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MASTER

SAGUARO POWER PLANT SOLAR REPOWERING PROJECT
VOLUME II—SYSTEM REQUIREMENTS SPECIFICATION

Final Technical Report, September 1979—July 1980

By
Eric R. Weber

July 1980

Work Performed Under Contract No. AC03-79SF10739

Arizona Public Service Company
Phoenix, Arizona

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Volume II

Final Technical Report

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System Requirements Specification

SAGUARO POWER PLANT SOLAR REPOWERING PROJECT

Sponsored By:

San Francisco Operations Office
Department of Energy

Period Covered:

September 1979-July 1980

Author:

Eric R. Weber

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FOREWORD

This report is submitted by the Arizona Public Service Company to the Department of Energy in accordance with provisions of contract DE-AC03-79SF-10739. This final technical report summarizes the work related to the conceptual design, cost and performance of the Saguaro Power Plant Solar Repowering Project that was performed during the period from September 24, 1979 through July 15, 1980. The final technical report is published in four volumes

Executive Summary

Volume I - Conceptual Design

Volume II - System Requirements Specification

Volume III - Appendices

This contract was under the direction of Mr. Larry E. Prince of the Department of Energy, San Francisco Operations Office, Oakland, CA. Mr. C. William Moore of Sandia National Laboratories, Livermore, CA was the Technical Manager.

The efforts performed by the Arizona Public Service team were as follows:

1) Arizona Public Service Company - Overall Program Management; Program Plan; Conceptual Design Lead; Development Plan Lead; Fossil Subsystems, EPGS, Interfaces and Environmental Impact.

2) Martin Marietta Corporation - Lead on System Requirements Specification; Lead on Selection of System Configuration; Solar System Conceptual Design, Analysis, Performance Estimates, and Optimization of the Collector Subsystem and Receiver; Cost Collection and System Economic Analysis; Reproduction of Major Study Documentation.

3) Badger Energy, Inc. - Conceptual Design, Analysis, Optimization, and Cost Data for the Receiver Supply and Return Piping, Energy Storage, and Salt/Steam Heat Exchanger High Temperature Salt Subsystems.

4) Gibbs and Hill, Inc. - Conceptual Design, Analysis, Optimization, and Cost Data for the Solar/Fossil Interfaces, Site and Site Facilities, and Tower; Existing Saguaro Power Plant Descriptive Data.

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This report has been prepared by Arizona Public Service Company for the Department of Energy with the written contributions of the following personnel:

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1. GENERAL

1.1 Scope This specification defines the system and subsystem characteristics, design requirements, and system environmental requirements for the Saguaro Power Plant Solar Repowering Project. Additional information on the plant characteristics and performance data, a description of the existing plant, economic data, simulation models, and repowered plant cost data are contained in Appendices D through H of the Final Technical Report. This project involves the solar repowering of all (120.2 MWe gross) of the 115 MWe net power No One steam-Rankine unit of the Arizona Public Service Company's Saguaro station. The receiver heat transport fluid is draw salt (60% sodium nitrate and 40% potassium nitrate) that is also used to provide 3.8 hours of sensible heat thermal energy storage. The quad-cavity type receiver is mounted on a tower within a single surrounding collector field of 10,500 second generation heliostats. A diagram of the repowered system is shown in Figure 1-1.

1.2 System Description The Saguaro Power Plant Solar Repowering system consists of the following major elements. The requirements of this specification do not apply to existing equipment. However, the existing equipment has been described herein.

Site
Site Facilities
Collector Subsystem
Receiver Subsystem
Master Control Subsystem
Fossil Energy Subsystem
Energy Storage Subsystem
Electric Power Generating Subsystem (including salt/steam heat exchangers)
Specialized Equipment

1.2.1 Site The project site is part of the Arizona Public Service Company's Saguaro Power Plant that is located near Red Rock Arizona, approximately 120 km (75 miles) south east of Phoenix, AZ. The power plant is located on 405 hectares (1000 acres) of desert land with 745 hectares (three sections) of unused state-owned land to the north and east. The Interstate 10 highway and the main line of the Southern Pacific Railroad lie just to the west of the site. Two spurs from the SPRR to the site are used to bring in oil for the fossil-fuel boilers and combustion turbines and large replacement parts for the power plant. The solar collector area is basically flat desert land which slopes slightly up to the north and east. The existing vegetation is low and sparse. There are a few shallow washes for drainage. It is anticipated that only minimal grading will be required for the collector field. Grading will be required for roads, tower area, energy storage subsystem area, and salt/steam heat exchanger area. The solar collector area is bounded by a high voltage transmission line on the north, a high voltage transmission

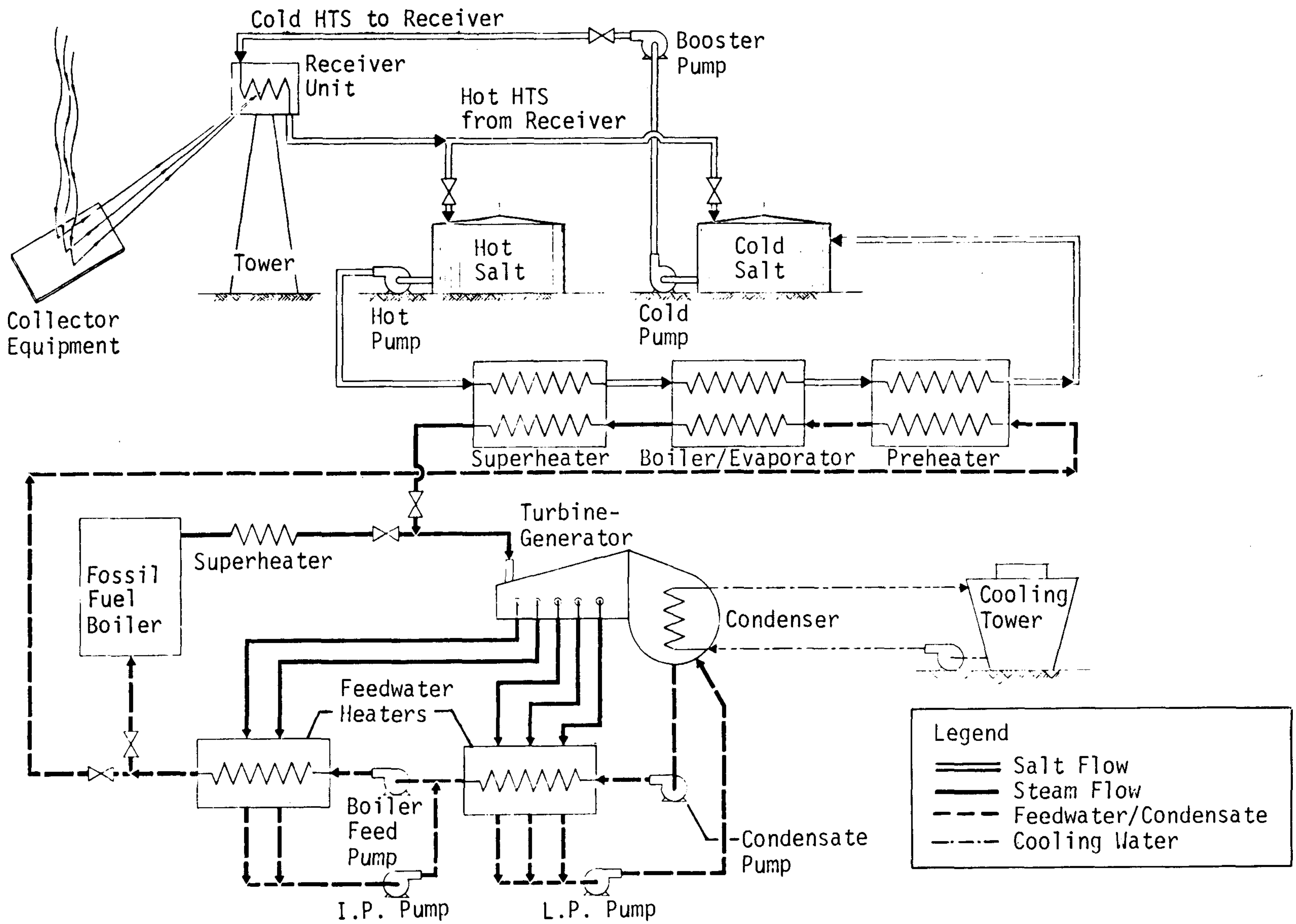

FIGURE 1-1 REPOWERED SYSTEM DIAGRAM

line easement on the west (plant side), a natural gas line on the south west, and a medium voltage (wooden pole) transmission line to the south. There are no nearby constraints to the east.

In addition to the 115 MWe net steam turbine that is to be repowered, the station also has a 99 MWe net steam turbine and two 55 MWe net combustion turbines. All of the usual facilities of a power plant are available such as wells for cooling water makeup, lunchroom, maintenance facilities, switch-yards, nine transmission lines, and full communications with all parts of the APS generating and distribution system. The site has a low seismic risk, low rainfall, and low wind risk. The prevailing wind direction is such that the evaporated cooling tower water will not normally drift over the heliostat field.

The site average direct normal solar insolation level is estimated to be 6.93 kwh/m^2-day based on the Phoenix, AZ, SOLMET typical Meteorological Year data.

1.2.2 Site Facilities The site facilities for the Saguaro Power Plant Solar Repowering Project have been grouped under the following headings:

Operations
Security
Storage and Maintenance

Where appropriate, existing facilities will be used or modified.

As part of Operations, the existing administration buildings appear inadequate for the added functions related to solar repowering. A new building will be constructed to house administrative and support personnel. Salt analysis equipment will be added to the existing water analysis laboratory. The control building will be extended to provide area for the display, control and data acquisition equipment related to the solar system and its control interfaces with the existing system. Office space for control and data acquisition support personnel as well as records storage facilities will be provided as part of the control building modifications. The new administrative building will also provide for instrument repair and maintenance. The existing communications system need not be modified.

Existing plant security provisions (fences, gates, lights, and alarms) will be extended to cover the solar system. In particular a 2.4 m (8 ft) high chain link fence will be installed around the outer perimeter of the collector field.

The existing storage and maintenance buildings will be increased for the solar system equipment by modifications and the addition of a new building. The construction staging and laydown area will be established south of the existing railroad spur and just to the west of an existing switchyard. It will not be necessary to modify the existing rail facilities. All other new transportation and lifting equipment is described as part of the specialized equipment. Similarly any new miscellaneous equipment is described as part of the specialized equipment.

Existing service water and fire loops will be extended to the tower, receiver, energy storage and heat exchanger areas.

