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MASTER

SYSTEM SPECIFICATION FOR FORT HOOD SOLAR COGENERATION FACILITY

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

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Preface

This document constitutes a draft update of a System Specification for a Solar Cogeneration Facility at the Fort Hood Army Base in Killeen, Texas. This specification has been prepared by the McDonnell Douglas Astronautics Company (MDAC) for review and approval by the Department of Energy (DOE) under Contract DE-AC03-81SF11495. This specification has been prepared in general accordance with the reporting instructions as specified in Enclosure III, Exhibit I, Attachment I of DE-RP03-80SF10768. Accordingly, this draft will be updated and a final System Specification submitted at the end conclusion of the study contract period ending 31 August 1981.

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Section 1.0

GENERAL

1.1 SCOPE

This specification (Sections 1 through 4) defines the characteristics and design and environmental requirements for a Solar Cogeneration Facility at the Fort Hood Army Base in Killeen, Texas. In addition, Section 5 of this specification summarizes the conceptual design, performance capabilities, cost and economic data and other information for the cogeneration facility that has been designed to meet these requirements.

The system requirements specified in Sections 3.0 and 4.0 shall be used for all conceptual design activities. It is intended that the system requirements herein can be ultimately verified by either analyses, similarity to existing equipment, or testing. This specification shall be periodically updated as the system concept is further defined, and shall remain as the complete specification for system performance requirements throughout the life of the program. During a subsequent development phase, this system specification will be supplemented with development specifications for the detailed design, development and production of the facility and subsystems/components.

1.2 PROJECT DESCRIPTION

1.2.1 Project Objectives

The specific objectives of this project is to initiate the development of a solar cogeneration facility by conducting site-specific conceptual design studies and by defining subsequent development plans. This solar cogeneration facility shall:

- make effective use of solar thermal energy from a solar central receiver system integrated into a cogenerating facility,
- have the potential for construction and high reliability operation by 1986,

- provide the best possible economics for the overall plant or facility application,
- have the potential to achieve wide commercial success, and
- offer the potential for significant saving in critical oil and gas fuels.

This effort will provide the DOE and industry with:

- definitions of possible solar cogeneration facility designs;
- preliminary estimates of system performance and costs;
- preliminary estimates of technical, economic institutional, regulatory, and environmental benefits of, and barriers to, solar cogeneration facility projects;
- preliminary estimates of development test requirements, costs, and schedules for subsequent demonstration projects; and
- an indication of potential user cost sharing arrangements with the Department of Energy for subsequent demonstration projects.

1.2.2 Major Milestones

Major project milestones that can be identified at this time are as follows:

- December 1, 1980 - Contract authorization for conceptual study
- August 31, 1981 - Contract completion (9 mos.)
- June 1, 1982 - Resumption of project activities (9 mos.)
- January, 1986 - Initial Operational Capability (IOC)

1.2.3 Project Management

The Department of Energy (DOE) has sponsored the initial (Phase I) contract effort for the conceptual design of a solar cogeneration facility at Fort Hood. Business administration for this contract is handled by the DOE San Francisco Operations Office (DOE/SAN), Oakland, CA. Technical direction has been assigned to the National Sandia Laboratories, Livermore, CA.

The McDonnell Douglas Astronautics Company (MDAC), Huntington Beach, CA has been selected by DOE/SAN as the prime contractor for the Phase I effort. MDAC is supported by two subcontractors: (1) Stearns-Roger, who will provide architectural and engineering services, and (2) University of Houston Energy Laboratory, who will perform collector field optimization.

The U. S. Army, Directorate of Facilities Engineering at Fort Hood, Killeen, Texas will provide site-specific coordination and support to MDAC and DOE on an as-required basis.

The responsibilities and roles for subsequent development phases by DOE, MDAC, U. S. Army, and others, are to be determined at a later date.

1.2.4 Government Furnished Equipment and Facilities

The following equipment and facilities shall be furnished by the government for this cogeneration facility:

1. Housing and other facilities to be serviced by the solar equipment.
2. Land area for solar equipment installation.
3. Site access provisions (roads).
4. General utilities (water, telephone, power).
5. Electrical distribution grid and interconnections at the plant site.

1.2.5 Project Documentation

Major system documents to be prepared during Phase I are listed below:

1. System Specification
2. Final Technical Report

1.3 SYSTEM DESCRIPTION

Characteristics of the system and major elements are described in this section. Design and environmental requirements are specified in Sections 3.0 and 4.0, respectively. Design, performance and economic data for the system designed to meet these requirements are summarized in Section 5.0.

1.3.1 System

The Fort Hood solar cogeneration facility is a total energy system designed for both electrical power production and the generation of heat for space conditioning and domestic hot water. An illustration of the installation at Fort Hood Complex 87000 is shown on Figure 1.3-1, a schematic of the solar equipment is shown on Figure 1.3-2, and a diagram of the system energy flow process on Figure 1.3-3. As illustrated on these figures, a field of heliostats concentrates solar insolation on a tower-mounted receiver. To absorb the heat, a heat-transfer salt (HITEC) is pumped through the receiver and routed to storage tanks. The stored heat is then transferred to a water-steam loop via a steam generator producing super-heated steam. The steam is expanded through a conventional steam rankine axial turbine which drives a generator producing electricity. Turbine exhaust steam is also used to heat water for use in providing room heating, air conditioning, and hot water for the Army complex. During periods of low insolation or startup periods, the plant is capable of accepting thermal energy from an auxiliary fossil-fueled heater. Major facility characteristics are summarized on Table 3-1.

[FIGURES TO BE REVISED]

Figure 1.3-1. Solar Cogeneration Facility at Fort Hood

Figure 1.3-2. Solar Cogeneration Facility Arrangement

Figure 1.3-3. System Schematic

Table 1.3-1

Fort Hood Solar Cogeneration Facility Characteristics

General Characteristics

- Facility type Cogeneration (electric and thermal energy)
- Location. Fort Hood Army Base, Killeen, Texas
- Installation. Complex 87000 (20 buildings, 1650 troops)
- Availability. 1986 IOC

Subsystem Characteristics

- Heliostats. MDAC Second Generation; North Field Configuration
- Tower Free-Standing Steel Tower
- Receiver. Conical Partial Cavity
- Heat Transfer Fluid HITEC (53% KNO_3 , 40% NaNO_2 , 7% NaNO_3)
- High-temp. Storage. Separate Hot and Cold Tanks
- Fossil-fired Heater Gas-fired HITEC heater
- Turbine Steam rankine
- Plant Controls. Semi-automatic; trailer mounted
- Cooling Equipment Absorption chiller; wet cooling tower
- Thermal Distribution. Existing steam and chilled water lines
- Low-temp. Storage Existing hot water tanks in barracks

The Fort Hood Solar Cogeneration Facility system shall consist of the following major elements:

- Site
- Site Facilities
- Collector Subsystem (CS)
- Receiver Subsystem (RS)
- Tower Subsystem (TS)
- Energy Transport and Storage Subsystem (ETSS)
- Fossil Energy Subsystem (FES)
- Electrical Power Generating Subsystem (EPGS)
- Plant Control Subsystem (PCS)
- Space Conditioning Subsystem (SCS)
- Domestic Hot Water Subsystem (DHWS)
- Specialized Equipment

A further breakdown of subsystem elements is shown on Figure 1.3-4. Preliminary characteristics of each major subsystem are given below.

1.3.2 Site

The Fort Hood Army Base is located immediately west of Killeen, Texas, approximately midway between San Antonio and Fort Worth in a region of favorable insolation ($\approx 5 \text{ KWh/m}^2/\text{day}$). The climate is humid subtropical with hot summers, although the site is located very near the western boundary of this climatic region. The site receives an average of 32 inches of precipitation per year, most of which is rain. The terrain is reasonably flat and well suited for a central receiver type solar system.

[TO BE UPDATED]

Figure 1.3-4 Solar Facility Elements

The solar cogeneration facility will service Complex 87000, which is located at the eastern edge of the base. This complex consists of a group of 20 buildings of contemporary Army design that provides the housing, food services, administration, dispensary, PX, storage, recreational and central energy for a brigade-size complement of troops (approximately 1,650) as illustrated on Figure 1.3-5. The solar equipment will be located to the east of the 87000 troop housing complex, and will directly interface with the existing central power plant that presently provides all power and space conditioning for the complex.

The proposed site for the installation of the solar collectors is bounded by existing roads. A small parking lot within this area would be relocated. Site development for the solar cogeneration facility will include minor grading, drainage provisions, and the installation of underground pipe/cableways, service roads, parking areas, walkways, and basic utilities (water, gas, power, communications).

1.3.3 Site Facilities

Site facilities are the additional buildings and special equipment required for the installation and operation of the solar system. These facilities for the Fort Hood installation include the plant control housing (mobile trailer), main plant equipment building (housing the skid-mounted steam generator, turbine, generator, and other equipment), security fencing, special service equipment (fire protection, lightning protection, and area lighting). The main plant equipment building will be used for necessary storage and maintenance. There are no plans for a special visitors' center.

1.3.4 Collector Subsystem (CS)

The collector subsystem (CS) consists of a field of sun tracking mirrors (heliostats) which reflect the sun's energy to a tower mounted receiver located south of the heliostat field.

[ART TUBE REVISED]

Figure 1.3-5. 87000 Complex and Collector Field

The CS includes the following:

- Heliostat Assembly - Reflective surface, structural support, drive units, control sensors, pedestals, foundation, instrumentation and electrical wiring.
- Heliostat Controllers - Individual heliostat controllers, heliostat field controllers, control system interface electronics, and power and control cabling.

For the Fort Hood solar cogeneration facility, MDAC Second Generation heliostats will be installed directly east of Complex 8700, as illustrated on Figure 1.3-5. The heliostats were designed to conform to the A10772, Sandia Livermore Laboratory, except as noted in Section 3.4 of this specification. The heliostats meet requirements of small field installations and can be transported to the site in modules. Each heliostat consists of four major subassemblies: the mirror modules, the drive unit, the pedestal support and foundation, and controls. Fourteen laminated glass mirror modules form the heliostat reflective surface. The drive unit incorporates an actuator for elevation positioning and a drive for azimuth positioning. A pedestal is used to mount the heliostat in the field to a precast concrete foundation. A representative heliostat configuration is shown in Figure 1.3-6.

The heliostats are connected to the Heliostat Field Controllers (HFC) by buried electrical cables. The heliostat field controllers communicate between groups of heliostats and the Heliostat Array Controller (HAC), which is remotely located in the centralized plant control trailer and is the interface between the CS and plant control subsystem. The heliostat array controller calculates the position of the sun and individual heliostats, calculates positioning errors and directs corrective motions via the field controllers. The individual heliostat controllers calculate actual heliostat position, compare with command position from the field controller, and drive the motors to correct the errors indicated.

Figure 1.3-6 MDAC Second Generation Heliostat

1.3.5 Receiver Subsystem (RS)

The Receiver Subsystem (RS) provides a means of transferring the incident radiant solar energy from the collector subsystem into a suitable working fluid. The RS consists of the following:

- Elevated Receiver Assembly - Energy absorbing unit, structural assembly (including housing and doors), piping and manifold, insulation, heaters, and pressure relief valving.
- Control/Instrumentation - Instrumentation, power and control cabling, and control console.

The tower, riser and downcomer piping, fluid pumps, and control valves are covered under other subsystem categories.

For the Fort Hood installation, the tower-mounted receiver is a partial cavity design facing north and tilted downward. The absorber unit consists of spiral tubes with the heat transfer fluid entering at the periphery of the aperture and exiting at the apex of the cone. Insulated doors close over the receiver aperture during periods of no insolation in order to minimize heat loss. Trace heaters keep the HITEC fluid from cooling and solidifying. A representative configuration is shown on Figure 1.3-7.

Figure 1.3-7. Receiver and Central Tower

1.3.6 Tower Subsystem (TS)

The Tower Subsystem (TS) provides support for the receiver subsystem and the HITEC riser and downcomer lines. Tower elements include the basic tower structure, supporting wires and foundations, working platforms and access provisions, service elevator and ladders, lights, lightning protection, helio-stat target device, electric power lines, and supports for heat transfer fluid lines, nitrogen purge lines, instrumentation and pneumatic lines.

For the Fort Hood application, the tower assembly is a free-standing steel design which can be transported as prefabricated sections. A representative tower configuration and major design features are shown on Figure 1.3-7.

The tower assembly shall be designed to operate under the most severe wind and seismic conditions expected with minimum receiver sway.

1.3.7 Energy Transport and Storage Subsystem (ETSS)

The energy transport and storage subsystem (ETSS) provides a means of transferring and storing the thermal energy received by the receiver subsystem, and subsequently transferring the energy from the storage tanks to a steam generator serving the electrical power generating subsystem. The ETSS consists of the following:

- Transport Assembly - Piping lines, pumps, control valves and actuators, pipe expansion joints, pipe supports and foundations, insulation, trace heaters.
- Storage Tanks - Tanks, insulation, submerged heaters, vent/relief valves, nitrogen purge system, storage media (HITEC).
- Steam Generator - Generator unit, insulation, trace heaters.
- Control/Instrumentation - Instrumentation, power and control cabling, control console.

A representative schematic of the ETSS for the Fort Hood installation is shown on Figure 1.3-8. HITEC that is heated in the receiver is routed to a "hot" storage tank where it is stored for use in generating steam for the electrical generation subsystem. The flow of HITEC to the steam generator, which is independent of receiver flow, shall be regulated by the demand for turbine inlet steam. After passing through the steam generator, the cool HITEC shall be returned to a separate "cold" storage tank. The storage tanks shall permit the storage of excess thermal energy as sensible heat during periods of high insolation for use in generating electricity during periods of low insolation. For prolonged periods of low or no insolation, the auxiliary fossil-fueled energy subsystem shall be used to generate heat for the system.

Figure 1.3-8. Energy Transport, Storage, and Fossil Heat Subsystems

1.3.8 Fossil Energy Subsystem (FES)

The Fossil Energy Subsystem (FES) consists of an auxiliary gas-fired heater that enables plant operation during cloudy days or during periods of excessively high energy demand. The FES consists of a gas-fired fuel reactor, heat exchanger, exhaust stack, gas supply lines and associated lines, pumps, valves, instrumentation and controls.

A representative auxiliary heater assembly for the Fort Hood application is shown on Figure 1.3-9. The heater is located in the HITEC inter-tank loop. HITEC from the cold thermal storage tank is pumped through the heater and into the hot thermal storage tank, as required. The FES unit is pre-assembled and skid mounted for minimum site assembly.

[ART TO BE
REVISED]

Figure 1.3-9. Representative Fossil-Fueled Auxiliary Heater Assembly

1.3.9 Electrical Power Generating Subsystem (EPGS)

The Electrical Power Generating Subsystem (EPGS) converts thermal energy into electrical power and distributes the power into an existing electrical power transmission network. The EPGS consists of the following:

- Steam/Feedwater Equipment - Condenser, cooling tower, feedwater heater/deaerator, water treatment, water/steam piping, valves/actuators, circulation pumps, insulation.
- Power Generation Assembly - Turbine, gearbox, generator, support systems.
- Power Distribution Equipment - Power lines, switch gear, circuit breakers, transformers, emergency power supply.
- Controls/Instrumentation - Instrumentation, control console, power/control cabling.

For the Fort Hood application, the EPGS utilizes a water/steam fluid loop for energy conversion, as shown on Figure 1.3-10. High temperature/high pressure steam is produced in the steam generator which draws heat from the heat transfer salts. The superheated steam is expanded through a turbine-generator assembly to produce electrical power. The electric power distribution equipment transforms, switches, regulates and controls the electrical output of the turbine-generator assembly to ensure compatible integration into an existing electrical power transmission network. The steam discharged from the turbine is condensed, cooled, treated and reheated for recirculation into the steam generator. All equipment is skid-mounted at the factory, as illustrated on Figure 1.3-11 with the remaining connections to be made at the site. A single building will house all EPGS equipment except the cooling tower and control console.

[ART TO BE UPDATED]

Figure 1.3-10. Electrical Power Generation Subsystem

Figure 1.3-11. EPGS Layout

1.3.10 Plant Control Subsystem (PCS)

The Plant Control Subsystem (PCS) is used to sense, monitor and control all system parameters necessary to ensure safe and proper operation of the entire integrated cogeneration facility. The PCS consists of the following:

- Control Equipment - Collector field control, plant process control, central control computer, remote control units, control software, instrumentation, control consoles.
- Auxiliary Equipment - Displays/keyboards, printers/plotters, storage devices.

The system architecture for the Fort Hood application consists of the control and monitoring of two distinct areas: concentrator subsystem collectors and plant processes. Redundant computers provide control and interface with all subsystems. A serial signal communications network provides independent control of all heliostats. For process control, remote control units stationed throughout the plant respond to commands from the central control unit to provide the actions necessary to control each process subsystem. The PCS permits the integrated operation and coordination of all subsystem processes, either automatically or manually, under the direction of a single plant operator. The PCS also enables the gathering and processing of plant data. All PCS equipment will be preassembled and checked out in a mobile control trailer at the factory prior to delivery to the site. The control trailer, which is located adjacent to the EPGS building, also contains necessary space conditioning equipment and operator conveniences. The control trailer is illustrated on Figure 1.3-12, together with key design features.

- Single Operator
- Growth for Full Automation
- Redundant Computers
- Serial Network
- Remote Control Units
- Pre-Assembled Control Trailer and Equipment

Figure 1.3-12. Plant Supervisory Control Subsystem

1.3.11 Space Conditioning Subsystem (SCS)

The Space Conditioning Subsystem (SCS) is the equipment used to provide room heating and air conditioning. The SCS consists of the following:

- Air Conditioning Equipment - Absorption chiller, steam lines, chilled water lines, storage tanks, insulation, instrumentation, controls.
- Room Heating Equipment - Heat exchangers, steam distribution lines, steam accumulator, condensate receiver, insulation, instrumentation, controls.

A schematic of the space conditioning subsystem for the Fort Hood application is shown on Figure 1.3-13. Room heating on the base is provided by the circulation of hot water through existing forced air heaters and lines. The heat source is provided by steam generated at the turbine exhaust which is used to provide low pressure steam to the barracks and other buildings. Room air conditioning on the base is provided by the circulation of chilled water through existing forced air blowers and lines. The source of the chilled water is provided by an absorption chiller which distributes chilled water through existing lines to storage tanks in the barracks and other buildings. The absorption chiller is powered by turbine exhaust steam.

[ART TO BE REVISED]

Figure 1.3-13. Space Conditioning and Hot Water Subsystems

1.3.12 Domestic Hot Water Subsystem (DHWS)

The Domestic Hot Water Subsystem (DHWS) is the equipment used to provide hot water for domestic use. The DHWS includes the following:

- Water Heating Equipment - Heat exchanger, steam distribution lines, steam accumulator, condensate receiver, insulation, instrumentation, controls

Domestic hot water at Fort Hood is supplied from existing hot water generators located at specific locations throughout the complex. The heat source for these hot water tanks will be the same as described for room heating. Turbine exhaust steam in the turbine condenser will be used to generate steam for room heating and domestic water heating via existing steam lines, as shown on Figure 1.3-13.

1.3.13 Specialized Equipment

Specialized equipment includes all equipment required to service, maintain, repair or overhaul any of the elements of the solar cogeneration facility. This equipment includes the following:

- Service Vehicles - Service van, mobile crane
- Tools and Equipment - Maintenance tools, checkout/calibration equipment, handling fixtures/slides, work platforms/ladders.

For the Fort Hood application, this equipment will be housed in existing maintenance and storage areas on the base.

1.4 MODES OF OPERATION

The facility operates in two principal modes: energy collection and energy utilization. The plant is capable of operating in either mode independently, and/or both modes simultaneously. The system is also operational in transitional and standby/inactive modes.

1.4.1 Energy Collection Mode

In the energy collection mode, thermal energy is collected and stored in the energy storage tank for subsequent use in the energy utilization mode. The thermal energy is normally collected during the day from the reflected solar energy, which is absorbed in the receiver subsystem and transferred to the energy storage tanks. During the periods of low or no insolation, thermal energy can be provided to the storage subsystem from the fossil energy subsystem. For energy collection, the possible steady-state modes of operation are:

- (1) Solar only (sun following)
- (2) Fossil only (set power).
- (3) Hybrid (solar and fossil).

1.4.2 Energy Utilization Mode

In the energy utilization mode, thermal energy that is stored in the thermal storage tanks is used to generate steam for electrical power generation, space conditioning, and domestic water heating. This mode is independent of the energy collection mode provided that sufficient thermal energy has been previously stored in the thermal storage tanks. For the energy utilization mode, the possible steady-state operating modes are:

- (1) Electric power only (set power levels or load following).
- (2) Electric/thermal power.
- (3) Thermal power only.

1.4.3 Transitional Modes

The system is capable of several transitional operations including normal startup and shutdown, intermittent cloud operation, emergency stop and normal transitions between operating modes.

1.4.4 Standby/Inactive Mode

The system is capable of being held in an overnight standby mode, a maintenance mode, or an inactive mode for extended shutdown periods.

1.5 DEFINITIONS AND ABBREVIATIONS

The definitions and abbreviations that apply to this specification are given below. The solar power system shall be described primarily in International units followed by English units in parentheses.

1.5.1 Definition of Terms

Beam Pointing Error - The angular difference between the aim point and the beam centroid of a mirror.

Capacity Factor, Nonsolar - Annual nonsolar MWh divided by the product of 8760 hrs. and facility or unit rating in MW_t .

Capacity Factor, Overall - Annual solar MWh plus annual nonsolar MWh divided by the product of 8760 hrs. and facility or unit rating in MW_t .

Capacity Factor Annual, Solar - Solar MWh divided by the product of 8760 hrs. and facility or unit rating in MW_t .

Cogeneration - The combined production of electrical or mechanical energy and useful thermal energy.

Conversion Efficiency, Gross - Gross output provided by a conversion device divided by total input power at specified conditions.

Conversion Efficiency, Net - Actual net output (after deducting parasitics) provided by a conversion device divided by the required input power at specified conditions.

Demand - The power versus time profile of the energy required to satisfy the energy needs of the final consumer or end use consuming process.

Design Point - The time and day of the year at which the collector subsystem is sized with reference insulation, wind speed, temperature, humidity, dewpoint and sun angles.

Direct Insolation - Non-scattered solar flux falling on a surface oriented normal to the sun (watts/m^2).

Field Receiver Power Ratio - Maximum heliostat field power output divided by maximum receiver power absorption capability.

Fluid, Receiver - The fluid used to cool the solar receiver and distribute the absorbed solar energy to other parts of the system; heat transport fluid of the receiver.

Fluid, Working - The fluid used in the turbine or other prime mover.

Geometric Concentration Ratio - The ratio of the projected area of a reflector system (on a plane normal to the insolation) to the absorber area.

Levelized Busbar Energy Cost - That price per unit of energy (in mills per kilowatt hour) which, if held constant throughout the life of the system, would provide the required revenue, assuming that all cash flow interim requirements or excesses are borrowed or invested at the facility's internal rate of return.

Payback Period - A traditional measure of economic viability to investment project. A payback period is defined in several ways, one of which is the number of years required to accumulate fuel savings which exactly equal initial capital cost of system. Payback often does not give an accurate representation of total life-cycle values.

Receiver Efficiency - Ratio of thermal power output at receiver base to incident solar power upon receiver.

Solar Cogeneration - Utilizing solar central receiver technology for the combined production of electrical or mechanical energy and useful thermal energy.

Solar Flux - The rate of solar radiation per unit area (watt/m^2).

