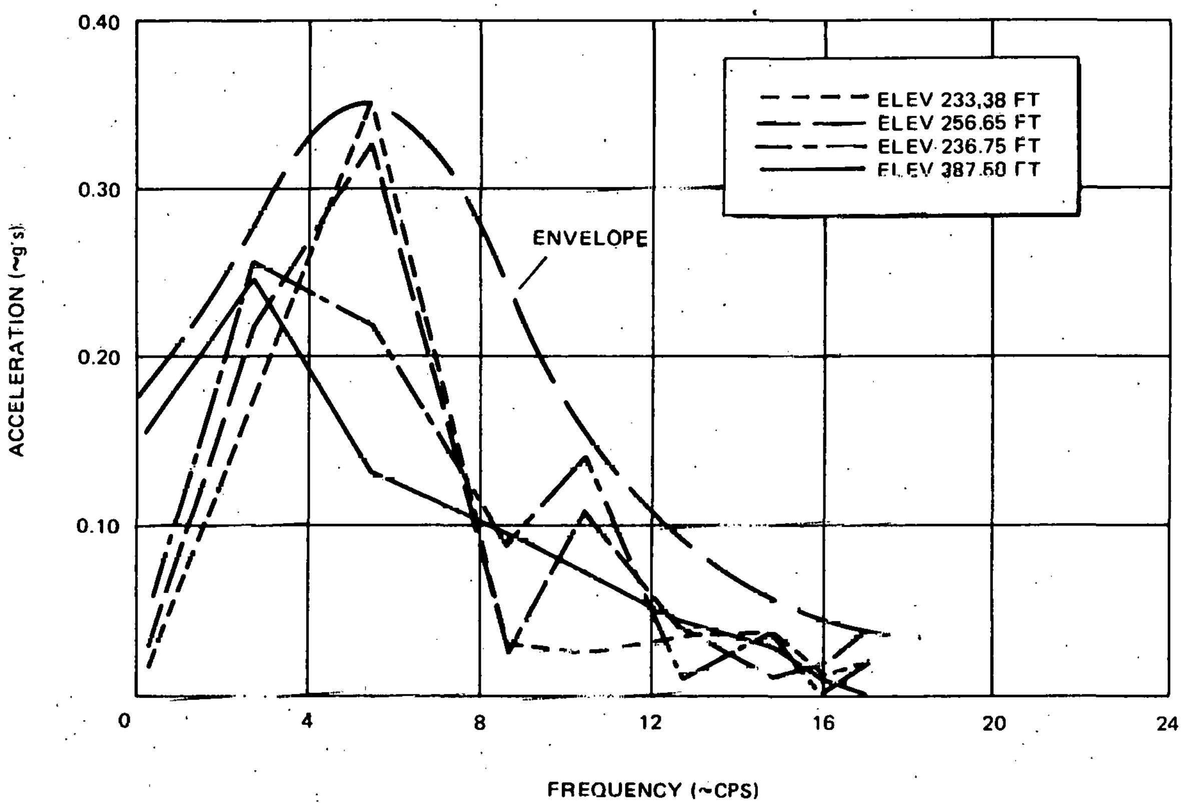


Figure 4-4. Horizontal Seismic Acceleration Response For 213 Ft Tower

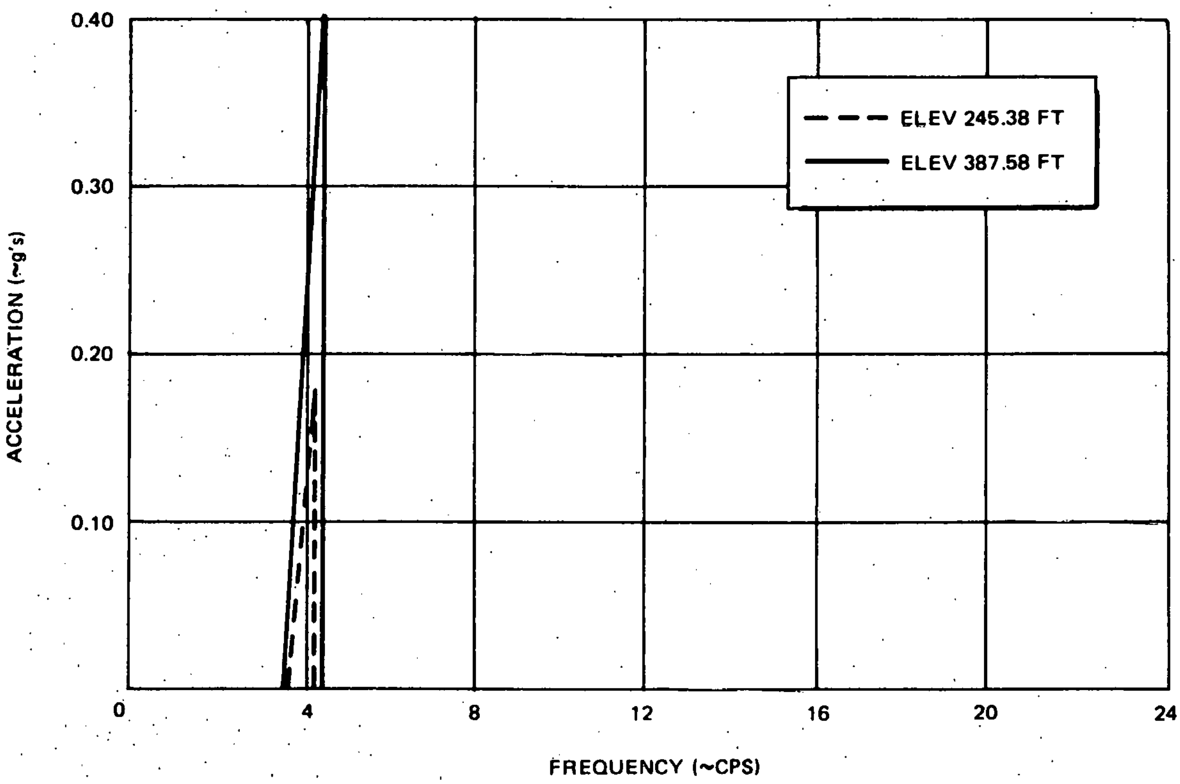


Figure 4-5. Vertical Seismic Acceleration Response For 213 Ft Tower

E = Modulus of elasticity at temperature, psi

I = Moment of inertia, $in.^4$

W_y = Weight/ft of pipe = $1.10\,(W_{pipe} + W_{insul}) + W_{fluid}$

System	f_n (cps)	L_{crit} (ft)
MS-1	12.0	16.8
MS-2	12.0	14.5
MS-3	12.0	11.9
CO-1	12.0	12.1
FW-1	12.0	14.2

- Seismic Primary Stress. By assuming the pipe is simply supported with a length $L = L_{crit}$, then the maximum pipe bending moment in ft-lb due to the structure's seismic response is

$$M_{smax} = \frac{W_y L^2 (g)}{8}$$

Where g is the maximum root mean square horizontal acceleration of the structure.

$g = 0.744$

The maximum bending stress in psi is,

$$S_{bs} = \frac{6(M_{smax})\ (D_o)}{I}$$

System	L (ft)	M_{smax} (ft-lb)	S_{bs} (psi)
MS-1	16.8	1, 750	1, 180
MS-2	14.5	330	1, 240
MS-3	11.9	300	1, 250
CO-1	12.1	200	1, 390
FW-1	14.2	634	1, 290

To obtain the occasional loading primary stress, the seismic stress is combined with the dead weight and pressure stress. The resulting stresses are shown in Table 4-2 for MS-1 and MS-3, and Table 4-5 for MS-2, CO-1, and FW-1.

- <u>Seismic Secondary Stress.</u> The secondary stresses on the pipes in the tower are obtained by taking the root mean square displacements from the structural analysis and applying them in both horizontal directions to the pipes at its supports.

  A simple flexibility analysis has been performed between elevations 92.79m (304.36 ft) and 90.08m (295.47 ft) for the MS-1 line. The resulting stress as reported in Table 4-2 is 870 psi.

Table 4-5

SUMMARY OF PIPE STRESSES, PIPELINES MS-2, CO-1, AND FW-1

Loading Condition	Maximum Stress in Pipeline (psi) MS-2	CO-1	FW-1	Allowable Stress (psi)
1. Dead Weight	1,500	1,500	1,500	N/A
2. Internal Pressure	1,400	1,160	3,930	N/A
3. Primary Stress (Item 1 + 2)	2,900	2,660	5,430	15,000
4. Seismic Primary Stress	1,240	1,390	1,290	N/A
5. Occasional Stress (Item 3 + 4)	4,140	4,050	6,720	18,000

<u>Stress Summary</u>--All calculated stresses for MS-1 and MS-3 are shown in Table 4-2. All maximum stresses are less than the allowables provided by ANSI-B31.1-1973. For pipelines MS-2, CO-1, and FW-1, the longitudinal pressure stress and the primary seismic stress have been calculated; the dead weight stress has been estimated. All of these stresses are less than the allowables. (See Table 4-5.) Thermal stresses should be satisfactory because MS-1 and MS-3 are satisfactory.

An estimate was made of the forces on the box guide restraints. The maximum thermal load on any restraint is 781.8 kg (1,720 lb). The maximum seismic load for MS-1 is,

$$F = \frac{W_y (L_{crit}) (g)}{2}$$

$$F = 190.9 \text{ kg } (420 \text{ lb})$$

The loads on the other pipes are even smaller. Thus, if each box guide is designed for 762.2 kg (2,500 lb) in either direction, the design should be satisfactory.

4.3.7.2 Admission Steam Piping

The admission steam piping defined herein includes that piping from the thermal storage steam generator interface to the turbine admission steam inlet.

<u>Requirements</u>

Applicable Code	ANSI B31.1 Power Piping
Pressure Required at Turbine Inlet	2.65 MPa (385 psia)
Temperature Required at Turbine Inlet	374.4°C (525°F)
Maximum Allowable Pressure Drop	1.03 MPa (15 psi)
Design Admission Flow	13.21 kg/s (104,700 lb/hr)

<u>Design Characteristics</u>

Design Pressure	3.38 MPa (490 psia)
Design Temperature	287.8°C (550°F)
Pipe Size (Nominal)	20.3 cm (8 in.) Sch 40
Pipe Material	Carbon Steel ASTM A106 - Grade B
Unit Weight	42.6 kg/m (28.6 lb/ft)
Insulation	8.9 cm (3.5 in.) Calcium Silicate with Aluminum Jacket

4.3.7.3 Thermal Storage Feedwater Piping

The feedwater piping described herein includes that piping from the booster pump to the thermal storage steam generator interface.

<u>Requirements</u>

Applicable Code	ANSI B31.1 Power Piping
Pressure Required at Inlet to Steam Generator	2.90 MPa (420 psia)
Temperature Required at Thermal Storage Subsystem Interface	121°C (250°F) Maximum
Design Feedwater Flow	13.21 kg/s (104,700 lb/hr)

Design Characteristics

Design Pressure	4.93 MPa (715 psia)
Design Temperature	135.0°C (275°F)
Pipe Size (Nominal)	10.2 cm (4 in.) Sch 40
Pipe Material	Carbon Steel, ASTM A106 Grade B
Unit Weight	16.1 kg/m (10.8 lb/ft)
Insulation	3.8 cm (1.5 in.) Calcium Silicate with Aluminum Jacket

4.3.7.4 Balance of Pilot Plant EPGS Piping

The balance of the Pilot Plant EPGS piping lying within the scope of the subsystem, including turbine extraction, condensate and feedwater piping, and miscellaneous piping systems, will be designed in accordance with the required turbine cycle performance requirements, using ANSI B31.1 Power Piping Code when applicable, in accordance with accepted power plant design practice.

4.3.8 Electric Plant Systems

4.3.8.1 Main Electrical System

The generator will be connected to the main power transformer by a 15-kV circuit breaker (switchgear unit). Connections from the generator to the switchgear, and from the switchgear to the main power transformer, will be cable. Two unit auxiliary transformers will be connected to the main power transformer by cable, as shown on Figure 4-6. Surge protection will be provided for the generator.

The main power transformer will step up generator voltage to the voltage required by the transmission system. This voltage is expected to be 115 kV. The main power transformer will be rated 115-13.2 kV, 12/16 MVA, OA/FA, 55°C rise for 50°C ambient. The 115 kV winding will be wye-grounded, the 13.2-kV winding will be delta. The 115-kV winding will be provided with surge arresters.

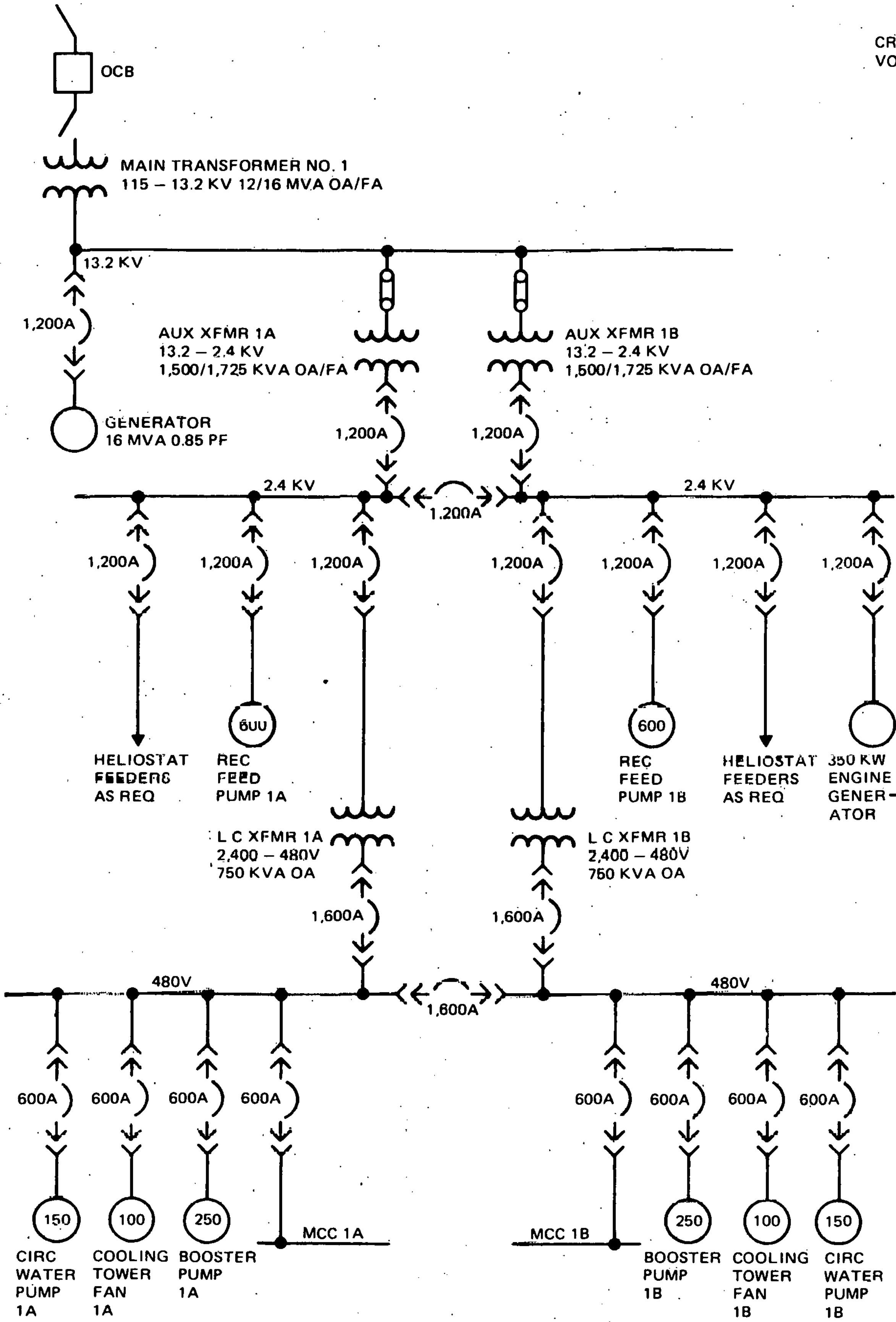


Figure 4-6. Pilot Plant Electrical One Line Diagram

The main power transformer will be connected to the transmission system by an overhead line, oil circuit breaker, and disconnecting switches. The oil circuit breaker and disconnecting switches will be rated 115 kV, 1, 200 amperes. The switches will be mounted on a steel structure. The 115-kV switching equipment will be as required by the utility.

The startup transformer will not be required, as auxiliaries can be supplied by the unit auxiliary transformers when the generator is shut down.

4.3.8.2 Auxiliary System

Auxiliary power will be supplied by the two-unit auxiliary transformers. Each transformer will be rated 13, 200-2,400V, 1, 500/1, 750 kVA, OA/FA, 55°C rise for 50°C ambient. The primaries will be delta and the secondaries will be resistance-grounded wye. The secondary of each transformer will feed a section of 2, 400V bus with a bus tie circuit breaker between sections. The secondary connection from the transformer will be cable or bus duct. The 2, 400V bus will supply directly the heliostat feeds, 600-hp receiver feed pump motors, and 2, 400/480V load center transformers.

The two-unit auxiliary transformers provide redundant capacity based on their emergency short-time overload capacity.

Each load center transformer will be rated 2, 400-480V, 750 kVA, OA, and will provide 100% redundant capacity. The primary will be delta, and the secondary will be grounded wye. The secondary connections will be bus duct. The secondary of each transformer will feed a section of 480V bus with a 480V tie breaker between sections. The 480V bus will feed motors of 100 hp or more and motor control centers.

The two motor control centers, one fed from each load center bus, will have molded circuit breaker combination starters for motor drives and molded case circuit breakers for lighting transformers, battery charger, and miscellaneous service.

4.3.8.3 Emergency Generator

A 350-kW emergency power diesel engine generator will provide power for safe shutdown and emergency service. The generator will be rated

1, 000 kVA, 80% power factor, 2, 400V. The generator will be connected to one of the two 2, 400V switchgear bus sections. The diesel will be automatic starting.

4.3.8.4 Heliostat Field Feeders

The heliostats will be served by 2, 400V feeders as required by the collector subsystem.

4.3.8.5 DC System

The Pilot Plant DC system will consist of a battery, battery charger, distribution panels, and an inverter. The battery will be a 60-cell lead acid, 125V, 185 ampere-hour, pasted plate type. The battery charger will be automatically regulated 125VDC float, 140VDC equalizing charge, 460VAC supply. The main distribution panel will supply service of over 100 amperes. There will also be a smaller distribution panel that will supply all services of 100 amperes and less. Both distribution panels will use switches and fuses. A 2, 000-Watt inverter will be provided to supply critical control requiring 120 VAC.

4.3.9 Auxiliary Power

The Pilot Plant auxiliary power requirements for various operating modes are shown in Table 4-6.

The maximum auxiliary power requirements occur at equinox noon when generating rated power. As indicated in the table, the major auxiliary power requirements are for the receiver feed pump, booster pump, cooling tower fans, circulating water pumps, and plant HVAC.

During evening operation on thermal storage steam, the major auxiliary power users are the booster pump, cooling tower fans, circulating water pumps, and thermal storage extraction pumps.

During nighttime standby, auxiliary power is required for condensate transfer pump, instrument air compressor, bearing cooling water pump, lighting, water treating systems, HVAC, condenser vacuum pump, turbine AC oil pump, and auxiliary steam boiler.

Table 4-6 (Page 1 of 2)

PILOT PLANT AUXILIARY POWER REQUIREMENTS

Component	Receiver Operation: Equinox 11.3 MW Net kW	Receiver Operation: Winter (Design) 10.0 MW Net kW	Evening Thermal Storage 7.0 MW Net kW	Night Standby kW	Emergency Power: AC kW	Emergency Power: DC kW
Receiver Feed Pump	325	282	-	-	-	-
Booster Pump	90	77	77	-	-	-
Hotwell Pump	20	18	18	-	-	-
Condenser Vacuum Pump	22	22	22	22	-	-
Condensate Trans Pump	-	-	-	7	-	-
Service Air Compressor	50	50	-	-	-	-
Instrument Air Compressor	28	28	28	28	28	-
Cooling Tower Fans	150	150	150	-	-	-
Circ Water Pumps	203	203	203	-	-	-
Gland Seal Vacuum Pumps	2	2	2	2	-	-
Bearing Cool Water Pump	15	15	5	5	15	-
Turbine AC Oil Pump	-	-	-	13	13	-
Turbine DC Oil Pump	-	-	-	-	-	13
Lube Oil Filter Pump	1	1	1	1	-	-
Chemical Pumps	3	3	3	-	-	-
Motor-Operated Valves	-	-	-	-	3	-
Raw Water Pump	20	18	18	12	-	-
Clarified Water Pump	12	10	10	5	-	-
Water-Treating System	16	14	14	8	-	-
Jockey Pump (Fire Water)	5	5	5	5	-	-
Auxiliary Boiler	-	-	-	10	-	-
Turbine Turning Gear	-	-	-	3	3	-
Computer	10	10	10	5	10	-
Miscellaneous DC	-	-	-	-	-	10
Controls and Computer HVAC	41	41	33	33	33	-
Plant HVAC	150	138	22	-	-	-

Table 4-6 (Page 2 of 2)

PILOT PLANT AUXILIARY POWER REQUIREMENTS

Component	Receiver Operation: Equinox 11.3 MW Net kW	Receiver Operation: Winter (Design) 10.0 MW Net kW	Evening Thermal Storage 7.0 MW Net kW	Night Standby kW	Emergency Power: AC kW	Emergency Power: DC kW
Thermal Storage Charging Pump	-	-	-	-	-	-
Thermal Storage Extraction Pump	-	-	104	-	-	-
Sewage Treat Plant	1	1	1	1	-	-
Potable Water Pump	4	4	4	-	-	-
Receiver Tower Elevator	-	-	-	-	15	-
Heliostats and Controllers	30	30	-	-	200	-
Lighting and Misc AC	202	78	70	50	10	-
TOTAL	1,400	1,200	800	210	330	23

AC power for emergency shutdown is provided by one 350-kW diesel engine-generator set. Emergency power is provided for the heliostat field, instrument air compressor, lighting and miscellaneous AC power, turbine AC oil pump, turbine turning gear, computer, computer and controls HVAC, and the receiver tower elevator.

The heliostat field for the Pilot Plant requires a total of approximately 805 kW when operating all drive motors simultaneously, such as could occur during an emergency slew condition. However, the engine generator is sized to provide power to one-half the field, and then only to the elevation drive motors, which reduces the emergency power demand to approximately 200 kW.

4.3.10 Water Treatment

4.3.10.1 Requirements

The discussion of water pretreatment, circulating water treatment, final treatment, condensate polishing, impact of water quality requirements on water-treatment costs, and the feedwater treatment for the Commercial Plant in Section 3.3.11 will also apply to the Pilot Plant water-treatment requirements.

For the Pilot Plant, it was assumed that the cooling tower circulating water concentration would be held under eight cycles and, based on a typical water analysis from the Barstow site, clarification and not lime softening of the cooling tower makeup water was required.

4.3.10.2 Treatment Equipment

Pretreatment

One - Clarifier, rated capacity 1.89 m/min (500 gpm), 8.54m (28 ft) diameter.

Lot - Clarifier chemical feed equipment (polymer/coagulant/aluminum feed equipment).

Circulating Water

One - Cooling tower acid tank 22.7m^3 (6,000 gal).

Two - Cooling tower acid feed pumps (1 spare) 11.3 l/min (3 gph), 1/4-hp DC motor.

One - Cooling tower chemical feed tank, 0.19m^3 (50 gal), Type 304 stainless steel.

Two - Cooling tower chemical feed pumps (1 spare) 7.6 l/min (2 gph), 1/4-hp DC motor.

One - Cooling tower chlorinator, 454.5 kg/day (1,000 lb/day), V-notch chlorinator.

Final Water Treatment

Two - Makeup water demineralizers, full-size, three bed trains.

Rating, 0.19 m^3/min (50 gpm) per train

Effluent quality

Total dissolved solids	50 ppb maximum
Silica	10 ppb maximum

Two - Makeup water demineralizer sand filters, each full size, 0.19 m^3/min (50 gpm) each.

One - Demineralizer acid storage tank, 22.7m^3 (6,000 gal).

Two - Demineralizer acid pumps (1 spare), 0.38 m^3/hr (100 gph), 3/4-hp, 460 VAC motor.

One - Demineralizer caustic storage tank, 22.7m^3 (6,000 gal).

Two - Demineralizer caustic pumps (1 spare), 0.15m^3/hr (40 gph), 1/3-hp, 460 VAC motor.

Condensate Polishing

Two - Full-size, mixed-bed units, 1.70m^3/min (450 gpm) per vessel. Effluent quality 30-40 ppb total dissolved solids, 90% suspended solids removal, with regeneration tanks and controls.

Feedwater Treatment

Two - Feedwater chemical feed tanks, 0.19m^3 (50 gal), Type 304 stainless steel (hydrazine and ammonia).

Three - Feedwater chemical feed pumps (1 spare), 7.6 liter/hr (2 gph), with 1/4-hp, 460 VAC motor.

4.3.11 Miscellaneous Plant Equipment

Descriptions for the Pilot Plant EPGS and balance of plant equipment not covered in the previous sections can be found in Appendix D.

4.3.12 Buildings

4.3.12.1 Power House

The power house contains the equipment required for operation of the electric power-generation subsystem. The building will be approximately 30m x 18m x 14m (100 x 60 x 46 ft) with two main floors and one partial floor. The superstructure will be a truss-type structural steel frame pre-engineered and of prefabricated design. The building will be the design of a manufacturer who is regularly engaged in the design and fabrication of prefabricated structures conforming to the standards of the Metal Building Manufacturers' Association and the uniform building code. The building will be designed and fabricated to withstand all environmental loads of the specific site.

Stairs using structural steel and grating will be provided at each end of the building to provide access to all levels. All structural steel will be fabricated in accordance with the American Institute of Steel Construction (AISC). Appropriate platforms, railings, and other safety features will be provided.

Corrugated, prepainted panels of proper thickness and configuration to provide the load-carrying capabilities required will be provided for exterior siding. Panels will be of the interlocking type with proper sealant as required to provide a weather-tight enclosure. Walls will have an insulation coefficient (U value) of 0.20, installed as part of the building. Protection from noise and fire will be provided.

The ground and operating main floors will be finished concrete of minimum compressive strength of 3,000 psi at 28 days with steel reinforcement. Proper expansion joints and floor joint sealant will be supplied as required. All materials will conform to applicable industrial or Federal specifications. The HVAC and deaerator floor will be fabricated of structural steel, according to AISC standard, and have a steel grating floor. Personnel doors will be heavy-duty industrial-type hollow metal with panic hardware. Doors and frames will conform to the current issue of US Department of Commerce Standard CS 211. A steel slat roll-up, motor-operated service door will be provided for maintaining equipment and large items in the power house.

The roof will be steel roof panels, galvanized, or aluminum coated on both sides by continuous hot-dip method. Roof panels will be of standard interlocking design of minimum 20-gage material and of such configuration to provide the necessary load-carrying capabilities and requirements. Proper sealant will be provided for a weather-tight enclosure. Roof insulation with maximum heat-transfer coefficient (U value) of 0.16 will be installed as part of the building.

A 20-ton overhead bridge crane with 5-ton auxiliary hook will be provided for maintenance of the turbine-generator. Supports for the crane will be integrated into the building superstructure.

The power house will be heated by steam in the operating areas. Evaporative cooling will be provided in operating areas. The operating and ground floor computer and control rooms will use localized air-conditioning and heating units, and appropriate humidity control for the computer room will be provided as required by the installed electronic equipment.

Operating areas within the power house will be protected from fire by the use of local fire hose reels and fire extinguishers at critical points throughout the building. Automatic sprinkler systems will be provided for turbine lube oil reservoir and storage tank and oil piping inside the building, and on the main power transformer and auxiliary transformers outside the building. All equipment will be specified and designed to comply with all NEPA and OSHA regulations. Computer and control rooms will be protected from fire by a Halon 1301 fire-suppression system or acceptable alternate. The system will be capable of extinguishing fires involving ordinary combustible materials, flammable liquids, gases, greases, etc. and also fires associated with energized electrical equipment. The system will not reduce oxygen level below that required for support of human life in normal extinguishing concentrations.

4.3.12.2 Technical and Administration Building

The technical and administration building will contain area and facilities for plant management, visitor control, and technical support. The building will be approximately 11m x 18m x 7m (35 x 60 x 22 ft) with two stories. The superstructure will be a clear-span rigid structural steel fram, pre-engineered and prefabricated to design of the requirements described for the power house. Stairs will be provided at appropriate areas to provide access to all levels. Corrugated, prepainted panels will be provided for exterior siding with architectural facing on the main entrance side. Panel construction and insulation will be the same as described for power house. Interior walls will be standard commercial steel stud with gyp-board siding. Standard acoustical drop ceilings will be used.

Floors will have standard, economic coverings suitable for offices.

Doors will be standard office-type with lock hardware and panic hardware for emergency exits.

The roof will be of the same material, construction, and insulation described for the power house.

The administration building will include a guarded entrance area for visitor control. An intercom system will assist management and security in monitoring all plant areas. Proper visitor waiting areas will be provided.

The administration building will be steam-heated with an absorption chilling system for air-conditioning. The master control computer area will have separate air-conditioning and heating units and humidity control equipment.

The administration building will have a commercial water sprinkler system for fire protection with accessible fire hydrants outside the building. Sprinkler spray nozzles will be temperature-controlled on-off type, not fusible link type.

The master control room will have a Halon-type fire-suppression system as described for the power house control room.

4.3.12.3 Water Treatment Building

The water treatment building will house all equipment for treatment and distribution of process water. The one-story building will be approximately 9m x 11m x 5m (30 x 35 x 15 ft). The superstructure will be a clear-span rigid structural steel frame, pre-engineered and of prefabricated design. Appropriate catwalks and service platforms will be put at critical equipment operating and service areas. Roof and siding construction, including insulation, will be the same as the power house.

The floor will be finished concrete with steel reinforcement with the requirements described for the power house. All service platforms, catwalks, and stairs will be fabricated of structural steel in accordance with AISC. The floor will be steel grating.

Personnel doors will be the same as those in the power house. A similar overhead roll-up door will also be provided.

The building will be steam-heated with no air-conditioning equipment.

Fire hydrants and extinguishers and emergency showers will be provided at critical areas for fire and personnel protection in accordance with NFPA and OSHA regulations.

4.3.12.4 Warehouse and Assembly Building

The warehouse and assembly building will contain equipment required for shipping, receiving, and assembly operations and sufficient bin and floor storage area for assembly parts. The one-story building will be approximately 29m x 18m x 6m (95 x 60 x 20 ft). A raised dock will be provided for truck loading-unloading operations. A drive-in area will also be provided to allow warehouse access for small vehicles and maintenance equipment. The superstructure will be the same as described for the power house.

Exterior wall and roof panels, including insulation, will be the same as those for the power house.

The floor will be finished concrete with structural steel reinforcement consistent with the requirements described for the power house. Personnel doors will also be identical. Roll-up doors, the same as described for the power house, will be provided for dock and drive-in areas.

A 10-ton overhead bridge-type crane with 2-ton auxiliary hook will assist in assembly operations. Supports for the crane will be integrated into the building superstructure.

The warehouse assembly building will be heated by steam. No air-conditioning will be provided.

Areas within the warehouse-assembly building will be protected from fire by fire hydrants and extinguishers at critical areas, in accordance with NFPA and OSHA regulations.

4.3.13 Yardwork

Yardwork as described in this section is limited to localized development or excavation within the plant operating area. Areas will be cleared of any items that would interfere with construction. Any depressions will be filled and compacted unless further excavation is required. Excavation will be done as required by the terrain of the specific site. Excavation will include building foundations and trenching for the utility system (including underground pipeways), excavation for paved areas, and all work included in these operations. Unsatisfactory material encountered or anticipated from soils data at normal grades for installed foundations will be removed and replaced with satisfactory material and be compacted as required. Grading will be performed so that the area of the site and areas affecting operations at the site will be continually and effectively drained.

Compaction requirements for grading and excavation operations cannot be determined until appropriate soils data are available. Compaction requirements will be identified and the soil moistened or aerated to obtain the specified compaction.

Backfill of satisfactory material and compaction as required will be used to bring areas up to finish grade. Caution will be observed when using heavy compaction equipment around building foundations and over utility trenches. No landscaping is anticipated except for dust control or to meet environmental conditions warranted by local site conditions.

4.4 DRAWINGS AND SCHEMATICS

The following drawings have been developed for the Pilot Plant EPGS preliminary design and are included in this section:

	Drawing No.	Revision	Title
Plot Plan			
Figure 4-7	L-22755 SK-Y1	P1	Plot Plan
General Arrangements			
Figure 4-8	L-22755 SK-G1	P1	Ground Floor
Figure 4-9	L-22755 SK-G2	P2	Mezzanine Floor
Figure 4-10	L-22755 SK-G3	P1	Operating Floor
Figure 4-11	L-22755 SK-G4	P1	HVAC and Deaerator Floor
Figure 4-12	L-22755 SK-G5	P1	Roof Plan
Figure 4-13	L-22755 SK-G6	P2	Section
Flow Diagram			
Figure 4-14	L-22755 SK-P1	P2	Steam and Condensate
Figure 4-15	L-22755 SK-P2	P	Composite Flow Diagram (Simplified)