1.2.3 Collector Subsystem The Collector Subsystem is composed of an array of heliostats and supporting power and control elements which interact with the Master Control Subsystem. The heliostat array reflects solar radiation onto the receiver and provides auxiliary functions for other modes of operational and non-operational positioning. The Collector Subsystem components consist of:

a. Heliostats, including reflective surface, structural support, drive units, control sensors, pedestals, foundations, cabling, and cable array installations.

b. Electromechanical and electrical controllers, including individual heliostat and heliostat field controllers, control system interface electronics, and power supplies.

c. An Heliostat Array Computer that provides the man/machine interface for Collector Subsystem control and the interfaces with the Master Control Subsystem and the Data Acquisition System.

The primary requirement for the Collector Subsystem is to direct solar radiation onto the receiver absorber surfaces in a cost effective manner that satisfies the receiver incident heat flux requirements. The Collector Subsystem takes the form of a single collector field of second generation "standard" heliostats surrounding the receiver in a radial stagger pattern (See Figure 1-2). The standard heliostat can be considered as a 12 facet, glass/steel, inverting stow unit. An interruption in the heliostat spacing in a south-westerly direction from the receiver tower to the field boundary is used to provide space for the piping runs, utilities, and for an access road.

The Collector Subsystem can also execute alternative drive modes in response to commands from the Master Control Subsystem for emergency defocusing of the reflected energy or to protect the heliostat array against environmental extremes. The heliostat can be properly positioned for repair or maintenance in response to either master control or local commands. Heliostat design provides for a stowed or safe position for use at night, during periodic maintenance and during adverse weather conditions.

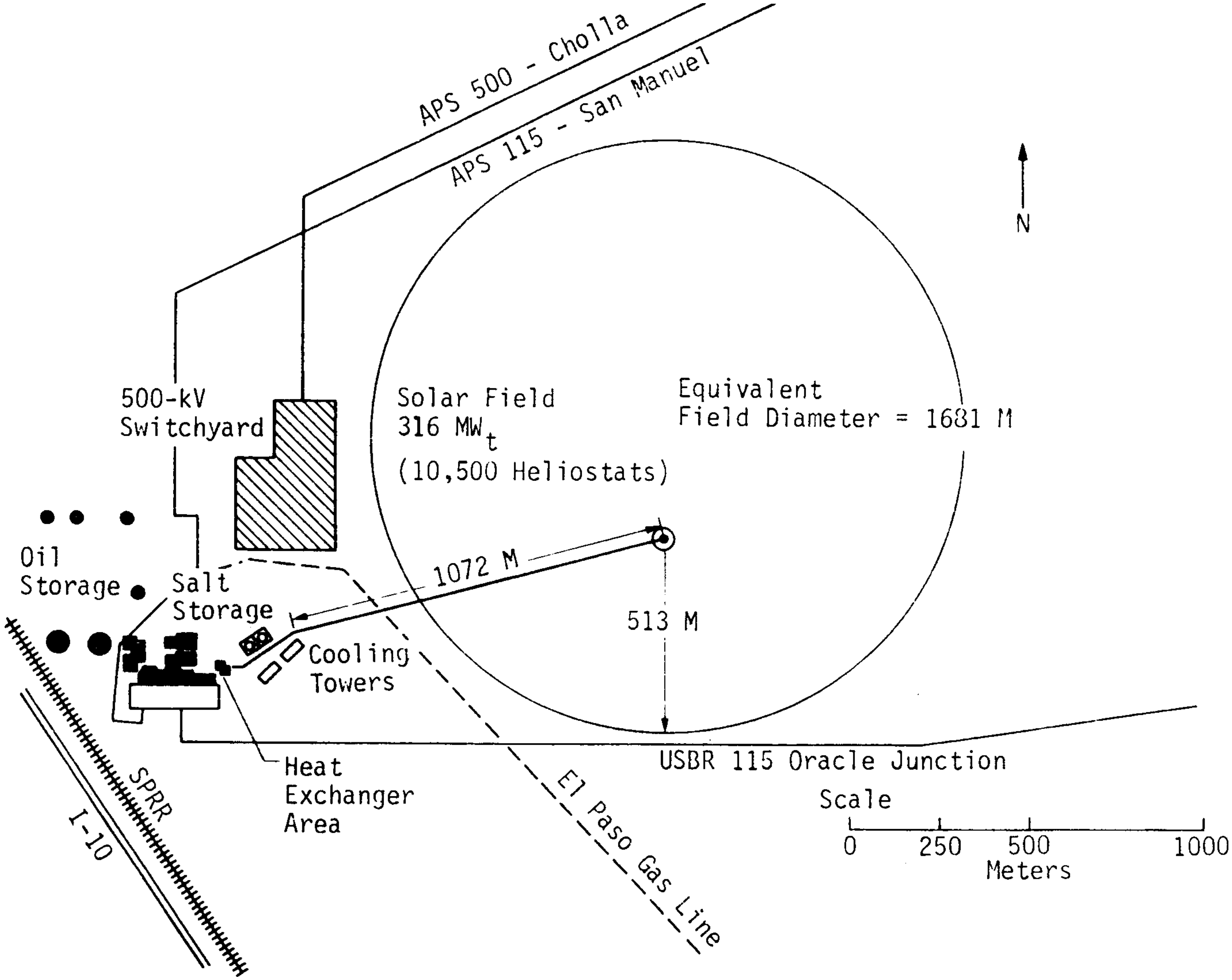

FIGURE 1-2 COLLECTOR SUBSYSTEM LOCATION

1.2.4 <u>Receiver Subsystem</u> The Receiver Subsystem provides a means of transferring the incident radiant flux energy from the Collector Subsystem into the molen salt heat transport fluid. The Receiver Subsystem consists of an elevated receiver to effectively intercept the radiant solar flux reflected from the Collector Subsystem, the tower structure to support the receiver, the heat transport (receiver) fluid riser piping from the ground to the receiver and downcomer piping from the receiver to the ground, and the horizontal supply and return piping from the energy storage area to the tower. The Receiver Subsystem also includes the pumps, valves, and control system necessary to regulate the fluid flow, temperature and pressure, and the required control system components necessary for safe and efficient operation, startup, shutdown, and standby.

A quad-cavity type receiver on a conical concrete tower will be used. Receiver booster pumps will be located near the base of the tower along with control valves to maintain a specific fluid level in the cold salt surge tank in the receiver. A drag valve will be used at the lower end of the downcomer to maintain a specific fluid level in the hot salt surge tank. An air compressor and air storage tank will be located near the top of the tower to provide the required air pressure to the two surge tanks. The hot and cold salt surge tanks will be located within the receiver center structure at appropriate elevations to simplify receiver fill and drain. Main circulation pumps will be located near the energy storage tanks to provide a positive suction head to the receiver booster pumps. Drain provisions will be included. Access to the receiver equipment will be provided for maintenance and inspection, provisions will be made for user safety, and the design will be consistent with the intent of the appropriate ASME boiler codes. Cavity doors will be provided for survival protection and to decrease the cooldown rate. The doors will be fitted with ablative material to absorb the full solar flux during emergencies. The receiver heat transport fluid is an eutectic salt (60% sodium nitrate and 40% potassium nitrate) and the receiver will have provisions for gravity drain of the heat transport fluid. The receiver apertures will be sized for the best combination of spillage and thermal loss. The north cavity is the largest, south the smallest, and the east and west cavities are intermediate in size.

The receiver and its superstructure support use a beam column-type construction utilizing standard AISC structural shapes. The bulk of the construction is bolted using high-strength bolts that will resist wind, seismic and torsional loads.

Maintenance and personnel safety will be considered throughout the conceptual design. Piping and valves will be located to allow access for maintenance and removal. Most of the piping and valves will be located in the east, west and south cavities below the lower shields. These cavities are smaller than the north cavity and allow more working room between the floor and the lower radiation shield.

Absorber panels will have connections on both the upper and lower crossovers that allow for complete panel replacement as well as repair-in-place maintenance. Provisions will be made for a hoist to be installed on top of the receiver structure for raising and lowering equipment, piping, valves, etc. and complete absorber panels. A crane can be installed early in the construction phase to support structural assembly of the receiver.

All platforms and openings will be protected by rails or safety chains. The area under the receiver floor above the tower top will be enclosed with heavy wire mesh. Combined with a floor at the top of the tower this will provide a safe well-ventilated and daylighted work area for receiver maintenance operations. Lightning protection will be provided by lightning rods installed at the high points on each door guide frame.

1.2.5 Master Control Subsystem The Master Control Subsystem is used to sense, detect, monitor and control all system and subsystem parameters necessary to ensure safe and proper operation of the Saguaro Power Plant Solar Repowering Project. The Master Control Subsystem will be integrated into the control system of the repowered station and will consist of:

Operational Control Subsystem
Collector Control Subsystem
Receiver Control Subsystem
Energy Storage Control Subsystem
Fossil Energy Control Subsystem
Electric Power Generation Control Subsystem
Salt/Steam Heat Exchanger Control Subsystem

Each control subsystem will include its own display, control, logic, and actuators. It will be possible to independently control each subsystem as well as to manually control the major system elements. A separate Data Acquisition Subsystem will be provided that interfaces with each of the control subsystems.

1.2.5.1 Operational Control Subsystem - The Operational Control Subsystem (OCS) will be adapted from the existing control system that ties the boiler, turbine and generator control systems together and interfaces them with the APS power generation central dispatch system. A power proportioning logic element will be added to proportion the energy requested by central dispatch between the fossil and the solar steam generating systems. The OCS will be an all digital control system that uses either a primary panelboard or a secondary video console/keyboard for the man/machine interface. All operating procedures will be stored in an associated computer for access through the video console/keyboard. The OCS will interface with each of the other control subsystems and integrate their actions with each other.

1.2.5.2 Collector Control Subsystem - The Collector Control Subsystem (CCS) will use the technology, philosophy, equipment and software being developed for the Barstow 10 MWe Pilot Plant Collector Subsystem. This is an all digital system of automatic control with direct manual control by exception. It uses color cathode ray tube alpha-numeric and graphic displays and keyboard type controls. Alarms are accompanied by audio signals and flashing text. Remote control modes include: field activation, heliostat stow, washing, beam characterization measurements, maintenance and emergency actions.

1.2.5.3 Receiver Control Subsystem - The Receiver Control Subsystem (RCS) will use current versions of the technology, equipment and logic used for the existing boiler, turbine, and generator control systems. An interface for operational coordination and emergency shutdown will be established with the CCS as well as with the OCS. The RCS will be an all digital control system with local controllers in the energy storage area, at the base of the tower, and at the top of the tower. Communications will be by redundant coaxial cables. The man/machine interface will be primarily through the panelboard or secondarily through the video console/keyboard.