Solar Fraction, Annual - Ratio of solar energy to the process divided by the total energy consumption (annual average) measured at turbine inlet.

Solar Fraction, Design Point - As above at design point.

Solar Multiple - Defined at the design point as thermal power from receiver after downcomer and piping losses divided by thermal power, prime mover (definition below).

Storage Capacity - The amount of net energy which can be delivered from a fully charged storage system (MW_{eh} or MW_{th}).

Thermal Power, Fossil Heater Output - Thermal power input to transport fluids from the fossil heater after stack and miscellaneous losses.

Thermal Power, Prime Mover - Thermal power input to turbine or other prime mover at design point. For cogeneration, thermal power to operate the balance of the system is included.

Thermal Power, Receiver Output - Thermal power derived from the receiver, not including electrical parasitic or downcomer thermal losses.

1.5.2 Abbreviations

DHWS	Domestic Hot Water Subsystem
DOE	U. S. Department of Energy
EMI	Electromagnetic Interference
EPGS	Electrical Power Generating Subsystem
ETSS	Energy Transfer and Storage Subsystem
FES	Fossil Energy Subsystem
GFE	Government Furnished Equipment
HAC	Heliostat Array Controller
HC	Heliostat Controller
HFC	Heliostat Field Control
ID	Inside Diameter
kg	Kilogram
kV	Kilo-volts
KW	Kilowatts
MDAC	McDonnell Douglas Astronautics Company
mm	Millimeter
mrad	Milli-radians
MTBF	Mean Time Between Failure
MW _e	Megawatt Electrical
MWh	Megawatt Hours
MW _t	Megawatt Thermal
O&M	Operations and Maintenance
OD	Outside Diameter
OSHA	Occupational Safety and Health Administration
P&ID	Piping and Instrumentation Diagram
PCS	Plant Control Subsystem
PSIA	Pounds per square inch absolute
RS	Receiver Subsystem
SCS	Space Conditioning Subsystem
TS	Tower Subsystem
UPS	Uninterruptible Power Source
VAC	Voltage alternating current
VDC	Voltage direct current

Section 2.0

REFERENCES

The equipment, materials, design, and construction of the solar plant shall comply with all federal, state, local and user standards, regulations, codes, laws, and ordinances currently applicable for the specific site and the user. These shall include but not be limited to the references listed below. If there is an overlap in, or conflict between, the requirements of these references 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 references (of the issue in effect on the date of contract start) form a part of this specification to the extent specified herein. In the event of conflict between the references herein and the contents of this specification, the contents of this specification shall be considered a superseding requirement.

2.1 STANDARDS AND CODES

1. Uniform Building Code - 1979 Edition by International Conference of Building Officials.
2. Regulations of the Occupational Safety and Health Administration (OSHA):
 - a. OSHA Title 29, Part 1910 - Occupational Safety and Health Standards
 - b. OSHA Title 29, Part 1926 - Safety and Health Regulations for Construction
3. Regulations of the Federal Aviation Administration (FAA)
4. Regulations of the Civil Aeronautics Board (CAB)
5. International System of Units, 2nd Revision, NASA SP-7012

6. Military Standards:
 - a. MIL-STD-454C, Standard General Requirements for Electronic Equipment.
 - b. MIL-STD-1472 and -810C, Human Engineering Design Criteria.
 - c. MIL-STD-490, Specification Practices.
 - d. MIL-STD-810B, Method 510, Environmental Test Requirements.
7. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code
 - a. Section I - Power Boilers
 - b. Section II - Materials Specifications
 - c. Section V - Nondestructive Tests
 - d. Section VIII - Unfired Pressure Vessels
 - e. Section IV - Welding and Brazing
8. Institute of Electrical and Electronic Engineers (IEEE) Codes.
9. National Fire Protection Association (NFPA) National Fire Codes -- 1979.
10. Design, Construction and Fabrication Standards:
 - a. AISC (American Institute of Steel Construction)
 - b. ACI (American Concrete Institute)
 - c. TEMA (Tubular Exchanger Manufacturer's Assn.)
 - d. API (American Petroleum Institute) Std. 650 - Welded Steel Tanks for Oil Storage
 - e. NRC Regulatory Guide 1.60
 - f. NR Regulatory Guide 1.61
 - g. ANSI (American National Standards Institute) A58.1 B31.1- Power Piping
11. (Others TBD)

2.2 OTHER PUBLICATIONS AND DOCUMENTS

1. Collector Subsystem Requirements Specification A10772 (Second Generation Heliostats, Issue C).

2.3 PERMITS AND LICENSES REQUIRED

1. Construction Permit - (TBD)
2. Operating Permit/Environmental Impact Assessment - (TBD)
3. Aviation Hazard Permit - (TBD)
4. (Others TBD)

2.4 APPLICABLE LAWS AND REGULATIONS

1. National Energy Conservation Policy Act of 1978.
2. Power Plant and Industrial Fuel Use Act of 1978.
3. Natural Gas Policy Act of 1978.
4. Energy Tax Act of 1978.
5. Environmental Legislation:
 - a. National Environmental Policy Act (NEPA)
 - b. Clean Air Act Amendment of 1977, PI 95-95; Prevention of Significant Deterioration (PSD) Provisions.
6. (Others TBD)

Section 3.0 REQUIREMENTS

The solar cogeneration facility shall be designed to meet the performance requirements of this section. This specification is applicable as a design requirement to only the new or modified portions of the solar cogeneration facility. The solar cogeneration design specifications shall make maximum use of completed or ongoing DOE solar R&D activities.

3.1 SYSTEM REQUIREMENTS

3.1.1 System Design and Performance Requirements

The solar cogeneration system for Fort Hood Complex 87000 shall be designed to meet the following nominal performance requirements:

- Net Power Rating:
 - Maximum 0.6 MW_e
 - Minimum 0.3 MW_e
- Energy Storage Capacity:
 - High temperature storage. 20 MW_{th}
 - Low temperature storage 5 MW_{th}
 - Chilled Water Storage 7.5 MW_{e h}
- Annual Power Output Capability 2498 MW_{e h}

Net power rating shall be the net output of the facility after subtracting all plant electrical operating requirements and when operating solely from insolation. The solar facility shall be capable of delivering the maximum net electrical power of 0.6 MW_e to the electrical distribution grid serving the complex for a period of at least (TBD) hours on the "Plant Design Best Day,"

as defined by the environmental conditions in Section 4.0. The facility shall be capable of accepting the maximum thermal power available on the "Plant Design Best Day" without necessarily defocusing any portion of the collector field. The facility shall also be capable of operating with a maximum insolation level of 1000 w/m² at any time.

The facility shall be capable of delivering 0.6 MW_e of electrical power for four hours to the grid when operating solely from fully charged high-temperature thermal storage tanks. Stored thermal energy shall also be used to maintain equipment in a hot standby condition during plant operation, in a blanketed condition during non-operating periods, and provide sufficient thermal energy for turbine startup.

The solar cogeneration facility at Fort Hood shall meet the above performance requirements under the following overall system design limitations:

- Land area for collector field. 5.4 Hectares (13.4 acres)
- Heliostat type MDAC Second Generation
(56.84 m² each)
- Receiver type Conical Partial Cavity
- Energy transport fluid HITEC
(53% KNO₃, 40% NaNO₂,
7% NaNO₃)
- Maximum salt temperature 454°C (850°F)
- Maximum steam temperature. 399°C (750°F)
- Turbine type Marine

3.1.2 System Operational Requirements

The solar system shall be capable of controlled and safe operation in two basic operating modes: Energy Collection and Energy Utilization, as well as all associated Transitional and Standby/Inactive modes, as defined below.

3.1.2.1 Energy Collection Mode - In the energy collection mode, the system shall be capable of collecting and storing thermal energy from either the solar energy equipment (solar-only mode), the fossil-fueled energy equipment (fossil heater only mode), or both simultaneously (hybrid mode) as described below:

- a. Solar-Only Mode - The Solar-Only Mode is the normal steady-state mode of operation in which solar energy is collected during the daytime by the collector/receiver subsystems and to the thermal storage tanks. A schematic of this mode is shown on Figure 3.1-1. Under normal conditions, all heliostats are operated (sun following mode) to maximize the use of available solar energy. However, under some conditions, such as very high insolation and/or low thermal demands, only selected heliostats in the field may be in an active sun tracking mode, while others are held in a standby mode (partial heliostat loading).
- b. Fossil Heater Only Mode - During periods of no insolation (nighttime or totally overcast conditions), the fossil energy subsystem (FES) shall be capable of providing all necessary heat requirements. In this mode, the CS and RS are dormant and the FES shall operate at full capacity to heat the molten salt solution being circulated into the thermal storage tank. A schematic of this mode is shown on Figure 3.1-2.
- c. Hybrid Mode - During periods of low insolation (cloudy or hazy day) or very high heat demands, when the CS/RS is incapable of producing sufficient useful heat, the fossil-fueled energy equipment shall be operated in parallel with the solar heating equipment in order to adequately charge the thermal storage tank. A schematic of this mode is shown in Figure 3.1-3.

Figure 3.1-1. Energy Collection - Solar Only Mode

Figure 3.1-2. Energy Collection - Fossil Heater Only Mode

Figure 3.1-3. Energy Collection - Hybrid Mode

3.1.2.2 Energy Utilization Mode - In the Energy Utilization Mode, the system shall be capable of utilizing the heat stored in the thermal storage tank to produce steam for electrical power generation (Electric Power-Only Mode), for both electrical power and thermal applications (Electric/Thermal Power Mode), or for only thermal applications (Thermal Power-Only Mode) which includes room heating, air conditioning and heating of domestic water. These modes are described below.

- a. Electric Power-Only Mode - In this mode, the system produces electrical power only. Steam produced in the ETSS steam generator is injected into the turbine which drives a generator to produce electrical power. The steam, which is expanded through the turbine, is used for deaeration and feedwater heating. Exhaust steam from the turbine also enters the condenser where it is condensed and routed into the feedwater loop (condensate polisher, deaerator, pumps, lines, etc.) Exhaust heat collected by the condenser is totally expended into the atmosphere. Heat is not used for any other purposes than producing electrical power. In the Electric Power-Only Mode, the steam flow rate into the turbine can either be continually varied for electrical power load following, or the steam flow can be set at fixed flow rates for set electrical power levels, as required. A schematic of this mode is shown on Figure 3.1-4.
- b. Electric/Thermal Power Mode - In this mode, the system produces both electrical power and heat for space conditioning and domestic hot water. For electrical power, steam is injected into the turbine to drive the generator unit. Exhaust steam is used for the deaerator, feedwater heater and absorption chiller (for air conditioning, as required). For room and water heating, heat introduced into the exhaust condenser is used to develop low pressure steam for downstream room heating and water heating. In this mode of operation, both the electrical power output and thermal heat loads can be variable. A schematic of this mode is shown on Figure 3.1-5.

[FIGURES TO BE UPDATED]

Figure 3.1-4. Energy Utilization - Electric Power-Only Mode

Figure 3.1-5. Energy Utilization - Electric/Thermal Power Mode

- c. Thermal Power-Only Mode - In this mode, the system produces steam for thermal applications only. Steam from the ETSS steam generator bypasses the turbine and is routed to the absorption chiller for air conditioning and through the deaerator for the heat needed for domestic hot water and space heating applications. Under normal operations, the Electric/Thermal Power Mode shall produce enough heat for 24-hour operation of hot water and room conditioning equipment. This mode will be required only when the turbine-generator is shut down for servicing. A schematic of this mode of operation is shown on Figure 3.1-6.

3.1.2.3 Transitional Modes - The plant shall be capable of controlled and safe operations for startup and shutdown and transitioning functions between all the operating modes. Transitions between operating modes shall be carried out in a logical sequence of activities in a preprogrammed manner. The plant shall be capable of transitioning between operating modes, either in a manual or automatic control mode (automatically sequenced transitions shall be initiated through operator command). Transitional operations shall include the following:

- a. Startup - System startup shall be coordinated through the plant control subsystem. Startup will begin with a signal from the operator which initiates a series of prestart checks (valve positions, temperatures, pressures) and system conditioning. Any out-of-normal startup operating conditions shall be monitored at the plant control station. System conditioning including condensate cleanup shall be initiated prior to sun acquisition by the heliostats.

For the energy collection mode, the heliostats shall be oriented to their predicted sun acquisition positions (standby target) prior to startup using power from the existing electrical network or an auxiliary source. The plant shall be capable of initiating collector/receiver startup at sunrise on representative clear days. The heliostats shall be directed from a standby target onto the receiver in a prescribed manner to achieve full system powerup. All heliostats shall be focused on the receiver by the time the sun reaches an elevation angle of 100°.

[FIGURE TO BE UPDATED]

Figure 3.1-6. Energy Utilization - Thermal Power-Only Mode

Under normal conditions, the receiver will have been in an overnight standby mode and fluid temperatures will have been maintained at 177°C (350°F) by residual heat in the system or by trace heaters. At startup command, flow valves will open, pumps will start, and fluid flow will begin. Once steady state flow has been established, the receiver doors will be opened and solar heating will commence. Warm fluid developed in the receiver shall be recycled through the receiver until temperatures and flow conditions can be stabilized, and until the thermal storage tanks build sufficient thermal charge to operate the steam generator loop.

In the Energy Utilization Mode, the turbine feedwater will be preheated to 177°C (350°F) before entering the ETSS steam generator unit. Steam produced in the steam generator shall then be introduced into the turbine at a controlled rate for turbine heating and startup. The turbine shall be loaded and the electrical power shall be synchronized with the inter-connecting power network. Excess thermal energy developed by the CS/RS over turbine requirements will be stored in the thermal storage tank.

- b. Intermittent Operation - Since the electrical power generating subsystem (EPGS) operates from thermal energy stored in the thermal storage tank, the EPGS is buffered from any short-term insolation transients. Consequently, this transient operation applies only to the energy collection mode.

During periods when excessive transients in solar insolation occur due to intermittent cloud cover, the fluid flow rate through the receiver shall be altered to control outlet temperature and protect the receiver. For intermittent operations, a 100% change in heat flux may occur in 10 seconds as the clouds sweep across the collector field. When reduced insolation no longer permits heat addition to the hot thermal storage tank, the total receiver flow will be reduced to a minimum operating valve and directed back to the cold storage tank.

- c. Normal Shutdown - An integrated system shutdown shall be coordinated through the plant control subsystem. The system shall be capable of initiating shutdown from any of the above operating modes.

In the energy collection mode, collection of solar energy by the CS/RS shall be terminated when insolation falls to such a level that no net energy can be collected in the thermal storage tanks. The heliostats will be sequentially rotated to an overnight standby position. Fluid flow through the RS will be stopped and the RS doors closed.

In the energy utilization mode, the shutdown of the EPGS shall be automatically initiated when the steam temperature to the turbine falls below a specified value. At this point, the electrical generator shall be taken off-line, and the steam flow to the turbine reduced in a manner consistent with the turbine specifications.

- d. Emergency Stop - The instrumentation and control subsystem shall monitor the status of all subsystems at all times and shall be capable of diagnosing subsystem malfunctions. In the event a malfunction is deemed "serious" (leading to potential equipment damage or safety hazard), an emergency shutdown procedure shall be automatically initiated with manual backup. The procedure shall depend on the nature of the failure, but in all cases shall be designed to maximize safety while minimizing equipment damage.

In the event of approaching adverse environmental conditions (high wind, sandstorm, hail, etc.) while in the energy collection mode, heliostat reorientation shall be executed after issuance of command by the plant control subsystem. The heliostats shall be off-targeted in a prescribed manner to ensure a controlled receiver shutdown. They shall then be directed to a minimum damage orientation in a manner compatible with reflected beam safety considerations. The timing for such shutdown shall be based on minimizing equipment damage and providing maximum safety. The minimum shutdown times shall be based on

fluid circulation failure in the receiver. During such an occurrence, the radiation incident on the receiver surface shall be reduced to 3% of its initial value within 30 seconds.

System shutdown may be limited only to the concentrator and receiver subsystems if sufficient energy exists in the thermal storage subsystem to maintain operation of the power conversion equipment. In the event of emergency stop while in the energy utilization mode, the electrical generator shall be taken off-line and the steam flow to the turbine reduced in a manner consistent with turbine specifications.

3.1.2.4 Standby/Inactive Modes - The plant shall be capable of being maintained safely in various standby/inactive modes, which include Overnight Standby, Maintenance Standby, and Extended Shutdown.

- a. Overnight Standby - Equipment shall be operated in an idle mode during overnight standby. Trace heaters and the heaters in the receiver and thermal storage tanks will be operated to maintain heat transfer fluid temperature at or above 177°C (350°F). The plant control subsystem shall remain active to monitor appropriate temperatures and pressures.
- b. Maintenance Standby - Under some conditions, equipment normally operating in the energy collection or energy utilization modes may be temporarily isolated or inactivated to permit short-term inspection, maintenance, repair or calibration, as required, without shutdown of the entire plant.
- c. Extended Shutdown (Inactive) - For extensive maintenance, repair, equipment modifications or other reasons, the total system may be infrequently subjected to extended shutdown periods. The plant shall be capable of inactivating the total system, and reactivating independent subsystems, as required. Nitrogen purge of the RS, ETSS and EPGS elements will be maintained to prevent air from entering the lines. After an extended shutdown period, fluid flow will not be initiated until all heat transfer fluid, fluid lines and valves have been brought up to 177°C (350°F).

3.1.3 System Interface Requirements

3.1.3.1 System/Subsystem Interfaces - All subsystems of the facility shall be physically and functionally compatible. Specific system/subsystem interface requirements are given in Sections 3.4 through 3.12.

3.1.3.2 Power Grid Interfaces - The facility shall be physically and functionally compatible with the local power distribution network for the Complex. Appropriate electrical conditioning and interface equipment (transformers, capacitors, circuit breakers, cables, connectors and controls) shall be included to enable power to be drawn from the existing power network for subsystem operations during nonoperational periods of the turbine-generator equipment. The electrical interface with the power grid shall be redundant (i.e., backup electrical lines, transformers, circuit breakers, etc.) shall be provided, thus assuring uninterruptible power source (UPS) to the facility. However, brief power transients may occur during the switching to the backup system. Operating interfaces with the existing power grid shall include considerations of power profiles, dynamic interactions, and emergency operations. Interfaces shall include considerations of startup and shutdown sequencing, outage due to planned or forced maintenance, and extended shutdown periods.

3.1.3.3 Base/Regional Interfaces - In the design, installation and operation of the facility, considerations shall be given to the environmental issues, personal safety, and specific base and regional requirements. Environmental issues shall include natural environmental resources (geology, hydrology, air quality) and human environmental resources (traffic, transportation, operational services). Safety concerns shall include explosion, fire, leaks, glare, and aircraft flight hazards.

3.2 SITE

3.2.1 Site Location Requirements

The solar cogeneration facility shall service Complex 87000 of the Fort Hood Army Base, Killeen, Texas. The main base and Complex 87000 are identified on Figure 3.2-1. The solar collector field shall be located immediately east of Complex 87000 within the 6.0 hectare (13.4 acre) plot bounded by 15th Street, Battalion Avenue, the proposed Central Avenue extension, and Martin Drive, as shown on Figure 3.2-2.

Additional solar equipment (such as thermal storage tanks, electrical power generating building, cooling tower, control trailer, etc.) shall be located in the southwest portion of the field.

3.2.2 Site Preparation Requirements

Preparation of the site shall comply with all applicable military requirements and territorial environmental laws and standards. Specific requirements are given below.

1. Grading - Grading at the site shall be limited to a minimum amount of stripping and cut/fill to provide for adequate drainage. There are no existing structures on the sites designated for solar equipment except for small parking lots, which will require relocation.
2. Site Surfacing - The site shall be surfaced with local sand/gravel materials, compacted and treated for dust and vegetation control.
3. Drainage - Adequate drainage provisions will be provided.

Figure 3.2-1. Complex 87000 at the Fort Hood Army Base, Killeen, Texas

Figure 3.2-2. Complex 87000 Layout

4. Foundations - A maximum allowable net soil bearing pressure of 191.5 KPa (4000 lb/ft²) shall be assumed for foundation design for the collector field, tower and other major equipment installations.
5. Pipe/Cableways - All pipe/cableways shall be placed underground.
6. Roads and Parking Lots - An all-weather access road from the existing roads to the site entrance shall be provided. On-site roads and parking lots shall be hard-surfaced. Roads and parking lots shall be capable of supporting heavy duty construction vehicles.
7. Walkways - Walkways between buildings and parking lots shall be provided.
8. Utilities - Standard utility services shall be provided to the site. These services shall include water, power, sewage, and communications (telephone). Service lines shall be placed underground, as much as possible. In the event that the solar plant becomes inoperative, up to (TBD) KWe power shall be provided from the existing power supply system for auxiliary solar facilities services (area lighting, trace heating, controls, pumps, fans and other miscellaneous equipment).

3.3 SITE FACILITIES

3.3.1 Site Facilities Design Requirements

The requirements for new facilities and services to accommodate the addition of the solar-related portion of the facility are given below.

1. Plant Control Housing - All plant control equipment shall be located in a small mobile control trailer equipped with appropriate electrical, space conditioning, and communications equipment.
2. Plant/Equipment Housing - A building shall be provided to house the steam generator, feedwater equipment, turbine, generator and associated electrical power distribution equipment. An overhead crane on monorail shall be provided to assist in the installation and maintenance of major equipment. The building shall include necessary washroom and locker room facilities.
3. Storage and Maintenance - Space will be provided in the Plant Equipment building for maintenance work and the storage of non-hazardous materials, equipment and spare parts.
4. Facility Services - Special facility services including fire and lightning protection shall be provided. Fire protection shall include water, foam and chemical equipment as required to meet fire protection standards. Lightning rods shall be installed on each building and appropriately grounded per standards.
5. Fencing - A chain link security fence shall be installed around the site perimeter to control site access. Additional localized control fencing shall be provided where required.
6. Area Lighting - Area lighting will be provided consistent with operational, safety and security requirements.

3.3.2 Site Facilities Interface Requirements

The facilities shall be physically and functionally compatible with the environment and soil conditions at the site. Foundations shall be of sufficient area to distribute the compressive load at rates less than soil-bearing strength as defined by site geological and hydrological data under all specified environmental conditions.

The placement of site facilities shall provide efficient interface arrangement of subsystems and components, and minimize construction costs consistent with operation, maintenance and personnel safety requirements.

3.4 COLLECTOR SUBSYSTEM (CS)

The Collector Subsystem (CS) shall be comprised of a field of individually controlled reflectors (heliostats) which redirect solar radiation onto the receiver subsystem (RS). The aiming of each heliostat shall be automatically controlled in elevation and azimuth by the plant control subsystem (PCS) to track the sun and continually direct reflected sunlight onto the receiver in a manner which satisfies receiver incident heat flux requirements. In addition, the CS shall respond to commands from the PCS for emergency defocusing of the reflected energy or to protect the heliostat array against environmental extremes. The heliostats shall be properly positioned for repair or maintenance in response to either automatic control or manual commands. Heliostat design shall provide for stored or safe position for use at night, during periodic maintenance and during adverse weather conditions. The CS shall be designed to match the receiver design and provide energy to the receiver working fluid consistent with the end energy requirements of the facility.

Design/performance, functional and interface requirements of the collector field and heliostat subassemblies are given below. More detailed characteristics of the CS subassemblies designed to meet these requirements are summarized in Section 5.0 of this specification.