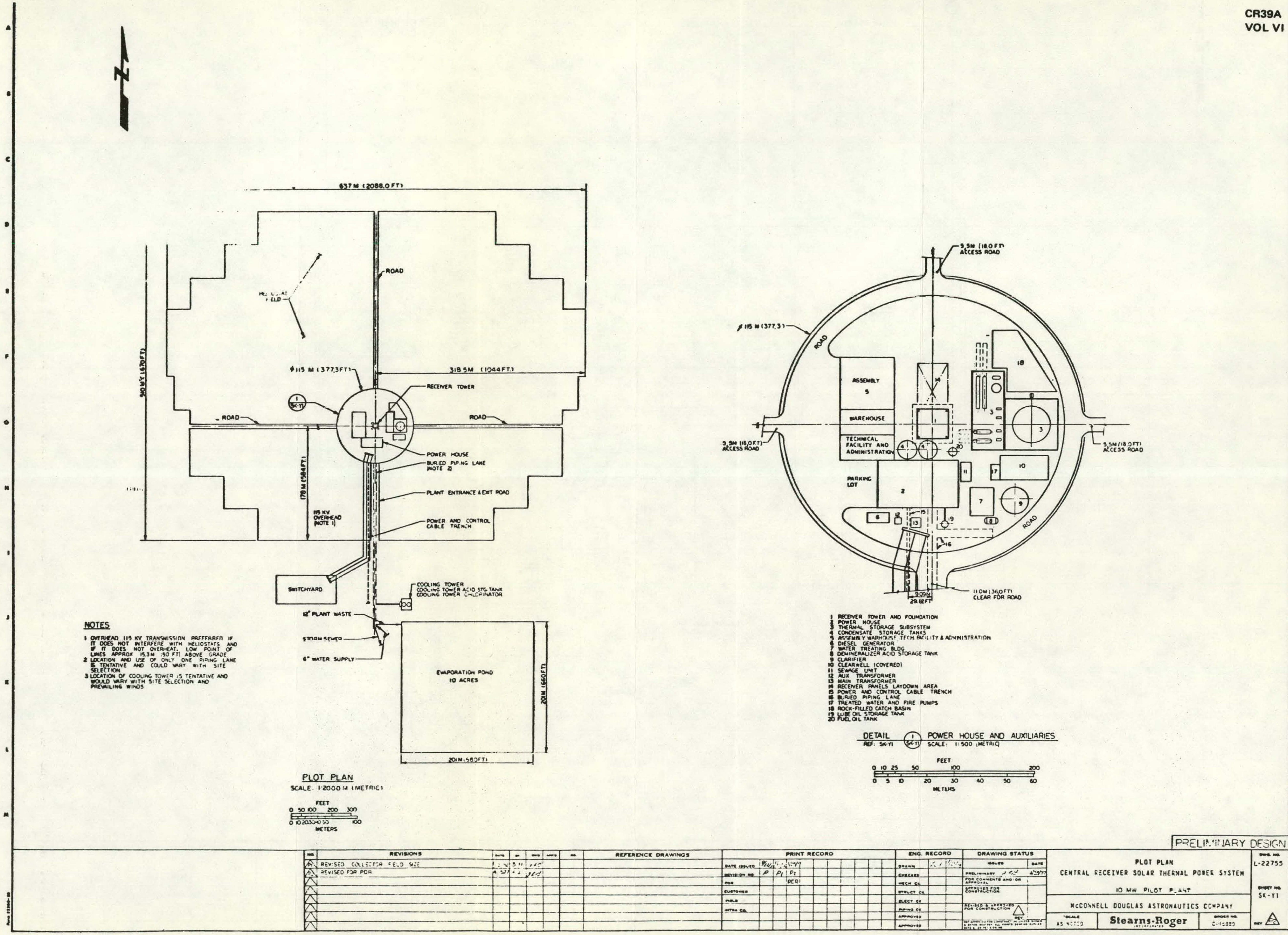


Figure 4-7. Plot Plan of 10-MW Pilot Plant

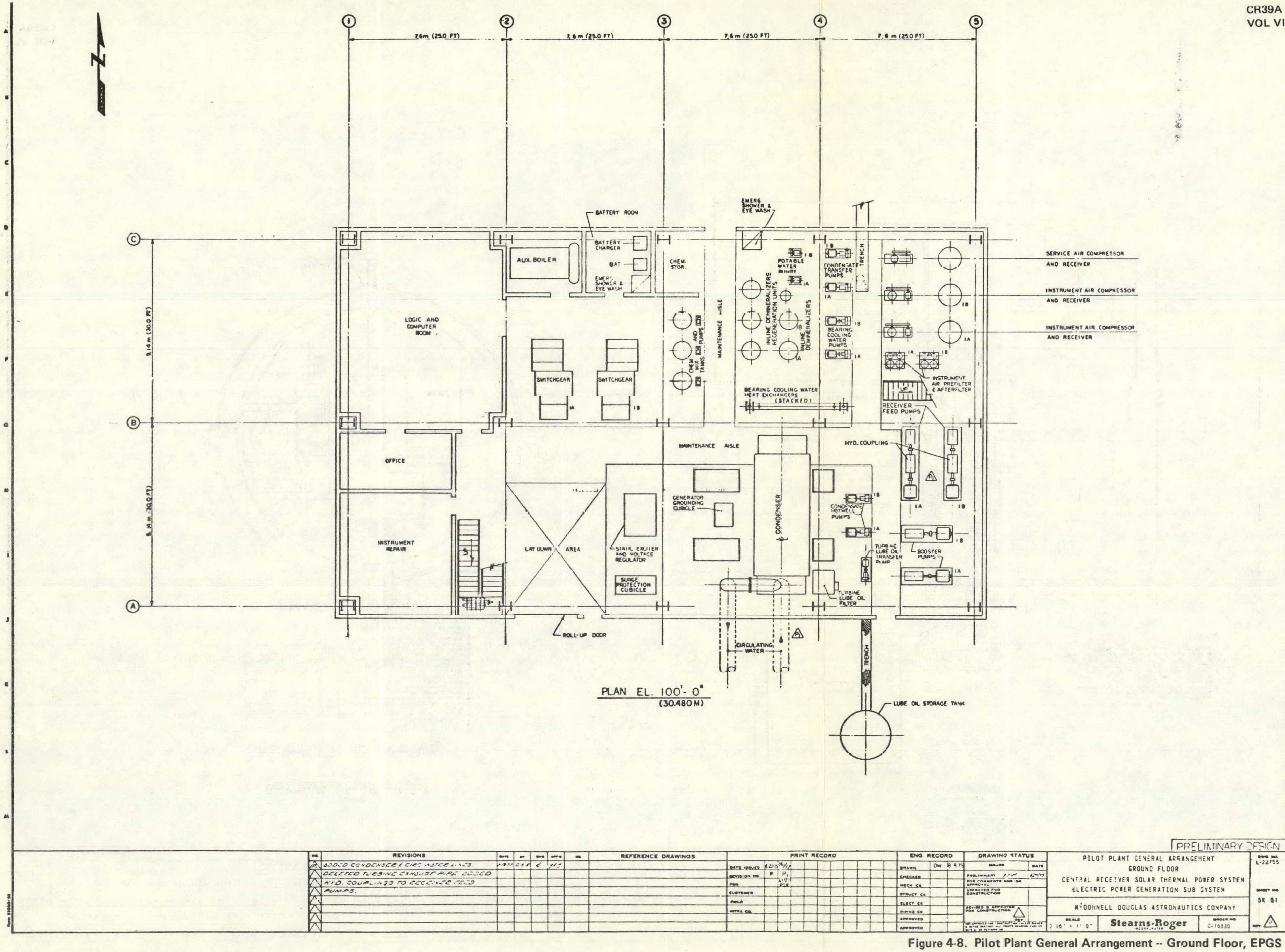


Figure 4-8. Pilot Plant General Arrangement -- Ground Floor, EPGS

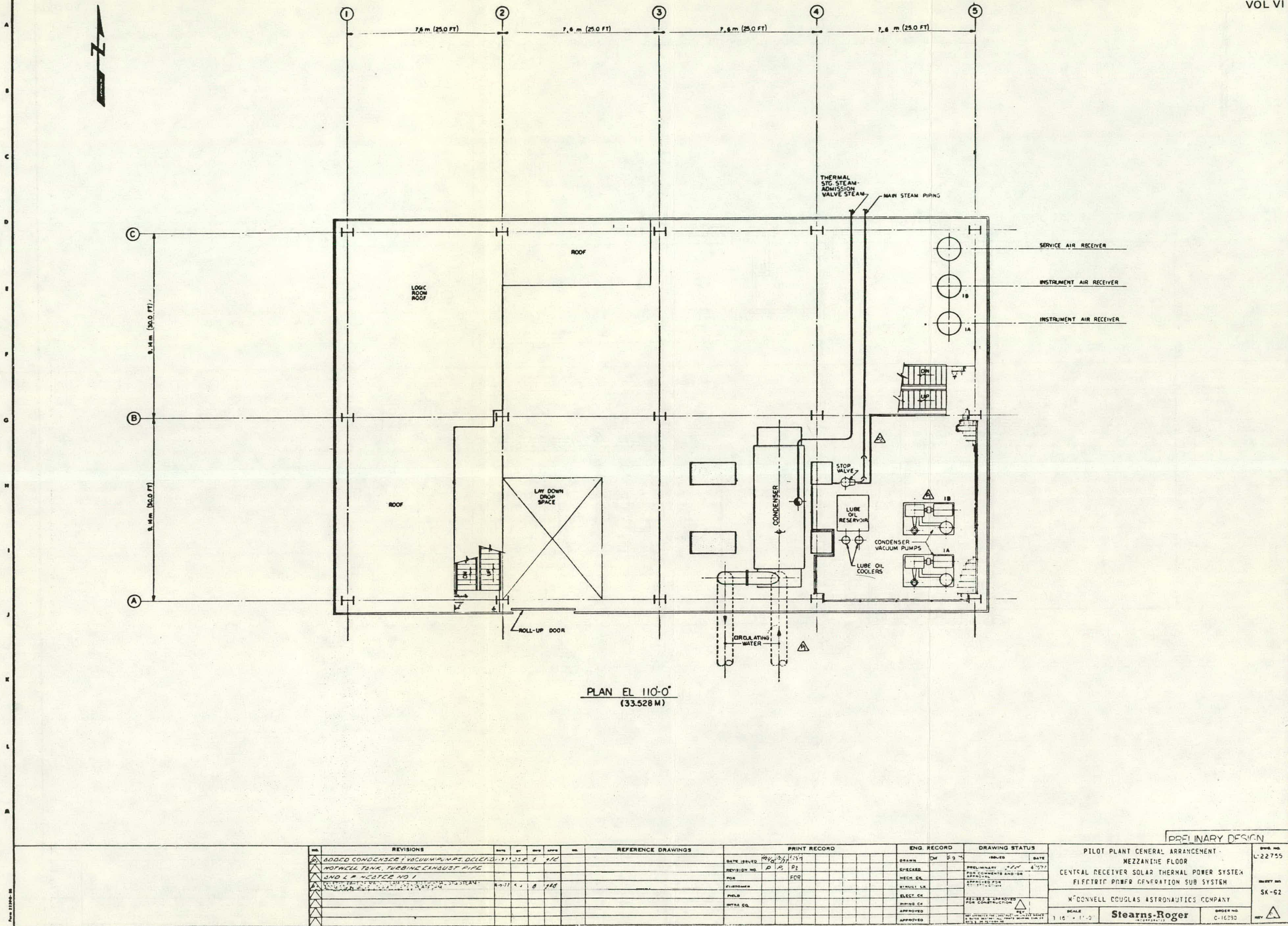


Figure 4-9. Pilot Plant General Arrangement -- Mezzanine Floor, EPGS

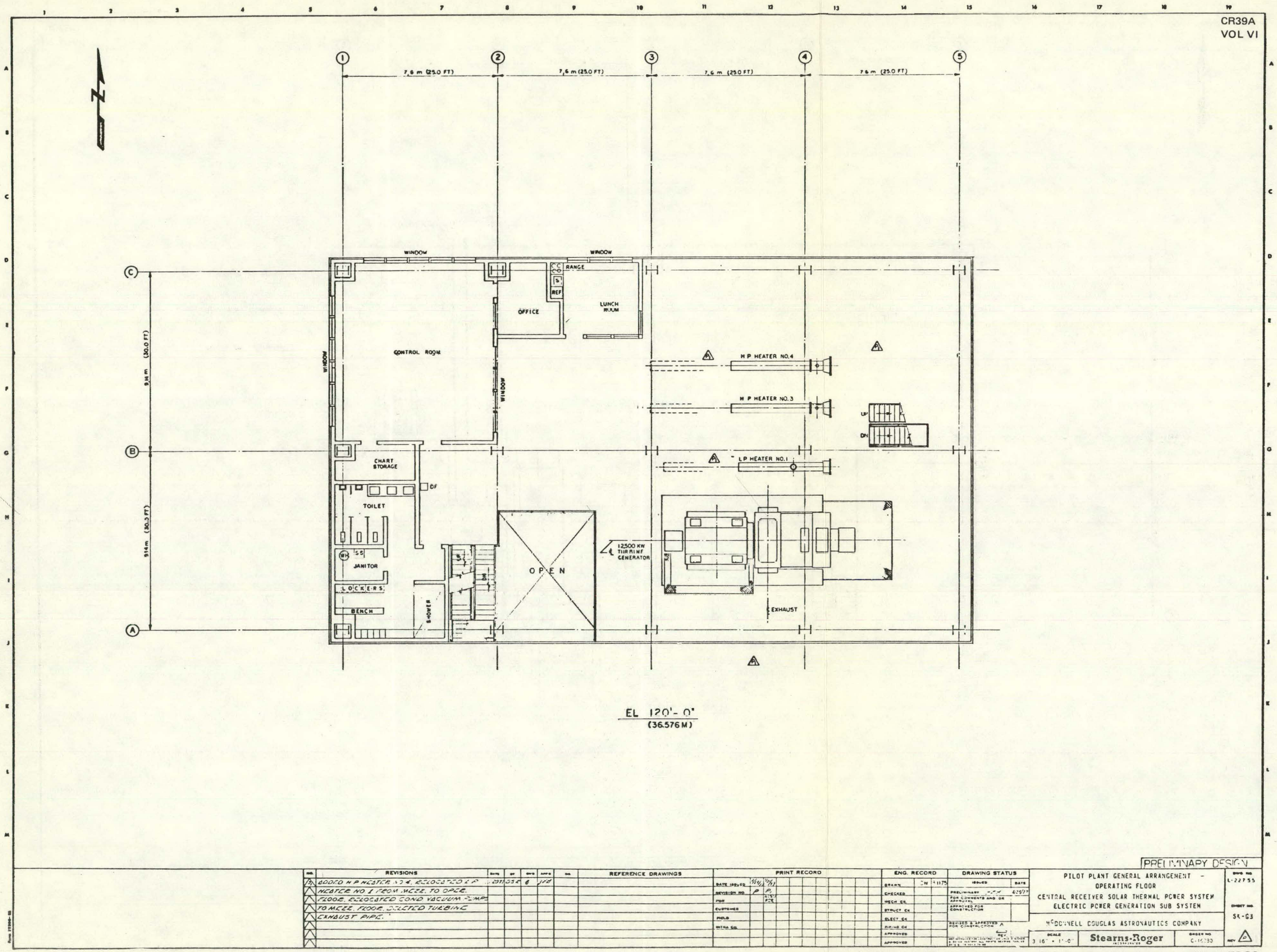


Figure 4-10. Pilot Plant General Arrangement -- Operating Floor, EPGS

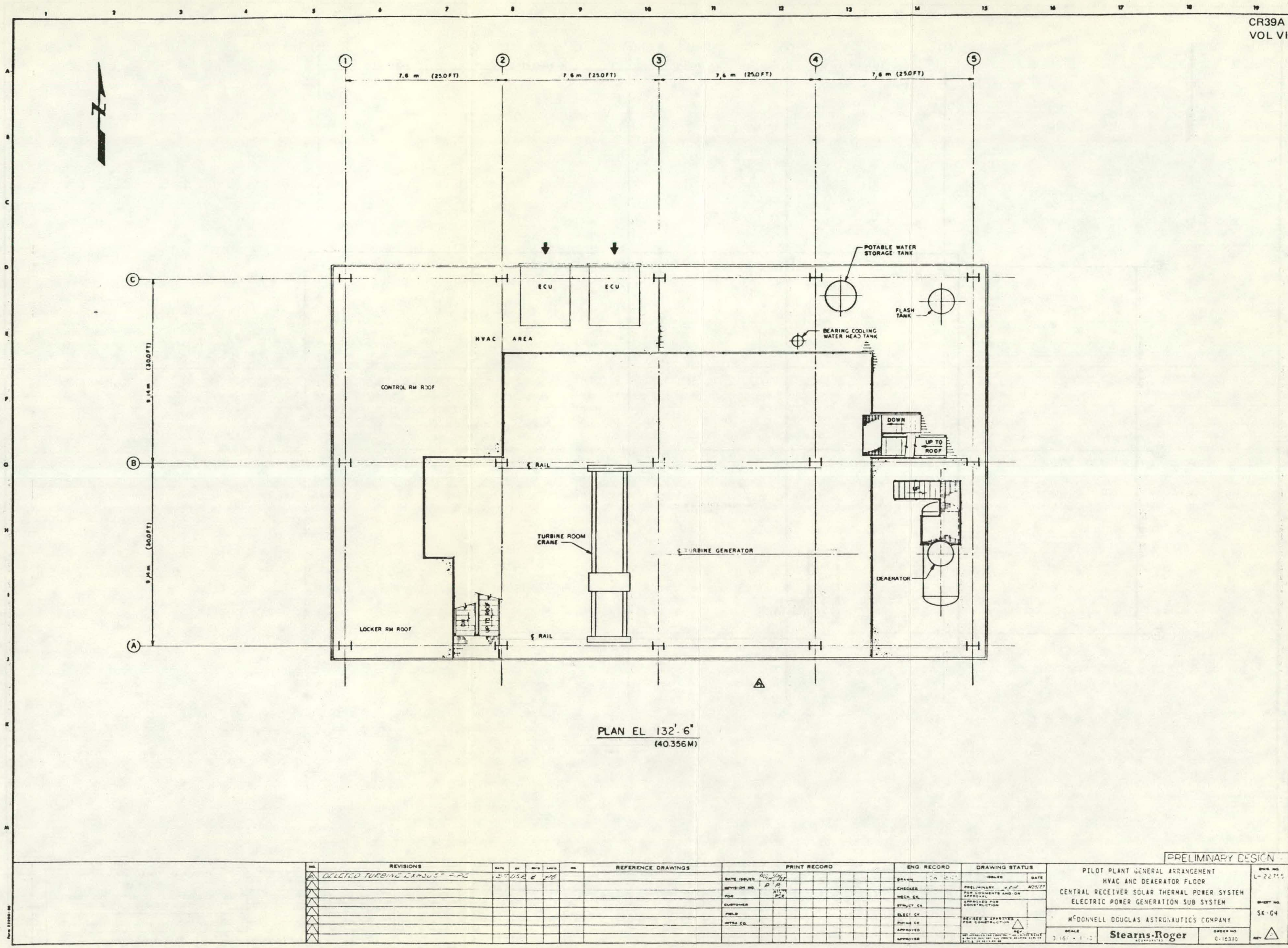


Figure 4-11. Pilot Plant General Arrangement -- HVAC and Deaerator Floor, EPGS

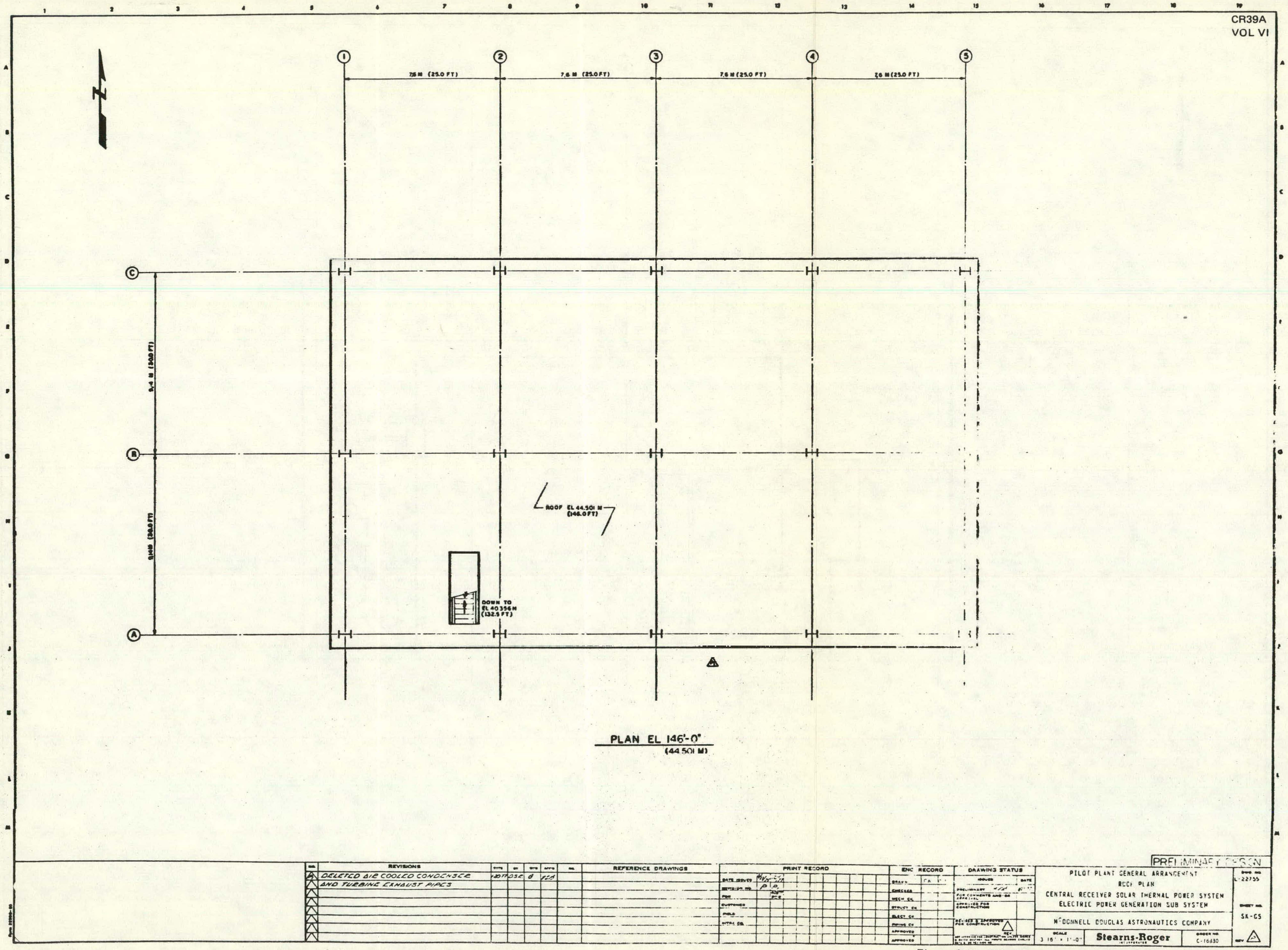


Figure 4-12. Pilot Plant General Arrangement -- Roof Plan, EPGS

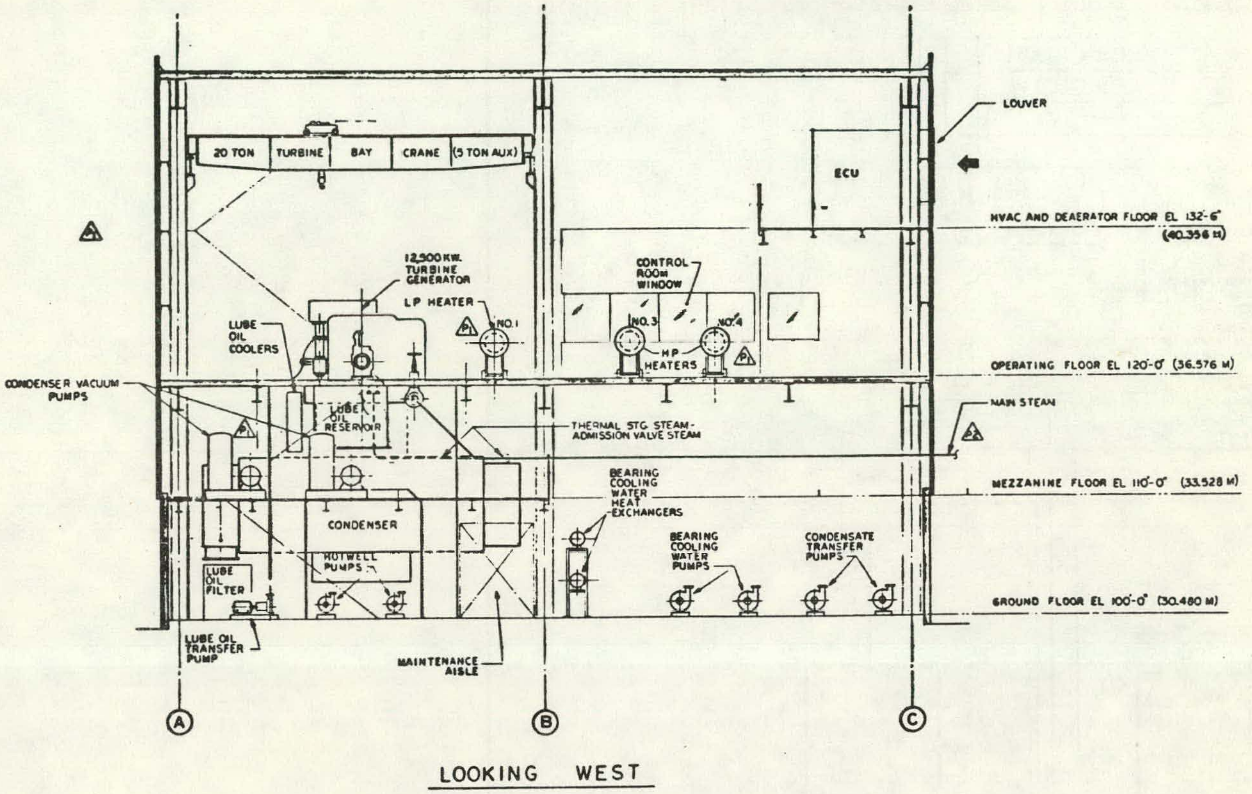


Figure 4-13. Pilot Plant General Arrangement -- Section of EPGS

NO.	REVISIONS	DATE	BY	CHKD	APPD	NO.	REFERENCE DRAWINGS
P1	DELETED AIR COOLED COND. & TURBINE EX-	12-07-77	DSE	[illegible]	[illegible]		
	HAUST PIPE. ADDED H P HEATER NO 4. RE-						
	LOCATED L P HEATER NO 1 & COND VACUUM						
	PUMPS. ADDED CONDENSER.						
P2	ADDED THERMAL STG STEAM-ADMISSION VALVE STEAM CHANGED [illegible] MAIN STEAM [illegible]	4-11-77	KJ	[illegible]	[illegible]		

PRELIMINARY DESIGN

PRINT RECORD				ENG. RECORD			DRAWING STATUS	
DATE ISSUED	[illegible]	[illegible]	[illegible]	DRAWN	DW	[illegible]	ISSUED	DATE
REVISION NO.	P	P1	P2	CHECKED			PRELIMINARY [illegible]	[illegible]
FOR			PDR	MECH. CK.			FOR COMMENTS AND/OR APPROVAL	
CUSTOMER				STRUCT. CK.			APPROVED FOR CONSTRUCTION	
FIELD				ELECT. CK.				
INTRA CO.				PIPING CK.			REVISED & APPROVED FOR CONSTRUCTION	REV
				APPROVED				
				APPROVED			NOT APPROVED FOR CONSTRUCTION UNLESS SIGNED & DATED. DESTROY ALL PRINTS BEARING EARLIER DATE & OR REVISION NO.	

PILOT PLANT GENERAL ARRANGEMENT
SECTION
CENTRAL RECEIVER SOLAR THERMAL POWER SYSTEM
ELECTRIC POWER GENERATION SUB SYSTEM

McDONNELL DOUGLAS ASTRONAUTICS COMPANY

DWG. NO. L-22755
SHEET NO. SK-66
SCALE 3/16" = 1'-0"
Stearns-Roger INCORPORATED
ORDER NO. C-15330
REV. P2

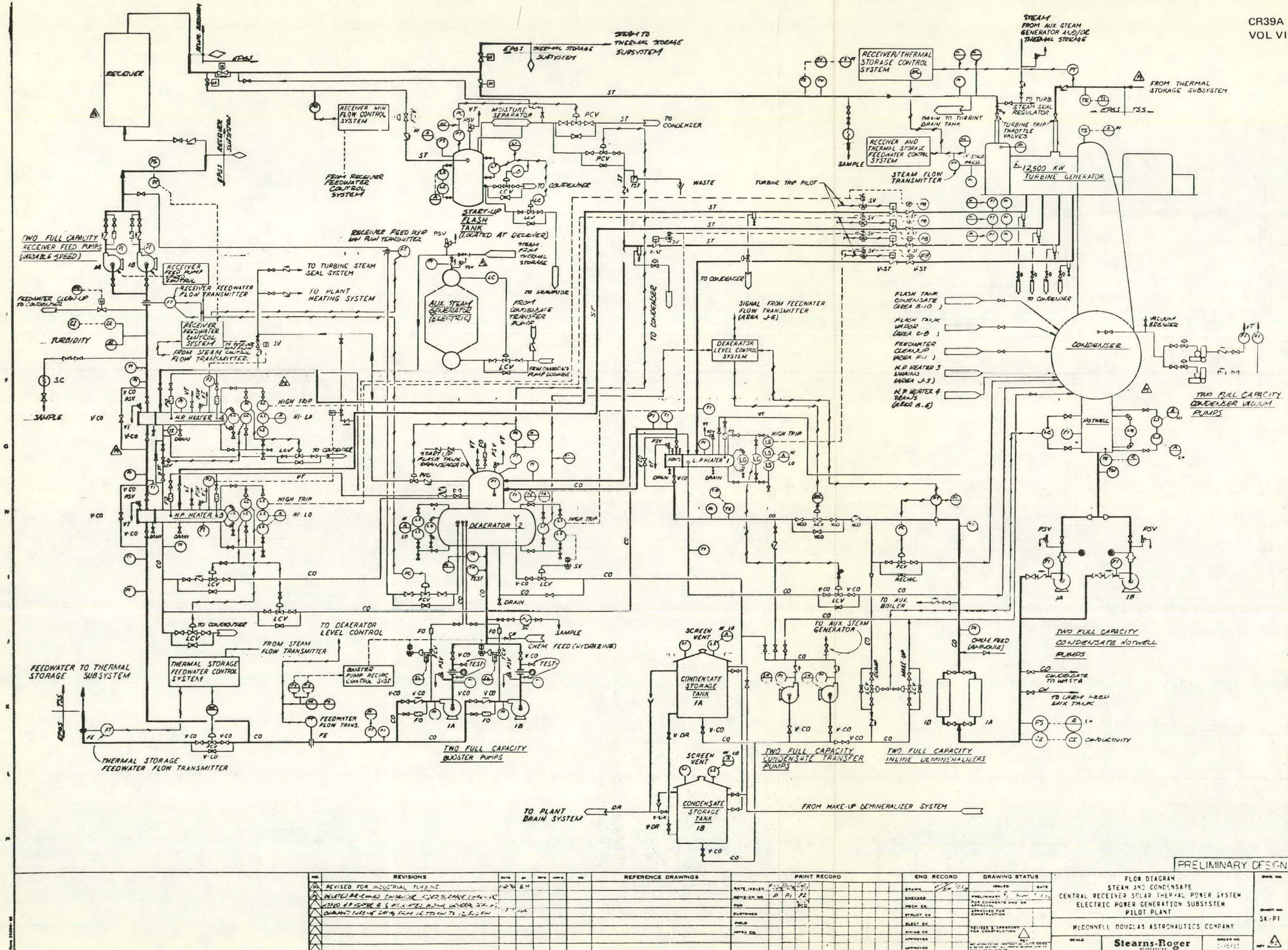


Figure 4-14. Flow Diagram -- Steam and Condensate, Pilot Plant EPGS

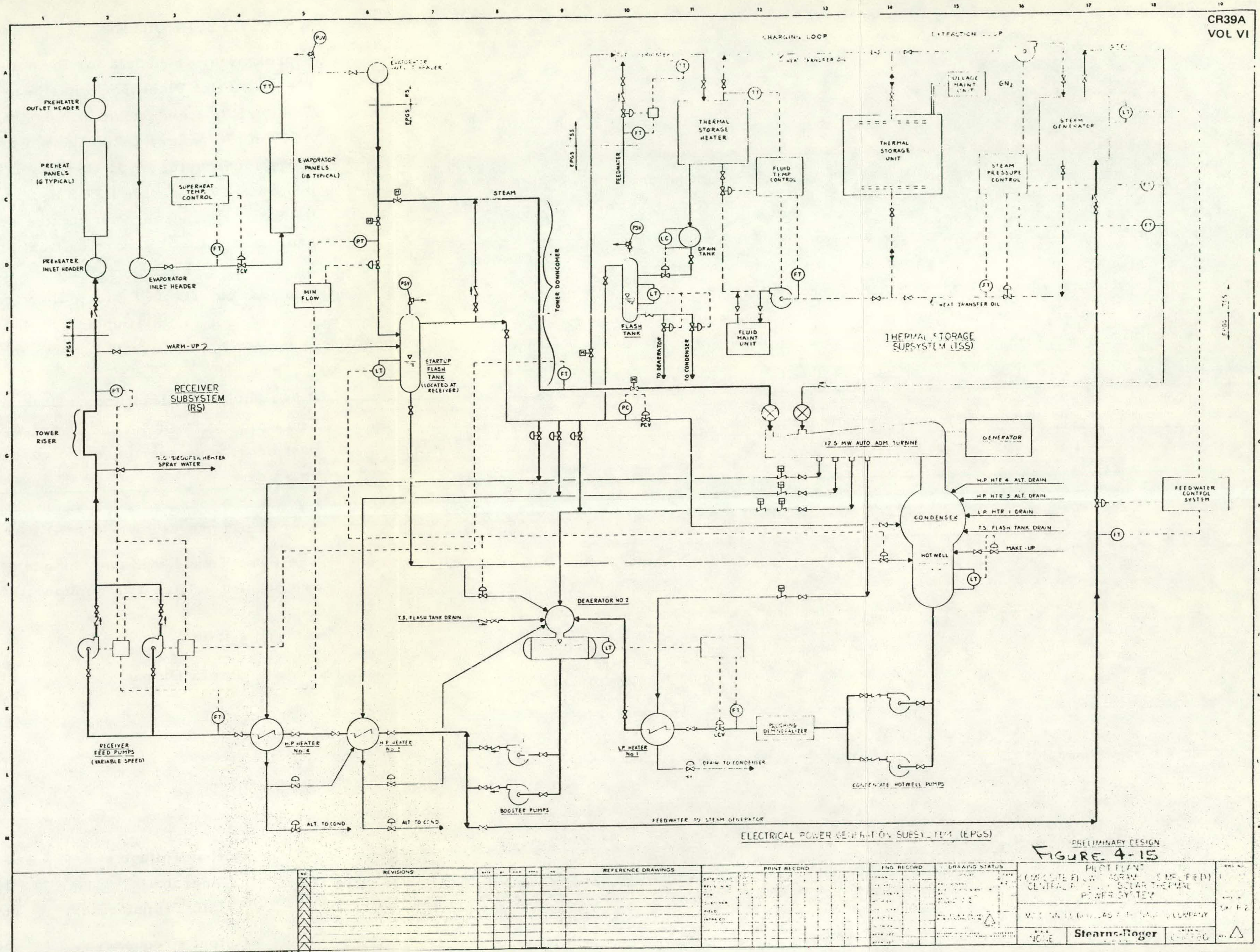


Figure 4-15. Pilot Plant -- Simplified Composite Flow Diagram

4.5 EPGS SCHEDULE

A preliminary schedule for the activities and equipment associated with the 10-MWe Pilot Plant EPGS has been defined, and is shown in Figure 4-16. The overall schedule for implementation of the program following an assumed ATP on 15 January 1978 allows a total of just under 3 years to achieve operational status by 31 December 1980, prior to initiating the 2-year test program. The pacing EPGS equipment items in making that schedule are the turbine-generator set and the receiver feed pumps, with the turbine-generator being the more critical of the two. A 20-month leadtime for fabrication and delivery of the equipment to the site is shown, based upon information received informally from General Electric. An additional 5 months for installation and checkout of the equipment prior to the initiation of the 6-month integrated system test is also shown.

Other equipment leadtimes will fit within the overall schedule framework. The time spans shown here were developed by Stearns-Roger, based upon past operating experience and current leadtime projections on major equipment.

4.6 PILOT PLANT EPGS AND BALANCE OF PLANT DESIGN SUMMARY

The Pilot Plant EPGS and balance of plant configuration and design conditions are presented here as a summary of Section 4.3.

<u>Overall</u>

Power Output	12,500 kW_e gross 11,100 kW_e net	Turbine Rating
	11,200 kW_e gross 10,000 kW_e net	Winter Solstice 2 PM Design Point
	7,800 kW_e gross 7,000 kW_e net	Nighttime
Output Voltage		
Generator	13,800V	
Main Transformer	115,000V	
Output Frequency	60 Hz Nominal	

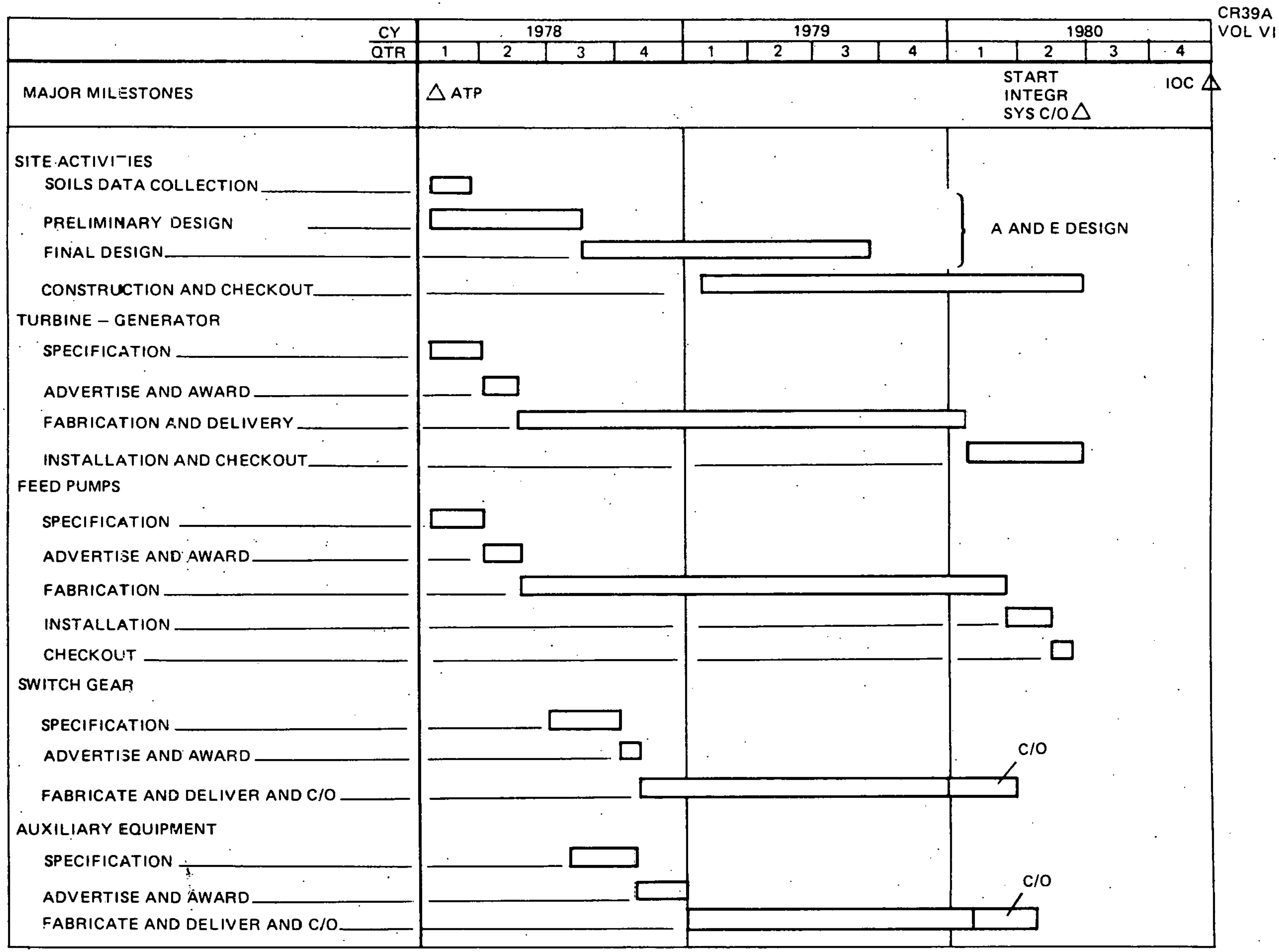


Figure 4-16. Pilot Plant EPGS Schedule

Turbine

Single automatic admission, tandem-compound single flow (TCSF-11.4 in. LSB), extracting, condensing turbine. Turbine rating 12,500 kW at 8.46kPa (2.5 in. HgA).

Four extraction points for low-pressure heater, deaerator heater, and two high-pressure heaters.

Inlet Steam Conditions (from Receiver)

Pressure	10.1 MPa (1,465 psia)
Temperature	510°C (950°F)
Enthalpy	3399 kJ/kg (1461.2 Btu/lb)

Admission Steam Conditions (from Thermal Storage)

Pressure	2.65 MPa (385 psia)
Temperature	274.4°C (525°F)
Enthalpy	2,939 kJ/kg (1,263.4 Btu/lb)

Throttle Flow	12.93 kg/s (102,440 lb/hr) at 11,200 kW gross (Winter Design)
Admission Flow	13.21 kg/s (104,700 lb/hr) at 7,800 kW gross
Turbine Exhaust Pressure	8.46 kPa (2.5 in. HgA)
Shaft Speed	3,600 rpm

Generator

Generator Rating	16,000 kVA
Power Factor	0.85
Output Voltage	13,800V
Frequency	60 Hz
Cooling	Air Cooled
Exciter	Static Excitation System
Shaft Speed	3,600 rpm

Condenser

Type	Shell and Tube, 2- Pass
Surface	1,115m^2 (12,000 ft^2)
Tube Material	90-10 Copper Nickel
Tube Diameter (OD)	19.05 mm (0.75 in.)
Tube Wall Thickness	0.89 mm (0.035 in.) 20 BWG
Tube Length (Effective)	6.1m (20 ft.)
Condenser Pressure	8.46 kPa (2.5 in. HgA)
Heat Rejection	94.95 GJ/hr (90 x 10^6 Btu/hr.)
Cooling Water Flow	0.725 m^3/s (11,500 gpm)
Water Velocity	2.13 m/s (7.0 fps)
Cooling Water In	29.4°C (85.0°F)
Cooling Water Out	38.2°C (100.7°F)

Cooling Tower

Quantity	One
Type	Mechanical Draft, Cross Flow
Number of Cells	2
Fan Motor Size	2 - 75 kW (100 hp)
Design Wet Bulb Temperature	23°C (73.4°F)
Cold Water Temperature	29.4°C (85.0°F)
Hot Water Temperature	37.9°C (100.2°F)
Circulating Water Flow	47.3 m^3/min (12,500 gpm)
Heat Rejection	100 GJ/hr (95 x 10^6 Btu/hr)

Circulating Water Pumps

Quantity	Two, Half-Size
Type	Horizontal, Double Suction
Capacity, Each	23.6m^3/min (6,250 gpm)
Head	18.3m (60 ft)
Efficiency	78%
Brake Horsepower	90 kW (121 hp)
Motor Size	112 kW (150 hp)

Feedwater Heaters

One low-pressure heater, horizontal, stainless-steel tubes, carbon-steel shell with drain cooler.

One direct contact deaerating heater, stainless-steel trays and vent condenser, carbon-steel shell. Horizontal condensate storage section carbon steel, with 18.92m^3 (5,000 gal) working capacity. Two high-pressure heaters, horizontal, carbon-steel tubes, carbon-steel shell with drain cooler.

Booster Pump

Quantity	Two, Full Capacity
Type	Horizontal Split Case, Multistage, Centrifugal
Capacity, Each	2.2 m^3/min (575 gpm)
Head	355.5m (1,166 ft)
Efficiency	75%
Brake Horsepower	158 kW (212 hp)
Motor Size	186.5 kW (250 hp)

Receiver Feedpump

Quantity	Two, Full Capacity
Type	Double-Case, Barrel-Type, Horizontal, Centrifugal 11 Stage. 3,465 rpm.
Drive	Variable-Speed, Hydraulic, Coupling Connected to 448-kW (600 hp), 3,560 rpm Motor.
Capacity	1.32 m^3/min (350 gpm)
Inlet Pressure	3.10 MPa (450 psia)
Developed Head	1,423.7m (4,670 ft)
Efficiency	65%
Brake Horsepower	407.4 kW (546.1 hp)

Main Power Transformer

Quantity	One
Rating	12/16 MVA OA/FA
Voltage	13.2/115 kV

Auxiliary Transformers

Quantity	Two
Rating	1,500/1,725 kVA, OA/FA
Voltage	13,200/2400V

Emergency Shutdown Power

Diesel Generator

350 kW, 1,000 kVA, 0.80 Power Factor, 2,400 VAC

Feedwater Treatment

Demineralized Water Makeup

Two Demineralizers - Each rated 0.19 m^3/min (50 gpm).

Normal Requirements - Approximately 0.15% of rated receiver steam flow.

Maximum Capability - Approximately 22% of rated steam flow.

In-line Demineralizers

Two Full-Capacity Demineralizers - Each rated 1.73 m^3/min (450 gpm).

Feedwater Purity Levels

Solids content controlled to 20-50 ppb dissolved solids; pH maintained at 9.5 to meet receiver requirements.

Feedwater Treatment Chemicals

Ammonia (pH control) and hydrazine (oxygen scavenger)

Feedwater Piping/Riser

Feedwater Leaving Turbine Building to Receiver (Riser)

Design Pressure	19.9 MPa (2,890 psia)
Design Temperature	232.2°C (450°F)
Pipe Size (Nominal)	10.2 cm (4 in.) Sch 160
Pipe Material	Carbon-Steel, ASTM A106 Grade B
Unit Weight	33.5 kg/m (22.5 lb/ft)
Code	ANSI B31.1 Power Piping
Insulation	6.35 cm (2.5 in.) Calcium Silicate with Aluminum Jacket

Feedwater to Thermal Storage Steam Generator

Design Pressure	4.93 MPa (715 psia)
Design Temperature	135°C (275°F)
Pipe Size (Nominal)	10.2 cm (4 in.) Sch 40
Pipe Material	Carbon Steel, ASTM A106 Grade B
Unit Weight	16.1 kg/m (10.8 lb/ft)
Code	ANSI B31.1 Power Piping
Insulation	3.8 cm (1.5 in.) Calcium Silicate with Aluminum Jacket

Steam Piping/Downcomer

Steam Leaving Receiver (Downcomer)

Design Pressure	11.82 MPa (1,715 psia)
Design Temperature	537.8°C (1,000°F)
Pipe Size (Nominal)	15.24 cm (6 in.) Sch 160
Pipe Material	Low Alloy Steel, ASTM A335 Grade P22 (2 1/4 CR - 1 Mo)
Unit Weight	67.4 kg/m (45.3 lb/ft)
Code	ANSI B31.1 Power Piping
Insulation	12.7 cm (5 in.) Calcium Silicate with Aluminum Jacket

Main Steam to Turbine

Design Pressure	11.82 MPa (1,715 psia)
Design Temperature	537.8°C (1,000°F)
Pipe Size (Nominal)	15.24 cm (6 in.) Sch 160
Pipe Material	Low Alloy Steel, ASTM A335-Grade P22 (2 1/4 CR - 1 mo)
Unit Weight	67.4 kg/m (45.3 lb/ft)
Code	ANSI B31.1 Power Piping
Insulation	12.7 cm (5 in.) Calcium Silicate with Aluminum Jacket

Steam to Thermal Storage Heater

	Before Superheater	After Superheater
Design Pressure	11.82 MPa (1,715 psia)	11.82 MPa (1,715 psia)
Design Temperature	537.8°C (1,000°F)	357.2°C (675°F)
Pipe Size (Nominal)	15.2 cm (6 in.) Sch 160	15.2 cm (6 in.) Sch 120
Pipe Material	Low Alloy Steel, ASTM A335 Gr. P22 (2 1/4 CR-1 Mo)	Carbon Steel, ASTM A106 Gr. B
Unit Weight	67.4 kg/m (45.3 lb/ft)	54.2 kg/m (36.4 lb/ft)
Code	ANSI B31.1 Power Piping	ANSI B31.1 Power Piping
Insulation	12.7 cm (5 in.) Calcium Silicate with Aluminum Jacket	8.9 cm (3.5 in.) Calcium Silicate with Aluminum Jacket

Admission Steam to Turbine (from Thermal Storage)

Design Pressure	3.38 MPa (490 psia)
Design Temperature	287.8°C (550°F)
Pipe Size (Nominal)	20.3 cm (8 in.) Sch 40
Pipe Materal	Carbon Steel, ASTM A106 Grade B

Unit Weight	42.6 kg/m (28.6 lb/ft)
Code	ANSI B31.1 Power Piping
Insulation	8.9 cm (3.5 in.)
	Calcium Silicate with Aluminum Jacket

Auxiliary Steam Boiler

Type	Scotch Marine
Capacity	4536 kg/hr (10,000 lb/hr)
Pressure	310.2 kPa (45 psia)
Fuel	Light Oil
Code	ASME

Buildings

Power House (Turbine Building),
30m x 18m x 14m (100 x 60 x 46 ft).

Technical and Administration Building,
11m x 18m x 7m (35 x 60 x 22 ft).
two stories,

Water Treatment Building,
9m x 11m x 5m (30 x 35 x 15 ft),
single story.

Warehouse and Assembly Building,
29m x 18m x 6m (95 x 60 x 20 ft),
single story.

Section 5
SITE ACTIVITIES

5.1 COMMERCIAL SYSTEM ACTIVITIES

5.1.1 Yardwork

Yardwork as described in this section relates to general site excavation and grading not associated with a particular subsystem. Areas will be cleared of items that would interfere with construction operations. Depressions will be filled and compacted unless further excavation is required. Excavation will be performed as required dependent upon the terrain of the specific site. Excavation will include trenching for utility systems, including underground pipeways, excavation for paved areas, and all work included in these operations. Unsatisfactory material encountered or anticipated from normal soils data at normal grade for roads and utility trenches will be removed and replaced with satisfactory material and compacted as required. Grading will be performed so that the area of the site and areas affecting operations at the site will be continually and effectively drained. Grading for the heliostat field will shed maximum storm water (100-year worst potential) via drainage ditches to safe runoff areas.

Compaction requirements for grading and excavation operations cannot be known until appropriate soils data are available. Areas to be paved and other areas requiring compaction will be identified and the soil moistened or aerated to obtain the specified compaction.

Backfill and compacting as required will bring areas to finish grade. No landscaping is anticipated except for dust control or environmental conditions as warranted by the local site conditions.

5.1.2 Site Access and Lighting

Main access roads into the area and the parking lot will be paved with asphalt with a coarse aggregate base. Roads and the parking lot will be designed and constructed in accordance with applicable American Association of State Highway Officials (AASHO) and American Society for Testing and Materials (ASTM) specifications. The roads and parking lot surfaces will be approximately 0.15m (6 in.) of coarse aggregate on compacted subgrade with primer coat and 0.05m (2 in.) of bituminous asphalt covering. Exact materials and depths shall be determined from actual soils data and traffic loads required at the specific site. The main South access road to the operating area will be 11m (36 ft) wide with additional access roads at the North, West and East quadrants, each 5.5m (18 ft) wide.

Normal road markings and signs for traffic control at critical areas will be installed. Heliostat location signs will be placed throughout the field and along access roads to aid in maintenance operations. Access roads off the main thoroughfares into the heliostat field will be graded as required by the specific site terrain with no additional surfacing. A guardhouse with lighting, heating, and communication will be provided at the main entrance road to the site.

The entire plant site will be enclosed with a 2.43m (8 ft) high chain link fence with three wire outriggers. Each access road will have a lockable gate. The fencing material and all accessories will be fabricated in accordance with applicable Chain Link Fence Manufacturers Institute (CLFMI) standards.

Outdoor lighting will be provided along access roads, parking areas, operating areas, and the operating area perimeter. Mercury vapor lights will be used with astrological clock control. The approximate average horizontal foot candles (lumens per square foot) will be 1.5. Outdoor lighting will also be provided for all building entrances, loading docks, and equipment locations outside the buildings.

Walkways will be provided between all major buildings and from the parking area to the administration building. Walkways will be approximately 0.15m (6 in.) concrete surface on compacted subsoil with width requirements determined by projected personnel traffic.

5.1.3 Sanitary Sewer System

A packaged prefabricated sewage treatment plant system will be used for sewer system treatment and disposal. The anerobic aeration system will be capable of handling 15.1m^3 (4,000 gal) per day of sewage. The plant will include a welded structural steel tank divided into three major compartments--aeration compartment, settling basin, and chlorine contact basin. All necessary auxiliary equipment will be provided with the system. The sewage, in general, will be aerated for 24 hours, then settled for 4 hours on average daily flow. Water from the system will be reused for irrigation or evaporated, maintaining zero discharge.

5.1.4 Evaporation Pond

All excess water from the Commercial solar thermal power system will be routed to a 141,713m^2 (35 acre) evaporation pond for maintaining zero discharge. The operating water depth will not exceed approximately 1.52m (5 ft). Specific depths will be determined from site climatological evaporation data and rainfall records. The evaporation pond will be excavated; all sharp rocks, stones, roots, and other sharp objects that might puncture the membrane will be removed or covered with a few inches of sand or other fine-textured soil. Sides will be built up as fill and compacted to minimize settlement.

Vinyl (PVC) will be used as the impermeable membrane because of high puncture resistance and durable life as well as capability to yield with soil deflections. A perimeter trench of approximately 0.3m (12 in.) square will be prepared above the water and wave line for anchoring the upper edge of the liner. Connections to pipe and other structures will be easily made using the vinyl described.

5.2 PILOT PLANT SYSTEM ACTIVITIES

5.2.1 Yardwork

Yardwork as described in this section relates to general site excavation and grading not associated with a particular subsystem. Areas will be cleared of items that would interfere with construction operations. Depressions will be filled and compacted unless further excavation is required. Excavation will be performed as required, depending upon the terrain. Excavation will include trenching for utility systems, including underground pipeways, excavation for paved areas, and all work included in these operations. Unsatisfactory material encountered or anticipated from normal soils data at normal grade for roads and utility trenches will be removed and replaced with satisfactory material and compacted as required. Grading will be performed so that the area of the site and areas affecting operations at the site will be continually and effectively drained. Grading for the heliostat field will shed maximum storm water (100-year worst potential) via drainage ditches to safe runoff areas.

Compaction requirements for grading and excavation operations cannot be known until appropriate soils data are available. Areas to be paved and other areas requiring compaction will be identified and the soil moistened or aerated to obtain the specified compaction.

Backfill of satisfactory material and compacted as required will be used to bring areas to finish grade. No landscaping is anticipated except for dust control or environmental conditions as warranted by the local site conditions.

5.2.2 Site Access and Lighting

Main access roads into the area and the parking lot will have a coarse aggregate base. Roads and the parking lot will be designed and constructed in accordance with applicable American Association of State Officials (AASHO) and American Society for Testing and Materials (ASTM) specifications. The roads and parking lot surfaces will be approximately 0.15m (6 in.) of coarse aggregate on compacted subgrade with primer coat and 0.05m (2 in.) of bituminous asphalt covering. Exact materials and depth shall be determined from actual soils data and traffic loads required at the specific site. The

South access road to the operating area will be 11m (36 ft.) wide with additional access roads at the North, West, and East quadrants, each 5.5m (18 ft.) wide.

Normal road markings and signs for traffic control at critical areas will be installed. Heliostat location signs will be placed throughout the field and along access roads to aid in maintenance operations. Access roads off the main thoroughfares into the heliostat field will be graded as required by the specific site terrain with no additional surfacing. A guardhouse with lighting, heating, and communication will be provided at the main entrance road to the site.

The entire plant site will be enclosed with a 2.43m (8 ft) high chain link fence with three wire outriggers. Each access road will have a lockable gate. The fencing material and all accessories will be fabricated in accordance with applicable Chain Link Fence Manufacturer's Institute (CLFMI) standards.

Outdoor lighting will be provided along access roads, parking areas, operating areas, and the operating area perimeter. Mercury vapor lights will be used with astrological clock control. The approximate average horizontal foot candles (lumens per square foot) will be 1.5. Outdoor lighting will also be provided for all building entrances, loading docks, and equipment locations exterior to the buildings.

Walkways will be provided between all major buildings and from the parking area to the administration building. Walkways will be approximately 0.15m (6 in.) concrete surface on compacted subsoil with width requirements determined by projected personnel traffic.

5.2.3 Sanitary Sewer System

A packaged prefabricated sewage treatment plant system will be used for sewer system treatment and disposal. The anerobic system will be capable of handling 11.3m^3 (3,000 gal) per day of sewage. The plant will include a welded structural steel tank divided into three major compartments--aeration compartment, settling basin, and chlorine contact basin. All necessary auxiliary equipment will be provided with the system. The sewage, in general, will be aerated for 24 hours, then settled for 4 hours on average daily flow. Water from the system will be reused for irrigation or evaporated, maintaining zero discharge.

5.2.4 Evaporation Pond

All excess water from the Pilot Plant solar thermal power system will be routed to a 40,489m^2 (10 acre) evaporation pond to maintain zero discharge. The operating water depth will not exceed approximately 1.52m (5 ft). Specific depths will be determined from site climatological evaporation data and rainfall records. The evaporation pond will be excavated, with all sharp rocks, stones, roots, and other sharp objects that might puncture the membrane removed or covered with a few inches of sand or other fine-textured soil. Sides will be built up as fill and compacted to minimize settlement.

Vinyl (PVC) will be used as the impermeable membrane because of high puncture resistance and durable life as well as capability to yield with soil deflections. A perimeter trench of approximately 0.3m (12 in.) square will be prepared above the water and wave line for anchoring the upper edge of the liner. Connections to pipe and other structures will be easily made by using the vinyl described.

Section 6
MASTER CONTROL

6.1 MASTER CONTROL CONCEPTS

The master control subsystem provides a centralized Pilot Plant operation control center that uses both manual and automatic control techniques. The centralized approach incorporates a full complement of manual controls and computer equipment to provide the operator and engineers with the flexible control and operational tools required to optimize, expand, and develop the plant control performance criteria for producing electrical power from a solar energy source.