1.2.5.4 Energy Storage Control Subsystem - The Energy Storage Control Subsystem (ESCS) will also use current versions of the technology, equipment and logic used for the existing boiler, turbine, and generator control system. The ESCS will interface with the OCS for operational and emergency functions. The ESCS will be an all digital control system with a local controller in the energy storage area. Communications will be by redundant coaxial cables. The man/machinea interface will be primarily the panelboard or secondarily through the video console/keyboard.

1.2.5.5 Fossil Control Subsystem - The Fossil Control Subsystem (FCS) will use its existing equipment. A large benchboard in the control room is used for operational controls and displays and for emergency functions. The functions controlled are gas flow, fuel flow, combustion air flow, feedwater flow and superheat temperature. The control approach is that of indexing, or calibrating, the system and then trimming the control signals based on measured variables. Most of the controllers are pneumatically operated. The existing benchboard is the main OCS interface. An interface between the boiler controls and the turbine first stage steam pressure is used to establish desired steam flow. The first stage steam pressure signal will be used to proportion the requested steam demand between the solar and fossil systems. Data recording instruments are on the rear of the benchboard.

1.2.5.6 Electric Power Generation Control Subsystem - The Electric Power Generation Control Sybsystem (EPGCS) will also use the existing equipment on the large benchboard in the control room. The EPGCS controls and displays are integrated on the same board as those of the FCS. The function explicity controlled is the main steam valve. Control is either direct or remotely from central dispatch. A full complement of the usual turbine controls, e.g. turbine speed synchronizing, is provided. Data recording instruments are on the rear of the benchboard.

1.2.5.7 Salt/Steam Heat Exchanger Control Subsystem - The Salt/Steam Heat Exchanger Control Subsystem (SHCS) will use current versions of the technology, equipment and logic used for the existing boiler, turbine, and generator control systems. An interface with the OCS will be established. The SHCS will be an all digital control system with a local controller in the energy storage area. Communications will be by redundant coaxial cables. The man/machine interface will be primarily through the panelboard or secondarily through the video console/keyboard.

1.2.6 Fossil Energy Subsystem The Fossil Energy Subsystem is the fossil-fuel based energy subsystem that was used to generate steam before the addition of solar repowering. It will be used to parallel solar operation as well as to maintain normal plant operation during periods of reduced or no insolation. The only changes to the Fossil Energy Subsystem are in terms of interfacing its controls with the Operational Control Subsystem. The Fossil Energy Subsystem consists of the fuel supply, fuel storage and transfer facilities, boiler, stack, draft fans, pumps, valves and control system necessary to regulate the steam flow, temperature, and pressure; and the required control necessary for safe and efficient operation, startup, shutdown, and standby of the Fossil Energy Subsystem.

The No. One steam generator unit includes an economizer, water-wall boiler and a superheater section. The unit is designed for corner-firing of natural gas, oil, or a combination of the two. The steam generator has been elevated above grade elevation to provide a means to increase the furnace size and permit the installation of an ash hopper. These modifications and others were required for the possible conversion to burning of pulverized subbituminous coal. The unit is of the outdoor type and is complete with all accessories. Steam temperature is controlled by burner tilt.

The oil fuel supply consists of four oil storage tanks with the necessary oil and steam piping and metering equipment. A spur line from the Southern Pacific Railroad is used to bring oil to the site. The gas supply system consists of the gas supply line and a flow meter.

The 49m (160 ft) high chimney serves both steam generators and was built so it can be extended for coal burning. Both induced and forced draft fans are used with an air heater to recover some of the flue gas heat.

1.2.7 Energy Storage Subsystem The Energy Storage Subsystem provides a means of transferring to stored energy all of the thermal output from the Receiver Subsystem and subsequently providing stored energy in a form suitable for use by the salt/steam heat exchangers.

The Energy Storage Subsystem consists of the storage containment equipment, storage media, foundations, foundation cooling water supply, return and control, cover gas conditioning equipment, heat transport fluid startup melting system, salt conditioning equipment, valves, and control system necessary for safe and efficient operation, start-up, shutdown and standby of the Energy Storage Subsystem.

Thermal energy is stored as sensible heat in the receiver heat transport fluid. The storage subsystem is charged from the Receiver Subsystem and discharged to the salt/steam heat exchangers. It acts to decouple the Receiver Subsystem from the salt/steam heat exchangers. Separate hot and cold storage tanks will be used. The tank shapes will be cylindrical. The external walls and tops of both of the hot and cold tanks are covered with insulation. The foundations for each are water-cooled insulating concrete bases. The hot tank also uses internal insulation and a waffle shaped thin internal metal liner that keeps the hot salt out of the internal insulation while providing for thermal expansion and transmission of fluid pressure directly to the internal insulation and then to the tank shell. The Energy Storage Subsystem will be located near the salt/steam exchangers and just to the north of the No. One cooling tower (see Figure 1-3). It will be diked to control any inadvertent salt leaks. A drain tank will be provided to collect warm salt from the receiver and to drain the salt/steam heat exchangers when they are to be shut down for an extended period. The drain tank is located near the heat exchangers.

1.2.8 Electrical Power Generating Subsystem (EPGS) The Electrical Power Generating Subsystem provides the means for converting to electrical power the thermal energy of the heat transport fluid from the Energy Storage Subsystem and the working fluid (steam) energy from the Fossil Energy Subsystem. The output from the EPGS will be regulated for integration into the APS electrical power system network. The EPGS consists of:

- Steam Turbine
- Condensers
- Cooling Towers
- Water Treatment Equipment
- Feedwater Heaters
- Pumps
- Piping
- Valves
- Controls
- Salt/Steam Heat Exchangers
- Electrical Generator
- Transformers
- Relays
- Plant Auxiliaries
- Emergency Power
- Electrical and Interfacing Control System

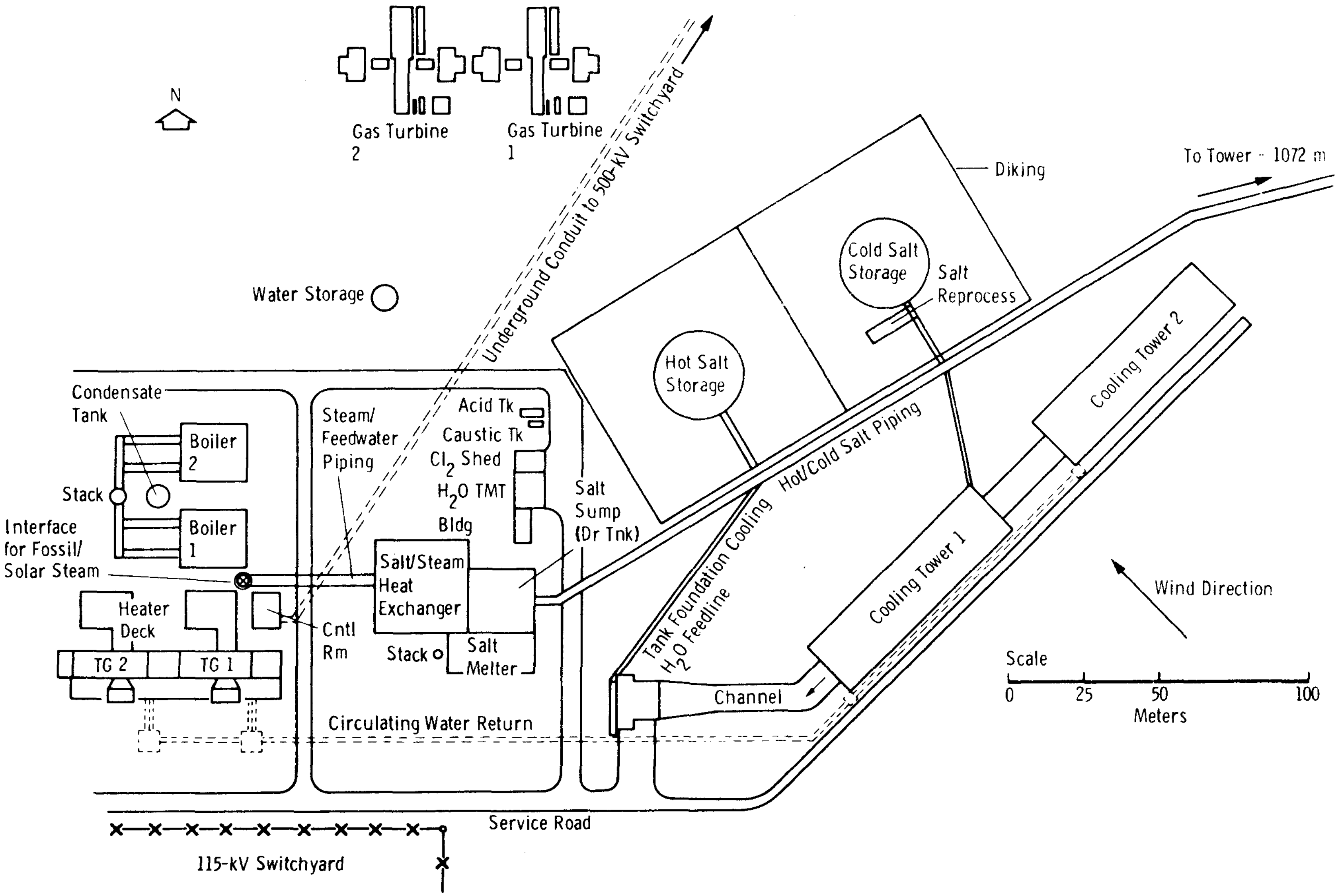

FIGURE 1-3 Repowered System Plot Plan

The turbine is a double cylinder, tandem-compound, double flow, impulse type with 21 stages and operates at 377 rad/sec (3600 rpm). It is suitable for outdoor service with the exciter and turning gear enclosures completely removable and the front end enclosure has a removable roof. The turbine is provided with following accessories: one oil operated, chrome alloy steel turbine stop valve with removable steam strainer, oil pressure control for automatic closing, low vacuum tripping device and solenoid operated emergency trip; one hydraulic main operating governor with remote control speed changer and synchronizing motor; emergency overspeed governor with provision for remote electrical tripping; initial pressure regulator; motor-operated turning gear; oil-actuated air relay valve to operate extraction valves; lubricating oil system consisting of two 130 percent duty lubricating oil coolers, main oil reservoir, one main oil pump, one auxiliary oil pump, one turning gear oil pump, one emergency bearing oil pump vapor extractor; and appropriate instruments.