3.4.1 CS Design/Performance Requirements

3.4.1.1 Collector Field - The collector field design shall provide the optimum heliostat layout considering the following:

- o Insolation characteristics
 - Sun position (latitude)
 - Insolation levels
 - Atmospheric attenuation
- o Heliostat performance
 - Reflectivity
 - Beam quality and pointing errors
 - Shading and blocking

- o Receiver performance
 - Height
 - Aperture size and angle
 - Spillage
 - Absorptivity
- o Costs
 - Heliostat capital costs
 - Operating and maintenance costs
 - Field wiring costs
 - Land costs
- o Other
 - Land availability and restrictions
 - Reliability
 - Heliostat spacing restrictions (mechanical limits)

For the Fort Hood site, the heliostats will be oriented in a north-field configuration (heliostats located north of the tower). Spacing between heliostats in the field must permit vehicular access to all heliostats for cleaning and maintenance equipment. This spacing shall also permit the heliostats to be rotated to a safe position to meet environmental design conditions.

The collector field shall be designed to meet the performance requirements shown on Table 3.4-1.

Table 3.4-1
Collector Subsystem Performance Requirements

- Total Energy Incident on Receiver
 - Summer solstice, noon TBD MW_t
 - Winter solstice, noon TBD MW_t
- Peak Flux on Receiver (at any time). 8.9 MW_t
- Peak to Average Incident Flux. 2:1 (Max.)
- Spillage (annual average, noon). 3% (Max.)

3.4.1.2 Heliostats - The heliostats shall generally conform to the design and performance specified by the U. S. Department of Energy (DOE) Second Generation Heliostat program, covered under the Collector Subsystem Requirement Spec A10772, Issue D, DOE Sandia Livermore Laboratories. For the Fort Hood Solar Cogeneration Facility, deviations are required to the Collector Subsystem Requirements Specification which are summarized on Table 3.4-2.

Design/performance requirements for the major CS components are summarized on Table 3.4-3 and reviewed below. The design and performance characteristics of the current MDAC Second Generation Heliostats designed to meet these requirements are summarized in Section 5.0 of this specification.

Table 3.4-2

Revisions to Collector Subsystem Requirements Specification
(Specification A10772, Issue D, 10-10-79)

<u>Section No.</u>	<u>Revision</u>	<u>Rational</u>
2.1	Delete "Soil and Foundation Investigation Report, 5MW, STTF Sandia Labs"	Not applicable
3.1.d	Delete	Heliostat field controllers are not required for this application
3.1.2.1	Delete "physical arrangement, outer boundaries of the array of heliostats"	Heliostat field characteristics to be defined by system integration contractor for collector subsystem contractor
3.1.2.2	Delete "the receiver is a vertical cylinder approximately 12.0m (39.4 ft.) in diameter and 12m (39.4 ft.) high and the center is 140m (459 ft.) above ground level."	Not applicable
3.1.2.5	Delete reference to Data Acquisition System (DAS)	A separate DAS is not planned for this application
3.1.2.6	Delete reference to beam characterization (BCS)	An on-site BCS is not planned for this application; however, a BCS target will be mounted on the tower
3.2.1a 3.2.1b 3.2.1c 3.2.6.2	<div style="display: inline-block; vertical-align: middle;"> <div style="font-size: 3em; vertical-align: middle; margin-right: 5px;">}</div> Change temperatures from: 0° to 50°C (32 to 122°F) to: 0 to 44°C (32 to 111°F) </div>	Site specific values to be used
3.2.1a	Azimuth angles - delete "except during gimbal angles"	Not applicable
3.2.2d	Delete reference to south field	Not applicable
3.2.2f	Delete reference to Heliostat Field Controller (HFC)	Not required for this

Table 3.4-2
(Continued)

<u>Section No.</u>	<u>Revision</u>	<u>Rational</u>
3.2.3a	Change to read: "The Collector Subsystem shall be capable of emergency defocusing to a standby point off the receiver upon command to reduce peak incident radiation on the receiver to less than 3% of initial value within 30 seconds."	More rapid defocusing time required to prevent receiver damage.
3.2.6.2	Change temperatures for functional operation of heliostats from: 0°C (32°F) to 50°C (122°F) to: -23°C (-10°F) to 47°C (116°F)	Site specific values be used
3.4.4	Delete "Plant documentation (drawings, specifications, instructions, etc.) shall be compatible with Southern California Edison Format"	Not applicable

Table 3.4-3

Heliostat Performance Requirements

o Reflectivity	
- Clean	.90 - .92
- Average	.89
o Beam Quality*.	
.90% Minimum	
o Beam Pointing Error**.	
1.5 mrad (1σ)	
o Reflective Surface Deflection	
- Single heliostat	.3.6 mrad (1σ)
- Field average	.1.7 mrad (1σ)

* Theoretical beam shape plus 1.4 mrad fringe width.

** Sun at least 0.26 rad above horizon; includes pedestal and foundation deflection

Mirror Modules

Each heliostat shall consist of several mirror modules consisting of a second surface mirror bonded to a glass back panel. The mirrors shall be second surface silvered by a standard commercial process resulting in an expected clean reflectivity of .90 - .92. Under normal operational usage with periodic heliostat cleaning, the average heliostat reflectivity shall be at least 0.89. Surface degradation rate shall be minimized consistent with a 30-year mirror module life. The glass back panel shall be slightly curved to enhance focusing (nominally 17,000 inch radius). The modules shall be attached to stringers which are, in turn, bolted to support beams. The attachments for each module shall be adjustable, and each panel shall be canted to the individual slant range, as required.

Reflector Assembly

The reflector assembly shall provide the structural support for the mirror modules. The reflector assembly shall consist of two main panels bolted to a main rectangular beam which is connected to a drive unit. Each panel shall be supported by cross beams and braces which provide adjustable attachments for each mirror module, maintain the alignment of the mirror modules and provide a rigid attachment to the drive unit. The mirror modules shall be assembled to each panel before shippage to the site and final assembly shall be conducted at the site. After site installation and mirror module adjustment, the beam quality for each heliostat shall be such that a minimum of 90 percent of the reflected energy at target slant range (when the sun is at least 15° above the horizon) shall fall within the area defined by the theoretical beam shape plus a 1.4 mrad fringe width. Heliostat beam quality shall be met throughout 60 days without realignment.

Drive Unit

Each heliostat shall incorporate a drive unit consisting of actuators for elevation and azimuth positioning. The drive unit must be capable of positioning the heliostat reflector surfaces such that at any time the maximum mirror normal pointing error for each gimbal axis shall be 1.5 mrad (one standard deviation) whenever the sun is at least 0.26 rad above the horizon, including pedestal and foundation deflection. (Pointing error or tracking accuracy is defined as the difference between the aim point and the measured beam centroid for any track aim point.) Elevation and azimuth drives shall not drift from last commanded position due to environmental factors. The drive unit must also be capable of positioning the heliostat from any operational orientation of stowage, cleaning, maintenance or any other desired positions. Provisions shall also be provided that enable the heliostat to be stowed manually without the use of the drive motors. Drive systems shall be environmentally sealed, and corrosion protection shall be provided for all exposed parts.

Pedestal

A central steel pedestal concept shall be employed. The pedestal shall be rigidly attached to a reinforced concrete pier foundation.

Foundation

The foundation shall be a drilled concrete pier (cast on-site). A tapered steel shell establishes the mounting surface for the pedestal and serves as a form for the protruding end of the pier. Foundation design shall include consideration of soil stratigraphy and geological phenomena. The maximum allowable foundation settlement or elastic displacement limits are 0.5 mrad.

Overall structural supports for the heliostats shall be designed to limit reflective surface static deflections from exceeding 1.7 mrad one standard deviation for a field of heliostats under normal operations in a 12 m/s (27 mph) wind. Wind deflections of the foundation, pedestal, drive mechanism, and mirror support members shall be included, but not the slope errors due to gravity and temperature effects. Wind deflection limits apply to the mirror normal projection (not reflected beam) for each axis fixed in the reflector plane. Both beam quality and beam pointing are affected. To assure that the net slope errors

of a field of heliostats is less than 1.7 mrad, the rms value of the slope errors taken over the entire reflective surface of an individual heliostat, computed under the worst conditions of wind and heliostat orientation (but excluding pedestal deflection), shall be limited to 3.6 mrad for a single heliostat. This limit represents a 3-sigma value for the field derived by subtracting maximum allowable pedestal deflection (0.5 mrad) from the total surface slope error. The maximum pedestal deflection of 0.5 mrad is the elastic deflection limit placed on the foundation design, which is included in the 1.7 mrad structural support deflection limit above. The standard deviation to be used in these requirements shall be determined from a standard of at least 20 data points from each individual heliostat tested.

Heliostat Controller (HC)

Each heliostat shall have a controller which operates the drive motors to point the heliostat in the commanded direction. The heliostat controller (HC) will verify gimbal axis position data by gimbal axis sensor output and provide gimbal axis position data to the Plant Control Subsystem (PCS). Heliostat controllers shall be able to determine actual heliostat position, compare with command position from the Heliostat Array Controller and drive the motors to correct the errors indicated. The HC shall be mounted on the heliostat pedestal at eye level.

Heliostat Array Controller

A Heliostat Array Controller (HAC) shall be a small computer co-located with the Plant Control Subsystem (PCS) equipment in the control trailer. The HAC will command collector subsystem operating modes, in response to PCS commands. The array controller calculates the sun's position and directs individual heliostat motions, via the heliostat controller. The collector subsystem shall also be capable of being operated manually by a plant operator independent of the PCS.

Power and Control Cabling

Power and control wiring between the HAC and HC shall be routed along circular arcs to the greatest extent practical. Instrumentation/control wiring will be underground in a common trench with the electrical power cables to the maximum extent possible. However, the instrumentation and control wiring shall be adequately separated from the power cabling so as to minimize electrical interferences. Field wiring shall terminate at a junction box located on the drive unit pedestal. All control data shall be routed via a single twisted-wire pair from the HAC to each HC in the string, decoded by the addressed heliostat, and ignored by other HCs unable to match the address code. Acknowledgment of receipt of a message and status shall also be transmitted. High voltage power from the electrical power generating subsystem shall be distributed to transformers in the field that step down the supply voltage to appropriate levels. Branch feeder cables from the transformers shall dispatch power to each heliostat.

3.4.2 CS Operational Requirements

The Collector Subsystem (CS) shall be compatible with all modes of plant operation, as follows:

Energy Collection Mode - In the energy collection mode, the heliostats shall be continuously moved in azimuth and elevation to track the sun (redirect the solar insolation to the receiver in a prescribed manner). This tracking action shall include the capability of controlling the number of heliostats so as to vary the redirected flux to the receiver between zero and the maximum achievable level. Elevation and azimuth gimbals drives shall not drift from last commanded position due to environmental loading. Drive systems must be capable of resolving field control singularity (i.e., "over-the-shoulder" limits or gimbal lock) within 15 minutes.

Energy Utilization Mode - (Not applicable. The CS operates in the energy collection mode only and is independent of the energy utilization mode.)

Startup Mode - Upon a signal from the control system, the heliostats shall be rotated sequentially from their storage position to a common focal point and then in prescribed groups and by prescribed routes to the standby position (a preselected point in the vicinity of the receiver). Heliostat to receiver orientation shall be possible when the sun elevation angle is approximately 5 degrees and completed when the sun elevation angle reaches 10 degrees. The reflected sunlight shall be applied to the receiver at predetermined aim points to prevent the peak receiver heat flux from exceeding specified values. Reflected beam position updates shall maintain each heliostat image within prescribed tolerances of the aim points.

Intermittent Operation Mode - During intermittent cloud cover, heliostat sun tracking will be automatically continued as in the normal tracking mode. At other times, during normal tracking operation, some groups of heliostats may be momentarily rotated to and kept in a predetermined stationary or standby position for a short time duration. These transitions are performed to provide the desired receiver startup/shutdown operations and/or flux levels on the receiver.

Normal Shutdown Mode - Normal tracking operation shall be maintained until the direct solar insolation falls to a level that does not permit charging of the thermal storage tank. At this point, the heliostats shall be sequentially rotated from their sun tracking positions to standby, and then in groups by prescribed routes to their stowage positions (approximately vertical for normal stow). Drive systems must be capable of positioning a heliostat to stowage, cleaning, or maintenance orientation from any operational orientation within 15 minutes.

Emergency Shutdown Mode - In the event of an emergency, the heliostats shall be off-targeted to standby as rapidly as possible. The heliostats shall be reoriented to a safe stowage position in a manner compatible with reflected beam safety and weather conditions. The time for such reorientation shall be determined to minimize equipment damage and provide maximum safety. The minimum off-target shutdown time shall most likely occur as a result of fluid circulation failure in the RS. During such an occurrence, the radiation incident on the absorber surface shall be reduced at a rate equal to or greater than that which would linearly reduce peak incident radiation on the receiver to less than 3 percent of initial value within 30 seconds. An override provision shall be included in the drive unit to permit manual feathering of the heliostat. Limit switches shall prevent damage to the heliostat if it is driven beyond the normal operating limits. Automatic non-operational heliostat slewing provisions shall be incorporated so that the entire array of heliostat reflectors can be (1) aligned horizontally within 15 minutes to accommodate high winds or sand/dust storm conditions, and (2) aligned in any preferred orientation with 15 minutes to facilitate cleaning or maintenance. In the event of power failure, the azimuth and elevation drives shall remain in their last commanded position for all operating or non-operating conditions.

Standby/Inactive Mode - The heliostats shall be rotated to and kept in a pre-determined stationary position for overnight storage, servicing or safety reasons. The heliostats shall be properly positioned in response to either automated plant control or manual commands.

3.4.3 CS Interface Requirements

The CS shall interface with the following plant subsystems:

<u>Subsystem</u>	<u>Interface Type</u>
RS	Solar heat flux
TS	Alignment target; heat flux
EPGS	Electrical power (heliostat drive units, control, service); solar radiation/reflectivity
PCS	Control; data transmission

Interface requirements are specified below:

CS/RS Interfaces - Individual heliostats shall automatically track the sun and concentrate the redirected solar energy onto the RS absorber in accordance with preselected aiming strategy. Flux density on the absorber panels shall not exceed $.40 \text{ MW}_t/\text{m}^2$. Uncooled elements of the RS shall not be exposed to heat fluxes greater than $30 \text{ KW}/\text{m}^2$ at any time.

CS/TS Interfaces - a 5m x 5m heliostat alignment target shall be mounted on the tower directly below the receiver facing the collector field. The target will be used for periodic heliostat alignment.

The collector field shall be operated in such a way that tower elements are not exposed to heat fluxes greater than $30 \text{ KW}/\text{m}^2$ at any time.

CS/EPGS Interfaces - The EPGS shall provide the necessary electrical power to the CS for heliostat drive units and data transmission. In the event of main power dropout from the EPGS, power from the existing network shall be used to repower the collector field and heliostat controls. The CS should be able to accept normal electrical power transients and a momentary loss of total power without major operational problems. One or more _____ volt power cables shall run from the EPGS to field stepdown transformers. After power stepdown, feeder lines shall be used to distribute power from the field transformers to

individual heliostats. The power cables, transformers and feeder lines shall be sized to allow all heliostat motors to start simultaneously and to permit sequential rotation of all heliostats for emergency storage conditions. Power cables to the individual heliostats shall be of sufficient length for termination at a junction box located above the foundation on the pedestal. Cabling shall be routed underground to prevent interference with heliostat movement and to minimize the potential of interference with cleaning or maintenance equipment and personnel.

CS/PCS Interfaces - The CS shall respond to all control commands issued by the PCS. A two-way digital communications grid shall be used between the PCS and CS to transfer commands, status information, functional data and information requests. All interface connections shall be physically and functionally compatible.

3.5 RECEIVER SUBSYSTEM (RS)

The Receiver Subsystem (RS) shall provide a means of transferring the incident solar radiation from the Collector Subsystem into the fluid (HITEC) that is circulated through the RS. The RS shall include an energy absorber unit, receiver structural assembly (including housing and doors), pipe and manifolds, heaters, insulation, vent and relief valves, instrumentation, and a control console located in the plant control trailer. Design/performance, functional and interface requirements of the receiver subsystem are given below. Detailed characteristics of the RS subassemblies designed to meet these requirements are given in Section 5.0 of this specification.

3.5.1 RS Design/Performance Requirements

The RS shall be designed to circulate fluid through partial-cavity absorber arrangement. The RS shall be mounted on a tower with the aperture facing north and tilted downward. The receiver shall be configured for best thermal efficiency consistent with acceptable heat transfer/fluid flow characteristics and low costs. The RS unit shall also be designed to provide access for maintenance and inspection of receiver elements. Consideration shall be given to ease of maintenance. Adequate provisions shall be made to ensure crew safety at all times for required operations, inspection, maintenance and repair. The receiver design shall be consistent with the intent of the appropriate ASME boiler codes.

RS performance requirements for design purposes are summarized on Table 3.5-1. Design requirements for major RS components are given below.

Energy Absorber Unit

The absorber unit shall be an assembly of small diameter stainless steel pipe, configured to absorb the energy from the heliostat field without exceeding fluid temperature limits. The piping shall be connected to form one or more flow paths for the receiver fluid. The aperture design shall accept high peak fluxes at the center of the aperture (approximately

Table 3.5-1

Receiver Performance Requirements

Receiver fluid HITEC (53% KNO_3 , 40% NaNO_2 ,
7% NaNO_3)
Peak heat flux 40 KW_t/m^2 (____ Btu/hr. ft.^2)
Peak to average flux 2:1
Peak absorbed power. 14.9 MW_t (____ Btu/hr.)

Inlet Conditions:

- Temperature. 260°C (500°F)
- Pressure 1.0 Bar (145 psia)
- Flow rate by weight. ____ kg/hr (____ lb/hr)
- Flow rate by volume. ____ l/sec (____ gal/hr)

Outlet Conditions:

- Temperature. 454°C (850°F)
- Pressure 1.0 Bar (14.5 psia)
- Flow rate by weight. ____ kg/hr (____ lb/hr)
- Flow rate by volume. ____ lb/sec (____ gal/hr)

Max. inside tube wall temperature. 478°C (892°F)

Maximum velocity ____ m/sec (____ ft/sec.)

Pressure drop (maximum). 6.9 Bars (100 lb/in.^2)

Pumping power. ____ KW hyd.

Efficiency (Goals):

- Absorptivity 0.96
- Thermal* 0.93
- Overall RS efficiency. 0.98

* Includes radiation, convection and insulation losses.

2 MW_t/m²) and reduced solar flux at the absorber walls (approximately 0.4 MW_t/m²) by proper selection of tube configuration and diameter. The aperture shall be sized to provide low thermal losses, low spillage, and high collector efficiency. The behavior of bulk fluid temperature, tube wall temperature, and heat flux shall remain within conservative limits. No gasketed joints shall be permitted in the fluid flow paths of the absorber. Pressure drop through the receiver should not exceed 6.9 bars (100 lb/in²). The absorber must be removable, as a single unit, from the receiver assembly. Absorber support connections shall be pinned or bolted to facilitate removal. Fluid inlet/outlet disconnection may require the cutting of welds. The absorber shall be designed for accessibility for inspection, maintenance and repair without removing the entire receiver unit from the top of the tower. Capabilities must be provided that would enable the absorber unit to be removed from the RS structural housing and lowered to the ground for maintenance or replacement.

Structural Support, Housing and Doors

The RS structural frame shall be a weldment or a built-up assembly which supports the absorber unit and the other elements of the receiver, and provides for attachment to the tower. This structural assembly will be enclosed within a weatherproof housing which must provide access for inspection and maintenance of the receiver subassemblies.

The absorber shall be supported within the RS housing by linkages that allow adequate absorber movement to minimize undesirable thermal stress concentrations. Insulated doors shall close over the absorber to prevent excessive heat loss during periods of no insolation. An overall heat transfer coefficient less than 8.5×10^{-4} kW/m² °C (0.15 Btu/hr. ft²°F) is required. Door operating mechanisms will be electric motor driven. Maximum time to open or close shall be 60 seconds. A thermal shield will also be required at the edge of the receiver aperture to prevent damage to the tower and receiver structure from normal radiation spillage and heliostat aiming transients. Energy incident on the shield will be reflected or reradiated.

Piping and Manifolds

The RS piping and manifolds shall distribute the HITEC fluid through the absorber unit. The riser carrying colder fluid shall enter a distribution manifold before entering the absorber unit. This entry manifold shall be designed to ensure equal flow rate of coolant to the absorber unit tubes. Separate throttling valves or flow meters shall not be used. The lines carrying fluid from the manifold to the absorber inlet lines shall contain bends to aid in reducing differential expansion forces transmitted to the absorber rim by the piping system. Heated fluid leaving the absorber unit shall flow through an exit manifold which permits the absorber unit to be joined directly with a single larger fluid-outlet pipe. The outlet pipe shall make several turns before attachment to the downcomer in order to further isolate the absorber from thermal expansion forces. At the highest point, and on the upper crown of the fluid outlet pipe, a pressure relief valve and vent valve shall be attached. The exit of these two valves shall be connected together to a common vent pipe which extends to a sump at the bottom of the tower.

Insulation

Thermal insulation shall be required for the back side of the absorber assembly and for all fluid piping, vent piping and high-temperature components. Design values for the maximum heat transfer coefficient for the insulation assembly are $5.67 \times 10^{-4} \text{ KW/m}^2\text{°C}$ ($0.1 \text{ Btu/hr.ft.}^2\text{°F}$) for the absorber and connecting piping, and $1.70 \times 10^{-3} \text{ KW/m}^2\text{°C}$ ($0.3 \text{ Btu/hr.ft.}^2\text{°F}$) for the valves and instrumentation.

Heaters

An electrical trace heating system shall be required for the absorber and all fluid piping and valves to keep the HITEC fluid from cooling and solidifying during periods of low or no insolation. The system must be capable of heating the absorber, piping, valves, etc., to a temperature of at least 177°C (350°F) from a 20°C (68°F) ambient in no more than 12 hours. The heaters shall be automatically shut off when the fluid reaches its minimum specified operating temperature.

Controls and Instrumentation

There shall be no control valves in the receiver subsystem. Appropriate orificing may be installed to: (1) proportion the fluid flow through the parallel circuits of the absorber unit, if required, (2) provide necessary pressure control or venting of gases. Temperature, pressure, and flow sensors will be provided at appropriate locations within the receiver.

RS Control Console

A RS Control Console shall be located in the plant control trailer. This console shall operate independently of the main plant controls, and shall provide the plant operator with real-time information from RS instrumentation plus appropriate engineering displays, alarms, and controls (vent valve, doors, trace heating).

3.5.2 RS Operational Requirements

The RS shall be compatible with all modes of plant operation, as follows:

Energy Collecting Mode - In the energy collecting mode, the RS doors will be opened, and solar insolation will be redirected into the RS absorber unit. Fluid flow rate through the absorber will be varied (by the ETSS) in proportion to the solar radiation so that receiver outlet fluid temperature will be maintained at rated values.

Energy Utilization Mode - (Not applicable. The RS operates in the energy collection mode only, and is therefore independent of the energy utilization mode.)

Startup Mode - Receiver startup operations will begin with a signal from the operator which initiates a series of receiver prestart checks (valve positions, temperatures, pressures). Any out-of-normal receiver startup operating conditions will be monitored at the plant control station. Under normal conditions, the receiver will have been in an overnight standby mode and fluid temperatures will have been maintained at 177°C (350°F) by residual heat in the system or by the trace heaters. At startup command, flow valves (in the ETSS) will open, pumps will start, and fluid flow will begin. Once steady state flow has been established, the receiver doors will be opened by the operator and solar heating will commence. For cold starts after an extended shutdown period, fluid flow will not be initiated until all heat transfer fluid, fluid lines and valves have been brought up to 177°C(350°F).