The computer equipment provides the flexibility required in a development and demonstration pilot facility in two instances:

A. Responsive changes to new and unique operating functions, not characteristic of conventional plants, are paramount in solar power-generation plant operation.

B. Prompt and often immediate evaluations and analyses of plant operations data are required to effect expedient changes or modifications during development phases.

The need for automated operation is identified with the following development, demonstration, and operation functions:

A. Monitoring and control of the collector subsystem.

B. Balancing the steam and feedwater loop under variable collector heat input conditions.

C. Allocating thermal storage heat to plant processes under variable heat input conditions and/or varying thermal storage capacity.

D. Monitoring, logging, and reducing plant operations data for the day-to-day and long-term examination, comparisons, diagnosis, evaluation, and interpretation of subsystem operations.

E. Implementing expedient changes to the subsystem control operations, procedures, and methods without disrupting the plant hardware configuration.

The large number of collectors needed to produce the required heat for the receiver subsystem cannot be controlled effectively in a manual mode of operation. Master control is designed to control and monitor the performance of the collector subsystem with the computer in the automatic mode. Simple and straightforward operator commands initiate startup and shutdown of the collector field from master control. Master control's computer communicates with each of the field controllers of the collector subsystem to execute operator commands and monitor collector status. In addition, the subsystem's flexibility provides the capability to implement effective controls to automatically correct receiver hot or cold spots, and correct position errors of the collector system based on receiver heat input. Using current meteorology data, together with continuously updated plant performance data, the computer can analyze and provide the plant operator with forecasts of collector field efficiency and receiver heat input data, along with optimized plant control parameters to use for the remaining solar day.

The solar power-generation plant differs from conventional plants in that the heat source is variable, thereby requiring continous adjustments to maintain the proper temperature and pressure balances of the steam and feedwater system. Using master control in the automatic mode, variations from this balance are minimized. Balancing these variations is particularly important to get the plant up and operating when the sunlight is first available. In light of the fact that (1) the thermal storage is variable and limited to support steam and feedwater systems at startup, and (2) variations occur in receiver heat input because of fixed heliostat locations with respect to the receiver panels and the wide differences between Winter and Summer sunrises, strategy for getting the plant line on in the shortest time possible can significantly affect power-generation efficiency. The computer system assures minimum deviations from the optimum path in plant startup.

A limited thermal storage capacity requires judicious control of the allocation of stored heat to the using power plant subsystems. Again, this is essential at startup and at times of low thermal storage heat. Programming the thermal storage allocation to the various subsystems at critical times may be more than the operator can contend with and keep the plant operational.

However, the flexibility built into master control, providing both manual and automated control capability, offers the alternative of manual control for thermal storage use.

Master control uses the computer capability to provide the engineers with the ability to monitor all of the data relating to plant operations. An appreciable amount of instrumentation is included in the Pilot Plant design to provide engineers the measurements and parameters with which to analyze subsystem and overall power-generation performance. The computer system monitors all of the plant instrumentation, reduces the data to engineering form, and makes the data available to the engineer at both regular intervals and upon request. The timely reduction and analysis of this data by the master control computer saves manpower and time in the development and tuning of the plant process operation and control.

MDAC recognizes that a Pilot Plant demonstration undergoes modifications to perfect the processes and obtain the performance needed to provide an operational model system. The design concept of master control includes the capabilities to: (1) substitute and try expedient software change alternatives ahead of making expensive hardware or plant configuration changes, and (2) use an automated control system alternative approach in the model system with which to experiment and develop for future solar power-generation systems.

The MDAC approach to master control uses the prevailing manual power plant operating concepts and augments this concept with proven computer automated process control techniques. Built in to this operational concept are three modes of control and monitoring that the operator can select. These modes are:

1. Fully manual mode using the prevailing manual techniques commonly incorporated into existing power-generation plants.
2. Fully automatic mode using present-day computer process control technology to perform the control and monitoring functions.
3. A combination mode using manual control supported by computer monitoring and alarm.

All manual control operations are executed from a central operator control console. All analog input control signals are monitored by analog and analog-to-digital conversion displays and control output signals are sent to the operating elements from manual switches and set point controllers. Annunciators provide system operating status supported by a visual illuminating operations flow chart for each subsystem. All phases of plant control and monitoring are available to the operator from this console. Subsystem startup, operating mode changes, shutdown, and emergency safing—together with continuous realtime monitoring of all plant control functions—are included in the master control design.

Inasmuch as the collector subsystem is primarily under computer control, the central control console provides the operator with manual controls sufficient to fail-safe the collectors and monitor and command the position of an individual heliostat or group of heliostats through two-way communications with the field controllers.

A group of continuous analog recorders provides the engineer and operator with the capability to monitor and correlate any of the instrumented parameters. A patchboard arrangement allows the user the flexibility to group the signals on the recorders as desired.

Master control uses a common "steering logic" interface for manual and computer control signals, thus eliminating redundant wiring from the subsystems to the controller elements (i.e., manual control panel, and computer). This "steering logic" switches command control paths to the relays and analog controllers when the operator activates the manual or automated control mode.

Instrumentation signal inputs interface to master control through patch panels. Analog feedback signals from control elements of each subsystem can be multiple-patched to (1) the manual monitoring systems in the control console, (2) the computer, and (3) the continuous analog recorders, maintaining isolation and minimizing redundant measurements throughout. Again, these patch panels provide flexible operation for a development project and significantly reduce the number of wires from each subsystem to master control.

Discrete inputs (i.e, binary functions) interface to master control through a junction box where multipole relays tie each signal to the master control console and the computer. In this manner, fewer wires are required from subsystems to master control.

All sensor power supplies, signal conditioning, and temperature references are located at the subsystem, close to the sensing elements. Instrument analog signals from the subsystems are transmitted over hardwires at volts level, reducing potential noise problems.

Manual and automatic control and monitoring functions of master control share the same field wires to the subsystem sensor and control elements, thus eliminating duplication costs and redundancies. Size, types of wire, and connectors are standardized wherever possible. Cable trays are used to route wires within the control room.

The automated control mode uses a small commercially available mini-computer interfaced to the operator at the control console by a keyboard/printer and a printer/plotter to perform automatic control and data-reduction functions. The system selected has excellent growth potential and can be upgraded to handle future system expansions. Consequently, the software and hardware can be used in larger solar power-generation plants of the same or similar type.

The computer interfaces to the plant subsystems through the "steering logic" for discrete and continuous analog control commands and the master patch panel and relay junction box for analog instrument inputs and discrete input functions.

The master control computer is connected through the input/output bus to the steering logic, patch panel, master control console, and junction box by the following devices:

A. Analog to Digital Conversion System. Connected to the master control patch panel. The device digitizes the transducer and sensor signals.

B. Digital to Analog Conversion System. Connected to master control steering logic. The device outputs analog control signals to the master control controllers.

C. Discrete Input System. Connected to master control relay junction box. It reads the "on/off" and "open/close" binary functions.

D. Discrete Ouput System. Connected to master control steering logic. The device outputs binary control functions to subsystems.

E. Collector Subsystems Interface. Connected directly to the field controller wiring. The device monitors and commands the field controllers. The interface is also connected with the manual collector subsystem control devices located on the master control console.

F. Time of Day Generator. Connected directly to the computer. It is also interfaced to the master control console to display time of day.

The computer interfaces to peripheral devices to store programs and data, load programs, interact with programmers and the operator, and print or plot information. These devices include two disks, a printer/plotter, keyboard/printer, two magnetic tape cassettes, memory, a realtime clock, and hardware arithmetic and floating point equipment.

The computer system is free standing, except for the keyboard/printer and printer/plotter. These two peripheral devices are integrated into the master control console and serve as the only interface required for the operator. All message and information inputs and outputs are directed to and from the operator with this equipment.

The master control computer uses a commercially available program operating system. The system provides a multitasking foreground mode complemented with a background mode for low-priority, noncontrol functions. The background mode is assigned to the data-reduction tasks on a noninterference basis with plant control operations.

Where practical, the control and data-reduction programs are written in Fortran IV, a conversational high-level language. Device handlers and program routines that demand high throughput rates are written in an assembly language. Using Fortran IV to code the control and data-reduction programs provides an easy and expedient method of interpreting, modifying, and adding routines both during the development phase and after the plant becomes a production power-generation facility.

Master control is designed to provide diagnostic test of the control system hardware and automatic calibration of instrumentation. Computer programs under control of the operator functionally test the control system electronic logic (i.e., steering logic, setpoint controllers, displays) in the master control console. Transducer calibration routines permit the operator to automatically determine functional status of the sensor and field wiring, and at the same time provides calibration data for use in data reduction and in determining transducer failure or degradation.

The master control concept provides for fail-safe operation in either the manual or automated mode of control. The operator is furnished with controls in the master control console for: (1) activating the safing of the collector subsystem, (2) terminating power generation, and (3) transferring control from automatic to manual and vice versa. In addition, the automatic mode, through the use of a "deadman" timer alerts the operator at the control console of a master control computer failure.

In the event of a complete power failure to master control, MDAC uses an uninterruptible power source (UPS) to provide a sufficient electrical supply from lead-calcium batteries to manually operate the subsystem controls (i.e., collector, field controllers, turbine-generator, receiver, thermal storage), for a period of time adequate to make the plant safe. This system is located in series with the main power source in a manner whereby the main power continually charges the battery and master control power is drawn from the batteries. An automatic bypass switch is incorporated to assure continuous power in the event the UPS fails.

6.2 SUBSYSTEM INTERFACE DEFINITION

Master control consists of a central control computer and four subsystems as shown in Figure 6-1. Plant operator control and monitoring is integrated into a central control console. The central control console provides for

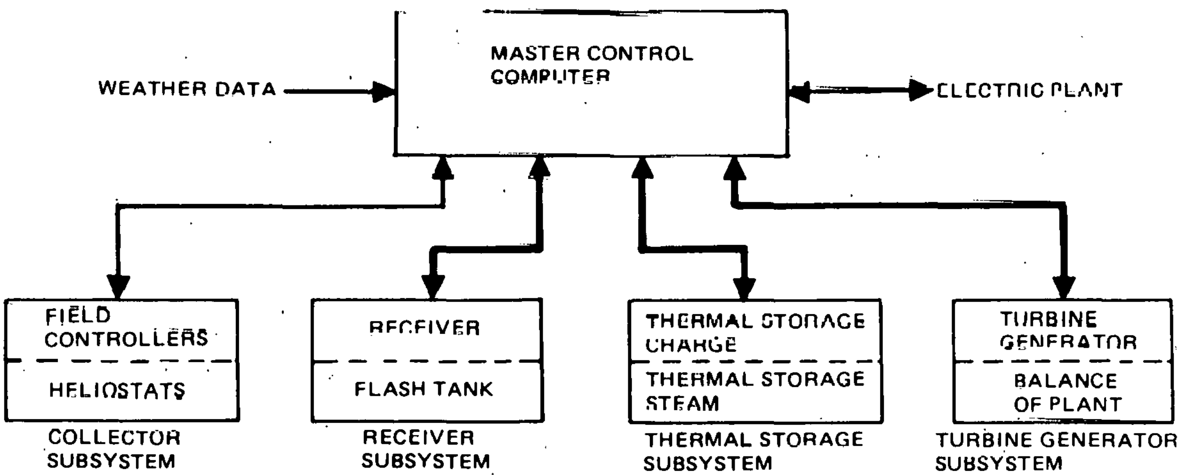


Figure 6-1. Master Control Subsystem Interface Definition

individual control and monitoring of the master control computer and each of the four subsystems. The plant operator may direct the master control computer to automatically coordinate the operation of all four subsystems, or may place them under manual control. In addition, manual control of any one or more subsystems will facilitate plant development and system integration on a subsystem basis.

6.2.1 Collector Subsystem

The primary interface between the central master control room and the collector field is a communication data bus. This data bus links all collector field controllers to the master control computer and central control console.

Because of the large number of field controllers and their respective heliostats, the master control computer is required to efficiently coordinate the collector field for normal operation. However, the operator is provided with manual controls for operation in a degraded and/or less efficient manner. In addition, manual control of any one individual heliostat, field controller, or group of field controllers is available to the operator for error control checking and maintenance.

6.2.2 Receiver Subsystem

The receiver subsystem interfaces to the central master control room via individual wires to each control or instrumentation component. The master control computer automatically provides control of the receiver subsystem processes at the discretion of the plant operator. Manual control is available to each receiver component via the receiver subsystem control panel of the master control console.

The receiver subsystem major components germane to master control consist of: (1) preheat panels, (2) boiler panels, (3) tower flash tank, (4) downcomer, and (5) control and instrumentation sensors, signal conditioning and valve actuators.

Because of the relatively fast change of input heat flux at the receiver, compared to fossil fuel boilers, automatic control of the receiver subsystem processes by the master control computer is anticipated for best system efficiency. Manual operator control complements plant operation by providing backup receiver subsystem operation and continued plant production of electricity. In addition, subsystem test and integration may be performed independent of the master control computer or system operation to a considerable extent.

6.2.3 Thermal Storage Subsystem

Interface to the central master control room, computer, and console from the thermal storage subsystem is via individual wires to each control or instrumentation component in a manner similar to the receiver subsystem.

The thermal storage subsystem major components relevant to master control are: (1) thermal storage unit, (2) ullage maintenance unit, (3) fluid maintenance unit, (4) thermal storage heater and desuperheater, (5) steam generator, (6) auxiliary feedwater heater, and (7) the control and instrumentation sensors, signal conditioning, and valve actuators.

Although the thermal storage subsystem response time is not stressing to plant control when adequately charged or during normal solar power periods, the allocation of stored energy during startup or low thermal storage is critical. Therefore, automatic control by the master control computer may be required during critical operational mode changes.

6.2.4 Turbine Generator and Balance of Plant

The interface between turbine generator/balance of plant and the central master control room is similar to both the receiver and thermal storage subsystems, i.e., individual hardwires to each control or instrumentation component. As for each subsystem, the master control console provides a panel for either automatic computer operation or plant operator manual control. The turbine generator subsystem may be the least satisfactory for operating time and manual control. However, the coordination of the turbine-generator and balance of plant equipment requirements with the entire plant operation may be significantly more efficient under automatic master computer control.

The turbine generator and balance of plant subsystem major components associated with master control consist of: (1) turbine generator, (2) condenser, (3) water treatment, (4) feedwater heaters, (5) feedwater pumps, and (6) the thermal storage flash tank.

6.3 REQUIREMENTS

6.3.1 Performance

6.3.1.1 Functional Requirements

The functional requirements for the master control subsystem are to provide the following:

A. A stable plant condition to enable production of electric power from solar energy.

B. Control over the collector field of solar mirrors including focusing, defocusing, and maintenance.

C. Control over the receiver subsystem for creation of superheated steam for input to the thermal storage and turbine generator subsystems.

D. Control over thermal storage for the storage of solar heat and the generation of auxiliary steam when required.

E. Control over the turbine generator to generate electricity and recirculate steam exhaust.

F. A control panel for operator control of all plant operations under either automatic or manual control.

G. Plant operation history logs that indicate plant status during operation.

6.3.1.2 Operating Requirements

Master control operates under the following requirements:

A. Provides plant operation modes that are a capability of master control operation. The modes operate plant equipment as shown by the Figures 6-2 through 6-7:

1. Normal Solar (Figure 6-2). Used for clear day, full sun operation.
2. Low Solar (Figure 6-3). Used for overcast day operations.

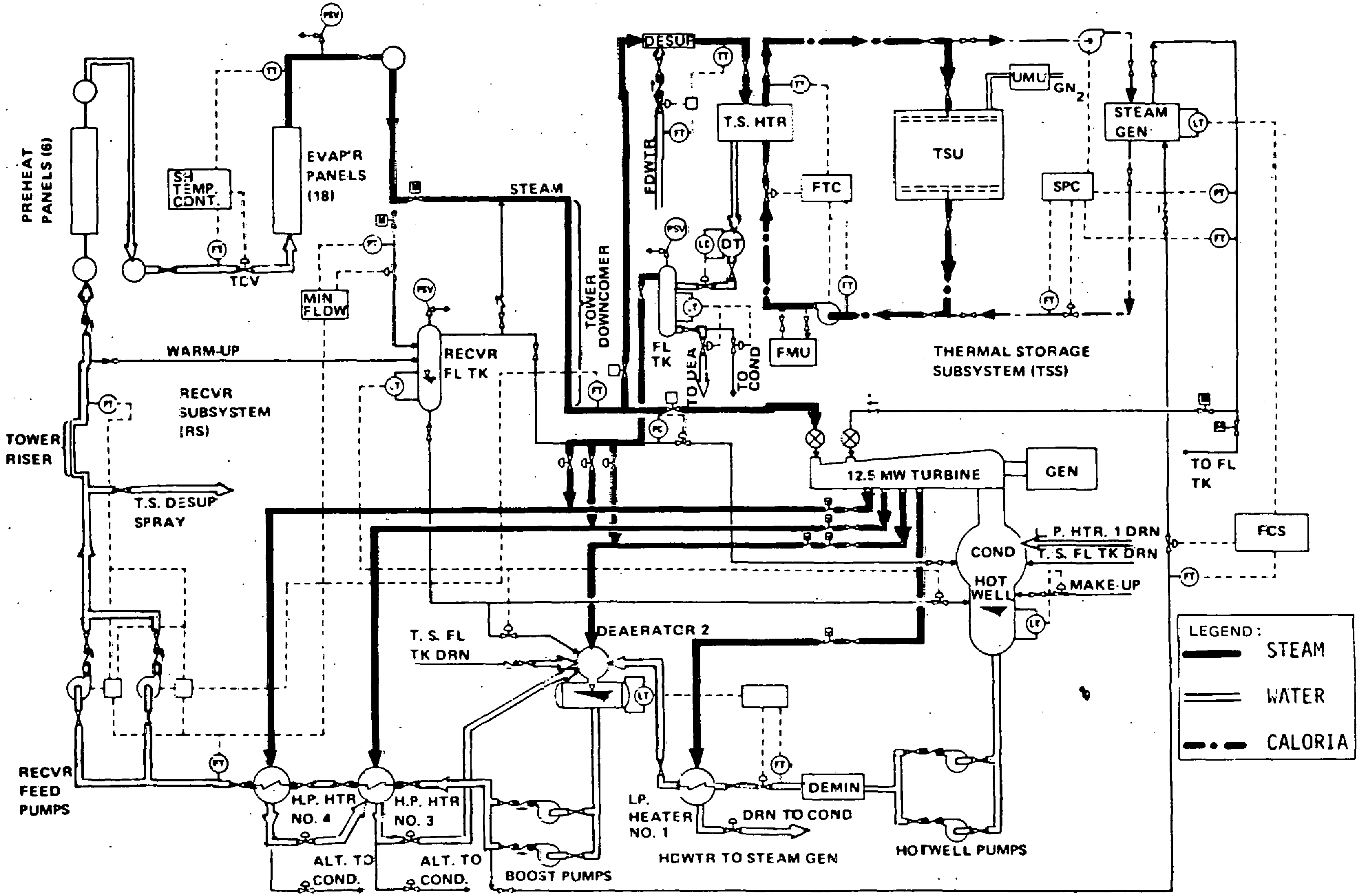


Figure 6-2. Normal Solar Operation (Pilot Plant)

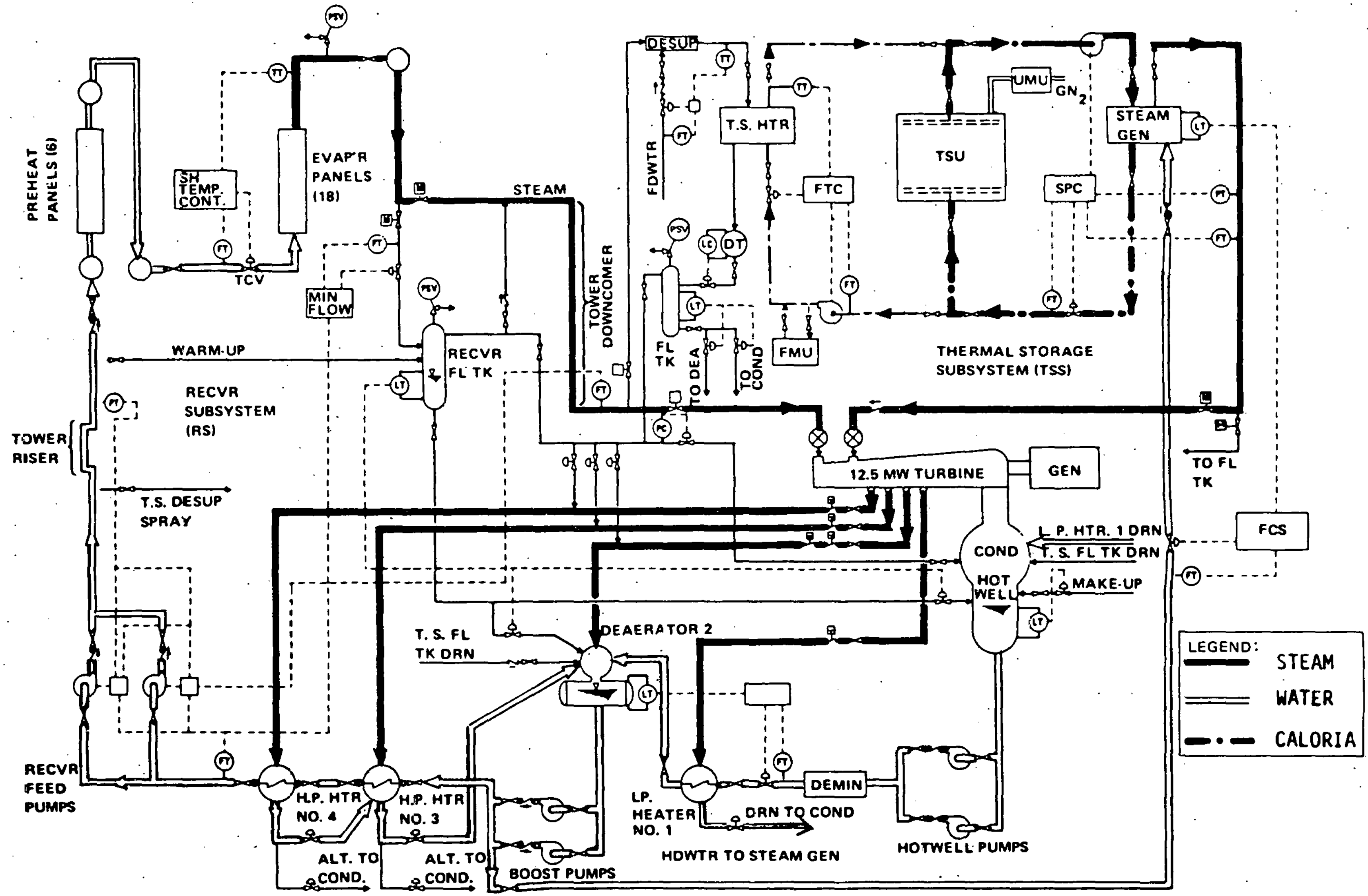


Figure 6-3. Low Solar Power Operation (Pilot Plant)

3. Intermittent Cloud (Figure 6-4). Used for days of frequent cloud passage shielding the sun from the helostat field.
4. Extended Operation (Nighttime) (Figure 6-5).
5. Charging Thermal Storage Only (Figure 6-6). No electric generation; only charging storage.
6. Fully Charged Thermal Storage (Figure 6-7). Same as normal operation, but thermal storage is not being charged.

B. Performs power plant startup and shutdown procedures.

C. Transitions the plant operation to any different mode.

D. Monitors plant safety continuously, and performs emergency shutdown.

E. Provides direct hardwire control to all valves, set points, motors, pumps, etc.

F. Provides visual indication of all sensing devices such as temperatures, pressures, flows, valves status, motor rates, power conditions, etc.

G. Provides continuous focus of the mirror field throughout the day.

H. Controls and monitors status of thermal storage, and provides indication of its charged capacity.

I. Provides calibration data for all measurement devices within its control.

J. Contains the following operational control features:

1. Automatic control of power plant operation from startup to shutdown with full manual override.
2. Complete manual control over all power plant control devices.
3. Direct hardwire control from master control to control device or sensor.
4. Automatic/manual control of control devices uses the same hardwire.
5. Centralized control console containing all auto/manual control points and readouts.
6. Single computer controlling the receiver subsystem, thermal storage subsystem, turbine generator subsystem, collector subsystem and the control console.
7. Distributed microprocessors controlling the collector field of mirrors.

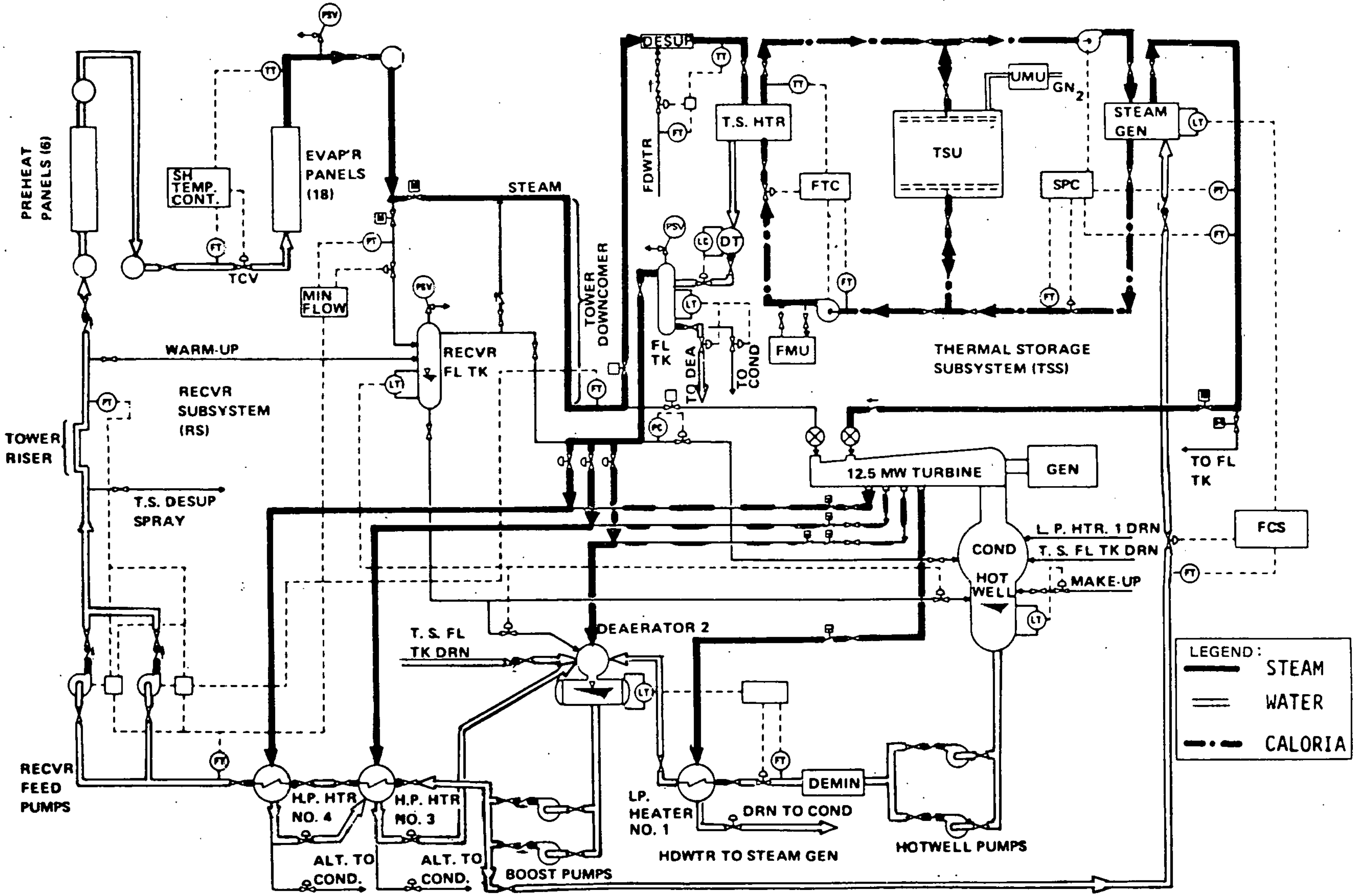


Figure 6-4. Intermittent Cloud Operation (Pilot Plant)

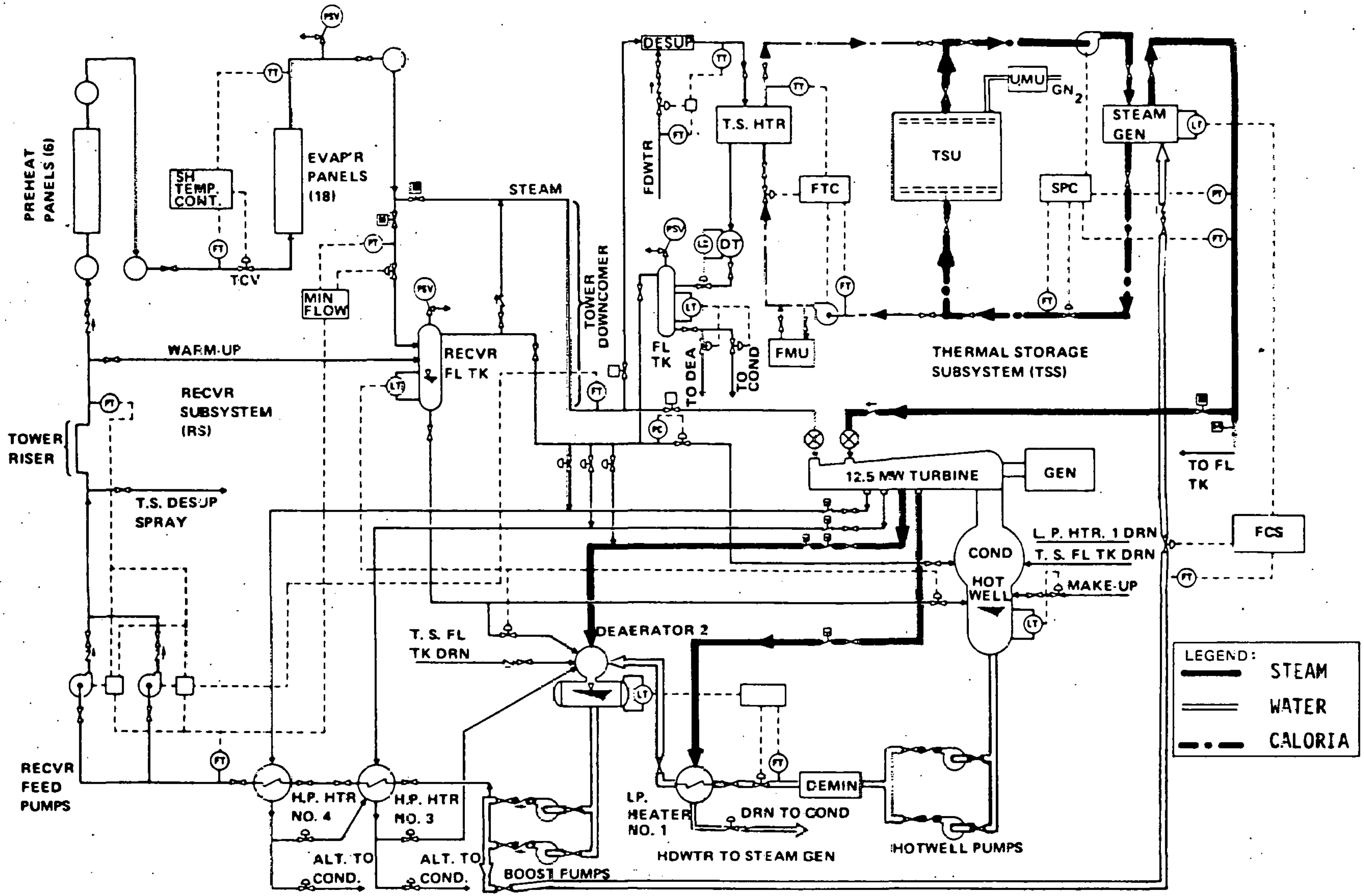


Figure 6-5. Extended Operation (Pilot Plant)

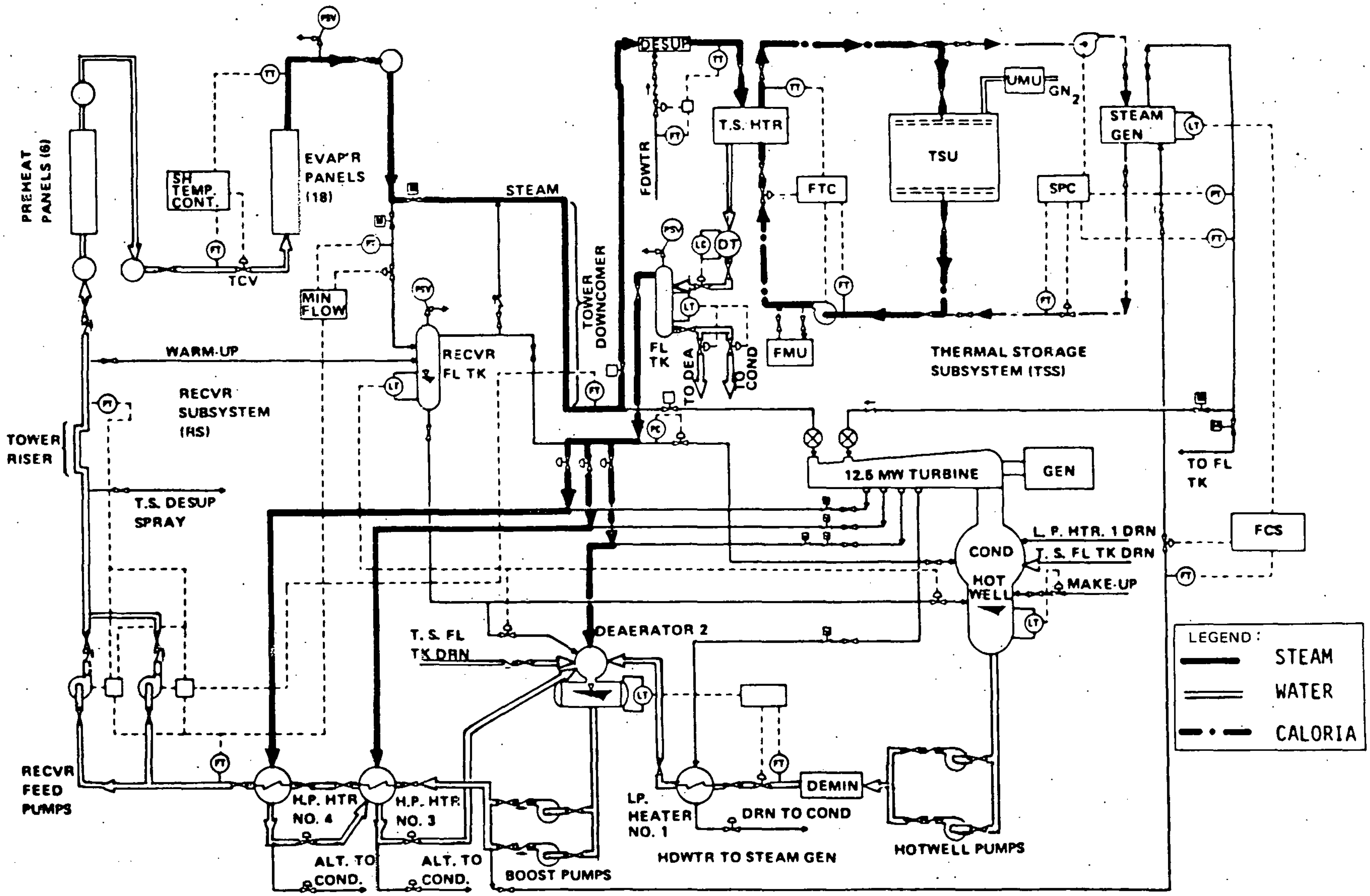


Figure 6-6. Charging of Thermal Storage Only (Pilot Plant)

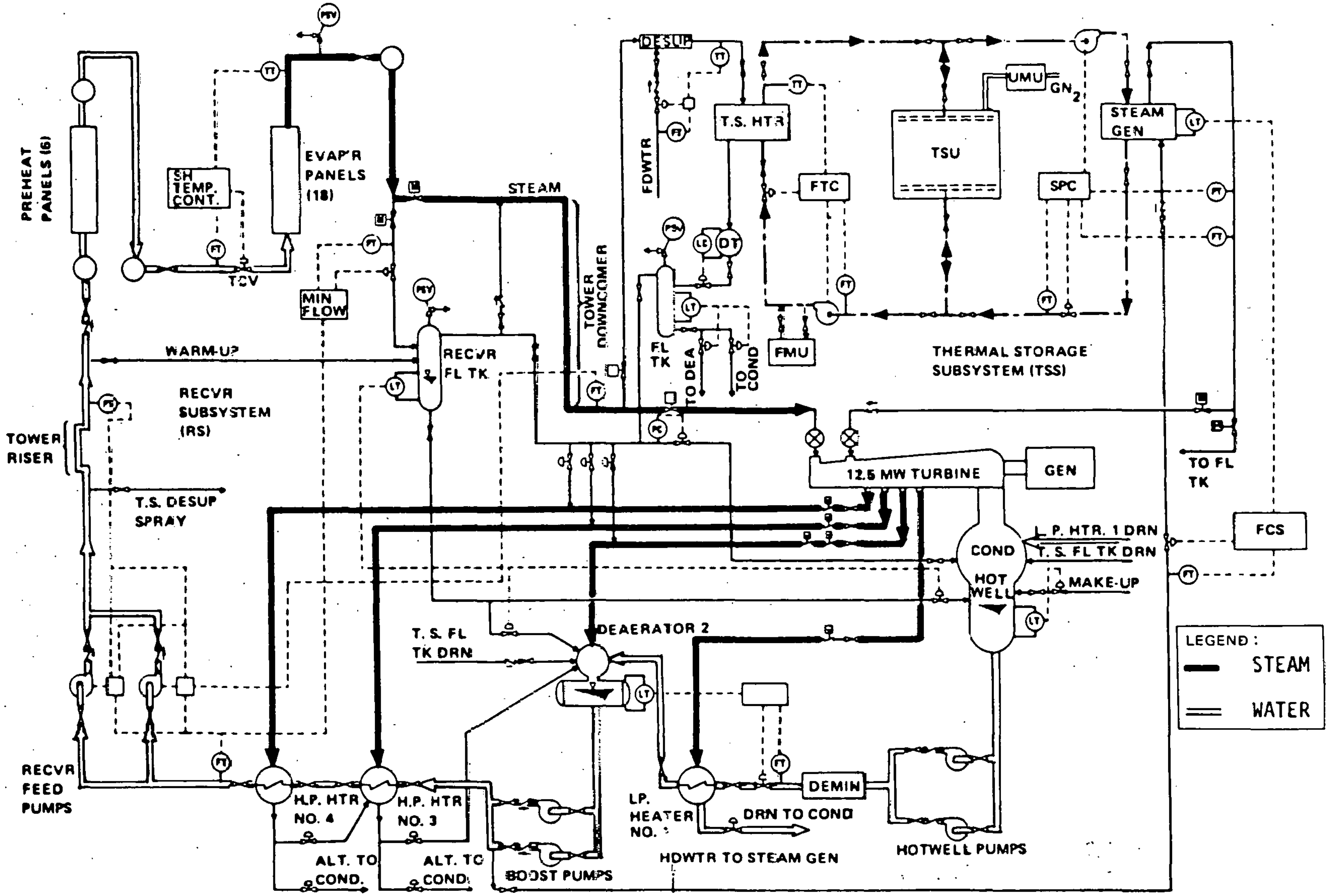


Figure 6-7. Fully Charged Thermal Storage (Pilot Plant)

8. Fail-safe concept for any component failure, including master control computer.
9. Automatic detection of computer failure.
10. Redundancy limited to devices whose failure would create costly equipment loss or human injury.
11. Self-check capability by computer control for total system.
12. Computer displays all values in engineering units.
13. Use of standard devices for status displays being used today by utilities.
14. English language used for all computer/operator communication.
15. Verification by computer of all operator inputs.
16. Backup power supply in case of power failure or interruption.
17. Automatic calibration by the computer of all sensing devices.
18. Control software of computer coded in a high-level functional language.
19. Annunciator and alarm panels used-lights and audio alarm signals.
20. Capability for data reduction and recording by computer (master control).
21. Emergency shutdown capability under complete manual or automatic control.

6.3.1.3 Availability Requirements

The master control subsystem in the automatic mode will be rated to operate 13 hours continuously each day. With manual operation backup, the 99.95% availability requirement will be met. Equipment maintenance will be performed in the remaining 11 hours on any equipment necessary to maintain this rate of availability.

6.3.2 Design

Master control allows the plant operator to select one of the three basic operating modes: (1) full manual control, (2) full automatic control, and (3) manual control with automatic monitor and alarm.

Master control is designed to provide plant control of nine steady-state operating modes and the transitions between these modes. The nine modes of control embrace: (1) startup, (2) normal power, (3) low solar power, (4) intermittent cloud, (5) extended day, (6) thermal storage charge, (7) fully charged thermal storage, (8) planned shutdown, and (9) emergency shutdown.

Master control is designed to be flexible and accommodate expansion changes and modifications expediently without incurring major alterations to hardware and software design. The design shares instrumentation and control field wiring between the manual and automated control systems, making trouble-shooting and diagnostics simpler and saving the costs of duplication.

Master control equipment is centrally located, either adjacent to or as part of the turbine generator building complex to minimize wire lengths and cost. Placement of equipment in the central control room is shown in Figure 6-8. The layout provides maximum operator visibility and control from a single location. System power and interconnecting wiring is routed in suspended overhead cable trays with minimum practical distances between the field wiring, computer, peripherals, UPS, patch panels, and control console.

A preliminary count of the quantity of interface control and instrumentation signals to the central master control room from all but the collector field is shown in Table 6-1.

6.3.2.1 Master Control and Collector Subsystem

Functional Interface

The functional interface between master control and the collector subsystem with beam sensors has been documented in the 1976 Preliminary Design Baseline Review (PDBR). If future study and analysis should select collector field control without beam sensors, the sun acquisition and tracking command data exchange will be changed from that previously described. In addition, new or modified operating functions will be analyzed, including heliostat calibration and verification of position and alignment.

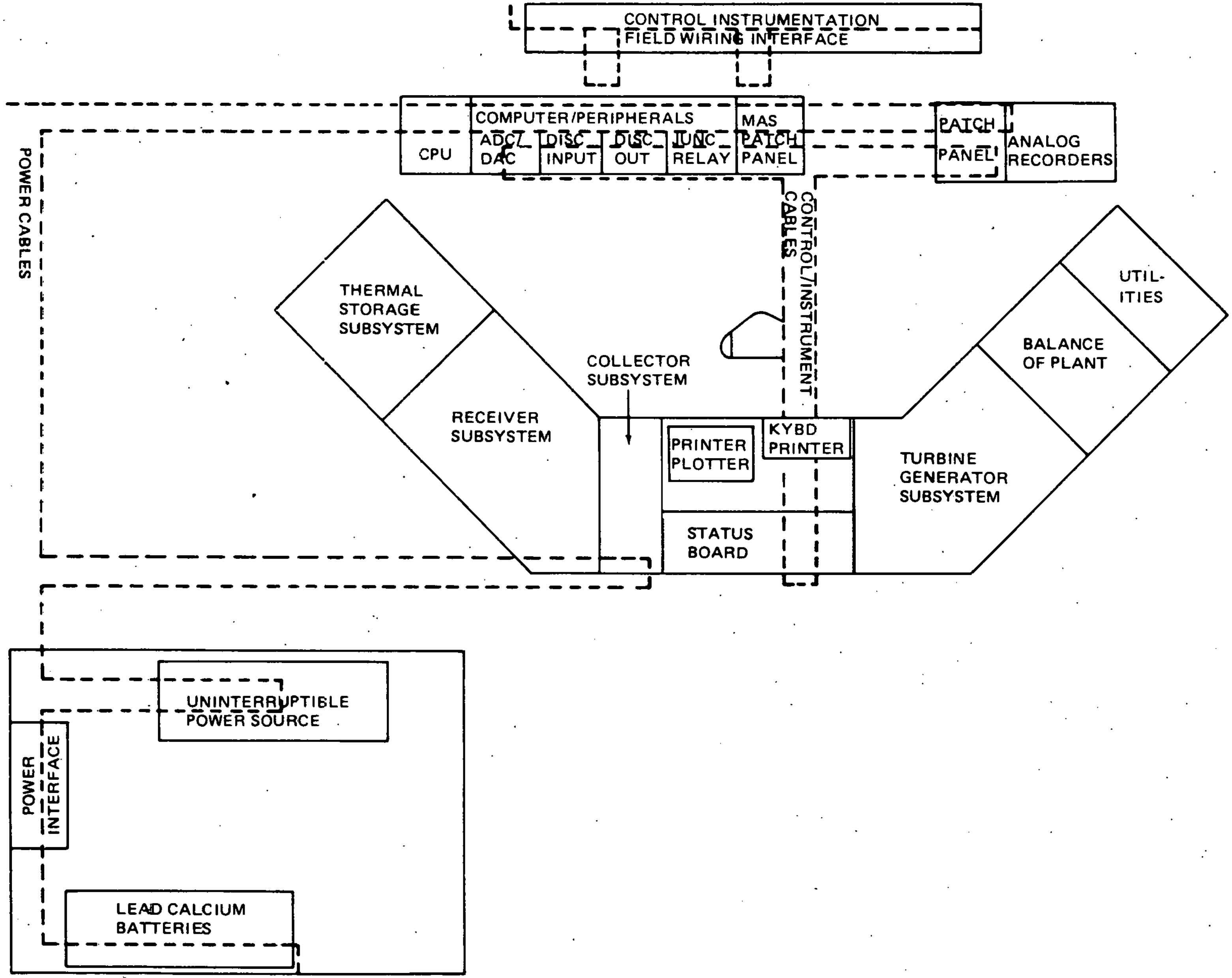


Figure 6-8. Master Control Room and Equipment

Table 6-1

MASTER CONTROL INTERFACE SIGNALS

	Input				Output	
	Control		Instrumentation		Control	
Subsystem	Discrete	Analog	Discrete	Analog	Discrete	Analog
Receiver	12	43	2	69	6	2
Thermal Storage	29	76	4	21	17	10
Turbine Generator BOP	25	28	2	49	18	14
Subtotals	66	147	8	139	41	26
20% Contingency	13	29	2	28	8	5
Totals	79	176	10	167	49	31

Physical Interface

The physical interface between master control and the collector subsystem consists of a digital data transmission bus. Data will be transmitted using biphase encoding with DC isolation. Each master control message requires an acknowledgement from the addressed field controller. Each field controller will have an unique address but will recognize a common emergency slew command.