A cooling tower is provided for the condensing water system. Concrete canals convey the circulating water to the pumps. Makeup water is obtained from on-site wells. The turbine steam condensers are twin units with a Tee connection to the turbine. The condenser cooling water is also used for the hydrogen and lubricating oil coolers.

The turbine supplies bleed steam to a five stage boiler feed heating cycle. Drips from the feedwater heaters are cascaded to lower pressure heaters and pumps. Three motor driven boiler feed and condensate pumps, each of half capacity, are provided. Piping, in general, is not protected from freezing weather.

The salt/steam heat exchangers provide a means of transferring the energy contained in the molten salt of the Energy Storage Subsystem to the water/steam of the repowered electrical power station. The salt/steam heat exchangers consist of superheater, boiler, and preheater heat exchangers, steam disengaging drum, hot salt pumps, salt recirculation pump, preheater water recirculation pump, piping and support structure as well as the valves and control system necessary to regulate the fluid flow, temperature, and pressure (both fluids) and the required thermal control necessary for safe and efficient operation, startup, shutdown and standby. It also includes the primary interface equipment (valves and piping) between the solar equipment and the repowered station.

The electrical generator is a hydrogen cooled, three phase, 60 Hz, outdoor service unit. It is provided with a direct geared, shunt-wound main exciter. Automatic voltage regulation is provided with an amplidyne pilot exciter. Manual voltage regulation is accomplished through a motor operated main exciter field rheostat. The amplidyne, motor operated rheostat and associated voltage regulation circuit components are housed in an outdoor type excitation cubicle with all necesary controls remotely located at the main control board.

The main power transformer is a forced-air and forced-oil cooled unit, equipped with three full capacity taps above and one full capacity tap below rated 115 kv. This transformer is equipped with high voltage bushing potential device used as a potential device for initial starting of coolers and for synchronizing. Lightning arresters connected to the 115 kv terminals are included. One wound type metering accuracy current transformer is installed inside the tank on each of the three neutral ends of the 115 kv windings and one bushing current transformer is installed on the neutral terminal. Additional transformers for auxiliary power and station service are provided.

Eight oil circuit breakers, 3 pole with common base mountings are used. The breakers have pneumatic operating mechanisms and bushing type current transformers. One breaker, which is used for the inspection bus feeder, is equipped with a bushing potential device for synchronizing.

Fire protection is provided for all buildings, cooling towers, fuel oil storage tanks and station equipment. The following equipment is provided: one 0.063 m^3/sec (1000 gpm) fire pump, one 379 m^3 (100,000 gallon), 46 m (150 ft) high elevated water storage tank, a loop piping system, hydrants, hose, fog nozzles and accessories for a complete system. Tranformers and oil switching equipment are protected by manually operated fog nozzles.

Station startup power is obtained from the 115KV switchyard. Emergency DC power is obtained from the station battery system. The station battery and charger comprises a unit of sufficient size to handle a two unit station based on minimum emergency lighting and restricted use of dc power. The battery charger is a diverter-pole motor-generator set.

1.2.9 Specialized Equipment This category includes the specialized equipment required to service, maintain, repair, and overhaul all of the functional elements of the solar repowered plant described above. The equipment descriptions clearly identify the system functional elements that they are designed to support.

a. Specialized collector equipment - Included is equipment for alignment, beam characterization, washing, and maintenance.

b. Specialized receiver equipment - Included is handling and maintenance equipment.

c. Specialized master control system equipment - Includes capability for instrument repair.

d. Specialized fossil energy equipment - All such equipment is currently part of the station and has been included in paragraph 1.2.6.

e. Specialized energy storage equipment - Includes equipment for salt analysis and maintenance.

f. Specialized electrical power generating equipment - Includes maintenance equipment for the salt/steam heat exchangers. The specialized equipment for the rest of the EPGS has been included in paragraph 1.2.8.

1.2.10 Operational Modes - The number of operational modes for the repowered Saguaro plant is low because the large storage volume effectively decouples the solar energy collection process from the use of the solar energy in the EPGS. The five basic steady state operating modes can be logically combined into three equivalent modes that are just more than one basic mode operating at the same time. The elements involved in establishing the modes, and transitions between modes are:

1) Collector and Receiver
2) Standby
3) Storage
4) Fossil Boiler
5) EPGS

Standby means that the equipment involved is not in one of the other operating modes and that it can be readily transitioned into another operating mode. It is defined differently for each of the modes, e.g. collector and receiver standby means the receiver is full of salt and warm with the heliostats stowed. Note that each of the elements goes through standby when it is being started from a complete shutdown or being shut down for an extended period.

The basic steady state modes are:

1) Collector and receiver operating and filling storage with hot salt.

2) Standby

3) The EPGS and salt/steam heat exchangers operating and removing hot salt from storage.

4) The EPGS operating with steam properly proportioned from both the solar and fossil steam generators. The solar system is removing hot salt from storage.

5) The EPGS operating with steam only from the fossil steam generator.

As the five basic modes are not mutually exclusive certain equivalent steady state modes can be usefully considered. These are where the elements operate in parallel.

1) and 3) Collector and receiver operating and filling storage while the salt/steam heat exchanger removes heat from storage to generate steam for the EPGS.

1) and 4) As in the 1) and 3) combination except that steam for the EPGS is also being generated by the fossil steam generator in the desired proportion.

1) and 5) The collector and receiver operating and filling storage while the EPGS operates on steam from the fossil steam generator.

In none of the three equivalent modes are there significant interactions between the basic modes. Consideration of the various operating conditions during representative operating days shows that the normal transitions only involve going between the basic modes even though the equivalent modes may exist for some parts of the day. The days considered included: all solar with immediate or smart dispatch, all fossil, and combined solar and fossil. The result is that only five, two-way, transitions need be considered during normal operation. These are:

1) and 2) Collector and receiver operating to and from standby.

3) and 2) EPGS and salt/steam heat exchangers operating to and from standby.

3) and 4) Steam generation by salt/steam heat exchanger to and from steam generation by both solar and fossil systems.

5) and 2) EPGS and fossil steam generator operating to and from standby.

5) and 4) Steam generation by fossil steam generator to and from steam generation by both fossil and solar systems.

1.3 Definitions of Terms

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

Capacity Factor - The total generation divided by the product of the period hours and the unit capacity (nameplate rating).*

Capacity Factor Annual - Fossil+ - Annual fossil MWh divided by the product of 8760h and plant or unit rating* in MW.

Capacity Factor Annual - Overall+ - Annual solar MWh plus annual fossil MWh divided by the product of 8760 hr and plant or unit rating* in MW.

Capacity Factor Annual - Solar+ - Annual solar MWh divided by the product of 8760h and plant or unit rating* in MW.

Concentration Ratio - The ratio of the received energy on a small area from multiple surfaces with perfect reflectivity to that arriving from the sun. Often measured in "Suns". Commonly used to refer to the ratio of reflector to receiver areas.

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 system is sized with reference insolation, wind speed, temperature, humidity, dewpoint, and sun angles.

Direct Insolation - Non-scattered solar flux falling on a surface of given orientation (watts/m2).

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.

+Note: For utility applications MWh are electrical, net, from respective source. For industrial process heat MWh are net, thermal.

*Usually nameplate unless otherwise specified. Additional references: EPRI "Technical Assessment Guide" EPRI PS-1201-SR, Special Report, July 1979.

Fluid, Storage - The fluid used for the sensible heat storage of thermal energy.

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) divided by absorber area.

Hybrid System A combination of solar and non-solar technology to provide a single plant system that is capable of continuous operation.

Levelized Busbar Energy Cost - That price per unit of energy 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 utility's internal rate of return.

Nameplate Rating - The full-load continuous rating of a generator, prime mover, or other electrical equipment under specified conditions as designated by the manufacturer.

Payback Period - A traditional measure of economic viability of an 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.

Present Value - The present value of a set of cash flows (such as annual operating costs or fuel savings) is a single value representing the cash flows when they have been brought back to a reference time in a manner that accounts for escalation rates and rate of return on capital.

Receiver Efficiency - Ratio of thermal power from the output of the receiver to the incident solar power upon the receiver.

Repowered/Industrial Retrofit Plant - A plant that uses central receiver technology and solar energy to partially displace non-renewable (fossil) fuels.

Repowering Percent - Design Point - Given design point insolation, the steam flow (MW_t (BTU/hr)) at the turbine inlet from the solar receiver (water/steam systems) or main steam generator (molten salt/liquid metal systems) is ____% of the rated throttle steam flow for the turbine.

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

Solar Fraction - Annual - Ratio of solar energy to the process divided by the total energy consumption, annual average, measured at turbine inlet or process heating end-use device inlet.

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

Solar Multiple - Defined at the design point as thermal power from receiver(s) 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 subsystem (MWh_e or MWh_t).

Thermal Power, Fossil Heater Output - Thermal power input to working fluid or heat transport fluid from the fossil heater at design point after stack and miscellaneous losses.

Thermal Power, Prime Mover - Thermal power input to turbine or other prime mover at design point.

Thermal Power, Receiver Output - Thermal power derived from the receiver at design point, does not include electrical parasitic or downcomer thermal losses.

2. DOCUMENTS

The following documents, of the issue in effect on the date of the contract award, form a part of this specification to the extent stated herein.

2.1 Standards and Codes

Uniform Building Code - 1976 Edition by International Conference of Building Officials

OSHA Regulations

- OSHA Title 29, Part 1910 - Occupational Safety and Health Standards

ASME Boiler and Pressure Vessel Code

- Section I - Power Boilers, including: ANSI B31.1-1977 Power Piping
- Section II - Materials Specifications
- Section VIII - Unfired Pressure Vessels

NRC Regulatory Guide 1.60
NRC Regulatory Guide 1.61

Institute of Electrical and Electronic Engineers (IEEE) Codes, as applicable

National Fire Protection Association (NFPA) National Fire Codes - 1975

Human Engineering Design Criteria

- MIL-STD-810C
- MIL-STD-1472

Design, Construction and Fabrication Standards

- Standards of AISC (American Institute of Steel Construction)
- Standards of ACI (American Concrete Institute)
- Standards of TEMA (Tube Exchanger Manufacturer's Association)
- Standards of ASTM (American Society of Testing Materials)
- Standards of ANSI (American National Standards Institute)
- Standard 650 of API (American Petroleum Institute) - Welded Steel Tanks for Oil Storage
- Standards of NEMA (National Electrical Manufacturer's Association)

2.2 Other Publications and Documents

Heliostat Requirements

- Collector Subsystem Requirements Specification, A10772, Issue C, November, 1979.