Intermittent Mode - For intermittent cloud passage, the fluid flowing through the receiver will be reduced to maintain rated receiver outlet temperature as long as possible. When reduced insolation no longer permits rated output conditions, the total receiver flow will be reduced to a minimum operating value of 10 percent of nominal and directed back to the cold storage tank. For intermittent operations, the receiver must withstand a 100% change in heat flux in 10 seconds as clouds sweep across the collector field.

Normal Shutdown Mode - When the insolation approaches the point where the specified outlet temperatures cannot be maintained at a minimum flow rate of 10% of nominal, a controlled shutdown process will begin. In a coordinated manner, the fluid flow will be stopped, the heliostats slewed away from the receiver, the receiver doors closed, and trace heating initiated (if required).

Emergency Shutdown Mode - In the event of abnormal operation of the receiver (as indicated by low or high flowrates, pressures or temperatures), the receiver instrumentation systems must detect the abnormality and alert the plant operator. If operator remedial actions cannot resolve the problem before trip limits are exceeded, the control system will automatically begin an emergency shutdown procedure. Emergency slewing of the heliostats off the receiver to remove the heat source will begin, and fluid flow rates will be reduced. If necessary, excessive receiver tube pressures will be vented. When the heat flux from the heliostat field has been significantly reduced, the receiver doors will be closed, and the fluid flow stopped. System checkout and inspection procedures will then be initiated to determine the cause of the abnormal operation. Typical conditions which could result in emergency shutdowns are: a loss of receiver fluid at the inlet, a large leak in the receiver, an obstruction in the tubing, or a sudden and significant change in the radiation from the heliostat field.

Inactive Mode - Extended RS shutdown with fluid/component temperatures reduced to ambient conditions may be required for prolonged adverse weather conditions, and will be required for maintenance or repair of certain receiver elements or other subsystems. For extended shutdown without trace heating, the heat transfer fluid will solidify. The shutdown mode for these conditions is the same as for normal shutdown, except that trace heaters will not be activated. Hot fluid in the receiver will be drained into the thermal storage tank by GN_2 purge. Provisions for drainage of receiver fluid is required. In this condition, maintenance or repair can be conducted safely on the absorber unit or other receiver elements. For startup with the receiver tubes in this condition, trace heaters must raise the temperature in the receiver unit to at least 177°C (350°F) before fluid flow is begun.

3.5.3 RS Interface Characteristics

The RS shall interface with the following subsystems:

<u>Subsystems</u>	<u>Interface Type</u>
CS	Solar heat flux
TS	Structural attachments; grounding
ETSS	Fluid and vent lines
EPGS	Electrical power (doors, instruments, servicing)
PCS	Data transmission; control (vent, doors, heaters)

Interface requirements are specified below:

RS/CS Interface - (Covered in Section 3.4.3, CS/RS Interfaces.)

RS/TS Interfaces - Provisions will be included in the receiver structural assembly for bolting the total receiver unit to the top of the tower. The tower shall be equipped with appropriate platforms to permit inspection and maintenance of the RS, as required. RS lightning arrestors shall be properly grounded via the tower.

RS/ETSS Interfaces - Fluid connections between the receiver and the energy transport and storage subsystems for the riser, downcomer, and vent piping shall be located inside the receiver housing, near the receiver/tower interface plane. All piping shall be physically and functionally compatible.

RS/EPGS Interfaces - The electrical power generating subsystem shall provide power for the RS door mechanism, heaters, lighting, and service outlets. An electrical power service box will be located inside the receiver housing, near the receiver/tower interface plane.

RS/PCS Interfaces - The RS shall respond to all control commands issued by the PCS. Service box and terminal strips will be located inside the receiver housing, near the receiver/tower interface plane, for the purpose of transmitting instrument readings (temperature, pressure, flow rates, valve and door position) and control (doors, heaters, vent). The RS console located in the plant control trailer shall be physically and functionally compatible with the plant control subsystem and supporting facilities and equipment.

3.6 TOWER SUBSYSTEM (TS)

The Tower Subsystem (TS) shall support the receiver subsystem, riser and downcomer piping, and necessary ancillary equipment. The tower assembly includes the basic tower structure, supporting structures and foundations, working platforms, service elevator, ladders, lights, lightning protection, and supports for heat transfer fluid lines, vent/relief lines, electric power cables, and instrumentation/control cables. Design, functional and interface requirements of the tower subsystem are given in the following sections.

3.6.1 TS Design Requirements

The tower shall be a low-cost free-standing steel structure designed to support the weight of the receiver and ancillary equipment, and to operate under the most severe wind and seismic conditions expected with minimum receiver sway. Overall tower design requirements are summarized on Table 3.6-1.

Table 3.6-1

Tower Design Requirements

Tower Height	54 m (177 ft)
Dry Receiver Weight.	____ kg (____ lb)
Wet Receiver Weight.	____ kg (____ lb)
Deflection Limits	
During Operation	.150 mm (6 in.)

Tower structural life shall exceed 30 years. Design stresses for the tower and supports shall not exceed the maximum allowed by standard tower building codes. No combustible materials shall be used in the tower subsystem. Tower components should be designed so as to operate satisfactorily without causing power plant shutdown at any time. Necessary maintenance shall be conducted during nonoperating plant periods or on a noninterference basis with plant operation. The tower shall be designed to provide ingress, egress, and access for maintenance and inspection of tower structure, receiver steam lines, controls, and other subsystem elements. Adequate safety provisions shall be provided.

Design requirements for major TS elements are given below. More detailed characteristics of the TS subassemblies designed to meet these requirements are summarized in Section 5.0 of this specification.

Tower Structure

The tower structure shall be constructed using commercial steel structure and drag bracing with angle depth and width to accommodate specific local load conditions. The tower will be constructed of standard steel structural members that are welded or bolted, as appropriate. Segments of the tower structure may be prefabricated and transported by track to the plant site for final assembly. Prefabricated tower segments shall be installed at the plant site by crane. All steel members shall be painted for environmental protection and for site aesthetics. Component installation shall be conducted after tower erection. Special provisions shall be included for the attachment of pipes and cables, a caged ladder, a service elevator and other equipment.

Foundations

The tower foundation shall be a reinforced concrete mat design of sufficient area to distribute the compressive load at a rate less than the soil bearing strength limit of ____ kg/m^2 (____ lb/ft^2) at a ____ m (____ ft) depth.

Ladders

A caged access ladder shall be provided from the ground to the tower top with intermediate platforms. The design will be developed in accordance with OSHA requirements and will include the necessary intermediate rest platforms.

Service Elevator

A small service elevator shall be mounted on the side of the tower to provide direct access to the work platform at the top of the tower. The elevator shall be designed to accommodate two people plus lightweight tools. The elevator shall be capable of stopping at intermediate locations for maintenance and repair, as required. At each location, adequate safety provisions will be made for the maintenance personnel. There are no requirements for a crane on the tower. A truck crane or helicopter shall be used to lift large items to the top of the tower.

Working Platform

A working platform shall be constructed at the top of the tower with adequate space for personnel operations plus equipment needed for receiver installation, inspection, maintenance and other services. The platform will include appropriate safety provisions such as guard rails and tiedowns in accordance with OSHA regulations. Access to the platform shall be provided by the caged ladder or service elevator. Safety gates surround these access openings. Special portable working platforms with protective railings may also be required for inspection and servicing of the receiver subsystem, energy transport subsystem (riser and downcomer piping, insulation and trace heaters), and tower elements. Portable platforms shall have suitable tiedowns or structural supports for safe manned servicing operations. At points along the caged ladder route, permanent intermediate platforms shall be located which can serve both as rest and local inspection work area. These platforms shall be made of steel gratings and utilize standard safety railings. Hard hats will be required for any inspection or maintenance procedure in the vicinity of the tower. Safety harnesses shall be used by personnel for servicing operations in potentially dangerous positions on the tower.

Interconnects and Supports

Structural supports and appropriate mechanical attachments shall be provided for all interconnecting cables and piping. Special support provisions shall be incorporated to allow for thermal expansion of the rise and downcomer pipes. Sufficient clearance will be maintained between the final bend and the ground or ground-mounted structures to allow for this pipe growth. Instrumentation and control lines will be mounted to the tower, and shielding and protection will be selected to isolate these lines from both environmental and electromagnetic interference.

Lights

Lights shall be provided for necessary personnel operations and safety at the tower base, along the ladder and at the working platforms. In addition, aircraft warning lights shall be incorporated in accordance with aviation regulations. A white, high-intensity light shall also be mounted at the highest point of the receiver and tower structure. Safe access will be provided to each light to facilitate maintenance.

Lightning Protection

The tower shall be shielded from lightning by air terminals (masts) projecting above the top of the receiver. These terminals will be grounded with copper cables insulated from the tower with porcelain insulators.

Electric Power

Electrical outlets, cables and junction boxes will be included to provide 240-V power at the tower top working platform for servicing operations, service elevator and other necessary equipment. In addition, 115-V ac convenience outlets will be provided for small hand tools, lighting, and other small power accessories. Appropriate electrical outlets shall also be provided at the intermediate work levels, as required.

Heliostat Alignment Target

A small target for heliostat alignment will be mounted on the side of the tower immediately below the top of the tower facing the heliostat field. This device is an inactive flat surface nominally 5 x 5m (16.4 x 16.4 ft), with a white diffuse reflecting surface.

3.6.2 TS Functional Requirements - (Not applicable to tower subsystem.)

3.6.3 TS Interface Requirements - The TS shall interface with the following subsystems:

<u>Subsystem</u>	<u>Interface Type</u>
CS	Solar flux limits; heliostat target
RS	Structural, mechanical
ETSS	Piping (riser, downcomer, vent)
EPGS	Electrical power
PCS	Data transmission; control

Interface requirements are specified below.

TS/CS Interfaces - (Covered in Section 3.4.3, CS/TS Interfaces.)

TS/RS Interfaces - (Covered in Section 3.5.3, RS/TS Interfaces.)

TS/ETSS Interfaces - The tower shall provide appropriate structural supports for the riser and downcomer piping. These provisions shall also accommodate the thermal expansion and contraction of this piping.

TS/EPGS Interfaces - The tower shall provide appropriate structural support and shielding for electrical power lines required for RS operations, riser/downcomer trace heating, and tower services (elevator, lights, service outlets, etc.)

TS/PCS Interfaces - The tower shall provide adequate structural support and shielding for the instrumentation and control cabling required for the RS and other equipment, as required.

3.7 ENERGY TRANSPORT AND STORAGE SUBSYSTEM (ETSS)

The Energy Transport and Storage Subsystem (ETSS) includes all the equipment and fluids necessary to efficiently transfer and control the thermal energy between the receiver, thermal storage tanks, and steam generator. The ETSS elements include HITEC pipes, pumps, control valves, thermal storage tanks, steam generator, and associated insulation, heaters, supports, foundations, inert gas system, instrumentation, and a control console in the plant control trailer. Design/performance, functional, and interface requirements of the ETSS are given below. Detailed characteristics of the ETSS subassemblies designed to meet these requirements are summarized in Section 5.0 of this specification.

3.7.1 ETSS Design/Performance Requirements

The ETSS shall be designed to transfer the thermal energy absorbed in the receiver to the storage tanks and thence from the storage tanks to the steam generator in the most efficient and economical manner. The design shall maximize the use of available thermal energy and minimize thermal energy losses. Specific capacity, size, shape and configuration constraints shall be governed by plant economics and by designing the plant layout to facilitate efficient and safe operation and maintenance. All elements shall be arranged with consideration for reasonable access for inspection, maintenance and repair. Piping and interface connections shall comply with standard utility building codes.

The ETSS shall consist of a receiver loop, a steam generation loop, and an inter-tank, fossil-fueled heater loop. In the receiver loop, HITEC shall be drawn from the cold thermal storage tank, pumped through the solar receiver where the HITEC is heated, and returned to hot thermal storage tank. In the steam generation loop, HITEC shall be drawn from the hot thermal storage tank, pumped through the steam generator that services the electrical power generating subsystem, and returned to the cold thermal storage tank. In the inter-tank/heater loop, the HITEC shall be transferred between tanks, as required, and a fossil-fueled HITEC heater (Fossil Energy Subsystem) may be used to inject additional heat into the system when needed. Separate pumps shall be required in the receiver and steam generator loops, and flow shall be independently controlled to achieve desired temperatures. These

independent loops shall enable the electrical power generating subsystem and the energy collection subsystems to operate independently of each other.

Piping

ETSS piping shall be required to transport molten HITEC throughout the receiver, steam generator and inter-tank/heater loops. Piping materials shall be stainless steel for hot (454°C, 850°F) HITEC lines and carbon steel for cold (260°C, 500°F) HITEC lines. Pipe-to-pipe connections shall be butt welded where possible to ensure leak integrity. Pipe connections with major system equipment and valves shall use ring joint flanges to permit maintenance and repair/replacement as required. Required minimum wall thickness of the piping shall be determined using the Piping Codes referred to in Section 2. Scheduled pipe should be used, and the calculated minimum wall thickness shall be increased by the manufacturing tolerance of the pipe being used. In addition, shut-off pressures must not be greater than the allowable working pressure of the pipe calculated in accordance with the Piping Codes.

Pumps

Pumps are required to circulate the HITEC in the receiver and steam-generator loops. Both pumps shall be centrifugal with vertical shafts and sleeve bearings submerged in the molten salt. The receiver loop feed pump (cold tank pump) must be capable of pumping HITEC from the cold thermal storage tank to the receiver unit on the tower and back to the hot thermal storage tank at the required flow rates. The steam-generator loop feed pump (hot tank pump) must be capable of pumping HITEC from the hot thermal storage tank through the steam-generator and back to the cold storage tank at the required flow rates. These pumps shall also be used to circulate HITEC in the inter-tank/heater loop. Each pump must be able to backspin without damage to allow HITEC to drain back to the storage tanks following plant shutdown. Pump performance requirements are summarized in Table 3.7-2.

Table 3.7-2
PUMP CHARACTERISTICS

	<u>Receiver Loop</u>	<u>Steam Generator Loop</u>
Material	Carbon Steel	Stainless Steel
Pump Type	Submerged Bearing Centrifugal, vertical shaft	Same
Liquid	HITEC	HITEC
Temperature	260°C(500°F)	454°C(850°F)
Flowrate	___ kg/hr (___ lb/hr) ___ m ³ /hr (___ gal/min)	___ kg/hr (___ lb/hr) ___ m ³ /hr (___ gal/min)
Head Rise	___ bar	___ bar

Thermal Storage Tanks

Two thermal storage tanks shall be used to contain the hot and cold HITEC heat transfer fluid. Both tanks shall be horizontally mounted, cylindrical tanks with dished heads. Tank diameters shall be limited to 12.0 ft (3.66m) to permit highway transportation from the manufacturing shop to the plant site. The tanks shall be mounted on a low density concrete pad or dry soil of adequate bearing strength.

The high temperature vessel (hot tank) shall accumulate hot 454°C (850°F) HITEC flowing from the receiver. The maximum thermal storage capacity (thermal power absorbed into the energy storage subsystem) shall be 20 MW_th (equivalent to the thermal power level required to operate the turbine at a 0.6 MWe net power output level for ____ hours). The hot tank shall be made of stainless steel with an outside diameter of 3.66m (12.0 ft). The tank shall accommodate at least ____ kg (____ lb.) of molten salt.

The cold temperature vessel (cold tank) accumulates the cool 260°C (500°F) HITEC flowing from the exit of the steam generator. The cold tank shall be made of carbon steel with an outside diameter of 3.66m (12 ft.). The tank shall accommodate at least ____ kg (____ lb.) of molten salt.

Tank design requirements are summarized on Table 3.7-3. Each tank shall be equipped with fill and drain valves, relief valve, safety rupture disk, thermocouple wells, liquid level indicators and pressure transducers. In addition, the tanks shall be designed to accommodate external insulation, submerged pumps, immersion heaters, and nitrogen purge.

Table 3.7-3
THERMAL STORAGE TANK DESIGN REQUIREMENTS

<u>Tank Design</u>	<u>Cold Tank</u>	<u>Hot Tank</u>
Quantity	1	1
Tank Material	Carbon Steel	Stainless 316
Diameter (Max OD)	3.7m (12 ft)	3.7m (12 ft)
Storage Fluid	HITEC	HITEC
Nom. Storage Temperature	260°C (500°F)	454°C (850°F)
Nom. Storage Pressure	___ Bar (___ psi)	___ Bar (___ psi)
Charge/Discharge Rate (Max)	___ MW _t /hr	___ MW _t /hr
Thermal Leakage Rate	___ % per day	___ % per day
Ullage Volume (fully charged)	___ %	___ %
Ullage Medium	Nitrogen	Nitrogen

Storage Volume (HITEC Wgt.):

- Minimum	___ kg (___ lb)	} (SAME)
- Buffer	___ kg (___ lb)	
- Total	___ kg (___ lb)	

Design Accommodations:

<ul style="list-style-type: none"> ● Main Line Interfaces ● Submerged Pumps ● Immersion Heaters ● External Insulation ● External Supports ● Fill and Drain Valves ● Relief Valves ● Rupture Discs ● Thermocouples ● Liquid Level Sensors ● Pressure Transducers ● Nitrogen Gas Purge System 	} (SAME)

Nitrogen Gas Purge System

A gaseous nitrogen system shall be utilized in the ETSS to provide an inert blanket in the HITEC tanks and lines to prevent oxidation of sodium nitrite, the formation of sodium hydroxide from atmospheric moisture, and the formation of sodium carbonate from the absorption of carbon dioxide. These reactions would lead to increased melting points of the HITEC, corrosion, and precipitate formation. Nitrogen pressure will be regulated automatically to maintain a minimum pressure of 5 psig (0.34 bars differential) in the tanks. As nitrogen fills the hot tank and warms up, the pressure shall be allowed to increase to approximately 0.7 bars (10 psig differential).

Steam Generator

The steam generator shall be a natural circulation type heat exchanger consisting of separate preheater, boiler and superheater sections. HITEC shall be contained in the shellside of the preheater and superheater and the water/steam serving the power conversion equipment shall be contained within the tubes. The preheater section shall consist of horizontal U-tube heat exchangers with a longitudinal baffle on the shellside. The boiler shall be a horizontal natural recirculation "kettle type". The superheater section shall be composed of a single horizontal U-tube heat exchanger with longitudinal baffle. A line and control valve shall be included permitting the steam drum to blow down for removal of water impurities. Design requirements are given on Table 3.7-4.

Table 3.7-4
STEAM GENERATOR DESIGN REQUIREMENTS

	<u>Preheater</u>	<u>Boiler</u>	<u>Superheater</u>
Type -----	2 Pass U-Tubes in series; Longit. Baffle	Kettle-type	2-Pass U-Tubes in Series; Longit. Baffle
Shell Material -----			
Tube Material -----			
Heat Exchanged -----	1.07 MW _t	3.86 MW _t	.93 MW _t
Total = 5.86 MW _t			

Salt Flow Conditions (Nominal):

- Inlet Temperature ----- 454°C (850°F)
- Outlet Temperature ----- 260°C (500°F)
- Flow Rate ----- 7000 kg/hr 154,000 lb/hr
- Pressure ----- 7 bar (100 psi)

Water/Steam Flow Conditions (Nominal):

- Inlet Water Temperature ----- 163°C (325°F)
- Outlet Steam Temperature ----- 399°C (750°F)
- Flow Rate ----- 8500 kg/hr (18,800 lb/hr)
- Outlet Steam Pressure ----- ___ bar (___ psi)

Valves and Actuators

Control valves shall be designed to be compatible with the operating temperature and line size in which they are located. All valves shall be required (1) to respond automatically to commands from operating personnel and/or from plant control subsystem, (2) to change smoothly and rapidly from one operating mode to another, and (3) to respond smoothly and rapidly to changes in thermal charging rate or extraction rate or both. The time response of valves shall be on the order of tens of seconds. In general response times need not be rapid since the large thermal inertias involved in the total system are expected to provide the controlling lag time in all control loops. Remote control valves shall use pneumatic actuators. The main flow control valve located at the base of the receiver downcomer shall be designed to also dissipate the tower hydrostatic head. Safety valves shall be provided at appropriate locations in the ETSS to protect against overpressure. Pressure and temperature transmitters shall be appropriately located to enable system control.

All valves shall be rated at 21 bars and contain high temperature asbestos gaskets. It is desirable to have the same pressure-temperature valve rating criteria for all ETSS valves and to purchase them under one standard rating rather than having to make selected valve classes at different locations throughout the subsystem. However, in the interest of economics, it is permissible to purchase standard class rated valves in the portion of the system where design conditions would allow, and only purchase special rated valves for use in the part of the system which has elevated design conditions making the special valve class requirement mandatory.

Insulation - Piping, Valves, Steam Generator

All HITEC lines, valves and steam generator elements shall be externally insulated and protected with a weather cover to minimize heat losses and comply with building codes. All insulation joints shall be sealed with an insulating cement.

Insulation - Thermal Storage Tanks

Both thermal storage tanks shall be covered with an external insulation and a weather cover.

Trace Heaters - Piping, Valves, Steam Generator

Trace heaters shall be used for all HITEC lines, valves, and the steam generator element to insure that the temperature of the heat transfer salt is maintained above 177°C (350°F) to prevent salt solidification. All trace heaters shall be insulated electrical heating cables and covered with a stainless steel sheath for high temperature operation. The heaters shall be attached prior to application of the external insulation. The trace heaters shall be installed over given segment lengths and for elements with electrical plugs to facilitate maintenance and repair. Separate circuits shall be provided for each major pipe segment.

Tank Heaters

An immersion heater will be utilized in each thermal storage tank to melt the salt during initial salt filling operations or following extended shutdown periods when the salt was allowed to solidify. The heaters will also be used to maintain salt in the tank at minimum operating temperature during long standby modes. Heat paths shall be provided to distribute the heat throughout the tank cavity during heater operation.

ETSS Control Console

An ETSS control console shall be located in the plant control trailer. This console shall operate independently of the main plant controls, and shall provide the plant operator with real-time information from ETSS instrumentation plus appropriate displays, alarm, and controls (pumps, valves, purge, auxiliary heater).

Heat Transfer Media

The heat transfer media of the ETSS shall be a molten salt solution termed "HITEC". HITEC is a eutectic mixture of potassium nitrate 53%, sodium nitrite 40%, and sodium nitrate 7%. Properties of the material are given in Table 3.7-5.

HITEC was developed in the 1930's by DuPont Chemical Company, and has been used safely in numerous applications in the chemical, petroleum, and metal treatment industries. In the majority of applications, HITEC is used as a heat recovery fluid in which it is pumped from a salt tank, through a reactor where it picks up heat from exothermic reaction, into a steam generator to be cooled, and back to the tank to be recycled.

HITEC is used because it has a relatively low melting point, high heat transfer coefficient, thermal stability, and low cost. HITEC is a white granular solid which turns yellow when heated. It is nonfouling, nonflammable, nonexplosive and evolves no toxic vapors under normal conditions. It has a low degree of corrosivity and can be used with carbon steel up to 454°C (850°F). Maximum operating temperature is 538°C (1,000°F). The vapor pressure below 450°C is essentially zero. Although very stable up to high temperatures, the salt undergoes a slow thermal breakdown of the nitrite to nitrate. In contact with air, the nitrite is slowly oxidized by atmospheric oxygen. Carbon dioxide can be absorbed to form carbonates and water to form alkali metal hydroxides. These reactions tend to raise the freezing point and are essentially eliminated by using a nitrogen cover gas. Using nitrogen as a cover gas will give maximum control of side reactions resulting in minimal salt replacement.

