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THE BOEING ENERGY
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Solar Energy Water Desalination System Design

Final Report Volume II

Pilot Plant Preliminary Design

SERI Contract AF-1-9115-2

August, 1981

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SOLAR ENERGY WATER DESALINATION SYSTEM DESIGN

FINAL REPORT VOLUME II

PILOT PLANT PRELIMINARY DESIGN

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ABSTRACT

This report describes the preliminary design for a solar energy brackish water desalination pilot plant on a site in Rankin, Texas. Key features of the plant are discussed and its design objectives, requirements, configuration, operation, performance, and test plans are presented.

The water treatment technology used in the plant is ion exchange pretreatment and single stage reverse osmosis desalination utilizing high-flux membranes. Electrical power needed for plant operation is produced by a solar energy system, which is based on the Brayton cycle with air as the working fluid. Primary solar system components are: heliostat field, central cavity-tube receiver, receiver support tower, thermal energy storage, and a commercial gas turbine generator set. The thermal energy storage subsystem is of the sensible heat type and provides a capability for power generation at night.

The pilot plant simulates essential features and operations of a commercial-size plant meeting the SOLERAS requirements for stand-alone solar powered operation. After a demonstration test period, the pilot plant can be operated as a municipal potable water supply.

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1.0 SUMMARY

The preliminary design is described for a solar energy brackish water desalination pilot plant on a site near Rankin, Texas. Key features of the plant are presented along with its design objectives, requirements, configuration, operation, performance and test plans. Figure 1-1 is an artist's illustration of the pilot plant installation. The pilot plant simulates essential features and operations of a larger, stand-alone commercial SOLERAS plant. After a demonstration test period, the pilot plant can be operated as a municipal potable water supply.

The following design objectives guided the pilot plant preliminary design effort:

- Develop a pilot plant configuration to SERI size constraints.
- Demonstrate technical feasibility of commercial plant.
- Utilize existing hardware to minimize schedule time, cost and technical risk.
- Develop a pilot plant that will be suitable for Upton County to operate as a long-term source of desalinated water.
- Develop a plant that will provide relevant cost, and performance data for detailed design of the commercial plant.

1.1 Pilot Plant Design Concept

The pilot plant's design concept is based on the commercial SOLERAS plant system described in Volume I of this report. The system concept is based on selecting the best combination of the two areas of technology involved -Solar and Desalination -leading to a practical integrated system. Reverse Osmosis (RO) desalination is selected over other brackish water desalting methods because of its acceptable capital cost, low power consumption, and mature technology. An open Brayton cycle solar-thermal electric power plant provides energy compatible with the RO requirements and is selected based on its economics, maturity of technology, and availability of equipment.

Electrical power needed for plant operation is produced by a solar energy system, which is based on an open Brayton cycle having air as the working

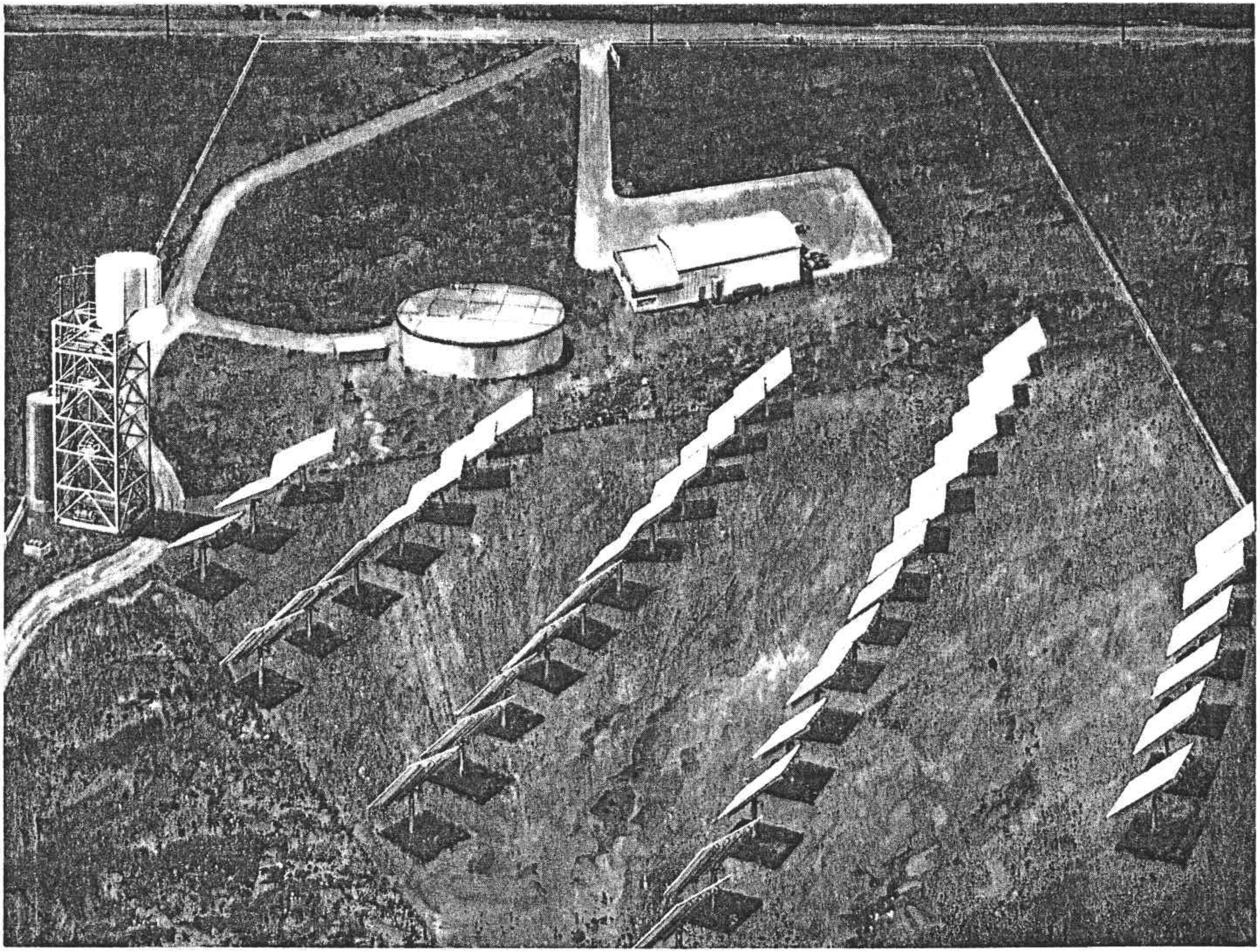


Figure 1-1. Solar Energy Water Desalination Pilot Plant

fluid. Primary solar system components are: heliostat field, central cavity-tube receiver, receiver support tower, thermal energy storage, and a commercial gas turbine generator set. The thermal energy storage subsystem is of the sensible heat type and provides a capability for power generation at night.

Because of its planned near-term construction (constraining major features to available equipment) and its small size, the pilot plant efficiency and operating hours are reduced compared to the commercial plant design. The turbine-generator has the most influence on the design by limiting the power production and, since storage charging consumes power, the amount of thermal energy storage. As a consequence, the plant is designed to be connected to the electric power grid so that during solar operation, power requirements not directly in the solar power/water treatment path can be met. The grid also can provide power to extend operation times and total water production as necessary.

The water treatment technology used in the plant is weak acid cation (WAC) exchange pretreatment and single stage reverse osmosis (RO) desalination utilizing high-flux membranes. These processes were selected for the commercial plant based on cost considerations and compatibility with the varying nature of power production. WAC ion exchange process is a simple on/off operation but its treated water output has relatively high concentration of percipitable ions; therefore, single stage RO is used resulting in a product water recovery of 72%.

1.2 System Description

The pilot plant system is configured as shown in Figures 1-2 and 1-3. Subsystems which comprise the selected system are listed below:

Solar Energy Collection Subsystem -Solar thermal central receiver system has 42 heliostats in a north field array. Energy is directed to a tower mounted air-cooled central cavity receiver with aperture at 23 m elevation.

Energy Delivery Subsystem - Titan gas turbine generator set produces a peak power output of 78.8 kW at system design point conditions. Electric power

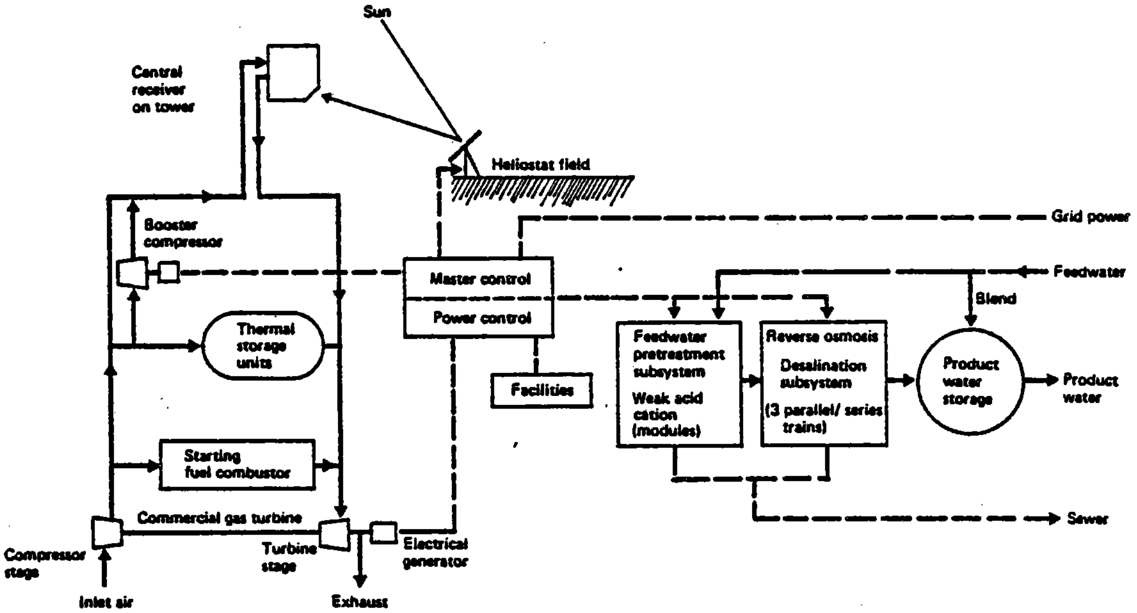


Figure 1-2. General System Schematic

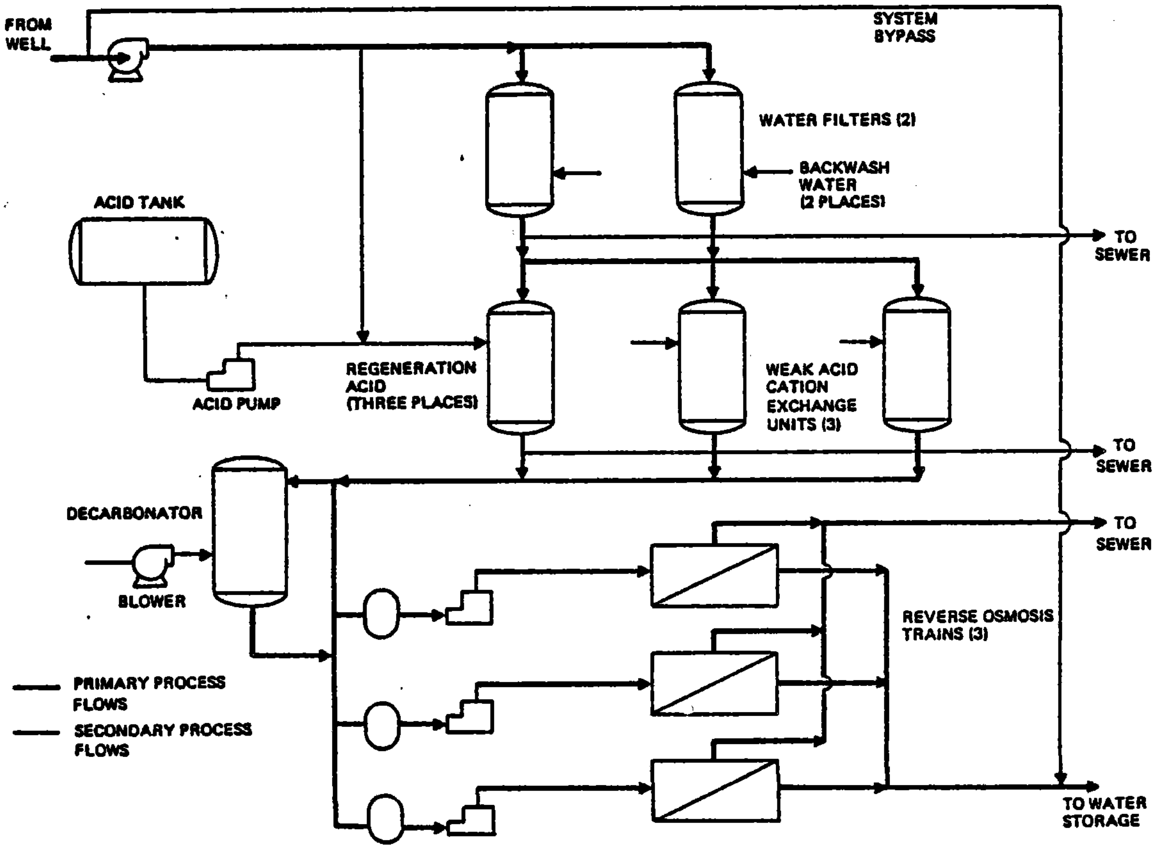


Figure 1-3. Solar Energy Water Desalination Pilot Plant Simplified Flow Schematic

distribution within the plant is at 480 volts. Plant air supply is provided for valve actuation.

Energy Storage Subsystem - A single sensible heat thermal energy storage (TES) unit is used. Storage medium consists of packed alumina pebbles with a total mass of 94,190 kg. Air flow recirculation through TES and back to the receiver inlet during discharge is produced by a variable speed, positive displacement booster compressor.

Backup Power Subsystem - Fossil fuel supply for starting and emergency operation of the main turbine. Standby power (non-emergency) provided by electrical power grid. Emergency standby power for control supplied by uninterruptable battery supplies.

Feedwater Pretreatment Subsystem - Three WAC units operate in parallel. The units are periodically regenerated with acid flush regeneration equipment. A decarbonation/pH control unit, in parallel with the feed line to the RO, removes CO_2 resulting from the reaction in the WAC units.

Desalination Subsystem - Three parallel RO units contain non-cellulosic, high flux membranes. Positive displacement, high pressure pumps are mounted on each RO unit. Recovery in the RO units is 75%.

Controls and Instrumentation Subsystem - Master control computer is linked to distributed digital controllers. These controllers provide control and data links to instrumentation for heliostats, power generation, and water processes.

Data Acquisition Subsystem - This equipment stores plant operating parameters, computed data, and operator data.

Water Storage and Delivery Subsystem - Existing feedwater and product water tanks of $397 m^3$ and $1136 m^3$ (one peak day supply) volume capacity respectively, are incorporated. The feedwater tank is located at a remote well field; feedwater will be delivered by an existing water line. Product water will be stored in the tank on-site and delivered by a new line to Rankin.

Waste Disposal Subsystem - Disposal of process and sanitary wastes to Rankin sewer system is via a new sewer line.

Site and Facilities - The site is reasonably level, rectangular, with an area of 4.05×10^4 m^2. Industrial type of building, with $297m^2$ floor area, contains office, control room, water processing equipment, electrical/mechanical/equipment, laboratory and maintenance areas.

1.3 Plant Operations

The plant is designed to simulate operation of the commercial plant within the limits of scaled down solar collector and power conversion equipment. Typically, the plant will operate throughout the day on solar power; water production will be reduced while TES is being charged. After sunset, power will be produced using energy withdrawn from TES. After a succession of clear days, the plant could be operated 24 hours with reduced water production (as during commercial plant simulation testing). After starting, operation will be computer controlled with minimal operator intervention. Electrical grid power can be used to increase water production; maximum electrical power consumption would be 911,000 kW/h annually.

Based on a preliminary analysis of the mean time between failures and the mean time to repair for all the major elements in the plant, the overall plant availability is at least 0.85.

Analysis of the plant operations shows that a total of 6 employees would be required to operate, administer, and maintain the plant. Some of the personnel would not be needed full time and could be shared with other utilities. Annual costs of operation and maintenance amount to $271,900 (1981 $) with the grid power used to increase water production and 0.85 plant availability. Water production can vary from 327,000 m^3 to 394,000 m^3 depending on grid power usage strategy. The corresponding range of product water cost, assuming free feedwater, is $0.74 to $1.29/m^3$.

1.4 Plant Performance

Annual plant performance has been analyzed using a system operations model based on quasi-steady state simulation of the various components in the plant. The model utilizes ambient temperature and direct normal insolation measurements obtained at Midland-Odessa, Texas, in 1978 and 1979. The model operating strategy maximizes the turbine inlet temperature at all times to produce the most electricity. A more sophisticated strategy, including anticipatory logic might improve plant performance.

Results of the performance analysis provide confidence that the plant will operate as intended. Annual performance of the plant at 100% availability is summarized in Table 1-1. The annual water production shown for solar only operation is equivalent to 287 m^3/d (244 m^3/d at .85 availability). With grid additional power, total ideal water production can be from 1055 m^3/d (corresponding to Table 1-1 data) to 1262 m^3/d, depending on grid power usage strategy. The predicted water production, with grid subsidy, meets the annual demand in Rankin for potable water.

Annual plant efficiency data for solar operations are presented in Figure 1-4. The losses due to various mechanisms and the net power available at each component, starting with the direct insolation, are charted. The current plant design allows good simulation of the commercial plant performance. Overall pilot plant efficiency is relatively low because of the previously mentioned turbine-generator limitations, and the preliminary status of the design. Further optimization and refinements of the pilot plant components, specifically the thermal energy storage subsystem, during detailed design will provide increased pilot plant performance.

1.5 Pilot Plant Design Assessment

The design analyses show that the pilot plant will satisfy the design objectives. The results of the analyses are summarized as follows:

- Pilot plant design is feasible and is supported by related development programs.
- Good simulation is provided of commercial plant features and operations.

Table 1-1. DESAL Pilot Plant Annual Performance Data – Factored 1978 Midland Data

Month	Solar only operation		Grid connection			Total water (m^3)
	Water production (m^3)	Hours of operation	Water production (m^3)	Hours of operation	Power requirement (kWe-hr)	
Jan	8,256	217	27,931	527	36,890	36,187
Feb	10,270	270	21,306	402	28,140	31,576
Mar	9,564	308	23,108	436	30,520	32,672
Apr	11,348	402	16,854	318	22,260	28,202
May	8,416	283	24,433	461	32,270	32,849
Jun	6,748	225	26,235	495	34,650	32,983
Jul	10,141	393	18,603	351	24,570	28,744
Aug	6,721	236	26,924	508	35,560	33,646
Sep	5,764	286	23,002	434	30,380	28,766
Oct	10,094	348	20,988	396	27,720	31,082
Nov	6,388	195	27,825	525	36,750	34,213
Dec	11,030	311	22,949	433	30,310	33,979
Year	104,740	3,474	280,158	5,286	370,020	384,898

- 1978 Midland data corrected to long term average
- Collector field data weighted to hours of operation

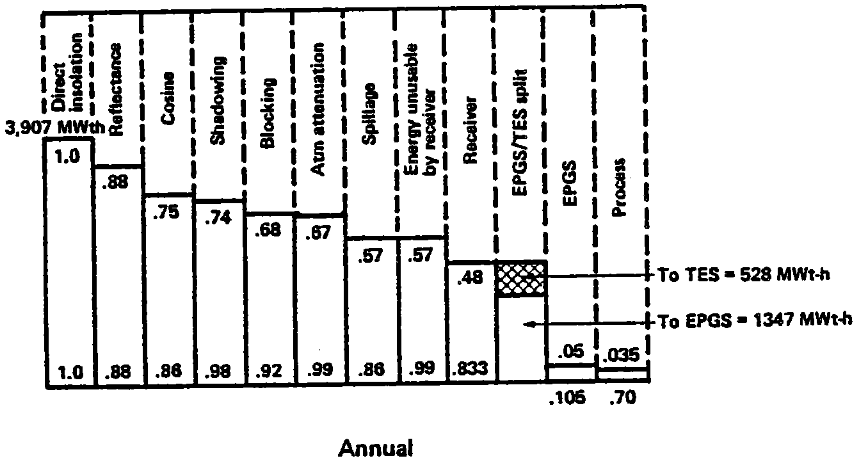


Figure 1-4. DESAL Pilot Plant Efficiency Train

- Pilot plant operation will provide a data base for commercial plant design.
- Solar subsystems performance will demonstrate the potential of commercial plant.
- Pilot plant performance is limited by available turbine and program cost constraints.
- The baseline TES mass is too large and should be reduced during detailed design.
- Pilot plant will satisfy Rankin's water demands with grid power subsidy.
- Operating and maintenance costs will be attractive to Upton County Water District.

2.0 INTRODUCTION

Boeing Engineering and Construction (BEC) under subcontract from the Solar Energy Research Institute (SERI) is preparing a design for a solar energy water desalination system that would transform brackish well water into potable water for a community in southwest Texas. BEC is performing overall project management, system engineering, and solar subsystem design. Resources Conservation Company, a partly-owned subsidiary of BEC, is providing designs for the water-related subsystems.

The 10 month contract which began in October, 1980, covers Phase 1 of a 3-phase program that is sponsored jointly by the governments of Saudi Arabia and the United States as part of the SOLERAS agreement and administered by the Solar Energy Research Institute (SERI). A primary objective of the SOLERAS agreement is to advance the development of solar energy technology in the two countries. In Tasks 2 and 3 of Phase 1, a commercial plant system requirements and design concept were defined in accordance with SOLERAS requirements[1]. The commercial plant study is reported in Volume I; system requirements are contained in a separate document, System Performance Specification, Commercial Plant. Task 4 is concerned with preliminary design of a pilot plant as reported in Volume II (this volume). Task 5 covers pilot plant program plans (Volume III) and commercial plant cost trades (Volume IV). Phase 2A will involve detail design of a pilot plant and, Phase 2B will cover pilot plant construction, and Phase 3 operation and training of personnel. Operation of the pilot plant will provide a data base for the design of the large-scale commercial plant.