6.3.2.2 Master Control/Receiver Subsystem

Functional Interface

The interface between master control and the receiver subsystem (as defined in Section 6.2.2) is characterized by the following operating functions:

A. Receiver subsystem checkout. Includes verifying sensor operation, control valve functionality, water inlet pressure and flow conditions, flash tank level, and pneumatic pressure level.

B. Continuous monitor. Identify and analyze out-of-tolerance conditions such as burn wire open or boiling at single-pass panel inlet.

C. Determine corrective action options for alarm or out-of-tolerance conditions.

D. For all nine quasi steady-state plant operating modes:
   1. Determine temperature control set points.
   2. Determine pressure control set points.
   3. Determine control valve positions.
   4. Command temperature and pressure control control valve positions.

E. For each plant operating mode transition, repeat Item D.

F. Establish motor valve interlock sequencing.

G. Monitor and display all receiver subsystem parameters.

H. Provide emergency safing control.

I. Provide night temperature control.

Physical Interface

The physical interface between master control and the receiver subsystem is via discrete hardwires from the receiver components through the steering logic for the discrete digital and continuous analog output control commands and through the master patch panel and relay junction box for the discrete digital and analog instrument input signals.

A preliminary count of the type and quantity of interface control and instrumentation signals is shown in Table 6-2.

Table 6-2
RECEIVER SUBSYSTEM INTERFACE SIGNALS

	Input				Output	
	Control		Instrumentation		Control	
Receiver Signals	Discrete	Analog	Discrete	Analog	Discrete	Analog
Motor Valves (On-Off)	12		2		6	
Temperature Sensors/Control		21		46		1
Pressure Sensors/Control		3		22		1
Flow Meters		18				
Level Detectors		1		1		
Total	12	43	2	69	6	2

6.3.2.3 Master Control/Thermal Storage Subsystem

Functional Interface

The interface between master control and the thermal storage subsystem (as defined in Section 6.2.3) is characterized by the following operating functions:

A. Thermal storage subsystem checkout.
B. Continuous monitor. Identify and analyze out-of-tolerance conditions.
C. Determine corrective action options for out-of-tolerance conditions.
D. Provide emergency safing control.
E. Determine temperature control set points.
F. Determine pressure control set points.
G. Determine control valve positions.
H. Determine anticipated charging rate.
I. Determine anticipated discharging rate.
J. Calculate status of thermal charge in tank.
K. Position control valves per plant operating mode status
L. Command inlet steam flow control valve.
M. Command desuperheater temperature control valve.
N. Command charging side oil flow control valves (2).
O. Command charging pump speed settings (2).
P. Command discharging pump speed settings (2).
Q. Command auxiliary pump (on-off).
R. Command discharge oil flow control valves (2).
S. Command superheater oil bypass modulating valves (2).
T. Command feedwater level-control valves (2).
U. Command all motor valve positions (12) with suitable interlock restrictions.
V. Monitor and display all thermal storage subsystem parameters.
W. Provide night (non-use period) control.

Physical Interface

The physical interface between master control and the thermal storage subsystem is similar to the receiver previously described. A preliminary count of the quantity and types of interface control and instrumentation signals is shown in Table 6-3.

Table 6-3

THERMAL STORAGE SUBSYSTEM INTERFACE SIGNALS

Thermal Storage Signals	Input				Output	
	Control		Instrumentation		Control	
	Discrete	Analog	Discrete	Analog	Discrete	Analog
Motor Valves (On-Off)	24		4		12	
Modulating Valves (Continuous)						10
Temperature Sensors/ Control		62		17		
Pressure Sensors/Control		8		3		
Flow Rate		5				
Level Detector		1		1		
Speed Sensors/ Control	5				5	
TOTALS	29	76	4	21	17	10

6.3.2.4 Master Control/Turbine Generator and Balance of Plant

Functional Interface

The interface between master control and the turbine generator/balance of plant subsystem is characterized by the following operating functions:

A. Turbine generator/balance of plant subsystem checkout.

B. Continuous monitor. Identify and analyze out-of-tolerance conditions.

C. Determine corrective action options for out-of-tolerance conditions.

D. Determine pressure and temperature set points.

E. Determine turbine control mode-speed/load for startup and initial pressure for running.

F. Develop throttle valve and/or admission valve position commands.

G. Open bypass valve during admission steam-only operation with interlock.

H. Develop extraction port control valves position commands.
I. Command receiver feedwater pump speed setting.
J. Control condenser fans.
K. Control primary level control valves.
L. Control boost, hotwell, condenser water, and condenser vacuum pumps (on-off).
M. Command thermal storage flash tank set points.
N. Monitor and display all turbine generator/balance of plant parameters.
O. Provide night steam blanket for turbine control.

Physical Interface

The physical interface between master control and the turbine generator/balance of plant subsystem is similar to both the receiver and thermal storage subsystem previously described. A preliminary count of the quantity and types of interface control and instrumentation signals is shown in Table 6-4.

6.3.2.5 Reliability

High reliability in the master control subsystem will be obtained by use of standard and proven off-the-shelf hardware and software from quality commercial suppliers. Conservative environmental and component operating margins will be selected. Single point failures that disable the automatic mode of system operation will be minimized with full manual backup provided. In cases where elimination of a single point failure is impractical, a dead-man timer will alarm the operator.

6.3.2.6 Maintainability

Maintainability will be achieved by designing to a high degree of standardization and modularity throughout master control. This will ensure identical hardware components and types where practicable, such as cabling, controlling, monitors, displays, and wire connectors. All control and instrumentation signals will be standardized throughout the master control subsystem. Master control design is such that maintenance and test points can be easily reached, electronic modules easily replaced, and elements subject to wear or damage, such as displays, typewriters, and printers, can be conveniently serviced or replaced.

Table 6-4

TURBINE GENERATOR AND BALANCE OF PLANT SUBSYSTEM INTERFACE SIGNALS

Turbine Generator and Balance of Plant	Input				Output	
	Control		Instrumentation		Control	
	Discrete	Analog	Discrete	Analog	Discrete	Analog
<u>Turbine Generator</u>						
Motor Valves (On-Off)	10		2		5	
Modulating Valves (Continuous)						2
Temperature Sensors/Control		7		45		
Pressure Sensors/Control		2				
Speed Sensors/Control		1				
Generator Output/Load		1				
<u>Balance of Plant</u>						
Motor Valves (On-Off)	4				2	
Modulating Valves (Continuous)						2
Temperature Sensors/Control		9		1		
Pressure Sensors/Control		7		2		2
Flow Rate/Control	9				9	
Level Detectors/Control						8
Speed Sensors/Control	2	1		1	2	
TOTALS	25	28	2	49	18	14

Malfunction indication and fault-isolation information for master control will be displayed at the central control console. System components that do not have a redundant mode of operation will be accessible for on-line repair or replacement.

Master control is designed so that service can be performed by personnel with the standard tools and technical ability required for similar equipment.

6.3.2.7 Environmental Conditions

The majority of master control hardware (and software) will be housed in a central control room that is environmentally conditioned as follows.

A. Air temperature, 21°C ± 3°C (70°F ± 5°F).

B. Relative humidity, 40% to 50%.

C. Electrical transients caused by inductive or capacitive coupling and switching will be no greater than ±10% on the digital power bus.

D. Electromagnetic radiation susceptibility and generation by the master control equipment will be minimized by a control room ground system and appropriate signal shielding.

6.4 MASTER CONTROL SUBSYSTEM ANALYSIS

The detailed design and analysis of the master control subsystem can be divided into four specific areas of analysis and investigation as shown in Figure 6-9. These four areas are the analysis of top-level performance requirements and the mapping down of these requirements into both design and performance requirements in the major subsystems, the design and analysis of the plant control system for each of the major subsystems, the design and analysis of the master control subsystem, and, finally, the total system performance analysis, verification, and evaluation relative to the design and performance requirements. The detailed design of the plant controls and master control remains as a future task. The primary control loops and control valves have been configured based primarily on both the functional requirements and a preliminary assessment of the performance requirements of each subsystem. In the following paragraphs the approach to the detailed design of the master control system and the analysis techniques used to support that future design effort are presented and discussed.

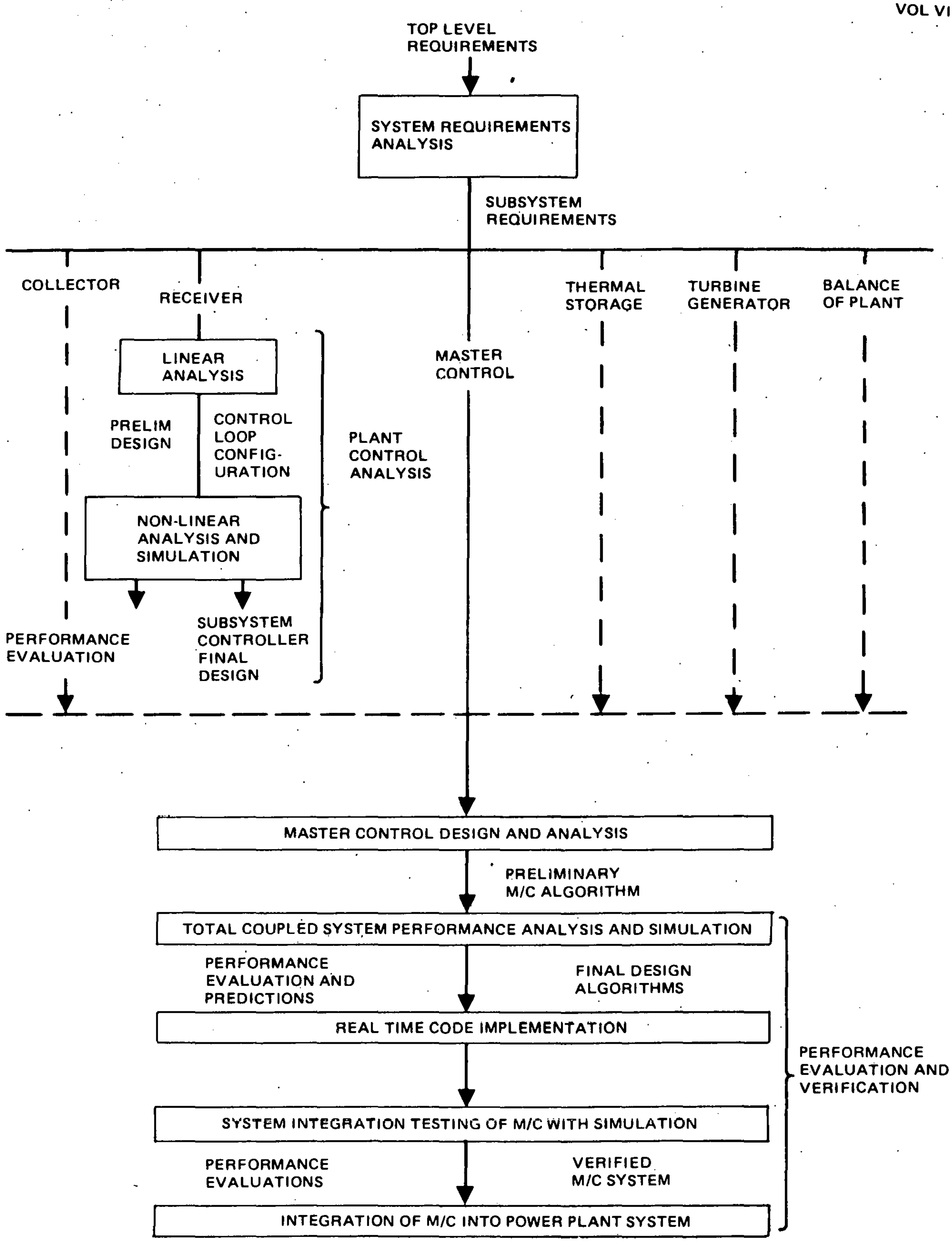


Figure 6-9. Master Control System Analysis Functional Flow

6.4.1 Subsystem Performance Requirements Analysis

The subsystem requirements for the control systems are derived based on the top-level system performance requirements as described in Section 4 in Volume II. The requirements, primarily in terms of response time and system accuracy, are allocated down to each of the major subsystems and derived for each of the major plant control systems such as the collector, receiver, turbine-generator, and thermal storage unit control systems. For example, the receiver response time and control system accuracy requirements are firmly established and the detailed design of the closed-loop temperature controller for each heater panel is systematically performed. With this analysis accomplished, the appropriate sensors, valves, actuation systems, and control system compensators are designed and selected to be compatible with both self-imposed control system stability requirements as well as the allocated subsystem performance requirements. The requirements analysis and design procedure is similar for all of the control systems within the major subsystems. In the following paragraphs, the methods used in the design and analysis approach, the design implementation, verification, and performance evaluation are described for those plant control systems which lie within the realm of the master control system.

6.4.2 Plant Control System Analysis

Each major plant control system is analyzed in detail with respect to its stability and transient response characteristics. A rather extensive linear analysis is performed on the subsystem that is to be controlled in order to define the dominant control frequencies and time constants within the system and to determine the frequency response characteristics of the plant to be controlled. By means of a linear analysis of the subsystem, a direct insight is obtained into both the system dynamic operation as well as its ability to accurately control to a desired steady-state condition. By means of a linear analysis, a direct quantitative measure is made of both the control system accuracy (i.e., error analysis) as well as direct measure of system dynamic response sensitivity (stability) to major subsystem design parameters. For example, a simplified linear model of the receiver is shown in Figure 6-10. With this model, an understanding of both the uncoupled and coupled system frequencies is obtained as well as the design parameters which directly

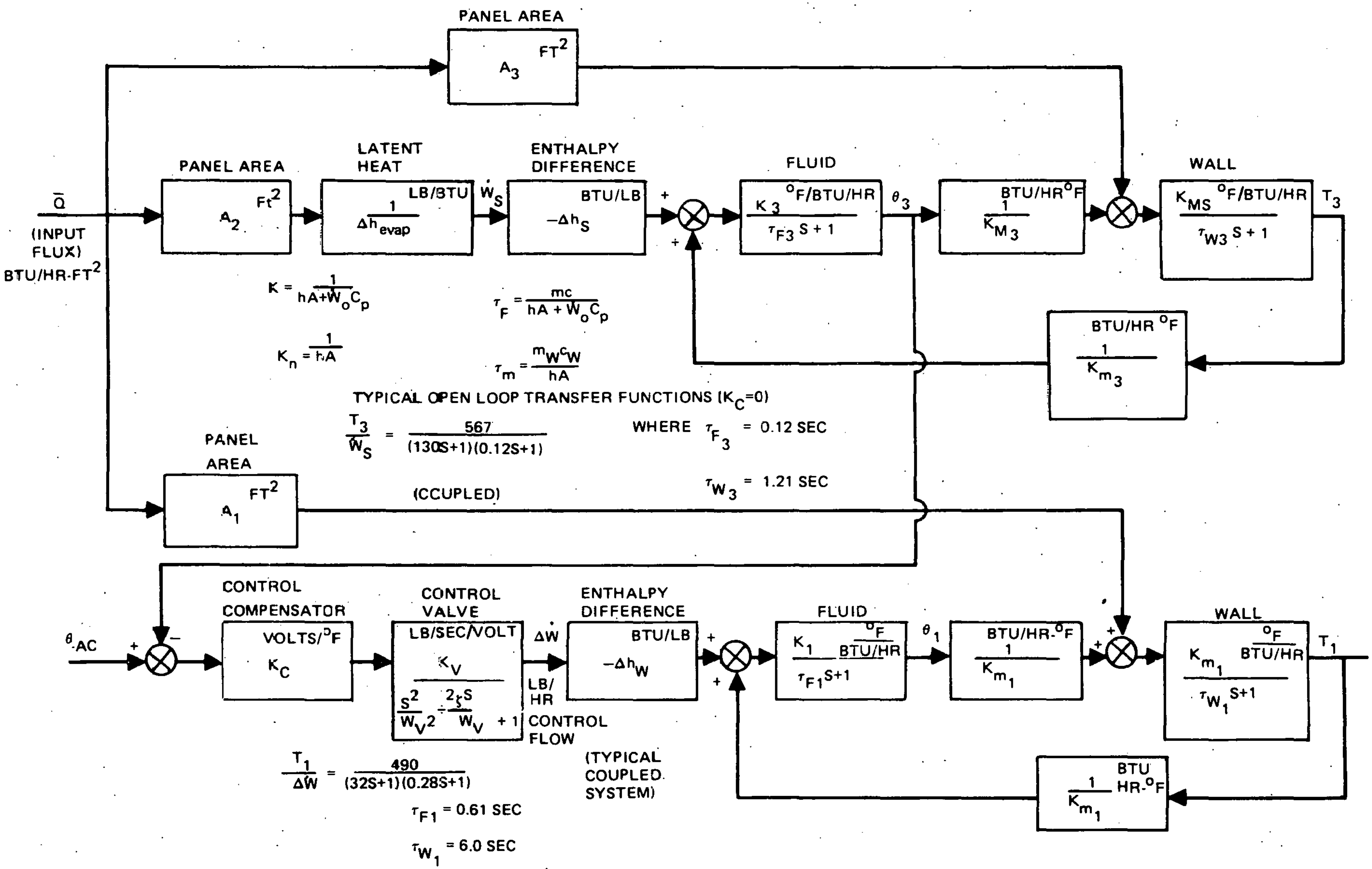


Figure 6-10. Receiver Control System Block Diagram (Perturbation Model)

influence the system frequency response, accuracy, and stability. By means of this type of linear analysis the relative stability of the control system (i.e., stability margin) is qualified and the critical design conditions for both stability and transient response can be identified. By designing the control system compensation to ensure closed-loop control system stability at these critical design points the total subsystem stability is assured throughout the full operating range of the subsystem.

The coupled linear analysis of the control systems is performed with the MDAC linear analysis program NUHYAP. The program is capable of analyzing both continuous and sampled data linear systems in both the frequency domain of the S plane and Z plane as well as the time domain (transient response).

The large signal and nonlinear stability and transient response characteristics of each major subsystem are analyzed by simulation of the total closed-loop control system. The simulation tool used is the power plant simulation (POPS). The POPS simulation is a time-domain nonlinear hybrid simulation of the total solar power plant system and is described in detail in Section 4.7 of Volume II.

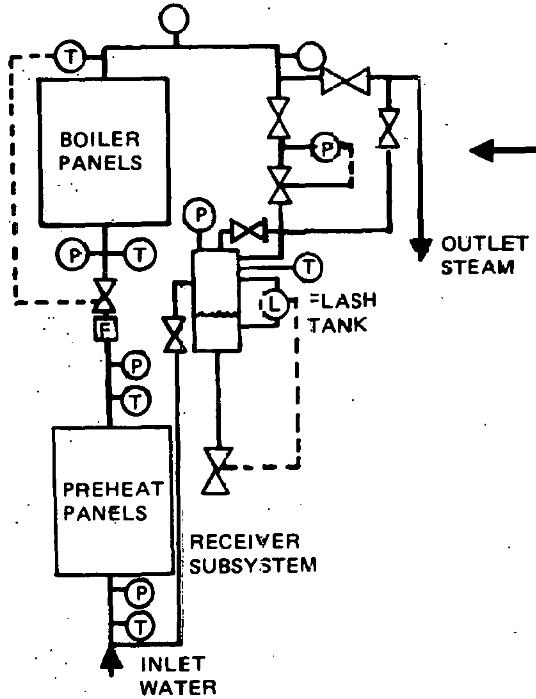
In the large signal transient analysis each subsystem is subjected to realistic inputs throughout its full range of operating and environmental conditions. The full impact of system nonlinearities such as valve flow characteristics, hardware saturations, nonlinear heat transfer, and thermodynamic characteristics, are assessed and their impact on stability and transient response evaluated. Modifications to the control compensation, control algorithms, or hardware can then be made to meet the desired design and performance characteristics. Final control loops are configured and firm requirements established on the sensors and supporting hardware. The requirements on the sensors, valves, actuators, etc., are defined in terms of the sensor type, operating range, accuracy, linearity, and frequency response. The control system design is mechanized into its real hardware configuration, tested and the performance of its major elements verified relative to its design and performance requirements. The control systems analysis and simulations are updated to reflect the exact real hardware configuration and the stability margins and transient performance is again verified. Subsystem stability margins and performance predictions are then made and compared to actual test results to verify the integrity of the real hardware and the control system models.

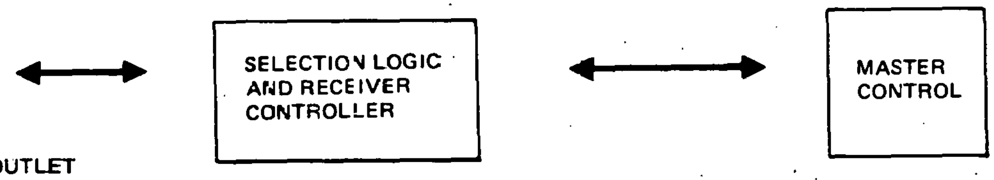
6.4.3 Master Control Algorithm Analysis

The formulation and design of master control algorithms is based upon the functional and the performance requirements of the total system. The functional requirements for master control are dictated by the subsystem hardware configuration and the different modes of operation within the power plant. The master control performance requirements are driven by the general requirement to maintain a stable and well-controlled power plant in the presence of large variations in solar input and also by the design goal to optimize the power plant output and operating efficiency over a wide range of operating modes and conditions. In the following paragraphs, the design and analysis considerations which impact the definition and performance of the master control subsystem with respect to both functional and performance requirements are discussed.

6.4.3.1 Functional Design and Analysis Considerations

The design of the master control algorithm incorporates the functional requirements for operation of the power plant. The functional algorithm analysis includes the discrete control that selects the appropriate operating modes based on available and predicted solar insolation, electrical load, and present status of the power plant. The mode select function incorporates the selection of the appropriate operational mode of the major subsystems and issues discrete commands to initiate preprogrammed logic to actuate on-off valves and initiate startup or shutdown of ancilliary devices. Typical operating functions for the receiver, collector, and thermal storage subsystems are shown in Figures 6-11 through 6-13. The operating functions are defined for the hardware subsystem itself, the steering logic which incorporates the subsystem controller, and the master control system which performs the executive and supervisonal control function over the major subsystems. For example, in the receiver subsystem as shown in Figure 6-11, the receiver itself is controlled by proportional valve controls on





OPERATING FUNCTIONS

- OPERATE PROPORTIONAL CONTROL VALVES
  - TEMPERATURE (18)
  - PRESSURE (1)
  - LEVEL CONTROL (1)
- OPERATE ON/OFF VALVES
  - RECEIVER OUTLET
    - FLASH TANK INLET
    - MAIN DOWNCOMER
  - FLASH TANK VAPOR OUTLET
  - DOWNCOMER WARMUP
  - RECEIVER BYPASS
- MONITOR SENSORS
  TEMPERATURE, PRESSURE, FLOW

OPERATING FUNCTIONS

- PERFORM CLOSED-LOOP CONTROL FUNCTIONS
  - TEMPERATURE CONTROL
  - PRESSURE CONTROL
  - LEVEL CONTROL
- PERFORM MANUAL SET POINT ADJUSTMENTS ON CLOSED-LOOP CONTROLLERS
- INITIATE ON/OFF VALVE OPERATION BASED ON SELECTED MODE
  - WARM-UP (BYPASS)
  - FLASH TANK IN LOOP
    - LIQUID FLOW
    - LIQUID AND VAPOR FLOW
    - DOWNCOMER WARMUP
  - FLASH TANK OUT OF LOOP
  - MAIN DOWNCOMER
- SELECT OPERATIONAL MODE
  - MANUAL
  - AUTOMATIC
- SET VALVE POSITIONS IN MANUAL MODE
- IDENTIFY OUT-OF-TOLERANCE CONDITIONS AND TRANSMIT TO MASTER CONTROL
  - BURN WIRE
  - BOILING AT SINGLE-PASS INLET VALVE
- PERFORM RECEIVER SELF-CHECK AND VALVE INTERLOCK CAPABILITY
- CONDITION AND TRANSFER DATA TO MASTER CONTROL

OPERATING FUNCTIONS

- DETERMINE SET POINT CONTROLLER COMMANDS
  - TEMPERATURE
  - PRESSURE
  - LIQUID LEVEL
- DETERMINE OPERATIONAL MODE
- ACCEPT, PROCESS AND DISPLAY DATA
  - TEMPERATURE, PRESSURE, FLOW, LIQUID LEVEL, VALVE POSITIONS
- ANALYZE ALARM OR OUT-OF-TOLERANCE CONDITION AND DETERMINE CORRECTIVE ACTION
- INITIATE AND ANALYZE RESULTS OF CONTROLLER SELF-CHECK SIGNAL

Figure 6-11. Receiver Subsystem Functional Operation Description

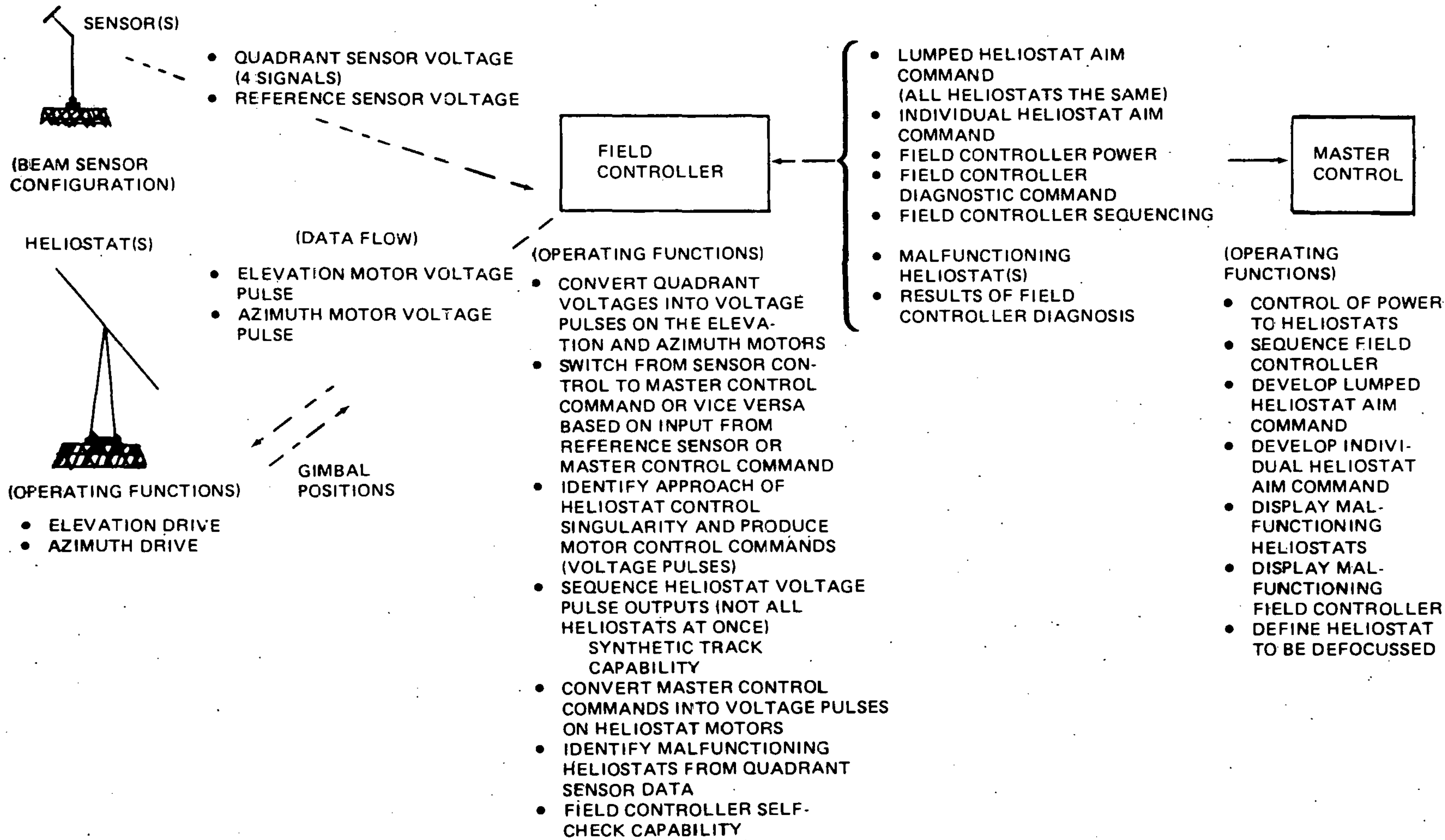


Figure 6-12. Collector Subsystem Functional Operation Description

OPERATING FUNCTIONS (Thermal Storage Unit Subsystem)

CHARGING SIDE

- OPERATE CONTROL VALVES
  - STEAM INLET
  - DESUPERHEATER TEMPERATURE
  - T/S HEATER OIL INLET (2)
- OPERATE SHUTOFF VALVES
  - STEAM INLET (2
  - OIL BYPASS
- SET OIL PUMP SPEED (2)
- MONITORING SENSORS

STORAGE UNIT

- OPERATE INLET AND OUTLET SHUTOFF VALVES

EXTRACTION SIDE

- OPERATE CONTROL VALVES
  - OIL FLOW (2)
  - OIL SPLITTER (2)
  - FEEDWATER INLET LEVEL (2)
- OPERATE SHUTOFF VALVES
  - SEAL STEAM
  - WATER INLET (2)
  - OIL LINE (2)
- SET OIL PUMP SPEEDS (3)
- MONITORING SENSORS

OPERATING FUNCTIONS (Selection Logic Subsystem Controllers)

- PERFORM CLOSED-LOOP CONTROL FUNCTIONS
  - INLET STEAM FLOW
  - DESUPERHEATER TEMPERATURE
  - OIL FLOW CONTROL (CHARGING AND EXTRACTION)
  - FEEDWATER LEVEL CONTROL
  - STEAM GENERATOR BYPASS CONTROL
- PERFORM MANUAL SET POINT ADJUSTMENTS TO CLOSED-LOOP CONTROLLERS
- INITIATE SHUTOFF VALVE OPERATION BASED ON SELECTED MODE
- MANUAL OPERATION OF SHUTOFF VALVES
- COMMAND PUMP SPEED SETTINGS (AUTOMATIC AND MANUAL)
- CONDITION AND TRANSFER DATA TO MASTER CONTROL
- IDENTIFY OUT-OF-TOLERANCE CONDITIONS AND TRANSFER TO MASTER CONTROL
- PERFORM THERMAL STORAGE SELF-CHECK AND VALVE INTERLOCK CAPABILITY

OPERATING FUNCTIONS (Master Control)

- DETERMINE SET POINT CONTROLLER COMMANDS
  - STEAM INLET FLOW
  - STEAM GENERATOR OUTLET TEMPERATURE
  - DESUPERHEATER TEMPERATURE
- DETERMINE T/S SYSTEM OPERATIVE MODE
- DETERMINE SHUTOFF VALVE POSITIONS
- DETERMINE PUMP SPEED SETTINGS
- DETERMINE ANTICIPATED CHARGING AND EXTRACTION SEQUENCE AND RATES
- ACCEPT, PROCESS, AND DISPLAY DATA AND CRITICAL PARAMETERS (CHARGING, STORAGE, EXTRACTION)
- ANALYZE ALARM OR OUT-OF-TOLERANCE CONDITIONS AND DETERMINE CORRECTIVE ACTION
- INITIATE AND ANALYZE RESULTS OF T/S CONTROLLER SELF-CHECK STATUS

Figure 6-13. Thermal Storage Subsystem Functional Operation Description

the receiver inlet and outlet based upon sensed temperature and pressure. In addition, these are discrete valves operating the flash tank inlet and outlet, downcomer inlet, warmup valve, and receiver bypass valve. The function of the steering logic is to close the control loop from the temperature and pressure sensors and to receive set point commands from either master control in the automatic control mode or from manual control in manual mode. The steering logic also initiates commands to the on-off valves based on the selected operating modes. Additional functions include receiver controller self-check capability, valve interlocks, and identification and transmission of out-of-tolerance conditions to master control. The function of the master control algorithm is to determine and send the temperature and pressure set point commands to the receiver controller and to define the receiver operating mode. In the manual mode, pressure and temperature set points are set by manual inputs in addition to manual selection of the operating mode. Additional supervisory functions performed by master control include data displays of primary functions, analysis of self-check, alarm or out-of-tolerance signals, and determination and initiation of corrective action. A similar functional flow and definition of the operation functions for the collector subsystem is shown in Figure 6-12 and for the thermal storage unit in Figure 6-13. The master control system algorithm design and analysis will incorporate all of the above functional operations and will encompass all of the prescribed operating modes for the power plant.

6.4.3.2 Performance Analysis Considerations

Performance analysis considerations related to the design of the master control algorithms deal with the impact of those algorithms on the dynamic stability of the total coupled power plant system and the optimization of the subsystem performance and use to maximize overall plant efficiency.

Master control algorithms affect the stability of the total power plant because variations in the set point of one subsystem such as the temperature set point in the receiver affects the dynamic performance of all other subsystems such as the inlet steam flow conditions to the turbine and thermal storage unit. Although the operation of each subsystem controller is designed to be stable by itself and provide good transient response characteristics as an independent subsystem, all of the subsystems are coupled together through the master control subsystem, and the stability of the overall coupled system is therefore influenced by master control algorithms.

To assure overall system stability throughout the full range of operating modes and operating conditions, the total system must be analyzed as a complex coupled control system. The algorithms are designed to afford overall system stability and good transient response characteristics during the normal mode of operation, transition between modes of operation, and in the presence of subsystem failures and external disturbances. Some of the major parameters which influence the coupled-system performance and stability other than the inherent stability of the open-loop system is the accuracy and the update rate at which the master control system issues proportional and discrete commands to the major subsystems. The influence of master control algorithms on system dynamic performance is analyzed as a coupled linear system using the NUHYAP computer program and as a coupled nonlinear system using the POPS simulation. By means of these design and analysis tools, master control algorithms and their accuracy and update rates will be designed to ensure stable system operation and good transient performance throughout all of the desired operating conditions.

In addition to dynamic performance analysis of master control algorithms, the analysis is extended to investigate methods of optimizing power plant output and overall system efficiency based on the electrical load, available and anticipated solar insolation, present system status, and predicted conditions and needs. The effectiveness and feasibility of incorporating energy management algorithms are investigated to optimize system performance. In addition, an analysis of prediction methods and correlation techniques in predicting weather, solar insolation, and energy requirements will be addressed to optimize plant operation.

6.4.4 Total System Performance Analysis

The performance of the total solar power plant system is determined by means of a simulation of the integrated major subsystems linked together by a simulated master control system. The performance of the system is measured in terms of system response time, system capability to achieve and accurately maintain its desired output performance, as well as its ability to meet its specified design and performance requirements. The quality of system performance is also measured by the demonstrated relative stability of the overall system and the manner in which the system transitions from one operating mode to another. In verifying the system capability to meet its performance requirements, the total system simulation is subjected to realistic inputs in terms of solar insolation and electrical load. The total system simulation, including master control, then drives each of the major subsystem simulations by means of mode control, discrete control, and proportional control signals to achieve the desired plant performance. The operational modes that are simulated include system startup, normal and low solar mode, intermittent-cloud conditions, and normal and emergency shutdown modes. In addition, the conditions for thermal storage charging, fully charged thermal storage, nighttime operation, and standby mode are examined.

To assure that the system will operate in a satisfactory and stable manner, not only nominal but also nonnominal operating conditions, including proposed subsystem failure modes, are simulated and analyzed. Such nonnominal conditions as two-sigma variations in solar insolation, system pressure, and critical hardware component gain characteristics are evaluated with respect to the ability of the master control system to maintain the total power plant within its design requirements. Effects of dynamic subsystem failures such as malfunctions in discrete valves, control valves, temperature and pressure sensors, or subsystem plant control systems are evaluated with respect to the formulation and design of master control algorithms. In addition, the capability of master control to maintain the performance of the total plant within its design and operating requirements is evaluated when the system is subjected to a variety of proposed failure modes.

The performance of the master control system algorithms is verified by means of the POPS simulation, as described in Section 4.7 of Volume II. An extension of this simulation also provides for the capability to debug and check out the actual master control algorithms when implemented within the master control computer. This simulation, as shown in Figure 6-14,

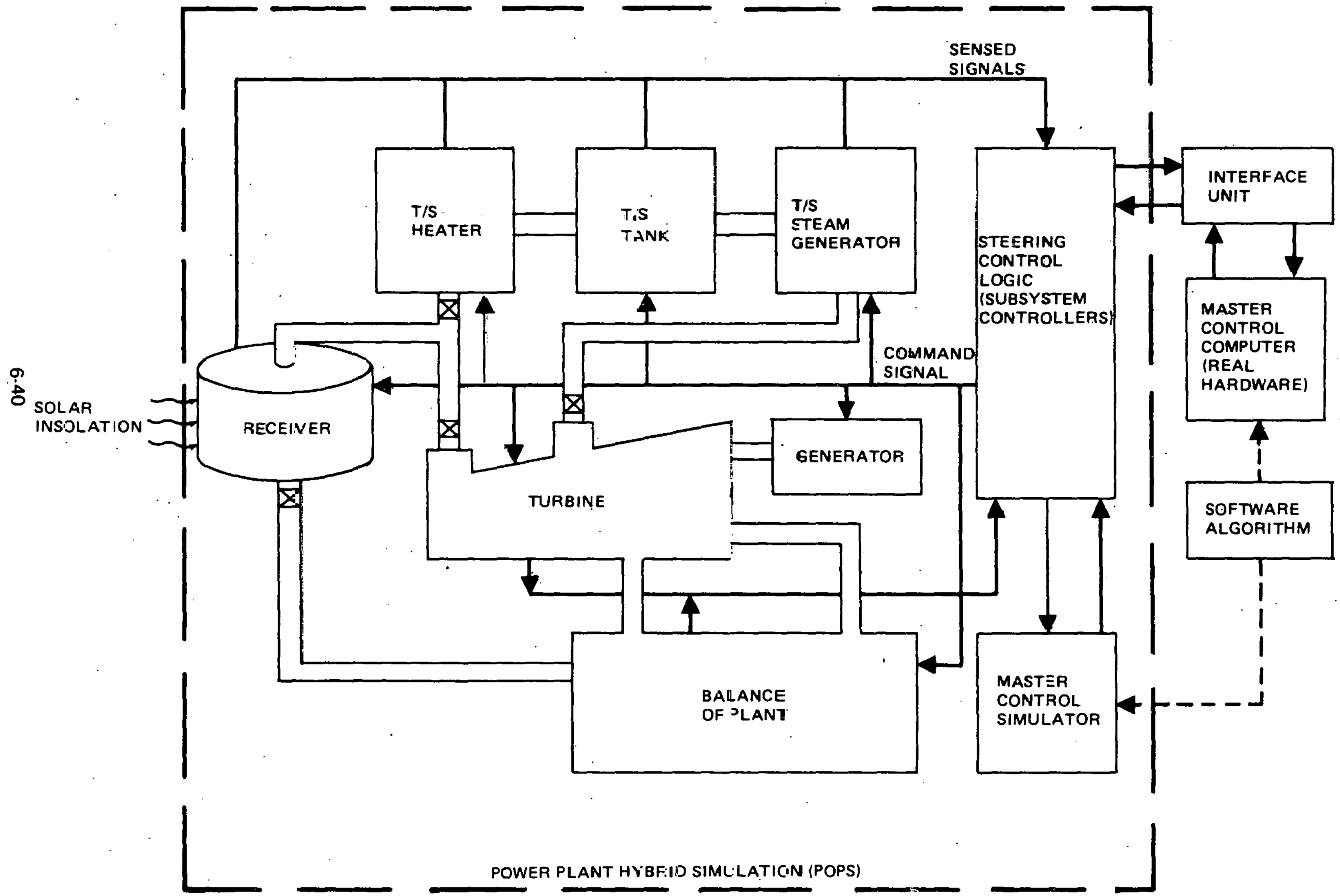


Figure 6-14 — al System Performance Simulation for Real Hardware Integration Testing serves as a simulated test bed for system integration testing of the master control algorithms and computer.

The major subsystems are simulated in addition to the interface units between the master control computer and the major subsystems. The system simulation is then subjected to realistic inputs, operating modes, and typical transition sequences between operating modes to verify satisfactory operation of both the master control system and the manual interface system with total simulated plant operation. The resultant product of this integration testing is a master control system computer and master control software that has undergone a high level of verification and checkout before integration into the actual power plant system.

6.5 DESIGN CHARACTERISTICS

Master control design characteristics provide development and expansion flexibility, incorporate manual and automatic modes of plant control, use conventional proven control and instrumentation techniques, and use commercially available "off-the-shelf" hardware throughout.

6.5.1 Overall Subsystem

The overall subsystem design characteristics applied to the manual and automatic modes of master control follow these guidelines:

A. Provide development and expansion flexibility.
B. Standardize interfaces.
C. Use commercially available hardware and systems software.
D. Design for a single operator interface.
E. Minimize redundancies and duplications.
F. Incorporate fail-safe systems.
G. Employ conventional power plant control room operational concepts.
H. Write software in a conversational high-level language.
I. Build in self-test and diagnostic tools.

The schematic shown in Figure 6-15 relates the overall master control design characteristics to the subsystem interfaces.

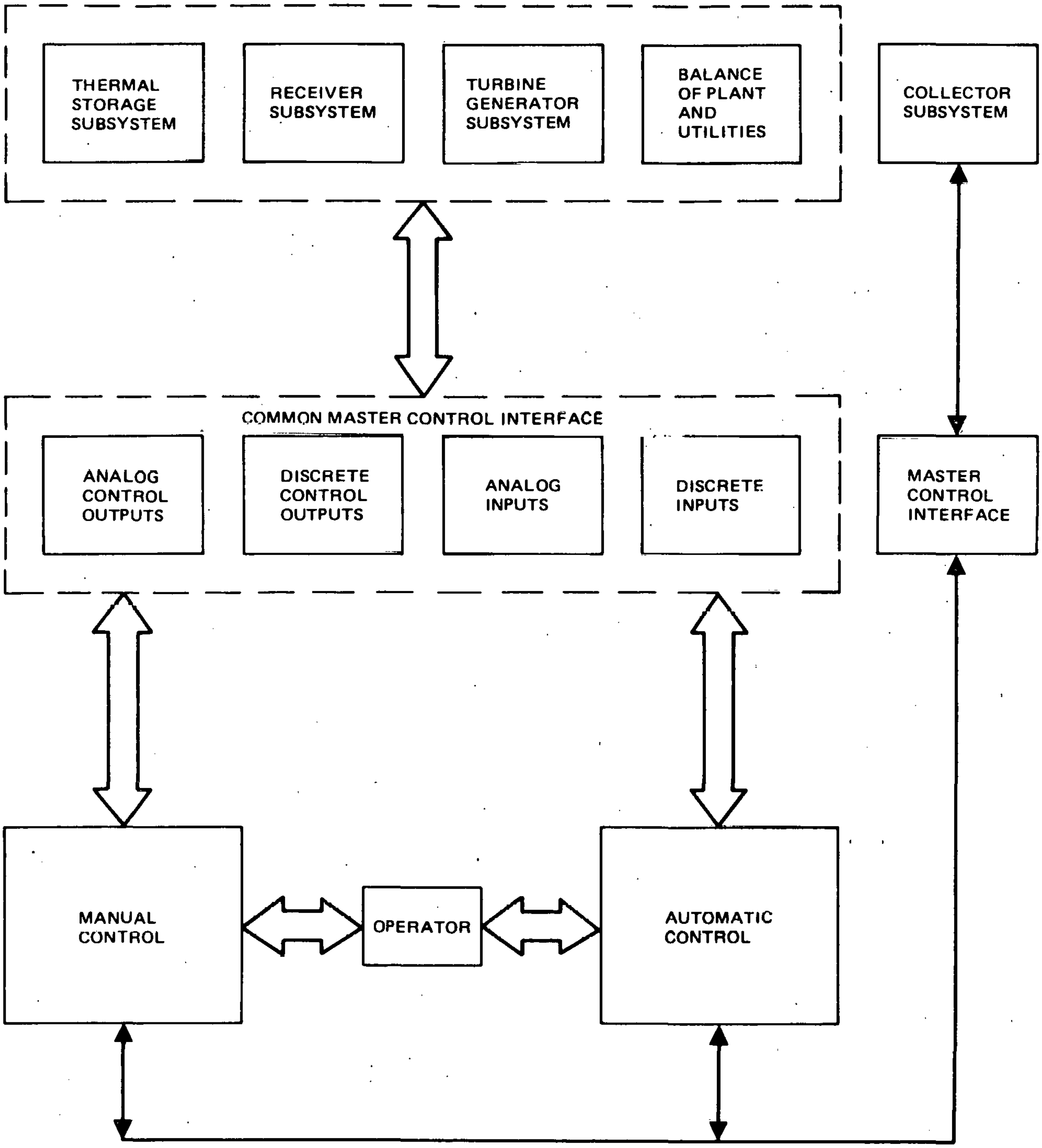


Figure 6-15. Overall Master Control to Subsystem Interfaces

6.5.1.1 Development and Expansion Flexibility

The design of master control includes the characteristic to expand, develop, change, and modify the control concepts without making major changes within master control. To accomplish this, flexibility is incorporated into interface types and designs between master control and the subsystems to allow for expansion and control configuration changes. The overall master control hardware configuration is shown in Figure 6-16.

For example, all field wiring to master control from the receiver, thermal storage, turbine generator, balance of plant, and utilities share a common interface with the manual and automated control subsystems. Consequently, new additions, modifications, deletions, and changes to control and instrumentation field wiring can be adapted to both the manual and automatic systems of master control quickly and economically. This common interface is accomplished through (1) a common modular switchable control steering logic interface between the computer and the manual control console controlling outputs, and (2) by incorporating modular master patch panels and relay junction boxes to share the analog and digital inputs to master control.