The majority of chemical and petroleum process industries using HITEC operate below 842°F and use carbon steel exclusively with no unusual corrosion problems. Corrosion rates on carbon steel are on the order of 0.1 to 0.4 mm/yr between 842°F and 970°F. Above 842°F, stainless steel has been used with minimal corrosion problems.

Table 3.7-5

PHYSICAL PROPERTIES OF HITEC

<u>Property</u>	<u>Value (English)</u>	<u>Value (Metric)</u>
Composition, % wgt.	53% Potassium Nitrate (KNO_3) 40% Sodium Nitrite (NaNO_2) 7% Sodium Nitrate (NaNO_3)	
Melting Point	288°F	142°C
Maximum Operating Temperature	1000°F	538°C
Density	123 lb/ft ³ (300°F) 118 lb/ft ³ (500°F) 110 lb/ft ³ (800°F) 105 lb/ft ³ (1000°F)	1,970 kg/m ³ (149°C) 1,890 kg/m ³ (260°C) 1,770 kg/m ³ (427°C) 1,680 kg/m ³ (538°C)
Viscosity	43.6 lb/ft-hr (300°F) 10.42 lb/ft-hr (500°F) 4.36 lb/ft-hr (800°F) 2.66 lb/ft-hr (1000°F)	.0180 Pa.s (149°C) .0043 Pa.s (260°C) .0018 Pa.s (427°C) .0012 Pa.s (538°C)
Specific Heat	0.373 Btu/lb-°F	1,560 J/kg-°K
Thermal Conductivity	0.33 Btu/hr-ft-°F	0.61 W/m -°K
Heat Transfer Coef.	800-2900 Btu/hr-ft ² -°F	4,600-16,700 W/m ² -°K
Expansion Coef:		
- Linear	$2.85 \times 10^{-5}/^\circ\text{F}$	$5.13 \times 10^{-5}/^\circ\text{C}$
- Cubic	$2.03 \times 10^{-4}/^\circ\text{F}$	$3.64 \times 10^{-4}/^\circ\text{C}$
Latent Heat of Fusion	35 Btu/lb	81.4 J/gm
Cost (1979 approx)	\$0.35/lb	\$0.77/kg

3.7.2 ETSS Operational Requirements

The ETSS shall be compatible with all modes of plant operation, as described below.

Energy Collecting Mode - In the solar-only energy collecting modes, HITEC shall be circulated from the cold storage tank through the receiver subsystem (where the HITEC is heated) and returned to the hot storage tank. Flow rate shall be controlled by a control valve to maintain proper temperature in the receiver loop. Bypass lines shall be closed. If the solar insolation is not adequate to maintain proper temperatures, the auxiliary heater may also be employed to add heat to the loop. In the fossil heater only-mode, the receiver is not in operation and appropriate valves are activated to permit the HITEC to be heated in the Fossil Energy Subsystem (FES) and flow into the hot thermal storage tank. In the hybrid mode, both the receiver and FES shall be utilized to heat the HITEC.

Energy Utilization Mode - In the energy utilization mode, the thermal energy in the hot thermal storage tank shall be used to provide the heat for the operation of the EPGs. HITEC shall be pumped from the hot tank through the steam generator, and returned to the cold tank. All bypass lines shall be closed. The steam generated in the water/steam loop of the EPGs shall be subsequently used for electrical power generation, space conditioning and water heating, as required.

Startup Mode - During receiver startup, when the HITEC leaving the receiver is below the acceptable temperature band, the receiver flow shall be controlled to divert flow back to the cold tank, bypassing the hot tank. Once the design receiver outlet temperature is reached, appropriate control valves shall be activated to allow flow into the hot tank. Steam generator warmup can be accomplished by metering both hot and cold HITEC flow into the steam generator until the steam generator has reached acceptable temperature levels. The steam generator can also be brought up to operating temperatures with electrical trace heaters and then switched over to the hot salt system.

Intermittent Operation - For intermittent cloud passage, the HITEC flow rate through the receiver shall be reduced to maintain rated receiver outlet temperature at 454°C (850°F). If flow rate is reduced to 10 percent of nominal conditions or less, the flow from the receiver will be diverted to the cold storage tank, as in the receiver startup mode. Intermittent cloud passage has no effect on the steam generator loop of the ETSS since the equipment operates from thermal energy stored in the hot storage tank.

Normal Shutdown Mode - The receiver ETSS loop will be normally shutdown when the insolation decreases to a level where the specified receiver outlet temperature cannot be maintained at a minimum HITEC flow rate of 10 percent of nominal. Fluid flow through the receiver will be diverted to the cold storage tank. Subsequently, flow through the receiver will be discontinued by stopping the receiver pump. Trace heaters will be actuated, as required, to maintain a minimum temperature of 177°C (350°F) in the HITEC lines and receiver unit. The steam generator loop shall be normally shutdown in a similar manner when energy in the hot storage tank is not sufficient to maintain rated conditions at the steam generator. At this point, the hot tank pump shall be stopped and the trace heaters activated.

Emergency Shutdown Mode - In the ETSS receiver loop, an emergency shutdown shall be accomplished by stopping the receiver loop pump and venting the receiver lines, if necessary. Appropriate valves shall be either opened or closed depending upon the nature of the problem causing the shutdown action. In the ETSS steam generator loop, an emergency shutdown shall also be accomplished by stopping the steam generator pump and activating appropriate valves. An emergency shutdown of either the receiver or steam generator loop may not necessarily require the shutdown of both loops simultaneously. For example, shutdown may only be limited to the concentrator and receiver subsystems if sufficient energy exists in the thermal storage system to maintain operation of the power conversion equipment. Likewise, shutdown may only apply to the steam generating loop if the thermal storage system is capable of accepting additional thermal energy.

Overnight Standby - For normal overnight standby, the fluid pumps shall be inoperative and trace heaters shall be operated to maintain HITEC pipe temperatures at or above 177°C (350°F). Valves shall be actuated to drain HITEC from the steam generator loop into the cold storage tank. HITEC will not be drained from the receiver and the feed pump will be activated to circulate at minimum flow if receiver temperatures fall below the minimum set point.

Extended Shutdown - For extended shutdown periods, the HITEC shall be drained from all lines into the storage tanks, and the nitrogen purge system shall be used to prevent air from entering the lines and storage tanks. Manual valves shall be included in the inter-tank energy transport loop to allow direct transfer of fluid from one storage tank to the other storage tank, as required. The trace heaters shall be inactive until the system is to be actuated. Fluid flow shall not be initiated until all HITEC lines and valves have been brought up to 177°C (350°F).

3.7.3 ETSS Interface Requirements

The ETSS shall interface with the following plant subsystems.

<u>Subsystem</u>	<u>Interface Type</u>
RS	Fluid and vent lines
TS	Piping supports (riser, downcomer, vent) vent)
FES	Fluid lines
EPGS	Feedwater/steam lines; Electrical power (pumps, valves, heaters) heaters)
PCS	Data transmission; control

Interface requirements are specified below.

ETSS/RS Interface

(Covered in Section 3.5.3, RS/ETSS Interfaces).

ETSS/TS Interfaces

(Covered in Section 3.6.3, TS/ETSS Interfaces).

ETSS/FES Interfaces

The ETSS and fossil energy subsystem shall have HITEC line interfaces that are physically and functionally compatible.

ETSS/EPGS Interfaces

The energy transport and storage subsystem and electrical power generating subsystem shall have a physical interface at the ETSS steam generator. EPGS feedwater and steam lines shall be attached to the appropriate inlet and outlet connections of the steam generator. All piping shall be physically and functionally compatible. The EPGS shall also provide the necessary electrical power for ETSS pumps, valves and heaters. In addition, electrical service outlets shall be appropriately located to provide power for on-site ETSS maintenance, as required.

ETSS/PCS Interfaces

The ETSS shall respond to all commands issued by the PCS. Appropriate instrument readings shall be transmitted to the PCS. A separate ETSS control console shall be located in the control trailer, but shall operate independently of the main plant controls.

3.8 FOSSIL ENERGY SUBSYSTEM (FES)

The Fossil Energy Subsystem (FES) shall provide additional thermal energy to the system in order to enable facility operation during cloudy days or periods of excessive energy demand. The FES shall consist of a fossil fuel reactor, heat exchanger, exhaust stack, fuel supply source, and associated pipe lines, pumps, valves, instrumentation and controls.

Design/performance, functional and interface requirements of the FES for the Fort Hood cogeneration facility are given below. Detailed characteristics of the FES designed to meet these requirements are summarized in Section 5.0 of this specification.

3.8.1 Design/Performance Requirements

The FES shall add thermal energy to the heat transfer fluid (HITEC) in the ETSS loop by means of a gas-fired auxiliary heater located in the inter-tank loop. HITEC from the cold thermal storage tank shall be pumped through the heater and into the hot thermal storage tank. FES design/performance requirements are summarized on Table 3.8.1.

All HITEC lines external to the heat exchanger shall be externally insulated. Electrical trace heaters shall be added to insure that the temperature of the HITEC is maintained above 177°C (350°F) to prevent salt solidification. The heat exchanger shall be oriented such that the HITEC lines can be adequately drained for overnight standby or extended shutdown. The lines shall be constructed of materials that are compatible with the operating temperatures expected.

Existing natural gas lines at Complex 87000 shall be used as the fuel source for the auxiliary heater. Additional pipe line valves, and instrumentation shall be added, as appropriate, to service and control the FES.

Table 3.8-1

FOSSIL ENERGY SUBSYSTEM DESIGN AND PERFORMANCE REQUIREMENTS

Design

- Type Heater ----- Gas Fired, radiant & convective
- Heat Exchanger Orientation ----- Vertical (for drainage)
- Fluid ----- HITEC
- Line Materials:
 - Cold Lines ----- Carbon Steel
 - Hot Lines ----- Stainless Steel
- Heat Transfer Rate ----- 6 MW_t (20x10⁶ BTU/hr)

Flow Conditions

- Temperature (Nominal)
 - Inlet ----- 260⁰C (500⁰F)
 - Outlet ----- 454⁰C (850⁰F)
- Flow Rate
 - Maximum ----- 69,500 kg/hr (153,500 lb/hr)
 - Minimum ----- 7,500 kg/hr (16,530 lb/hr)
- Pressure ----- 6.6 Bar (100 psi)

3.8.2 FES Operational Requirements

The FES shall be compatible with all modes of plant operation, as described below.

Energy Collection Mode - In the solar-only energy collection mode, the FES is inoperative. In the fossil heater only-mode and the hybrid mode, the FES is operating. HITEC shall be circulated from the cold storage tank through the FES (where the HITEC is heated) and returned to the hot storage tank.

Energy Utilization Mode - (Not applicable - the FES operates in the energy collection mode only, however, the heat provided to the hot thermal storage tank can be subsequently used in the energy utilization mode.)

Startup Mode - In the startup mode, the FES shall be activated by firing the gas heater at a low rate until the HITEC in the lines reaches a temperature approaching 454°C (850°F), at which time flow of HITEC through the heater will be initiated.

Normal Shutdown Mode - The FES shall be shutdown when there is sufficient insolation to meet the overall heat requirements of the cogeneration facility. The normal shutdown procedure shall be initiated by terminating gas flow to the reactor and reducing the fluid flow through the FES in a controlled manner, as prescribed by the auxiliary heater manufacturer.

Emergency Shutdown Mode - The procedures for emergency shutdown of the FES are as described above for the Normal Shutdown Mode.

Overnight Standby - For overnight standby, the gas fired reactor shall be inoperative and trace heaters shall be operated to maintain HITEC pipe temperatures at or above 177°C (350°F).

Extended Shutdown - For extended shutdown periods, the HITEC shall be drained from the FES loop, and the nitrogen purge system shall be used to prevent air from entering the lines. Trace heaters shall also be inactive until startup.

3.8.3 FES Interface Requirements

The FES shall interface with the following plant subsystems:

<u>Subsystem</u>	<u>Interface Type</u>
ETSS	HITEC lines
EPGS	Electrical power (valves, trace heaters)
PCS	Control; data transmission

Interface requirements are specified below:

FES/ETSS Interfaces

(Covered in Section 3.7.3, ETSS/FES Interfaces)

FES/EPGS Interfaces

The electrical power generating subsystem shall produce the electrical power for FES operation (valves, trace heaters, controls, instrumentation).

FES/PCS Interfaces

The FES shall transmit instrument readings and respond to all commands issued by the plant-control subsystem.

3.9 ELECTRICAL POWER GENERATING SUBSYSTEM (EPGS)

The Electrical Power Generating Subsystem (EPGS) shall convert thermal energy into electricity and also provide useful heat for space conditioning and domestic hot water. The EPGS shall consist of four major assemblies, which are:

1. Power Generation (turbine, gearbox, generator, support systems)
2. Steam/Feedwater Equipment (condenser, heat rejection, feedwater heater/deaerator, water treatment, piping, valves, actuators, pumps, insulation)
3. Power Distribution (power lines, transformers, circuit breakers, switches, relays, connectors)
4. Control/Instrumentation (instruments, control console, power and control cabling)

Design/performance, functional and interface requirements of the EPGS are given below. Detailed characteristics of the EPGS subassemblies designed to meet these requirements are summarized in Section 5.0 of this specification.

3.9.1 Design/Performance Requirements

The EPGS shall convert thermal energy in the form of steam into electricity using a Rankine cycle steam turbine. Rejected heat shall be utilized downstream of the overall solar system for space conditioning (room heating or air conditioning) and the heating of domestic water.

The design of the EPGS shall provide for safe and reasonable access for inspection, maintenance, and repair of subsystem elements. The elements of the EPGS shall be so configured and located within or relative to other systems as to minimize adverse interfaces with operations of the other systems.

The subsystem shall employ commercial equipment as much as possible. The use of used, reconditioned or reconfigured apparatus shall be acceptable where appropriate. Equipment shall be mounted on skid units which are factory assembled and checked out, transported to the site, and installed with minimum assembly operations. All EPGS equipment shall be installed in the EPGS building, except the cooling equipment and EPGS control console, which shall be located in the control trailer unit.

Design/performance requirements for major EPGS components are given below.

Turbine

A conventional axial steam turbine shall be selected. Turbine design/performance requirements are given on Table 3.9-1. Turbine accessories shall include: electro-hydraulic controls and throttle, emergency overspeed governor, inter-connecting piping connections and valves, hydraulic and lubricating oil system, moisture separator and drainage provisions, steam sealing system, insulation for steam piping and valves, AC motor operated turning gear, instrumentation, alarms and protective devices and required turbine casing and support fixtures. The turbine shall be designed for rapid startup and continuous operation when the steam pressure rises but does not exceed 105% of rated pressure. During transient operation, when the synchronous generator is isolated from the utility grid, overspeeds shall not exceed 120% of rated speed.

The turbine, generator, and gearbox shall be assembled at the factory on a skid plate together with all necessary ancillary equipment, and then factory-tested before shipment. Internal steam piping shall be preassembled and preflushed at the factory. The equipment shall exhibit high reliability. The size, shape, dimensions and weight of the turbine shall be specified by the commercial supplier.

Table 3.9-1
Turbine-Generator Requirements

Type	Rankine
Rating, max.	600 kW _e
Rating, min.	300 kW
Turbine type	Single stage
Steam inlet temperature	399°C (750°F)
Steam inlet pressure	49 bar (700 psig)
Steam back pressure	4.4 bar (50 psig)
Speed	6000 RPM
Generator rating	600 kW, 750 KVA
Electrical	480/277V, 3 ϕ , 60 cycle
Generator type	Air-cooled, self-excited
Generator speed	1800
Control function required	
1. Speed governor	Yes
2. Automatic unattended operation	Yes
3. Automatic start/stop, synchronize	Yes
4. Operation safety trips	Yes

Generator

A single commercial generator capable of providing up to 600 kW_e shall be connected to the turbine. The turbine to generator drive coupling will be geared. The generator shall be of a revolving field, synchronous, 480V/3 phase, 60 cycle closed-loop, air-cooled type, equipped with space heaters and cooling air filter systems. Generator accessories shall include: current transformers, temperature detectors and indicators, space heater, air-coolers, cooling air filter system/protective devices, special tools and slings, and appropriate attach fittings. The generator shall operate continuously at rated output at any voltage from 95 to 105% of rated voltage and at power factors from 0.9 lagging to 0.95 leading, without exceeding temperature rise or causing harmful localized heating or other damage. The turbine generator circuit shall be capable of 60 seconds of operation with the generator frequency at 57.6 hZ (isolated from the utility grid) without permanent damage. The size, shape, dimensions and weight of the generator shall be as specified by the commercial supplier.

Heat Converter and Heat Rejection Equipment

A kettle-type heat converter will utilize energy from the turbine exhaust steam or accumulator steam to produce low pressure steam to be delivered to the complex. Performance requirements are given in Table 3.9-2.

Table 3.9-2

Heat Converter Design Requirements

Type Kettle

Maximum Steam Inlet Conditions:

- Temperature. 148 °C (298 °F)
- Pressure 3.5 bar (50 psi)
- Flow rate. _____ kg/hr (_____ lb/hr)

Condensate Outlet Conditions:

- Temperature. 121 °C (250 °F)
- Pressure 1.0 bar (15 psi)
- Flow rate. _____ kg/hr (_____ lb/hr)

Feedwater Heater/Deaerator

Feedwater heating and deaeration shall be accomplished with steam extraction from the turbine exhaust. A single feedwater heater shall be used in the form of a direct contact spray deaerator. This unit shall be sized to reduce dissolved oxygen to less than 0.005 cc/l, and provide 10 minutes of feedwater at design flow rate. The feedwater heater shall be elevated sufficiently to supply the required head to the boiler feed pump. This unit shall be delivered as a skid-mounted package complete with level controller and valve, safety valve, pneumatic drain valve and level switches and alarm. Feedwater design requirements are summarized in Table 3.9-3.

Table 3.9-3

Feedwater Heater/Deaerator Design Requirements

Type Direct contact spray deaerator

Steam Inlet Conditions:

- Temperature °C (°F)
- Pressure bar (psi)
- Flow rate kg/hr (lb/hr)
- Heat rate J/g (Btu/lb)

Feedwater Inlet Conditions:

- Temperature °C (°F)
- Pressure bar (psi)
- Flow rate kg/hr (lb/hr)
- Heat rate J/g (Btu/lb)

Feedwater Outlet Conditions:

- Temperature °C (°F)
- Pressure bar (psi)
- Flow rate kg/hr (lb/hr)
- Heat rate J/g (Btu/lb)

Storage Capacity min. of full flow

Water Treatment Equipment

Water treatment equipment shall be provided to maintain feedwater and steam chemistry at the levels specified for receiver and turbine operation. This equipment shall include a condensate storage system, makeup demineralizer, polisher, steam generator chemical feed unit, and necessary transfer pumps.

A condensate storage tank shall be provided to (1) store several days' makeup requirements so that the demineralizer can be regenerated during operating periods, and (2) allow for equipment down time for repairs. The storage tank shall have a capacity of approximately 1,000 gallons.

The makeup demineralizer system shall consist of a strongly acidic cation exchange vessel, followed by a strongly basic anion exchange vessel, and a mixed bed exchange vessel.

A condensate polisher capable of handling the entire flow shall be used to ensure proper cleanup of the feedwater before beginning normal operations. The filter system shall be periodically replaced as its ability to absorb ions is exhausted.

A chemical feed system shall be provided to feed chemicals to the steam boiler loop in order to control the chemistry of the feedwater in the boiler and condensate system. Water quality shall be monitored by the use of local instrumentation, cocks, analyzers and recorders. The rate at which the chemicals are fed to the water shall be controlled automatically.

Feedwater/Condensate Pumps

The EPGS shall include four pumping stations in the water/steam loop, which are: (1) steam generator feedpump, (2) condensate pump, (3) condenser exhaust vacuum pump, and (4) condensate transfer pump. The design requirements for these pumps are defined in Table 3.9-4. In all cases, a single full-capacity pump shall be used.

Table 3.9-4

Feedwater/Condensate Pump Performance Requirements

<u>Pump</u>	<u>Capacity</u> <u>kg/hr (gpm)</u>	<u>Total Head</u> <u>m(ft)</u>	<u>Efficiency</u> <u>(%)</u>
1. Steam generator feed pump			
2. Condensate pump			
3. Condensate transfer pump			
4. Condenser exhauster vacuum pump			
5. Circulating water pump			

Piping and Insulation

EPGS piping shall be designed to circulate feedwater/steam through the feedwater/steam loop. Piping design requirements are summarized on Table 3.9-5. Pipe-to-pipe connections shall be butt welded where possible to insure leak integrity. Pipe connections with major system equipment and valves shall use ring joint flanges to permit maintenance and repair/replacement as required. Required minimum wall thickness of the piping shall be determined using the Piping Codes referred to in Section 2. Scheduled pipe should be used, and the calculated minimum wall thickness must be increased by the manufacturing tolerance of the pipe being used. Shutoff pressures must not be greater than the allowable working pressure of the pipe calculated in accordance with the Piping Codes. All feedwater/steam lines shall be externally insulated and protected with an aluminum weather cover to minimize heat losses and comply with building/safety codes. All insulation joints shall be sealed with an insulating cement.

Table 3.9-5

EPGS Piping Design Requirements

<u>Pipeline</u>	<u>Temperature °C (°F)</u>	<u>Pressure bars (psi)</u>	<u>Flow Rate kg/hr (lb/hr)</u>
o Steam Generator Feedline			
o Turbine Feedline			
o Turbine Bypass			
o Condenser Feedline			
o Condenser Polisher Feedline			
o Deaerator Feedline			
o Deaerator Recirculation			
o Extraction Line for Space Conditioning			

Valves and Actuators

Control valves shall be designed to be compatible with the operating temperature and line size in which they are located. All valves shall be required (1) to respond automatically to commands from operating personnel and/or from plant control subsystem, (2) to change smoothly and rapidly from one operating mode to another, and (3) to respond smoothly and rapidly to changes in thermal charging rate or extraciton rate or both. In general, valve response times need not be rapid since the large thermal inertias involved in the total system are expected to provide the controlling lag time in all control loops. The time response of valves shall be on the order of tens of seconds. Remote control valves shall use pneumatic actuators. Safety valves shall be provided at appropriate locations in the ETSS to protect against overpressure. Pressure and temperature trans mitters shall be located to provide system control.

High pressure valves shall be rated at 62 bars (900 psi). It is desirable to have the same pressure-temperature valve rating criteria for all EPGS valves and to purchase them under one standard rating rather than having to make selected valve classes at different locations throughout the subsystem. However, in the interest of economics, it is permissible to purchase standard class rated valves in the portion of the system where design conditions would allow, and only purchase special rated valves for use in the part of the system which has elevated design conditions making the special valve class requirement mandatory.

EPGS Controls and Instrumentation

The EPGS shall include control, alarm and instrumentation equipment sufficient to permit control of the EPGS by the Plant Control Subsystem (PCS), identification of failure events, protection of the EPGS equipment, and evaluation of subsystem performance. The PCS will generate appropriate signals to automatically adjust turbine operations or generator load as part of the PCS coordinated control routines. Remote manual control of turbine operation may be accomplished through the PCS or directly via a governor speed changer device. Subsystem controls must have the capability of manual operation for required control and alarm functions independent of the PCS.