This volume documents the work done in Phase 1 under Task 4, Preliminary Design of Pilot Plant, dealing with the preliminary design of a pilot plant that simulates the commercial SOLERAS plant. The pilot plant preliminary design is presented along with results of performance, operations and maintenance analyses. Preliminary test plans for the subsequent detail design, construction and operational phases are also defined. System requirements for the pilot plant are documented in a separate System Specification[2].

3.0 SYSTEM REQUIREMENTS

3.1 GENERAL

The pilot plant is primarily intended to demonstrate the technical feasibility of reliably producing potable water by the reverse osmosis process when powered by a storage-coupled, open-Brayton-cycle solar-electric power system. It is also to be used to provide detailed data, such as evaluation of the interaction between the power subsystems and the water desalination subsystems. The data and operating experience from the pilot plant will provide the basis for the commercial plant design.

3.2 DETAILED SYSTEM REQUIREMENTS

The performance, design and quality assurance requirements for the pilot plant are contained in BEC specification S277-10243-1. A copy of the specification is provided separately.

4.0 PILOT PLANT SYSTEM DESIGN

A pilot plant system design that satisfies the design objectives and requirements is shown in Figure 4-1. The system simulates all subsystem functions found in the commercial plant except for the absence of an evaporation pond and the connection to the electrical power grid. The pilot plant system design is governed by three factors:

1. Selection of the Solar Titan Turbine (the only suitable machine available);
2. Selection, based on costs of a solar multiple of 2.0 (see definition below);
3. Stand-alone water production rate of 100 to 400 m^3/day.

Like the commercial plant, the pilot plant system design is based on open Brayton cycle power generation, weak acid cation feed water pretreatment and reverse osmosis water desalination.

The design basis for the pilot plant water system was estabished during the Task 3 System Analysis effort. During this evaluation, two critical factors, the turbine selection and solar multiple ratio, were determined as appropriate for the pilot plant design. The turbine characteristics essentially establish component sizes and capacities in the plant including overall plant production. The size of the pilot plant as measured by the annual average daily water production depends primarily on the solar multiple (S/M), the ratio of the peak thermal power of the solar collection subsystem to the peak thermal power to the turbine. The design at S/M = 2.0 is considered capable of providing a satisfactory simulation of the critical features of the commercial plant design required for the pilot plant including the application of reverse osmosis (RO units with high flux membranes), a pretreatment system for RO feed, and an equivalent control system to that expected for the commercial plant.

The design requirements for the pilot plant water system were established by BEC Specification No. S277-10243-1, "Performance, Design, and Quality Assurance Requirements for a Solar Powered Reverse Osmosis Water Desalination Pilot Plant," a separate document accompanying this report. Additional

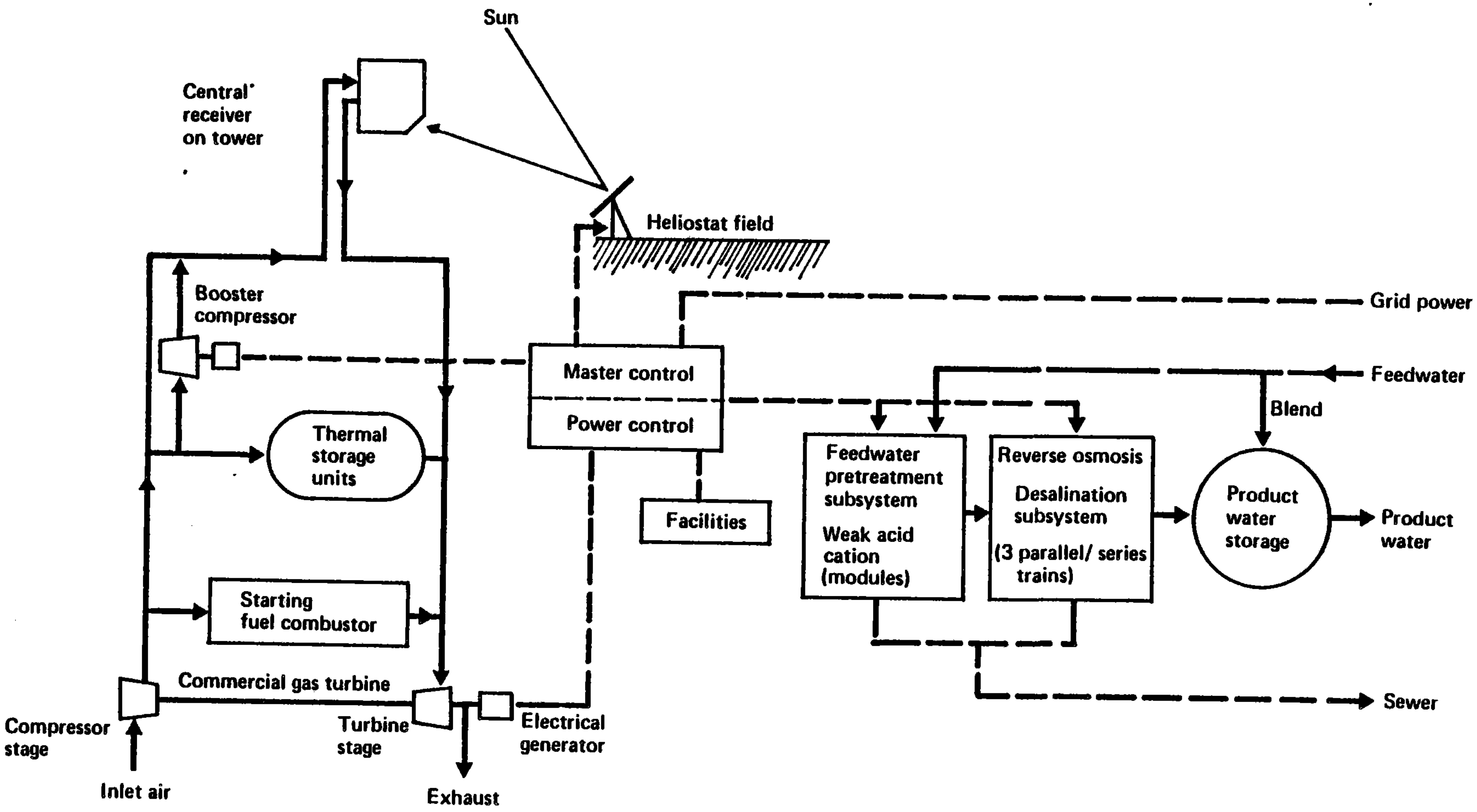


Figure 4-1. General System Schematic

requirements were incorporated subsequent to the preliminary design review for the pilot plant held at Boeing on the 9th and 10th of June, 1981.

4.1 Solar Subsystems

Power needed for plant operation is generated by a modified commercial gas turbine/generator set. System components related to energy collection storage are: heliostat field, central cavity receiver, tower, thermal energy storage (TES) unit, booster compressor and controllers. Air is used as a solar system working fluid in order to (1) simplify design of the receiver, thermal storage units, fluid lines, and interfaces; (2) allow use of commercial turbomachinery; and (3) simplify interfaces with these components because of the common working fluid. With this type of system, fossil fuel can be burned in a modified turbine combustor to provide starting capability and emergency standby power.

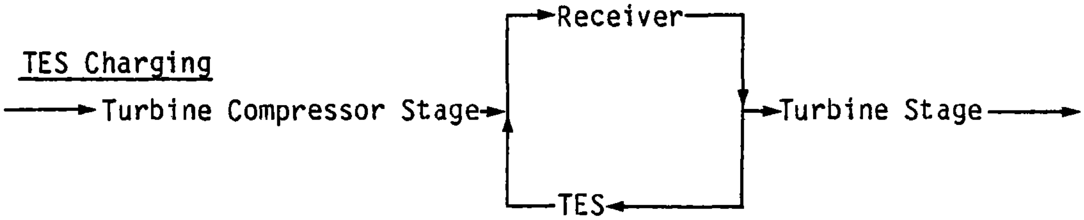
Typical operations of the solar subsystems are:

Start in morning on fossil fuel.
Begin power generation by discharging TES for a short period.
Switch over to receiver operation and cease TES discharging when solar insolation is available.
Phase in TES charging in mid-morning
Terminate TES charging in mid-afternoon
Terminate receiver operation and phase in TES discharging at end of solar insolation
Generate power by discharging TES until nearly depleted but with reserve storage for morning start.

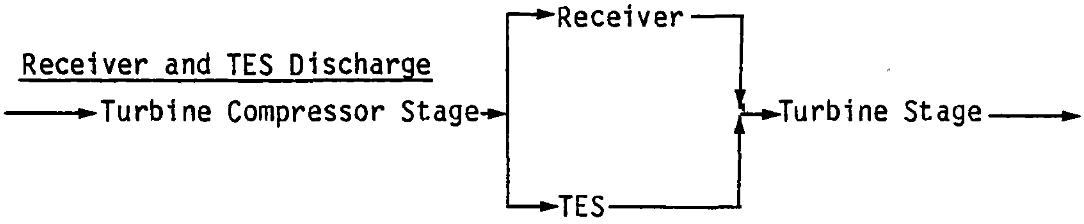
These operating modes are accomplished by controlling air flow through the receiver, storage and turbine using pneumatically-actuated valves. No high temperature air valves are required in this system design. Five air flow routes are provided:

Receiver Only

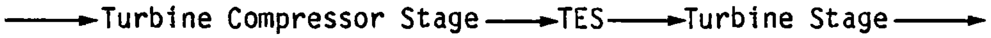
TES Charging



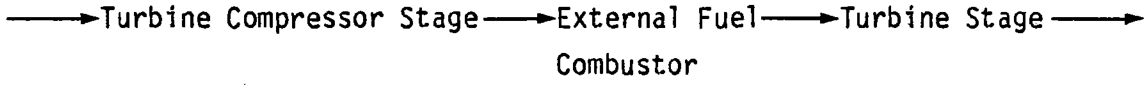
Receiver and TES Discharge



TES Discharge



Starting



A booster compressor is required to overcome the pressure drop in the TES charging loop. This compressor pulls air through the TES and injects it into the receiver inlet line.

Bottoming-cycle power generation using reject turbine heat is not included in the pilot plant because packaged equipment is not available for the Solar Titan. If available, bottom cycling would significantly improve plant efficiency.

The plant can operate in any of three electrical modes: Solar power only, solar plus grid power and grid power only. In the combined solar plus grid mode, the solar power is allocated to the booster compressor, electrical power generation control computer, heliostat controls and drives, and water treatment; all of these loads represent the significant transient loads (i.e., control problem) found in the commercial plant. Solar only operation will be possible with lower water production for demonstration purposes. Normally the grid will be used to supply power to the master computer and low level building loads.

Based on the selection of the Solar Titan turbine and solar multiple of 2.0, the solar subsystems are sized for a noon winter solstice condition with the receiver operating at full flow and thermal energy input and the thermal energy storage unit at full charging flow. Because of the power demands of the booster compressor, the water production rate is reduced during storage charging.

4.2 Water Subsystems

The system requirements that govern design of the water subsystems are:

Feedwater Supply
    Source - well field near Rankin, Texas
Potable Water
    Rate - 100 to 400 m^3/d average from solar power
    Quality - per State of Texas, code "Drinking Water Standard", Revised 11-1-80
    Recovery Rate - minimum 0.72
    Production - Will vary to match the available power
    Waste Disposal - to Rankin, Texas sewer system

A process flow schematic of the pilot plant water system is shown in Figure 4-2. It incorporates those features necessary to demonstrate the technical feasibility of producing potable water for the reverse osmosis desalination process. Two water subsystems are illustrated; the feedwater pretreatment and the desalination subsystems. The feedwater pretreatment reacts with compounds which could precipitate and cause fouling of the RO membranes.

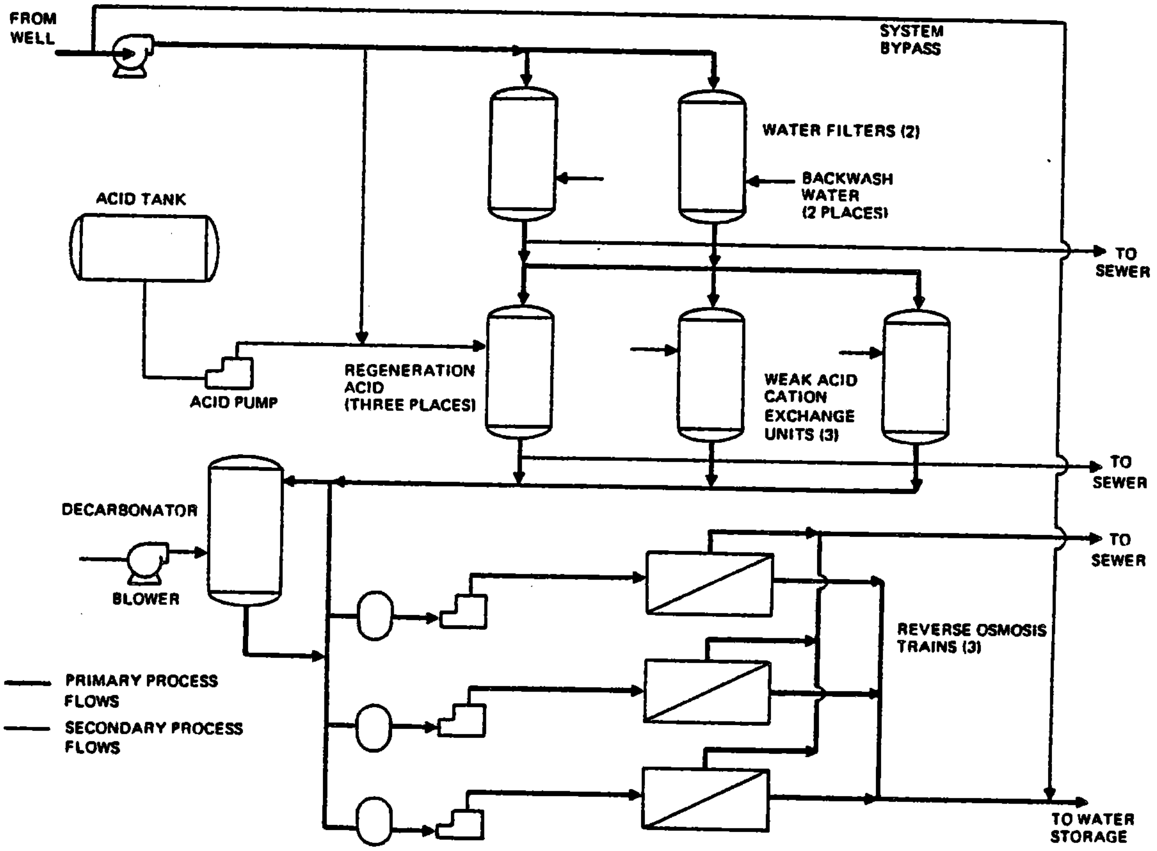


Figure 4-2. Solar Energy Water Desalination Pilot Plant Simplified Flow Schematic

Feedwater is obtained from the existing well supply of the Rankin, Texas municipal supply and is pressurized by the feed pump in the pilot plant pretreatment subsystem. A manual bypass prior to the feed pump is provided to permit blending of permeate water and feedwater prior to distribution to the Rankin system. Water pretreatment consists of two full flow anthrafilt filters, three weak acid cation exchange beds and a decarbonator unit. The filters are required to remove any silt or suspended solids that would reduce the capacity of the ion exchange beds and affect RO membrane performance. Calcium cation concentration of the raw feedwater is reduced by the WAC beds and all the bicarbonate anion is converted to carbonic acid which is subsequently removed as carbon dioxide via the decarbonator unit. A bypass loop is provided around the decarbonator to control pH of the RO feed by blending WAC effluent with decarbonator product. Following pretreatment, the RO feed is pressurized to 2758 kPa (400 psig) and pumped to the three single stage reverse osmosis (RO) units.

The RO units are arranged in parallel with appropriate valving and piping to permit operation of any combination of the units. Motor speed controls are provided on the pump units to vary the water production rate with available power. An RO clean and flush loop is required for the periodic removal of foulants from the membranes. The permeate (RO product water) is overly pure so is blended with feedwater to increase production of water having the required quality. After blending, the product water is directed to the existing storage tank on the site. Waste effluents of the water system including filter backwash, spent regenerant and RO reject are gravity fed to the Rankin sewer system via a new sewer line.

The pilot plant water system has a water recovery rate of .72 with a design capacity of 232 gpm of product water equivalent to 1262 m^3/day. In addition to meeting the pilot plant performance specifications, the designated system is configured to simulate the full scale commercial plant and will provide performance and test data needed for its development. The plant's water system is suitable for Upton County, Texas, to acquire and operate as a long term primary source of desalinated water for the City of Rankin.

The water subsystems are sized for a 70 kW design point which is the condition of maximum generated power at noon winter solstice (78.8 kW) less power (8.8 kW) for electric power generation computer, heliostat computer and controllers, heliostat drives, and miscellaneous loads. If 70kW power is supplied continuously by the grid, the water production is rated at 1262 m^3/d which can satisfy Rankin's peak demand. Variable flow pumps are provided to allow smooth following of power production levels (an advantage in testing since both variable and discrete step flows can be simulated).

5.0 PILOT PLANT DESIGN CONFIGURATION

This section summarizes the pilot plant configuration with respect to general arrangement and design features. The configuration is comprised of subsystems that simulate respective subsystems in the commercial plant system design:

- Energy Collection
- Energy Storage
- Energy Delivery
- Back-Up Power Generation
- Feedwater Pretreatment
- Water Desalination
- Water Storage and Delivery
- Waste Disposal
- Controls and Instrumentation
- Data Acquisition
- Site and Facilities

5.1 General Plant Layout

The general pilot plant layout appears in Figure 5-1 (BEC Drawing 277-10350). Because of nearly level topography and property boundary locations, the plant fits the site well and is compatible with the existing water storage tank and adjacent properties. The heliostat field, utilizing a BEC heliostat design, just fits the site confines; additional land is available south of the site should a longer field be desired.

The plant building is located where (1) it is safe from reflected sunlight, (2) plant observation and control can be easily done, (3) connections to subsystems are reasonably short, and (4) it is close to the highway. Plant water and sewer lines will conveniently connect to an existing water line trench easement leading to Rankin and the storage tank. Figure 5-2 (a portion of BEC Drawing 277-10360) is a building floor plan showing the arrangement of water treatment equipment, control room, and other building spaces.