2.3 Permits and Licenses Required

- Environmental Protection Agency will require a particulate dust permit for construction phase. Saguaro is in a particulate non-attainment area. A formal PSD or non attainment review is not anticipated.
- Environmental Protection Agency - National Pollution Discharge Elimination Standards permit is not expected to be required as all waste water is contained on the property and the addition of the solar system will not change the existing waste disposal system.
- Arizona Power Plant and Transmission Line Siting Committee requirements only apply to new installations over 100 MWe and thus do not apply.
- Pinal County will require building permits. The installation fee for generating facilities of 100 MWe or larger is not believed to apply.
- Federal Aviation Administration permit and special lighting will be required for receiver and tower.
- State Water Rights laws are being revised by the State of Arizona. It is anticipated that a permit for the existing plant including the effects of the solar system will be required.

2.4 Applicable Laws and Regulations

All applicable laws and regulations will be complied with. A project environmental impact estimate will be conducted in accordance with the Code of Federal Regulations 36CFR800. Specific applicable laws and regulations include:

National Energy Conservation Policy Act of 1978
Power Plant and Industrial Fuel Use Act of 1978
Public Utilities Regulatory Policy Act of 1978
Natural Gas Policy Act of 1978
Energy Tax Act of 1978
Environmental Legislation

- National Environmental Policy Act (NEPA)

3. REQUIREMENTS

The solar repowered plant shall be designed to meet the performance requirements of this section. This specification is applicable as a design requirement only to the new or modified portions of the solar repowered plant (as listed in Section 1). The environmental characteristics of Section 4 shall apply except as specifically modified herein. The solar repowering design specifications shall make maximum use of completed on ongoing DOE solar R&D activities. Design emphasis shall be on the solar to fossil interfaces. The repowered plant shall be designed to operate on solar alone, fossil alone, or solar and fossil together.

3.1 Site The site for the solar system is immediately to the east of the Saguaro power plant as shown in Figures 1-2 and 1-3. The land required for the Energy Storage Subsystem and the salt/steam heat exchangers is 6600 m^2 (1.6 acres) and the land required for the collector field and receiver tower is 2.2 x 10^6 m^2 (540 acres). The Energy Storage Subsystem area has been graded flat except for a shallow ditch to route runoff water away from the cooling water towers and the fossil steam generation equipment. This land will have to be regraded for the equipment foundations and to dike around the energy storage tanks. The drainage ditches will have to be rerouted.

The collector field and tower land is generally flat with a few shallow washes that run from the northeast towards the southwest. The vegetation is typical desert scrub and cacti. The area does not contain known geological faults and is not in an area where the land surface is separating or cracking due to the removal of large quantities of underground water. The underground water level in the site area is approximately 107 m (350 ft) below the surface.

The present land surface slopes from northeast to southwest with the highest elevation located approximately 16 Km (ten mi east). Due to this large drainage area, provisions will be made to intercept and route any surface water around the heliostat area. The land will have to be graded level enough for the heliostat locations and for the tower foundation. The grading should include a drainage ditch around the tower and perhaps an interceptor ditch between the collector field and the rest of the plant.

Area paving in the heliostat area will consist of 0.1 to 0.15 m (4 to 6 in.) of aggregate base coarse (ABC) in the roadway areas. For the more heavily traveled areas a penetrating oil coat will be applied. Depending on additional evaluation of the grading and drainage requirements, the areas under the heliostats will either be covered with ABC or left with the natural cover. One concern, however, is that the dried grama grass creates a fire hazard during early summer. It is recommended that the heliostat area be at least sterilized and compacted to reduce vegative growth.

The soil underlying the site consists of a surface stratum of clayey sand and sandy and silty clay of low to medium plasticity. These soils extend from 1 to 3 m (3 to 10 feet) below existing grade and are generally moderately firm to firm. Underlying the surface soils are strongly cemented clayey sands, sandy clays and silty sands with varying amounts of gravel. These soils are generally very firm to hard. No free ground water was encountered during test drilling and the soil moisture content was very low. Adequate provision for site drainage and moisture protection were recommended since some soils are weakened by moisture increase.

This environmental report classified the vegetation as creosote bush and palo verde desert scrub and may contain grama grass, sage brush, greasewood, cresote bush, saguaro and mesquite. In addition, the report does not list this area as containing historic or archaeological sites.

The existing control room is located at 111 deg., 17 min., 50 sec., west longitude, 32 deg., 33 min., 22 sec. north latitude and 589 m (1931 feet) above mean sea level.

3.2 Site Facilities Both new site facilities and modifications to existing site facilities are involved. These include the following general classes of facilities.

Operations
Security
Storage and Maintenance

3.2.1 Operations A new 372 m^2 (4000 ft^2) building is required for administrative and support personnel. The existing control house will be extended to the east on both floors for a total space increase of 268 m^2 (2880 ft^2). The new building and addition will be similar in design and construction to existing buildings. The control house extension will provide space for the panelboard, video console, computers, peripherals, office space, and data storage.

3.2.2 Security A 2.4 m (8 ft) high fence with associated gates will be provided around the collector field, horizontal piping and other parts of the solar system outside the existing fences.

3.2.3 Storage and Maintenance A portion of the administration building, 46 m^2 (500 ft^2), will be set aside for an instrument calibration and repair shop. A new 279 m^2 (3000 ft^2) maintenance building of sufficient height for heliostat maintenance (two units at one time) is required. The new building will be similar in design and construction to existing buildings.

3.3 Collector Subsystem The Collector Subsystem shall reflect solar radiation onto the Receiver Subsystem in a manner which satisfies receiver incident heat flux requirements during all solar insolation periods. In addition, the Collector Subsystem shall respond to commands from the Master Control Subsystem 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 master control or manual commands. Heliostat design shall provide for stowed or safe position for use at night, during periodic maintenance and during adverse weather conditions. The Collector Subsystem shall be designed to match the receiver design and provide energy to the receiver heat transport fluid consistent with the end energy requirements of the plant.

The collector subsystem consists of 10,500 heliostats arranged in a single field surrounding the receiver tower. The design point is solar noon on summer solstice with a reference insolation of 950 w/m^2.

3.3.1 Collector Field The Collector Field design shall provide the optimum heliostat layout considering the following:

a. Heliostat capital cost
b. Operating and maintenance cost
c. Field wiring cost
d. Land availability
e. Land cost
f. Heliostat performance
g. Receiver aperture size
h. Receiver tower height
i. Reliability
j. Shading and blocking
k. Atmospheric attenuation
l. Sun position

The collector field is arranged in a radial stagger array with the heliostat locations calculated by the University of Houston RCELL programs. The north/south dimension is 1703 m (5590 feet), the east/west dimension is 1660 m (5450 feet) and the tower is located 513 m (1680 feet) from the south field boundary. The clear area radius around the base of the tower is 110 m (360 feet). A 12 m (40 feet) wide clear area extends from the tower in a direction slightly south of west to the Energy Storage Subsystem area. This clear area provides room for the hot and cold horizontal salt piping and for access to the tower. A heliostat reliability of 0.997 was used for design stairstep.

3.3.2 Heliostats The heliostats shall be designed to satisfy the requirements of the Collector Subsystem Requirements Specification, A10772 Issue C, with the exceptions listed below. These second generation heliostat characteristics have been used in the design analyses. The following are exceptions to specific paragraphs of A10772. Unless noted here, paragraphs and sentences of A10772 are not changed.

2.0 Documents
The site is at Red Rock, Arizona. The using utility is the Arizona Public Service Company. Conflicts between requirements will be resolved by Arizona Public Service Company.

2.1 Standards
Soil and Foundation Investigation Report, Sergent, Hauskins and Beckwith, April 29, 1975.

3.1.2.2 Collector/Receiver Subsystem
The Collector Subsystem shall concentrate the redirected energy into the receiver apertures. The receiver has four apertures: North - 16 x 16 m (52.5 x 52.5 feet), East and West - 13 x 13 m (42.7 x 42.7 feet), and South 9 x 9 m (29.5 x 29.5 feet). The centerline of the apertures is 176.2 m (578.1 feet) above ground level.

3.1.2.3 Collector/Plant Power
Uninteruptible power is to be applied to the heliostat array controller. Power to the heliostat field controllers and to each heliostat junction box may be interrupted under emergency conditions.

3.2.1 Performance
In order to attain overall plant field performance such that 98.6% of the redirected design point energy at the receiver will enter the receiver apertures, the following requirements have been established for designing and evaluating individual heliostats.

b. Facet Alignment - Facet images are to be superimposed at the receiver aperture for each heliostat, using on-axis facet alignment procedures.

3.2.3 Safety
a. The Collector Subsystem shall be capable of emergency defocusing upon command to reduce peak incident radiation at the receiver apertures to less than 3% of initial value within 20 seconds.

3.2.5 Physical Characteristics

a. Reflective area of 49.05 m^2 (528 ft^2) and an average between washings reflectivity of 0.90. Alternative sizes and reflectivities, that are more cost effective, may be substituted.

3.2.8 Power Usage

3.2.8.1 Track Mode

An individual heliostat shall not require more than an average of 31 watts when operating in the track mode.

3.2.8.2 Slew Mode

An individual heliostat shall not require more than an average of 175 watts when operating in the slew mode.

3.2.8.3 Heliostat Array Controller

The heliostat array controller and its peripherals shall not require more than 4 KW of power on the average when operating.

3.2.8.4 Emergency Defocusing

The power required to meet the emergency defocusing requirement of paragraph 3.2.3, Safety, shall not average more than 270 watts per heliostat during the emergency defocusing operation.

3.2.8.5 Field Wiring

The collector subsystem shall operate correctly when powered with a field wiring system that is sized for a maximum of 5 amperes at 120 volts, 60 Hz, single phase, per heliostat.

3.4.4 Format

Plant documentation (drawings, specifications, instructions, etc.) shall be in conformance with Arizona Public Service Company purchase order.

4.1 General Requirements

Quality assurance activities shall be conducted in accordance with a plan to be prepared by the contractor and approved by Arizona Public Service Company.

4.2 Responsibility

These activities may be witnessed by Arizona Public Service Company or its representative or the witnessing may be waived.

Appendix 1 - Environmental Conditions

1.1 Scope

This Appendix lists evnironmental conditions for the heliostat for the Saguaro Power Plant Solar Repowering Project.

3.6 Soil Properties

The soil properties to be used for heliostat foundation design are taken from the Sergent, Hauskins and Beckwith Soil Foundation Investigation Report of April 29, 1975 for the Saguaro 500 KV Switchyard. The terrain is basically flat with a few shallow washes draining toward the southwest, and has a light growth of brush and cacti. There is no free ground water and the soil moisture is very low. The 500 KV switchyard is immediately to the west of the area planned for the collector field.