The computer used in automated subsystem control provides flexibility through programming. Expedient changes, additions, deletions, and modifications to the computer control and processing software can be accomplished.

The uniqueness of the collector system operation (i.e., field controller processors communicating with master control) requires a separate interface to master control. The flexible design characteristics within master control that provide latitude in expansion, modification, and change to the collector subsystem control are integral with programming the master control computer.

6.5.1.2 Standardized Subsystem Interfaces

Considering the importance of maintainability when there are several major contractors supplying hardware for the 10-MW_e solar Pilot Plant—coupled with the fact that both automatic and manual facility controls are integrated into the system—the MDAC approach to master control requires a high

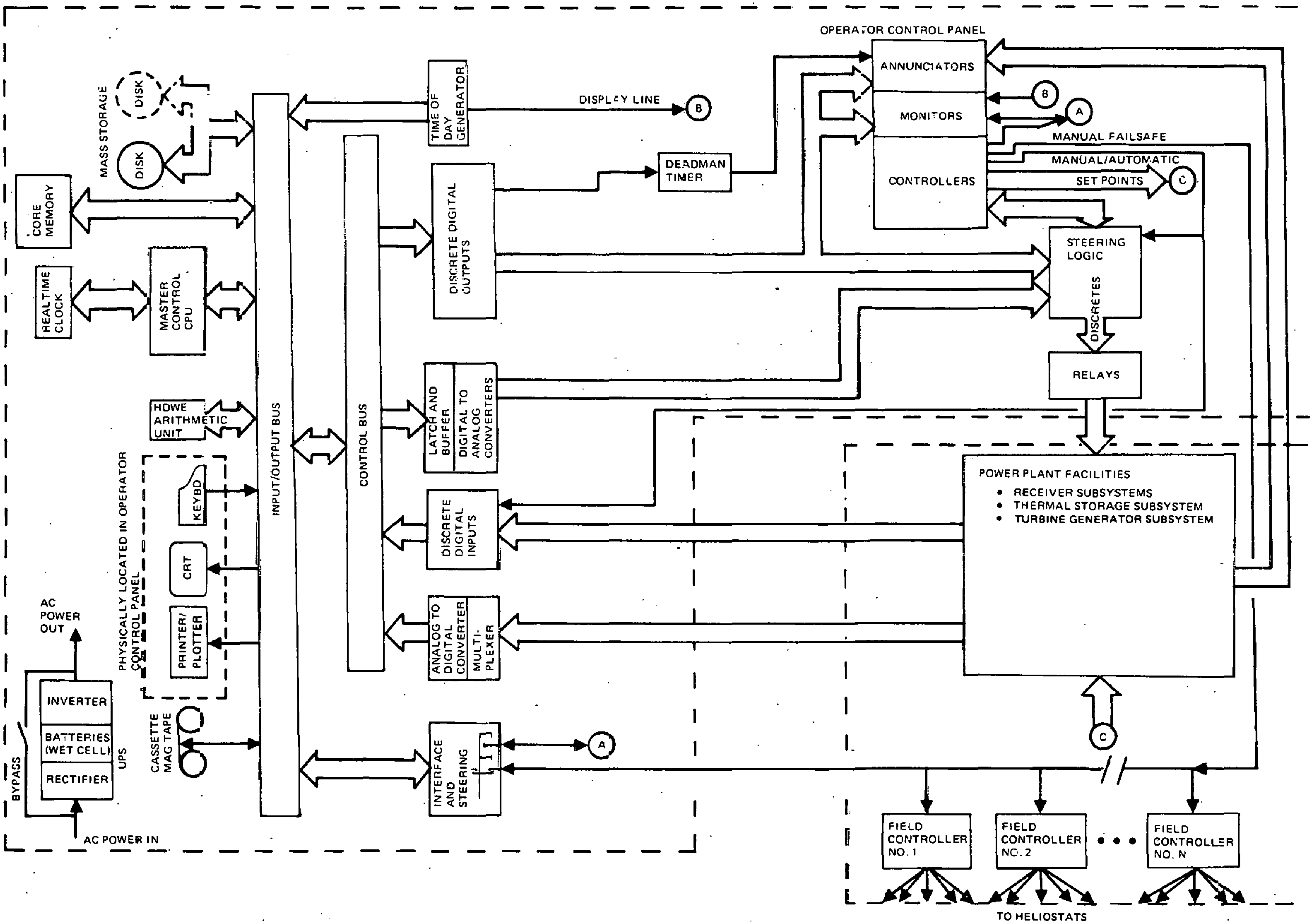


Figure 6-16. Master Control Hardware Configuration

degree of hardware standardization. Compatibility of control signal and instrumentation signal levels with all subsystems is paramount. Cabling types, controllers, equipment bays, monitors, displays, and wire connectors must be standardized in master control where practical. A block diagram of a typical subsystem (turbine generator) is shown in Figure 6-17.

This philosophy is also carried through regarding human interfaces. The computer programmers interface with the computer for the development and modifications of applications software through an industry-standard, high-level, machine-independent programming language (Fortran IV). The operator interface with the computer is designed to provide a standard question-and-answer type of vocabulary. Control switch types, placements, and locations of elements on the control console follow standard guidelines.

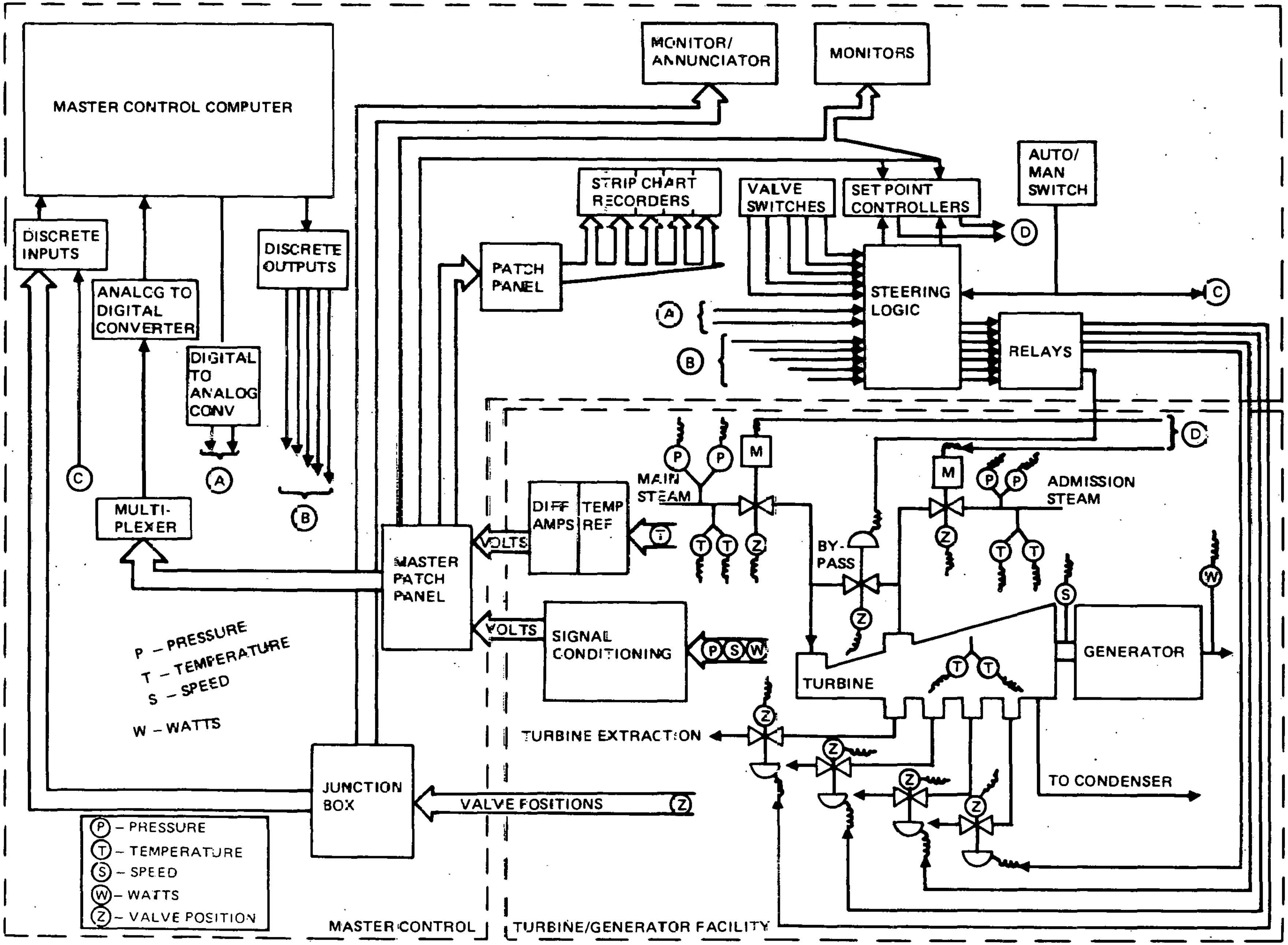
6.5.1.3 Use of Commercial Hardware and Software

Where possible, standard off-the-shelf hardware and software are used in master control. The components and equipment are of commercial quality. Custom designs (i.e., steering logic interface and the collector subsystem interface) also use commercial-grade components.

6.5.1.4 Single-Operator Interface

Both manual and automatic modes of plant control and operation are designed into one master control console. The console shown in Figure 6-18 houses all of the elements needed to control the plant. It is engineered for single-operator use with visibility and reach such that the operator can be seated at all times.

The computer, patch panels, recorders, and free-standing equipment not required for the continuous observation and control of plant activities are located in close proximity to the control console. These devices require the operator to move away from the control console when they need attention yet they are located where the console is in his complete view.



Figu ‾ 17. Block Diagram of Turbine-Generator Subsystem

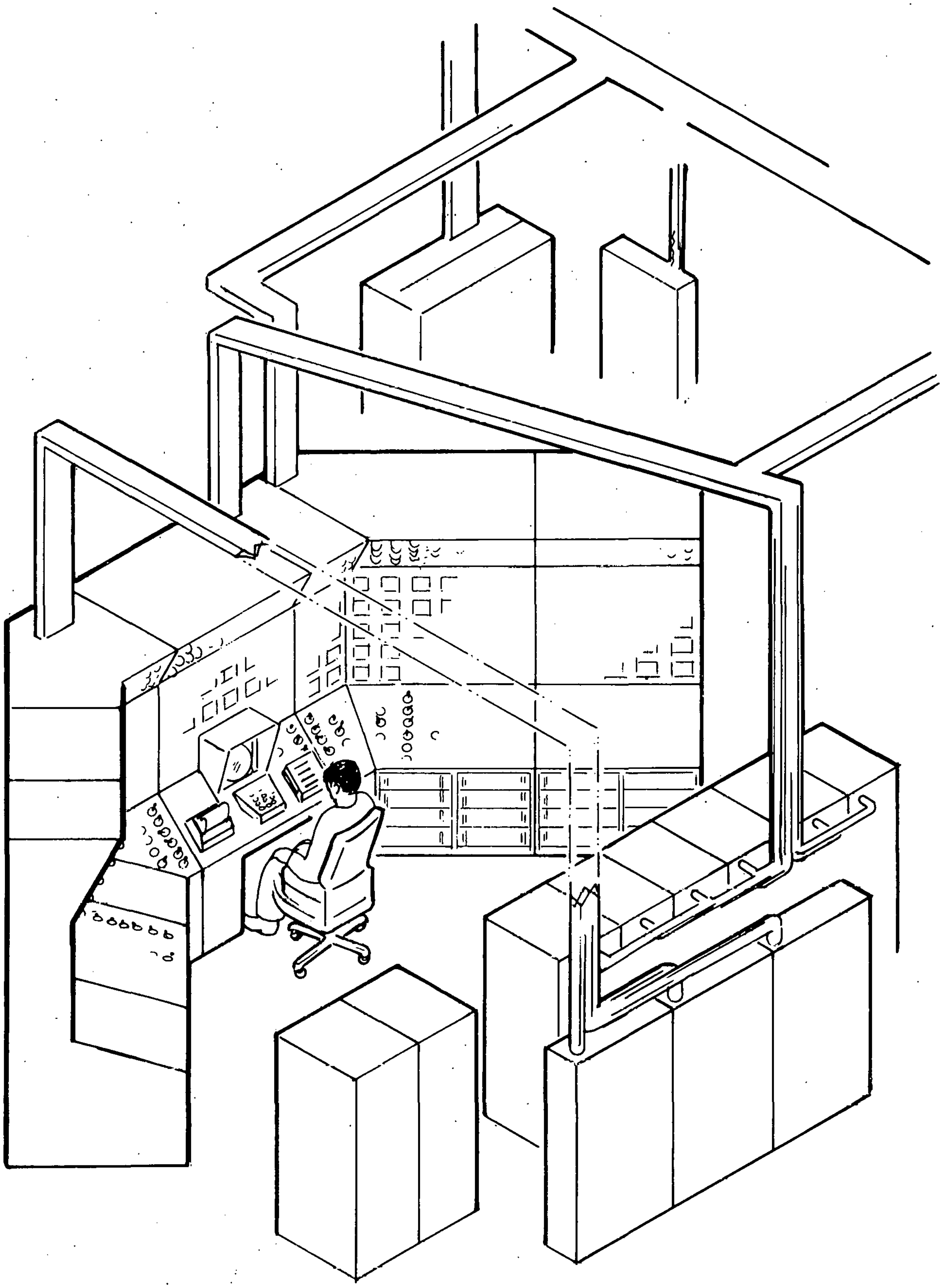


Figure 6-18. Central Master Control Console

6.5.1.5 Minimal Redundancies and Duplications

Master control design is characterized by the common interface shared by the manual and automatic control system hardware. This interface eliminates the dual set of field wiring commonly used when two types of control (i.e., manual and automatic) are employed. Instrumentation provisions used in plant control and monitoring are only duplicated where required for plant and personnel safety. Isolation and buffer amplifiers, together with multipole relays, provide the isolation and capacity to direct the bulk of signals to the control console, computer, and analog recorders.

6.5.1.6 Fail-Safe Systems

Fail-safe systems incorporated into master control design provide the operator with the capability to: (1) maintain continuous electrical power for the duration required to safe the plant from the control console in the event of a power failure, (2) fail-safe the collector system from a single switch, and (3) make emergency transfer control from the automated mode to the manual mode when the computer fails.

An uninterruptible power source (UPS) supplies AC power to master control and all of the critical subsystem control elements in the event a power failure occurs. This equipment is designed to maintain sufficient power from lead-calcium batteries to operate for a period estimated at one-half hour.

A "deadman" timer is used in conjunction with the computer and the automatic control and monitoring modes to alarm the operator of a computer failure. An emergency transfer switch on the control console switches steering logic control from automatic to manual. Under normal operations, an operator-computer protocol, followed by a multiswitch operation, is required to transfer from manual to automatic and vice versa.

6.5.1.7 Conventional Power Plant Operating Concepts

From the power plant operation point of view it is important that deviations from existing power plant operating concepts be minimized. Because the primary man-machine interface is at master control, the MDAC design carries forth where possible the types and locations of devices and methods of operating in the master control architecture with which power plant operators and engineers are familiar. The benefits in the approach are self-evident.

The control console is engineered to group the annunciators, monitors, and controllers in the patterns most familiar to electrical plant operators. Illuminated status boards are of the same type used in power plants.

Equipment types (i.e., meters, recorders, switches, and light displays) are of the types used in power plant control where possible.

6.5.1.8 High-Level Language Software Generation
Plant control applications programs, data-reduction programs, and self-test/diagnostics routines are written in Fortran IV, a conversational high-level language. Although this is a design characteristic that is prominent throughout the computer programs, exceptions are necessary where throughput is crucial to performance. For these special cases, assembly language coding obtains the needed results.

6.5.1.9 Self-Test and Diagnostic Tools
The control computer performs tests of master control components and signal paths. The analog-to-digital converters (ADC), digital-to-analog converters (DAC), discrete inputs, and outputs are tested by the computer. Linearity, offset, and full-scale tests are performed by the computer on the ADC's and DAC's. Signal simulation hardware is connected to the discrete inputs and monitored by the computer tests functional operation of the discrete inputs. Discrete output commands from the computer are monitored by circuits and displayed in the steering logic chassis.

The steering logic design includes diagnostic test hardware features that provide the operator with the capability of locally diagnosing and isolating switching path problems. This diagnostic hardware is also used in conjunction with the computer or the control panel to monitor individual discrete output functions.

Collector system field controllers loops are tested by master control computer software diagnostics. Test word patterns are sent to each field controller and transmitted back to master control to determine operational status.

The control console uses lamp test features for the annunciators and status board displays to diagnose light failures.

Millivolt references and electrical substitution calibrations are monitored and interpreted by the master control computer and serve in diagnosing sensor, signal conditioning, and instrumentation field wiring troubles.

Programs furnished by the diagnostic computer manufacturer are used to test the computer and computer peripherals.

6.5.2 Computer

The computer system integrated into master control is an off-the-shelf commercial computer, specifically tailored for industrial process control applications. The computer architecture uses a common bus concept as illustrated in Figure 6-19. Within this concept a family of peripheral devices is connected to the central processing unit and all other devices via the bus. Features of the master control computer include:

A. Single and double operand instructions.
B. Hardware multiply and divide instructions.
C. Floating point hardware.
D. 16-Bit word size.
E. Direct addressing of 32K words.
F. Parity detection on each 8-bit byte.
G. Hardware address expansion and protection allowing memory addressing to 124K words.
H. Word or byte processing.
I. Asynchronous operation.
J. Direct memory access for multiple devices.
K. Four-line, multilevel automatic priority interrupt.
L. Vectored interrupts.
M. Power fail and automatic restart.

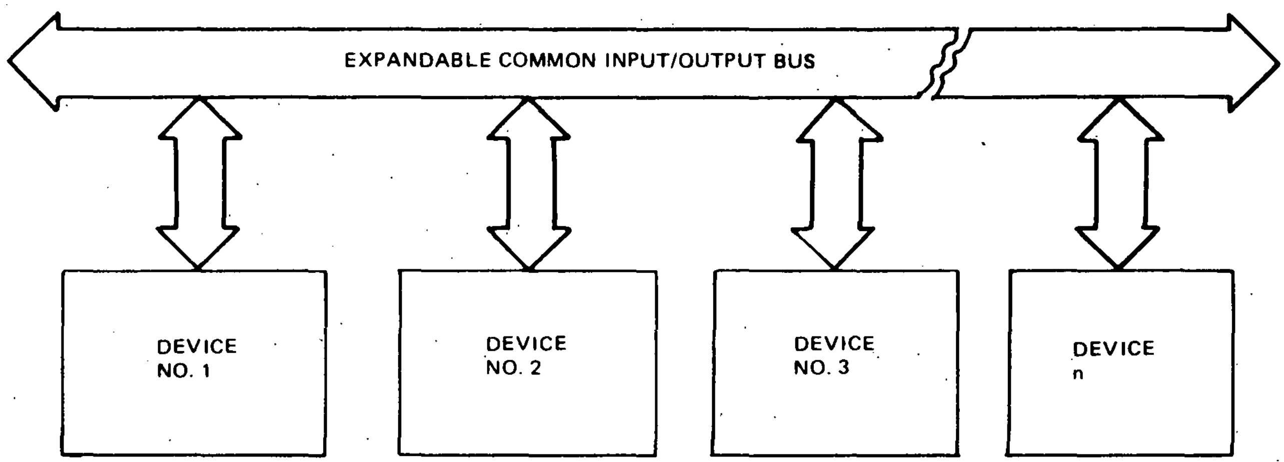


Figure 6-19. Master Control Computer Architecture

N. Cycle time of 1.0 microseconds.

O. Average instruction execution time of approximately 4 microseconds.

The computer CPU, memory, power supplies, and space for standard peripheral devices are housed in a 10 1/2-in. chassis that mounts in a standard 19-in. cabinet.

Important to the control of the power plant processes using master control is the bidirectional asynchronous communications concept of the computer. Each device on the bus can send, receive, and exchange data independently without processor intervention. For example, the printer/plotter can obtain data from a disk file while the CPU attends to other tasks.

A hardware "bootstrap" allows the operator to bring the computer up from a single instruction keyed in from the front panel.

6.5.3 Peripheral Equipment

The master control computer has standard peripheral devices supplied by the computer manufacturer and nonstandard peripherals furnished by MDAC and others.

A block diagram of the master control computer hardware configuration is shown in Figure 6-20.

6.5.3.1 Standard Peripheral Equipment

All of the standard computer peripheral devices used in master control are supplied by the computer vendor. Consequently, maintainability is simplified and the task of writing software to support the peripherals is reduced.

Keyboard/Printer

The keyboard/printer is the device used by the operator for bidirectional communications with the computer and the control and data reduction applications software. All program messages are printed on the equipment. The device is also the primary programmer tool for entering program code and performing system builds and software checkout.

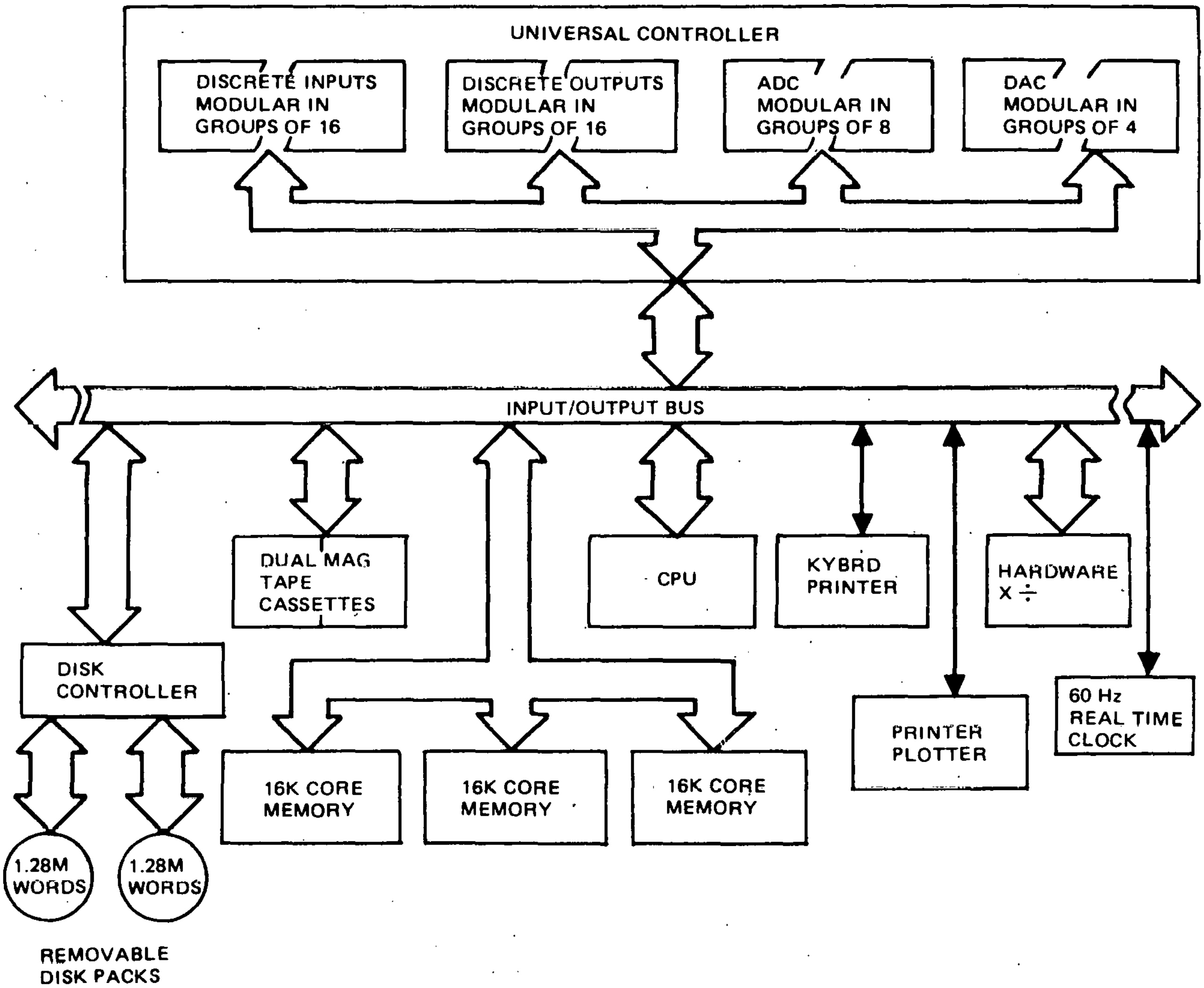


Figure 6-20. Master Control Computer Hardware Configuration Block Diagram

The keyboard/printer contains 128 ASCII upper- and lower-case character set with 95 printable characters. The equipment operates over a serial full duplex line, interfaced to the computer bus, and prints at the rate of 30 characters per second.

The device is located in the master control console.

Disk Mass Storage

Two mass storage devices are used by the master control computer to store the operating system, compilers, utility programs, application programs and routines, and data collected from power plant instrumentation.

These disks are the moveable head type and use removable disk cartridges that store up to 1.2 million words each, or a total of 2.4 million words of data storage.

Average access time is 70 milliseconds and transfers at rates up to approximately 90,000 words/second can be achieved. The system provides accurate data transfers by means of hardware write check and check-sum functions.

These devices are located in the same equipment bay that houses the CPU.

Printer/Plotter

The printer/plotter is a high-speed electrostatic device and is used in the system to print the individual status of each device as well as all of the measured parameters. The equipment also plots historical data used by engineers in analyzing plant performance and operation.

The printer/plotter uses the entire ASCII character set and prints 132 columns per line at 500 lines per minute. In the plotting mode, the printer/plotter outputs up to 122,880 dots per second with a resolution of 1,024 dots per line.

The equipment is located in the master control console.

Dual Magnetic Tape Cassettes

Two magnetic tape cassettes are incorporated into the master control computer configuration to provide a media for (1) storing information to be processed by other computer systems, (2) storing programs and routines as backup to the disks, and (3) providing the basic media input from other sources.

Maximum capacity of each tape is 92,000 bytes. Data are stored in a single bit-serial track form and are sequentially recorded and retrieved as in conventional magnetic tape systems. An average read and write speed of 9 in./sec and a search speed of approximately 22 in./sec are tape-motion characteristics of the recorders.

The two drives run not simultaneously and use Phillips-type cassettes.

The equipment is located in the computer system bay housing the CPU and disk drives.

Floating Point Hardware

A floating point processor is included in the peripherals of the master control computer. The device serves to replace the software floating point techniques commonly used and provides high speed in the execution of arithmetic operations. Consequently, conversions of raw digital data to meaningful engineering forms are accomplished many orders of magnitude faster over the software method, freeing the computer CPU for longer periods of time to do high-priority functions.

The floating point processor features both single and double precision (32 or 64 bit) floating point modes.

The equipment is located in the CPU chassis.

Hardware Multiply and Divide

Integer multiplications and divisions are performed by the hardware multiply and divide element. The device, interfacing to the bus and located in the CPU chassis, performs these operations in approximately 6 to 7 microseconds.

Real-Time Clock

A 60-Hz real-time clock is used by the computer under interrupt control and in conjunction with the system and applications control software to time out operations and program action delays. The device is integral to the CPU and is located in the CPU chassis.

6.5.3.2 Nonstandard Peripherals

Two special-purpose devices are connected to the master control bus that are considered computer peripherals: (1) the time code generator, and (2) the collector subsystem field controller interface. Both devices use the computer bus logic and software systems communications protocol.

Time Code Generator

Time of day (IRIG-B format) is recorded for each control event. The master control computer extracts the day, hour, minute, and second in parallel BCD form.

A time code translator is also connected to the generator unit and displays time of day at the master control console. The time code generator is located in an equipment bay adjacent to the computer. Resets and synchronization are done manually from the front panel of the generator.

Collector System Field Controller Peripheral Interface

The master control computer and the control console communicate with the collector subsystem field controllers and heliostats through the field controller peripheral interface. This equipment, of MDAC design, formats and structures the inputs and outputs to the computer, checks each transmission for errors, codes and decodes data commands, and displays inputs from the operator console and provides logic and communications compatibility with the computer and field controllers. A layout of the manual controls located in the control console is shown in Figure 6-21.

The equipment is located in a chassis mounted in an equipment bay adjacent to the master control computer CPU.

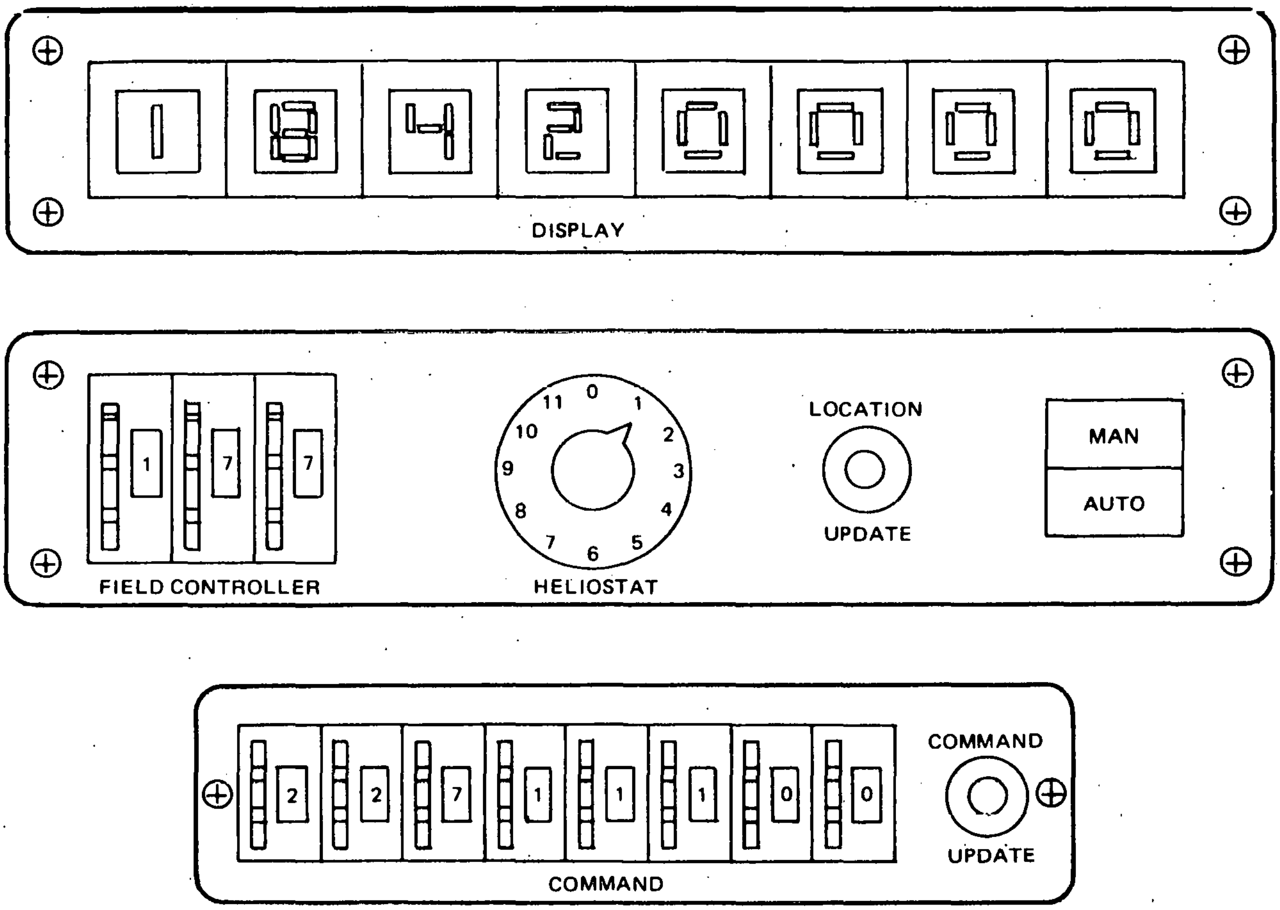


Figure 6-21. Master Control Console to Collector Field Controllers

6.5.4 Control Panels and Equipment

Master control (see Figure 6-18) uses a custom central control console concept, designed to facilitate the control and monitoring of plant operation by one operator.

Control panels in the console contain three sections for each subsystem: annunciator, monitor, and control.

Access to wiring and power is provided from the backthrough full-length doors. Power circuits and protection is accomplished at the rear by using power strips and a main circuit breaker for each cabinet with separate circuits and breakers for each section.

In addition, the equipment needed by the operator to communicate to and from the computer is integrated into the control console along with a time-of-day display from the time code generator.

6.5.4.1 Annunciators

The annunciators in the control panel, located slightly above normal eye level, display alarm status for each subsystem. Each annunciator is of a standard size and shape and illuminates when displaying the alarm condition. An English language descriptor, etched or printed on the face of the illuminating portion of the indicator, identifies the annunciated function when lit. An example of a portion of an annunciator panel is shown in Figure 6-22.

Each subsystem annunciator panel contains a lamp test feature, activated manually from a switch.

6.5.4.2 Monitors

Wide latitude is provided in the design of the monitor section of each subsystem module considering the variations in the types and numbers of control-monitoring devices associated with the subsystems. The monitor sections are located at eye level and grouped within the section by function. Gages and meters make up the monitors and, where possible, the meters and gages display the functions in engineering units.

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6.5.5.1 Steering Logic

The steering logic, located in the control console, provides the control signal paths from the computer and control console to the discrete control functions and from the computer to the set point controllers in the control console for the set point command.

The auto-manual switch, in conjunction with the run button, switches the signal paths in the steering logic from manual signal inputs to computer signal inputs. Front panel lights and switches are used to diagnose steering logic availability and assist the operator in systems checkout with the computer.

6.5.5.2 Master Patch Panel

A master patch panel in master control is used to patch instrumentation inputs from the subsystems to the computer, control console, and analog recorders. The panel is the fixed-board type and uses isolation amplifiers for patching a single analog signal to multiple points.

Where critical control points use redundant feedback transducers, one transducer input is patched to the control console and the redundant measurement to the computer. Flexibility in using the patch panel allows the operator to switch the duplicate transducer inputs between monitor points when a transducer problem occurs or maintenance of one transducer system is required.

The ancillary instrumentation, that instrumentation used for plant monitoring, which is not crucial to the plant operation and not a redundant measurement, is patched to the computer or the control console. Any 32 measurements can be selected to be patched to the analog recorders and one of the other data input points (i. e., computer or control console).

6.5.5.3 Relay Junction Box

A relay junction box, located in master control, distributes the discrete input functions to the computer and control console. Multipole relays route inputs from common subsystem field wiring to the equipment and systems in master control.

6.5.5.4 Analog Recorders

Four 8-channel analog oscillographic recorders in master control allow the engineer and operator to continuously look at any 32 instrumentation signals at chart speeds up to 200 MM per second. Each recorder is equipped with an amplifier per channel that provides span control, zero control, and calibration features.

An auxiliary patch panel allows the operator to patch the input channels to the recorder of his choice.

6.5.6 Software

Automatic control of the power plant operation depends upon the computer programs of the master control computer. The software is designed to the requirements and contains the logic to monitor and control the solar plant automatically. The software is designed and developed in a highly modular structure to allow for additions, changes, and growth. Programming and coding standards are followed to ensure production of cost-effective, well-documented software.

Most importantly, the software design adheres to a concept established by the operating concepts, which is to maintain a highly visible man-machine interface that is easy to use and simple to understand. The software is designed and coded so that the solar plant engineer can understand the software operation and the logic that contains with a minimum of training. This approach is necessary so that the users of the automatic control system can have confidence in the software and sufficient knowledge to react to anomalous situations.

6.5.6.1 Software Types

The total software for the power plant is composed of five classes of computer programs: (1) development, (2) real-time system, (3) application, (4) maintenance, and (5) integration and test.

Development Software

This software is necessary to produce the remaining four classes of software. It is purchased as part of the computer system and delivered by the computer vendor as operational programs. The major programs of the class are as follows:

A. Batch Operating System. A computer operating system that allows the computer to be used as a support processor to execute all the remaining computer programs of this class.

B. Text Editor. A program that allows creation and alteration of source language programs.

C. Assembler. A program that accepts computer code in assembly language mnemonic form and outputs object code ready for insertion into the computer.

D. Compiler (Fortran IV). A program that accepts computer code in Fortran statements and outputs object code ready for insertion into the computer.

E. Debug Assistance Program. A program that allows controlled execution of other computer programs to enable debug. Such features as dumps, traces, breakpoints, etc., are capabilities of the program.

Again, the above software is delivered as part of the computer system and does not require effort to create it or make it operational. Its purpose is to provide the necessary development tools to allow creation of the software that will actually control the power plant operation.

Real-Time System Software

This software is delivered by the computer manufacturer. It is the main controlling software that is resident in the computer at all times. It provides the main supervisory functions for all application programs. The basic software, purchased from the computer vendor, requires a minimum of adaptation to meet the requirements of solar power master control. The major components are as follows:

A. Real Time Executive. Supervises all real-time operations scheduling and controlling program execution.

B. Input/Output Controller. Supervises program handling all computer communication with peripheral equipment and solar plant devices.

C. Interrupt Processor. Reacts to and determines source of all interrupts and takes action indicated by source.

D. Loader Program. Works to load programs, mainly application, into computer memory and resolve all addressing before execution begins.

E. Display Controller. Provides the communication control with the display CRT device. Much of this program is created especially for the solar application.

F. Data Recording Routine. Records selected data for historical purposes. It is specialized to the needs of solar power and the data formats generated by the sensing devices.

G. Data Retrieval Conversion Program. Converts all data as input to the computer from the external devices into engineering units. The program is peculiar to solar power.

H. On-Time Control Routine. Corresponds with the operator and decodes and encodes messages. It is peculiar to the solar power operation and contains many special-purpose messages and specialized operator control features.

I. Functional Control Routines. Control the plant through such routines as ones to close valves, open valves, establish set points, read temperatures, read pressures, etc. Any function that must be done on a repetitive basis will be incorporated into a subroutine. The application programs make extensive use of the subroutines to provide automatic control over all plant operations.

<u>Application Software</u>

This set of software programs is written specifically to control plant operations. The programs contain all the logic and intelligence to sense plant operation and make decisions to effect plant control. It is all tailored to the solar application and is designed and coded by MDAC.

The application software will be coded in a language and under a set of rules specific to solar power. The coding is done in a form of high-level language using verbs that are descriptive of the action to be performed. For instance, to open a valve, the coder would write

OPENVALV V1

where V1 is a unique schematic identifier of the valve to be opened. A whole set of action verbs are defined for the coding language to be used in the application programs. Examples of several are as follows:

Code Verb	Action
CLOSVALV	Close Valve
OPENVALV	Open Valve
SETPOINT	Establish Set Point
READTEMP	Read a Temperature
READPRES	Read a Pressure
TEST	Conditional Branch Statement
GOTO	Unconditional Branch
DISPLAY	Output Message to Operator
LOAD	Load a New Application Program
DELAY	Delay Program execution
EMER	Execute Emergency Shutdown Routine

The coding language is designed to be easily read and understood, or self-documenting. The language does not require a computer because the language is formed using the macro capability, resulting in the assembler program, which is a vendor-delivered software item. Use of the macro assembler provides an easy and effective means of generating a complete language for the solar power control. Each macro defined produces an object code that calls one of the functional control routines, described previously.

The application programs that are generated using the control languages are as follows:

A. Startup. Accomplishes the plant startup operation at the beginning of each day.

B. Shutdown. Accomplishes the plant shutdown operation at the end of each day, or whenever necessary.

C. Normal Power. Maintains plant operation once startup is complete, and it is desired to operate in the normal power mode.

D. Intermittent Cloud. Maintains plant operation in the intermittent-cloud mode of operation.

E. Low Solar. Maintains plant operation in the low solar mode of operation.

F. Extended Operation. Maintains plant operation in the extended-operation mode.

G. Thermal Charge Only. Maintains plant operation in the thermal charge only mode.

H. Fully Charged Thermal Storage. Maintains plant operation in the fully charged thermal storage mode of operation.

I. Heliostat Control. Maintains control and communicates with the field controller computers of the heliostat field.

J. Emergency Shutdown. Performs an emergency shutdown of the plant operation.

K. Mode Transition Programs. Facilitate movement from one mode of plant operation to another. The type mode transition will select the proper mode transition program.

Maintenance Programs.

These programs do not run in real time and are not involved with direct control of plant operations, but are required to process data necessary for master control operation. The programs are as follows:

A. Data Reduction Program. Processes the history data which has been collected and stored during plant operation. It reads the data, formats it, converts it to engineering units and outputs to a printer, plotter, strip chart, or other display device.

B. Data Description Program. Maintains a file of information describing all the sensing and control devices on the power plant that are connected to master control. Such data information as the following are maintained:

1. Eight-character unique identifier.
2. Type of device.
3. Patch panel location.
4. Nominal value position.
5. Nominal range of sensor.

C. Calibration Program. Maintains data upon the calibration information for all sensing and control devices. This program computes calibration constants to be used during real time to convert sensor and control device analog voltage information into engineering units for display or application program usage.

Integration and Test Program

This is a program that serves a two-fold purpose: (1) to serve as a software program that aids in the integration of hardware and software during equipment buildup of the master control equipment, and (2) as a self-test program to be used to test the integrity of the master control system on a daily basis. The program is written in the control language of the application program, the patch panels back to the computer as a sensor input. In this manner, the master control computer tests the integrity of all circuits and hardware logic paths under its control. Such a program eases and expedites the integration period of hardware and software. Also, the software maintains a useful purpose and becomes a cost-effective software program as time and system usage progresses.

6.5.6.2 Software Operation

The real-time system software is the supervisor controlling all master control automatic functions. Its principal function is to allocate time to the execution of memory resident application programs.

Normally three application programs will be memory-resident at once, although all are available on disk. Those resident will be as follows:

A. Emergency Shutdown.
B. Safety Item Monitor.
C. A Mode Control Application Program, such as Normal Power.

The real-time executive allocates an amount of processing time in a round-robin fashion to Programs 2 and 3 of the list. The amount of time allocated to each program is a variable that can be adjusted by operator or automatic control, depending upon the circumstances. The emergency shutdown program is only executed if needed, but is kept memory-resident so that immediate response can be maintained.

In addition to the application program control, the real-time executive is performing a periodic function that is to keep a memory-resident data base updated to the latest state of all power plant sensing or control devices.

Internal to the computer is stored all the data concerning the status of each sensing and control device, including operator annunicators and switches. The information is kept in a specific area of memory and is updated at least every 2 sec. Thus, within each 2-sec period, the real-time executive has sampled all sensing devices. The state of control devices, such as valves, is normally updated when the application program creates a change of state. When a state change is requested, the real-time executive automatically monitors the control device to ensure that it responds as directed. If a failure occurs, an error alarm is indicated to the operator and a control flag set for the application program. It is also possible to command sample the state of all control devices and store the state in the memory data base. This function is performed at the beginning of plant startup to establish conditions for computer control.

The remaining principal functions being performed by the real-time executive are the periodic recording of history data and the processing of external interrupts. The recording of history data is under control of the operator or the application program. Variations can be selected in the period of recording and the parameters being recorded, or recording can be totally suppressed. Interrupts normally take priority over any other processes occurring, but that can also be controlled. Normally, interrupts will occur as a result of input/output operation. The real-time executive processes the interrupt upon its occurrence, which normally takes only a few milliseconds. One function that is processed as a result of interrupts is the heliostat control program resident in the real-time system. An interrupt from the field controllers indicates a need for service which then causes the real-time executive to schedule the heliostat control program for execution. The servicing of this interrupt could possibly take priority over all other functions being performed by master control with the possible exception of the emergency shutdown program.

The foregoing description has applied to the operation occurring inside the computer in the automatic mode. If the manual mode has been selected and the computer is still active, the computer continues to perform all functions except execution of the resident application programs, although the operator could select to maintain computer execution of the safety item monitor and emergency shutdown programs. This allows him manual control over plant operation, but provides computer assistance to monitor instrumentation and alarms the operator of out-of-tolerance conditions.

6.5.7 Control Wiring

Control and instrumentation wiring forms a significant expense to install, check out, and maintain for the large number signals required for plant control and development. Therefore, it is necessary to standardize the wire types where applicable and provide accessibility for change and maintenance.

6.5.7.1 Field Wiring

Control and instrumentation field wiring for all subsystems except the collector is routed to master control through common redwood-covered precast concrete trenches. Collector subsystem wiring, because of long distances, is buried.

Twisted-pair shielded wire, of a common size and in jacketed and shielded bundles, is used throughout. The wires are terminated at the signal conditioners and master control in screw-type terminals and terminal strips. All power cables are routed in separate trenches.

6.5.7.2 Master Control Wiring

Control and instrumentation wiring within master control is routed to the cabinets and equipment through open, suspended cable trays. Twisted-pair shield wire and wire bundles of the same type and size are used throughout, along with screw terminals and terminal strips.

6.5.8 Special Test Program Instrumentation and Equipment

Instrumentation provided for the 10-MW pilot station interfacing to master control is supplied by the contractors for each plant subsystem. An estimate of the quantities and general types is shown in Table 6-5.

Table 6-5

SPECIAL TEST INSTRUMENTATION ESTIMATE

	Digital	Analog
Receiver		
Motor Valves (On-Off)	2	0
Temperature Sensors/Control	0	46
Pressure Sensors/Control	0	22
Flow Meters	0	0
Level Detectors	0	1
Thermal Storage		
Motor Valves (On-Off)	4	0
Modulating Valves (Continuous)	0	0
Temperature Sensors/Control	0	17
Pressure Sensors/Control	0	3
Flow Rate	0	0
Level Detector	0	1
Speed Sensors/Control	0	0
Turbine Generator		
Motor Valves (On-Off)	2	0
Modulating Valves (Continuous)	0	0
Temperature Sensors/Control	0	45
Pressure Sensors/Control	0	0
Speed Sensors/Control	0	0
Generator Output/Load	0	0
Balance of Plant		
Motor Valves (On-Off)	0	0
Modulating Valves (Continuous)	0	0
Temperature Sensors/Control	0	1
Pressure Sensors/Control	0	2
Flow Rate/Control	0	0
Level Detectors/Control	0	0
Speed Sensors/Control	0	1
TOTALS	8	139

Master control interfaces to subsystem instrumentation through the signal conditioning and field wiring into the patch panels and display/readout devices.