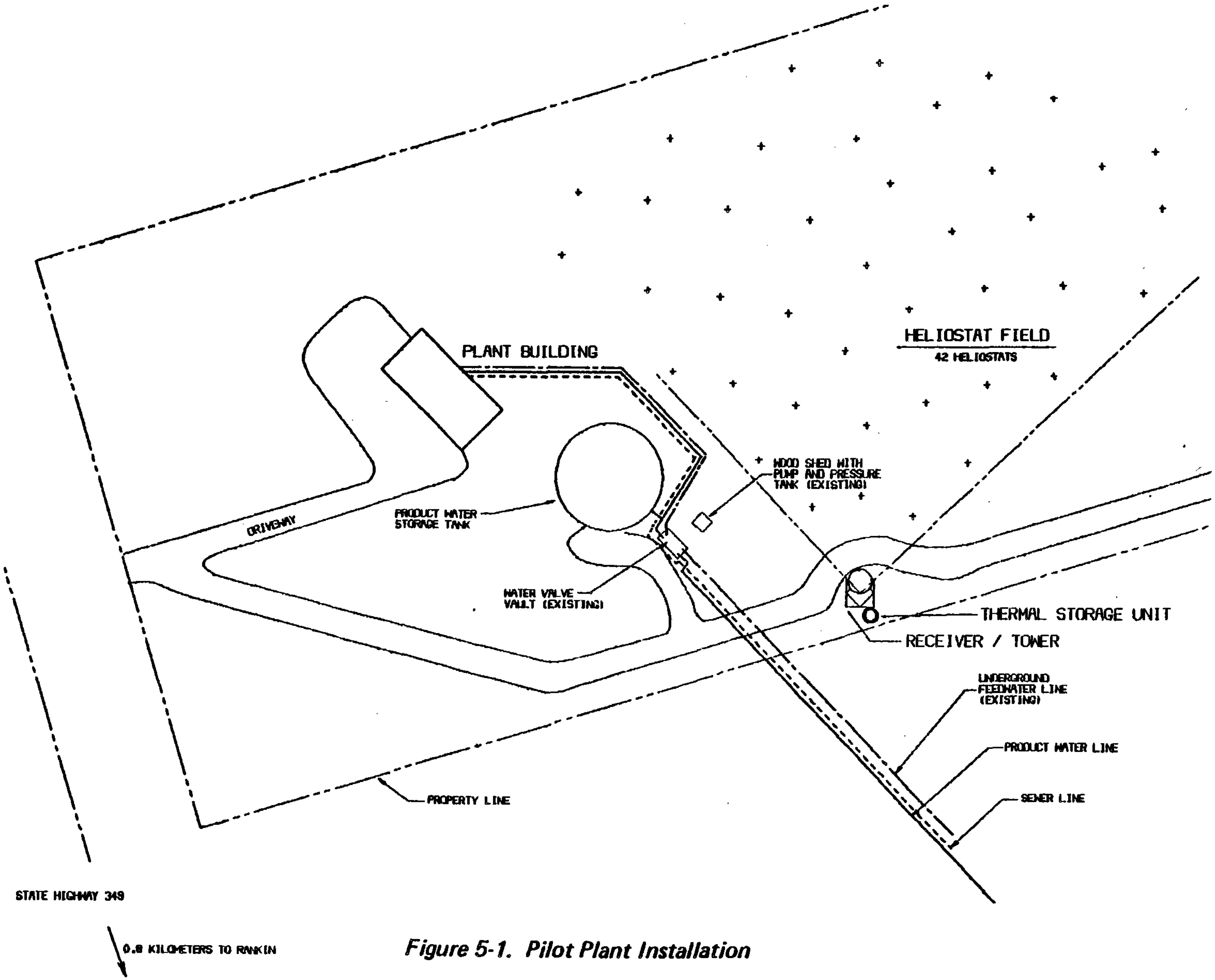


Figure 5-1. Pilot Plant Installation

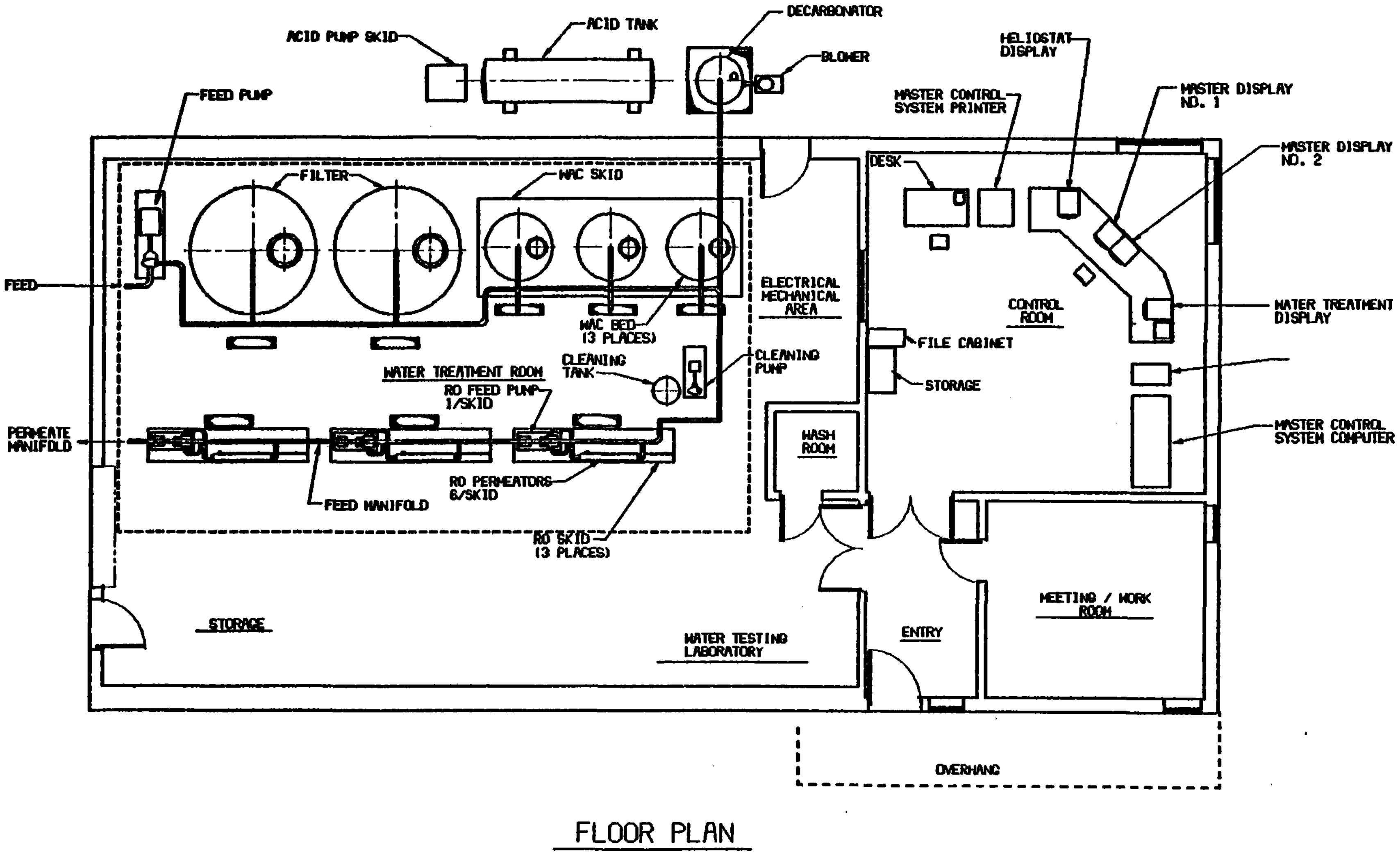


Figure 5-2. Pilot Plant Building

Figure 5-3 (BEC Drawing 277-10351) illustrates the general arrangement of the solar subsystem components. Power generation and energy storage components are mounted at the base of the tower in close proximity. As discussed later in Section 6.4, a late design change in the thermal energy storage unit prevented optimization of the air piping, booster compressor and turbine arrangement. During detail design, the turbine and booster compressor will be relocated for a more optimum piping layout. The thermal energy storage unit is located on the south side of the tower and will be positioned to minimize shadowing. Control and power lines between the heliostat field, tower and building are located in trenches (refer to the installation drawings in the appendix for specific lines and locations).

5.2 Plant Design Features

Site

Location	0.8 km north of Rankin, Texas, on State Highway 349, Upton County (Section 23, Block B, HE & WT RR Co. survey) Longitude 101.93°W Altitude 579 m (1900 ft) Latitude 31.93°N
Site Dimensions	125m x 323m
Area	4.05×10^4 m^2 (10 acres)

Facilities

Industrial warehouse/office building	
Type	Pre-engineered insulated metal
Size	12 x 24 m (40 x 80 ft)
Area	297 m^2 (3200 sq ft)
Electric power interconnect to grid	

Solar Energy Collection Subsystem

Heliostats:	
Type	BEC 2nd Generation heliostat prototype
Mirror Area	42.6 m^2 (net) 44.6 m^2 (gross)
Heliostat Surfaces	Cylindrical focus glass/foamglass sandwich

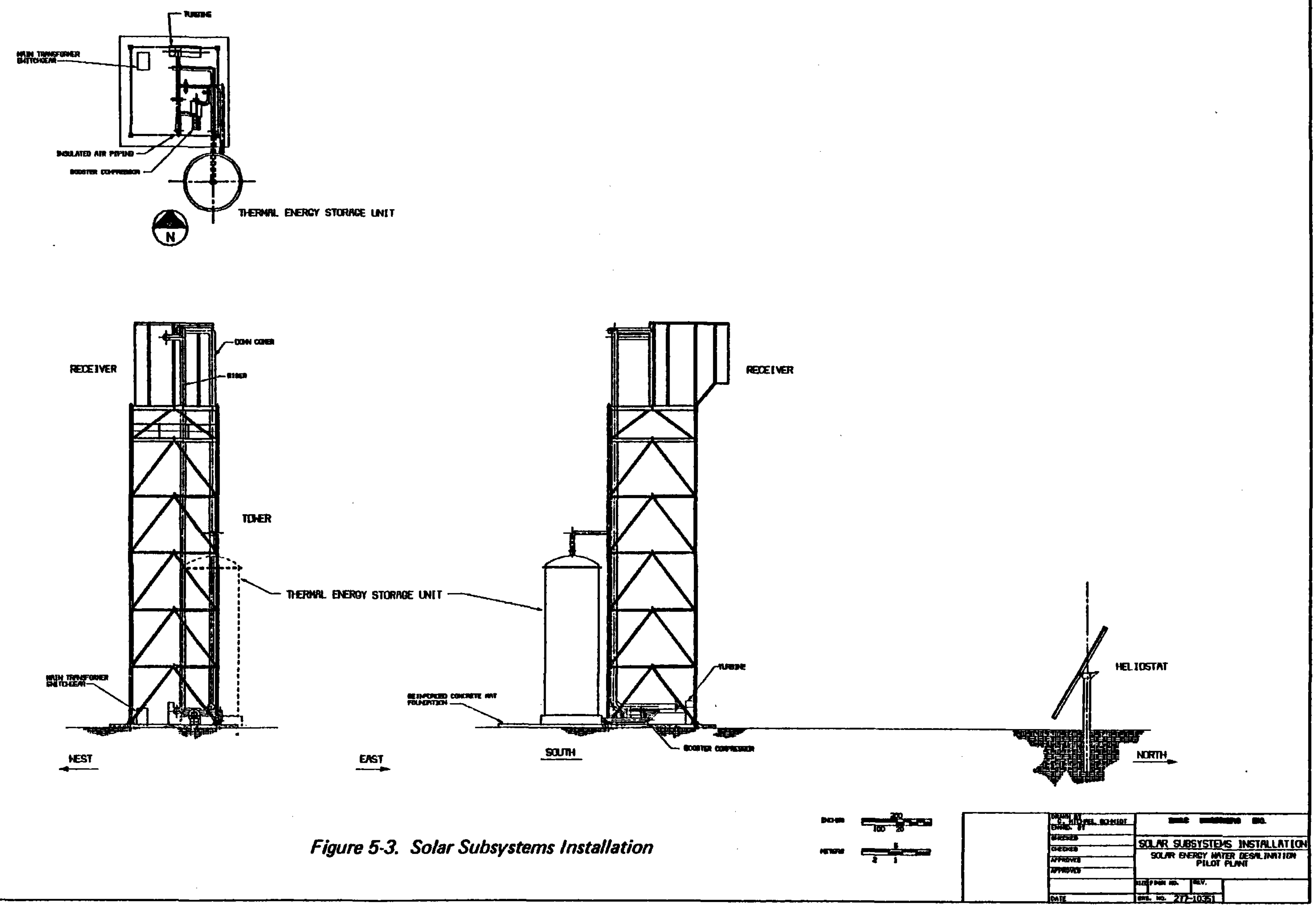


Figure 5-3. Solar Subsystems Installation

42x42.6 = 1789 m^2 net

Heliostat Field:	
Number of heliostats	42
Field shape	90° sector x 114m radius north of tower
Reflective surface	1781 m^2 (net)
Receiver:	
Receiver cavity dimensions	5.2 m wide x 5.4 m high
Aperture area	7.13 m^2
Aperture height	23 m
Aperture inclination	40° from vertical
Insulation thickness	0.20 m
Heat exchanger panels	8
Total number of tubes	236
Tube material	Inconel 617
Tube Dimensions	
Length	5.67 m
Outside diameter	12.7/14.7 mm
Wall thickness	.89 mm
Panel width	1.42 m
Header material, diameter	Inconel 617, 100 mm diameter
Manifold material, diameter	CRES, 250 mm diameter
Tower	
Tower type	Structural steel
Tower height	21.8 m
Tower plan dimensions	3 m x 3 m
Foundation	7.62 m square x .9 m deep Concrete mat
Tower materials	ASTM A-36 steel
Air Piping	
Riser material	Carbon steel
Riser diameter	254 mm diameter
Downcomer material	Stainless steel
Downcomer diameter	305 mm diameter
Insulation material	Jacketed Kaowool external insulation
Insulation thickness	50 mm

Energy Storage Subsystem

Number of storage tanks	1
Tank configuration	Single pass vertical cylinder Welded steel construction
Tank material	ASTM A515 Grade 70 steel
Insulation material	Insulating firebrick
Insulation thickness	1 m
Storage material material	Tabular Alumina (pebbles) Nominal diameter 1.6 cm (0.625 in)
Storage material weight	94,190 kg (209,000 lb)
Storage material dimensions	
Cross section area	3.6 m^2 (38.5 sq ft)
Diameter	2.1 m (7.0 ft)
Length	10.4 (34 ft)
Installed density	2563 kg/m^3 (160 pcf)
Booster compressor	
Type	M-D Pneumatics Model 557-5511 Positive displacement, rotary blower with water-cooled inlet air
Variable speed drive	Reeves Vari-Drive
Inlet air pre-cooler type	ITT Bell and Gossett Model QGC85-102 shell and tube heat exchanger
Coolant flow rate	71.9 l/m (19 gpm)

Energy Delivery Subsystem

Gas Turbine Generator Set	Alturdyne (modified)
Turbine	Solar Titan Model T62T.32 with external combustor start
Fuel	JP-4 (used for starting)
Rated electric power	90 W (15.6°C, sea level)
Generator	480V, 60HZ, 3 phase, 4 wire
Starter motor	12 volt DC motor
Switchgear	Power switching options: solar only solar and grid grid only

Backup Power Generation

JP-4 fuel supply for turbine	
Grid electric power	
Uninterruptable power supplies	10 KVA, 3 Phase, 120/208 VAC Elgar UPS 103-3A, BP10A-0109 6.5 KVA, 1 Phase, 120/240 VAC Elgar UPS 652-1A, BP05A-050G

Feedwater Pretreatment Subsystem

Filters	2 units
Weak acid cation exchange	3 units
Capacity each unit	1/2 the peak flow
Regeneration frequency	24 hours or more
Tank size	1.5 m diameter x 1.5 m high
Exchange material	Acrylic divinyl benzene
Regeneration	Dilute HCl Wash
Decarbonator	1 unit
Tank size	Less than 1.5 m diameter
Blower capacity	0.6 m^3/s

Desalination Subsystem

Reverse Osmosis Units	3 trains
Capacity each unit	1/3 the peak flow
Design flow, total	1270 m^3/day
Membrane elements	High flux polymeric
Pumps	Variable speed, positive displacement

Waste Disposal Subsystem

Method of brine disposal	Disposal in Rankin sewer system via new 1493 m (4900 ft) 15.2 cm (6 in) sewer line from site

Water Storage and Delivery Subsystem

Interconnect to existing water supply	
Feedwater storage at well field	379 m^3
Product water storage on site	1136 m^3

Product water will be delivered to Rankin via new 1036 m (3400 ft) 25.4 cm (10 in) water line.

Controls and Instrumentation Subsystem

Main Components:	Master control computer 2 color master video displays Heliostat video display
Peripheral controllers:	Power generation Heliostat field (5 units) + controllers on each heliostat Process computer

Data Acquisition Subsystem

Main Components:	Printer Magnetic tape data storage Interface with master control computer

6.0 SOLAR ENERGY COLLECTION SUBSYSTEM

The Solar Energy Collection Subsystem includes all the components for collecting solar energy, transforming it to thermal energy, and transferring it to the Energy Delivery Subsystem. Major components in this subsystem are the solar receiver, the receiver tower, air distribution piping, and the collector field consisting of an array of heliostats. These components are arranged as shown in Figure 5-3.

6.1 HELIOSTAT FIELD

Performance requirements for the heliostat field are:

1. Provide 1263 kW into the receiver aperture at the design point condition;

2. Have less than 15% spillage on an annually averaged basis,

3. Operate when solar elevation is more than or equal to 10°;

4. Provide a design point field efficiency greater than 70%.

The heliostat field design is required to comply with Sandia Specification A10772, Revision D, 12/11/79, and the System Specification [2] including Sections 3.2.1.5a (Concentration Requirements) and 3.2.5 (Environment).

The heliostat field design developed to satisfy these requirements consists of 42 BEC Second Generation pre-production heliostats arranged in a 90° radially staggered pattern (refer to BEC drawings 277-10365 and 277-10115) and a receiver aperture height of 23 m.

A photograph of a BEC heliostat tested at Sandia's Central Receiver Test Facility in Albuquerque appears in Figure 6-1. Each mirror panel is nominally 1.2 m by 3.0 m and will be cylindrically curved in the short direction; the panels are canted to achieve good focus in the receiver's oblong aperture (1.75 m by 4.45 m). The mirror panels have a glass/foamglass/glass sandwich construction so that thermally induced distortions are minimal. The net heliostat area (active reflective area) is 42.6 m^2.

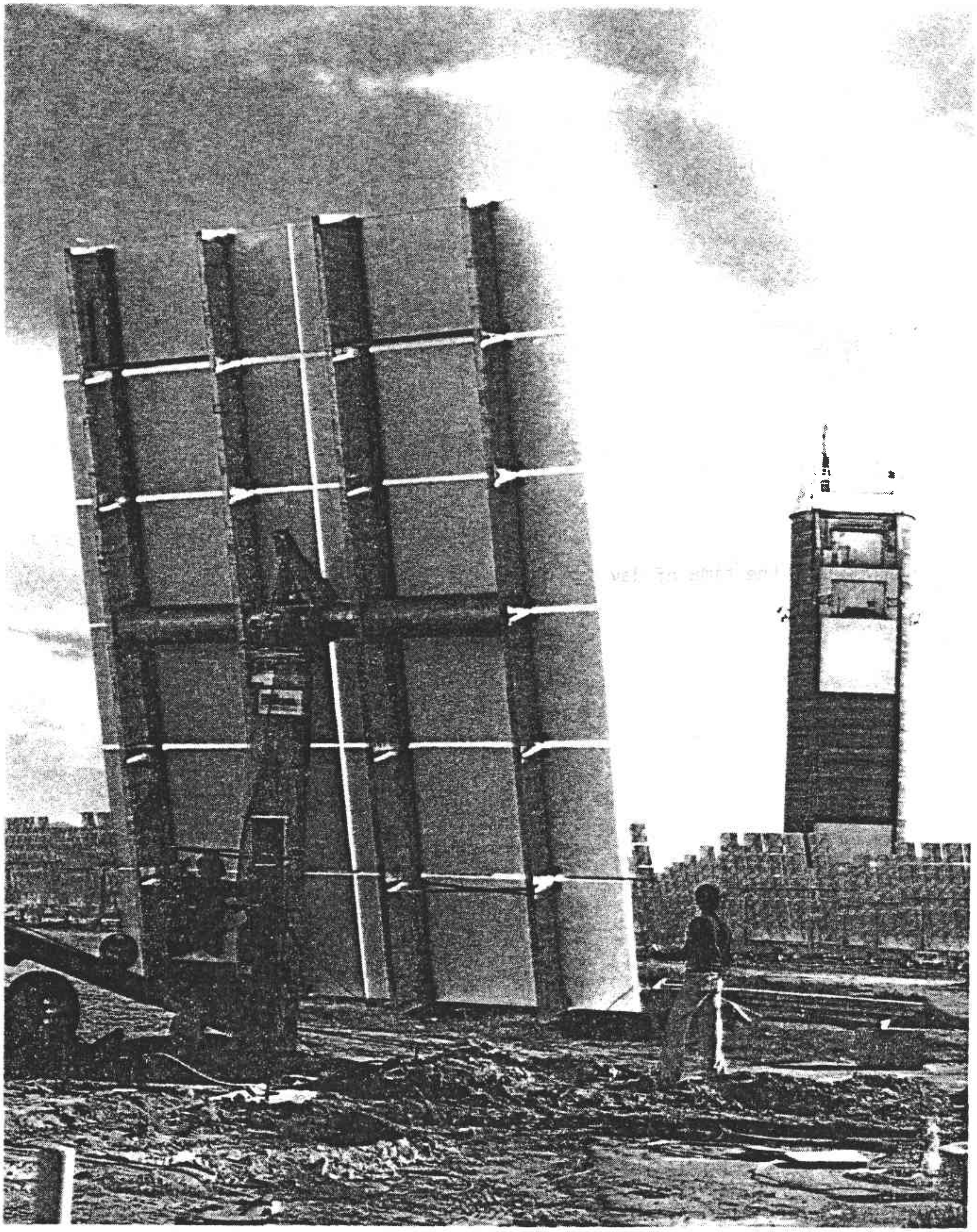


Figure 6-1. BEC Second Generation Heliostat

The field was sized by an iterative procedure that varied tower height, aperture configuration and number of heliostats. Sizing was performed for an estimated average mirror reflectivity of 0.88 with rain washing only [1]. A complicating factor was the small field size which precluded the use of automatic computer aided field optimization as is done for large fields where the heliostats are smeared in zones. For the pilot plant, various field designs were input to a newly developed code called DELSOL II [4] which computed field performance for the design day. Comparison of results led to a field/tower/aperture combination that appears to have reasonable proportions and good performance.

Heliostat Field Performance

The selected heliostat field design was analyzed using the Sandia DELSOL generalized computer code. Losses due to reflection, cosine, shadowing, blocking, atmospheric attenuation, and aperture spillage were calculated as a function of the time of day for a day for each month of the year. The resulting data were used as input to the solar desalination system analysis
1682 model, DESAL (see Section 17.1). Design point data are presented in Figure 6-2. As is shown, 1680 kW is potentially available to the heliostat mirrors
x.75 if they were all pointed normal to the insolation. Seventy-two percent of 75%
1261 that amount, 1263 kW_t, is delivered into the receiver aperture. The fraction of available energy delivered to the receiver aperture, i.e, the field efficiency, can be averaged over the day. The variation of the daily averaged field efficiency with day of the year is depicted in Figure 6-3. The field efficiency is highest in December and lowest in June. The available solar resource variation is nearly the reverse, being highest on the longest solar days of summer and lowest on the shorter winter days. The resulting total solar power input to the receiver is relatively constant over the year.

6.2 TOWER

The tower's primary function is to support the receiver and air lines (riser and downcomer). Other functions are to provide a work platform under the receiver and stairway to the work platform. Design requirements for the tower are low cost, good appearance, and modular assembly for ease of shipping and erection. Performance requirements are given in the Uniform Building Code (also ANSI A58.1) and the System Specification.

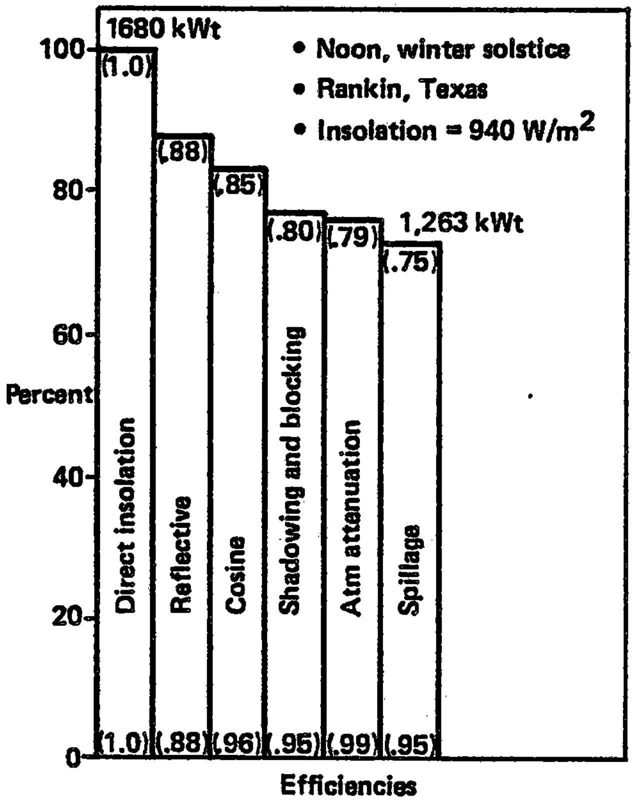


Figure 6-2. Design Point Field Efficiency Train

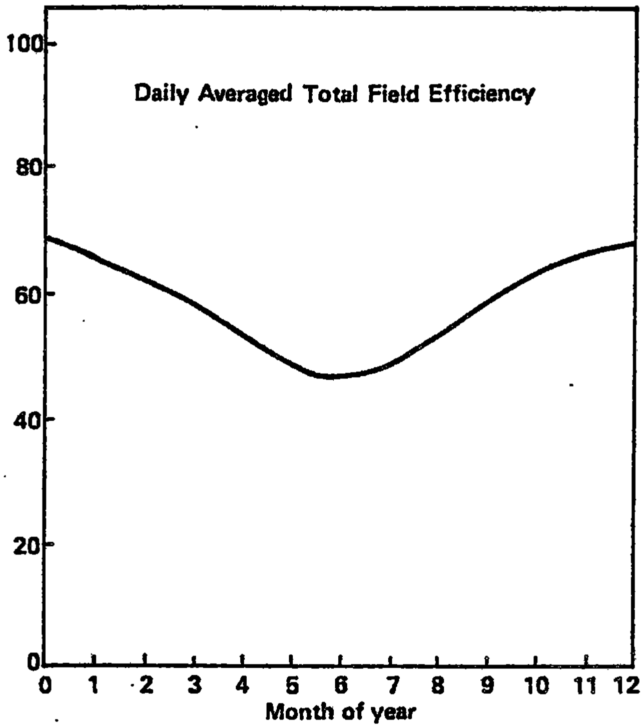


Figure 6-3. Annual Performance

The tower design basically consists of a welded tubular steel framework with "K" wind bracing (refer to BEC drawing 277-10397). This configuration was selected in a study of various structural bracing arrangements, the "K" bracing approach is most effective for the tower's proportions and design conditions and is commonly used. Welded and tubular steel construction offers light weight and pleasing appearance. Field joints are provided at the "K" bracing center points and interior bracing is arranged so that the tower can be conveniently shipped in four corner modules. Open steel grating is used for the field-installed stairway and work platform in order to minimize gravity and wind loads. A reinforced concrete mat foundation is provided in this preliminary design. During the detailed design, results from a planned soil boring investigation should allow use of a more economical uplift pile foundation concept.