An EPGS control console shall be located in the control trailer. This console shall operate independently of the main plant controls, and shall provide the operator with real-time information from EPGS instrumentation plus appropriate displays, alarms, and controls.

Electrical Power Distribution Network

The electrical power distribution network shall be designed to distribute electrical power from the turbine-generator unit to the electrical grid serving Complex 87000. The network shall also distribute power to the electrically powered elements of the solar facility, and be capable of switching to a source of emergency power (uninterruptible power supply) for critical components in the event of loss of power from the main generator or from the electrical grid serving the base. The distribution system shall include circuit breakers, switchgear, transformers, and conventional electrical network equipment (connections, cabling, meters, relays, switches and controls). The design shall maximize the use of conventional electrical equipment. All main electrical lines shall be underground. All elements shall be arranged with consideration for safe operations and maintenance. Equipment design and installation shall conform to the construction codes specified in Section 2.0.

EPDS design requirements for major components are summarized on Table 3.9-6.

Table 3.9-6

Electrical Power Distribution Network Performance Requirements

o Main Generator Output.	_____ Vac (_____ MW _e)
o Uninterruptible Power Supply	_____ Vdc
o Plant Auxiliary Transformer.	_____ KVA
o Distribution Transformer	_____ KVA
o Heliostat Transformer.	_____ KVA

A main electrical transmission line shall connect the electrical generator to the electrical grid servicing Complex 87000. Appropriate transformers and circuit breakers between the grid and the generator shall be installed. The electrical tie-in for plant auxiliary power shall be located between these circuit breakers. A plant auxiliary transformer shall be installed to step the generator voltage down to 480 volt (60 Hz, 3 phase ac) for plant auxiliary equipment. Appropriate electrical equipment shall also be included to provide auxiliary power at 120 volt (60 Hz, 1 phase ac).

A tabulation of the representative auxiliary power requirements are shown in Table 3.9-7. The tabulation depicts both anticipated daytime and nighttime operation as well as nighttime standby and emergency power requirements. These values shall be used to design the plant electrical network, transformers, breakers, and uninterruptible power supply.

Electrical power distribution for plant auxiliary equipment shall be divided into a main and emergency power bus. The main bus shall supply power to all motors and miscellaneous electrical equipment which are not vital to facility operation during periods of emergency shutdown (receiver pump, steam generator pump, and other electrical motors and loads). For the operation of these items, electrical power shall be drawn from the generator/grid tie-in and stepped down in voltage to 480V. In this manner, power can be drawn from either the existing grid or main plant generator.

Critical items, which must be powered during an emergency shutdown (when connections with the grid and main generator are lost), shall be connected to an emergency bus. These plant items include plant instrumentation and control equipment, heliostat motors, turbine lubrication oil pump, lights and certain heating, ventilating and air conditioning (HVAC) equipment. When power is lost from both the main generator and grid, a breaker connecting the two buses shall open and electrical power from an uninterruptible power supply (UPS) shall be provided. The UPS shall be derived from a 125 Vdc plant battery pack which is charged from the 480 Vac power through appropriate inverters and chargers.

Table 3.9-7

Representative Plant Auxiliary Power Requirements (Preliminary)

Component	Daylight Operation (kW)	Evening Operation (kW)	Night Standby (kW)	Emergency Power (kW)
<u>EPGS Equipment</u>				
Steam Generator Feed Pump	23.0	23.0	No	No
Condensate Pump	2.3	2.3	No	No
Condenser Exhauster Vac. Pump	6.0	6.0	No	No
Condensate Transfer Pump	No	No	0.1	No
Plant Air Compressor	2.8*	2.8*	0.5**	No
Circulating Water Pump	13.8	13.8	No	No
Cooling Tower Fan	15	15	No	No
Turbine DC Oil Pump	No	No	No	No
Chemical Pumps	1.9	1.9	No	No
Plant Air Dryer	0.7***	0.7***	0.7***	No
Condensate Polisher Recirc. Pump	No	No	Neg.	Neg.
Heating, Ventil. Air Conditioning	5.0	5.0	3.0	5.0
Lighting	3.0	3.0	2.0	1.0
Uninterruptible Power Supply	7.5	7.5	7.5	8.3
Transformer/Transmission Loss	1	1	Neg.	Neg.
<u>ETSS/RS Equipment</u>				
Receiver Pump	40	No	No	No
Hot Storage Pump	6	6	No	No
Trace Heating	No	No	1.7****	1.7****
<u>CS Equipment</u>				
Heliostats	6.0	No	No	24.9
Total	134.0	88.0	15.5	40.9

*Estimated average power requirement during operation-maximum requirement 11.9 kW.

**Estimated average power requirement during standby-maximum requirement 11.9 kW.

***Average requirement based on one regeneration per 4 hours - requirement is 1.8 kW for 1-1/2 hours.

****Estimated average power requirement during 14-hour standby.

3.9.2 EPGS Operational Requirements

The EPGS shall be compatible with all modes of plant operation as described below.

Energy Collecting Mode - (Not applicable. The EPGS operates in the energy utilization mode only, and is independent of the energy collection mode, provided there is adequate thermal energy stored to operate the EPGS equipment. However, in this mode, the EPGS shall distribute necessary electrical power to operate heliostat motors and appropriate valves, pumps, heaters and instrumentation. Power requirements shall be normally provided by the main electrical generator. If the generator is not operating, the power shall be provided from the existing grid or the uninterruptible power source, depending upon operating conditions.

Energy Utilization Mode - In the energy utilization mode, the thermal energy delivered to the steam generator by the ETSS shall be used to produce steam for: (1) electrical power generation (Electric Power-Only Mode), (2) electrical power and thermal applications (Electric/Thermal Power Mode), or (3) thermal applications only (Thermal Power-Only Mode).

In the Electric Power-Only Mode, steam produced in the steam generator shall be injected into the turbine which drives a generator to produce electricity. Turbine inlet steam flow shall be controlled at a fixed flow rate for set electrical power levels or at variable flow rates for electrical power load following, as required. Turbine exhaust steam shall be routed through a condenser/cooling tower which shall expend all exhaust heat into the atmosphere.

In the Electric/Thermal Power Mode, which is the normal mode of operation, both electrical power and heat for space conditioning and domestic hot water are produced. Steam from the steam generator is injected into the turbine to drive the electrical generator, and turbine exhaust steam shall be used to deaerate and heat the feedwater, as described above

in the Electric Power-Only Mode. For room air conditioning, additional steam is routed to an absorption chiller unit. The turbine exhaust steam shall also be routed through a heat recovery condenser in which the exhaust heat can be used to generate low pressure steam for distribution to the downstream hot water and space heating equipment. In this overall mode of operation, both the electrical power output and thermal heat loads can be variable, as required.

Startup Mode - The turbine feedwater pump shall be started in parallel with steam generator warmup. During feedwater warmup, the turbine supply valve will be closed and a turbine bypass valve opened. In this manner, the feedwater will be recirculated through the steam generator until turbine operating temperatures are reached. This procedure shall also warm the turbine steam supply line, precluding condensation in the supply line. When turbine operating temperatures are reached, the steam shall be permitted to enter the turbine in a controlled manner for turbine roll and load, as prescribed by the turbine manufacturer. At the appropriate time, the turbine/generator shall be loaded and the electrical power synchronized with the power network. All startup sequences shall be in accordance with the turbine/generator shall be loaded and the electrical power synchronized with the power network. All startup sequences shall be in accordance with the turbine/generator manufacturer's specifications. The turbine/generator unit is expected to be cycled through a startup to operating conditions, and to a standby mode a minimum of once per day.

Intermittent Operation

Since the two major loops of the system, solar energy collection and power conversion, are fully decoupled, the operation of the power conversion equipment is not affected by transients due to intermittent cloud passage. The turbine/generator shall continue to operate in a normal manner from the heat stored in the ETSS.

Normal Shutdown Mode - Normal EPGS shutdown will be automatically initiated when the steam to the turbine falls below prescribed operational conditions. At this point, the electrical generator shall be taken off-line and the steam flow to the turbine automatically reduced in a controlled manner consistent with turbine specifications. The turbine bypass valve will be opened and the steam flow rate further reduced consistent with steam generator cooldown characteristics. When turbine operating conditions fall below prescribed limits, the electrical generator shall be taken off-line, and remaining plant electrical loads shall be switched to the existing electric grid.

Overnight Standby - For normal overnight standby, the turbine feedwater pump will operate in an idle mode. The equipment for the Thermal Power-Only Mode may be operational depending upon thermal load requirements and thermal storage capabilities. The electrical power distribution equipment shall remain active, and provide the power to operate instruments, controls, heaters, lights, and other plant equipment, as required.

3.9.3 EPGS Interface Requirements

The EPGS shall interface with the following plant subsystems:

<u>Subsystem</u>	<u>Interface Type</u>
CS	Electrical power (helio-stat drive units, service)
RS	Electrical power (doors, heaters, service)
TS	Electrical power (lights, elevator, service)
ETSS	Electrical power (pumps, valves, heaters, service); steam generator feedwater/steam lines
FES	Electrical power (pumps, valves, heaters)
PCS	Electrical power (controls, instruments, service)
SCS	Steam/hot water lines; electrical power (pumps, valves, blowers, service)
DHWS	Steam/hot water lines; electrical power (pumps, valves)

Interface requirements are specified below.

EPGS/CS Interfaces - (Covered in Section 3.4.3, CS/EPGS Interfaces.)

EPGS/RS Interfaces - (Covered in Section 3.5.3, RS/EPGS Interfaces.)

EPGS/TS Interfaces - (Covered in Section 3.6.3, TS/EPGS Interfaces.)

EPGS/ETSS Interfaces - (Covered in Section 3.7.3, ETSS/EPGS Interfaces.)

EPGS/FES Interfaces - (Covered in Section 3.8.3, FES/EPGS Interfaces.)

EPGS/PCS Interfaces - The EPGS shall provide necessary electric power for the operation of plant controls, instrumentation, data recording, and control trailer services. The EPGS shall respond to all commands issued by the PCS. A separate EPGS control console shall be located in the control trailer, but shall operate independently of the main plant controls.

EPGS/SCS Interfaces - The EPGS and space conditioning subsystem shall utilize steam/hot water line interfaces that are physically and functionally compatible. The EPGS shall also provide necessary electric power for the operation of the SCS equipment (pumps, valves, blowers, service outlets).

EPGS/DHWS Interfaces - The EPGS and domestic hot water subsystem shall utilize steam/hot water line interfaces that are physically and functionally compatible. The EPGS shall also provide necessary electric power for the operation of the DHWS equipment (pumps, valves).

3.10 PLANT CONTROL SUBSYSTEM (PCS)

The Plant Control Subsystem (PCS) shall include all the equipment, facilities, and software to sense, detect, monitor, control and record all system and subsystem parameters necessary to ensure safe and proper operation of the solar energy facility from a single central location.

Design/performance, functional and interface requirements of the PCS are given below. Detailed characteristics of the PCS designed to meet these requirements are summarized in Section 5.0 of this specification.

3.10.1 PCS Design/Performance Requirements

The PCS shall be designed to integrate the independent controls of all solar plant subsystems and provide effective single console control and evaluation capability of the total system. The PCS shall incorporate the following performance capabilities:

- o Control and command of the subsystems' components (valves, motors, blowers, etc.) to establish and/or maintain plant stability through all phases of operation.
- o Sense all subsystem operations to assess safe and proper operation of the plant.
- o Display and/or record all sensed parameters in a form pertinent to the evaluation of plant performance, operation and safety.

PCS design architecture shall involve two primary functions: (1) collector field control (heliostat controllers) and (2) plant process control.

Collector field control shall be primarily automatic with implementation by means of signals from the plant process computer to the heliostat controllers. Plant process control shall be primarily semi-automatic with operator control through three independent interfaces, which are:

1. Central control console directly connected to a plant process computer.
2. Subsystem operator control console directly connected to a central control unit.
3. Remote control panels.

Normal plant operations shall be monitored and controlled by a single operator through the central control console. Process control with less automation shall also be possible using the subsystem control consoles. Remote control panels will be used primarily for local test and checkout of subsystems and equipment.

General design requirements imposed on the PCS are simplicity, reliability and cost effectiveness of both design and operation. To meet these requirements, the PCS shall incorporate the following:

- a. Design simplicity, requiring:
 - o Resemblance to existing control systems
 - o Standard control practices
 - o Simple, well-defined control interfaces
- b. Operational simplicity, requiring:
 - o Automatic control with operator override
 - o Easily read displays
 - o Convenient control arrangement and access
- c. Design reliability, requiring:
 - o Use of proven designs
 - o Elimination of single-point failures (through modular and/or redundant elements where feasible)
- d. Operational reliability, requiring:
 - o Separation of plant controls from data acquisition equipment
 - o Independent subsystem controls for manual operation, if necessary
- e. Cost effective design, requiring:
 - o Selection of off-the-shelf equipment
 - o Use of modularity among the major elements of the PCS
 - o Use of generically similar equipment

Additional system-oriented PCS design requirements are as follows:

- o The PCS shall integrate the control of all subsystems.
- o The controls of each subsystem shall be independent so that the plant can be operated without the PCS; failure of the PCS shall not prevent manual control of the plant.
- o The primary operating mode is automatic with operator override or manual backup capability; the PCS shall require only one operator at the console in the automatic mode
- o In either the automatic or manual mode, the plant shall be capable of being operated from a single console
- o For significant plant or subsystem abnormalities, the PCS shall provide alerts or alarms and automatically initiate safety or protective actions; single point failures shall be minimized consistent with cost effectiveness
- o The PCS shall contain sufficient flexibility in control and display to start up and shut down the plant, automatically control the plant in the steady-state modes, including transients between modes, and to safely handle external disturbances or emergency situations.
- o The PCS shall be capable of the testing of plant equipment and the gathering displaying, and logging of sufficient data for the purpose of evaluating plant performance.
- o Most PCS equipment shall be housed in a mobile control trailer which contains necessary space conditioning equipment; control equipment will be preassembled and checked out in the trailer before delivery to the site.

PCS design requirements for major PCS elements are summarized on Table 3.10-1 and reviewed below.

Table 3.10-1
PCS GENERAL REQUIREMENTS

<u>Collector Field Control</u>	Individual heliostat controllers; control network independent of other plant processes; automatic operating mode
<u>Plant Process Computer (PPC)</u>	Redundant computer units and consoles for plant process and collector field control
<u>Central Control Unit (CCU)</u>	Microprocessor, time/counter unit, and operator console for subsyst control independent of PPC.
<u>Remote Control Units</u>	Remote input/output modules for on-off signals, analog, or loop access monitoring and control
<u>Software</u>	Semi-automatic plant controls; automatic subsystem control
<u>Instrumentation</u>	State, position, pressure, temperature, flow rate, levels, voltage, current, frequency, environmental conditions
<u>Control Room Equipment</u>	Centralized mobile trailer, semi-automatic; single operator

Collector Field Control

Collector field control commands shall be initiated in the plant process computer and delivered to individual heliostat controllers (HC) which, in turn, provide the intelligence to control and monitor the status of the single heliostat. The HC shall incorporate a microprocessor that shall control the tracking motors, monitor position and determine gimbal axis rotation limits. The HC shall be located on each heliostat pedestal in a weatherproof housing and shall coexist with a motor control circuit board and a power supply. An independent serial signal communications network shall separate the control of the heliostats and other plant processes.

Because there is a significant number of collectors in the field with requirements to continually track and maintain safe plant operation, the primary operating mode of the collector field shall be automatic. However, a semi-automatic mode for collector operation shall also be provided to permit the operator to move a single heliostat or a group of heliostats for maintenance, checkout alignment, calibration or emergency purposes. Operator control of the individual heliostats shall be provided through the central control console using signals from the plant process computer to the heliostat controllers. Individual heliostat control from the field shall also be provided by portable plug-in equipment.

Plant Process Computer and Central Control Console

The Plant Process Computer (PPC) shall consist of two redundant computer units plus associated software that are designed to share all collector field and plant control functions. A central control console, to provide supervisory and coordinated control functions, shall be provided for the two plant process computers. The console shall include appropriate keyboards and displays. Manual control of individual subsystem shall not be provided by this console. A separate subsystem operator console connected to the central control unit shall be used for this purpose. The interfaces between the plant process computer and the plant control hardware shall consist of serial bi-directional hard wire communications channels. The PPC shall be supported by mass storage devices capable of storing appropriate program codes and plant status data. A printing device shall also be connected to each computer to log and report plant status in hardcopy form.

Subsystem Operator Control and Central Control Unit

A subsystem-operator control console connected to a Central Control Unit (CCU) shall allow the operator to control individual plant subsystems from the central control station without the plant process computer in the loop. This hardware shall combine sequential, timing, counting, data handling, interlock, and mathematic function capabilities for controlling the individual element controllers of each subsystem. CCU hardware shall consist of a microprocessor capable of solving three mode control algorithms (proportional, integral, derivative), performing sequential logic operations simultaneously, and storing variables (set points, alarms, controller gains and bias functions, and engineering unit conversions). A timer/counter unit shall be connected to the control unit which provides display and adjustment of individual and programmable timers and counters for control and monitoring functions. The operator console shall enable the operator to program sequential logic, timing, counting, math functions and loop control functions into the CCU. The terminal shall also incorporate a visual display to monitor messages and data.

The CCU shall interface with (1) the host plant process computer (PPC) for supervisory control and monitoring command instruction, (2) the operator for manual control and monitoring command instruction, and (3) the remote control units for individual element monitoring and control. The CCU shall also interface with a simulator which shall be used for diagnostic testing and troubleshooting in the program logic, input/output modules or interconnect cables.

Remote Control Units

Remote control units shall be stationed throughout the plant and shall respond to commands from the central control unit to provide the actions necessary to control each process subsystem. These remote control units, which shall be located in the proximity of sensors and control actuators, shall interact directly with the subsystem components, and contain the electronics to convert actuator and instrument signals (ac or dc) to a form that can be used by the central control computer. Conversely, the remote units shall convert digital signal outputs by the central control computer system to electrical forms usable by the control actuators. These remote control units shall include the following:

1. Discrete input and output modules to control and monitor "on-off" functions (limit switches, solenoids, starters, contactors)
2. Analog input and output modules to control and monitor analog devices (valve positioners, flow, pressure, temperature)
3. Loop access modules for the monitoring and control of three mode type control functions (variable control valves, blowers, motors).

The remote control units shall be strategically located close to the subsystem equipment in clusters that maintain short signal wire runs and efficiently utilize the control equipment capacities. These units shall be rack mounted in environmental enclosures and shall require no special temperature environmental conditioning.

Software

Plant automation capabilities will require the development of the basic software architecture and hardware systems to automatically control subsystem elements for all modes of operation including transitions between steady state modes. Software modules for specific events shall be executed on a priority time schedule that can be modified by executive functions on the operator. Applications software tasks shall execute to completion and drop through to the next task in the priority sequence, or shall suspend execution if a higher priority task, under interrupt or operator control, is designated for execution. Upon completion of the higher priority tasks, the suspended task resumes execution. A round-robin plant supervisory control strategy shall be designed to allow on-line diagnostics of the computer system hardware to be conducted during idle time.

Instrumentation

Standard instrumentation shall be employed as much as possible. Consideration shall be given for the use of common items including instrumentation, wiring connectors, attachments, and support brackets in order to facilitate interchangeability. The equipment shall be readily accessible for inspection, calibration and repair or replacement, as required. Instrumentation redundancy is not required; however, the quality, quantity and location of instrumentation shall be such that the plant can be operated safely at all times. Appropriate warning devices shall be installed to provide alarm messages for out-of-tolerance or control conditions.

Control Room Equipment

The control center for the overall plant shall be centralized in a mobile control trailers. The control room shall be arranged for optimum operational flexibility using a single operator concept. The physical size of the operational control area within the control room shall be minimized, consistent with the amount and numbers of controls required to be located within the control room. The plant control console surrounding the operator shall be comprised of the central control console (associated with the plant process computer) and the subsystem operation console (associated with the central control unit). All peripheral equipment not required for the continuous observation and control of plant activities shall be located in close proximity to the central console within the control trailer.

The plant controls shall be located at arm level and mounted on the horizontal or incline plane of the control console. Monitoring instrumentation shall display all functions in engineering units and be located on the vertical console panels within direct visual access of the operator. The operator's console section shall contain an alpha-numeric keyboard(s) for data entry and computer communication, function selection switches and pushbuttons, color CRT displays, and peripheral controls (as appropriate), hard copy printer(s), and such other equipment as may be required to perform control functions. In addition to computer derived monitoring displays, sufficient analog or conventional monitoring instrumentation shall also be provided to permit plant control without computer operation.

The computer interfaces 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. Peripheral devices include a keyboard printer, disk mass storage devices, printers/plotter, dual magnetic tape cassetts, floating point hardware, hardware multiply and divide, real-time block, time code generator and appropriate subsystem control interface connections.

For manual control, the control equipment shall provide for designated operator entries into the programmed sequence. The control consoles shall display conditions from which the operator can make a decision and respond with a command through independent keyboards. The operator shall view the control operation via displays using graphic and tabular data to interpret each control function. An overview display shall provide the operator with a scenario of all the controller functions for a given subsystem. Scanning this display, the operator shall be able to quickly notice changes that demand his attention. Alternatively, the operator shall be able to dedicate a display to each subsystem for independent display and control in a cascade mode.

3.10.2 PCS Operational Requirements

The PCS shall operate in any one of three modes which are:

1. Automatic - computer automatic operation with PCS operator monitoring only (no operator interaction required)
2. Semi-automatic - computer automatic operation with PCS operator interaction at decision-making points.
3. Manual - direct PCS operator manual control of subsystems at each step or sequence of the operating procedure.

The two primary modes for plant operation are automatic and semi-automatic. Collector field control shall be primarily automatic, and shall be implemented by signals from the plant process computer to the heliostat controllers. Plant process control shall be primarily semi-automatic, and shall be implemented by the plant process computer, the central control unit, and the remote control units. The manual mode of operation shall be used when the plant process computer is inoperative and where checkout and test of individual controls and components is required. The plant shall be capable of operating with a single subsystem in manual while the balance of the system is being operated automatically.

The control system shall be capable of operating the plant in any of the three modes above for any of the system operational modes specified in Section 3.1.2, which includes the energy collection mode, energy utilization mode, transitional modes (startup, intermittent, shutdown, emergency stop) and standby modes (overnight standby, maintenance standby). Only for extended shutdown periods shall the PCS become inactive.

All subsystems shall have independent controls which are compatible with operation by either automatic or manual control. Automatic control shall be capable of operating the plant within steady-state operating modes and during transitions between operating modes. The controls for each subsystem shall be capable of protecting the subsystem from damage or creating unsafe conditions during anomalous events. During critical "out-of-tolerance"

conditions, the control system shall place the subsystem in a fail-safe condition. The control system shall be capable of maintaining plant operation during reasonable externally induced transients in insolation or electrical demand.

The PCS shall be configured for operation by a single operator who shall normally initiate the particular PCS operating mode (automatic, semi-automatic, or manual), via the keyboard the PCS control console. A conversational English language dialogue shall be displayed for the operator to establish the operating criteria for the operation and control of the plant. Along with providing the operator with the conversational dialogue, the computer shall continuously test each computer input for correctness, completeness and validity. If any of the criteria are not met, the computer shall acknowledge the error and initiate a dialogue that leads the operator to change, correct or complete the request. Upon completion of the dialogue between the operator and PCS computer, and upon initiation of the computer program, the operation sequence is automatic, with operator override capability. Monitoring data shall be automatically displayed on the console as instructed by the program code or as requested by the operator. During critical or out-of-tolerance conditions, the control system shall automatically place the subsystem in question in a fail-safe condition.