Sixteen exploratory borings were drilled to depths of about 6.4 to 11 m (21 to 36 feet) below existing grade. Logs of the test borings are available. The soils underlying the test site consist of a surface stratum of clayey sand and sandy and silty clay of low to medium plasticity. These soils extend from 1 to 3 m (3 to 10 feet) below existing grade and are generally moderately firm to firm. Underlying the surface soils are strongly cemented clayey sands, sandy clays and silty sands with varying amounts of gravel. These soils are generally very firm to hard.

Classification test data, penetration testing and consolidation testing performed on similar soil deposits in the general area of the site indicate that some of the soils would be weakened by moisture increase. Thus, adequate provisions for site drainage and moisture protection are an important design consideration.

Due to the nature and magnitude of the loads transmitted from the angle and dead end switchyard towers, straight drilled piles or drilled-and-belled caissons are recommended for the support of these heavily loaded structures.

Drilled-and-belled caissons (straight drilled shafts with enlarged bases) bearing at a depth of 4.6 m (15.0 feet) or more below existing grade can be used for support of the structures. A maximum safe soil bearing pressure of 192 KPa (4,000 psf) should not be exceeded in design for determining the safe downward capacity. This value is based on manual cleaning of the entire end areas of the caissons. Ultimate upward capacities should be calculated on the basis of the weight of soil contained within a frustum of a cone defined by lines projected outward from the edge of the bell at an angle of 0.52 rad (30 degrees) from the vertical. A soil density of 1.76×10^3 Kg/m^3 (110 lb/ft^3) can be used in uplift capacity calculations.

3.4 Receiver Subsystem The Receiver Subsystem shall provide a means of transferring the incident radiant flux energy from the Collector Subsystem into molten salt receiver heat transport fluid and transport of the energy charged fluid to the Energy Storage Subsystem.

Receiver Height = 31.0 m (101.7 ft)
Receiver Width (East-West) = 25.0 m (82.0 ft)
Receiver Width (North-South) = 24.0 m (78.7 ft)
Size of Square Apertures
North = 16 m (52.5 ft)
South = 9 m (29.5 ft)
East = 13 m (42.7 ft)
West = 13 m (42.7 ft)

Number of Absorber Panels = 20

Receiver is designed to meet Section I of the ASME Boiler and Pressure Vessel Code.
Optical Characteristics
Pyromark series 2500 high temperature protective coating
Tempil Division
Big Three Industries, Inc.
South Plainfield, NJ 07080
Panel absorbing surfaces, $\alpha s = 0.95$, $\epsilon = 0.90$ (Black)
Inactive surfaces, $\alpha s = 0.32$, $\epsilon = 0.84$ (White)

3.4.1 Structural Design The receiver and tower shall be designed to provide access for maintenance and inspection of tower structure, receiver, heat transport fluid, instruments and controls, power conversion equipment that may be located on the tower, utilities, etc. 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 appropriate ASME Boiler codes.

The receiver structure shall be composed of A36 structural steel sections, 14 gauge corrugated steel siding and 0.8 mm (0.032 in) industrial aluminum roof covering. Each receiver aperature will be fitted with a vertical sliding door. Each aperature door will be insulated, and fitted with an exterior ablative surface. Each door drive will be electrically operated and fitted with brakes that do not require electrical energy for emergency door closing within 6 seconds. A crane will be provided for initial assembly and provisions for a removable hoist for maintenance will be made. The receiver will be erected in place. Work platforms and personnel safety provisions will be included.

3.4.2 Receiver The receiver will be the four aperture cavity type. The receiver design and operating parameters are as follows.

a. Receiver active surface area -	2084 m^2
b. Design flux limit of receiver -	0.63 MW_t/m^2
c. Average operating flux (aperture area) -	0.47 MW_t/m^2
d. Receiver power rating -	316 MW_t
e. Receiver fluid velocity -	3.2 m/sec
f. Receiver fluid mass flow rate -	2.55×10^6 kg/hr
g. Receiver peak tube wall temperature -	598 ^oC
h. Receiver peak tube weld temperature -	584 ^oC
i. Receiver fluid inlet temp. -	277 ^oC
j. Receiver fluid outlet temp. -	566 ^oC
k. Receiver tube material -	Incoloy 800
l. Receiver tube O.D. -	38 mm
m. Receiver tube wall thickness -	1.7 mm
n. Receiver dry weight -	7.68×10^5 kg
o. Weight of receiver fluid (excluding risers/downcomers) -	1.40×10^5 kg
p. Weight of structure -	612,754 kg
q. Weight of insulation -	52,177 kg
r. Weight of headers -	4,845 kg
s. Weight of absorber panels (excluding headers) -	21,554 kg
t. Weight of supports -	31,126 kg
u. Weight of piping, valves, and pumps of receiver proper -	45,114 kg

v. Construction techniques - Receiver absorber panels, piping subassemblies, doors, and fabricated girders and trusses are fabricated in a shop. All structural steel is erected in the field. All preassembled parts and insulation are assembled in place on tower.

w. Worst case tube life (fatigue life) - 30 yrs

x. Overall receiver efficiency - 91.57%

y. Cold salt surge tank volume - 33.4 m3

z. Hot salt surge tank volume - 33.4 m3

aa. Air storage tank volume - 11.3 m3

ab. Air compressor capacity - 0.094 S m3/s (200 SCF/M)

3.4.3 Receiver Fluid The receiver fluid is a mixture of 60% sodium nitrate and 40% potassium nitrate by weight.

T, °C	(°F)	ρ, kg/m3	(lb/ft3)	c_p, J/kg-°C	(Btu/lb-°F)	μ x 10³, Pa-s	(lb/ft-s)	K, W/m-k	(Btu/h-ft-°F)	Pr	β x 10⁴, 1/°C	(1/°F)
Liquid												
260	(500)	1928.6	(120.4)	1553.3	(0.371)	4.00	(2.69)	0.398	(0.23)	15.62	3.4	(1.89)
316	(600)	1888.6	(117.9)	1553.3	(0.371)	2.80	(1.88)	0.398	(0.23)	10.92	3.4	(1.91)
371	(700)	1848.5	(115.4)	1553.3	(0.371)	2.10	(1.41)	0.398	(0.23)	8.01	3.5	(1.96)
427	(800)	1819.7	(113.6)	1553.3	(0.371)	1.63	(1.10)	0.398	(0.23)	6.45	3.6	(2.00)
482	(900)	1789.3	(111.7)	1553.3	(0.371)	1.30	(0.880)	0.398	(0.23)	5.66	3.7	(2.04)
538	(1000)	1741.2	(108.7)	1553.3	(0.371)	1.07	(0.721)	0.398	(0.23)	3.91	3.7	(2.08)
Solid												
37	(100)	1922.2	(120)	1553.3	(0.371)			0.363	(0.21)			
93	(200)	1922.2	(120)	1553.3	(0.371)			0.363	(0.21)			

Receiver Fluid(Molten Salt)Properties

3.4.4 Receiver Fluid Circulation Equipment The Receiver Fluid Circulation Equipment shall provide a method for transporting receiver molten salt from the thermal energy storage to the receiver and to return that molten salt from the receiver to thermal energy storage as part of receiver normal operations. It shall also provide means for filling and draining the receiver. The receiver circulation equipment consists of main circulation pumps, receiver booster pumps, horizontal piping, riser, downcomer, recirculation piping, receiver booster pump recirculation cooler, and necessary valves, vents and connections. Design parameters are:

a. Each pump set (main circulation and receiver booster) shall have one spare pump installed in addition to those necessary to meet the design flow requirements.

b. Design molten salt mass flow rate 2.55×10^6 kg/hr

c. Maximum molten salt mass flow rate 2.81×10^6 kg/hr (spare pump may be used to obtain maximum salt mass flow rate).

d. Booster pump recirculation cooler shall be able to remove heat at a rate equivalent to 50% of design hydraulic horsepower of one booster pump.

3.4.5 Receiver Tower The tower that supports the receiver, piping, and other elements of the receiver subsystem shall have the following characteristics. The tower will be fitted with an elevator, aircraft warning lights, and work platforms.

a. Tower height (to base of receiver) -	155 m
b. Base dimensions -	19.81 m
c. Structural type -	Reinforced Concrete
d. Tower taper -	0.0243 rad from vertical
e. Material -	Reinforced Concrete
f. Environmentally induced structural criteria (survival)	
o Wind-induced moment	6.99×10^8 Nm (5.16×10^8 ft lb)
o Seismic-induced moment	1.36×10^8 Nm (1.21×10^8 ft lb)
g. Tower base elevation (above salt/steam heat exchanger base) -	12 m (40 ft)

3.5 Master Control Subsystem

3.5.1 Modes of Operation A Master Control Subsystem shall be provided to sense, detect, monitor, record, analyse, and control all system and subsystem parameters necessary to ensure safe and proper operation of the solar energy producing portion of the repowered plant.

3.5.1.1 Operational Control Subsystem The Operational Control Subsystem (OCS) coordinates other subsystem controls, proportions power required between solar and fossil, interfaces with central dispatch, monitors all critical parameters, provids necessary alarms, and initiates emergency actions. The OCS interfaces with all other control subsystems and with the Data Acquisition Subsystem (DAS). Computations involve digital and analog signals. Communications are by data bus, individual wires, and by pneumatics. The man/machine interface uses a panelboard for the primary system and a video console/keyboard for the secondary system.

3.5.1.2 Collector Control Subsystem The Collector Control Subsystem (CCS) will be adapted from that used for the Barstow 10MWe Pilot Plant and will control the heliostats in all modes of operation including activation, stow, washing, and beam characterization. The CCS interfaces with the OCS, RCS and the DAS. Computations are digital, and communications are by data bus. A video console with keyboard is used for the man/machine interface.

3.5.1.3 Receiver Control Subsystem The Receiver Control Subsystem (RCS) involves the main circulation pumps, receiver booster pumps, receiver temperature, drag valve, and salt return flow. The RCS interfaces with the OCS, CCS, and DAS. Computations are digital and communication is by data bus. The primary man/machine interface is through the panelboard and the secondary interface is through a video console/keyboard.

3.5.1.4 Energy Storage Control Subsystem The Energy Storage Control Subsystem (ESCS) involves control of foundation coolant flow, drain tank salt level, salt reprocessing and salt melting. Control of these two latter functions will be at the equipment. The ESCS interfaces with the OCS and the DAS. Computations are digital and communication is by data bus. The primary man/machine interface is through the panelboard and the secondary interface is through a video console/keyboard.