The governing tower design condition is wind loading as specified by the Uniform Building Code: 1197 Pa (25 psf) at 9.1 m (30 ft) which is equivalent to 40.2 m/s (90 mph) wind speed plus 10% for gust. The resulting wind loads on each of the two loaded tower faces are listed in Table 6-1. These loads produce a total overturning moment of 1773000 Nm (1308000 ft-lb).

Elevation		Pressure		Line Load		Point Load		Loaded Parts
m	ft	Pa	psf	N/M	lb/ft	N	lb	
24	77	1532	32	-	-	22241	5000	Receiver
15-22	50-72	1436	30	1700	117	-	-	Tower
9-15	30-50	1197	25	1416	97	-	-	Tower
0-9	0-30	958	20	1131	77.5	-	-	Tower

Table 6-1. Wind Loads on Each Exposed Tower Face

The reinforced concrete mat [7.6 m square by 0.91 m thick (25 ft square by 3 ft)] develops a resisting moment, neglecting friction, of 4767000 Nm (3516000 ft/lb). The resulting factor of safety against overturning is 2.69 which exceeds the required factor of 1.5. The structural steel tower parts were conservatively designed assuming a 38 m (125 ft) tower height (an early configuration in the collector field analyses). Four 3.8 cm (1.5 in) diameter anchor bolts are specified at each column which gives an ample factor of safety of 3.9 on bolt yielding.

Material quantities for the tower design are as follows:

WEIGHTS

	kg	Tons
Structural steel		
Shapes and plates	19100	21
Connections	909	1
Pipe handrail	1045	1.15
Concrete reinforcement bars	2045	2.25

AREAS

Steel grating	46.5 m^2 (500 sq ft)

PARTS	QUANTITY
Stair treads	90
Anchor bolts - A307 steel 3.8 cm dia x 1 m long (1.5 in dia x 40 in long)	16
Reinforced concrete foundation	53 m^3 (70 cu yd)

6.3 RECEIVER

The receiver's function is to capture solar energy reflected from the heliostats and transfer it to the air flowing through heat exchanger tubes.

Specific performance requirements are:

1. Accept up to 1300 kW of solar input;
2. Accept massflow from 0.45 to 1.84 kg/s with a pressure drop of less than 36 kPa;
3. Have collection efficiency of greater than 83% at design point conditions;
4. Operate at outlet temperatures up to 816°C (1500°F).

Design requirements for the receiver are:

1. Provide design life of 20 years;
2. Accept up to 170 kW/m^2 on untubed cavity insulation walls while local insulation temperature is less than 1300°C (2372°F) for 5 calendar years;
3. Accept 60 kW/m^2 on aperture rim shield while local temperature is less than 740°C (1365°F) for 5 calendar years;
4. Accept 300 kW/m^2 during "lock and drift" of heliostat field while local temperature is less than 1370°C (2498°F);
5. Pipe design allowables for pressure-temperature-stress per ANSI B31.3;
6. Pipe welding, inspecting & testing per ANSI B31.1 or 31.3;
7. Structural welding per AWS D1.1;
8. Structural components per AISC steel construction manual;
9. Expansion joints per Expansion Joint Manufacturers Association standards;
10. Structural loads per system specification;
11. Interior components must be accessible for inspection and servicing;
12. Aperture rim shield shall have a simple configuration and be easily replaced.

Receiver Design

A vertical cylindrical receiver design having a low aperture was developed to satisfy the pilot plant's requirements; the design appears on BEC Drawing 277-10390 included in the Appendix. Receiver components and their respective weights are listed in Table 6-2.

Part	Material	Weight	
		kg	lb
Structural Steel Shell	ASTM A-36 Carbon Steel	6540	14350
Inlet and Outlet Manifolds 25.4 cm dia. (10 in) Schedule 10	304 Stainless Steel	13.8	2900
Headers 10.2 cm dia. (4in.) Schedule 10	Inconel 617	405	890
Heat Exchanger Tubes			
12.7 mm O.D. x 0.89 mm wall (0.5 in O.D. x 0.035 in wall)	Inconel 617	240	528
14.68 mm).D. x 0.89 mm wall (0.578 in O.D. x 0.035 in wall)	Inconel 617	160	352
Cavity Insulation			
Typical wall	Kaowool blanket		4940
Cavity lower rear area	Kaowool blanket, 2600 ST board composite		740
Ceiling and Floor	Kaowool blanket		2212
Aperture in Shield 38.1 mm (1.5 in)	3000 board	43	95

Table 6-2. Receiver Weight Distribution

External dimensions of the receiver are 5.6m (18.3 ft) diameter by 5.44m (17.8 ft) high. A flat, canted oblong aperture has a length in the horizontal direction of 4.45m (14.6 ft) and a slant height of 1.75m (5.7 ft). This aperture geometry is a result of both the heliostats' reflected image sizes on the aperture plane and the positioning of heliostats (collector field shape). The aperture dimensions are determined interactively with the collector field sizing described in Section 6.1. Overall receiver dimensions are governed by several factors, including limiting solar flux on interior walls to acceptable levels, reducing reradiation out the aperture to an acceptable level, and providing the required heat exchanger area.

Cutaways of the receiver shown in BEC Drawing 277-10390 show its major features. Eight panels of heat exchanger tubing are located around the interior walls. Incoming air is provided to the heat exchangers via the riser, inlet manifold located in the cavity, and headers. After passing through the heat exchangers, the air exits through to the outlet manifold mounted in the interior of the receiver, and then is ducted to the downcomer leading down the tower. Nineteen percent (19%) of the first incident solar power impinges directly on three southern most panels directly opposite the aperture. The remaining 81% of the first incident flux impinges on untubed insulated cavity walls. Energy is reflected and reradiated to the heat exchanger surfaces. However, since three panels receive a direct solar component in addition to an indirect solar/thermal component, the available power is not uniform circumferentially around the receiver. Tubing dimensions and tube number per panel differ slightly among the panels to provide the required mass flow for different heating rates with an acceptable pressure loss. Pressure losses can be balanced with panel-to-panel orifice plates at the manifold/ header connections during system checkout to provide the required mass flow distribution. Use of interior manifolds results in minimum manifold length weight and pressure drops and eliminates heat loss compared to a location outside of the receiver.

Inconel 617 alloy, produced by Huntington Alloys, is selected for the heat exchanger tubing and headers. This material has demonstrated capability for 871°C service and is one of the best available commercial alloys in terms of strength, creep resistance, corrosion resistance, formability and weldability. Inconel 617 was successfully used in the BEC/EPRI Bench Model Receiver and is currently specified for the BEC/EPRI Full System Experiment receiver. The manifolds are shielded with insulation and therefore will not be hotter than the peak exit air temperature of 816°C (1500°F); this temperature limit allows use of standard 304 stainless steel tubing and fittings for the manifolds.

The heat exchanger tubes have a simple loop configuration and are hung in a vertical position. This arrangement is advantageous because (1) the tubes are structurally independent (thermally-induced bending deflections can occur freely) and (2) gravity will not produce high stresses and creep bending deflections.

Cavity insulation consists of two types: a Kaowool blanket/board composite in the lower rear area of the cavity which is directly radiated and a Kaowool multilayer blanket in all other areas. The composite insulation in the "hot" areas has the following components:

Layer Location	Product	Thickness	
		cm	in
Cavity Surface	Kaowool 3000 board	3.8	1.5
Middle	Kaowool 2600 board	3.8	1.5
Middle	Kaowool 2.7 Kg (6 lb) blanket 2 layers 5.1 cm each	10.2	4.0
Next to Shell	Kaowool 2.7 Kg (6 lb) blanket	2.5	1.0
		20.36	8.0

The multilayer insulation in the cooler areas (behind the panels, roof and ceiling) is made up as follows:

Layer Location	Product	Thickness	
		cm	in
Cavity Surface	Kaowool 3.6 Kg (8 lb) blanket 10.2 cm (4 in) overlap	2.5	1.0
Middle	Kaowool 2.7 Kg (6 lb) blanket	2.5	1.0

Middle	Kaowool 2.7 Kg (6 lb) blanket 2 layers 2.5 cm each	10.2	4.0
Next to Shell	Kaowool 2.7 Kg (6 lb) blanket	5.1	2.0
		20.3	8.0

The insulation design is based on recent high temperature experiments conducted by BEC for EPRI and recommendations from the insulation supplier, Babcock & Wilcox. All of the cavity insulation will be attached to the steel shell by ceramic spikes and retaining washers, a method that has been previously proven and permits insulation replacement.

The aperture rim shield is a single layer of Kaowool 3000 board with 3.8 cm (1.5 in) thickness. The shield would be fabricated in flat sections from 45.7 cm (18 in) square stock panels. As discussed later, the flux levels on the aperture rim are low, so insulation temperatures will be within allowable limits. Of concern is the durability of the insulation in the presence of moisture. This issue will be addressed during detailed design by testing and coordination with the supplier. Attachment details using clips and mortar will be designed that allow easy replacement of the aperture rim insulation during maintenance periods.

A structural steel shell supports the piping components, insulation, lightning protection, and an aircraft warning light. The shell is designed to efficiently support the loads and have good access for inspection and maintenance. Access to the cavity is through the large aperture opening; all components can be removed through the aperture. An access door could also be provided in the receiver floor if found to be necessary during detailed design.

The receiver shell is welded 10 gage ASTM A-36 carbon steel with a thickness of 3.4 mm (0.1345 in). The body is cylindrical for maximum buckling strength and stiffness. Rolled angle stiffening is provided at the ceiling and floor connections to control circularity prior to field assembly and for strength. The only concentrated loads supported by the cylindrical shell are at the manifold brackets which are designed to maintain precise concentric manifold positioning during heating and cooling. Channel stiffening is welded locally at the manifold brackets to distribute the manifold loads. The receiver roof is dished slightly upward for drainage. Both the roof and floor sheets are stiffened with tubular steel sections to react wind, snow, and gravity loads.

Assembly of the receiver could be done at a shop in the Midland-Odessa area or at the site (to be determined during detailed design). If field assembled, the receiver parts would be shop fabricated and shipped in major assemblies. During erection, the receiver will be rigidly welded to the tower columns and bracing at numerous points.

Receiver Performance Analysis

The selected receiver design was analyzed with a number of analytical tools as displayed in Table 6-3. The tool, its source, and main use are presented. The receiver design was also developed using an experimental data base depicted in Table 6-4. The various design consideration interactions using these analytical tools and data base are represented in Figure 6-4. The basic receiver cavity geometry interacts with the heat removal system in the heat exchanger design and heat delivery system in the aperture. By far the most complex interaction is the radiative interchange within the cavity and from tube-to-tube. The solar input distribution for the selected aperture/field configuration is obtained from the DELSOL II analysis. The analysis of re-reflection, absorption, and re-emission of the input energy is accomplished with detailed radiative interchange modeling of the cavity and tube geometry and radiative properties. Once the heat exchanger tube heat is defined, the forced convective heat transfer inside the tube is calculated, yielding the gas temperatures, pressure drop, and tubing wall temperatures. These data support the performance predictions and the stress analysis.

The first incident solar flux on the receiver cavity walls is displayed in Figure 6-5. Nineteen percent of the incoming solar flux is incident on panels 2, 3, 4. The remaining 81% of the solar flux is incident on untubed cavity walls and is reflected and reradiated to the heat exchanger panels indirectly. The peak insulation flux of 166 W/m^2 occurs on panel 3 approximately 1.0 meters above the aperture centerline. Detailed flux maps of this peak flux region indicate the 166 kW/m^2 value is a broad maximum with no localized hot spots. Preliminary calculations of the maximum insulation temperature in this

Analysis tool	Source	Uses
DELSOL II	Sandia Labs	Heliostat field analyses solar flux maps
RADSIM	Boeing Aerospace	Generalized radiative interchange
BETA	Boeing	Generalized thermal analysis
EASY	Boeing Computer Services	Generalized dynamic system analysis
ANSYS	Swanson Analysis Systems	Generalized stress analysis
TESSIZ	BEC	Thermal energy storage sizing
DESAL	BEC	System performance analysis
Simplified models	BEC	Engineering oriented simple programs, e.g. for programable hand held calculators
GGP	Boeing Computer Services	Graphics display of performance data

Table 6-3. Receiver Design and Performance Analytical Tools

Type of data	Source	Function
Heat exchanger tubing • Materials data	• Vendor, e.g. Huntington Alloys • Boeing materials lab	• Stress analysis
• Fabrication data	• BMSR program	• Fabrication methods
• Heat transfer	• BMSR program • Published literature	• Thermal analysis • Pressure loss
Insulation • Materials data	• Vendor, e.g. Babcock & Wilcox • Boeing materials lab.	• Thermal analysis
• Solar radiation exposure	• BMSR program • BEC/EPRI insulation test program • Sandia labs testing program	• Temperature and flux limits
Controls	• BMSR program • BMSR air supply	• Setpoint control methods • Interface with CRTF
Test methodology	• BMSR program	• Test planning instrumentation • Data reduction

Table 6-4. Receiver Design and Performance — Experimental Data Base

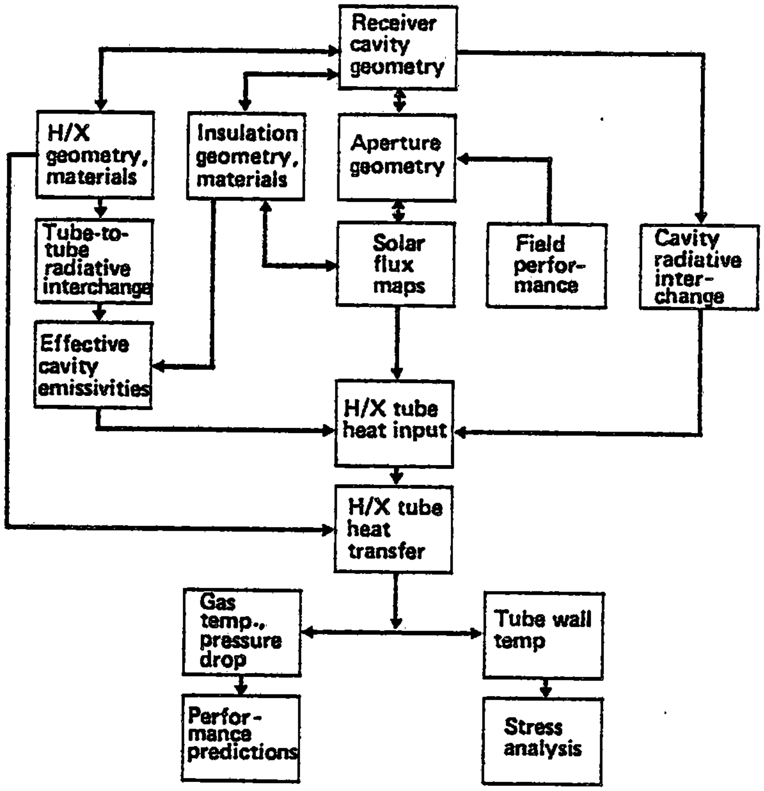
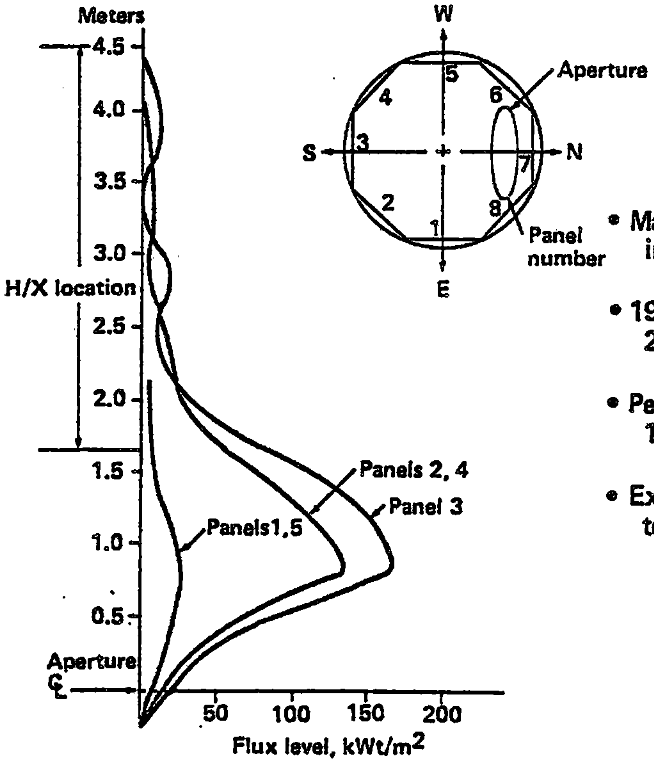


Figure 6-4. Receiver Design Consideration Interactions



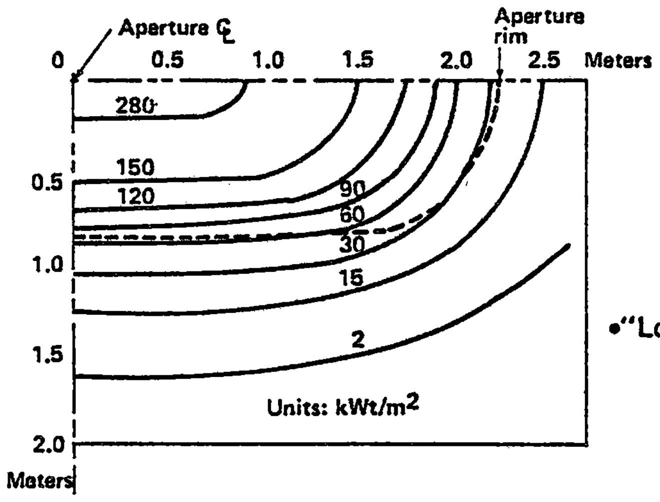
- Majority of solar flux indirectly irradiating H/X tubes
- 19% first incident flux on panels 2,3,4
- Peak flux on insulation walls = 166 kWt/m^2
- Expected maximum insulation temperature = 1,292°C (2,357°F)

Figure 6-5. Receiver Wall Flux Map

peak flux region is 1292°C (2357°F). This temperature level is within the thermal capabilities of the insulation design. Figure 6-6 presents a similar solar flux map for the aperture plane. The peak flux of about 60 kW/m^2 is also within the aperture insulation materials capability.

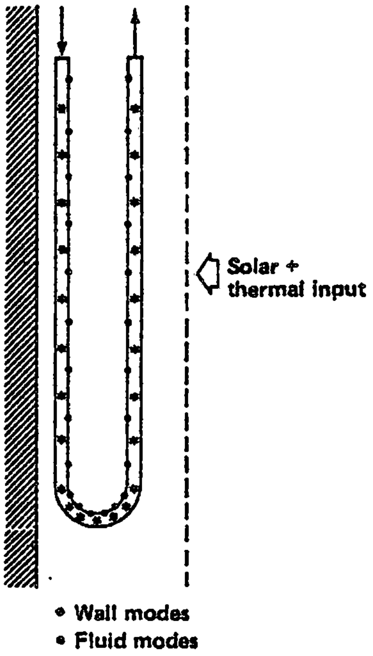
Figure 6-7 illustrates the simplified receiver performance model. The return bend heat exchanger tube is divided into 24 nodal lengths. Solar plus thermal input are determined from the cavity radiative analysis. Reradiation losses to the aperture are calculated. Convective heat transfer correlations appropriate for the flow regime experienced are included. Sample results from the analysis are presented in Figure 6-8. Air enters the tube at 292°C and exits at 816°C. The average tube wall temperature basically follows air temperature but also responds to the local incident heat input. The peak wall temperature is about 871°C and occurs near the exit. Figure 6-9 shows the effect of massflow reductions on the tube wall temperature. As the solar input is reduced from the design value, the massflow is reduced to maintain a constant 816°C outlet air temperature. The peak tube wall temperature corresponding to the condition is seen to rise slightly as receiver massflow is reduced, however the wall temperature remains less than 910°C even at 20% of design flow.