3.10.3 PCS Interface Requirements

The PCS shall interface with the following plant subsystems. Specific subsystem interface requirements are summarized in the sections denoted.

<u>Subsystem</u>	<u>Section</u>	
CS	3.4.3	Data transmission; control (heliostat position)
RS	3.5.3	Data transmission; control (doors, heaters, vents)
TS	3.6.3	Data transmission (elevator position)
ETSS	3.7.3	Data transmission; control (valves, pumps, heaters)
FES	3.7.3	Data transmission; control (valves, pumps, heaters)
EPGS	3.9.3	Data transmission; control (valves, pumps, heaters, switches, relays)
SCS	3.11.3	Data transmission; control (valves, pumps)
DHWS	3.12.3	Data transmission; control (valves, pumps)

A two-way data communications grid shall be used between the PCS and other subsystems to transfer commands, status information, functional data and information requests. Physical interfaces between the PCS and the various subsystems shall be via discrete hardwires through the master patch panel and relay junction boxes. All electrical interfaces shall be physically and functionally compatible.

The principal PCS equipment shall be located in a control trailers. The control trailer shall be adequately sized for all PCS equipment and arranged for operational flexibility using a single operator concept. Additional control and data evaluation equipment not required for continuous observation and control of plant activity shall also be located near the operator within the trailer. Appropriate equipment consoles, attach supports, and electrical connections shall be provided.

3.11 SPACE CONDITIONING SUBSYSTEM

The Space Conditioning Subsystem (SCS) includes all equipment used to provide room heating and air conditioning. The SCS shall consist of the following:

- o Air conditioning equipment (absorption chiller, steam lines, chilled water lines, pumps, storage tanks, insulation, instrumentation, controls).
- o Room heating equipment (heat exchangers, steam/hot water lines, pumps, accumulator, condensate receiver, insulation, instrumentation, controls).

Design/performance, functional and interface requirements of the SCS are given below. Detailed characteristics of the subassemblies designed to meet these requirements are summarized in Section 5.0 of this specification.

3.11.1 SCS Design/Performance Requirements

The SCS shall be designed to utilize steam from the turbine for room heating and air conditioning in the most efficient and economical manner. The SCS shall contain all elements necessary to accept thermal energy from the turbine and store, convert and distribute this energy to meet space conditioning load demands. Existing steam/water lines, storage tanks and room conditioning equipment will be used as much as possible with minimum modifications. New equipment shall be based on conventional designs. All elements shall be designed and arranged with consideration for reasonable access, for inspection, maintenance and repair. Piping, interface connections and storage tanks shall comply with standard building codes.

SCS performance requirements for design purposes are summarized on Figures 3.11-1 and -2 and Table 3.11-1. Design requirements for major SCS elements are given below.

Absorption Chiller - An absorption unit operating on turbine exhaust steam shall be used to provide chilled water for air conditioning. The unit

[FIGURES TO BE UPDATED]

Figure 3.11-1. Monthly Demands of Complex 87000

Figure 3.11-2. Daily Demands of Complex 87000

Table 3.11-1

Space Conditioning Subsystem Design/Performance Requirements

o Daily Thermal Loadings (typical peak)

- Space Heating (Jan.) _____ MW_t h/day
- Air Conditioning (July). _____ MW_t h/day

o Monthly Thermal Loadings (typical)

- Space Heating (Jan.) _____ MW_t h/mo.
- Air Conditioning (July). _____ MW_t h/mo.

o Low Temperature Storage Capacity

- Chilled Water. _____ MW_t h
- Hot Water. _____ MW_t h

selected shall have a capacity of at least 600 tons when supplied with steam at 65 psia will be an existing commercial unit. The unit shall be skid mounted for installation at the site.

Chilled Water Lines - Existing chilled water lines shall be utilized.

Chilled Water Storage - Two storage tanks will be utilized to store chilled water from the chiller and return water from the complex.

Steam/Hot Water Lines - Existing steam lines shall be used to distribute energy for space heating.

Low Temperature Storage - A steam accumulator will be used to store high pressure water at saturated conditions corresponding to turbine exhaust pressure. It will deliver steam at a lower pressure to the heat converter to meet space heating and DHW demands of the complex.

Room Conditioners - Existing room conditioners (piping, ducts, heat exchangers, fans, etc.) shall be used.

3.11.2 SCS Operational Requirements

The SCS shall be compatible with all modes of plant operation including normal operating modes (energy collection, energy utilization) and transitory modes (startup, intermittent, normal shutdown, emergency shutdown, overnight standby, and extended shutdown) as described in Section 3.1.2.

The room conditioning shall also operate independently of the solar plant operation providing there is sufficient thermal energy stored in the low-temperature storage tanks to permit normal operations. Under typical conditions, the solar facility shall produce enough heat for 24-hour operation of space conditioning. Under abnormal conditions (poor insolation or solar plant shutdown), the thermal energy for space conditioning shall be provided by the existing electric and gas fueled equipment.

3.11.3 SCS Interface Requirements

The SCS shall interface with the following plant subsystems:

<u>Subsystem</u>	<u>Interface Type</u>
EPGS	Steam lines; electric power (pumps, valves, blowers, service)
PCS	Control; instrumentation
DHWS	Steam lines; hot water lines/tanks

SCS/EPGS Interfaces - (Covered in Section 3.9.3, EPGS/SCS Interfaces).

SCS/PCS Interfaces - (Covered in Section 3.10, PCS Interface Requirements).

SCS/DHWS Interfaces - The SCS and domestic hot water subsystem utilize common steam lines and hot water lines/tanks. All interfaces shall be physically and functionally compatible.

3.12 DOMESTIC HOT WATER SUBSYSTEM

Domestic Hot Water Subsystem (DHWS) includes all equipment used to provide domestic hot water. The DHWS shall consist of heat exchangers, steam/hot water lines, pumps, storage tanks, insulation, instrumentation, and controls. Design/performance, functional and interface requirements of the DHWS are given below. Detailed characteristics of the subassemblies designed to meet these requirements are summarized in Section 5.0 of this specification.

3.12.1 SCS Design/Performance Requirements

The DHWS shall be designed to utilize steam from the turbine for the heating of domestic water in the most efficient and economical manner. The DHWS shall contain all elements necessary to accept thermal energy from the turbine and store, convert and distribute this energy to meet water heating load demands. Existing steam/water lines, storage tanks and water heating equipment will be used as much as possible with minimum modifications. New equipment shall be based on conventional designs. All elements shall be designed and arranged with consideration for reasonable access for inspection, maintenance and repair. Piping, interface connections and storage tanks shall comply with standard building codes.

DHWS performance requirements for design purposes are summarized on Table 3.12-1. Design requirements for major DHWS elements are given below.

Steam/Hot Water Lines - Existing steam lines shall be used to distribute energy for water heating.

Low Temperature Storage - The steam accumulator will be used to store energy to produce steam used in the complex for hot water generation.

Table 3.12-1

Domestic Hot Water Subsystem Performance Requirements

- o Daily Thermal Loadings (Typical) _____ MW_{th}/day
- o Monthly Thermal Loadings (Typical) _____ $MW_{th}/mo.$
- o Storage Capacity _____ MW_{th}

3.12.2 DHWS Operational Requirements

The DHWS shall be compatible with all modes of plant operating including normal operating modes (energy collection, energy utilization) and transitory modes (startup, intermittent, normal shutdown, emergency shutdown, overnight standby, and extended shutdown) as described in Section 3.1.2.

The DHWS shall also operate independently of the solar plant operation, providing there is sufficient thermal energy stored in the low-temperature storage tanks to permit normal operations. Under typical conditions, the solar facility shall produce enough heat for 24-hour operation of hot water. Under abnormal conditions (poor insolation or solar plant shutdown), the thermal energy for water heating shall be provided by the existing electric and gas fueled equipment.

3.12.3 DHWS Interface Requirements

The DHWS shall interface with the following plant subsystems:

<u>Subsystem</u>	<u>Interface Type</u>
EPGS	Steam lines; electric power (pumps, valves, blowers, service)
PCS	Control; instrumentation
SCS	Steam lines; hot water lines/ tanks

DHWS/EPGS Interfaces - (Covered in Section 3.9.3, EPGS/SCS Interfaces.)

DHWS/PCS Interfaces - (Covered in Section 3.10. PCS Interface Requirements.)

DHWS/SCS Interfaces - (Covered in Section 3.11.3, SCS/DHWS Interfaces.)

3.13 SPECIALIZED EQUIPMENT

Specialized equipment required at the facility for operations and maintenance shall include service vehicles, maintenance tools, handling fixtures, work platforms, and special checkout/calibration equipment. Design, functional and interface requirements for major special equipment items are given below.

3.13.1 Equipment Design Requirements

Existing standard equipment shall be used as much as possible for operations and maintenance services. Where practical, equipment used for initial installation of various subsystems will be retained on-site for subsequent use during periodic and corrective maintenance. All equipment shall comply with standard safety requirements. Special equipment shall include the following items.

Service Vehicle

A small service van shall be provided for routine on-site maintenance and repair operations. The service van shall be equipped with standard hand tools, handling fixtures, and electronics checkout/calibration equipment.

Mobile Crane

A small mobile crane will be required on-site for lifting small items in the field including heliostat components, pumps, pipes, skid mounted equipment, etc. A crane will be brought on-site temporarily for lifting heavy or large items such as storage tanks, receiver unit, or other major components requiring replacement.

Reflector Panel Washing Truck

A truck shall be provided on-site for transporting the cleaning solution and rinse water for periodic reflector washing operations.

Maintenance Tools

Standard maintenance tools shall be provided for the service vehicles and maintenance areas. These tools shall include hand tools, welders, pipe cutters, paint-spray equipment, line splicers, jacks, etc. Sufficient electrical

outlets should be available for power tools and for lights to be used during night maintenance operations. A source of compressed air will be required for pneumatic tools.

Checkout/Calibration Equipment

Standard electronic equipment shall be provided in the service area and service van for checkout, calibration and repair of instruments, valves, heating elements, gauges, pumps, instrumentation and control lines and connections electrical distribution equipment, etc. A portable heliostat control unit shall be provided for the manual operation of individual heliostats during checkout and troubleshooting in the field. Provisions will be included to disable any heliostat from remote control while maintenance is being performed.

Handling Fixtures

Commercially available hoists and slings shall be provided, where possible. Special slings will be required for the heliostat panels, receiver unit, turbine, tanks, and other specialized elements.

Work Platforms and Ladders

Portable ladders and work platforms with protective rails will be required for inspection and servicing of components in inaccessible or dangerous locations, such as the receiver absorber unit or heliostat elements.

3.13.2 Equipment Operational Requirements

The specialized equipment for operations and maintenance services shall be available and functional at any time during a 24-hour period. The equipment shall be functionally compatible with checkout and maintenance operations. All equipment and operations shall comply with site safety requirements.

3.13.3 Equipment Interface Requirements

All specialized equipment shall be physically and functionally compatible with the elements of the overall system. Appropriate electrical connections shall be provided throughout the site so as to permit the operation of electrical hand tools, equipment, and lights for night-time work. Lifting points for

clevis/cable rigging attachments must be provided on all equipment to be hoisted. Special fittings shall be required on any equipment or support structure that requires the installation of portable work platforms and ladders for servicing or maintenance. Special provisions must be included to disable any equipment from remote control while maintenance is being performed.

3.14 SERVICE LIFE

The plant shall be designed for an overall service life of at least 25 years with no major equipment replacement. Appropriate inspection and servicing efforts shall be maintained. Components that are damaged due to extreme environmental conditions, malfunctions, or human error shall be replaced, as required. Reliability and maintenance requirements are specified in Section 3.15 and Section 3.16, respectively.

3.15 FACILITY AVAILABILITY AND RELIABILITY

The plant shall be designed for an availability goal* of 90% over a one year period exclusive of insolation conditions. Availability shall be defined as the percentage of the total scheduled operating time that the system is able to operate according to specified performance requirements over a one year period. Availability shall be calculated according to the following formula:

$$A = \frac{T_u - T_d}{T_u}$$

where

A = Availability of system for one year of operation.

T_u = Total scheduled operating time in one year.

T_d = Total down time during the scheduled operating time for scheduled and unscheduled maintenance.

Availability shall be as defined in the context of normal utility operation. No availability penalty shall be assessed if a component malfunction results in a reduction of total system power output of less than 2%. For reductions in plant output ranging from 2 - 100%, credit shall be taken for partial plant availability toward satisfying the 90% plant availability goals. No availability penalty shall be assessed if plant operation can be maintained through a change in operating mode unless plant output in the alternate operating mode is ultimately degraded as a result of the original malfunction.

Scheduled maintenance on more than one subsystem or component should be performed simultaneously whenever the plant is down. System down time will occur when either the plant must be shut down during normal operating times for scheduled maintenance (planned outage) or unscheduled maintenance (forced outage for the repair of malfunctioning components. Consideration shall be given in the design to achieving high reliability by providing design and operating margins and utilizing sound engineering design practices.

* The term "goal" is used to relax the need to allocate an absolute availability number to each subsystem or component of the plant which would require expensive and time-consuming availability testing of all components by hardware supplies. Availability shall be determined from documented reliability and maintainability assessments.

3.16 MAINTAINABILITY

The plant shall be designed for a mean-time-to repair (MTTR) goal of (TBD) hours over a one year period based exclusively on critical failures. Critical components are those components that, because of failure risk, down time, or effect on overall plant performance, materially affect the system availability or the system safety.

Maintainability shall be considered in all elements of plant design to meet the availability requirements and to minimize costs for maintenance and servicing. The solar plant shall be designed to be compatible with existing facility maintainability characteristics and practices in order to enable routine maintenance with a minimum loss of operating time. To achieve the required system maintainability, the system shall be designed such that:

1. Items that are critical to availability (because of high failure risk, high down time, or major effect on system performance) shall be provided with automatic failure detection.
2. The equipment shall be designed to contain the minimum number of test points required to ascertain satisfactory performance of all primary and redundant circuits.
3. Test points and instrumentation are accessible for inspection and calibration and repairs can be accomplished by module replacement.
4. Potential maintenance points can be reasonably reached and replaceable components (electronic units, sensors, motors, drives, etc.) can be readily replaced.
5. Elements subject to wear or damage can be easily inspected, serviced or replaced.
6. Equipment expected to require servicing or maintenance shall be designed to be accessible without the removal of other equipment, wire bundles and fluid lines.
7. Components shall be designed so that they cannot be installed improperly.

8. Automatic valves shall be designed to have manual bypass or shutoff capabilities.
9. Reservoirs and storage vessels shall be provided with shutoff valves for maintenance.
10. The plant can be serviced by personnel of normal skills requiring a minimum of specialized equipment or tools. Maintenance of specialized equipment may be performed by specialists under service contract.
11. Items which do not have a redundant mode of operation shall have the maximum capability for on-line repair or replacement, such as sensors and actuators.
12. On-line maintenance may be conducted without reducing subsystem performance.
13. Test points shall permit normal planned subsystem checkout to be made without disconnecting tubing or electrical connectors which are normally connected in service.
14. All lines shall be identified by contents, pressure and direction of flow.
15. All tanks shall have visual inspection capabilities.

3.17 SAFETY REQUIREMENTS

The facility shall be designed to minimize potential hazards to operating personnel, equipment and the general public. Potential hazards shall be eliminated or controlled by design and, if this is not possible, by safety devices, warning devices or special procedures.

General safety requirements for the facility are specified in (TBD)... In specific areas where (TBD) does not apply, additional safety criteria and requirements will be imposed by government agencies and/or project management. These will include specific design criteria and operational procedures to control the potential hazards from single and multiple heliostat beams. The procedures will include restricted areas and controls for operating personnel, visitors, trespassers, and airborne vehicles above the heliostat field.

3.17.1 Equipment Design and Materials

The facility design will incorporate the general requirement that all components shall fail in a fail-safe mode which will prevent injury to personnel or equipment. Sufficient analyses shall be conducted to assure that equipment design and the selection of materials include the following:

1. Incorporation of "fail-safe" principles where a failure would disable the system in order to prevent either injury to personnel or damage to equipment.
2. Grounding and insulation of electrical supplies and components.
3. Insulating parts or components with elevated temperatures or shock potential to prevent contact with or exposure to personnel.
4. Providing lightning protection, as necessary, in accordance with standard safety specifications.
5. Controlling and minimizing the potential damage to personnel and equipment from hazards which cannot be avoided or eliminated.
6. Minimizing fire hazards by using non-flammable materials and isolating hazardous components and fluids, as much as possible.

3.17.2 Safety Features and Warning Devices

Sufficient analyses shall be conducted to assure that adequate safeguards and warning devices are incorporated, including the following:

1. Providing appropriate circuit and line safeguard devices (such as current limiters, voltage regulators, relief valves and interlocks) for power source, personnel, and equipment protection.
2. Providing fire alarms, emergency shutoff valves and switches, fire extinguishers and fire escape paths for areas that have hazardous material or ignition sources.
3. Shielding moving elements to avoid entanglements and providing safety override controls and/or interlocks for servicing.
4. Isolating hazardous substances, components, and operations from other activities, areas, personnel, and incompatible materials.

3.17.3 Operational Safety Procedures

Sufficient analyses shall be conducted to assure that adequate safety procedures will be employed for all operating personnel and the general public, including the following:

1. Establishing criteria and recommendations for restricted operations or personnel access.
2. Locating equipment components so that access to them by personnel during operation, maintenance, repair, or adjustment, shall not require exposure to hazards such as burns, electrical shock, cutting edges, sharp points, insecure footing, or toxic atmospheres.
3. Avoiding undue exposure of personnel to physiological and psychological stresses which might cause errors leading to mishaps.
4. Providing suitable warning and caution notes in operation, assembly, maintenance, and repair instructions; and distinctive markings on hazardous components, equipment, or facilities for personnel protection.

3.18 ENVIRONMENTAL IMPACT REQUIREMENTS

The facility shall comply with the following specific environmental impact requirements.

<u>Item</u>	<u>Requirement</u>
Natural Environmental Resources:	
1. Geology	
2. Soils	(TBD)
3. Hydrology	
4. Climate and Meteorology	
5. Air Quality	
6. Biotic Resources	
Human Environmental Resources:	
1. Population	
2. Socio-Economic Factors	
3. Land Use and Planning Regulations	(TBD)
4. Traffic and Transportation	
5. Palentological, Archaeological and Historic Resources	
6. Environmental Health and Safety Regulations	
7. Aesthetic Resources	
8. Utilities and Public Services	

(NOTE - All factors shall be identified that could impact the environment at the site during construction and operation. Corresponding design and operational requirements shall be specified.)

3.19 DESIGN AND CONSTRUCTION STANDARDS

3.19.1 Materials, Processes and Parts

To the maximum extent possible, standard materials and processes shall be employed. Highly stressed components and unusual materials shall be avoided. As far as practical, off-the-shelf components used in industry shall be employed. Wherever possible, commercial specifications shall be employed.

3.19.2 Interchangeability

Consideration for spares and interchangeability shall be given for common items such as heliostat reflective panels, instrumentation, wiring connectors, attachment bolts, support brackets, etc. Components with common functions shall be produced with standard tolerances and connector locations to permit interchange for servicing. Components with similar appearance, but different functions, shall incorporate protection against inadvertent erroneous installation. Quantities of spares and repair parts to be available for the experimental plant shall be specified for each subsystem.

3.19.3 Nameplate and Product Marking

All deliverable end items shall be labeled with a permanent nameplate listing, as a minimum, manufacturing, part number, change letter, serial number, and date of manufacture. All access doors to maintainable items shall be labeled to show equipment installed in that area, and any safety precautions or special considerations to be observed during servicing.

3.19.4 Workmanship

The level of workmanship shall conform to practices defined in the codes, standards and specifications applicable to the plant site and the using utility. Where specific skill levels or certifications are required, current certification status shall be maintained with evidences 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 such a manner that it presents no unintended hazard to operating and maintenance personnel, is neat and clean, and presents a generally uniform appearance.

3.19.5 Human Performance Engineering

The system shall be designed to facilitate manual operation, adjustment, and maintenance as needed, and to provide the optimum allocations of functions for personnel or automatic control. Particular design attention shall be given in the receiver subsystem to location of equipment in relation to elevators, walkways, and ladders, provision of adequate lighting for night maintenance, and placarding of hazardous work areas. Human Engineering Design Criteria, shall be used as a guide in designing control stations and equipment, with considerations given to personnel operations and interfaces - e.g., displays, controls, labels and placards, equipment handling, and providing a desirable working environment.

3.19.6 Quality Assurance

All plant products shall be governed by an approved quality assurance plan to be prepared by the system integration contractor. The tests/verifications specified in this plan shall include components, subsystems and the integrated system. Tests/Verifications shall demonstrate that the system requirements specified in this specification have been satisfied. Specific test requirements for components shall be defined in the individual component procurement specifications.

All tests shall be classified in the quality assurance plan as follows:

- (a) Development - Tests for the purpose of developing design and performance feasibility.
- (b) Construction Qualification - Tests to verify integrity and completion of structures and equipment.
- (c) Startup - Tests to verify readiness of subsystems for acceptance tests.
- (d) Acceptance - Tests to measure plant performance and verify conformance to specified design requirements.
- (e) Operational - Major subassemblies may be subjected to testing or analysis where data are not sufficient to estimate mean time before failure (MTBF) for the given design configuration. Consideration shall be given to the need for testing such components as seals, valves and coatings to establish maintenance and life characteristics.

Test/verification efforts shall also be classified as critical, major or minor relative to their importance in meeting overall system design and performance requirements and major program milestones.

The integration contractor shall participate in the quality assurance/verification activities. These activities may be witnessed by government representatives, or the witnessing may be waived. In either case, substantive evidence of hardware compliance with all quality assurance requirements is required.

Quality assurance verification 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 and instrumentation to evaluate product performance.
- e. Demonstration - Exhibition of the product or service in its intended modes and conditions without test measurement or instrumentation.

Maximum use shall be made of test data available from the subsystem research experiments and hardware tests already completed. Where conformance to requirements can be established at less cost by analysis of such data, tests shall not be repeated. Component performance or material properties tests, previously performed shall not be repeated.

3.19.7 Electromagnetic Radiation and Electric Transients

The system shall be designed to minimize susceptibility to electromagnetic interference and to minimize the generation of conducted or radiated interference. Plant operation shall not be adversely affected by external or internal power line transients caused by normal switching or fault clearing. Plant equipment shall not be adversely affected by the following electrical power transients:

Normal Operating -- voltage $\pm 10\%$
-- frequency $\pm 0.1\%$

Equipment startup
or shutdown -- voltage - 25%, + 10% with recovery
within 5 cycles at 60 Hz

Emergency
Condition -- Momentary total loss of power

Lightning protection shall be provided for the receiver/tower, cooling tower, and major buildings. The balance of plant equipment and facilities shall avail itself of the umbrella of protection afforded by the specified protectors. No additional lightning protection shall be provided outside this umbrella.

3.20 TRANSPORTABILITY REQUIREMENTS

3.20.1 Size and Weight Limitation

System elements shall be designed for transportability within applicable Federal and state regulations by highway and railroad carriers using standard transport vehicles and materials 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
(Standard limitations in English units)

	<u>Truck</u>	<u>Rail</u>
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 Weight	73,280 lb, 18,000 lb/axle	200,000 lb

B. Transportability limits for special conditions-permits required
(Standard limitations in English units)

	<u>Truck</u>	<u>Rail</u>
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 Weight	100,000 lb, 18,000 lb/axle	400,000 lb

3.20.2 Shock and Vibration Limitations

The design requirements for component packaging and tiedown techniques shall be compatible with the following limit load factors.