6.5.8.1 Instrumentation Signal-Conditioning Characteristics

All of the signal-conditioning and instrumentation power supplies associated with the subsystem instrumentation are located as closely as possible to the sensors but in central locations. Low-level (millivolt and microvolt) signals are transmitted to the signal conditioning over relatively short distances with this arrangement. From the signal conditioning to master control all instrumentation signals are high level (Volts) and at a common full-scale output (i.e., ± 10V). This requirement reduces the noise problems often associated with transmitting low-level signals long distances and provides common and standard readout and display interface solutions for master control. A block diagram of the plant instrumentation system is presented in Figure 6-23.

Signal conditioning, although it varies with the transducers selected, conforms to the following guidelines where possible:

A. All voltage measurement inputs to master control are Volts level.
B. All measurements are represented by DC voltages.
C. All signals are differential.
D. Remote automatic calibration or references are provided in the signal conditioners.
E. All measuring systems (i.e., sensor and signal conditioner) use shielded wires and cables.

6.5.8.2 Instrumentation Field Wiring and Patch Panel Characteristics

Field wire from the signal conditioners to master control is of one specification where possible. For the most part, these wires are twisted-pair shielded wires grouped in jacketed and shielded covers. Barrier strips and screw terminals interface the instrumentation field wiring to the patch panels.

Instrumentation wiring within master control is of the same specification and type as used in the field. Terminations of the wires are via screw terminal strips.

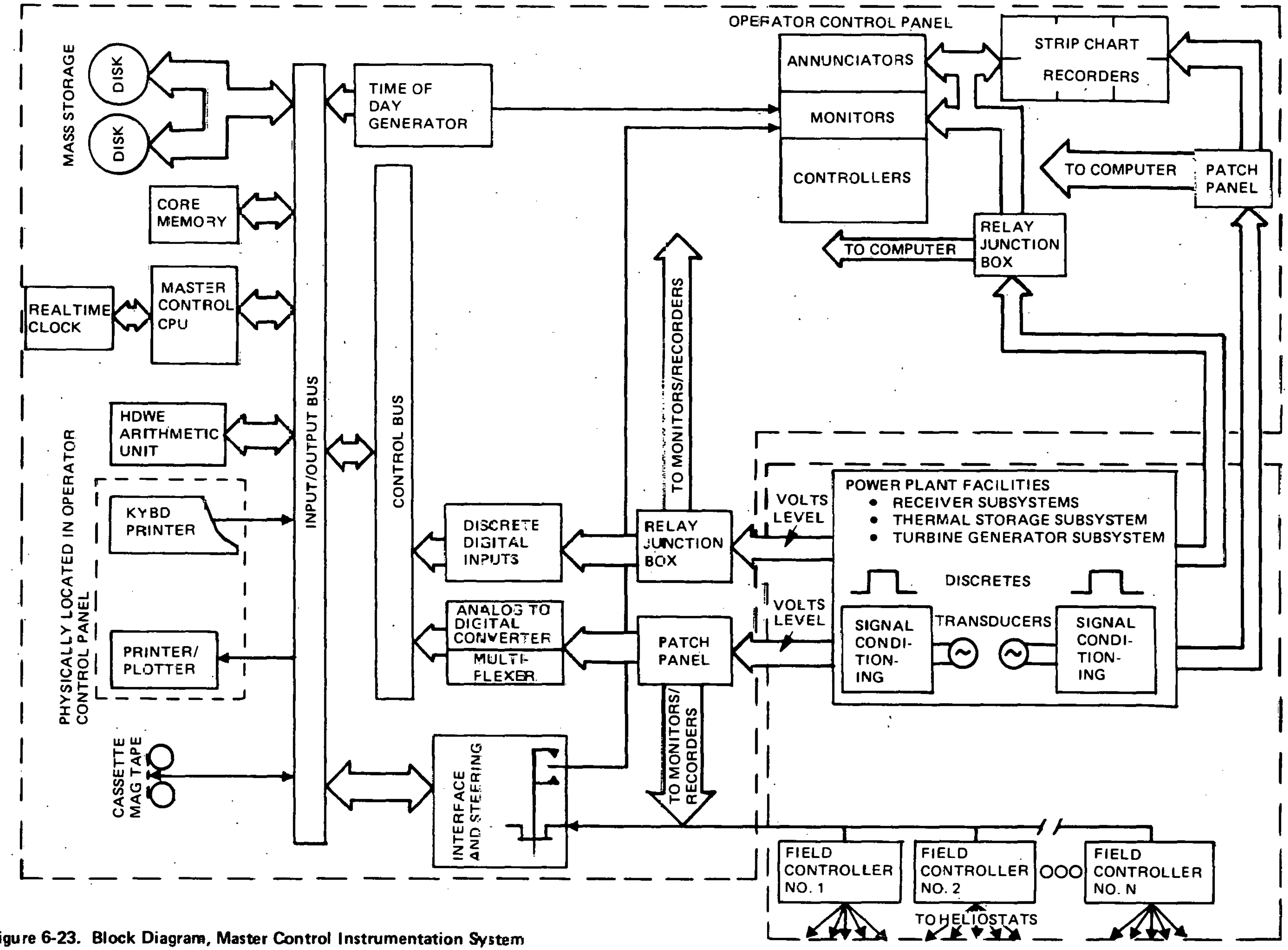

Figure 6-23. Block Diagram, Master Control Instrumentation System

The field wiring terminates in master control at the master patch panels. From these panels, the measurement signals are patched to the control console, computer, and analog recorders. Buffer amplifiers are used in the patch network where required to provide proper isolation between equipment.

6.5.8.3 Instrumentation Readout Display Devices

Three types of instrumentation readout and display devices are used in master control. When operating in the manual mode, the operator uses analog meters and displays at the control console for monitoring instrumentation of the subsystems. He depends on the printer/plotter to provide instrumentation readouts and graphs when monitoring instrumentation while in the automatic mode of operation. The analog recorders provide continuous monitoring of selected analog instrumentation when operating in either the manual or automatic mode.

6.6 OPERATING CONCEPTS

The operating concept of master control provides the operator with (1) a choice of modes to operate in, (2) centralized operations in one control console, and (3) changeability, expandability, and flexibility during plant operation development phases.

Master control allows for three basic operating modes: manual, automatic, and manual control supported with computer monitoring and alarm. For each mode, master control is designed for a single operator concept.

6.6.1 Man-Machine Operating Concept

Master control is designed to provide centralized and easy access to the control, monitoring, development, and troubleshooting of plant operations. The operator, engineer, and programmer use interfaces and concepts designed into master control to simplify these functions.

6.6.1.1 Operator Interface

The operator controls and monitors the plant from the master control console. The level of operator skill required to perform the control functions is equivalent to requirements for conventional power plant operators.

Written procedures walk the operator through each step when in the manual mode and through question and answer English language conversational instructions between the computer and the operator in the automatic mode. A sample of the computer conversational dialog with the operator is shown in Figure 6-24.

The control console layout simplifies the operator interface through the arrangement of subsystem annunciators, monitors, and controllers in a modular grouping using lighted label indicators and switches throughout.

A status board, located in the center of the control console, identifies each sequence of plant operation via lighted label indicators. Whether the operator is in the manual or automatic mode of operation, this panel provides him a display of each sequence when it occurs.

6.6.1.2 Systems Development Interface
Engineers and programmers access master control for development and troubleshooting functions, using built-in hardware and special software.

The programmer uses the keyboard/printer, removable disk cartridges, magnetic tape cassettes, and the CPU front panel switches and indicators to interface with the computer in performing program development functions at the plant site. The development software tools (i.e., compilers, editors, assemblers, etc.) form part of the overall software package stored on disk at all times to provide easy access to modify change and add programs and routines.

Diagnostic tools are built into master control to provide the engineer with convenient monitoring interfaces and simulation hardware for troubleshooting and diagnosing system problems. In addition, software is developed for the computer that automatically tests the functional capacity of the instrumentation, signal paths, control console annunciators, and status board.

Patch panels provide a convenient man interface for adding, deleting, or changing instrumentation signal paths to the computer, control console, and analog recorders.

OPERATOR:	RUN SOL-1	342:08:32:24		
COMPUTER:	RECEIVER WARM START PROGRAM			
	FACILITY STATUS			
	PARAMETER	E,U	VARIATION NORMAL	TOLERANCE
	TS-001	795 F	–325 F	+/– 100
	TS-002	845 F	–275 F	+/– 100
	TS-003	724 PSIA	–726 F	+/– 50
	TS-004	849 F	–271 F	+/– 100
	CONTROL STATUS			
	TSV-1	CLOSED		
	TSV-2	OPEN		
	TSV-3	CLOSED		
	ALL SYSTEMS GO			
	DO YOU WISH TO CHANGE A TOLERANCE VALUE?			
OPERATOR:	YES			
COMPUTER:	WHICH PARAMETER?			
OPERATOR:	TS-003			
COMPUTER:	OLD VALUE WAS +/– 50 PSIA			
OPERATOR TYPES NEW VALUE:	NEW VALUE IS +/– 100			
COMPUTER:	DO YOU WISH TO CHANGE A TOLERANCE VALUE?			
OPERATOR:	YES			
COMPUTER:	WHICH PARAMETER?			
OPERATOR:	TS-301			
COMPUTER:	INVALID NUMBER			
	DO YOU WISH TO CHANGE A TOLERANCE VALUE?			

Figure 6-24. Sample Computer Conversational Dialog

6.6.2 Plant Control Concepts

An operation control mode and maintenance mode make up the two phases under which master control functions. The computer with the control, monitoring, and diagnostic software is selectable and of significant value to support both modes.

6.6.2.1 Operation Mode Concepts

Within the operation mode concept the operator has three alternatives for controlling and monitoring the power-generation facilities: The alternatives are:

- Full Manual Control/Monitor
- Full Automatic Control/Monitor
- Combination Manual Control and Automatic Monitor

Under most conditions of the operating concept, the plant is under fully automatic control and monitoring. However, the alternatives provide flexibility to control and/or monitor with hands on.

Manual Operating Concepts

Prior to sunrise, the operator performs a preshift checkout of the master control console, patch panels, instrumentation, and field wiring and controls. Using written procedures and built-in hardwired diagnostic aids, calibration switches, monitors, and lights on the control panel, the operator completes the preshift checkout step by step.

The current master patch panel patching is checked against the patch list and the continuous recorders are patched to the parameters and readied for operation.

Prior to a manual startup, the operator depresses the manual switch, which (1) signals the computer that a manual operating mode has been selected, and (2) initiates a pulse to switch the steering logic to manual control. Henceforth, the operator controls and monitors the plant from the lights, dials, gages, and displays on the control console.

Automatic Operation

The preshift checkout concept is handled in much the same manner when operating automatic rather than manual. However, the operator can take advantage of the computer capabilities to perform diagnostic tests and monitor control and instrumentation parameters during this checkout. By depressing the automatic switch, the operator signals the computer that the automatic mode has been selected. The computer responds with a dialog on the keyboard printer at the control console, requesting the operator to identify which program he wants to run. The operator types the correct program neumonic, which the computer verifies to him on the keyboard/printer. From this point, the operator and computer are in a question and answer dialog until all of the checkout procedures that use the computer are completed.

Before the operator can start the automatic startup sequence the operator must select the startup program. A dialog between the computer takes place during which time the computer checks all of the plant instrumentation and control element positions and status. These data, printed on the printer/plotter, are compared with norms and tolerances. Anomalies must be corrected before the computer will arm the run switch. Satisfied that the system is ready for a start, the computer acknowledges this fact to the operator via the keyboard printer, arms the run switch (indicated by the arm switch light coming on), and waits for the operator to depress the switch. After the run switch has been depressed, the computer sequences through the startup sequence, printing status, updating the status board, and activating annunciators if required.

When the sequence is complete, the computer acknowledges, requests the operator to input the next program, and disarms the run button. A similar computer-operator dialog is completed, the run button armed and depressed, and the next control sequences are automatically executed.

Should the operator decide to change the mode from automatic to manual or vice versa during a sequence the following procedures are followed:

A. To transfer from automatic to manual the operator communicates with the computer via the keyboard/printer and requests the auto-manual program. The computer now goes into a hold mode (at the end of the current sequence), a short dialog takes place, and the computer outputs all of the command position control data and the latest instrumentation data on the printer/plotter. The computer waits for the auto-manual switch to be depressed after which the run button is disarmed and the operator is under manual control.

A panic switch is provided on the control console to allow the operator to switch immediately out of the automatic mode to the manual mode in the event of an emergency.

B. To go from manual control to automatic control the operator depresses the automatic switch and requests the manual-automatic program via the keyboard/printer. The computer and operator enter into a dialog, at which time the operator identifies the sequence number at which the transfer is to take place.

The computer verifies the request as a legal transfer point, monitors the control elements and instrumentation, and compares to the set of conditions and tolerances for that transfer point. The computer prints all discrepancies and waits until all discrepancies have been satisfied. When discrepancies have been satisfied, the run button is armed, and the transfer is made when the run button is depressed.

The concepts illustrated above demonstrate the protocol and degree of safety used in master control. In summary, the following rules are applied to manual and automatic operations:

A. The plant is either in full automatic control or full manual control and cannot be run with a mixture of automatic and manual control.
B. To go from automatic to manual or vice versa, two switches (MAN-AUTO and RUN) must be depressed to activate the action.
C. The computer arms and disarms the run button.
D. The collector subsystem can run under computer control independent of the control mode status of the remainder of the plant.

E. Manual control of the collector system is independently selected and does not affect the control mode status of the remainder of the plant.

F. The "dead man" timer forces the steering logic to manual and disarms the run switch.

G. A switch is provided to override the automatic mode in the event of an emergency.

H. Automatic operations are programmed as run program tasks.

I. The operator can transfer from manual to automatic only at selected entry points identified by a sequence number.

J. The automatic mode cannot be activated until all of the controlling criteria for the transfer sequence selected have been satisfied.

6.7 PILOT PLANT DEVELOPMENT ACTIVITIES

Production of master control hardware and software follows the classical approach for development of automated hardware/software system. The approach begins by establishment of a set of common requirements for the system. At this stage, and throughout the development period, the master control must always be considered a system and not a set of hardware and a set of software. The latter thought process will lead to development of two diverse pieces of equipment that will not fit together. After system requirements are established, the system design is performed. System design will generate two sets of design specification drawings describing the hardware and the software to be built. At this stage, the hardware and software can be separated to go into actual production and unit testing.

Once unit testing is complete, the hardware and software are integrated under a planned step-by-step approach. Satisfactory completion of all integration testing and demonstration of total system operation leads to the final step, which is hookup of master control to the other subsystems. This integration occurs under a well-planned and established set of test procedures to ensure rapid, efficient, and safe plant completion.

6.7.1 Software Development Approach

The computer software necessary to operate the plant is similar to that developed by MDAC for several automatic checkout systems. The type of software and the development principals involved are not new to MDAC. Our experience has shown the importance of the man-machine interface and of the operator's ability to provide manual control, plus the need to development quality and error-free software.

The software is developed as an integral part of the hardware, and is done by people experienced in developing control system software. The software systems designer designs, develops, and evaluates real-time system software, maintenance software, and integration and test software as required. Application software will be specified and designed by the person most knowledgeable with plant control, the solar plant engineer himself, although the actual coding of the program will be done by qualified computer programmers.

MDAC believes that the solar plant engineer should specify in complete flowchart fashion the logic to be coded into the application program. Experience has shown that this person is the only one who really understands how the system works and that the use of flowcharts creates a bridge between the plant engineer and the computer.

Testing of the application program is a joint effort between the design engineer and the software programmers. Working together, they can rapidly, efficiently, and at minimum cost, develop a control program that meets the intended requirements.

Under the division of responsibility described above, the software systems designer can proceed with design and development of the real-time system software requirements. This effort can be in production while application programs are still in early stages of design.

The master control system, both hardware and software, is developed at MDAC and fully built, integrated, and tested before being delivered to the solar power plant site. The MDAC design of the master control hardware allows the system to drive itself for the purposes of integration and test. This is made possible by the use of patch panel boards at the point where all external instrumentation equipment feeds into the system. By use of special diagnostic simulators, control signals sent out by the computer can be routed back to look like input data to the computer. In this manner, system integration tests can be written to check out almost all the master control equipment in a standalone configuration. The software programmers use the application program language to prepare such integration and test programs, which will remain with the system for its life cycle to become self-test programs.

The applications programs, such as normal power, are verified prior to installation at the power plant. Verification occurs by using the master control computer disconnected from the plant and stepping through the program in a controlled manner, monitoring outputs and providing selected input data to drive the application program through its logic. The process is well-planned and uses the monitor and display capability that is built into master control. Consequently, most software logic is exercised before the software is placed into actual service to control the solar power plant.

The first execution of software in control of the plant operation is performed under a specific plan and approach so that every sequence of the program is visually monitored and checked for proper performance. Several people are involved just to monitor displays and communicate the observed processes occurring. The software program is stepped through slowly by the plant engineer and software programmers until confidence was achieved that all hardware and software are functioning as designed and required. The display and monitor capability of master control, and the manual control capability, allow this process to proceed smoothly and rapidly to arrive at a fully validated application program that operates in a fully automatic mode.

6.7.2 Hardware Development Approach

The hardware will be developed with software as an integral part of the design. Hardware vs software tradeoff analyses will be made at the earliest possible date to ensure an economical and flexible design for the Pilot Plant. The man-machine interface will be engineered to provide efficient operator control and monitor of the Pilot Plant.

The master control computer will be specified early in the system design activities to assure its delivery in time for system test and development checkout. An off-the-shelf minicomputer will be selected for master control. It will provide the capability required, at minimum cost, for both the initial hardware purchase and software development by using production-type equipment and existing software programs.

All new equipment designs will be developed with the system standard interfaces, wiring, and components used whenever feasible. The master control hardware design will allow for system test and integration by use of patch boards whereby signals sent out by the computer can be routed back to computer inputs to check complete equipment groups and interconnecting wiring.

6.7.3 Program Support Requirements

A Systems Integration Laboratory (SIL) is to be established at MDAC for the development of master control. Initially, SIL will contain the master control computer and peripheral equipment only. The computer will be used initially as a software development facility for master control software. Much of the software can be developed and tested with only the master control computer.

As hardware is completed, it will be integrated in the SIL to the computer. The schedule phasing will be accomplished so that the first deliveries of hardware allow expansion and greater depth of software testing. The equipment integration will continue in the SIL until a complete working master control subsystem is tested and proven ready for shipment to the power site.

Design of master control is supported by the analysis effort performed using the solar power plant simulation that is an operational design tool at MDAC. By use of the simulation in the OLSF labs, the plant characteristics and responses that aid in design of master control software and hardware are studied.

Integration and test of master control in the SIL requires use of special patch boards wired to route computer command signals back to the computer inputs. Also, the patch boards may be connected to simulated test gear so the computer thinks external devices and sensors are active.

6.7.4 Development Schedule

The development schedule for the Pilot Plant master control is shown in Figure 6-25. The schedule includes both hardware and software design and development. The 30-month schedule includes system design through site assembly and checkout, but does not include system intergration with the Pilot Plant subsystem.

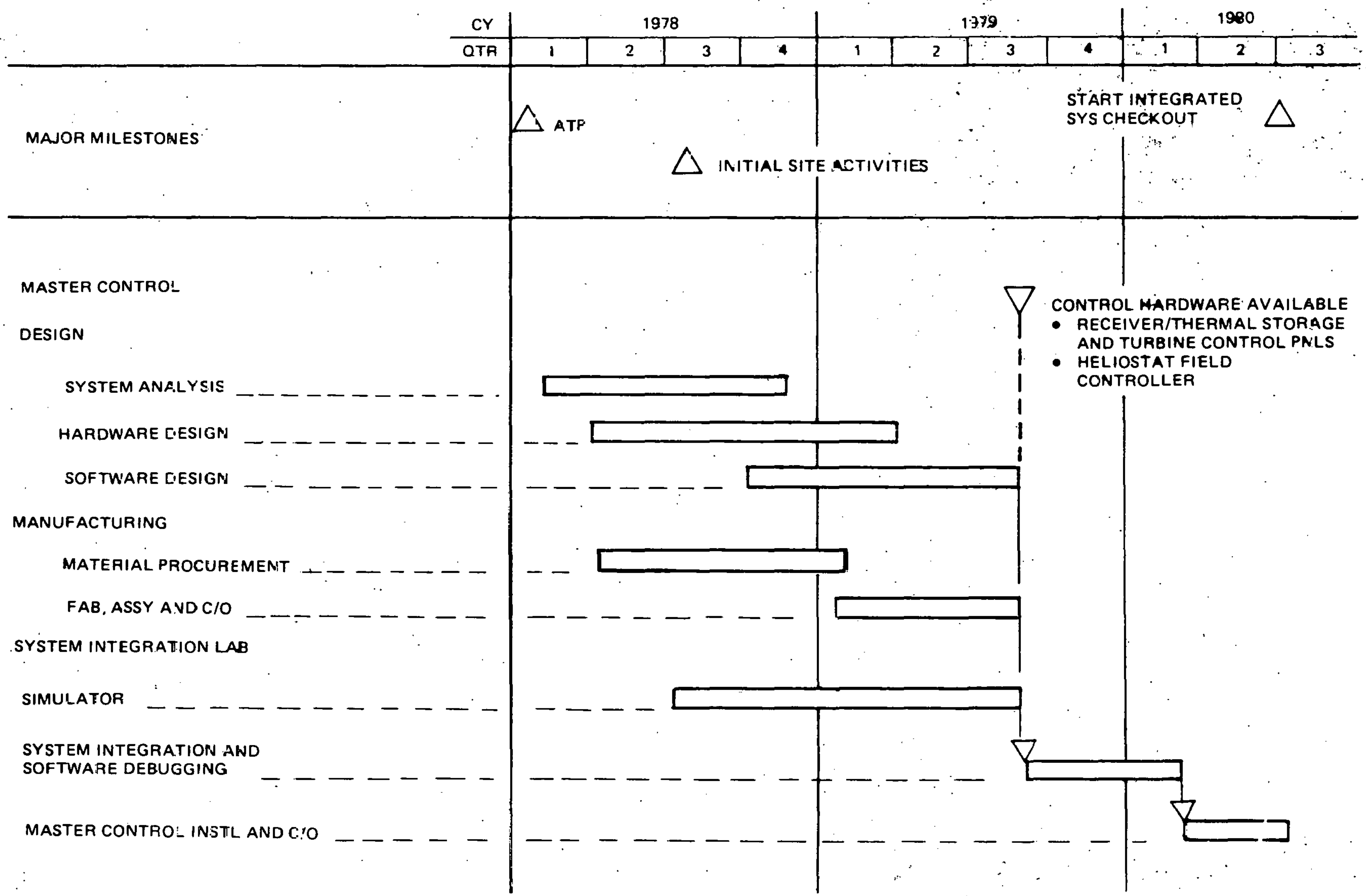

Figure 6-25. Master Control Schedule, Pilot Plant

CONTENTS

4.0 QUALITY ASSURANCE PROVISIONS (CONTINUED)

1.0 SCOPE

This specification establishes the performance design, and test requirements for the Pilot Plant electrical power generation subsystem (EPGS).

2.0 APPLICABLE DOCUMENTS

The equipment, materials, design, and construction of the electrical power generation subsystem shall comply with all Federal, state, local, and user standards, regulations, codes, laws, and ordinances which are currently applicable for the selected site and the using utility. These shall include but not be limited to the government and nongovernment documents itemized below. If there is an overlap in or conflict between the requirements of these documents and the applicable Federal, state, county or municipal codes, laws or ordinances, that applicable requirement which is the most stringent shall take precedence.

The following documents of the issue in effect on the date of request for proposal form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superseding requirement.

2.1 Government Documents

2.1.1 Specifications. Regulations of the California Occupational Safety and Health Administration (Cal/OSHA).

2.1.2 Other Publications.

National Motor Freight Classification 100B - Classes and rules apply on motor freight traffic.

Uniform Freight Classification 11 - Railroad Traffic Ratings Rules and Regulations

CAB Tariff 96 - Official Air Transport Rules Tariff

CAB Tariff 169 - Official Air Transport Local Commodity Tariff

R. H. Graziano's Tariff 29 - Hazardous Materials Regulations of the Department of Transportation

CAB Tariff 82 - Official Air Transport Restricted Articles Tariff

2.2 Nongovernment Documents

2.2.1 Standards.

American National Standards Institute - B31.1, Pressure Piping Codes

Institute of Electrical and Electronic Engineers Code - Switchgear and Transformers

National Electrical Manufacturers Association (NEMA) Standards - Motor, Starters

Instrument Society of America Standards

American Society for Testing Materials Standards

Uniform Building Code - 1973 Edition, Volume 1 by International Conference of Building Officials

American Society of Mechanical Engineers Pressure Vessel Codes including Unfired Pressure Vessels

American Society of Mechanical Engineers Power Test Codes - Heat Exchanger, Turbines, etc.

American Society of Mechanical Engineers Performance Code (Turbine Efficiency, Heat Exchanger, Condenser Performance, Pump Performance)

Hydraulic Institute Standards - Pumps

Welding Code

National Electrical Code, NFPA 70-1975 (ANSI C1-1975)

3.0 REQUIREMENTS

3.1 Electrical Power Generation Subsystem Definition

The electrical power generation subsystem (EPGS) for the Pilot Plant shall provide the means for transforming the thermal output of the receiver or thermal storage subsystems into 7 to 11.1 MWe net of 60 Hz electrical power at 13,800 volts. The output from the EPGS shall be regulated suitably for integration into an existing electrical power system network. The EPGS shall consist of:

(a) High-pressure steam supply header, automatic admission steam supply header, valves, and controls

(b) Steam turbine (prime mover)

(c) Electrical generator

(d) Surface condenser and air removal equipment

(e) Feedwater return piping, pumps, valves, heaters, and controls

(f) Water treatment equipment

(g) Controls required to (1) regulate the inlet steam pressure and admission steam pressure as well as the 60 Hz electrical output voltage and amperage, as required, and to (2) vary the electrical load as necessary to maintain the required working fluid conditions.

(h) Plant auxiliaries

(i) Emergency power

(j) Electrical connections, cabling, meters, relays, switches, transformers, controls to the electrical power transmission network.

The EPGS design shall not require new development in scaling to a commercial subsystem capable of producing power in the 100-MWe range. The Pilot Plant subsystem tests shall be controlled by the master control in coordination with the control of the receiver, thermal storage, and collector subsystems.

3.1.1 Electrical Power Generation Subsystem Diagram. Figure A-1 shows a schematic of the EPGS and its interfaces with other subsystems. Figure A-2 shows the functional flows between the major elements of the EPGS and between the EPGS and other interfacing subsystems.

3.1.2 Interface Definition. The physical and functional interfaces between the EPGS and other subsystems or elements thereof are described below.

3.1.2.1 Electrical Power Generation Subsystem/Receiver. Connections and mounting fixtures shall be provided to match those of the receiver subsystem. Power shall also be provided at 480 volts to operate receiver subsystem feed pumps, and at 110 volts to operate receiver valves and controls.

(a) Turbine Throttle/Downcomer: The EPGS shall be designed to connect the primary high pressure steam inlet with the receiver downcomer and accept superheated steam at the rated capacity of

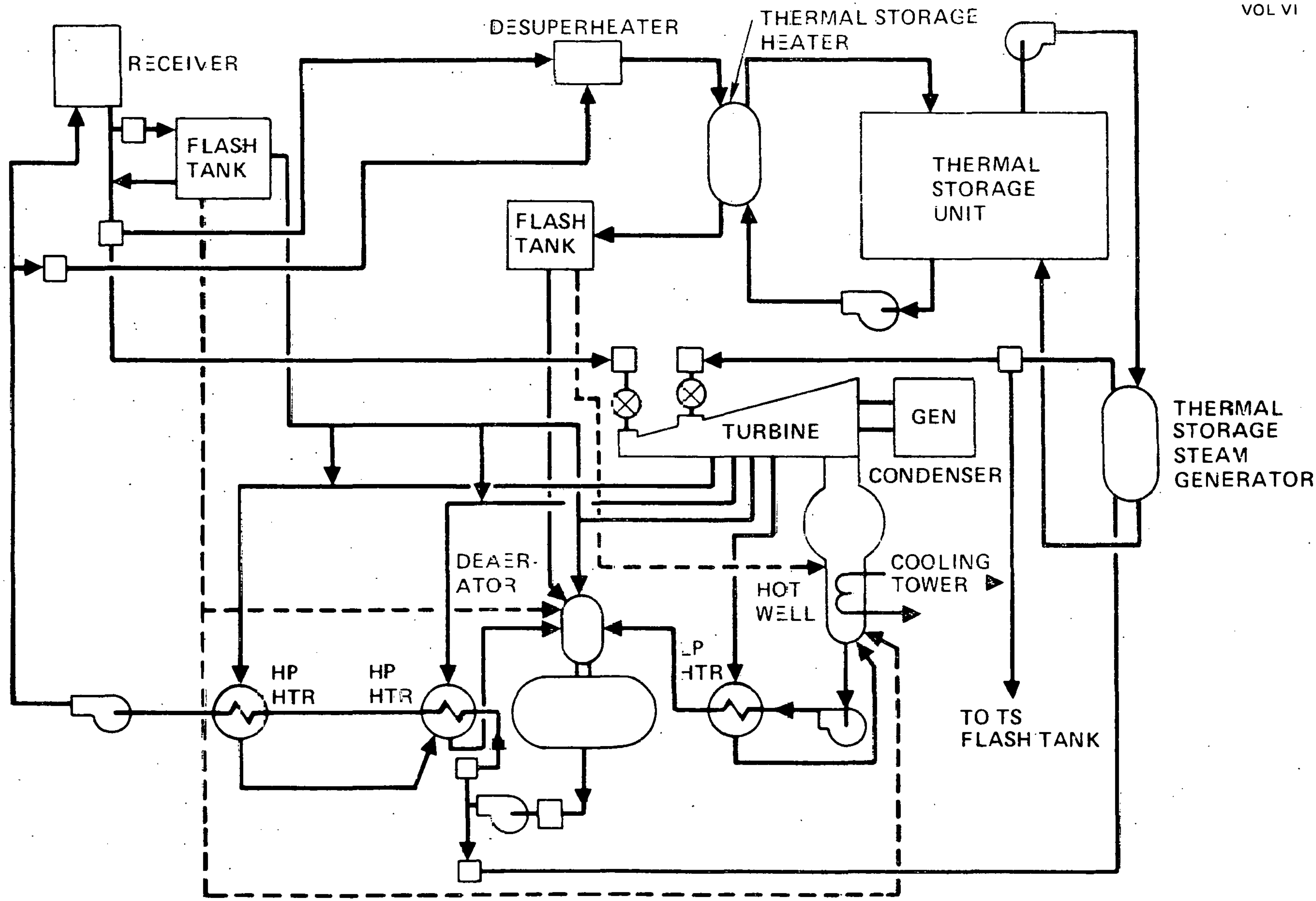

Figure A-1. Pilot Plant System Schematic

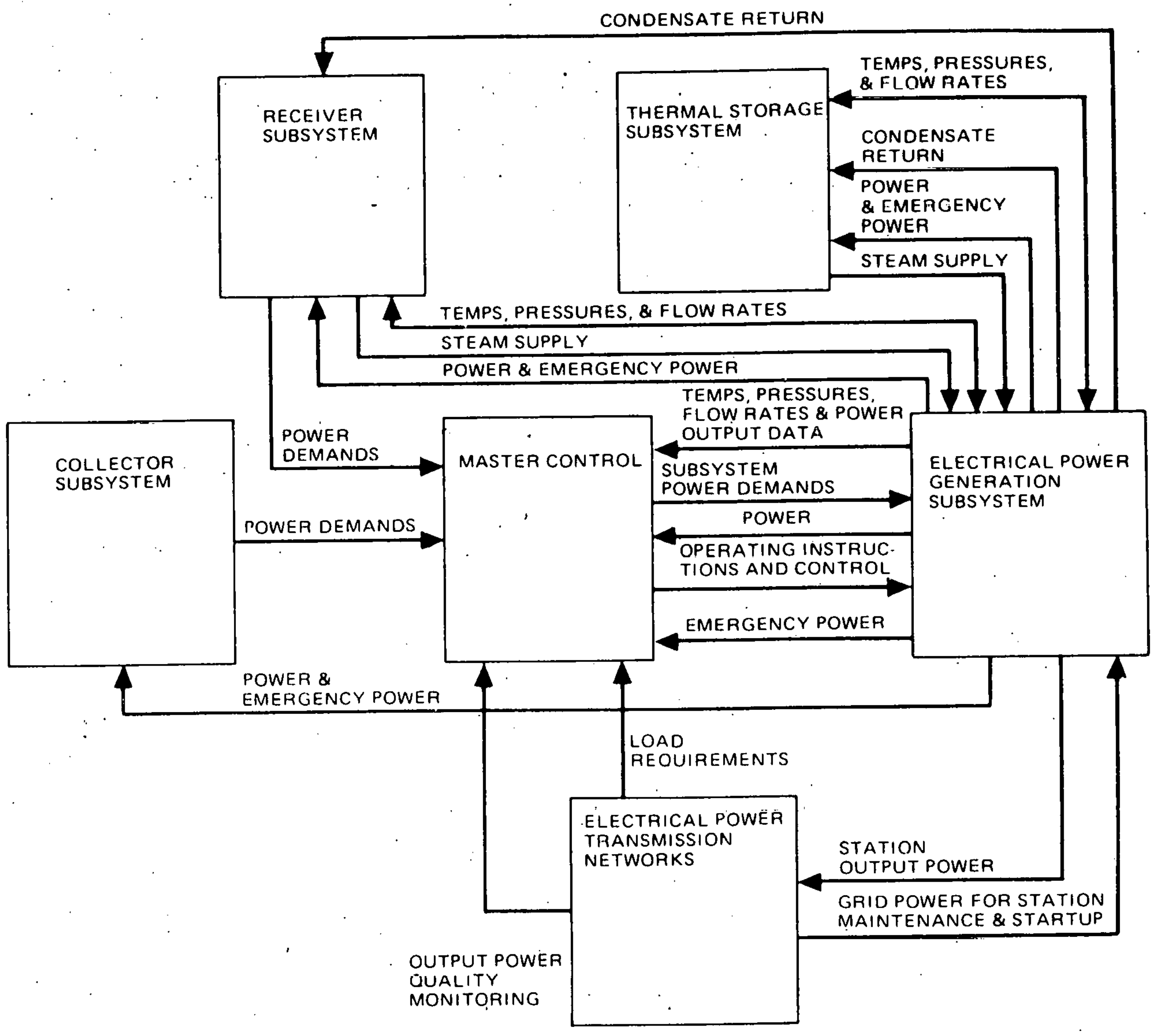

Figure A-2. Functional Interfaces Between the EPGS and Other Operating Elements

the receiver subsystem, including a maximum flow rate of 14.7 kg/s (116,500 lb/hr), static pressure 10.1 MPa (1465 psia), and a temperature of 510°C (950°F).

(b) Condensate Loop/Riser: The EPGS shall be designed to connect the condensate loop with the receiver riser and deliver condensate at the receiver inlet at a maximum flow rate of 16.5 kg/s (130,500 lb/hr) (associated with derated steam flow from the receiver) static pressure of 13.79 MPa (2000 psia), and a maximum temperature of 218°C (425°F).

3.1.2.2 Electrical Power Generation Subsystem/Thermal Storage. Connections and mounting fixtures shall be provided to match those of the thermal storage subsystem. Power shall also be provided at 480 volts to run thermal storage subsystem pumps and at 110 volts to operate TSS valves and controls.

(a) Automatic Admission Port/Steam Generator: The EPGS shall be designed to connect the automatic admission port with the thermal storage steam generator and receive the superheated steam at the rated delivery capacity of the thermal storage subsystem during thermal storage discharge at a maximum flow rate of 13.2 kg/s (104,700 lb/hr), static pressure of 2.66 MPa (385 psia), and a temperature of 274°C (525°F).

(b) Condensate Loop/Steam Generator: The EPGS shall be designed to connect the condensate loop with the thermal storage subsystem and deliver condensate to the steam generator of the thermal storage subsystem during thermal storage discharge at a maximum flow rate of 13.2 kg/s (104,700 lb/hr), static pressure of 3.45 MPa (500 psia), and nominal temperature of 101.3°C (250°F).

3.1.2.3 Electrical Power Generation Subsystem/Collector Subsystem. The EPGS controls shall be responsive to standard control signals (per power industry practice) from the master control.

3.1.2.4 Electrical Power Generation Subsystem/Electrical Power Transmission Network. The EPGS shall be designed to connect to an electrical power transmission network and deliver a nominal range from 7 to 11.1 MWe net of regulated 60 Hz electrical power at 115,000 volts to the network.

3.1.3 Major Components. The EPGS shall be composed of but not limited to the following:

(a) Turbine
(b) Generator and excitation system
(c) Surface condenser and air removal equipment
(d) Cooling tower
(e) Circulating water pumps
(f) Low-pressure feedwater heater
(g) Deaerator heater
(h) High-pressure feedwater heaters
(i) Hot well pumps
(j) Booster pumps
(k) Receiver feed pumps
(l) Water treatment equipment
(m) Transformers (main and auxiliary)
(n) Electrical connections, cabling, metering, controls, and switchgear
(o) Emergency power supply.

3.2 Equipment Design and Performance Characteristics

3.2.1 Turbine. One tandem compound, single flow, extraction with four extraction points, single automatic admission 12,500 kW (rating) at 8.46 kPa (2.5 In. Hg A) backpressure, with the following accessories:

Electrohydraulic control system complete with all stop and trip valves and control valves; emergency overspeed governor; protective devices; supervisory instrumentation; AC motor-operated lube oil pump; DC motor operated lube oil pump; lube oil reservoir and coolers; AC motor operated turning gear; sheet metal lagging and insulation and required turbine casing and interconnecting piping drain connections and valves; also throttle and automatic admission steam piping from turbine stop valves to turbine inlets.

Turbine Design Characteristics

Maximum calculated capability (valves wide open) - 13,625 kW gross
Shaft speed - 3,600 rpm

Inlet Steam Conditions

Pressure	10.1 MPa (1,465 psia)
Temperature	510°C (950°F)
Enthalpy	3,399 J/Kg (1,461.2 Btu/lb)
Throttle Flow	46,467 Kg/hr (102,440 lb/hr) at 11,200 kW gross

Admission Steam Conditions

Pressure	2.65 MPa (385 psig)
Temperature	274.4 °C (525°F)
Enthalpy	2,939 kJ/kg (1,263.4 Btu/lb)
Admission Flow	47,556 Kg/hr (104,700 lb/hr) at 7,800 kW gross.

Feedwater Heater Extractions

Four feedwater heater extractions (1 low-pressure heater, 1 deaerating heater, and 2 high-pressure heaters)

3.2.2 Generator. One direct connected 16,000 kVA (rated) 0.85 power factor 13,800 volts, 60 Hz air-cooled with static excitation system, with the following accessories:

Cooling system with circulating fans mounted on generator shaft, water coolers with 70-30 CuNi tubes mounted within generator, temperature detectors of resistance type imbedded in armature winding, similar detectors located in air inlet and outlet of each air cooler, field discharge resistor, generator bushing current transformers, special tools and slings.

3.2.3 Condenser. One 2-pass surface condenser in accordance with the following specifications:

Surface Area	1, 115m^2 (12, 000 ft^2)
Shell and Water Boxes	Carbon Steel
Tube Material	90-10 Copper Nickel
Tube Diameter	19. 05 mm (0. 75 in.)
Tube Wall Thickness	0. 89 mm (0. 035 in.) (20 BWG)
Tube Length (Effective)	6. lm (20 ft)
Condenser Pressure	8. 46 kPa (2. 5 in. HgA)
Heat Rejection	94. 95x10^6 GJ/hr (90x10^6 Btu/hr)
Cooling Water Flow	0. 725 m^3/s (11, 500 gpm)
Water Velocity	2. 13 m/s (7. 0 fps)
Cooling Water In	29. 4°C (100. 7°F)
Temperature Rise	8. 7°C (15. 7°F)

Accessories: Expansion joint between turbine and condenser.

3.2.4 Condenser Vacuum Pumps. Two Nash mechanical vacuum pumps, 3, 540 cm^3/s (7.5 scfm) 3.4 kPa (1 in. HgA) with 900 rpm, (22. 4 kW) 30 hp, 460V, 3 pH, 60 Hz motors.

3.2.5 Cooling Tower. One induced draft, cross flow, 2-cell cooling tower in accordance with the following specifications:

No. of Cells	2
No. of Fans	2
Fan Motor Size	2-75 kW (100 hp)
Overall Dimensions	(LxWxH) 17. 2x18. 5x8. 8m (56. 5x60. 83x29 ft)
Heat Rejection	100. GJ/hr (95. 0x10^6 Btu/hr)
Design Wet Bulb Temperature	23. 0°C (73. 4°F)
Cold Water Temperature	29. 4°C (85. 0°F)
Hot Water Temperature	37. 9°C (100. 2°F)
Temperature Range	8. 4°C (15. 2°F)
Circulating Water Flow	47. 3 m^3/min (12, 500 gpm)

Cooling tower to be of wood internal construction with cement asbestos casing and air inlet louvers. Complete with wet-down sprinkler system, lightning protection system, and fire protection system.

3.2.6 Circulating Water Pumps (Half Capacity). Two horizontal, centrifugal, double suction, in accordance with the following specifications:

Capacity (each)	23.6 m^3/min (6,250 gpm)
Head (TDH)	18.3m (60.0 ft)
Efficiency	78%
Motor Size (460V-3Ph-60Hz)	112 kW (150 hp)
Speed	1,750 rpm

3.2.7 Booster Pumps (Full Capacity). Two horizontal split case, centrifugal, 4-stage, in accordance with the following specifications:

Capacity (each)	2.2 m^3/min (575 gpm)
Head	355.5m (1,166 ft)
Efficiency	75%
Motor Size (460 V-3ph-60Hz)	186.5 kW (250 hp)
Speed	3,550 rpm

3.2.8 Receiver Feed Pumps (Full Capacity). Two double case, barrel type, centrifugal, 11-stage with hydraulic coupling for variable-speed operation in accordance with the following specifications:

Capacity (each)	1.32 m^3/min (350 gpm)
Head	1,423.7m (4,670 ft)
Efficiency	65%
Motor Size (460 V-3Ph-60Hz)	448 kW (600 hp)
Speed	3,465 rpm

3.2.9 Condensate Hotwell Pumps (Full Capacity). Two horizontal, centrifugal, horizontal split case in accordance with the following specifications:

Capacity (each)	1.68 m^3/min (450 gpm)
Head	70.1m (230 ft) TDH
Motor Size	37.3 kW (50 hp)
Speed	1,750 rpm

3.2.10 Condensate Transfer Pumps (Full Capacity). Two horizontal, end suction, centrifugal in accordance with the following specifications:

Capacity (each)	0.78 m^3/min (200 gpm)
Head	45.7m (150 ft) TDH

Motor Size (460 V-3Ph-60Hz)	14.9 kW (20 hp)
Speed	1,750 rpm

3.2.11 Low-Pressure Heater. One low-pressure closed feedwater heater, horizontal, 150-psi design tube side, with 304 stainless steel tubes and carbon steel shell with drain cooler.

3.2.12 Deaerating Heater. One vertical spray - tray direct contact deaerating heater, stainless steel trays and vent condenser carbon steel shell and carbon steel storage section:

Capacity 106,687 Kg/hr	235,200 lb/hr
Oxygen Removal	0.005 cc/liter O_2 in effluent
Storage Tank	Horizontal 18.92 m^3 (5,000 gal capacity)

3.2.13 High-Pressure Heaters. Two high-pressure closed feedwater heaters, horizontal, 750 psi design tube side, with carbon steel tubes and carbon steel shell with drain cooler.

3.2.14 Water Treatment Equipment.

(a) Makeup demineralizer - The makeup demineralizer will consist of two full-size, three bed trains. Removal from service will be automatically initiated by preset total flow, conductivity end point, or silica endpoint, whichever occurs first. Return to service will be pushbutton-initiated. Removal from service of final (mixed bed) units will occur independently of primary (cation and anion exchange) units.

Rating	0.2 m^3/min (50 gpm) (per train)
Effluent Quality	
Total Dissolved Solids	50 ppb maximum
Silica	10 ppb maximum

(b) Condensate Polishing Demineralizer - The condensate polishing demineralizer will consist of two full-size mixed bed units. Removal from service will be pushbutton-initiated. Regeneration will occur externally to the service vessels. Transfer of resin, regeneration, and return of resin to service vessels will be pushbutton initiated.