The previously described receiver performance model was exercised over a wide variety of operating conditions to develop the receiver map presented in Figure 6-10. The receiver performance map depicts the effect on receiver outlet temperature and Reynolds number caused by changing solar input values. The input air pressure and temperature are maintained at a constant 376 kPa and 292°C. Lines of constant massflow and pressure drop are also added. Lowering of solar input requires a reduction of massflow to maintain the desired outlet gas and tube wall temperatures. However, the pressure drop and the Reynolds number are also reduced. A Reynolds number of 4000 represents the minimum massflow condition. Further reductions in massflow could result in the airflow transitioning from turbulent to laminar flow with a resulting potential loss of control on the tube wall temperature. Increases in massflow above the design value are accomplished by a reduction in the outlet gas temperature or an increase in solar input. However, the 7% pressure loss line represents the maximum mass flow allowable before significant effects on the turbogenerator are experienced. As described in Section 17.3, the total



- Normal operating maximum flux on aperture rim = 60 kWt/m^2
- Rim temperature range = 443° – 740°C (830° – 1,365°F)
- "Lock and drift" max flux ≈ 300 kW/m^2 Temperature = 1,243°C (2,270°F)

Figure 6-6. Aperture Plane Flux Map



- Inlet temperature, pressure and mass flow fixed
- Solar + thermal input determined from cavity radiative analysis
- Loss by reradiation to aperture
- Low pressure operation produces low Reynolds numbers
  - Large tube-to-gas temperature differences
  - Significant variation in fluid properties, esp. air viscosity
  - Reynolds number, Nusselt number, friction factor modified per experimental data
  - Same methodology utilized on FSE receiver

Figure 6-7. Receiver Performance Model

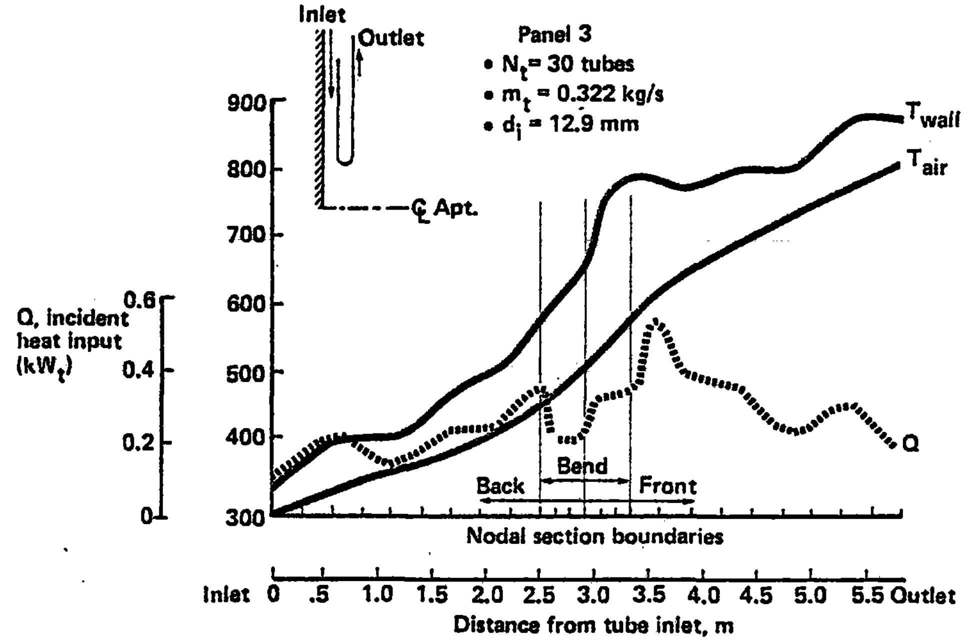


Figure 6-8. DESAL Pilot Plant Receiver Panel Heat Transfer

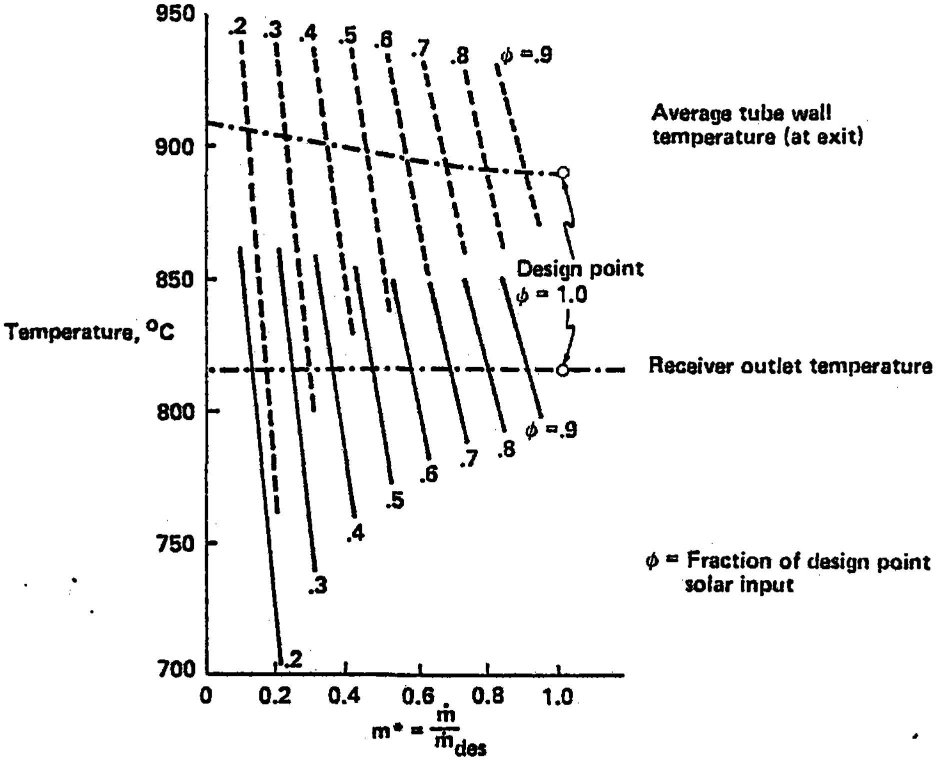


Figure 6-9. Effect of Mass Flow on Tube Wall Temperature

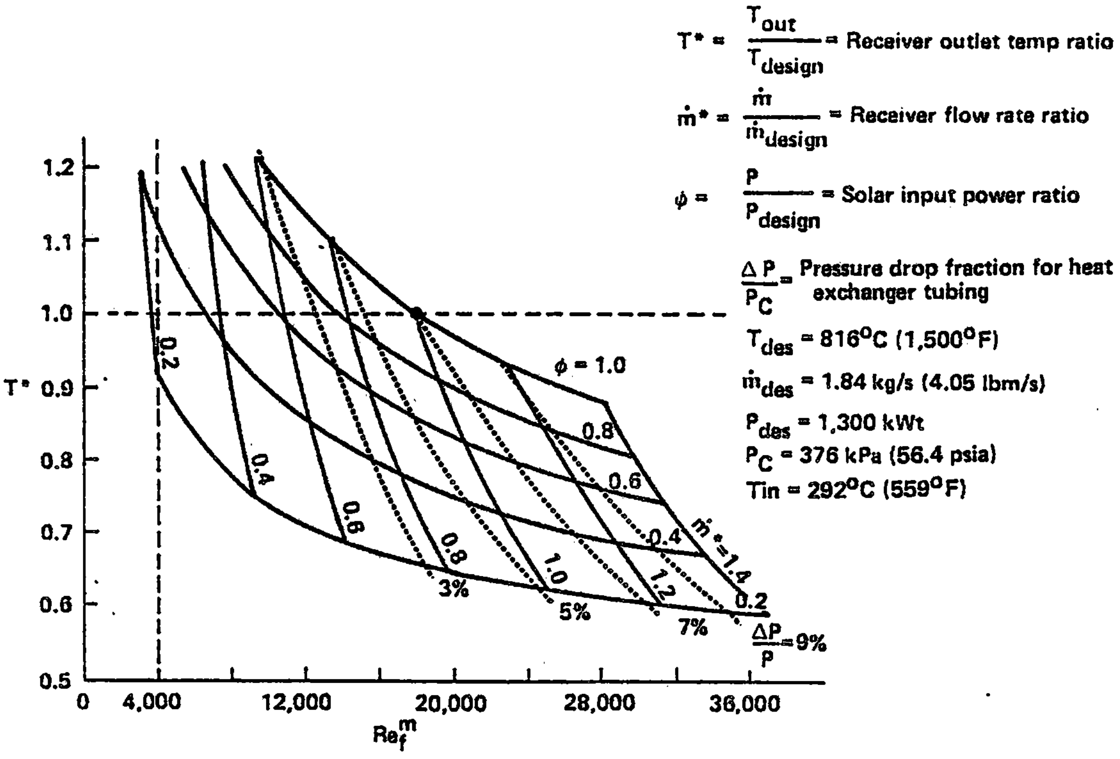


Figure 6-10. Receiver Performance Map

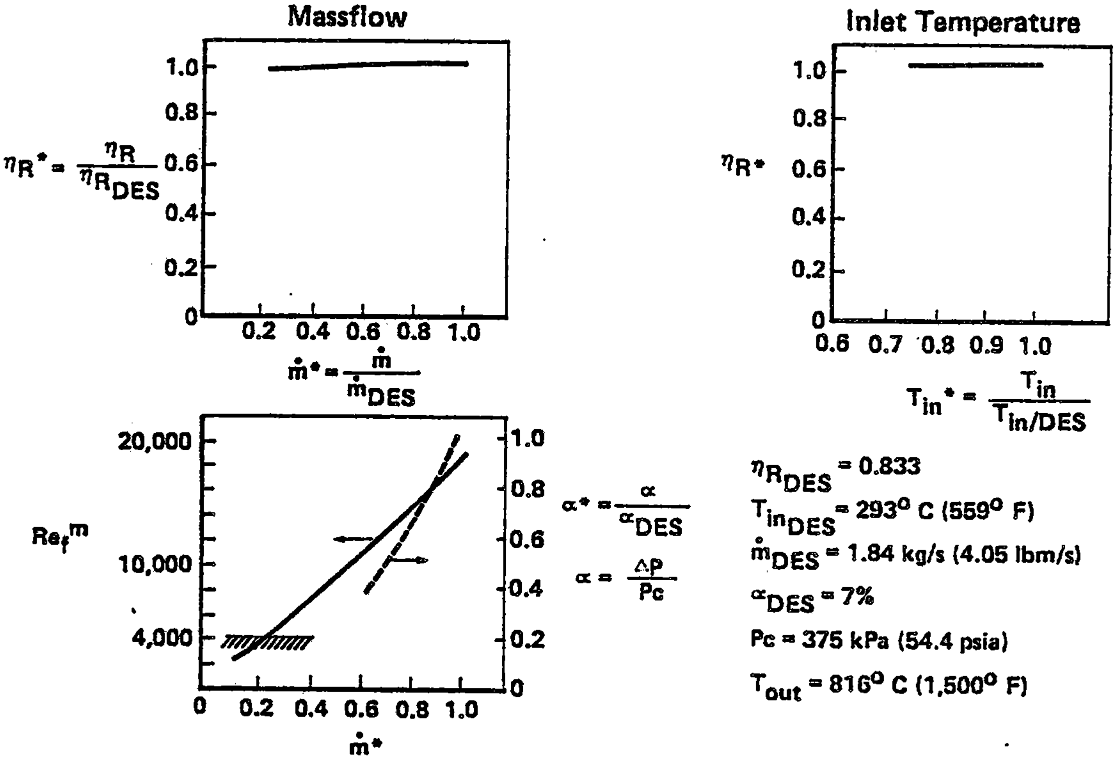
pressure loss budget from compressor outlet to turbine inlet is 10% of the compressor outlet pressure. If this 10% loss is exceeded, the compressor could be pushed into a "surge" condition, potentially damaging the unit. Seven percent of this 10% budget is allocated for the heat exchanger tubing, the remainder for supply piping, headers, manifolds, valves, etc. The data from Figure 6-10 indicate the receiver can maintain design outlet temperatures from full massflow down to about 25% of full flow.

The data of Figure 6-10 were for an inlet gas temperature of 292°C (559°F) which corresponds to a fully charged TES. If TES is not fully charged, the inlet temperature can be substantially less: as low as about 204°C (400°F). The effect of this change on the data of Figure 6-10 is to lower the constant solar input power ratio lines. Physically, this indicates for the same massflow more solar input can be accepted. More importantly, the pressure loss is also reduced. The lower average gas temperature reduces the viscosity thus reducing friction losses and consequently pressure losses. The massflow can, therefore, be increased above the design point while still being within the compressor surge limit. Although the receiver is designed for 1300 kW at the design point (TES nearly fully charged), on cool, clear mornings before TES is fully charged, the receiver heat exchanger system can accept greater than 1300 kW_t inputs. In the annual performance analysis (see Section 17.6), occasionally the receiver accepted 1500 kW without exceeding the pressure loss criteria.

Figure 6-11 presents the effect of inlet temperature and massflow on receiver efficiency. As is shown, both parameters have relatively little effect on the total receiver efficiency. These data indicate an almost constant receiver efficiency of 0.833. Table 6-5 presents the receiver energy loss breakdown for the design point conditions.

Table 6-5. Receiver Energy Losses

Loss	%
Reflection	3.1
Conduction	0.4
Convection	9.2
Reradiation	4.0
	16.7



$\eta_{R_{DES}} = 0.833$

$T_{in_{DES}} = 293^\circ$ C (559° F)

$\dot{m}_{DES} = 1.84$ kg/s (4.05 lbm/s)

$\alpha_{DES} = 7\%$

Pc = 375 kPa (54.4 psia)

$T_{out} = 816^\circ$ C ($1{,}500^\circ$ F)

Figure 6-11. Effect of Massflow and Inlet Temperature on Receiver Performance

Receiver Heat Exchanger Tubing Stress Analysis

An analysis was performed of the receiver's heat exchanger tubing stresses and deflections. The heat exchanger tubing was selected for analysis because it is the most critical structural component in the receiver with respect to long life and cost. Specific concerns are initial heating stresses and deflections, long term stresses, and material durability for 20 year life.

The structural analysis was performed using an ANSYS finite element computer model. ANSYS is a general purpose finite element computer code that is widely used in the power industry for analyzing similar components. The model was developed for a typical heat exchanger tube located at the rear of the cavity where incident flux is maximum.

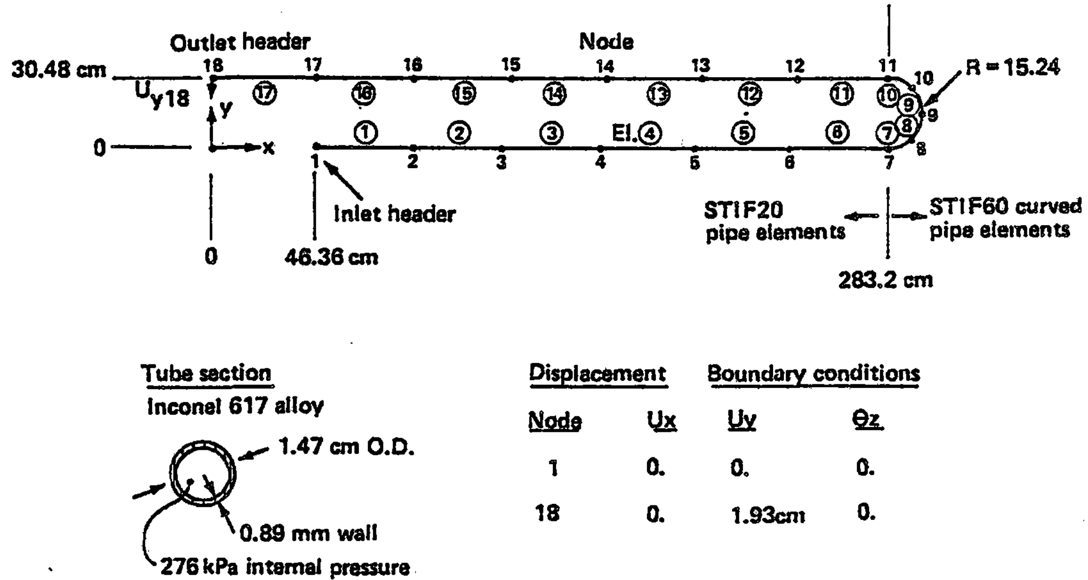
Key features of the model are shown in Figure 6-12. Conditions that were modeled are:

Manifold thermal deflection boundary conditions;
Pressure and gravity loads;
Temperature dependent material properties;
Time dependent material properties.

Temperatures given previously from a thermal model at the receiver design point were used to define linear temperature gradients at each element section along the tube length as shown in Figure 6-13.

Initial heating stresses and deflection results are shown in Figure 6-14. The deflections are within allowable limits; ample clearance remains to the cavity insulation. Maximum stresses occur at the header connections where deflections were assumed to be the same as the manifolds. The header/manifold assembly was assumed to be rigid in torsion and bending in this analysis so actual stresses would be less than shown. The computed stresses are substantially less than the 1000 hour allowable stress of 35 MPa (5100 psi) for Inconel 617 alloy as computed per ASME Section I Power Boiler Code.

Long term stresses were computed by using an incremental time dependent response analysis procedure in the ANSYS code. Huntington Alloys, the supplier of Inconel 617, furnished creep strain data at 871°C (1600°F) which was converted to a form used by ANSYS.



Displacement		Boundary conditions	
Node	Ux	Uy	θz
1	0.	0.	0.
18	0.	1.93cm	0.

Figure 6-12. ANSYS Model of Receiver Heat Exchanger Tube

Element ID	Mid-wall temperature (°C)			STIF type
	T_{avg}	T_{90}	T_{180}	
1	364.97	364.97	358.51	20
2	393.92	393.92	386.49	20
3	405.48	405.48	399.35	20
4	441.37	441.37	434.09	20
5	483.45	483.45	475.06	20
6	532.64	532.64	520.55	20
7	589.53	589.53	603.00	60
8	615.34	615.34	627.56	60
9	629.08	629.08	617.20	60
10	661.90	661.50	645.90	60
11	776.86	776.86	808.06	20
12	793.53	793.53	818.07	20
13	792.19	792.19	810.57	20
14	813.75	813.75	829.22	20
15	815.83	815.83	827.31	20
16	856.24	856.24	868.61	20
17	879.22	879.22	850.75	20

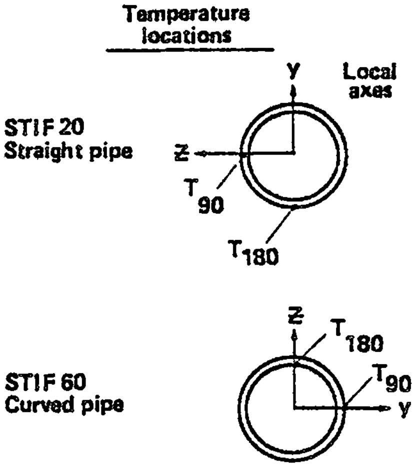
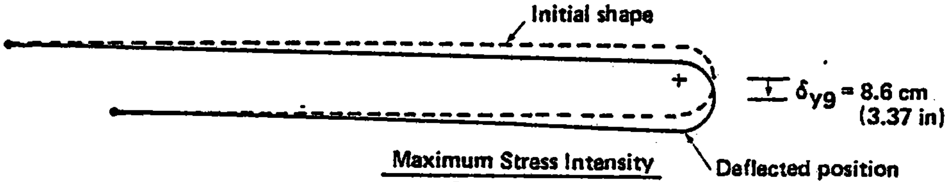


Figure 6-13. Element Temperatures Used in ANSYS Model of Receiver Heat Exchanger Tube



Element	Maximum Stress Intensity lb/in^2	Maximum Stress Intensity MPa
1	3,371	23.2
2	3,052	21.0
3	2,732	18.8
4	2,413	16.6
5	2,093	14.4
6	1,774	12.2
7	1,502	10.4
8	1,374	9.5
9	1,337	9.2
10	1,450	10.0
11	1,731	11.9
12	2,058	14.2
13	2,386	16.5
14	2,713	18.7
15	3,040	21.0
16	3,386	23.2
17	3,695	25.7

Figure 6-14. ANSYS Model Elastic Analysis Results

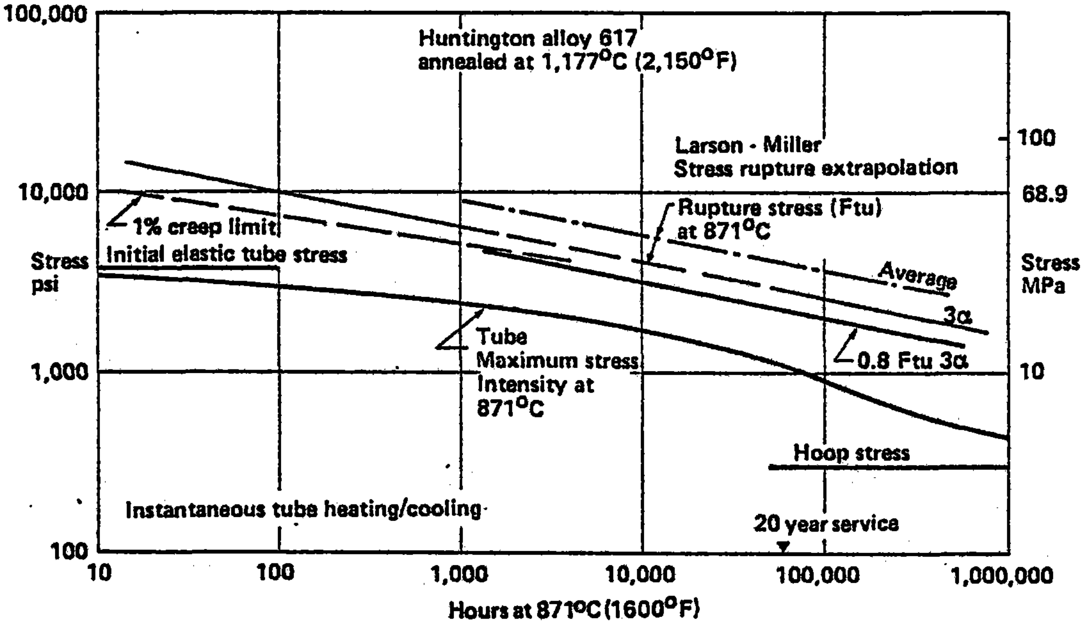


Figure 6-15. Receiver Heat Exchanger Tube ANSYS Stress Relaxation Analysis Results

Strain rate $\dot{\varepsilon} = c_1 \sigma^{c_2}$

where σ = effective uniaxial stress

$c_1 = 1.139 \times 10^{-32}$

$c_2 = 7.236$

This creep law was assumed for computing secondary (long term) stress relaxation. Primary stress relaxation (short term, less than 40 hours) was neglected, a very conservative assumption considering that shop stress relieving of welds is typically done by heating 2 hours at 1650°F.

Figure 6-15 displays the computed stress time history. The maximum stress intensity begins at the initial heating condition, as discussed previously, and reduces with time to levels approaching the primary pressure induced hoop stress. At 51000 hours, the estimated hot time for 20 year service, the maximum tube stress intensity is well below the allowable stress as defined in the ASME Power Boiler Code as the lowest value of:

- o 100% of the average stress for creep rate of 0.01% per 1000 hours;
- o 67% of the average stress for rupture at the end of 100000 hours;
- o 80% of the minimum stress for rupture at the end of 100000 hours (governing condition).