Vibration

<u>Transportation Mode</u>	<u>Amplitude (G_{op})</u>	<u>Frequency Range (Hz)</u>
Highway	±0.6	1 - 85
	±0.9	85 - 300
Air	±0.05 in D.A.	3 - 38
	±2.0	38 - 1,000
Rail	±1.0	1 - 100
	1.6	100 - 1,000

Shock Load Factors

<u>Transportation Mode</u>	<u>Acceleration (g)</u>		
	<u>Longitudinal</u>	<u>Lateral</u>	<u>Vertical</u>
Air	±3.0	±2.5	±2.0
Highway	±3.5	±2.0	±3.0
Rail			
Rolling	±3.0	±0.75	±3.0
Humping	±3.0	±2.0	±3.0
(Hydro cushion car)			

All critical 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 2 g's 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 7 g's vertical and 4 g's horizontal with a sinusoidal profile and a duration of 10 to 50 msec.

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

3.20.3 Preparation for Delivery

The preparation of plant equipment for delivery to the plant site shall be in accordance with the following requirements.

A. General Delivery Requirements

Packaging for subsystems and components shall provide adequate protection during shipment by common carrier from the supplier to the first receiving activity for immediate use or temporary storage. A complete packing list shall be included with each delivery to the construction site. The packing list shall include an itemized material list defining the quantity of each part of component contained in the delivery.

(1) Preservation and Packaging

Subsystem components that may be harmed when exposed to the normal transportation and handling environments shall be protected by inert environments, barrier materials, or equivalent techniques.

(2) Packing and Shipping Containers

Containers with gross weights exceeding 60 pounds shall have skids and other provisions for handling by standard material handling equipment. When feasible, container sizes and configurations shall be compatible with efficient utilization of transport vehicles.

(3) Marking for Shipping

Unless otherwise specified, container marking shall be in conformance with standard commercial practices.

B. Special Delivery Requirements

(1) Tower segments	(TBD)
(2) Thermal storage tanks	(TBD)
(3) Turbine/generator unit	(TRD)
(4) Other	(TBD)

3.21 INSTALLATION AND CHECKOUT REQUIREMENTS

Installation of the subsystem at the site shall be accomplished using standard transportation and handling equipment. Component breakdown shall be such that the equipment and labor for field installation (structural, fluid, electrical, instrumentation and control interfaces) are minimal. Major equipment installation requirements are summarized below.

- (a) Heliostats - A drill rig and crane shall be used to set the heliostat foundations and pedestals in place. The drive unit and reflector panels shall then be attached in the field and adjusted.
- (b) Tower - Prefabricated tower segments shall be installed at the plant site by crane. Segments may be bolted or welded as appropriate. Component installation shall be conducted after tower erection.
- (c) Receiver - The receiver unit shall be assembled and checked out at the factory, shipped to the site and mounted on the tower by means of a crane or helicopter.
- (d) Energy Transport and Storage Equipment - The thermal storage tanks shall be assembled at the factory, shipped to the site, and positioned by crane. Following tower erection, receiver assembly, and tank emplacement, all lines, valves and pumps will be installed at the site. Trace heaters, instrumentation and insulation will also be field installed.
- (e) Power Conversion Equipment - Power conversion equipment shall be factory assembled and skid mounted to as large as extent as possible. Interconnecting piping with other subsystems will be bolted or welded as appropriate at the site.
- (f) Instrumentation and Plant Control - Plant control equipment will be assembled in the control trailer and checked out in the factory to minimize field installation and development. Any new software will be integrated and debugged to the extent possible at this time. Field installation will require the transporting of the trailer to the site and interconnection of control elements and instrumentation. All plant equipment shall be installed in a manner to minimize susceptibility to electromagnetic interference and to minimize the generation of conducted or radiated interference.

3.22 SYSTEM ACCEPTANCE TESTS REQUIREMENTS

Formal qualifications of the integrated plant system shall be conducted in accordance with the quality assurance plan. Formal design qualification shall require the satisfactory completion of all development, qualification and acceptance testing of subsystems and completion of functional demonstration of the integrated system.

The contractor shall provide a system by which conformance of hardware to the approved design and any authorized changes thereto, will be verified prior to initiation of system/subsystem level acceptance tests. This verification of conformance to design 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 verification. In addition, evidence shall be maintained of satisfactory accomplishment of inspections and tests required by codes and standards applicable to the subsystems.

3.23 OPERATIONS AND LOGISTICS REQUIREMENTS

Operations and logistics requirements shall be considered in the development and operation of the solar facility. Logistics includes those maintenance and support resources to sustain operational performance, meet the specified system availability, and satisfy the system design requirements.

3.23.1 Facility Operations

The facility is to be installed and checked out by the system integrator and then taken over and operated as an operational power plant by designated military or government personnel. Operation and maintenance personnel requirements shall be satisfied by base personnel or recruitment from established local labor pools. Plant operations and maintenance skill levels requirements shall be minimized to the greatest extent possible.

3.23.2 Plant Maintenance

A general maintenance area near the site shall be provided. Maintenance vehicles shall be limited to a heliostat washing vehicle and a service van with standard hand tools, and standard electronics checkout/calibration equipment. Specific requirements for maintenance and repair equipment, such as hoists, slings, working platforms, etc., shall be determined when subsystem designs are completed. Servicing at the site is preferred for all permanently installed equipment such as heliostats, receiver, tower, thermal storage tank, turbine/generator, etc. Minor plant components (such as instrumentation, valves, heaters, fluid lines, electrical lines, switches, etc.) shall be serviced at the site using standard equipment and parts.

Maintainability requirements relative to solar plant design and availability are given in Sections 3.15 and 3.16. System/subsystem repair shall be accomplished in the most economical manner consistent with meeting availability requirements without degrading performance, reliability or safety. Repair methods for each of the solar plant major equipment groups shall be selected to satisfy this constraint. All maintenance activities shall be categorized in one of three maintenance modes, defined as follows:

(1) On-Line - On-line maintenance is performed on plant equipment while installed in its operating location. It includes scheduled and unscheduled corrective actions required to inspect, service, calibrate, fault isolate, replace components, repair in place, and reverify system/subsystem operation.

Scheduled on-line maintenance includes routine inspection, servicing, cleaning, painting, calibrating, testing, and component replacement or change-out, which can be accomplished during either normal system operation or daily non-operating periods, (i.e., overnight). Scheduled outage also includes the refurbishment or major overhaul of subsystem equipment which are scheduled concurrently when possible and planned well in advance to reduce down time and assure availability of maintenance support equipment, replacement parts, bulk materials and personnel. Scheduled maintenance for major equipment groups shall be integrated into a master schedule and loaded to provide efficient utilization of plant operation personnel time and skills.

Unscheduled on-line maintenance is performed as a result of condition monitoring or unscheduled/unpredicted malfunction or failure of plant equipment. Such actions are necessary to restore an item to a satisfactory condition by the correction of known or suspected malfunctions or defects that have caused degradation of the item below the specified performance level. Corrective maintenance processes include standard repair of non-operating components, functional assembly replacement, subassembly/detail part replacement, or remove/repair/reinstall techniques.

(2) Off-Line/On-Site - Off-line/on-site maintenance is performed on plant equipment after removal from its operating location or installed condition. Such maintenance is normally accomplished in an on-site maintenance building. Actions include disassemble, inspect, repair, service, calibrate, reverify item operation, and proof-test or load reverification. This maintenance is essentially limited to bench type repair which can be accomplished with standard (off-the-shelf) multipurpose tools and test equipment. Maintenance beyond this capability shall be accomplished off-site unless increased capability in the form of additional tools and test equipment is fully justified by program cost considerations or technical reasons. Repair parts and bulk materials to support maintenance of components designed as on-site repairable shall be stocked on site.

- (3) Off-Site - Off-site maintenance is performed on plant equipment at designated off-site locations, e.g., at associates maintenance facilities or component manufacturing facilities. This maintenance requires equipment, facilities or skills which are not economically available at the on-site shop level. Actions include repair, overhaul and rebuilding of equipment. Repaired or overhauled items shall be subjected to the original product acceptance test, or equivalent, prior to returning to spares stock.

3.23.3 Supplies and Spares

Spares, repair parts and bulk materials shall be procured and stocked to directly support the maintenance functions for each maintenance mode. Necessary spares and supplies for on-site maintenance shall be stored in a maintenance building. Specific requirements for spare parts shall be derived by application of the maintenance concept to each of the major subsystems. In accordance with the maintenance concept, spares requirements include the following:

(1) On-Line Maintenance

- Functional assemblies/line replaceable units (LRU's).
- LRU installation or attaching hardware subject to loss or damage upon replacement of the LRU.
- Detail parts such as switches, indicator lights, coupling, and connectors.
- Bulk materials and raw stock such as paints, solvents, lubricants, welding rod, electrical cables, piping and sheet metal.

(2) Off-Line/On-Site Maintenance

- Repair parts and materials for LRU repair.

(3) Off-Site Maintenance

- Repair parts and materials for LRU repair.

Spares requirements to support each maintenance mode shall be identified and quantities recommended for procurement based on mean-time-between-failure (MTBF), LRU repair cycle time, contingency stock, LRU discard factor and frequency of scheduled maintenance. Minimum quantities shall be recommended to satisfy system/subsystem availability requirements with due consideration for procurement lead time and line item cost. The quantities and mix for each subsystem shall be such that there is a 90% probability of a part being available on demand. Minimum and maximum quantities of spares and repair parts to be stocked shall be periodically adjusted as actual use rates are established.

3.23.4 Personnel Training

Solar plant operations and interfaces dictate a need for the additional training of skilled utility-oriented personnel , but do not necessarily establish a need for new skills or trades. Operations and maintenance training shall be provided in accordance with a training plan to be developed at a later date. Specific requirements shall be identified by a training requirements analysis in conjunction with development of Operations and Maintenance (O&M) manuals. The analysis shall identify the training required to adequately prepare plant personnel to operate and maintain the equipment under normal and emergency conditions and in a manner consistent with reliability and safety standards. The training program shall be implemented in sufficient time to provide job proficiency prior to work station assignment. Training documents are described in Section 3.23.5.

3.23.5 Operating Manuals

Documentation expected to be prepared for the operational phase shall include, but not be limited to, the following manuals.

Station Manuals - Station manuals consisting of the following volumes or books for each major subsystem or equipment grouping shall be prepared.

(1) System Description Book - Contains a general description of subsystem and equipment, functional descriptions, and operating characteristics. The book shall be suitable for training use and sufficient detail shall be provided to convey an understanding of the theory of operation and permit O&M personnel to make judgmental decisions based on subsystem status indicators and dynamic operating conditions. Descriptive data shall be in text format and reference shall be made to appropriate drawings, diagrams and schematics as necessary to support the text.

(2) Equipment Data Book - Contains instrument data sheets for functional assemblies and/or Line Replaceable Units (LRU's). The book shall be hardware or functionally oriented in a logical manner to facilitate location of data sheets for any given component within the subsystem. Data sheets shall identify the item name and functional subsystem, part number and manufacturer, and will contain maintenance oriented data to facilitate repair, test, calibration, and/or ordering of replacement parts as appropriate (e.g., operating ranges or set points; input/output voltage, current, frequency and phase; material specifications; replacement assemblies or parts; test

drawing or maintenance manual reference).

(3) Drawings and Diagrams - Contains single line elementary electrical schematics and Piping and Instrumentation Diagrams (P&ID). Structural drawings and wiring diagrams are not required.

User's Manual - User's manuals shall be provided which contain certain operating instruction and maintenance data including the following information, as appropriate.

(1) Operational Functions

- Startup, shutdown, and sequencing for standby
- Manual and automatic operations and mode transitions
- Operations condition monitoring and evaluation
- Emergency procedures and safety precautions

(2) Maintenance Functions

- Servicing and inspections
- Troubleshooting and fault isolation
- Subsystem and component repairs
- Component removal and replacement
- Adjustments and calibration
- System test and checkout
- Safety requirements and precautions

Operational functions shall be described in sufficient detail to permit development of overall system operating manuals. The minimum data required by a skilled and knowledgeable technician to accomplish maintenance functions shall be provided.

SECTION 4.0

ENVIRONMENTAL CRITERIA

The Fort Hood Solar Cogeneration Facility shall comply with the following environmental design requirements and environmental standards.

4.1 FACILITY ENVIRONMENTAL DESIGN REQUIREMENTS

4.1.1 Operating Environment

The solar facility shall be capable of operating in and surviving appropriate combinations of the following environmental conditions that include insolation temperature extremes, winds and gusts, dust and sandstorms, rain, hail, snow and ice, seismic loads, and lightning. The plant may take measures to protect vulnerable equipment at points beyond specified operational limits; however, the plant shall return to operational status after the environments return to within the operational limits specified below.

a. Solar Insolation

The facility performance requirements specified in Section 3.1.1 refer to the "Plant Design Best Day" (maximum energy available to the site on a clear day). This design day is the fall equinox (Sept. 21). Representative insolation on this date, on a clear day at the site, are given in Figure 4-1.

The minimum direct insolation for which the plant is to remain operational is 400 watts/m² on the basis that the collector field shall provide predictable solar flux when the sun is 10° above the horizon.

The maximum rate of change of insolation flux will be that which results from the passage of an opaque cloud across an otherwise clear sky where the sharp leading or trailing edges of the shadow move across the collector field at a velocity of 13 m/s from any direction.

b. Temperature

The facility shall be able to operate in the ambient air temperature range from -23 to 47°C (-10 to 116°F). Performance requirements shall be met throughout an ambient air temperature range of 0 to 44°C (32 to 111°F). The

Figure 4-1. Fort Hood Clear Day Direct Normal Insolation - Diurnal Variation

monthly mean and standard deviation of temperature at Fort Hood, Texas, is given in Table 4-2.

c. Winds and Gusts

Performance requirements shall be met for winds up to 12 m/s (27 mph) throughout the temperature range from 0 to 50°C. The facility shall be able to operate in winds up to 15.5 m/s (35 mph) with degraded performance allowed. The above wind speeds are at a reference height of 10m. Wind speed at other heights are determined from $V/V_{10} = (Z/10)^{0.15}$ where:

V_{10} = reference wind velocity at height of 10 meters

0.15 = power law exponent for flat open country

z = height in meters

v = mean wind velocity at height Z

The average clear day wind speed for receiver heat-loss performance analysis shall be 4.5 m/s (10 mph).

Wind direction at the plant site is nominally from the south.

A wind rise rate up to 1.3 mph/min shall be used in calculating wind loads during heliostat stowage. Gust induced angles of attack up to 10° shall be considered (applicable to the vertical velocity component).

Wind analysis shall satisfy the requirements of ANSI A58.1-1972.

d. Atmospheric Pressure

Atmospheric pressures at the facility are:

Design	<u>14.5</u> PSIA
Operational	<u>14.5</u> PSIA

e. Precipitation

The facility shall remain operational in the precipitation shown in Table 4-3, and also in cloudburst activity in which the precipitation rates may reach a maximum of 15.2 cm/hr (6 in/hr).

TABLE 4-2
FORT HOOD TEMPERATURES

<u>Month</u>	<u>Mean Temp. °C (°F)</u>	<u>Std. Deviation °C (°F)</u>
January	8.06 (46.5)	N/A
February	10.17 (50.3)	
March	14.56 (58.2)	
April	19.61 (67.3)	
May	23.28 (73.9)	
June	26.78 (80.2)	
July	28.56 (83.4)	
August	28.44 (83.2)	
September	25.22 (77.4)	
October	20.00 (68.0)	
November	14.39 (57.9)	
December	10.78 (51.4)	

TABLE 4-3
FORT HOOD PRECIPITATION RATES

<u>Month</u>	<u>Precipitation Rate (cm/hr)</u>	
	<u>Average</u>	<u>Maximum</u>
	<u>Mean</u>	<u>Greatest Daily</u>
January	3.96 (1.56)	5.59 (2.20)
February	6.17 (2.43)	10.16 (4.00)
March	4.26 (1.66)	5.23 (2.06)
April	8.15 (3.21)	10.44 (4.11)
May	10.24 (4.03)	11.68 (4.60)
June	8.38 (3.30)	16.26 (6.40)
July	3.28 (1.29)	7.95 (3.13)
August	4.90 (1.93)	9.65 (3.80)
September	8.05 (3.17)	14.10 (5.55)
October	9.22 (3.63)	12.57 (4.95)
November	5.77 (2.27)	6.10 (2.40)
December	5.26 (2.07)	7.11 (2.80)

f. Clouds

The facility shall be capable of operating through transient cloud coverage. The following model is to be used as the basis for design. The design cloud is a single water cloud with a base below 5,000 ft. which has sharply defined boundaries. The cloud may be larger than the heliostat field and, therefore, the assumption of a single cloud moving over the field is an adequate representation of actual expected conditions. The cloud velocity shall be 13 m/sec referenced to ground speed and may arrive from any direction. For intermittent cloud coverage, the cloud characteristics are similar to the single cloud model except for its finite length. For intermittent clouds, assume a sky coverage of 50% and a solar elevation of 40° with a resulting ground cloud coverage of 31%.

g. Earthquake

In the event of an earthquake, normal facility operation shall be stopped and facility shutdown initiated. The facility shall be inspected for damage and heliostat alignment shall be verified and/or corrected before resuming normal operation. Refer to Section 4.2 for earthquake survival requirements.

4.1.2 Survival Environment

The system shall be capable of surviving appropriate combinations of the environments specified below.

a. Solar Insolation

The maximum direct insolation that the plant must survive is 1000 watts/m². The likelihood of an insolation level above 1000 w/m² is small, but in such an event, defocussing of heliostats would protect the system components.

b. Temperature

The facility shall be able to survive in ambient air temperatures from -23 to 47°C (-10 to 116°F).

c. Winds

The facility shall survive winds with a maximum speed, including gusts of 40 m/s (90 mph) without damage. A local wind vector variation of +10° from the horizontal shall be assumed for the survival condition.

d. Wind Rise Rate

A maximum wind rise rate of .01 m/s² (0.2 mph/sec) shall be used in calculating wind loads during heliostat stowage. However, the facility should withstand, without catastrophic failure, wind of 22 m/s (50 mph) from any direction, such as might result from unusual rapid wind rise rates, e.g., severe thunderstorm gust fronts.

e. Dust Devils

Dust devils have not occurred at the site over a period of record 1965-1974. No special requirements are necessary other than the wind survival requirements indicated above.

f. Sandstorms

Sandstorms do not occur at the site, and no additional requirements are necessary.

g. Rain

The facility shall survive the following rainfall conditions:

- Average annual - 76.2 cm (30 in)
- Maximum 24/hr. rate - 15.2cm(6 in)

Flooding is not expected to be a problem at the site due to adequate drainage provisions.

h. Hail

The Plant survivability is directly dependent on that of the heliostats; and thus, the facility shall survive hail impact up to the following limits:

	<u>Any Orientation</u>
• Diameter:	2.5 cm (1 in)
• Specific Gravity:	0.9
• Terminal Velocity:	23 m/s (75 fps)

i. Ice

The facility shall survive freezing rain and ice deposits in a layer 5.0 cm (2 in) thick.

j. Snow

The facility shall survive a static snow load of 250 Pa (5 lb/ft²), and a snow deposition rate of 17.78 cm (7 in) in 24 hours.

k. Earthquake

Peak ground accelerations shall be as presented below per applicable UBC zone. This peak ground acceleration is combined with the response spectrum given by NRC Reg Guide 1.60 and the damping values given for the operating bases earthquake in NRC Reg Guide 1.61. Zone 2 values should be used for the baseline design.

<u>UBC Zone</u>	<u>Peak Ground Acceleration (Average or Firm Conditions)</u>
0 (Killeen, Texas)	0
2 (Design)	1 m/s ² (0.1 g)

All plant structures shall be designed so as not to sustain damage when subjected to this dynamic environment. Realignment of the concentrators after an earthquake is allowed.

4.1.3 Lightning Considerations

a. Protection

The facility shall be provided with a lightning protection system. For the period 1965-1974, the mean number of days which thunderstorms occurred was 42 days per year. The tower or other facility equipment may be expected to experience a direct lightning strike at least once every year. Consequently, the tower, main plant equipment building, water tower and control trailer shall be provided with lightning protection. Each of these structures shall be equipped with air terminals (masts) that are suitable grounded.

b. Direct Hit

Total destruction of a single heliostat and its controller when subjected to a direct lightning strike is acceptable.

c. Adjacent Strike

Damage to a heliostat adjacent to a direct lightning strike should be minimized. The central controller and the local controllers of heliostats adjacent to a direct lightning strike must be protected, or alternate control methods provided to minimize loss of collector subsystem control.

4.1.4 Special Environmental Considerations

Heliostats shall withstand sustained winds (as described in Section 4.1.2) at the periphery of the heliostat field. If it is determined that wind loading on interior heliostats is significantly altered by peripheral heliostats, this factor should be considered. Adequate protection shall be provided against heliostat degradation from exposure to humidity, temperature (transients and steady-state) and other environmental effects specified in Section 4.0.

4.2 ENVIRONMENTAL STANDARDS

4.2.1 Air Quality Control Standards

Under normal operations, the solar facility does not emit any pollutants into the atmosphere. When operated, the gas fueled HITEC heater shall comply with local pollution emission standards which limits emissions to ____ lb/million BTUs.

4.2.2 Water Quality Standards

The solar facility shall not discharge any effluent that adversely affects water quality.

Section 5.0

SYSTEM DESIGN DATA

This section contains summary data on the system that has been designed to meet the requirements of Section 3 and 4 of the System Specification.

The information, which is presented in summary forms, includes facility design and performance characteristics, cost and economic data, simulation models, and other supplemental backup data. The data presented in this section are not to be considered as formal requirements of this specification, but rather, a summary of the pertinent data used to determine the facility technical characteristics, performance, cost and economic evaluations.

5.1 FACILITY CHARACTERISTICS AND PERFORMANCE DATA

- 5.1.1 Collector Subsystem Data
- 5.1.2 Receiver Subsystem Data
- 5.1.3 Tower Subsystem Data
- 5.1.4 Energy Transport and Storage Subsystem Data
- 5.1.5 Fossil Energy Subsystem Data
- 5.1.6 Electrical Power Generating Subsystem Data
- 5.1.7 Plant Control Subsystem Data
- 5.1.8 Space Conditioning Subsystem Data
- 5.1.9 Domestic Hot Water Subsystem Data
- 5.1.10 Specialized Equipment Data

(Data TBD)

5.2 EXISTING FACILITY DESCRIPTION

- 5.2.1 Boiler Characteristics
- 5.2.2 Electrical Power Generating System Data
- 5.2.3 Space Conditioning System Data

5.3 FACILITY COST DATA

5.3.1 Costing Methodology and Assumptions

(Data TBD)

5.3.2 Capital Costs

- o Owner's Cost

- o Construction Costs

5.3.3 Operations and Maintenance Costs

5.3.4 Total Life Cycle Costs

5.4 ECONOMIC DATA

5.4.1 Economic Methodology and Assumptions

- o Site-owner Assumptions

- o Government DOD Assumptions

5.4.2 Comparative Costs with Alternate Energy Options

5.4.3 Economic Assessment

5.4.4 Energy Transfer Agreements

5.5 SIMULATION MODELS

5.5.1 Insolation Model

5.5.2 Facility Performance Model

5.5.3 Facility Economic Model

5.6 Other DATA (TRD)