Rating 1.76 m^3/min (450 gpm) (per vessel)
Effluent Quality:

Cation Resin in Hydrogen Form

Total Dissolved Solids	30 ppb maximum
Sodium	5 ppb maximum
Silica	10 ppb maximum
Iron, magnetite	90% removal
Ferric Oxide	50-60% removal
Copper	50-90% removal
Suspended Solids	90% removal

Cation Resin in Ammonia Form

Total Dissolved Solids	40 ppb maximum
Sodium	(20 ppb average) 50 ppb maximum
Silica	20 ppb maximum
Iron, Magnetite	90% removal
Ferric Oxide	50-60% removal
Copper	50-90% removal
Suspended Solids	90% removal

3.2.15 Transformers.

(a) One main power transformer, outdoor, oil-immersed, self-cooled/forced air cooled, rated as follows:

Continuous capacity, 55°C rise, at service conditions, self-cooled, MVA	12
Continuous capacity, 55°C rise, at service conditions, forced cooled, MVA	16
Maximum ambient temperature	50°C
Type of transformer	3 phase 2 winding wye-grounded

Low-voltage winding connection	delta
HV-LV phasor relationship	HV leads LV (standard)
Impedance on 12 MVA base	Manufacturer's minimum standard
Frequency, hertz	60
High-voltage winding voltage, kV	115
High-voltage winding, tap	Two 2-1/2 AN Two 2-1/2 BN
High-voltage winding BIL, kV	550
Low-voltage winding voltage, kV	13.2
Low-voltage winding voltage, BIL, kV	110
High-voltage line bushings voltage rating, kV	115
High-voltage line bushings BIL, kV	550
High-voltage neutral bushing, voltage rating, kV	15
High-voltage neutral bushing, BIL, kV	110
Low-voltage winding bushings, voltage rating, kV	15
Low-voltage winding bushings, BIL, kV	110
Surge arresters, voltage rating, kV (for high-voltage winding)	96

Overexcitation capability, no load, % of rated voltage	110
Overexcitation capability, full load, % of rated voltage	115
High-voltage connection	Overhead
Low-voltage connection	Cable (terminal box)

(b) Two auxiliary power transformers, outdoor, oil-immersed, self-cooled/future forced air cooled, rated as follows:

Continuous capacity, 55°C rise, at service conditions, self-cooled, kVA	1,500
Continuous capacity, 55°C rise, at service conditions, forced cooled, kVA	1,750
Maximum ambient temperature	50°C
Type of transformer	3 phase 2 winding
High-voltage winding connection	delta
Low-voltage winding connection	Wye
HV - LV phasor relationship	HV leads LV (standard)
Impedance on 1,150-kVA base	8.0%
Frequency, Hertz	60
High-voltage winding voltage, kV	13.2

High-voltage winding, taps	two 2-1/2 AN two 2-1/2 BN
High-voltage winding, BIL, kV	110
Low-voltage winding voltage, kV	2.4
High-voltage line bushings voltage rating, kV	15
High-voltage line bushings, BIL, kV	110
Overexcitation capability, no load, % of rating voltage	115
Overexcitation capability, full load, % of rated voltage	120
High-voltage connection	cable (terminal box)
Low-voltage connection	cable (terminal box)

3.2.16 Emergency Power Supply. One skid-mounted emergency diesel-engine generator unit, ancillary and auxiliary equipment, itemized and/or rated as follows:

(a)	Continuous net output capability at specified altitude and maximum ambient temperature, kW	350
(b)	Intermittent net overload capability at specified altitude and maximum ambient temperature, kW	350
(c)	Continuous generator capability, kVA	1000

(d)	Power factor	0.8
(e)	Output voltage, volts	2,400
(f)	Frequency, Hertz	60
(g)	Phase	3
(h)	Generator connection	4 wire solidly grounded
(i)	Synchronous speed, rpm	1200 or 1800
(j)	Maximum start to loading time, seconds	10
(k)	Applicable engine standard	SAE
(l)	Engine aspiration	Turbo-charged with intercoolers
(m)	Fuel injection	Direct
(n)	Cooling system	Integral radiator, fan, and standby jacket heaters
(o)	Starting system	Redundant air motors w/compressors and receivers
(p)	Lube oil system	Full pressure with oil sump heaters
(q)	Governor	Electronic for both isochronous and droop modes
(r)	Fuel system	Day tank w/transfer pumps
(s)	Engine control panel	Integral
(t)	Exhaust system	Suspended integral silencer
(u)	Excitation system	Rotating brushless or static exciter, either w/static voltage regulator
(v)	Generator and exciter control and protection panel	Skid adjacent mounted
(w)	Auxiliaries motor control	Skid adjacent mounted

3.2.17 Electrical Connections, Cabling, Metering, Controls, and Switchgear.

Cable and Raceways

All 13.8-kV power cables will be run in cable tray. Cables to the heliostat fields will be direct burial. All other cables will be run in cable tray except where tray is not suitable or economic. Cables that are not run in tray will be run in conduit or duct, overhead or underground, in trench or direct burial, as is most suitable or economic.

Cables of 15 kV will be EPR 133% level insulation, single conductor, shielded with neoprene jacket. Low-voltage power cables will be EPR insulation with neoprene jacket. Low-voltage power cables smaller than 250 MCM will be 3-conductor; 250 MCM and larger will be single-conductor. Multiconductor control cables will be EPR conductor insulation, with neoprene overall jacket. Lighting branch circuits will be single conductor type XHHW. Other types of wire and insulation will be used, where required by the service or service conditions.

Metering

The following indicating meters will be provided:

- Generator ammeter (1 meter and switch to read 3 phases)
- Generator wattmeter (kW)
- Generator varmeter (kilovars)
- Generator voltmeter (1 meter and switch to read 3 phases)
- Generator field and excitation system, meters will be provided as recommended by the manufacturer
- Generator frequency meter
- Incoming and running voltmeters
- Synchroscope
- Motor ammeters for drives that are critical

The following recording meters will be provided:

- Generator wattmeter
- Generator varmeter

The following kilowatt hour meters will be provided:

- Generator
- Auxiliary
- Net generation (to the transmission system)

The following transducers for telemetering will be provided:

- Generator kilowatt (if required by the utility)
- Generator kilovars (if required by the utility)

Control

The following will be controlled from the receiver-turbine-generator panel:

Generator 13.8-kV circuit breaker

115-kV circuit breaker (if desired by the utility)

Generator excitation system

Motors that require control by the control room operator

Motors that do not require control by the control room operator will be local control, automatic control, or as required by function.

3.3 System Characteristics

3.3.1 Performance. The EPGS shall be designed to efficiently convert the available thermal energy into 60 Hz electrical power at 13,800 volts which is synchronized with the electrical network. A net electrical power output of 10 MW shall be available at Winter solstice, 2 PM, when a steam flow rate of 46,467 kg/hr (102,440 lb/hr) at a temperature of 510°C (950°F) and pressure of 10.0 MPa (1,450 psig) is supplied at the turbine inlet with surface condenser pressure of 8.46 kPa (2.5 in. HgA). A net electrical output of 7 MW shall be available when the turbine is powered by steam from the thermal storage subsystem at conditions defined in Para. 3.1.2.2(a). During the 10-MW net electric design point operation, 25±3% of the turbine steam flow is extracted for feedwater heating. The feedwater temperature shall be elevated to a maximum of 2.18°C (425°F) while a maximum of 26.35 MWth (90×10^6 Btu/hr) heat shall be rejected to the condenser. During extended-operation periods, sufficient steam shall be extracted to raise the feedwater temperature to 102°-118°C (215-245°F) entering the steam generator. The water-treatment facility shall be capable of providing makeup feedwater at a flow rate of 0.25% of design steam flow during normal operation and a flow rate of 10% of design steam flow during maximum demand periods, with dissolved solids reduced to 20 to 50 ppb and the pH maintained at 9.5. Instrumentation and subsystem control equipment shall be compatible with the master control satisfying all interface requirements identified in Appendix B.

3.3.2 Physical Characteristics. Sizes, shapes, dimensions, and weights of a tandem-compound, single flow, single automatic admission industrial turbine with a nominal rating of 12,500 kWe are as specified by the turbine vendor. The Pilot Plant surface condenser shall be used for condensing and air removal. The entire subsystem shall be designed to provide safe ingress, egress, and access for proper inspection, maintenance, and repair of the structure, fluid flow lines, utilities, instrumentation, and controls for each element or component. The elements or components of the EPGS shall be configured and located within or relative to other portions of the solar thermal power plant to minimize adverse effects on the other subsystems.

3.3.3 Reliability. High reliability shall be achieved in the EPGS design by providing adequate operating margins, making maximum use of proven standard parts, and using conservative design practices so the reliability performance shall not degrade the capability to achieve the availability specified in Para. 3.2.5 when operated in the conditions specified in the annex.

Single-point failures that result in the loss of the capability to generate electrical power or maintain synchronization with the electrical power transmission network shall be eliminated wherever practical. In cases where it is impractical to eliminate such failure modes, suitable devices shall be used to detect and signal the occurrence of a failure.

3.3.4 Maintainability. The EPGS shall be designed so required services can be performed by people of normal skills using a minimum of nonstandard tools or special equipment.

The EPGS shall be designed to provide malfunction indication and fault isolation information data required by the master control concerning critical components (TBD). Critical components are those that can materially affect the capability to achieve the system availability requirements because of failure risk, downtime, or effect on the overall plant performance.

Items which do not have a redundant mode of operation shall incorporate maximum capability for on-line repair or replacement. These items might include, for example, temperature and pressure sensors, and actuators for valves. The EPGS shall be designed such that potential maintenance points can be easily reached, replaceable components such as electronic modules readily replaced, valves marked for visual indication of position, and elements subject to wear or damage such as pumps, valves, and gears, easily serviced or replaced.

3.3.5 Availability. The EPGS shall operate in accordance with Para. 3.2.1 performance requirements 93.05% of its scheduled operating time based on reliability and maintainability exclusive of isolation conditions. Determinations of availability shall use a period of one year as a time reference.

3.3.6 Environmental Conditions

3.3.6.1 General. The conditions described in Annex 1, Pilot Plant Environmental Conditions, are representative of the site characteristics and the transportation and operating environments to be encountered by the EPGS. Safety margins or protective devices shall be used commensurate with availability and performance requirements to ensure operation in accordance with Para. 3.2.1 during and/or after exposure to these conditions, as appropriate, for the 30-year life of the system.

The maximum pressure exerted by footings and foundations on the soil shall not exceed 10.3 MPa (1,500 psi).

All critical (frangible) components of the EPGS shall be designed or packaged such that the conditions described in Para. 3.2 of Annex 1 do not induce a dynamic environmental condition which exceeds the structural capability of the component. All components shall be designed to withstand handling/hoisting inertial loads up to 2 g's considering number, location, and type of hoisting points.

Practices recommended in the ASCE Paper 3269, Vol. 126 and the Uniform Building Code, 1973, Vol. 1 shall be employed in designing the EPGS for winds.

Subsystem components shall be protected from the electrostatic charging and discharging associated with sand and dust storms where appropriate.

3.3.7 Transportability. EPGS components shall be designed for transportability within applicable Federal and state regulations by highway and railroad carriers using standard transport vehicles and materials handling equipment. Wherever feasible, components shall be segmented and packaged to sizes that are transportable under normal commercial transportation limitations (see (a) below). Subsystem components that exceed normal transportation limits (see (b) below) shall be transportable with the use of special routes, clearances, and permits.

(a) Transportability Limits for Normal Conditions (Permits Not Required)

	Truck	Rail
Height	13 ft 6 in. above road	16 ft 0 in.
Width	8 ft 0 in.	10 ft 6 in.
Length	55 ft 0 in. - Eastern States	60 ft 6 in.
	60 ft 0 in. - Western States	
Gross wt	73,280 lb; 18,000 lb/axle max	200,000 lb

(b) Transportability Limits for Special Conditions

	Truck	Rail
Height	14 ft 6 in. above road	16 ft 0 in. above rail
Width	12 ft 0 in.	12 ft 0 in.
Length	70 ft 0 in.	80 ft 6 in.
Gross wt	100,000 lb; 18,000 lb/axle max	400,000 lb

The design requirements for component packaging and tiedown techniques shall be compatible with the following limit load factors:

Vibration

Transportation Mode	Amplitude (G_{op})	Frequency Range (Hz)
Highway	±0.6	1 - 85
	±0.9	85 - 300
Air	±0.05 in DA	3 - 38
	±2.0	38 - 1000
Rail	±1.0	1 - 100
	±1.6	100 - 1000

Shock Load Factors

Transportation Mode	Acceleration (g) Longitudinal	Lateral	Vertical
Air	±3.0	±2.5	±2.0
Highway	±3.5	±2.0	+3.0
Rail			
Rolling	±3.0	±0.75	±3.0
Humping (Hydro cushion car)	±3.0	±2.0	+3.0

All critical (frangible) components shall be designed or packaged such that the conditions described above do not induce a dynamic environmental condition which exceeds the structural capability of the component. These conditions reflect careful handling and firmly constrained (tied down) transporting via common carrier. All components shall be designed to withstand handling/hoisting inertial loads up to 2g, considering the number, location, and type of hoisting points.

Handling shock will result from normal handling drops of large packaged equipment. Corresponding acceleration peak may be of the order of 7g vertical and 4g horizontal with a sinusoidal profile and a duration of 10 to 50 milliseconds.

Smaller components shall be properly packaged to prevent structural damage during normal handling and inadvertent drops to a maximum specified height. The handling shocks for these components are a function of the weight and dimensions of the packaged item. Structural analyses shall be performed for critical items to establish the structural integrity of the packaged component for the shock levels experienced in the shipping package. The drop height noted below shall be used as design guidelines for the packaged item:

Gross Weight Not Exceeding (Lb)	Dimensions of Any Edge, Height, Diameter (In.)	Free Fall Height of Drop on Corners, Edges, or Flat Faces (In.)
50	36	22
100	48	16
150	60	14
No Limit	No Limit	12

3.4 Design and Construction

Design and construction standards compatible with the end use shall be employed.

3.4.1 Materials, Processes, and Parts. To the maximum extent possible, standard materials and processes shall be employed. No potentially toxic materials shall be used. Highly stressed components and unusual materials shall be avoided. As far as practical, off-the-shelf components used in industry shall be employed. Materials and components susceptible to environment deterioration shall be protected with a suitable coating or protective layer.

3.4.2 Electrical Transients. The subsystem operation shall not be adversely affected by external or internal power line transients caused by normal switching, fault clearing, or lightning. Switching transients and fault clearing functions shall require less than six cycles of the fundamental frequency (100 ms) and shall be limited to 1.7 PU voltage (1.7 per unit or 170%). EPGS components shall be protected from the lightning threat specified in the annex by surge protection.

3.4.3 Nameplate and Product Marking. All deliverable end items shall be labeled with a permanent nameplate listing, as a minimum, manufacturer, part number, change letter, serial number, and date of manufacture.

All access doors to replaceable/repairable items shall be labeled to show equipment installed in that area as well as any safety precautions or special servicing considerations to be observed during servicing.

3.4.4 Workmanship. The level of workmanship shall conform to practices defined in the codes, standards, and specifications applicable to the selected site and the using utility. Where specific skill levels or certifications are required, current certification status shall be maintained with evidence of same available for examination. Where skill levels or workmanship details are not specified, the work shall be accomplished in accordance with the level of quality currently in use in the construction, fabrication, and assembly of Commercial Power Plants. All work shall be finished in a manner such that it presents no unintended hazard to operating and maintenance personnel, is neat and clean, and presents a generally uniform appearance.

3.4.5 Interchangeability. Major components and circuit cards and other items with a common function shall be produced with standard tolerances and connector locations to permit interchange for servicing. Components that have similar appearance but different functions shall incorporate protection against inadvertent erroneous installation through the use of such devices as keying, connector size, or attachment geometry.

3.4.6 Safety. The EPGS shall be designed to minimize safety hazards to operating and service personnel, the public, and equipment. Electrical components shall be insulated and grounded. All parts or components with elevated temperatures shall be insulated against contact with or exposure to personnel. Any moving elements shall be shielded to avoid entanglements and safety override controls/interlocks shall be provided for servicing. All pertinent OSHA rules and regulations shall be observed.

3.5 Documentation

3.5.1 Characteristics and Performance. Equipment functions, normal operating characteristics, limiting conditions, test data, and performance curves shall be provided where applicable.

3.5.2 Instructions. Instructions shall cover assembly, installation, alignment, adjustment, checking, lubrication, maintenance, and operation. All phases of subsystem operation shall be addressed including startup, normal operation, regulation and control, shutdown, and emergency operations. A guide to troubleshooting instruments and controls shall be provided.

3.5.3 Construction. Engineering and assembly drawings shall be provided to show the equipment construction, including assembly and disassembly procedures. Engineering data, wiring diagrams, and parts lists shall be provided.

3.6 Logistics

Elements required to support the EPGS are:

(a) Maintenance
  (1) Support and test equipment
  (2) Technical publications
  (3) Field service
  (4) Data file

(b) Supply

(1) Spares, repair parts, and consumables

(2) Transportation, handling, and packaging

(c) Facilities

3.6.1 Maintenance. Maintenance activities are categorized as Level 1, on-line maintenance; Level 2, off-line, on-site maintenance; or Level 3, off-line, off-site maintenance.

Level 1, On-Line Maintenance: The following scheduled and unscheduled maintenance activities shall be identified for the electrical power generation subsystem.

Task	Frequency
Inspect visually	Daily
Remove and replace	(TBD)
Repair in place	(TBD)
Adjust	(TBD)
Align	(TBD)
Calibrate	(TBD)
Lubricate	(TBD)
Paint	(TBD)
Transport	(TBD)

Level 2, Off-Line On-Site Maintenance: The following maintenance activities shall be identified in the maintenance plan. Frequencies shall be (TBD).

Verify fault
Isolate fault to a removable item
Remove and replace a faulty item
Verify acceptable repaired item
Repair designated subtiered items
Service
Lubricate
Inspect visually
Transport

Level 3, Off-Line Off-Site Maintenance: Level 3 maintenance activities are those to be performed at the equipment supplier's facility. Frequencies and turnaround times shall be TBD.

3.6.2 Supply. The following criteria shall be used for selecting and positioning spaces, repair parts, and consumables:

Protection Level: Items shall be packaged in accordance with the requirements of Para. 5.0.

Demand Rate: The mean-time-between-maintenance actions shall be the initial basis for spares determinations. The quantities and mix shall be such that there is a (TBD) percent probability of a part being available on demand.

Pipeline: Pipeline quantities shall be determined on system location demand rate and repair cycle times. Resupply methods and distribution and location of system stocks shall be determined after site selection.

Procurement and Release for Production: Long-leadtime items shall be procured or drawings released early enough for the items to be on site 30 days prior to initial operation. Other items shall be procured or released leadtime away so as to minimize obsolescence due to design changes, except for those items for which significant cost savings can be achieved through acquisition concurrent with production.

Minimum/Maximum Levels: Minimum and maximum quantities of spares and repair parts to be stocked shall initially be determined by use of predicted failure rates. These levels are to be adjusted as actual usage rates are established.

3.6.3 Facilities and Facility Equipment. (TBD after site selection.)

3.7 Personnel and Training

3.7.1 Personnel. The Pilot Plant is to be installed, checked out, and tested by contractor personnel, then taken over and operated as a Commercial power plant by utility personnel. Operation and maintenance personnel requirements shall be satisfied by recruitment from the established utility labor pool. Specific skills and number of persons required for Pilot Plant operation are (TBD).

3.7.2 Training. System interface aspects of the EPGS dictate a need for training existing utility people but do not establish a need for new skills or trades. The types and numbers of utility people requiring training and the tasks are as follows:

Type	No.	Task
TBD	TBD	System startup and shutdown Subsystem control maintenance Safety requirements Emergency operations (Others TBD)

3.8 Precedence

Specific characteristic and requirement precedence shall be established based on system cost-effectiveness sensitivity analyses. This specification has precedence over documents referenced herein. The contractor shall notify the procuring activity of each instance of conflicting, or apparently conflicting, requirements within this specification or between this specification and a referenced document.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 General

4.1.1 Responsibility for Tests. All tests shall be performed by the contractor. These tests may be witnessed by ERDA or its representatives or the witnessing may be waived. In either case, substantive evidence of hardware compliance with all test requirements is required.

4.1.2 General Test Requirements. Tests shall be conducted in accordance with a test plan to be prepared by the contractor and approved by ERDA. Specific required tests are identified in Para. 4.2. Tests shall be classified in the test plan as:

(a) Development tests for the purpose of determining the design.

(b) Acceptance tests for the purpose of verifying conformance to design and determining acceptability of the product for further operations or for delivery.

(c) Qualification tests for the purpose of verifying adequacy of design and method of production to yield a product conforming to specified requirements.

Acceptance tests and qualification tests shall be defined for verifications as indicated in Para. 4.3. The test of the EPGS in conjunction with another subsystem is regarded as a system test and shall be as specified in the Pilot Plant System Requirements.

4.1.3 Previous Tests and Data. Maximum use shall be made of data available from equipment supplier's and hardware tests already completed. Where conformance to EPGS requirements can be established at less cost by analysis of such data, tests shall not be repeated.

4.2 Specific Test Requirements

Specific required tests are defined herein. Additional tests shall be defined by the contractor in the course of design where necessary to properly validate the performance and design integrity of the EPGS.

4.2.1 Subsystem Performance Tests. (This portion will define tests for evaluation of the EPGS as fully assembled to assure compatibility before attempting system tests.)

4.2.2 Assembly and Subassembly Performance Tests. (Definition TBD)

4.2.3 Environmental Tests. (Definition TBD)

4.2.4 Materials and Processes Control Tests. (Definition TBD)

4.2.5 Life Tests and Analyses. One set of each major subassembly shall be subjected to extended life testing as follows: (Methods TBD)

4.2.5.1 Mean Time Before Failure/Replacement. Sufficient data shall be gathered from the above life tests and also from component suppliers in order to estimate the MTBF and MTBR for the given design configuration.

4.2.6 Engineering Critical Component Qualification Tests. Components for which reliability data are not available shall be subjected to sufficient qualification testing to estimate their impact on overall device MTBF.

4.3 Verification of Conformance

Verification that the requirements of Sections 3 and 5 of this specification are fulfilled shall be performed by the contractor by the following methods.

(a) Inspection - Examination and measurement of product.

(b) Analysis - Examination of the design and associated data, which may include relevant test information.

(c) Similarity - Demonstration or acceptable evidence of the performance of a product which is sufficiently similar to permit conformance to be inferred.

(d) Test - Functional operation or exposure under specified conditions to evaluate product performance.

(e) Demonstration - Exhibition of the product or service in its intended modes and conditions.

4.3.1 Hardware Acceptance for Pilot Plant. The contractor shall provide a system by which conformance of hardware to the design will be verified prior to initiation of subsystem-level tests. This verification of conformance shall include proof-by-assembly and the examination of records as elements of inspection. A record shall be made of each inspection or test performed and of the verification. In addition, evidence shall be maintained of satisfactory accomplishment of inspections and tests required by codes and standards that apply to the EPGS.

CONTENTS

1.0 SCOPE

This specification established the performance, design, and test requirements for the Pilot Plant master control.

2.0 APPLICABLE DOCUMENTS

The equipment, materials, design, and construction of the master control shall comply with all Federal, state, local, and user standards, regulations, codes, laws, and ordinances which are currently applicable for the selected site and using utility. These shall include but not be limited to the Government and non-Government documents itemized below. If there is an overlap in or conflict between the requirements of these documents and the applicable Federal, state, county, or municipal codes, laws, or ordinances, that applicable requirement which is the most stringent shall take precedence.

The following documents of the issue in effect on the date of request for proposal form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superseding requirement.

2.1 Government Documents

2.1.1 Specifications

Regulations of the Occupational Safety and Health Administration (OSHA).

Regulations of the California Occupational Safety and Health Administration, Cal/OSHA - if required

MIL-H-46855, Human Engineering Requirements for Military Systems, Equipment and Facilities

2.1.2 Standards

MIL-STD-454, Standard Central Requirements for Electronic Equipment

NFPA Bulletin No. 78 (ANSI C5.1), Lightning Protection Code

MIL-STD-1472 Human Engineering Design Criteria for Military Systems, Equipment and Facilities

2.1.3 Other Publications.

National Motor Freight Classification 100B - Classes and Rules Apply on Motor Freight Traffic

Uniform Freight Classification 11 - Railroad Traffic Ratings Rules and Regulations

CAB Tariff 96 - Official Air Transport Rules Tariff

CAB Tariff 169 - Official Air Transport Local Commodity Tariff

R. H. Graziano's Tariff 29 - Hazardous Materials Regulations of the Department of Transportation

CAB Tariff 82 - Official Air Transport Restricted Articles Tariff

Design Handbook on Electromagnetic Compatibility, AFSC DH 1-4

Instrumentation Grounding and Noise Minimization Handbook, AFRPL-TR-65-1

Checklist of General Design Criteria, AFSC DH 1-X

2.2 Non-Government Documents

2.2.1 Standards

National Electrical Manufacturers Association (NEMA) Standard
National Electrical Code, NFPA 70-1975 (ANSI C1-1975)

3.0 REQUIREMENTS

3.1 Master Control Definition

The master control shall consist of the control and display equipment required to provide overall control and integration of the Pilot Plant. The master control shall provide automatic control via software resident in the central computer and a full complement of manual control for the plant operator.

The master control shall be capable of scaling to a larger commercial central receiver power generating system in the 100-MWe range. To accomplish this, the master control architecture shall be modular in design using standard building blocks that can be increased in quantity to handle the increased requirements of a larger plant.

3.1.1 Master Control Diagram. Figure B-1 shows the functional interfaces of the various end items within the master control as well as the interfaces of the master control and the subsystems.

3.1.2 Interface Definition. The physical and functional interfaces required between the master control and the subsystems are specified in the following paragraphs. The interface requirements defined in this section are those peculiar to each subsystem. General master control requirements are defined in Para 3.2.1.1. The master control physical interfaces with the various subsystems are illustrated in Figure B-2.

3.1.2.1 Master Control/Collector Subsystem

Functional Interfaces. The master control shall be capable of performing the following control and checkout functions with respect to the collector subsystem.

(a) Provide each collector field controller with a sun acquisition azimuth and elevation command. This command will point the individual heliostats in that group to the accuracy required to acquire the sun within the field of view of the beam sensor.

(b) Provide sun acquisition commands at a rate sufficient to position the heliostats within the field of view of the sensor to allow automatic reacquisition of the sun after the passage of a cloud shadow.

(c) Command all or a portion of the total collector field to slew off the receiver in the event the receiver malfunctions or shuts down.

(d) Command the total collector field to a stowage position.

(e) Provide overall control and scheduling of collector subsystem checkout.

(f) Detect and isolate faults in the transmission net between the master control and the field controllers.

(g) Display and store field controller and heliostat malfunction data relayed by the field controller.

(h) Store individual heliostat beam sensor alignment data.

(i) Provide manual control to field controller heliostat groups.

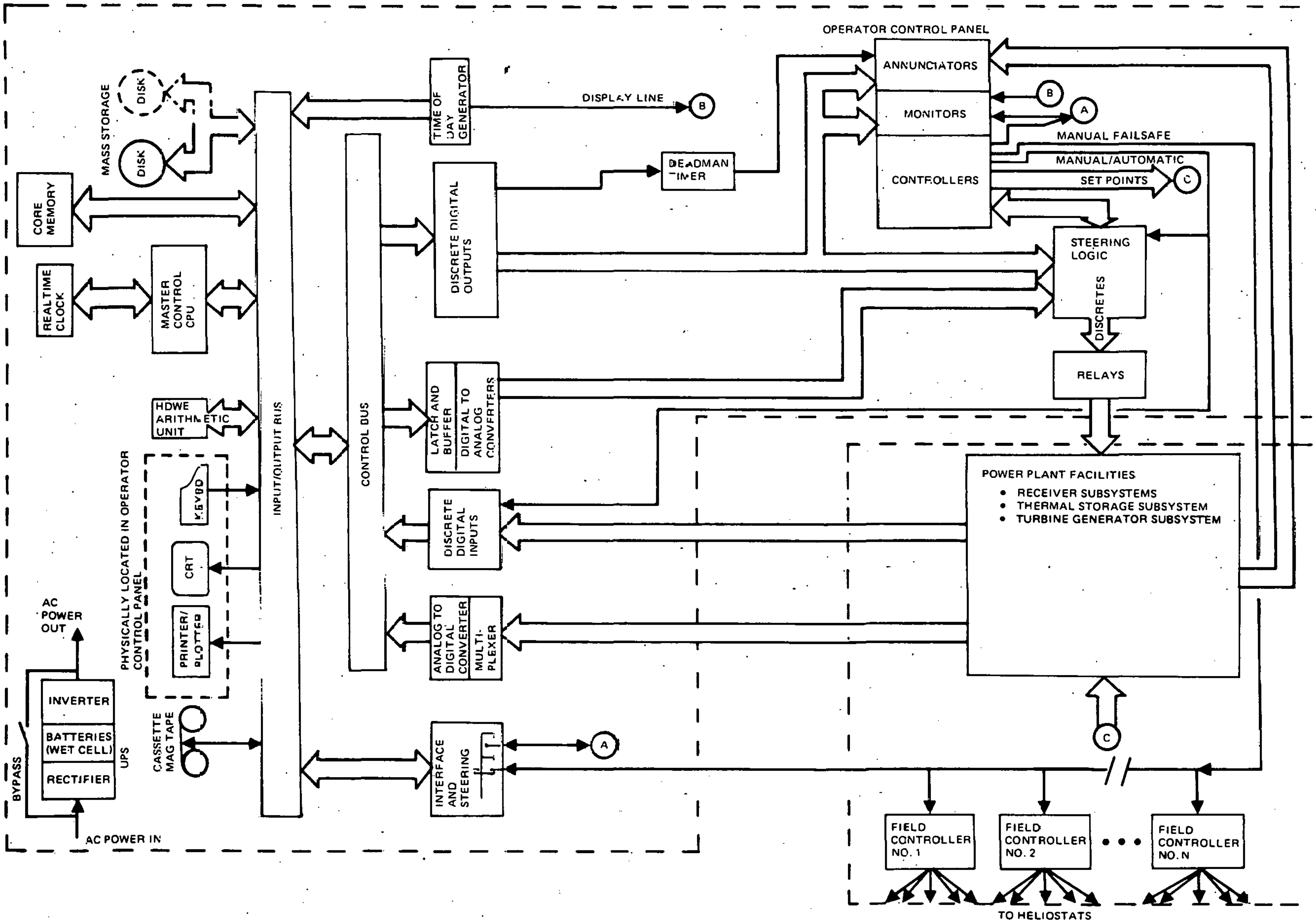

Figure B-1 Master Control Hardware Configuration

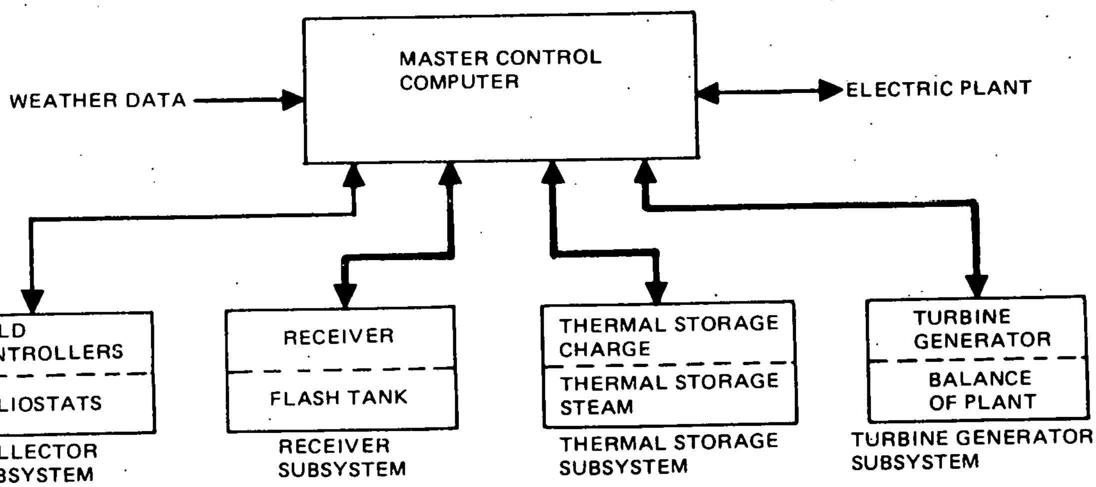

Figure B-2. Master Control Subsystem Interface Definition

Physical Interfaces. The hardware interface between the master control and the collector subsystem shall consist of a digital transmission bus. Biphase encoding shall be used with DC isolation at each interface. Each master control message requires an acknowledgement from the addressed field controller. Each field controller shall have a unique address but shall recognize a common emergency slew command. Erroneous messages shall be detected using reasonability logic at the field controller (e.g., verifying approximate agreement of heliostat pointing angles) and through periodic interrogation of collector status by the master control.

3.1.2.2 Master Control/Receiver Subsystem

Functional Interface

The interface between master control and the receiver subsystem shall be capable of performing the following operating functions:

(a) Receiver subsystem checkout. Includes verifying sensor operation, control valve functionality, water inlet pressure and flow conditions, flash tank level, and pneumatic pressure level.

(b) Continuous monitor. Identify and analyze out of tolerance conditions such as burn wire open or boiling at single pass panel inlet.

(c) Determine corrective action options for alarm or out-of-tolerance conditions.

(d) For all nine quasi steady-state plant operating modes:

   (1) Determine temperature control set points

   (2) Determine pressure control set points

   (3) Determine control valve positions

   (4) Command temperature and pressure control control valve positions.

(e) For each plant operating mode transition, repeat (d).

(f) Establish motor valve interlock sequencing

(g) Monitor and display all receiver subsystem parameters

(h) Provide emergency safing control

(i) Provide night temperature control

Physical Interface

The physical interface between master control and the receiver subsystem shall be via discrete hardwires from the receiver components through the steering logic for the discrete digital and continuous analog output control commands and through the master patch panel and relay junction box for the discrete digital and analog instrument input signals.

A preliminary count of the type and quantity of control and instrumentation signals that shall be interfaces is shown in Table 1.

Table 1
RECEIVER SUBSYSTEM INTERFACE SIGNALS

	Input				Output	
	Control		Instrumentation		Control	
Receiver Signals	Discrete	Analog	Discrete	Analog	Digital	Analog
Motor Valves (on-off)	12		2		6	
Temperature Sensors/Control		21		46		1
Pressure Sensors/ Control		3		22		1
Flow Meters		18				
Level Detectors		1		1		
TOTALS	12	43	2	69	6	2

3.1.2.3 Master Control/Thermal Storage Subsystem

Functional Interface

The interface between master control and the thermal storage subsystem shall be capable of performing the following operating functions:

(a) Thermal storage subsystem checkout
(b) Continuous monitor; identify and analyze out-of-tolerance conditions
(c) Determine corrective action options for out-of-tolerance conditions
(d) Provide emergency safing control
(e) Determine temperature-control set points
(f) Determine pressure-control set points
(g) Determine control valve positions
(h) Determine anticipated charging rate
(i) Determine anticipated discharging rate
(j) Calculate status at thermal charge in tank
(k) Position control valves per plant mode operating mode status
(l) Command inlet steam flow control valve
(m) Command desuperheater temperature control valve
(n) Command charging side oil flow control valves (2)
(o) Command charging pump speed settings (2)
(p) Command discharging pump speed settings (2)
(q) Command auxiliary pump (on-off)
(r) Command discharge oil flow control valves (2)
(s) Command superheater oil bypass modulating valves (2)
(t) Command feedwater level control valves (2)
(u) Command all motor valve position (12) with suitable interlock restrictions.
(v) Monitor and display all thermal storage subsystem parameters
(w) Provide night (nonuse period) control

Physical Interface

The physical interface between master control and the thermal storage subsystem shall be similar to the receiver previously described. A preliminary count of the quantity and types of control and instrumentation signals that shall be interfaced is shown in Table 2.

Table 2

THERMAL STORAGE SUBSYSTEM INTERFACE SIGNALS

Thermal Storage Signals	Input				Output	
	Control		Instrumentation		Control	
	Discrete	Analog	Discrete	Analog	Discrete	Analog
Motor valves (on-off)	24		4		12	
Modulating Valves (continuous)						10
Temperature Sensors/Control		62		17		
Pressure Sensors/ Control		8		3		
Flow Rate		5				
Level Detector		1		1		
Speed Sensors/ Control	5				5	
TOTALS	29	76	4	21	17	10

3.1.2.4 Master Control/Turbine Generator and Balance of Plant Functional Interface

The interface between master control and the turbine generator/balance of plant subsystem shall be capable of performing the following operating functions:

(a) Turbine generator/balance of plant subsystem checkout
(b) Continuous monitor; identify and analyze out-of-tolerance conditions
(c) Determine corrective action options for out-of-tolerance conditions
(d) Determine pressure and temperature set points
(e) Determine turbine control mode-speed/load for startup and initial pressure for running
(f) Develop throttle valve and/or admission valve position commands

(g) Open bypass valve during admission steam only operation with interlock
(h) Develop position commands for extraction port control valves
(i) Command receiver feedwater pump speed setting
(j) Control condenser fans
(k) Control primary level control valves
(l) Control boost, hotwell, condenser water, and condenser vacuum pumps (on-off)
(m) Command thermal storage flash tank set points
(n) Monitor and display all turbine generator/balance of plant parameters
(o) Provide night steam blanket for turbine control

Physical Interface

The physical interface between master control and the turbine generator/ balance of plant subsystem shall be similar to both the receiver and thermal storage subsystem previously described. A preliminary count of the quantity and types of control and instrumentation signals that shall be interfaced is shown in Table 3.

3.1.3 Major Components. The master control shall be composed of the following major components:

(a) Central computer
  (1) Bidirectional asynchronous data and control bus
  (2) 48K words of memory - expandable to 124K words
  (3) 16-bit word size
  (4) Direct memory access
  (5) Vectored and/or priority interrupt
  (6) Hardware multiply and divide
  (7) Floating point hardware
  (8) Interface and self-check logic
(b) Computer peripheral equipment
  (1) Keyboard printer
  (2) 2-disk mass storage files
  (3) Printer/plotter
  (4) Dual magnetic tape cassette
  (5) Real-time clock

Table 3

TURBINE GENERATOR AND BALANCE OF PLANT SUBSYSTEM INTERFACE SIGNALS

Turbine Generator and Balance of Plant	Input				Output	
	Control		Instrumentation		Control	
	Discrete	Analog	Discrete	Analog	Discrete	Analog
Turbine Generator						
Motor Valves (on-off)	10		2		5	
Modulating Valves (continuous)						2
Temperature Sensors/Control		7		45		
Pressure Sensors/Control		2				
Speed Sensors/Control		1				
Generator Output/Load		1				
Balance of Plant						
Motor Valves (on-off)	4				2	
Modulating Valves (continuous)						2
Temperature Sensors/Control		9		1		
Pressure Sensors/Control		7		2		2
Flow Rate/Control	9				9	
Level Detectors/Control						8
Speed Sensors/Control	2	1		1	2	
TOTALS	25	28	2	49	18	14

(c) Time code generator

(d) Master control to collector field controllers interface

(e) Control and display console

  (1) Annunciators

  (2) Monitors

  (3) Controls

(f) Software

  (1) Development

  (2) Real-time system

  (3) Application

  (4) Maintenance

  (5) Integration and test

3.2 Characteristics

3.2.1 Performance. The performance requirements of the master control hardware and software are defined in the following paragraphs.

3.2.1.1 General Master Control Functional Requirements. The master control requirements defined in this paragraph are common with respect to all subsystems. They supplement the functional interface requirements defined in Para 3.1.2.

The master control shall be capable of meeting the following functional performance requirements:

(a) Provide a stable plant condition to enable production of electric power from solar energy.

(b) Provide control over the collector field of solar mirrors including focusing, defocusing, and maintenance.

(c) Provide control over the receiver subsystem for creation of superheated steam for input to the thermal storage and turbine generator subsystems.

(d) Provide control over thermal storage for the storage of solar heat and the generation of auxiliary steam when required.

(e) Provide control over the turbine subsystem to generate electricity and recirculate the steam exhaust.

(f) Provide a control panel for operator control of all plant operations under either automatic or manual control.

(g) Provide plant operation history logs indicating plant status during periods of operation.

3.2.1.2 General Master Control Functional Requirements. The Master Control requirements defined in this paragraph are common with respect to all subsystems.

(a) The following modes of plant operation shall be a capability of master control operation.
   (1) Normal Solar - Used for clear-day, full-sun operation.
   (2) Low Solar - Used for overcast-day operations.
   (3) Intermittent Cloud - Used for days of frequent cloud passage shielding the sun from the heliostat field.
   (4) Extended Operation
   (5) Charging Thermal Storage Only - No electric generation.
   (6) Fully Charged Thermal Storage - Same as normal operation, but thermal storage is not being charged.

(b) Master control shall perform the power plant startup and shutdown procedures.

(c) Master control shall transition the plant operation to any different mode.

(d) Master control shall monitor plant safety continuously and perform emergency shutdown.

(e) Master control shall provide direct hardwire control to all valves, set points, motors, pumps, etc.

(f) Master control shall provide visual indication of all sensing devices such as temperatures, pressures, flows, valve status, motor rates, power conditions, etc.

(g) Master control shall provide continuous focus of the mirror field throughout the day.

(h) Master control shall control and monitor status of thermal storage, and shall provide indication of its charged capacity.

(i) Master control shall provide calibration data for all measurement devices within its control.

(j) Master control shall have the following operational control features:
   (1) Automatic control of power plant operation from startup to shutdown with full manual override.

(2) Complete manual control over all power plant control devices.

(3) Direct hardwire control from master control to control device or sensor.

(4) Automatic/manual control of control devices uses the same hardwire.

(5) Centralized control console containing all auto/manual control points and readouts.

(6) Single computer controlling the receiver subsystem, thermal storage subsystem, turbine generator subsystem, collector subsystem, and the control console.

(7) Distributed microprocessors controlling the collector field of mirrors.

(8) Fail-safe concept for any component failure, including master control computer.

(9) Automatic detection of computer failure.

(10) Redundancy limited to devices whose failure would create costly equipment loss or human injury.

(11) Self-check capability by computer control for total system.

(12) Computer displays all values in engineering units.

(13) Use of standard devices for status displays being used today by utilities.

(14) English language used for all computer/operator communication.

(15) Verification by computer of all operator inputs.

(16) Backup power supply in case of power failure or interruption.

(17) Automatic calibration by the computer of all sensing devices.

(18) Control software of computer coded in a high-level functional language.

(19) Annunciator and alarm panels used - lights and audio alarm signals.

(20) Capability for data reduction and recording by computer (master control).

(21) Emergency shutdown capability under complete manual or automatic control.

3.2.1.2 Master Control Operating Concepts

The master control shall have three modes of operation:

(a) Automatic

(b) Manual

(c) Manual control supported by computer monitor and alarm

The operating concept shall require the plant to be either in full automatic control or manual control. Under most conditions the plant shall be under full automatic control and monitor. The two manual operating modes shall provide flexibility by providing hard wire control by the plant operator.

In the automatic mode, the Pilot Plant system shall be under the control of application programs resident in the active central computer. The active programs shall provide control and monitoring of the various subsystems, fault detection and isolation, and generation of status and error data recording devices and operator displays. In the event of an anomaly requiring operator intervention, the software shall notify the operator of the problem and accept a request for manual control via the keyboard/printer.

A manual mode of operation shall also be provided wherein the operator has the capability of assuming control of the system via hardwired controls and displays. When the system is in the manual mode of operation, application program control shall be inhibited. The manual mode of operation shall be used in the event of computer hardware or software failure or to handle anomalies not previously defined in the application program.

3.2.1.3 Master Control Self-Check. The master control shall be capable of detecting and isolating master control failures to a line replaceable unit. The master control shall be capable of isolating failures between the individual subsystems. The master control hardwire design shall provide the capability of executing a system self-check application program without disconnection of electrical connections. The master control software shall be capable of simultaneously executing the system control program and system self-check routines.

3.2.1.4 Major Component Characteristics

(a) Central Computer

The computer system integrated into master control shall be an off-the-shelf commercial computer, specifically tailored for industrial process control applications. The computer architecture shall use a common bus concept. Within this concept a family of peripheral devices shall be connected to the central processing unit and all other devices via the bus. Features of master control computer include:

Single and Double Operand Instructions
Hardware Multiply and Divide Instructions
Floating Point Hardware
16-Bit Word Size
Hardware Address Expansion and Protection Allowing Memory Addressing to 124K Words
Word or Byte Processing
Asynchronous Operation
Direct Memory Access for Multiple Devices
Four Line - Multilevel Automatic Priority Interrupt
Power Fail and Automatic Restart
Cycle Time of 1.0 Microseconds
Average Instruction Execution Time of Approximately 4 Microseconds

(b) Peripheral Equipment

The master control computer shall be furnished with standard peripheral devices supplied by the computer manufacturer wherever possible. Peripherals include: (1) keyboard printer, (2) two disk mass storage devices, (3) printer/plotter, (4) dual magnetic tape cassettes, (5) floating point hardware, (6) hardware multiply and divide and (7) real-time clock, (8) time code generator, and (9) collector subsystem interface.

All of the standard computer peripheral devices used in master control are supplied by the computer vendor. Consequently maintainability is simplified and the task of writing software to support these peripherals is greatly reduced.

(1) The keyboard/printer shall be used for bidirectional communications with the computer and the control and data reduction applications software.

The keyboard/printer shall contain 128 ASCII upper and lower-case character set with 95 printable characters. This equipment operates over a serial full duplex line, interfaced to the computer bus and prints at the rate of 30 characters per second.

(2) Two mass storage devices shall be used to store the operating system, compilers, utility programs, application programs and routines, and data collected from power plant instrumentation.

These disks are the movable head-type and use removable disk cartridges that store up to 1.2 million words each. A total of 2.4 million words of data storage is provided with the equipment.

(3) The printer/plotter shall be a high-speed electrostatic device used in the system to print the individual status of each device as well as all of the measured parameters. The equipment shall plot historical data used by the engineers in analyzing plant performance and operation.

The printer/plotter shall use the entire ASCII character set, prints 132 columns per line at 500 lines per minute. In the plotting mode the printer/plotter shall output up to 122,880 dots per second with a resolution of 1,024 dots per line.

(4) Two magnetic tape cassettes shall be incorporated into the master control computer configuration to provide a media for storing information to be processed by other computer systems, storing programs and routines as backup to the disks, and providing the basic media input from other sources.

Maximum capacity of each tape shall be 92,000 bytes. Average read and write speed of 9 inches per second and a search speed of approximately 22 inches per second shall be tape motion characteristics of these recorders.

(5) A floating point processor shall be included in the peripherals of the master control computer. This device shall serve to replace the software floating point techniques commonly used to provide high speed in the execution of arithmetic operations.

(6) Integer multiplications and divisions shall be performed by a hardware multiply and divide element. This device, interfacing to the bus, shall perform these operations in approximately 6 to 7 microseconds.

(7) A 60-Hz real-time clock shall be used by the computer under interrupt control and in conjunction with the system and applications control software to time out operations and program action delays.

(8) Time of day (IRIG-B format) shall be recorded for each control event. The master control computer shall extract the day, hour, minute, and second in parallel BCD form.

(9) The master control computer and the control console shall communicate with the collector subsystem field controllers and heliostats through the field controller peripheral interface. This equipment shall format and structure the inputs and outputs to the computer, error check each transmission, code and decode data commands.

(c) Control Panels and Equipment

Master control shall provide a custom central control console, designed to facilitate the control and monitoring of plant operation by one operator. The control panels in the console contains the following sections for each subsystem: annunciator, monitor, and control.