3.5.1.5 Fossil Control Subsystem The existing Fossil Control Subsystem (FCS) involves control of feedwater flow, fuel flow, air flow, and steam superheat temperature. Interfaces are with the OCS and the EPGS. Computations are analog and communications are pneumatic and electric. The man/machine interface is through the boiler - turbine - generator board.

3.5.1.6 Electric Power Generation Control Subsystem The existing Electric Power Generation Control Subsystem (EPGCS) involves control of fossil steam flow, steam admission, circulating water flow, and condensate flow. Interfaces are with the OCS and the FCS. Computations use analog techniques and communications are pneumatic and electric. The man/machine interface is through the boiler-turbine-generator board.

3.5.1.7 Salt/Steam Heat Exchanger Control Subsystem The Salt/Steam Heat Exchanger Control Subsystem (SHCS) involves control of solar steam flow, solar steam temperature, feedwater flow, steam drum blowdown, hot salt pump, salt recirculation pump, and the water recirculation pump. Interfaces are with the OCS, DAS, and the EPGCS. Computations use digital techniques and communications are via data bus. The panelboard is used as the primary man/machine interface and a video console/keyboard is the secondary interface.

3.5.1.8 Data Acquisition Subsystem The Data Acquisition Subsystem (DAS) is used for data collection and processing for all subsystems and the DAS interfaces with all other subsystems. Computations are digital and communications are via data bus. The man/machine interface is a video console with keyboard.

3.5.2 Design Criteria The Master Control Subsystem shall incorporate the following:

a. Design simplicity, resembling standard power plant or process heat control systems:

- Standard control practices
- Simple, well defined interfaces between the Master Control Subsystem and the other plant subsystem controls.

b. Operational simplicity, requiring primary operation to be automatic with operator override capability.

- Single console control during both automatic and manual operations
- Easily read displays

c. Design reliability, requiring:

- Use of proven designs
- Elimination of single point failures through redundant elements whenever it is cost-effective to do so

d. Operational reliability, requiring:

- Separation of plant operational controls from data acquisition and evaluation equipments and from peripheral controls within the Master Control Subsystem (thus permitting each control to function independently)

- Manual operation of the plant in the event of failure of the Master Control Subsystem (thus requiring independent controls for the other plant subsystems).

e. Cost-Effective design, requiring:

- Selection of off-the-shelf equipment
- Modularity among the major subsystems of the Master Control Subsystem
- Generically similar equipment in each major Master Control Subsystem functional element.

The Master Control Subsystem shall also:

a. Provide for turbine operation by steam generated from solar system alone, fossil system alone, or both systems together in selectable proportions.

b. Adapt to the existing interface with the APS central dispatch system so the repowered system can be dispatched remotely.

c. When operating in a fossil only mode, Unit One shall operate similarly to Unit Two.

d. Control of the collection and storage of solar energy shall be decoupled from the control of the use of the stored thermal energy.

e. Control panel boards will display appropriate subsystem fluid flow diagrams.

3.6 Fossil Energy Subsystem The existing Fossil Energy Subsystem of the repowered plant has the following features. The fossil steam generator was built by Combustion Engineering in 1954. It can be fired by natural gas or No. 6 oil or a combination of both. The burners are corner located and can be tilted for adjusting the energy to the superheater section and thus the outlet steam temperature. The unit contains an economizer, water-cooled furnace walls and a superheater. It has both forced and induced draft fans and an inlet air superheater. Exhaust gases go to a 49 m (160 ft) stack. Steam generator rating is 126 Kg/sec (1,000,000 lb/hr) at 10.7 MPa (1550 psig) and 541°C (1005°F).

3.6.1 Interface Definitions The only interface with the solar system is through the steam demand proportioning element of the Operational Control Subsystem.

3.7 Energy Storage Subsystem The Energy Storage Subsystem shall be designed to maximize the economics and safe recovery of useful energy from storage and to minimize energy storage losses. Specific capacity, size, shape and configuration constraints will be governed by plant economics and by designing the plant layout to facilitate efficient and safe operation and maintenance. The Energy Storage Subsystem shall be designed to provide safe and reasonable access for proper inspection, maintenance and repair of the structure, fluid lines, utilities, instrumentation and controls, etc. The Energy Storage Subsystem shall meet the following requirements.

Storage tank type:	One hot and one cold tank.
Hot Tank Insulation Type:	External and internal insulation with Incoloy 800 liner between molten salt and internal insulation.
Cold Tank Insulation Type:	External
Storage media:	Molten draw salt (60% $NaNO_3$, 40% KNO_3). (See Paragraph 3.4.3 for details).
Storage media mass:	9.36×10^6 kg (2.06×10^7 lb)
Extractable capacity:	1166 MHh_t (4.0×10^9 Btu)
Charging rate:	348 MW_t (2.79×10^6 kg/hr)
Discharging rate:	305 MW_t (2.45×10^6 kg/hr)
Hot tank operating temperature:	566°C (1050°F)
Cold tank operating temperature:	277°C (530°F)
Salt melter mass flow rate:	35×10^3 kg/hr
Salt reconditioning process:	Oxygen-Nitrogen Dioxide Gas Absorption Contactor
Storage Tank Ullage Gas:	Ambient air

3.8 <u>Electrical Power Generating Subsystem</u> The existing Electrical Power Generating Subsystem has the following characteristics. The turbine generator is a General Electric unit that was originally installed in 1954. It was updated in 1972 with the addition of a larger high pressure turbine shell. It is a 21 stage, double flow, 377 rad/sec (3600 rpm) unit rated at 120.2 MW_e gross for 10 MPa (1450 psig), 538°C (1000°F) steam inlet conditions. The rated steam flow is 126 Kg/sec (1,000,000 lb/hr) at a condenser back pressure of 6.8 KPa (2.0 in Hg) and a gross cycle efficiency of 39.4% (8670 Btu per KWe). The generator is a 3 phase, 60 Hz, 15,500 volt, 141,430 KVA at 0.85 power factor unit. The Westinghouse condenser is a two pass, twin shell unit with a nondivided water box. It can handle a heat load of 169 MW_t (5.8×10^8 Btu/hr) using 4.44 m^3/sec (70,450 GPM) of circulating water with an approach temperature of 30°C (86° F). The condenser water is cooled in a wooden, forced-draft cooling tower. Makeup water is obtained from on-site wells.

Five Westinghouse feedwater heaters are used. These horizontal U-tube, 2-pass heaters use steam extracted from the 5, 9, 14, 17, and 19th turbine stages. They heat 127 KG/sec (1,011,000 lb/hr) of water at the 5th and 9th stages and 106 KG/sec (844,880 lb/hr) at the remaining stages.

3.8.1 Modifications and/or Additions to Existing EPGS The existing low pressure turbine water seals will be converted to steam seals. The control system will be adapted for integration with the solar system. The high intermediate pressure feedwater heater will be replaced. A Nash electrically powered vacuum pump will be installed to replace the existing steam jet air ejector. The turbine condition will be assessed to evaluate its need for modifications and anticipated lifetime under cyclic operation.

3.8.2 Salt/Steam Heat Exchanger Subsystem The Salt/Steam Heat Exchanger Subsystem shall include a feedwater preheater, steam disengaging drum, boiler, superheater, salt recirculation pump, and preheater water recirculation pump and shall be designed to provide the interface between the molten salt heat transport fluid of the solar portions of the system and the water/steam of the existing electrical power generating system in a safe, efficient and economical manner. It shall be designed to provide safe and reasonable access for proper inspection, maintenance and repair of the heat exchangers, fluid lines, utilities, instrumentation and controls. The Salt/Steam Heat Exchanger Subsystem design shall be consistent with applicable codes and it shall be located adjacent to the existing Fossil Energy Subsystem so as to minimize adverse interference with existing parts of the plant. The necessary valving and piping to interface with the existing plant are part of the Salt/Steam Heat Exchanger Subsystem.

The Salt/Steam Heat Exchanger Subsystem shall be capable of receiving thermal energy from the Energy Storage Subsystem. It shall also be capable of producing steam for and receiving water from the Electric Power Generating Subsystem either alone or in parallel with the Fossil Energy Subsystem.

The working fluid for the solar side of the heat exchangers will be molten salt (see paragraph 3.4.3) and for the Electric Power Generating Subsystem side will be water/steam. The Salt/ Steam Heat Exchanger Subsystem shall be designed to accept water from the existing Electrical Power Generating Subsystem as it has been conditioned by that system.

Sensing elements and control valves shall be provided as part of the Salt/Steam Heat Exchanger Subsystem. These components shall interface with the Master Control Subsystem and shall be adequate for efficient and safe monitoring and control of the Salt/Steam Heat Exchanger Subsystem during normal, transient and emergency conditions.

The Salt/Steam Heat Exchanger Subsystem shall be sized to allow power production at 120.2 MW_e gross.

Duty -	305 MW_t (1.04 x 10^9 Btu/hr)
Inlet salt temperature -	566°C (1050°F)
Outlet salt temperature -	277°C (530°F)
Salt flowrate -	2.46 x 10^6 kg/hr(5.41 x 10^6 lb/hr)
Water flowrate -	4.59 kg/hr (1.01 x 10^6 lb/hr)
Steam flowrate -	4.54 x 10^5 kg/hr (1 x 10^6 lb/hr)
Steam blowdown-	4.54 x 10^3 kg/hr (10 x 10^3 lb/hr)
Water recirculation capacity-	43 x 10^3 kg/hr (95 x 10^3 lb/hr)
Salt recirculation capacity-	144 x 10^3 kg/hr (318 x 10^3 lb/hr)

3.8.3 Existing Plant Interfaces The interfaces between the existing plant piping and the solar power additions shall be kept to a minimum. Down time of the existing plant during cut-in of the solar system shall be minimized. The interfaces between the solar parts of the system and the existing plant shall be such that non-operation of the solar part will not inhibit operation of the existing plant in the manner customary before the solar system was added. The specific interfaces required are as follows.

Feedwater - Tee connection in the existing 0.254 m (10 in) main feedwater line between the high pressure feedwater heater and the S-65 flow meter.

High pressure steam - Tee connections in the two existing 0.254 m (10 in) main steam lines between the S-12 flow meters and the hogging ejector tap.

Startup attemperator outlet steam - Tee connection in the 0.304 m (12 in) condensate makeup line as it enters condenser 1A.

Salt/steam [illegible] at exchanger steam drum drain - Tee connection in the 0.203 m (8 in) condensate return line as it enters condenser 1B.

Energy storage tank foundation cooling water supply - New centrifugal pump taking water from the circulating water canal.