Because of the thermally induced time dependent deflections are self limiting (the manifolds always deflect a limited amount), the heat exchanger tubing will not have a shake-down type of failure mode in cyclic service.

One area of concern in heat exchanger analysis is low cycle fatigue. The maximum residual stress 51000th hour cool down (room temperature) condition is 23 MPa (3400 psi) based on the ANSYS solutions. Assuming 100000 cycles of heating/cooling (very conservative for 20 year service), the actual cyclic stresses will be well below the material's rotating beam fatigue strength of 276 MPa (40000 psi).

Based on these results, the preliminary heat exchanger tubing design is structurally adequate and should show lower stresses in a detailed analysis when all structural flexibilities and short term stress relief are accounted for.

6.4 Air Piping

A layout that illustrates the air distribution piping concept is shown in BEC Drawing 277-10400. The drawing details are obsolete because of changes in the design and relocation of the thermal energy storage unit. During the detail design phase, the air piping will be redesigned and optimized for minimum pressure drop and heat loss. The drawing does illustrate the major components of the air piping:

Riser
Downcomer
Connections to:
    Turbine/Generator Set
    Thermal Energy Storage Unit
    Booster Compressor
Pneumatically-actuated control valves
Universal expansion joints
Pressure-balanced elbow expansion joints
Field connection flanged joints

The primary performance requirements of the air piping are:

1. Distribute and control air from the turbine compressor through the receiver, thermal energy storage unit, and booster compressor, and to the turbine;

2. Overall pressure drop associated with the air piping components shall be less than 2%.

The air piping is designed to satisfy applicable codes:

1. Pipe design allowables for pressure-temperature stress per ANSI B31.3;
2. Pipe welding, inspection and testing per ANSI B31.1 or 31.3;
3. Expansion joints per EJMA standards;
4. Piping components per applicable ANSI or ASME code.

Those sections of the air piping that handle low temperature air are fabricated from carbon steel. The high temperature sections, up to 871°C (1500°F), are 304 stainless steel. Expansion joints are strategically located to accommodate thermal expansions during operation. Pipe anchors and spring hangers are located along the riser and downcomer on the tower to react pressure, expansion and gravity loads. All piping is jacketed with 5.1cm (2 in) of weather proof thermal insulation. A summary of air piping weight, including fittings and expansion components, is presented in Table 6-6.

Pneumatically-actuated flow control valves are specified to be 10.2cm (4 in) Posiseal Butterfly Valves. These valves provide continuous control of air flow to the receiver and through the thermal energy storage unit and are located in "cool" lines so commercially available steel valves can be used. Similar valves were used previously in the BEC/EPRI Bench Model Receiver test program.

Pressure drops through the air piping are itemized later in Section 17.3. At the system design point, the overall pressure drop is 4.48 kPa (0.65 psi) which is 1.19% of the turbine compressor outlet pressure at 376.5 kPa absolute (54.6 psia). This pressure drop is relatively low due to use of large diameter piping. In the detailed design phase, the pressure drop should be reduced by rerouting pipe runs (shorter length, fewer elbows).

Run	Material	Kg	Lb
Turbine compressor to riser flange	Carbon steel	198	435
Riser	Carbon steel	1,518	3,339
Downcomer to turbine	Stainless steel	3,209	7,059
Downcomer to thermal storage	Stainless steel	95	209
Thermal storage to booster compressor	Carbon steel	187	412
Booster compressor piping	Carbon steel	147	324

Table 6-6. Air Piping Weight Distribution

7.0 ENERGY STORAGE SUBSYSTEM

The Energy Storage Subsystem consists of a single thermal energy storage (TES) unit and a booster compressor (blower). The main operating modes involving the thermal energy storage subsystem are shown in Figure 7-1. Solar energy received in excess of that required to operate the turbine is circulated through TES in the charging mode, Figure 7-1(a). After starting the booster compressor, the TES charge flow is started by opening the valves downstream of the unit. A thermocline in the heated storage medium advances along the length of the storage unit (from right to left in the schematic) as the unit is charged. The TES unit is fully charged when the bulk of the storage medium is at or near 816°C. However, a portion of the medium near the valve end remains downstream of the thermocline and serves as a buffer at reduced temperature to limit the valve temperatures during charging. At the fully charged condition, the air leaving the TES and flowing through the valve and entering the booster compressor is at a maximum temperature of 357°C.

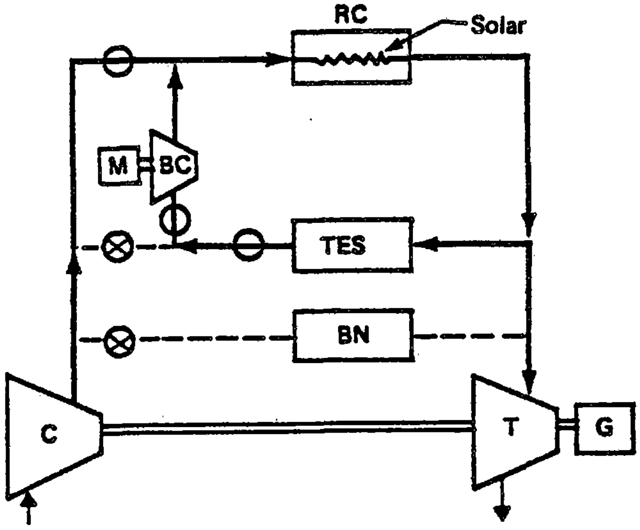
Flow through the TES is reversed for discharge as shown in Figure 7-1(b) and (c). The TES may be operated in parallel with the receiver to supplement the available solar energy, or the TES can supply all the thermal energy to the turbine. The flows through the receiver and TES are adjusted for these modes by the valves between Titan's compressor and these components.

7.1 Thermal Energy Storage Unit

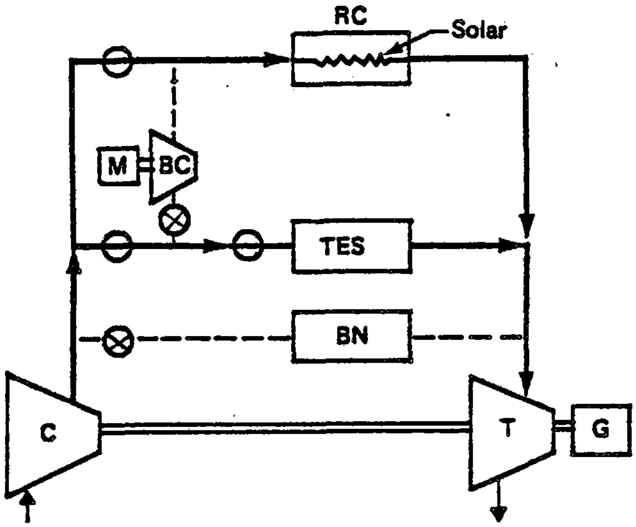
The TES unit is designed to satisfy the following performance requirements:

1. Thermal capacity shall be 7280 kW-hr when plant is operating normally;
2. Mass flow range shall be up to 1.01 kg/s with a maximum pressure loss of 25 kPa;
3. Heat loss shall be less than 4% of capacity in 24 hour on a hot, windless day;
4. Full receiver output shall be accepted during emergency conditions for 2 minutes;
5. Charging rates shall be accepted up to 700 kW;
6. Discharge rates shall be accepted up to 600 kW;
7. Inlet temperature shall be accepted up to 816°C (1500°F).

(a) TES charging



(b) Parallel receiver and TES discharge



(c) TES discharge

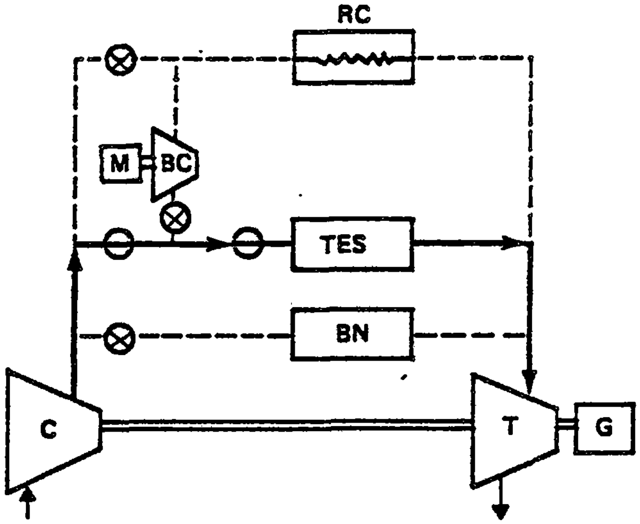


Figure 7-1. Alternate Thermal Energy Storage Operating Modes

Design requirements for the TES unit are:

1. Maximum design pressure is 243 kPa (35.2 psig);
2. Inspection access ports at vessel ends;
3. Maximum shell temperature: 260°C (500°F).
4. Environmental design criteria per System Specification Section 3.2.5;
5. Unit shall be self supporting;
6. Field installation of storage material and insulation.

Major interfaces of the TES unit are:

1. Smooth bearing surface on reinforced concrete foundation;
2. Piping connection flanges - Hot side: 200 mm (8 in) diameter, 136.4 kg, (300 lb) stainless steel flange; Cold side: 150 mm (6 in) diameter, 136.4.
3. Thermocouple instrumentation.

TES Baseline Design

The TES unit design shown in Figure 7-2 uses tabular alumina pebbles for sensible heat storage. A free standing cylindrical pressure shell will be fabricated from ASTM A515 Grade 70 steel; shop connections will be welded with 100% radiographic inspection and field connections will be bolted. The storage material chamber is surrounded by insulating fire brick (Babcock & Wilcox type K23). Differential expansion between the steel shell and fire brick is accommodated with a thin filling of bulk Kaowool insulation. Flow diffusers are provided at each end of the storage chamber. At the lower end, the alumina pebbles are supported by a steel grill.

The TES loads are supported by a reinforced concrete foundation. An analysis of overturning due to wind and seismic loads, neglecting soil friction and foundation weight, shows the TES unit has an ample factor-of-safety of 11.1. Reinforced concrete caissons are provided as protection against differential settlement and may be deleted during detailed design when a soil investigation is performed.

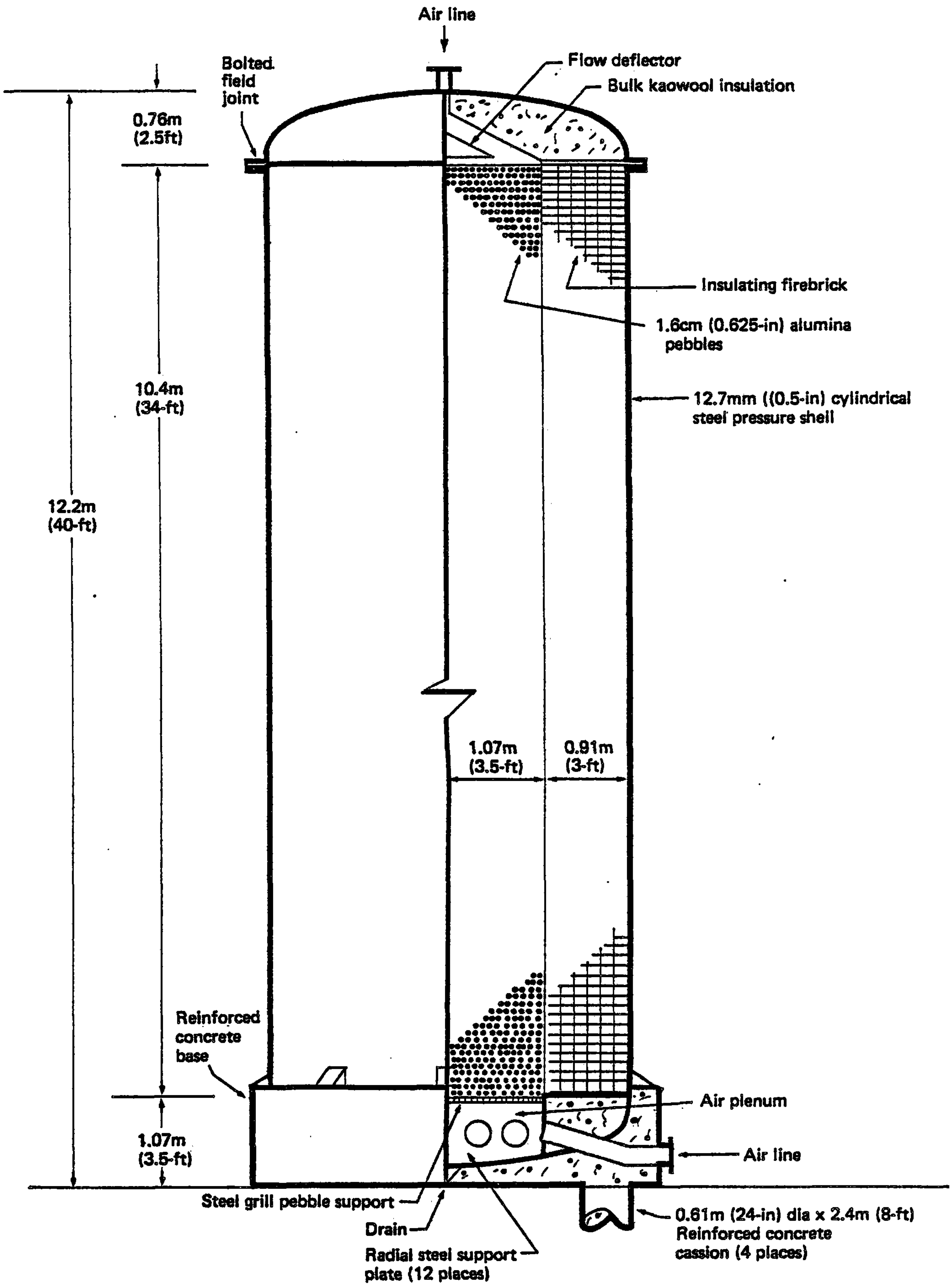


Figure 7-2. Thermal Energy Storage Unit

Charging air at 816°C (1500°F) enters the top of the TES unit. This vertical arrangement has several advantages:

- The base of the storage chamber and the pebble support grill is in the "cool" zone so common materials can be used where load transfer occurs.
- Hot air from the receiver enters the TES unit via the shortest air line route.
- The vertical storage cavity can be filled easily with good pebble placement control.

Tabular alumina pebbles are selected as a heat storage medium because of previous Boeing experience (see following discussion), current low price (compared to magnesia brick), and ease of construction. Thermal properties of alumina are similar to alternate materials such as magnesia, and alumina has excellent life in the pilot plant application. Tabular alumina is available from Kaiser Aluminum and Chemical (Baton Rouge Plant) and is mass produced in rotary kilns.

The TES design utilizes the product form called "converter discharge" which is obtained directly from the kilns and, therefore has lowest cost, compared to finer grades that are subject to further processing. The Select Converter Discharge grade is specified; this grade is inspected and screened to remove fines and spalls and has a nominal diameter of 1.59 cm (0.625 in). Current cost of this grade is $0.69/kg ($625/ton) FOB Baton Rouge.

Weight of the TES is distributed as follows:

	kg	lb
Pressure shell and fittings	17700	39000
Tabular alumina	95000	209000
Insulating fire brick	250000	561000
Total	367700	809000

Baseline TES Performance (Brick Medium)

The TES unit thermal analysis capacity requirement chosen for the solar desalination pilot plant is 7280 kW-hr. As discussed in Section 4.0, the pilot plant system design was based upon a solar multiple of 2.0 as compared to the 4.0 for the commercial plant design. By using the commercial plant TES design as a base and scaling to the pilot plant operating conditions, the 7280 kW_t-hr capacity was obtained. The commercial plant annual performance calculations indicated an annually averaged temperature delta across the TES medium of 244°C. Assuming a refractory storage medium heat capacity of 1143 J/kg, a baseline storage medium mass of 9.4×10^4 kg is specified.

The majority of the pilot plant performance calculations were made using a easier baseline TES medium/blower configuration having an off-the-shelf commercial unit with an assumed peak adiabatic efficiency of 65% and Freyn-type bricks for the storage medium. Figure 7-3 shows the storage medium temperature profile or thermocline as a function of nondimensional medium length. As can be seen, the effective TES capacity is only about 3300 kW-hr which allows a 7-8 hour discharge time. As described in the following subsections, more efficient medium design (packed bed) and blowers have been identified and will be pursued in the Phase II effort.

Another performance requirement on the TES unit is a massflow range capability of up to 1.01 kg/s with less than 25 kPa pressure loss. The selected TES blower has a 40% turndown yielding a 0.40 -1.0 kg/s flow range. Pressure drop calculations on the earlier baseline TES unit having a brick medium and baseline mass show a pressure loss of 22 kPa at 1.01 kg/s.

Insulation sizing was chosen such that the tank would lose 291 kW/h (4% of 7280) in 24 hours if the TES medium were held at 816°C with an ambient temperature of 38°C. At 0°C, the loss would be 4.5% of capacity.

The piping design allows venting of the TES cold end. Since the TES cold fluid temperature is equal to or less than 357°C during operation, a reserve capacity always exists to accept the full receiver output for short intervals.

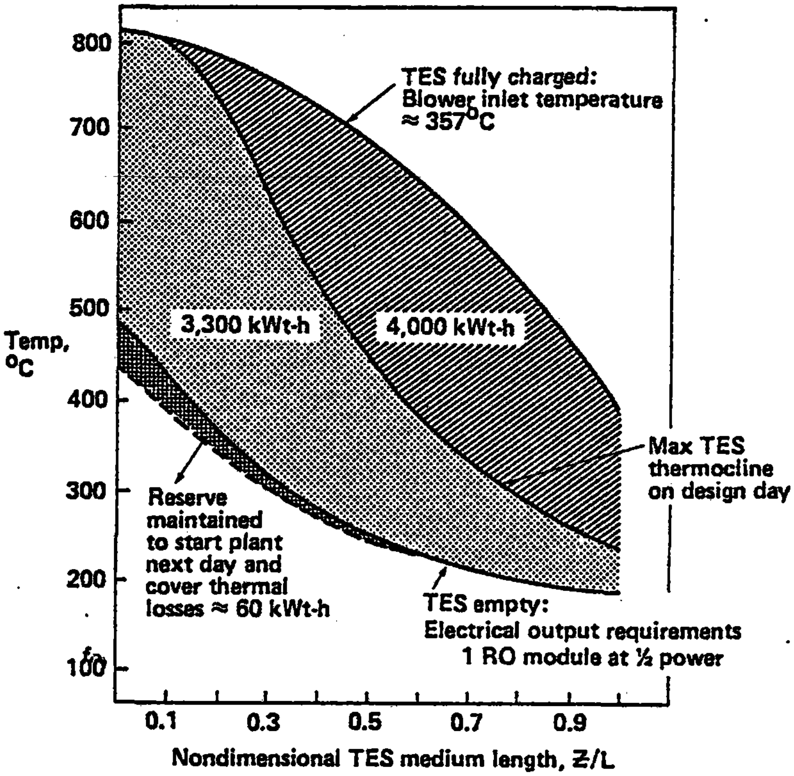


Figure 7-3. TES Performance — Thermocline Data

Also for maximum massflow conditions, the TES can accept 704 kW charging and provide 625 kW discharging, thereby meeting those performance requirements. Finally, the temperature capability of the TES medium and insulation exceeds 1000°C which is a significant margin above the 816°C requirements.

Roundtrip Efficiency

The TES roundtrip efficiency is defined as the ratio of electrical output during TES discharge to the potential additional electrical output during TES charging. If Pc = TES charge rate over a given time increment Δt, and η_C is the turbogenerator cycle efficiency over the same Δt, the potential additional electrical output is $P_C \times \eta_C \Delta t$. Similarly, the actual electrical output during TES discharge can be summed. The round trip efficiency then becomes

$$\eta_{RT} = \frac{\sum E_D \Delta t}{\sum P_c \, \eta_c \, \Delta t}$$

The results from the system analysis model indicate the round trip efficiency for the clear winter solstice day is $\eta_{RT} = 0.65$. The yearly averaged value is $\eta_{RT} = 0.54$. As indicated before, this round trip efficiency can be increased with a more efficient TES blower.

Packed Bed TES Performance

Because the baseline brick medium mass of 94,000 kg does not become fully charged, it was apparent that an equal mass of packed pebbles would also be too heavy. Lighter mass packed bed TES units were consequently studied using the heat transfer and pressure drop analyses presented in References 7 and 8. Two pebble masses were evaluated: 26,590 and 42,500 kg. The plant performance model was used to develop packed bed TES performance for a selected booster compressor efficiency of 72%. Figures 7-4 and 7-5 show resulting thermocline data for the respective pebble masses. The pebble bed TES units display more effective capacity utilization than the heavier brick TES configuration (characterized in Figure 7-3). Additional performance comparisons are presented in Section 17.7; the most effective medium appears to be packed alumina pebbles with a mass of 42,560 kg. During detailed design, the packed bed TES design will be optimized based on performance and cost.