(1) The annunciators in the control panel shall be located slightly above normal eye level, displaying alarm status for each subsystem. Each annunciator shall be of a standard size and shape and illuminate when displaying the alarm condition. An English language descriptor shall be etched or printed on the face of the illuminating portion of the indicator. Each subsystem annunciator panel shall contain a lamp test feature.

(2) The monitor section shall be located at eye level and grouped within the section by function. Gages and meters shall make up the monitors and where possible these meters and gages display the functions in engineering units. The center monitor section of the console shall house the control status board. This board, through illuminated indicators shall provide the operator with the current operation sequence of the plant, whether operating manually or automatically.

(3) The controls for the power plant shall be located in the control console. These devices shall be located at arm level when the operator is seated at the console and mounted on an incline plane. All switches shall contain descriptors that illuminate when the switch is activated. To prevent accidental switch activations, emergency switches shall be covered and all others are detented, push type.

(d) Signal Interface Equipment

Interface equipment in master control shall include: (1) steering logic for output control, a master patch panel for analog instrumentation input, a relay junction box for discrete inputs, and analog recorders and associated patch panel.

(1) The steering logic shall provide the control signal paths from the computer and control console to the discrete control functions and from the computer to the set point controller commands. An auto-manual switch in conjunction with a run button shall switch the signal paths in the steering logic from

manual signal inputs to computer signal inputs. Front panel lights and switches shall be used to diagnose steering logic availability and assist the operator in systems checkout with the computer.

(2) A master patch panel shall be located in master control to patch the instrumentation inputs from the subsystems to the computer, the control console and the analog recorders. This patch panel shall be the fixed board type and uses isolation amplifiers for the purpose of patching a single analog signal to multiple points.

The ancillary instrumentation, that instrumentation used for plant monitoring not crucial to the plant operation, shall be patchable to the computer or the control console. Capability to patch 32 measurements to the analog recorders shall be provided.

(3) A relay junction box shall distribute the discrete input functions to the computer and the control console. Multipole relays shall provide the convenience of routing the inputs from common subsystem field wiring to the equipment and systems in master control.

(4) Four 8-channel analog oscillographic recorders shall be supplied in master control. These recorders will allow the engineer and operator to continuously look at any 32 instrumentation signals. Each recorder shall be equipped with an amplifier per channel that provides span control, zero control, and calibration features. An auxiliary patch panel shall be provided to allow the operator to patch the input channels to the recorder of his choice.

3.2.1.5 Master Control Software

System Software

The system software shall consist of all software required for the assembly and execution of the Pilot Plant application programs. The system software shall be responsible for the following functions.

(a) Updating and servicing the controls and displays.

(b) Maintaining a system data base that defines calibration coefficients, parameter addresses, maintenance data, etc.

(c) Generating plant performance reports.

(d) Management of data bus transmissions, including fault detection and isolation.

(e) Self-checking the computer hardware.

(f) Controlling the input/output channels.

(g) Scheduling and executing the application programs.

The system software shall consist of the following:

(a) Real-time disk operating system responsible for application program execution, compiling and assembly, text editing, and real-time self-check.

(b) Standard input/output handlers for the disk, magnetic tape unit, line printer, and teletypewriter.

(c) Nonstandard input/output handlers for the controls and displays, time code translator, data bus transmission, and data base access.

Application Software

Application software shall be provided to perform the following general functions:

(a) System control.

(b) Data reduction and analysis.

(c) Fault detection and isolation.

(d) Prediction of system performance capability for the next 24 hours.

(e) Control and update of the system status display.

(f) Generation of operator error message.

(g) Decoding and execution of operator commands.

(h) Storage of maintenance and performance monitor data.

The application software shall be written in a real-time higher-order language.

Support Software

For the Pilot Plant to operate without support of another computer facility, support software is required. Support software will be run primarily during plant shutdown periods. The support software shall contain:

(a) Compilers for the applications programs

(b) Assemblers for the system software

(c) Data reduction and processing for maintenance and plant operation reporting

(d) Plant mathematical models for predicting plant short-term performance.

3.2.2 Physical Characteristics. The hardware shall be packaged in standard commercial racks with standard slide-in drawers and module frames. The components and modules shall be readily accessible for maintenance. Thermal control shall be provided by rack-mounted blowers where required.

3.2.3 Reliability. High reliability shall be achieved in the master control design by providing adequate operating margins, maximizing the use of proven standard parts, and using conservative design practices such that the reliability performance shall not degrade the capability to achieve the availability specified in Para 3.2.5 when operated in the environments specified in Para 3.2.6.

Single-point failures that disable the automatic mode of system operation shall be minimized. In cases where it is impractical to eliminate such failure modes, suitable devices shall be used to detect and signal the occurrence of a failure.

3.2.4 Maintainability. The master control shall be designed so required service can be performed by personnel of normal skills, using a minimum of nonstandard tools or special equipment.

The master control shall provide malfunction indication and fault isolation information at the control/display consoles for malfunctions within the master control and accept and process such information from the collector, receiver, thermal storage, and electrical power generation subsystems regarding critical components. Critical components are those that, because of failure risk, downtime, or effect on the overall system performance, materially affect the capability to achieve the system availability requirements.

The master control shall be designed such that potential maintenance and test points can be easily reached, replaceable components such as electronic modules readily replaced, and elements subject to wear or damage such as supporting wheels, displays, and typewriters easily serviced or replaced.

3.2.5 Availability. The master control shall be available 99.95% of the time required for management of the system functions. Availability is measured as the percent of the total scheduled operating time in a period of one year that the master control functions in accordance with the requirements of Para 3.2.1 to achieve the specified system performance.

3.2.6 Environmental Conditions. The conditions described in Annex 1, Pilot Plant Environmental Conditions, are representative of the site characteristics and the transportation environments to be encountered by the master control. Master control operating environments are defined below. For design purposes, safety margins shall be used commensurate with availability and performance requirements to ensure operation in accordance with Para 3.2.1 during and/or after exposure to these conditions, as appropriate, for the 30-year life of the system.

Operational: The master control equipment shall be located in an environmentally conditioned enclosure. The hardware shall be designed to operate in accordance with Para 3.2.1 and 3.2.5 during and after exposure to the following combined environments.

Temperature: Controlled air temperature of 21°C ±3°C (70°F ±5°F).

Humidity: Relative humidity maintained between 40 and 50%.

Lightning: In accordance with Para 3.3.7 of Annex 1.

Earthquake: In accordance with Para 3.3.8 of Annex 1.

3.2.7 Transportability. The master control components shall be designed to meet all applicable Federal and state transportation regulations and be transported by highway or railroad carriers using standard transport vehicles and material handling equipment. Whenever feasible, components shall be segmented and packaged to sizes that are transportable under normal commercial transportation limitations (see (a) below). Subsystem components that exceed normal transportation limits (see (b) below) shall be transportable with the use of special routes, clearances, and permits.

(a) Transportability Limits for Normal Conditions (Permits Not Required)

	Truck	Rail
Height	13 ft 6 in. above road	16 ft 0 in.
Width	8 ft 0 in.	10 ft 6 in.
Length	55 ft 0 in. - Eastern States 60 ft 0 in. - Western States	60 ft 6 in.
Gross Wt	73,280 lb or 18,000 lb/axle	200,000 lb

(b) Transportability Limits for Special Conditions

	Truck	Rail
Height	14 ft 6 in. above road	16 ft 0 in. above rail
Width	12 ft 0 in.	12 ft 0 in.
Length	70 ft 0 in.	80 ft 6 in.
Gross Wt	100,000 lb or 18,000 lb/axle	400,000 lb

The design requirements for component packaging and tiedown techniques shall be compatible with the following limit load factors.

Vibration

Transportation Mode	Amplitude (Gop)	Frequency Range (Hz)
Highway	±0.6	1 - 85
	±0.9	85 - 300
Air	±0.05 in DA	3 - 38
	±2.0	38 - 1000
Rail	±1.0	1 - 1000
	±1.6	100 - 1000

Shock Load Factors

Transportation Mode	Acceleration (g) Longitudinal	Lateral	Vertical
Air	±3.0	±2.5	±2.0
Highway	±3.5	±2.0	+3.0
Rail			
Rolling	±3.0	±0.75	±3.0
Humping (Hydro cushion car)	±3.0	±2.0	+3.0

All critical (frangible) components shall be designed or packaged such that the conditions described above do not induce a dynamic environmental condition that exceeds the structural capability of the component. These conditions reflect careful handling and firmly constrained (tied down) transporting via common carrier. All components shall be designed to withstand handling/hoisting inertial loads up to 2g considering the number, location, and type of hoisting points.

Handling shock will result from normal handling drops of large packaged equipment. Corresponding acceleration peak may be of the order of 7g vertical and 4g horizontal with a sinusoidal profile and a duration of 10 to 50 milliseconds.

Smaller components shall be properly packaged to prevent structural damage during normal handling and inadvertent drops to a maximum specified height. The handling shocks for these components are a function of the weight and dimensions of the packaged item. Structural analyses shall be performed for critical items to establish the structural integrity of the packaged component for the shock levels experienced in the shipping package. The drop height noted below shall be used as design guidelines for the packaged item.

Gross Weight Not Exceeding (Lb)	Dimensions of Any Edge, Height, Diameter (In.)	Free Fall Height of Drop on Corners, Edges, or Flat Faces (In.)
50	36	22
100	48	16
150	60	14
No Limit	No Limit	12

3.3 Design and Construction

3.3.1 Materials, Processes, and Parts. The materials and parts used in the design and construction of the master control shall be restricted to those which are commercially available and commonly used in the design and manufacture of conventional digital computers, peripheral equipment, and displays.

They shall also be compatible with exposure to, and operation in, the environment specified in Para 3.2.6 for 30 years. The materials chosen shall present a cost-effective approach to design solutions. All processes employed in the design and manufacture of the master control shall be fully developed, commercially available, and currently in use in conventional digital equipment.

3.3.2 Electrical Transients. The master control operation shall not be adversely affected by external or internal power line transients caused by normal switching, fault clearing, or lightning. Switching transients and fault clearing functions shall require less than six cycles of the fundamental frequency (100 ms). Power buses supplying the computer and other digital hardware shall be designed to eliminate electrical transients during the switchover from prime to backup power source. Power transients caused by inductive and capacitive coupling and switching shall not cause digital power bus transients greater than ±10%.

Components of the master control shall be shielded from the lightning threat specified in Para 3.2.6. Shielding shall protect the electrical components from both the bound charge and induced current threats.

3.3.3 Electromagnetic Radiation. The master control shall be designed to minimize susceptibility to electromagnetic interference and to minimize the generation of conducted or radiated interference. The design criteria contained in the following Air Force design handbooks shall be used to assure electromagnetic compatibility: Design Handbook on Electromagnetic Compatibility (AFSC DH1-4), Checklist of General Design Criteria (AFSC DH1-1), and Instrumentation Grounding and Noise Minimization Handbook (AFRPL-TR-65-1).

3.3.4 Nameplates and Product Marking. All deliverable end items shall be labeled with a permanent nameplate listing, as a minimum, manufacturer, part number, change letter, serial number, and date of manufacture.

All access doors to replaceable/repairable items shall be labeled to show equipment installed in that area and any safety precautions or special considerations to be observed during servicing.

3.3.5 Workmanship. The level of workmanship shall conform to practices defined in the codes, standards, and specifications applicable to the selected site and the using utility. Where specific skill levels or certifications are required, current certification status shall be maintained with evidence of such available for examination. Where skill levels or details of workmanship are not specified, the work shall be accomplished in accordance with the level of quality currently in use in the construction, fabrication, and assembly of commercial power plants. All work shall be finished in a manner such that it presents no unintended hazard to operating and maintenance personnel, is neat and clean, and presents a generally uniform appearance.

3.3.6 Human Engineering. Human engineering design criteria and principles shall be applied in the design of the master control so as to achieve safe, reliable, and effective performance by operator, maintenance, and control personnel, and to optimize personnel skill requirements and training time. Electronic equipment shall use MIL-H-46855 (Human Engineering Requirements for Military Systems, Equipment and Facilities) and MIL-STD-1472 (Human Engineering Design Criteria for Military Systems, Equipment, and Facilities) as guidelines in applying human engineering design criteria.

3.4 Documentation

3.4.1 Characteristics and Performance. Equipment functions, normal operating characteristics, limiting conditions, test data, and performance curves shall be provided where applicable.

3.4.2 Instructions. Instructions shall cover assembly, installation, alignment, adjustment, checking, maintenance, and operation. All phase of master control operation shall be addressed, including startup, normal operation, regulation and control, shutdown, and emergency operations. A guide to troubleshooting controls and displays shall be provided.

3.4.3 Construction. Engineering and assembly drawings shall be provided to show the equipment construction, including assembly and dissassembly procedures. Engineering data, wiring diagrams, and parts lists shall be provided.

3.4.4 Schematics. Master control end item functional schematics shall be provided. These schematics shall provide the level of detail required to fault isolate to a replaceable unit.

3.4.5 Software Documentation. Complete software listings and functional descriptions shall be provided.

3.5 Logistics

Elements required to support the master control are:

- (a) Maintenance
  - (1) Support and test equipment
  - (2) Technical publications
  - (3) Field service
  - (4) Data file
- (b) Supply
  - (1) Spares, repair parts, and consumables
  - (2) Transportation, handling, and packaging
- (c) Facilities

3.5.1 Maintenance. Maintenance activities are categorized as Level 1, on-line maintenance; Level 2, off-line on-site maintenance; or Level 3, off-line off-site maintenance.

Level 1, On-Line Maintenance: The following scheduled and unscheduled maintenance activities shall be identified for the master control:

Task

Self-check
Remove and replace
Repair in place
Adjust
Clean
Calibrate
Paint

Level 2, Off-Line On-Site Maintenance: The following maintenance activities shall be identified in the maintenance plan:

Verify fault
Isolate fault to a removable item
Remove and replace a faulty item
Verify acceptable repaired item
Repair designated subtiered items
Service
Calibrate
Inspect visually

Level 3, Off-Line Off-Site Maintenance: Level 3 maintenance activities are those to be performed at the equipment supplier's facility.

3.5.2 Supply. The following criteria shall be used for selecting and positioning spares, repair parts, and consumables:

Protection Level: Items shall be packaged in accordance with the requirements of Para 5.0.

Demand Rate: The mean-time-between maintenance actions shall be the initial basis for spares determinations.

Pipeline: Pipeline quantities shall be determined on the basis of system location demand rate and repair cycle times. Resupply methods, distribution, and location of system stocks shall be determined after site selection.

Procurement and Release for Production: Long-leadtime supply items shall be procured or drawings released early enough for the items to be on site 30 days prior to initial operation. Other items shall be procured or released leadtime away so as to minimize obsolescence due to design changes, except for those items for which significant cost savings can be achieved through acquisition concurrent with production.

Minimum/Maximum Levels: Minimum and maximum quantities of spares and repair parts to be stocked shall initially be determined by use of predicted failure rates. These levels are to be adjusted as actual use rates are established.

3.6 Personnel and Training

3.6.1 Personnel. The Pilot Plant is to be installed, checked out, and tested by contractor personnel, then taken over and operated as a commercial power plant by utility personnel. Operation and maintenance personnel requirements shall be satisfied by recruitment from the established utility labor pool.

3.6.2 Training. Unique aspects of the master control dictate a need for training existing utility people but do not establish a need for new skills or trades.

3.7 Precedence

The order of precedence of master control requirements and characteristics shall be as follows:

(a) Performance (including scalability to commercial plant requirements)
(b) Safety
(c) Cost

Specific characteristics and requirement precedence shall be established based on system cost-effectiveness sensitivity analyses. The specification has precedence over documents referenced herein. The contractor shall notify the procuring activity of each instance of conflicting, or apparently conflicting, requirements within this specification or between this specification and a referenced document.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 General

4.1.1 Responsibility for Tests. All tests shall be performed by the contractor. These tests may be witnessed by the Department of Energy or its representatives, or the witnessing may be waived. In either case, substantive evidence of hardware compliance with all test requirements is required.

4.1.2 General Test Requirements. Tests shall be conducted in accordance with a test plan to be prepared by the contractor and approved by DoE.

Specific required tests are identified in Para 4.2. Tests shall be classified in the test plan as:

(a) Development tests for the purposes of determining the design.

(b) Acceptance tests for the purpose of verifying conformance to design and determining acceptability of product for further operations or for delivery.

(c) Qualification tests for the purpose of verifying adequacy of design and method of production to yield a product conforming to specified requirements.

Acceptance tests and qualification tests shall be defined for verification as indicated in Para 4.3. The test of the master control in conjunction with one or more subsystems is regarded as a system test and shall be as specified in the Pilot Plant system requirements.

4.1.3 Previous Tests. Maximum use shall be made of test data available from the subsystem research experiments and hardware tests already completed. Where conformance to this specification can be established at less cost by analysis of such data, tests shall not be repeated.

4.2 Specific Test Requirements

Specific required tests are defined herein. Additional tests shall be defined by the contractor in the course of design and development where necessary to properly validate the performance of the master control.

4.2.1 Master Control Performance Tests. Simulations may be used for inputs from controlled subsystems pending compatibility and operational tests (including demonstration) under the Pilot Plant system requirements specification. (This portion will define tests for evaluation of the master control as fully assembled in order to assure compatibility before attempting system tests.)

4.2.2 Assembly and Subassembly Performance Tests.

4.2.3 Environmental Tests.

4.2.4 Materials and Processes Control Tests.

4.2.5 Life Tests and Analyses. One set of each major subassembly shall be subjected to extended life testing. Sufficient data shall be gathered from the above life tests and also from component suppliers in order to estimate the MTBF and MTBR for the given design configuration.

4.2.6 Engineering Critical Component Qualification Tests. Components for which reliability data are not available shall be subjected to sufficient qualification testing to estimate their impact on overall device MTBF.

4.3 Verification of Conformance

Verification that the requirements of Sections 3 and 5 are fulfilled shall be performed by the contractor using the methods specified in Table 4. The methods are defined as follows:

(a) Inspection - examination and measurement of product.
(b) Analysis - examination of the design and associated data, which may include relevant test information.
(c) Similarity - demonstration or acceptable evidence of the performance of a product which is sufficiently similar to permit conformance to be inferred.
(d) Test - functional operation or exposure under specified conditions to evaluate product performance.
(e) Demonstration - exhibition of the product or service in its intended modes and conditions.

Table 4

MASTER CONTROL REQUIREMENTS VERIFICATION MATRIX

Verification Methods	Test Categories
1. Inspection 2. Analysis 3. Similarity 4. Test 5. Demonstration	A. Acceptance Test B. Qualification Test (including life tests and critical component qualification)

N/A denotes "not applicable"

Requirement (paragraph)	Verification Method	Test Category	Remarks

4.3.1 Hardware Acceptance for Pilot Plant. The contractor shall provide a method by which hardware conformance to the design will be verified prior to initiation of master control tests. This verification of conformance shall include proof-by-assembly and the examination of records as inspection elements. A record shall be made of each inspection or test performed and of the verification. In addition, evidence shall be maintained of satisfactory accomplishment of inspections and tests required by codes and standards that apply to the master control.

5.0 PREPARATION FOR DELIVERY

5.1 General

Packaging for master control components shall provide adequate protection during shipment by common carrier from supplier to the first receiving activity for immediate use or temporary storage.

5.2 Preservation and Packaging

Master control components that may be harmed when exposed to the normal transportation and handling environments (annex, Para 3.2) shall be protected by inert environments, barrier materials, or equivalent techniques.

5.3 Packing

Shipping containers and their cushioning devices shall ensure protection of components when exposed to the shock and vibration loads defined in Para 3.2 of the annex. Containers shall meet, as a minimum, the requirements in the following regulations as applicable to the mode of transportation used.

(a) National Motor Freight Classification (highway transportation)
(b) Uniform Freight Classification (railroad transportation)
(c) CAB Tariff, 96 and 169 (air transportation)
(d) R. M. Graziano's Tariff 29 (for dangerous articles - surface)
(e) CAB Tariff 82 (for dangerous articles - air)

5.4 Handling and Transportability

Containers with gross weights exceeding 60 lb shall have skids and other provisions for handling by standard materials handling equipment. When feasible, container sizes and configurations shall be compatible with efficient use of transport vehicles.

5.5 Marking

Unless otherwise specified, container marking shall be standard commercial practice.

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PRELIMINARY DESIGN

EQUIPMENT	QUANTITY	I.D. NUMBER	DESCRIPTION	REMARKS
Turbine - Generator	1	1	112,000kW Single Auto Admission, Condensing	
			TC2F-20 LSB 1450PSIG-950°F-2.5"HgA: A.A @ 350PSIG-	
			565°F. Generator 135,000kVA, .90 P.F., 13,800V.	
			Hydrogen Cooled, Static Exicter, 3600RPM.	
			Accessories:	
			Turbine Gland Steam Condenser w/Exhauster	
			Generator Vapor Extractor	
			A. C. Lube Oil Pump	
			D. C. Lube Oil Pump	
			Lube Oil Reservoir w/Exhauster	
			Lube Oil Coolers	
			Generator Hydrogen Coolers	
			Electro-Hydraulic Control System	
Condenser	1	1	135,000 Sq.Ft., 2-Pass, Surface Condenser,	
			7/8" O.D. x 20BWG 90-10 Copper Nickel Tubes,	
			28'-0" Effective Length.	
Condenser Vacuum Pumps	2	1A, 1B	12.5 SCFM @ 1"HgA Nash Mechanical Vacuum Pump	Ea. Full Size
			700 RPM, 50HP, 460V.-3Ph-60Hz Motor	
Cooling Tower	1	1	6-Cell Cross Flow Mechanical Draft, 200 H.P.,	
			460V.-3Ph-60Hz Motors, 116,500 GPM, 815x10^{6}BTU/hr,	
			73.4°FWBT 88°FCWT.	

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EQUIPMENT	QUANTITY	I.D. NUMBER	DESCRIPTION	REMARKS
Circulating Water Pumps	2	1A 1B	Vertical Mixed Flow, Wet Pit Pump, 2 Stage	Ea. Half Size
			440 RPM, 1500HP, 4160V.-3Ph-60Hz Motor 57,750 GPM	
			@ 76 Ft. TDH	
Condensate Hotwell Pumps	2	1A, 1B	Vertical Turbine Can Type, 4 Stage 1750RPM,	Ea. Full Size
			200HP, 460V.-3Ph-60Hz. Motor. 1850 GPM @ 280 Ft.	
			TDH	
Thermal Storage Feed Pumps	2	1A, 1B	Horizontal, Centrifugal, 4 Stage, 3550 RPM,	Ea. Full Size
			800 HP, 4160V.-3Ph.-60Hz. Motor. 2200 GPM @	
			970 Ft.TDH	
Receiver Feed Pumps	3	1A,1B,1C	Horizontal, Centrifugal, Double Case Barrel Type,	Ea. Half Size
			7 Stage, 6300 RPM, with Hydraulic Variable Speed	
			Drive 2500HP 4160V.-3Ph.-60Hz. Motor. 1125GPM	
			@ 6625 Ft. TDH	
Condensate Transfer Pumps	2	1A, 1B	Horizontal, End Suction, Centrifugal, 30HP,	Ea. Full Size
			460V.-3Ph.-60Hz. Motor. 300GPM @ 220 Ft.TDH	
Low Pressure Heater	1	1	Horizontal, Stainless Steel Tubes, Carbon Steel	
			Shell (Located in Condenser Neck).	
Deaerating Heater	1	2	Horizontal Spray-Tray Type with Internal S.S.	
			Vent Condenser 1,000,000 Lb/hr. Capacity,	
			.005 cc/liter O_2 in Effluent Horizontal Storage	
			Tank 20,000 Gal Capacity	

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EQUIPMENT	QUANTITY	I.D. NUMBER	DESCRIPTION	REMARKS
High Pressure Heaters	3	3,4,5	Horizontal, Carbon Steel Tubes, Carbon Steel	
			Shell, 3600PSIG Design Tube Side	
Condensate Storage Tank	2	1A, 1B	100,000 Gal., Carbon Steel w/Plasite Lining	
			28'-0" Dia. x 22'-0" Hi.	
Turbine Lube Oil Filter Set	1	1	Cartridge Type, Dual Filter Pump Set 15GPM.	
			Gear Pump 3/4HP, 460V.-3Ph-60Hz. Motor	
Turbine Lube Oil Purifier	1	1	Centrifuge Separator, 15 GPM, 1HP, 460V.-3Ph-	
			60Hz. Motor	
Turbine Lube Oil Storage Tank	1	1	6000 Gal., 2 Compartment	
Turbine Lube Oil Transfer Pump	1	1	50GPM Gear Pump 1HP Motor	
Makeup Demineralizer System	2	1A 1B	100 GPM Capacity	Ea. Full Size
Inline Demineralizer System	2	1A 1B	1800 GPM Capacity	Ea. Full Size
Receiver Flash Tank	1	1	4'-0" Dia. x 7'-0" Str. Shell, 3/4" Pl., ASME Code	
Cooling Tower Acid Tank	1	1	6000 Gal., Horizontal 8'0" Dia x 16'1" Str. Shell 3/8" PL	
Cooling Tower Chlorinator	1	1	6000 lb/day V-Notch Chlorinator w/Evaporator	
Cooling Tower Chem Feed Tank	1	1	50 Gal., Type 304 Stainless Stesl	
Bearing Water Heat Exch	2	1A 1B	Horiz. Shell and Tube, Carbon Steel Shell, Cu-Ni	Ea. Full Size
			Tubes, 600 GPM	
Cooling Tower Chem. Feed Pump	2	1A, 1B	2 GPH, Posit. Displ. w/1/4 HP. D.C. Motor	Ea. Full Size

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EQUIPMENT	QUANTITY	I.D. NUMBER	DESCRIPTION	REMARKS
Bearing Cooling Water Pumps	2	1A, 1B	Horizontal, End Suction Centrifugal, Single Stage,	Ea. Full Size
			30HP, 460V.-3Ph.-60Hz. Motor. 600 GPM @ 130Ft.TDH	
Bearing Cooling Water Head Tank	1	1	Vertical Tank, 2'-0" O.D. x 4'-0"Hi	
Potable Water Pump	2	1A, 1B	Horizontal, End Suction, Centrifugal, 50GPM @	
			60 Ft.TDH 1.5HP Motor	
Potable Water Heater	1	1	150 Gal. Electric 440V.-3Ph.-60Hz.	
Potable Water Storage Tank	1	1	10.000 Gal. Vertical 12'-0" Dia. x12'-0" Hi (Lined)	3/8" PL
Sewage Treatment Plant	1	1	4000GPD, Aeration Unit	
Service Air Compressor	2	1A 1B	350SCFM @ 100PSIG, Reciprocating, Double Acting,	Ea. Full Size
			Two Stage, 75HP Motor	
Service Air Aftercooler	2	1A, 1B	Shell and Tube Type with Moist. Separator	Ea. Full Size
Service Air Receiver	1	1	350 Cu.Ft. Carbon Steel, ASME Code	
Instrument Air Compressor	2	1A, 1B	300SCFM @ 100PSIG, Reciprocating, Double Acting	Ea. Full Size
			Single Stage, Oil-Free Air, 50HP Motor,	
			460V.-3Ph.-60Hz.	
Instrument Air Aftercooler	2	1A, 1B	Shell and Tube Type with Moist. Separator	Ea. Full Size
Instrument Air Receiver	1	1	400 Cu.Ft. Carbon Steel, ASME Code	
Instrument Air Dryer	2	1A, 1B	300SCFM Desiccant Type, Dual Column,	Ea Full Size
			Electric Regeneration, - 40°F Dew Point.	

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EQUIPMENT	QUANTITY	I.D. NUMBER	DESCRIPTION	REMARKS
Instrument Air Prefilter	2	1A, 1B	300SCFM, Cartridge Filter	
Instrument Air Afterfilter	2	1A, 1B	300SCFM, Cartridge Filter	
Raw Water Clarifier (Lime Soft.)	1	1	3000 GPM, 65'-0" Dia.	
Make-up Demineralizer Sand Filter	2	1A, 1B	100 GPM, 6'-6" Dia.	Ea. Full Size
Demineralizer Caustic Storage Tank	1	1	6000 Gal. Carbon Steel, Horiz. 8'-0" Dia x 16'-1"	Shell 3/8" PL
Demineralizer Caustic Pump	4	1A,1B,1C,1D	120 GPH, Posit. Displ. w/3/4 H.P., 460V-3Ph-60 Hz	
Demineralizer Acid Storage Tank	1	1	6000 Gal. Carbon Steel, Horiz. 8'-0" Dia x 16'-1"	Shell 3/8" PL
Demineralizer Acid Pump	2	1A, 1B	100 GPH Posit Displ w/3/4 H.P., 460V-3Ph-60 Hz	In-line Demin.
Feedwater Chem. Feed Tank	2	1A, 1B	50 Gal., Type 304 S.S., Hydrazine and Ammonia	
Feedwater Chem. Feed Pump	3	1A, 1B	2 GPH, Posit. Displ. W/1/4 H.P., 460V-3Ph-60 Hz	1 Spare
Fire Pump (Motor Driven)	1	1A	1500 GPM @ 320Ft. TDH, Horiz. Centrifugal	
			200HP, 460V.-3Ph.-60Hz. Elect. Motor	
Fire Pump (Engine Driven)	1	1B	1500 GPM @ 320 Ft. TDH, Horiz. Centrifugal	
			200HP Diesel Engine	
Jockey Pump (Fire Maint.)	1	1	50 GPM @ 320 Ft TDH, Horiz. Centrifugal	
			10 HP 460V.-3Ph.-60Hz. Motor	
Diesel Generator	2	1A,1B	750 kW Diesel Engine Generator Unit, 4160V.	Emerg. Shutdown
Station Battery	1	1	125 V.D.C., 400 Amp. - Hr.	
Battery Charger	1	1	75 Amp 125V.D.C./460V A.C, 3-Ph-60Hz.	
Evaporative Cooler	4	1A,1B,1C,1D	70,000 CFM EA. Unit	
Demineralizer Acid Pump	2	1A 1B	200 GPH, Posit. Displ., 1 HP, 460V-3Ph-60 Hz	Makeup Demin.

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EQUIPMENT	QUANTITY	I.D. NUMBER	DESCRIPTION	REMARKS
Raw Water Pump	2	1A, 1B	Vertical Turbine, 3000 GPM @ 100Ft,125 HP Motor	Ea. Full Size
Clarified Water Pump	2	1A, 1B	Vertical Turbine, 3000 GPM @ 80 Ft., 100 HP Motor	Ea. Full Size
Demineralizer Feedwater Pump	2	1A, 1B	Horiz. End Suct., 250 GPM @ 110 Ft., 15 H.P. Motor	
Boiler Water Sample Panel	1	1	Boiler Water Sampling & Monitoring Panel	
Control Room Air Conditioner	1	1		
Cooling Tower Acid Feed Pumps	2	1A, 1B	3 GPH, Posit. Displ., 3/4 HP, D.C. Motor	1 Spare
Lime Silo	1	1	4000 Cu. Ft., 18' Dia. x 35'-0" Hi, carbon steel	
Lime Unloading/Conveying System	1 Lot	1	Railcar and/or Truck Lime Unloading System	
Lime Feeder	2	1A, 1B	1000 lb/hr	1 Spare
Lime Slaker	2	1A, 1B	1000 lb/hr	1 Spare
Clarifier Chem Feed Equipment	Lot	–	Polymer/Coagulant/Alum. Feed Equipment	
Thermal Storage Drain Pump	5	1A,1B,1C	Horizontal, Centrifugal, Double Case, Barrel Type,	
		1D,1E	5 stage, 3550 RPM, 1000 H.P., 4160v-3 Ph.-60 Hz.	
			Motor. 500 GPM @ 3880 Ft. TDH. Inlet Pressure	
			1400 PSIG @ 480°F.	
Turbine Room Crane	1	1	40 Ton Bridge Crane, 50'-0" Span (10 Ton Aux. Hook)	
Aux. Steam Boiler	1		50,000 lb/hr., 30 PSIG, Oil-Fired, ASME Code.	
Fuel Oil Storage Tank	1	1	Vertical Above Ground Tank, 25'-0" Dia x 18'-0" Hi.	API Std 650
			65,940 Gal. No. 2 Fuel Oil	

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ELECTRICAL POWER GENERATION SUBSYSTEM

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PROJECT 100 MW SOLAR THERMAL ELECTRIC PLANT

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PRELIMINARY DESIGN

EQUIPMENT	QUANTITY	I.D. NUMBER	DESCRIPTION	REMARKS
Main Power Transformer	1	1	130 MVA, FOA, 115-13.2 kV, Wye Grounded-Delta	
Aux. Power Transformer	1	1	13.44/22.4 MVA,OA/FA, 13.2-4.16 kV, Delta-Wye Resistance Grounded.	
Start-up Transformer	1	1	13.44/22.4 MVA,OA/FA, 115-13.2 kV, Wye Grounded-Wye Resistance Grounded.	
4160 Volt Switchgear	1	1	Metal Clad Switchgear with 22-5kV, 1200A.,	
			250 MVA Circuit Breakers	
480 Volt Load Center	2	1A 1B	Load Center, Double-Ended, 2-750kVA,4160-480V. Transformers.	
480 Volt Load Center	1	1C,1D	Load Center, Double-Ended, 2-1000kVA,4160-480V. Transformers.	
Outdoor Oil Circuit Breaker	1	1	121kV,1200 Amp., 20,000 Amp. short circuit current.	
Disconnect Switches	2	1A,1B	121kV,1200 Amp., 3 Pole Gang Operation	
Steel Structure	1	-	For 2-121kV, 1200 Amp. Disconnect Switches & Circuit Switcher	
Circuit Switcher	1	1	115kV, 1200 Ampere	
480 Volt Motor Control Center	2	1A-1B	Circuit Breaker & Circuit Breaked Combination Starters.	
480/120/208 V. Transformer	6	1A-1F	30kVA, Dry Type, 3 Phase	
120/208V. Distribution Panel	9	1A-1J		
D.C./A.C. Inverter	2	1A,1B	15kVA, 480 V., A.C., 3 Phase, 125 V.D.C.	
Isolated Phase Bus	1		15kV, 6000 Amp., with Surge Protection & V.T. Cubicle.	

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EQUIPMENT	QUANTITY	I.D. NUMBER	DESCRIPTION	REMARKS
Turbine - Generator	1	1	12,500 kW Single Auto Admission Condensing,	
			TCSF-11.4"LSB 1450PSIG-950°F - 2.5"HgA; A.A @	
			370 PSIG-525°F. Generator 16,000 kVA, .85P.F.,	
			13,800 V. Air Cooled, Static Exicter, 3600 RPM.	
			Accessories:	
			A.C. Lube Oil Pump	
			D.C. Lube Oil Pump	
			Lube Oil Reservoir	
			Lube Oil Coolers	
			Electro- Hydraulic Control System	
Condenser	1	1	12,000 Sq.Ft., 2-Pass, Surface Condenser,	
			3/4" O.D.x20BWG 90-10 Copper Nickel	
			20'-0" Effective Length.	
Condenser Vacuum Pumps	2	1A, 1B	7.5 SCFM @ 1"HgA Nash Mechanical Vacuum	Ea. Full Size
			Pump, 900 RPM, 30HP, 460V.-3Ph-60Hz Motor	
Cooling Tower	1	1	2-Cell, Cross Flow Mechanical Draft,	
			100HP., 460V.-3Ph-60Hz Motors, 12,500 GPM	
			95 x 10^6 BTU/hr., 73.4° FWBT, 85° FCWT	
Circulating Water Pumps	2	1A, 1B	Horizontal, Centrifugal, Double Suction, Single	Ea. Half Size
			Stage, 1800 RPM, 150HP., 460V.-3Ph-60Hz Motor	
			6250 GPM @ 60 Ft. TDH	

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EQUIPMENT	QUANTITY	I.D. NUMBER	DESCRIPTION	REMARKS
Condensate Hotwell Pumps	2	1A, 1B	Horizontal, Centrifugal, Horiz. Split Case	Ea. Full Size
			1750 RPM, 50 H.P., 460V.-3Ph-60Hz.	
			Motor, 450 GPM @ 230 Ft. TDH	
Booster Pumps	2	1A, 1B	Horizontal, Centrifugal, 4 Stage, 3550 RPM,	Ea. Full Size
			250 H. P., 460V.-3Ph.-60Hz. Motor. 575 GPM @	
			1166 Ft. TDH	
Receiver Feed Pumps	2	1A, 1B	Horizontal, Centrifugal, Double Case	Ea. Full Size
			Barrel Type, 11 Stage, 3465 RPM, with Hydraulic	
			Variable Speed Drive, 600 H.P., 4160 V.-3Ph.-60Hz.	
			Motor, 350 GPM @ 4670 Ft. TDH	
Condensate Transfer Pumps	2	1A, 1B	Horizontal, End Suction, Centrifugal, 20 H.P.,	Ea Full Size
			460V.-3Ph-60Hz. Motor. 200 GPM @ 150 Ft. TDH	
Low Pressure Heater	1	1	Horizontal, Stainless Steel Tubes, Carbon Steel	
			Shell	
Deaerating Heater	1	2	Vertical Spray-Tray Type with Internal S.S.	
			Vent Condenser. 235,200 Lb/hr Capacity,	
			.005 cc/liter O_2 in effluent. Horizontal	
			storage Tank 5000 Gal. Capacity.	

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EQUIPMENT	QUANTITY	I.D. NUMBER	DESCRIPTION	REMARKS
High Pressure Heaters	2	3,4	Horizontal, Carbon Steel Tubes, Carbon Steel	
			Shell, 750 PSIG Design Tube Side	
Condensate Storage Tank	2	1A, 1B	50,000 Gal., Carbon Steel w/Plasite Lining	
			22'-0" Dia. x 18'-0" Hi	
Turbine Lube Oil Filter Set	1	1	Cartridge Type, Dual Filter Pump Set 10 GPM,	
			Gear Pump, ½HP 460V-3Ph-60 Hz Motor	
Turbine Lube Oil Purifier	1	1	Centrifuge Separator, 10 GPM, ½HP, 460V.-3Ph-60	
			Hz Motor	
Turbine Lube Oil Storage Tank	1	1	4000 Gal., 2 Compartment	
Turbine Gland Seal Drain Tank	1	1	3'-0" Dia.x 6'-0" Hi., ¼" C.S. Plate	
			Atmospheric Tank.	
Turbine Lube Oil Transfer Pump	1	1	50 GPM Gear Pump, ½ HP Motor	
Makeup Demineralizer System	2	1A, 1B	50 GPM Capacity	Ea. Full Size
Inline Demineralizer System	2	1A, 1B	450 GPM Capacity	Ea. Full Size
Receiver Flash Tank	1	1	3'-0" Dia. x 6'-0" Str. Shell, 5/8" Pl., ASME Code	
Cooling Tower Acid Tank	1	1	6000 Gal. Carbon Steel, Horiz. 8'0" Dia x 16'1" Shell 3/8" PL	
Cooling Tower Chlorinator	1	1	1000 Lb/day V-Notch Chlorinator	
Cooling Tower Chem. Feed Tank	1	1	50 Gal, Type 304 Stainless Steel	
Bearing Water Heat Exch.	2	1A, 1B	Horiz. Shell and Tube, Carbon Steel Shell,	Ea. Full Size
			Cu-Ni Tubes, 150 GPM	
Cooling Tower Chem. Feed Pump	2	1A, 1B	2 GPH, Positive Displ. w/1/4 H.P. D.C. Motor	Ea. Full Size

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EQUIPMENT	QUANTITY	I.D. NUMBER	DESCRIPTION	REMARKS
Bearing Cooling Water Pumps	2	1A, 1B	Horizontal, End Suction Centrifugal, Single	Ea. Full Size
			Stage, 7½ HP, 460-V.-3Ph-60Hz. Motor.	
			150 GPM @ 100 Ft. TDH	
Bearing Cooling Water Head Tank	1	1	Vertical Tank, 2'-0" O.D. x 4'-0" Hi.	
Potable Water Pump	2	1A, 1B	Horizontal, End Suction, Centrifugal, 30GPM @	Ea. Full Size
			60 Ft. TDH, 1 HP Motor	
Potable Water Heater	1	1	150 Gal. Electric 440V. 3Ph-60Hz.	
Potable Water Storage Tank	1	1	6000 Gal. Vertical 9'-6" Dia x 12'-0" Hi.	
Sewage Treatment Plant	1	1	3000 GPD, Aeration Unit	
Service Air Compressor	2	1A, 1B	350 SCFM @ 100 PSIG, Reciprocating, Double Acting,	Ea. Full Size
			Two Stage, 75 HP Motor	
Service Air Aftercooler	2	1A, 1B	Shell and Tube Type with Moist. Separator	Ea. Full Size
Service Air Receiver	1	1	350 Cu.Ft. Carbon Steel, ASME Code	
Instrument Air Compressor	2	1A, 1B	250 SCFM @ 100 PSIG, Reciprocating, Double Acting,	Ea. Full Size
			Single Stage, Oil-Free Air, 50HP Motor,	
			460V.-3Ph-60Hz.	
Instrument Air Aftercooler	2	1A, 1B	Shell and Tube Type with Moist. Separator	Ea. Full Size
Instrument Air Receiver	1	1	350 Cu.Ft. Carbon Steel, ASME Code	
Instrument Air Dryer	2	1A, 1B	250 SCFM, Desiccant Type, Dual Column, Electric	Ea. Full Size
			Regeneration, - 40°F Dew Point.	
Water Sample Panel	1	1	Boiler Water Sampling & Monitoring Panel	

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EQUIPMENT	QUANTITY	I.D. NUMBER	DESCRIPTION	REMARKS
Instrument Air Prefilter	2	1A, 1B	250 SCFM, Cartridge Filter	
Instrument Air Afterfilter	2	1A, 1B	250 SCFM, Cartridge Filter	
Raw Water Clarifier	1	1	500 GPM, 28'-0" Diameter (Incl. Chem. Feed Equip.)	
Make-up Demineralizer Sand Filter	2	1A, 1B	50 GPM, 5'-0" Diameter	Ea. Full Size
Demineralizer Caustic Storage Tank	1	1	6000 Gal. Carbon Steel; Horiz. 8'0" Dia x 16'1" Shell 3/8" PL	
Demineralizer Caustic Pump	4	1A,1B,1C,1D	40 GPH Posit. Displ. w/1/3 HP, 460V-3Ph-60 Hz	Ea. Full Size
Demineralizer Acid Storage Tank	1	1	6000 Gal. Carbon Steel, Horiz 8'0" Dia x 16'1" Shell 3/8" PL	
Demineralizer Acid Pump	2	1A, 1B	24 GPH Posit. Displ. w/1/3 HP.,460V-3Ph-60 Hz	In-line Demin.
Feedwater Chem. Feed Tank	2	1A, 1B	50 Gal, Type 304 Stain Steel, Hydrazine & Ammonia	
Feedwater Chem Feed Pump	3	1A, 1B, 1C	2 GPH, Posit. Displ. w/1/4 HP, 460V-3Ph-60 Hz	One Spare
Fire Pump (Motor Driven)	1	1A	1500 GPM @ 320 FT. TDH, Horiz. Centrifugal	
			200HP, 460V-3Ph-60Hz. Elect. Motor	
Fire Pump (Engine Driven)	1	1B	1500 GPM @ 320 Ft. TDH, Horiz. Centrifugal	
			200HP Diesel Engine	
Jockey Pump (Fire Maint.)	1	1	50GPM @ 320 Ft. TDH, Horiz. Centrifugal	
			10 HP, 460 V-3Ph-60Hz. Motor	
Diesel Generator	1	1	350kW Diesel Engine Generator Unit, 480V., 440 kVA	Emerg. Shutdown
Station Battery	1	1	125 V.D.C., 185 A.H.	
Battery Charger	1	1	20Amp. 125V.D.C./460V.A.C.,3-Ph-60Hz	
Evaporative Cooler	2	1A, 1B	15,000 CFM EA--UNIT	
Demineralizer Acid Pump	2	1A, 1B	100 GPH Posit. Displ., w/3/4 HP, 460V-3Ph-60Hz	Makeup Demin.

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EQUIPMENT	QUANTITY	I.D. NUMBER	DESCRIPTION	REMARKS
Main Power Transformer	1	1	12/16 MVA OA/FA 115-13.2kV	
Auxiliary Power Transformer	2	1A, 1B	13.2-2.4 kV, 1500/1725 kVA OA/FA	Ea. Full Size
Generator Circuit Breaker				
Cubicle	1	1	15 kV, 1200 Amp. 250 MVA	
Generator Surge Protection				
Cubicle	1	1	3-15 kV Arresters and 3-Surge Capacitors	
Generator Grounding Cubicle	1	1	1 Distribution Transformer and Resister	
Transformer 480/120V.	3	1A, 1B, 1C		
480 Volt Load Centers	2	1A, 1B	Each with load center transformer rated 2400-480 v 750 kVA, OA	Ea. Full Size
Vertical Control Panel	1	1		
Control Console	1	1		
480 Volt Motor Control Centers	2	1A, 1B		
D.C./A.C. Inverter	1	1	2000 W., 125 V.D.C./120 V.A.C , 1 Phase	
Fuel Oil Storage Tank	1	1	Above Ground Tank, 15'-0" Dia x 18'-0" Hi, 23,730 Gal #2 Oil	API Std. 650
Turbine Room Crane	1	1	20 Ton Bridge Crane, 30 Ft. Span (5 Tone Aux. Hook)	
Auxiliary Steam Boiler	1	1	10,000 Lb/hr, 30PSIG, Oil-Fired Steam Boiler, ASME	Code
Raw Water Pump	2	1A, 1B	Horizontal, Centrifugal, Split Case 500GPM @ 100Ft. TDH, 25HP Motor.	Ea. Full Size
Clarified Water Pump	2	1A, 1B	Vertical Turbine Pump, 500GPM @50 Ft. TDH, 15 HP Motor.	Ea. Full Size
Demineralizer Feedwater Pump	2	1A, 1B	Horiz., Centrif., End Suct., 100GPM @ 115 Ft. TDH, 7 1/2 HP Motor.	Ea. Full Size
Cooling Tower Acid Pumps	2	1A, 1B	3 GPH Posit. Displ. W/1/4 H.P. D.C. Motor	Ea. Full Size