Energy storage tank foundation cooling water return - Tee conection into the Unit 1 circulating water return.

Salt melter fossil fuel supply - Tee connection to 0.356 m (14 in) main fuel natural gas supply line near the combustion turbines and separate conection to the No. 2 fuel oil supply line near the combustion turbines.

Receiver and tower services - Connections to the plant service water and fire loops.

Control system - Connection to the existing plant compressed air supplies.

4160 Volt, 3 Phase, 60 Hz, electrical power - Connection of two new transformers to the 12 KV transfer bus.

4160 Volt, 3 Phase, 60 Hz, alternative power - Connection of a new transformer automatically switched between the east and the west switchyard 115 KV distribution lines.

480 volt, 3 Phase, 60 Hz, 900 KW emergency power - Provison of an appropriate diesel generator near the receiver tower. This generator to have an automatic start capability.

3.9 Service Life The system shall be designed for a 30 year service life with no major component replacement required.

3.10 Plant Availability and Reliability The system shall be designed for 90 percent plant availability, based on documented reliability and maintainability assessment, exclusive of insolation conditions. Consideration shall be given in the design to achieving high reliability by providing design and operating margins and utilizing sound engineering design practices.

3.11 Maintainability The solar repowered plant modifications and new installations shall be designed to be compatible with existing plant maintainability characteristics and practices or improvements. Potential maintenance locations shall be easily reached and components such as electronic units, motors, drives, etc., readily replaced. Elements subject to wear and damage, such as supporting wheels, gears, etc., shall be easily serviced or replaced. The plant shall be capable of being serviced with a minimum of specialized equipment or tools.

3.12 Specialized Equipment The Collector Subsystem specialized equipment includes washing equipment, mirror assembly handling equipment, heliostat drive assembly and pedestal handling equipment, heliostat stimulators, mechanical and electronic hand tools and instruments, and a beam characterization system. The Receiver, Energy Storage, and Salt/Steam Heat Exchanger Subsystems each require similar type specialized equipment including: portable hoists, cranes, forklifts, welders, trucks, hand tools, instrument maintenance and repair equipment, and vent valve salt overflow collection equipment. The Master Control Subsystem will require mechanical and electronic tools and instruments for maintenance and repair.

Specialized equipment required for the Fossil Energy and the Electric Power Generating Subsystems and for site and facilities maintenance is available at Saguaro.

3.13 Specialized Requirements The solar repowered plant shall be designed to the following specialized requirements: (Not Applicable).

3.14 Design and Construction Commercial design and construction standards shall be employed. Where applicable, the Uniform Building Code (1976 edition) and the American Institute of Steel Construction's Manual of Steel Construction (8th edition) shall be used. ANSI A58.1 1972 and ASCE paper No. 3269, Wind Forces on Structures (ASCE Transactions, Vol 126, Part II, 1961) shall be used during design when determining loading due to winds. For electrical components, the National Electrical Code (ANSI C1), and MIL-STD-454 standards for electronic equipment shall be used.

3.14.1 Materials, Processes, and Parts To the maximum extent possible, standard materials and processes, and off-the-shelf components shall be used. Wherever possible, commercial specifications shall be employed. All non-commercially available parts shall be defined and documented in deliverable documents.

3.14.2 Electrical Transients All solar system equipment, except that connected to vital busses shall operate through the following power transient conditions:

a. Increasing Transient - one cycle of the fundamental frequency at 1.7 PU voltage followed by an exponential decay back to the original voltage in 5 cycles.

b. Decreasing Transients - A voltage dropout (zero volts) for 10 cycles maximum of the fundamental frequency.

The digital computer and data processing equipment is expected to tolerate power transients which are acceptable to the commercially available equipment suppliers.

3.14.3 Electromagnetic Radiation The Master Control Subsystem wiring shall be designed to minimize susceptibility to electromagnetic interference and to minimize the generation of conducted or radiated interference.

3.14.4 Flammability In a high temperature, low humidity environment of a typical desert, the solar equipment shall not be vulnerable to extensive fire damage.

Given that a fire exists in, any part of the equipment, the fire should not damage any other equipment that is not directly adjacent to the fire, due to burning of the equipment or wiring. If any equipment or any part of the equipment burns, for any reason, the fire should not spread to other parts of the solar system due to blowing winds, component explosions, or any other means.

3.14.5 Nameplates and Product Marking All major elements and assemblies shall be labeled with a permanent nameplate listing, as a minimum: manufacturer, part number, serial number, and date of manufacture.

3.14.6 Workmanship The level of workmanship shall conform to practices defined in the codes, standards, and specifications applicable to the Saguaro site and the Arizona Public Service Company. Where specific skill levels or certifications are required, current certification status shall be maintained with evidence of the status available for examination. All work shall be finished in a manner that presents no unintended hazard to operating and maintenance personnel, is neat and clean, and presents a uniform appearance.

3.14.7 Interchangeability Items with a common function shall have a common part number and be interchangeable. Components with a similar appearance, but different functions, shall incorporate protection against inadvertent erroneous installation.

3.14.8 Safety The solar system shall be designed to minimize safety hazards to operating and service personnel, the public, and equipment. Electrical components shall be insulated and grounded. All components with elevated temperatures shall be insulated against contact with or exposure to personnel. Any moving elements shall be shielded to avoid entanglements, and safety override controls/interlocks shall be provided for servicing.

3.14.9 Human Engineering The Solar System shall be designed to facilitate manual operation, adjustment, and maintenance as needed and provide the optimum allocation of functions between personnel and automatic control. The Solar System design shall provide electrical and electronic packaging which ensures rapid repair and replacement, placarding of hazardous work areas, and equipment for item removal and handling. MIL-STD-1472, Human Engineering Design Criteria, shall be used as a guide in designing equipment.

4. ENVIRONMENTAL CRITERIA

The environmental criteria of this section are to be used in establishng the system design, operating, maintenance, performance, and reliability characteristics of the equipment described in Section 3.

4.1 Plant Environmental Design Requirements The Solar System, additions to the existing plant, and modifications to the existing plant will be designed to meet the following environments.

4.1.1 Operating The system shall be capable of operating in and surviving appropriate combinations of the following environments:

a. Temperature: The plant shall be able to operate in the ambient air temperature range from -8 to +46 °C. Performance requirements shall be met throughout an ambient air temperature range selected to be consistent with efficient plant operation.

b. Wind: The plant shall be capable of operating given the following approximate wind profile as a frequency of function of height above ground level.

The wind speed specifications at a reference height of 10m (30 feet) shall be:

Speed, m/s	(mph)	Frequency, Percent
0- 2	(0-4.5)	29
2- 4	(4.5-9.0)	21
4- 6	(9.0-13.5)	19
6- 8	(13.5-18.0)	14
8-10	(18.0-22.5)	8
10-12	(22.5-27.0)	5
12-14	(27.0-31.5)	3
14-	(31.5-)	Less than 1

For the calculation of wind speed at other elevations, assume the following model:

$$V_H = V_1 (H/H_1)^c$$

Where: V_H = wind velocity at height H
V_1 = reference wind velocity
H_1 = reference height (assume 10m (30 ft))
c = 0.15

Performance requirements shall be met for the most adverse combination of wind and temperature conditions selected to be consistent with efficient plant operation. Wind analyses shall satisfy the requirements of ANSI A58.1-1972.

c. Earthquake: Peak ground accelerations shall be as presented below per applicable UBC zone. Seismic design loads shall be calculated in accordance with the UBC 1979 conditions. The applicable UBC zone is II.

Maximum Operational Ground Accelerations

UBC Zone	Peak Ground Acceleration Average or Firm Conditions
II	0.07 g

4.1.2 Survival The system shall be capable of surviving appropriate combinations of the environments specified below:

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

b. Wind Rise Rate: A maximum wind rise rate of 0.01 m/s^2 (1.3 mph/min) shall be used in calculating wind loads. However, the plant should withstand, without catastrophic failure, a maximum wind of 22 m/s (50 mph) from any direction, such as might result from unusually rapid wind rise rates, e.g., severe thunderstorm gust fronts.

c. Dust Devils: Dust devils with wind speeds up to 17 m/s (38 mph) shall be survived without damage to the plant.

d. Snow: The plant shall survive a static snow load of 250 Pa (5 lb/ft^2) and a snow deposition rate of 0.3 m (1 ft) in 24 hours.

e. Rain: The plant shall survive the following rainfall conditions:

Average annual - 340 mm (13.4 in)

Maximum 24-hr rate - 150 mm (6 in)

f. Ice: The plant shall survive freezing rain and ice deposits in a layer 25 mm (1 in) thick.

g. Earthquake: Peak ground accelerations shall be as presented below per applicable UBC zone. Seismic design loads shall be calculated in accordance with the UBC 1979 conditions. The applicable UBC zone is II.

Maximum Survival Ground Accelerations

UBC Zone	Peak Ground Acceleration Average or Firm Conditions
II	0.10 g

h. Hail: The plant shall survive hail impact up to the following limits:

	Any Orientation	Stowed
Diameter	19 mm (0.75 in)	25 mm (1 in)
Specific Gravity	0.9	0.9
Terminal Velocity	20 m/s (65 fps)	23 m/s (75 fps)

i. Sandstorm Environment: The plant shall survive after being exposed to flowing dust comparable to the conditions described by Method 510 of MIL-STD-810C.

4.1.3 Lightning Considerations The existing Saguaro plant lightning protection system shal be extended to the solar system equipments. Design considerations shall be those APS uses in its newer power plants. Transformers shall be fitted with lightning arrestors. For heliostat lightning protection see Collector Subsystem Requirements Specification, A10772, Issue C. The receiver and its tower shall be fitted with lightning rods at their highest points. The receiver lightning rods shall be connected to earth through appropriate copper conductors, interconnecting copper cables, and driven ground rods. All elecrical equipment enclosures, the energy storage tanks, horizontal piping and the various points of the salt/steam heat exchanger subsystem shall be bonded to earth using ground straps and earth driven ground rods.

4.2 Environmental Standards The Solar Thermal Power System, additions to the existing plant, and modifications to the existing plant shall be designed to meet the following environmental standards.

4.2.1 Air Quality Standards The plant pollution emission requirements are shown below:

Emission Limits for Oil Fired Units

	SO_x	NO_x	Particulates
Federal	None	None	None
State	County has juristication		
Pinal County	1.55 Kg/MWH_t* (1.0 lb/MBTU*)	None	0.265 Kg/MWH_t (0.1714 lb/MBTU)

*2 hour average

4.2.2 Water Quality Standards The existing plant complies with the National Pollution Discharge Elimination Standards. The addition of the solar system should not affect that compliance.