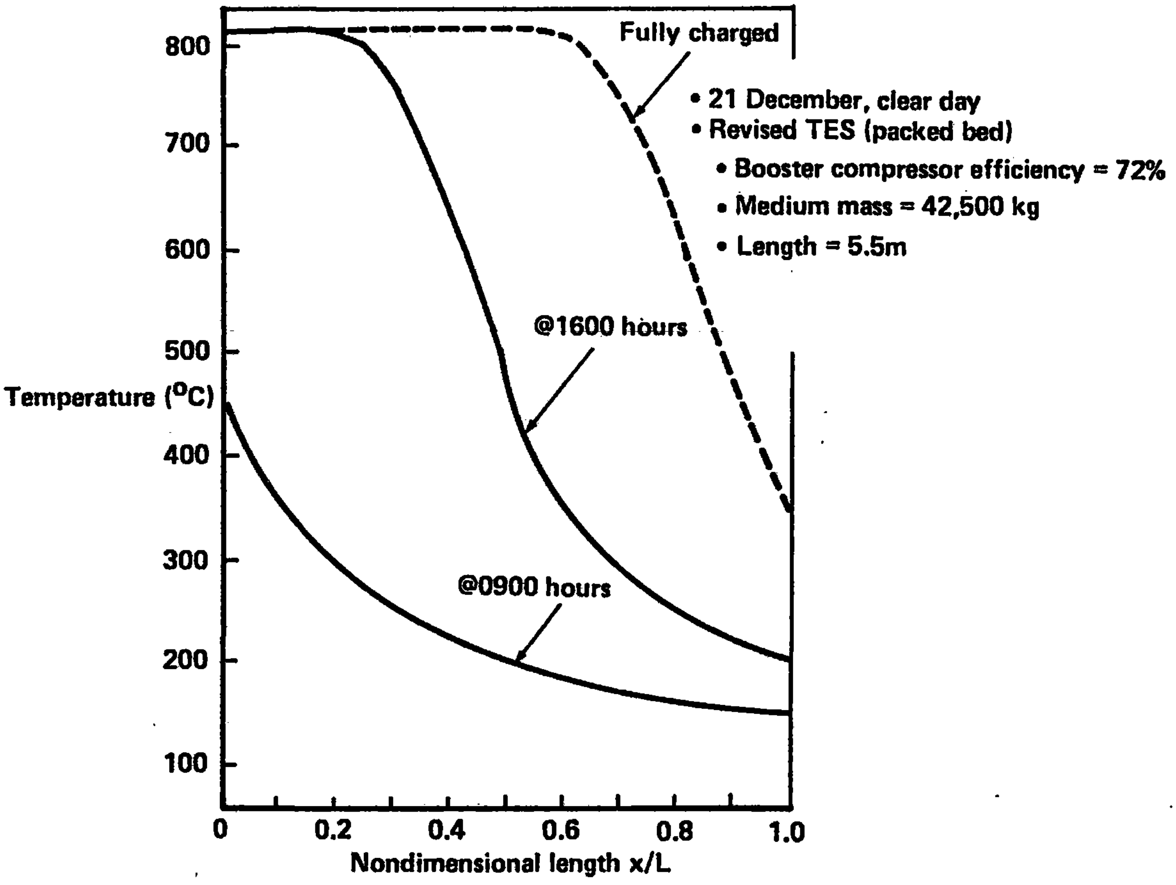


Figure 7-4. Packed Bed TES Thermocline Data (42,500 kg)

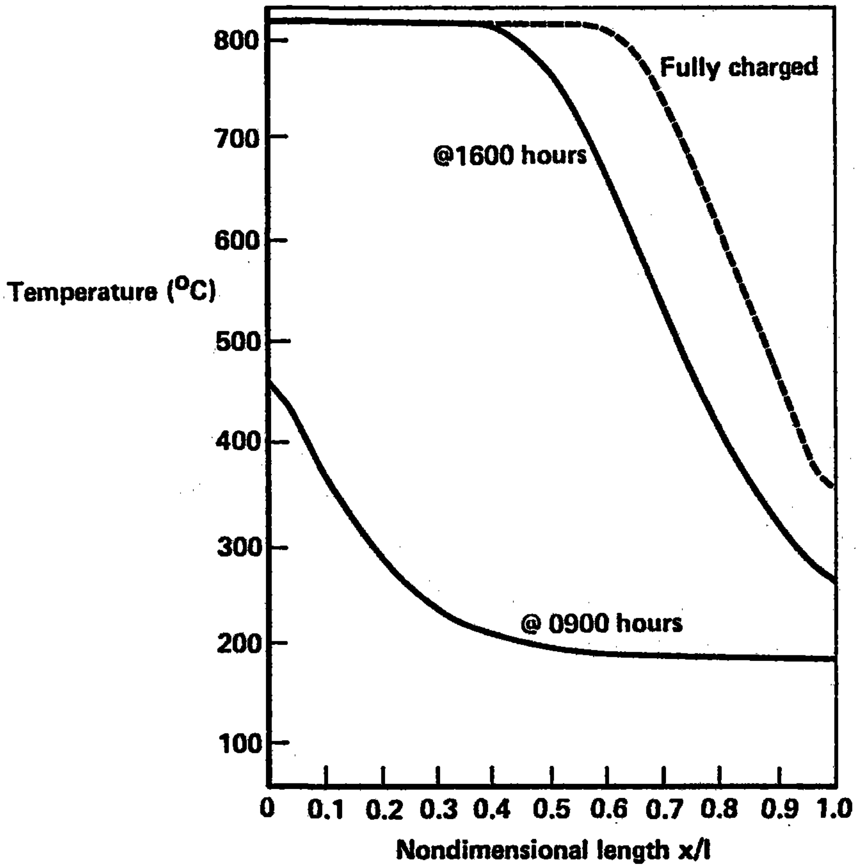


Figure 7-5. 26, 590 kg Packed Bed TES Thermocline Data

Packed Bed TES Related Experience

Boeing successfully operated a refractory/pressure vessel as an air preheating system for wind tunnel testing from 1964 to 1979 (the unit was dismantled because of remodeling). The system consisted of a packed bed of alumina spheres contained in a 1.5 m ID x 4.6 m (5 ft ID x 15 ft) steel tank lined with layers of insulating firebrick. Figure 7-6 shows a schematic of the heater. The tank shell was ASME code rated for 10342 kPa (1500 psi) gage and 344°C (650°F). The heater operated at maximum gage pressures of 8963 kPa (1300 psi) and over a temperature range of 816°-1372°C (1500°-2500°F).

The alumina was contained in a 0.7 m x 2.9 m (28 in x 114 in) central core. The bed was comprised of 0.95 cm (0.375 in) diameter pebbles with a layer of 2.54 cm (1 in) diameter pebbles on top and bottom to serve as diffusers for the gas flow and to restrain pebble movement. A superalloy grate supported the pebble bed.

A vertical flow arrangement was used. During the firing cycle, combustion products from a natural gas burner entered the top of the bed charging the storage medium. The lower temperature combustion gases exhausted to the atmosphere at the base. A water spray was used to cool the Hastelloy grate during charging of the bed. Figure 7-7 shows thermocline development in the packed bed during a typical charging cycle.

During discharge of the bed, high pressure air entered the bottom of the bed, flowed upward and exited a side port into the wind tunnel plenum. Figure 7-8 shows the variation between pebble surface temperature and wind tunnel plenum stagnation temperature during a typical test. The test cycle was only a few minutes in duration and the two temperatures remain very nearly constant during this period. Losses due to water cooled plenum and by-pass of air through the refractory brick insulation account for the difference between the pebble bed surface temperature and the plenum stagnation temperature. During the discharge time, the pebble bed transferred heat to the air at a rate of approximately 8 MW. The pebble bed contained approximatey 3% of the volume of storage material contained in the sensible heat TES design for the pilot plant.

Operational 1964 to 1979
Maximum flow = 4.5 kg/sec (10 lb/sec)

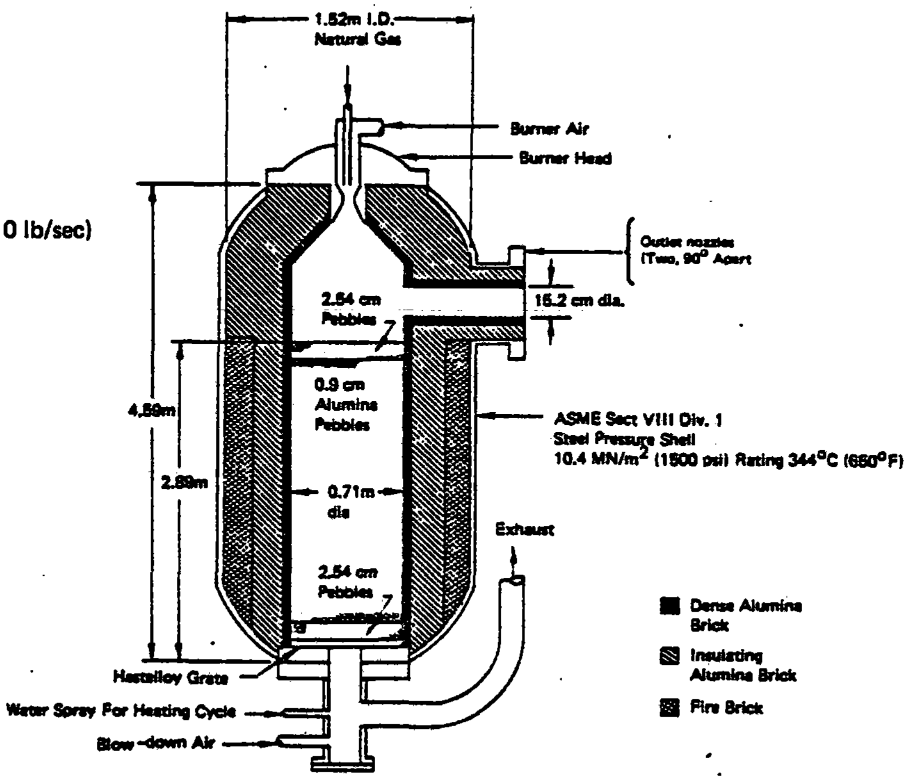


Figure 7-6. Pebble Bed Heater Schematic

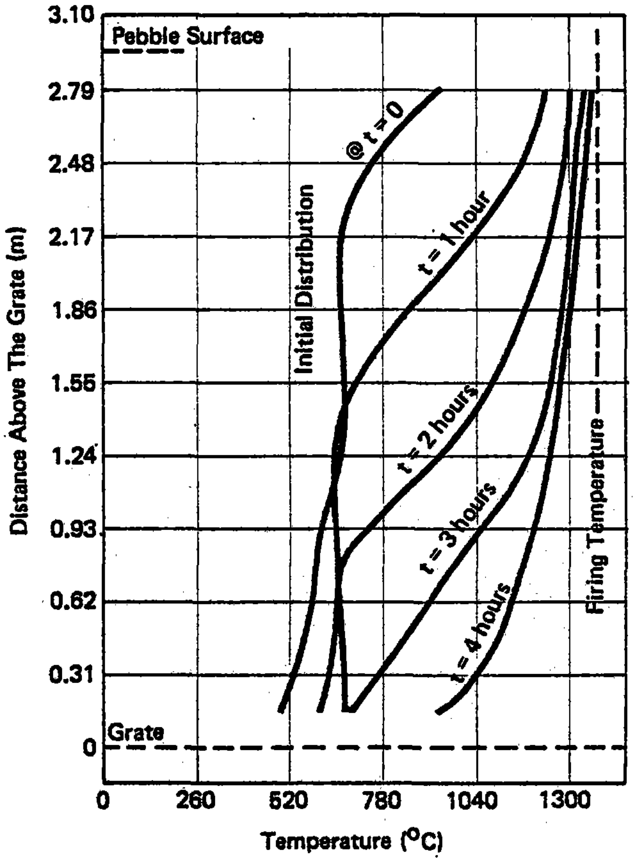


Figure 7-7. Thermocline Development in Packed Bed Heater During Charging Cycle

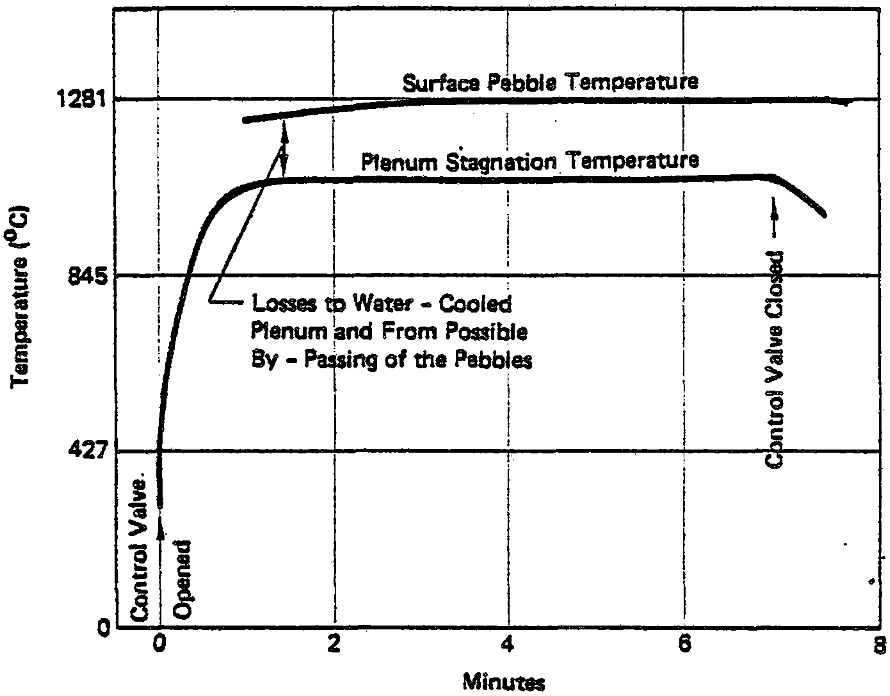


Figure 7-8. Typical Packed Bed Heater Performance Data During Discharge Cycle

Considerable experience has been gained on performance, heat transfer and refractory erosion as a function of temperature, mass flowrate, and time through operation of this system. Although this pebble bed heater has different design parameters than those for the pilot plant, the technology is directly applicable in the development of the pilot plant TES design. The successful long term operation of the wind tunnel's pebble bed heater is evidence that refractory TES is state-of-the-art.

7.3 BOOSTER COMPRESSOR

The booster compressor performance requirements are as follows:

1. Mass flow range shall be up to 1.01 kg/s of air at 579 m elevation;
2. Adiabatic compressor efficiency shall be $\geq$ 0.65 at design point conditions;
3. Motor efficiency shall be $\geq$ 0.90 at design point conditions;
4. Maximum inlet temperature to blower shall be 357°C (675°F);
5. 56.5 kPa compressor differential pressure at design mass flow and 317.2 kPa absolute inlet pressure;
6. Maximum case pressure 375 kPa absolute at design inlet temperature.

Specific design requirements are:

1. Variable speed electric motor drive 460V, 3 phase, 60 Hz;
2. 20 year design life;
3. Outdoor concrete slab mounting;
4. Inlet and outlet connections: 20 cm (8.0 in), 57 kg (125 lb) bolted flange.

A survey of suppliers revealed three models for booster compressors that will satisfy these requirements:

- M-D Pneumatics Model S57-5511
  - Single stage, rotary lobe, positive displacement
  - "Zero leakage" face type mechanical seals
  - Inlet air is cooled to 121°C (250°F) using an ITT Bell & Gossett Model QGC85-102 shell and tube water cooled heat exchanger
  - Required coolant flow: 71.9 l/m (19 gpm) at or below 32.2°C (90°F)
  - Water cooled oil cooler
  - Reeves Vari-Drive: 22.4 kW (30 hp) rating (17.9 kW required by compressor, 7.6 kW required for precooler and line pressure drop)
  - 2500 rpm at design flow
  - At least 20% turndown (could be less depending on inlet air temperature and duration)
  - 72% peak aerodynamic efficiency
  - 90% electrical efficiency
- Spencer Model 6050-H (modified)
  - Four stage centrifugal compressor
  - 91.4 cm (36 in) casing
  - Variable speed electric drive: 37.3 kW (50 hp) rating
  - 40% turndown
  - 62% peak aerodynamic efficiency
  - 90% electrical efficiency

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40kWe.

- Mechanical Technology Inc. (MTI) Custom Design
  - Single stage centrifugal compressor
  - High speed gearbox
  - Variable speed electrical drive: 28.9 kW (39 hp)
  - 50% turndown capability
  - 80% peak aerodynamic efficiency
  - 90% electrical efficiency

The M-D compressor is selected for the pilot plant because (1) all hardware is off-the-shelf and therefore, lowest cost; (2) high efficiency; (3) excellent turndown range; and (4) good flow control via positive displacement. A slight disadvantage with positive displacement compressors is their commercial limitations on inlet temperature due to problems with clearances and seals. A water cooled air precooler is specified that will limit inlet air temperature to 121°C (250°F) using a peak coolant flow rate that is only 8% of the peak water production rate. Air pressure drop through the precooler is only 2%. During detailed design, a study will be conducted with the supplier to increase allowable inlet temperature of the M-D compressor for our unique, intermittent conditions. An increase in allowable inlet temperature will lessen or eliminate the need for precooling. This compressor design approach appears to be best compared to the centrifugal compressor options: a modified Spencer compressor having low efficiency and the MTI compressor having high efficiency via high speed but high development cost.

8.0 ENERGY DELIVERY SUBSYSTEM

8.1 Gas Turbine Generator Set

The gas turbine generator set is comprised of a skid-mounted generator, combustor, compressor, and integral gas turbine engine, with an air inlet silencer, exhaust bellows, oil cooler, and local control with protective circuits. The turbine generator set, illustrated in Figure 8-1, is manufactured by the Alturdyne Company in San Diego, California, and has a sea level rating of 90 kW. Solar Turbines International (STI), also in San Diego, manufactured the turbine unit, a Solar Titan Model T62T-32, that is furnished with the set. General features of the turbine are shown in Figure 8-2.

The standard Titan is equipped with an annular combustor, located to the right of the air inlet in Figure 8-2 and shown schematically in Figure 8-3. This combustor would be modified by STI to an external combustor configuration with air inlet/outlets needed for the pilot plant system; these modifications appear in Figure 8-4. The modified turbine generator set will be identical to a set currently being prepared by STI for the BEC/EPRI Full System Experiment program.

Sea level performance of the turbine is given in Figure 8-5. The turbine generator set is rated at 90 kilowatts, lagging power factor 0.8 to 1.0 (0.8 continuous), 416-480 volts, 60 hertz, 3 phase, 4 wire, ABC phase rotation under all of the following conditions: Sea level, compressor inlet temperature of 80°F, and total turbine exhaust restrictions of 6" water gauge. The turbine generator set is controlled by an electric power generation controller that is located in an adjacent cabinet. This controller will have hardware and software common to a unit also being furnished to the Full System Experiment by STI. Section 13.4 describes the controller in detail.

8.2 Electric Power Distribution

To provide flexibility in routine plant operations and commercial plant simulations tests, design for dual power sources was incorporated. A

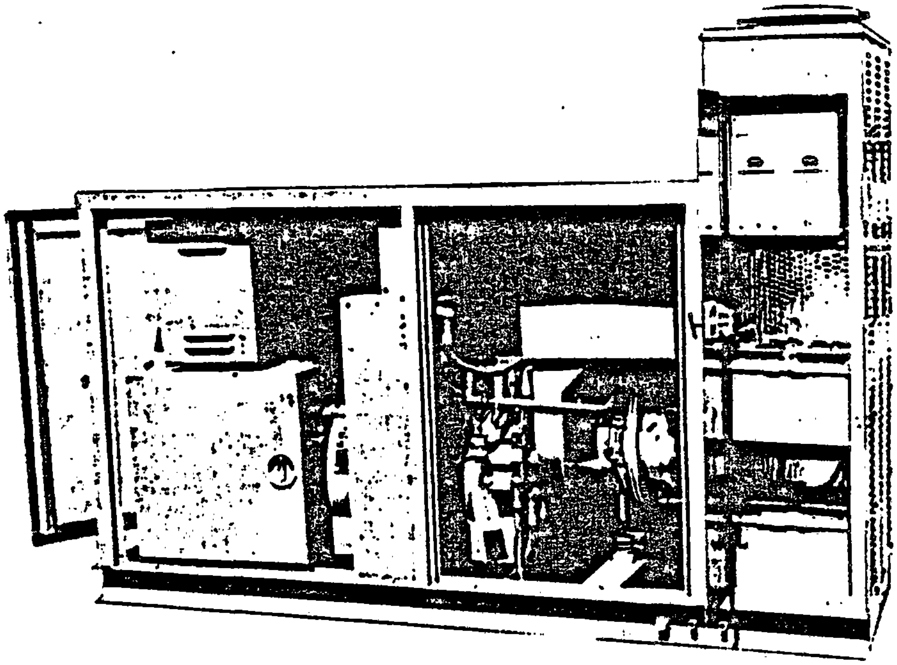


Figure 8-1. Alturdyne Turbine/Generator Set

- Gas Turbine manufacturer — Solar Turbines, International
- Power plant packager — Alturdyne

- Titan used on EPRI/FSE program
- External combustor constructed and tested
- Electrical output range compatible with pilot plant water production capacity

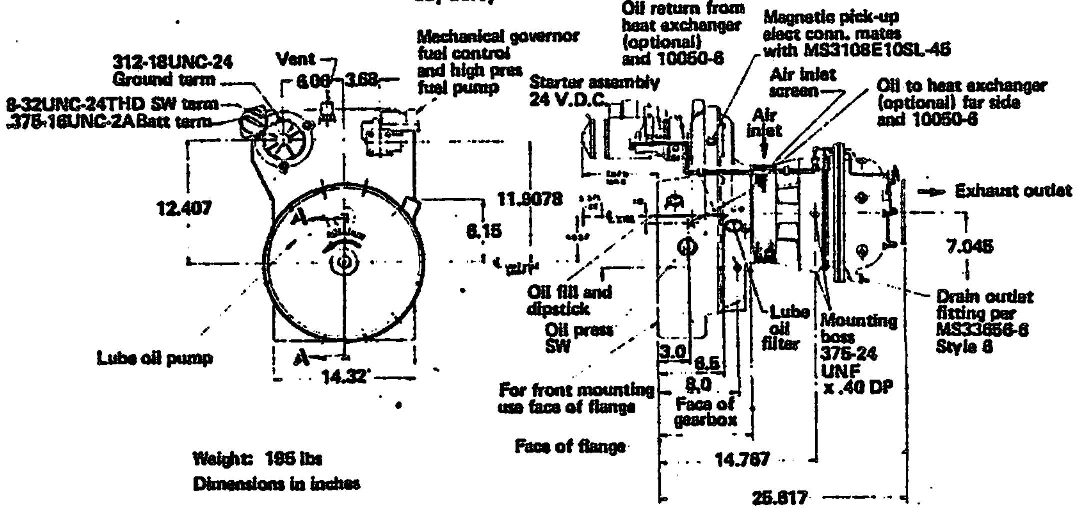


Figure 8-2. Turbine Subsystem

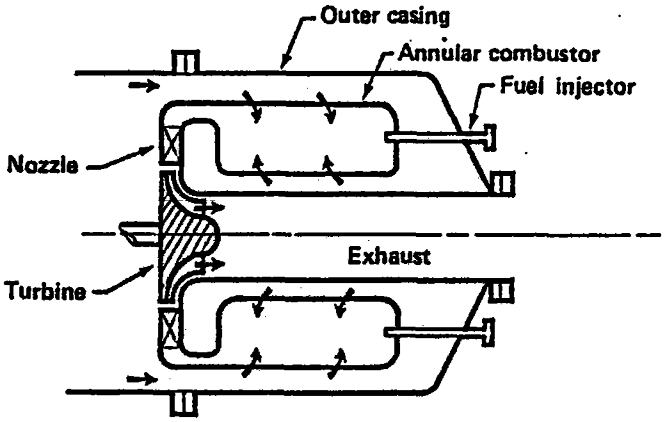


Figure 8-3. Trim Combustor/Flow Ducting Mods – Standard Annular

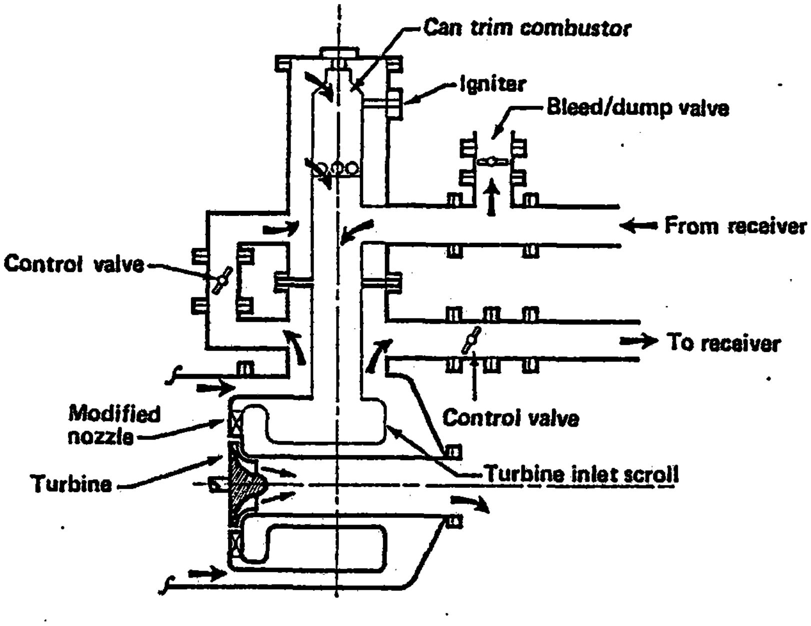
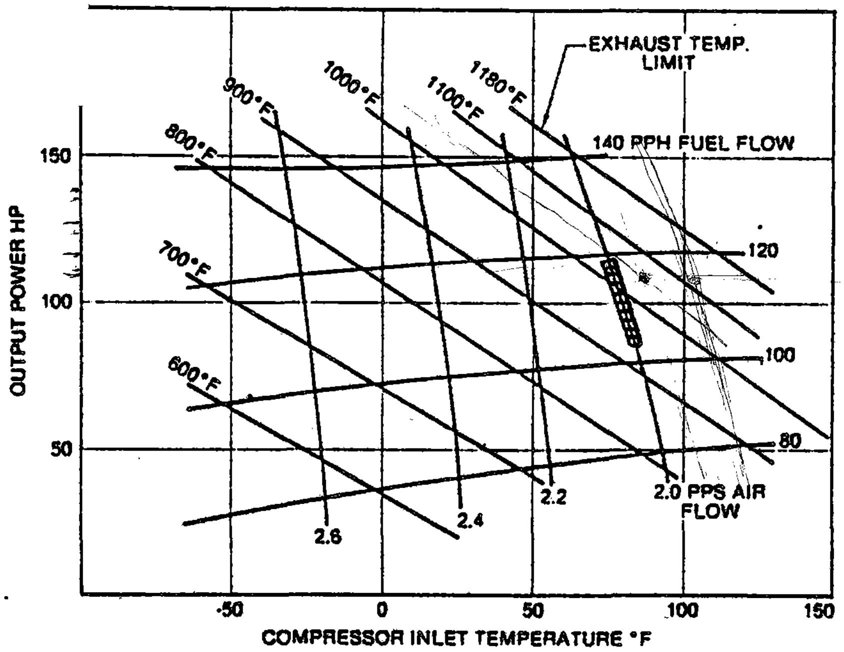


Figure 8-4. Trim Combustor/Flow Ducting Mods – Modified System

Alturdyne power plant performance map
—Sea level—

110 HP = 82 kw



115 peak

Figure 8-5. Turbine Performance

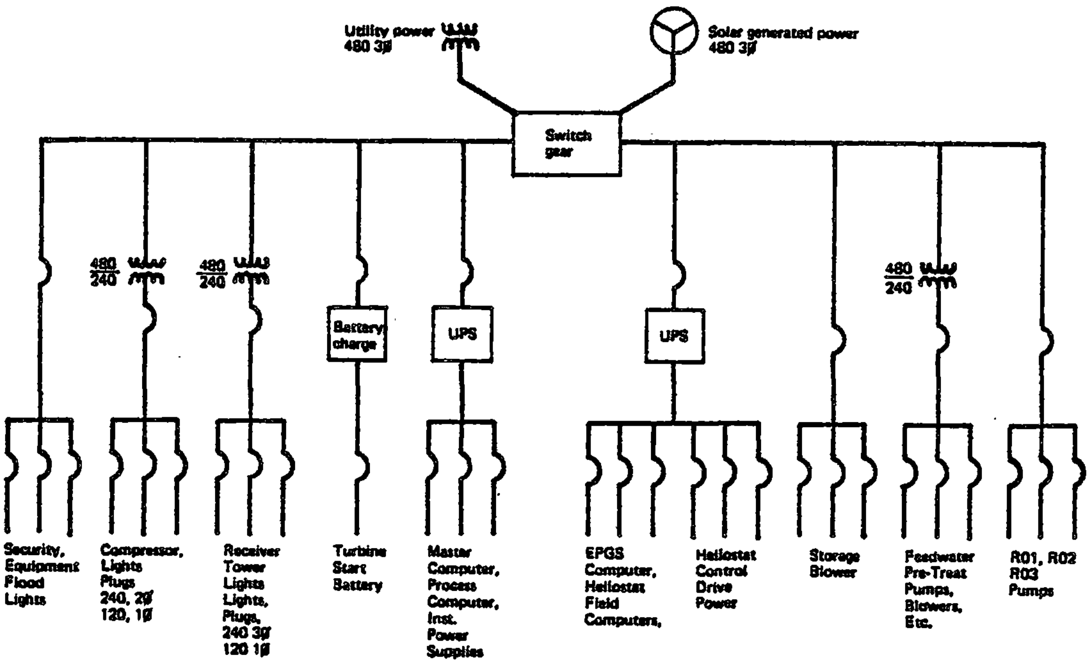


Figure 8-6. Power Distribution — Simplified One Line Diagram

simplified one line diagram of this power distribution system is given in Figure 8-6. There are three basic modes of electric power distribution: solar only; utility only; and split bus operation, i.e., a combination of solar and utility operating in parallel but not in a co-generation mode.

During dual mode operation, everything in Figure 8-6 to the left of the switchgear is dedicated to the utility source and to the right of the switchgear is solar generation dedicated. Items to the left of the switchgear include the facility and building requirements and master computer, and to the right of the switchgear include the heliostat and water treatment systems. During transition from one operational mode to another, there is a requirement to synchronize the electric power sources for up to 30 seconds.

The switchgear will be designed to manage the following power sources rated at 480V, 3 phase, 4 wire, 60Hz, 0.8 power factor:

112.5 KVA x .8 = 90 KW

Turbine Generator Set: 112.5KVA with high resistance grounding
Electric Power Grid : 260 KVA

The required switchgear design is shown in Figure 8-7. This design incorporates two circuit breakers (152 and 252) for overcurrent protection and source isolation. Bus isolation is accomplished with the tie breaker (24) and source synchronization with the synchronizer (25). Other protection devices are the generator ground fault (64) and generator loss of excitation (40). The rest of the devices are used for system monitoring of both sources, i.e., voltages, current, frequency, etc. The buses shown in the figure are dedicated as given here, bus 1 has the facility and building requirements and the master computer, bus 2 has the heliostat field and the water treatment subsystems.

A power consumption estimate was generated as a function of the pilot plant requirements. Table 8-1 gives this power consumption estimate as a minimum/maximum range that covers the needs of the pilot plant. Some of these loads, notably the booster compressor and the desalination feed pumps, have variable power demands and intermittent operation. Starting transients for the electric motors, if conventional starters were used, would be difficult to handle in stand-alone solar operation. Using "soft start" motors is a

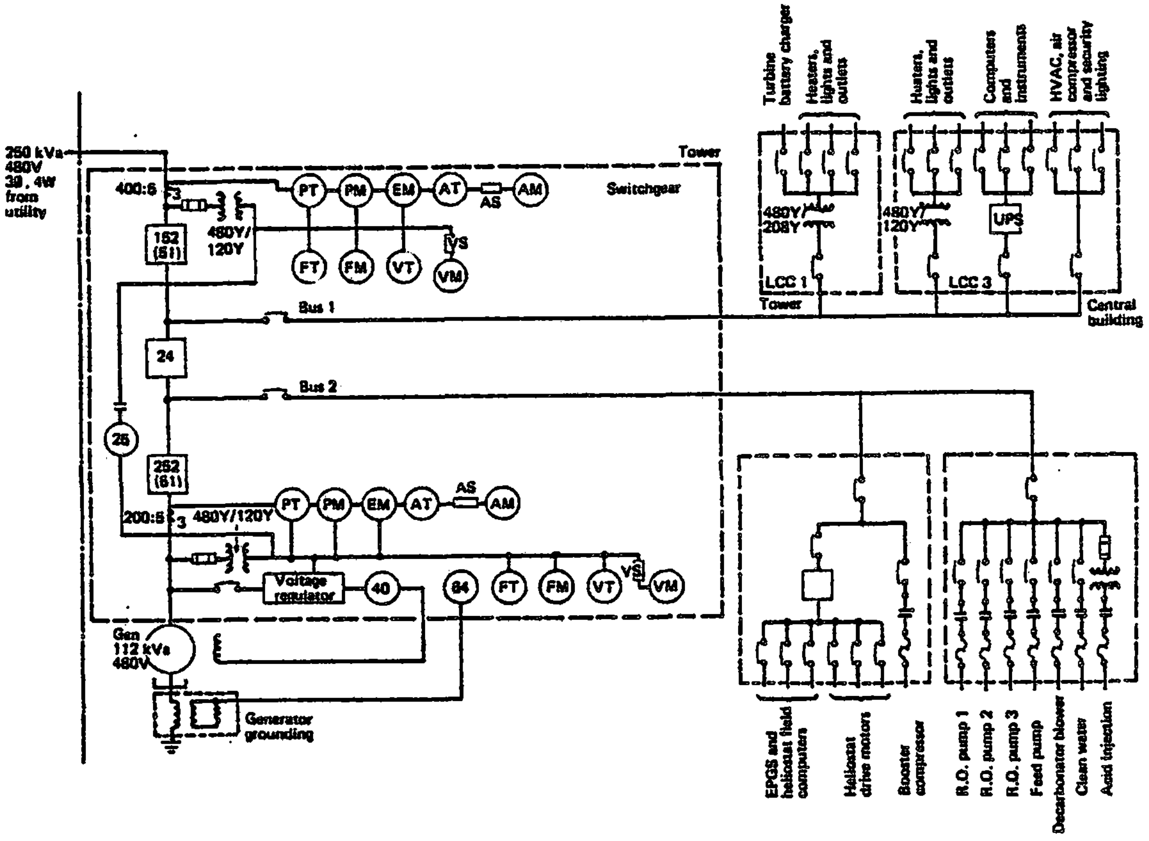


Figure 8-7. Switchgear Functional Diagram

Load	Power Consumption	
	Minimum (kW)	Maximum (kW)
Plant Building	25	50
Site lighting and security	1	5
Tower	1	2
Master Computer and Instrumentation	2	5
Heliostat and Electric Power Generation Computers	1	1
Heliostat Drive Power	2	6
Booster Compressor	0	40
Feedwater Pre-Treatment Equipment	7	7
Desalination Equipment	11	63
Miscellaneous Loads	4	4

Table 8-1: Estimated Power Consumption

practical and effective way to alleviate the problem. The "soft start" capability is easily incorporated into the variable speed drives of the pump motors and of the booster compressor with minimum added cost and is available as a standard feature from a few vendors. Transients associated with tripping motors off-line will be handled by venting excess energy from the receiver. Feasibility of adding a flywheel to the turbo generator set shaft to dampen the generator frequency transients will be investigated in the early stages of the Phase II design.

9.0 BACKUP POWER GENERATION SUBSYSTEM

Backup power will be supplied to the pilot plant from several sources: Fossil fuel, batteries and electric power grid. Both fossil fuel and batteries are options that directly relate to the backup power needs of the commercial plant. Fossil fuel and grid power are convenient power sources for pilot plant testing. Grid is the likely backup power source when the pilot plant is eventually operated by the Upton County Water District. Use of grid power is discussed in the preceding section.

Uninterruptable power supplies (UPS) using batteries are provided in the pilot plant design in two circuits: Heliostats and master computer. The UPS for emergency heliostat power is sized at 10KVA, 3 phase, 120/208 VAC, 60Hz. Equipment specified for this application are Elgar Corporation's Model UPS 103-3A and BP10A-0109 battery pack. The 10 KVA power rating is based on the estimated time needed to move all heliostat images off the receiver aperture which is 30 seconds with a slew rate of 12°/minute. Emergency power for the master computer will be provided by Elgar's UPS 652-1A with BP05A-050g battery pack rated at 6.5 KVA, 1 phase, 120/240 VAC, 60 Hz; 5 KVA is required.

For the fossil fuel option, JP-4 can be used to power the turbine generator set for extended periods. JP-4 will normally be used in starting the Titan. A 1.14m^3 (300 gallon) JP-4 storage tank will be located on the site which will provide an ample fuel supply for normal starting and intermittent operation. Natural gas was considered as an alternate fossil fuel for the Solar Titan because of its potential benefits: easier starting, lower fuel cost, local availablity, safety. The design currently does not have this option because of the added cost.

10.0 FEEDWATER PRETREATMENT SUBSYSTEM

The function of the feedwater pretreatment subsystem is to provide water of required quality to the reverse osmosis units. The most common membrane fouling in any reverse osmosis system is due to the precipitation of calcium carbonate and calcium sulfate on the membrane. Because the Rankin, Texas raw water source has a relatively high hardness content and the potential for scaling, two potential pretreatment schemes, acid injection and weak acid cation (WAC), are candidates for application in the pilot plant. The alternate pretreatment schemes, including approximate costs, are shown in Table 10-1. The acid injection and WAC ion exchange methods have similar costs. For example, the estimated average water pretreatment cost for a twenty year plant life is 0.058 $\$/m^3$ for WAC and 0.0604 $\$/m^3$ for HCl-acid injection. Sulfuric acid injection has the disadvantage that at the 75% recovery specified for the reverse osmosis system, the solubility limit of calcium sulfate would be exceeded, and the addition of a scale inhibitor such as sodium hexametaphosphate would be required.

The WAC ion exchange pretreatment method is selected for the pilot plant (and also the commercial plant). This pretreatment process is capable of essentially single step reduction of calcium and bicarbonate with effluent pH control, utilizing less acid than would have been required for bicarbonate destruction alone. In addition, the WAC pretreatment satisfies a Task 4 objective of demonstrating the technical feasibility of the commercial plant. An important factor is the control system features and operational procedures will be similar in the pilot and commercial plants.

WAC pretreatment is essential, technically speaking, as a pretreatment method for the commercial plant design. In the commercial plant, recovery rates greater than 80% could cause the dissolved salts to exceed their solubility limits. Salt precipitation would then occur, causing membrane fouling. In the commercial plant, the possibility of calcium sulfate and calcium carbonate precipitation is also eliminated by use of WAC ion exchange.

As previously shown in Figure 4-1, the feedwater pretreatment subsystem consists of two full flow anthrafilt filters in parallel, three weak acid cation units in parallel, a regeneration system with acid storage for these units, and a decarbonation/pH control unit. This pretreatment system was selected because of its on-line high reliability, flexibility, and compatibility with pilot plant intermittent operation, particularly important to integration in a solar dependent power system, its relatively simple control and operation, and minimum energy requirements.

Table 10-1. Alternate Pretreatment Schemes

Description	Reliability	Estimated Cost	pros	cons
WAC (baseline)		$167,000	Maximum water capacity. Lowest chemical cost.	Higher capital cost.
Acid Injection - HCl	equal to baseline	$ 30,000	Lower capital cost than baseline.	Lower water capacity, higher HCl cost than baseline.
Acid Injection - H_2SO_4 with inhibitor injection	less than baseline	$30,000	Lower capital cost than baseline	Lower water capacity, less reliable than baseline.
No Pretreatment	less than baseline	0	Lower capital cost than baseline.	Lower water capacity, less reliable than baseline, cannot get 72% RO recovery.

10.1 Feedwater Supply

The feedwater supply to the pilot plant is provided by a connection to the existing Upton County Water District water line coming to the site. A centrifugal booster feed pump provides the required hydraulic head for flow through the pretreatment subsystem. The pump is rated at $1642 m^3/d$ at 10.7m (300 gpm at 35 ft) total dynamic head and provides 241 kPa (35 psig) discharge flow to the anthrafilt filters. A bypass control loop around the feed pump controls the flowrates to the RO desalination subsystem. A hydraulic profile for the pilot plant water systems is shown in Figure 10-1.

The two feedwater filters are required to remove suspended solids, silt, and turbidity that is typical of well water. The filter units are arranged in parallel with each unit rated at half of system capacity. Each unit is 2.4m (8 ft) diameter by 0.9m (3 ft) straight section and has a 0.9m (3 ft) bed height of anthrafilt filter media. Backwash frequency is estimated at once per week. This is initiated when the pressure drop across the filter bed exceeds the manufacturers specification, normally 68.9-103.4 kPa (10-15 psig). Backwash sequence normally will be scheduled for the night shift operation or other periods of minimum water production. Product water will be used in this operation.

10.2 Ion Exchange Units

The weak acid cation exchange units are required to reduce the hardness and concentration of the RO feedwater. This softening reaction eliminates the potential for calcium scale formation in the RO membrane ensuring system reliability and production capability. In the softening reaction, the calcium ion is absorbed on the WAC resin and displaces a hydrogen ion. This hydrogen ion combines with the bicarbonate ion in the feedwater to form carbonic acid which is subsequently removed downstream in the decarbonator unit. The chemical reactions are identified in Figure 10-2. This reaction continues until no further calcium can be absorbed and regeneration of the bed is required. Regeneration of the resin in the WAC exchange unit is accommpl1shed by flushing the resin bed with hydrochloric acid, which removes calcium ions and replaces the hydrogen needed in the softening reaction.

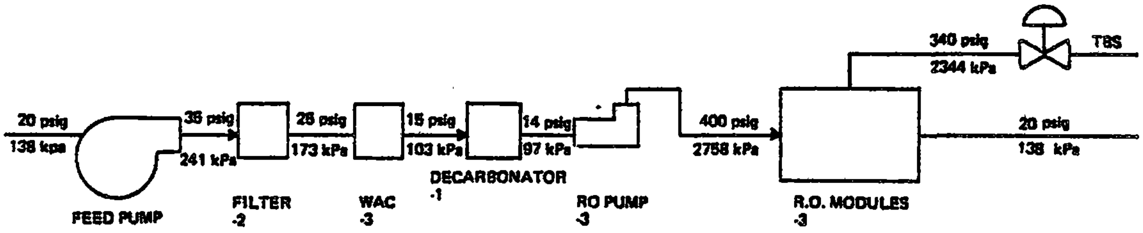


Figure 10-1. Hydraulic Profile, Solar Energy Desalination Plant, Rankin, Texas

SOFTENING REACTION

$$\begin{array}{c} \mathrm{Ca^{++}\,(HCO_3^-)_2 \;+\; 2\;\overline{RCOOH}} \\ \downarrow\uparrow \\ \mathrm{Ca^{++}\,(RCOO^-)_2 \;+\; 2H_2CO_3} \end{array}$$

DECARBONATION REACTION

$$\mathrm{H_2CO_3 \rightleftharpoons H_2O \;+\; CO_2}$$

REGENERATION REACTION

$$\begin{array}{c} \mathrm{Ca^{++}\,\overline{(RCOO^-)_2} \;+\; 2\;HCl} \\ \downarrow\uparrow \\ \mathrm{Ca^{++}Cl_2^- \;+\; 2\;\overline{RCOOH}} \end{array}$$

NOTE: RCOO IS THE RESIN BACKBONE AND ‾‾‾ SIGNIFIES RESIN PHASE.

Figure 10-2. Weak Acid Cation Ion Exchange

A schematic of one of the WAC exchange units and the regeneration system is shown in Figure 10-3. Normally one of the three WAC units is kept in a standby or regeneration status with the other two beds in production operation. In normal operation, the feedwater is distributed over the resin bed and flows down to the underdrain headers where it is collected and directed to the decarbonation system. The softening reaction occurs as soon as fresh resin is encountered; thus, the reacton front moves uniformly down through the bed, and the amount of softening remains constant as long as the reaction front remains above the drain headers. After a predetermined quantity of feedwater has flowed through the unit, it is replaced on-line by a fresh unit and is then regenerated. The regeneration cycle is automatically controlled through precalibrated timer instrumentation and is accomplished by isolating the unit, backflushing the bed contents, regenerant contact for a specified time period with dilute hydrochloric acid and final rinse with product water. The regeneration of each WAC bed will occur daily at system specification production capacity and will require an estimated two hours to complete.

Figure 10-4 illustrates the construction features of the WAC units. Each WAC unit is 1.5 m (5 ft) diameter by 1.5 m (5 ft) straight section with a 0.9 (3 ft) resin bed height. The ion exchange resin is a divinyl benzene type. The three WAC units are skid mounted with all piping, valves, and controls assembled. The regeneration components include an acid storage tank, feed pump and in-line mixer. The acid tank has a 3.79 m^3 (1000 gallon) capacity and is constructed of corrosion resistant materials. The acid feed pump is a positive displacement reciprocating type, rated at 0.32 l/s (5 gpm) at 21.3 m (70 ft) head.

10.3 Decarbonator Unit

The decarbonator unit function is to precondition the RO feed by removing excess acidity in the WAC product effluent. The acidity is in the form of carbonic acid; the result of the ion exchange reactions shown in Figure 10-2. The decarbonator unit removes the dissolved carbon dioxide by desorption within a packed bed column. The WAC product effluent is distributed downward through the relatively large surface area of the packing media. A counterflow

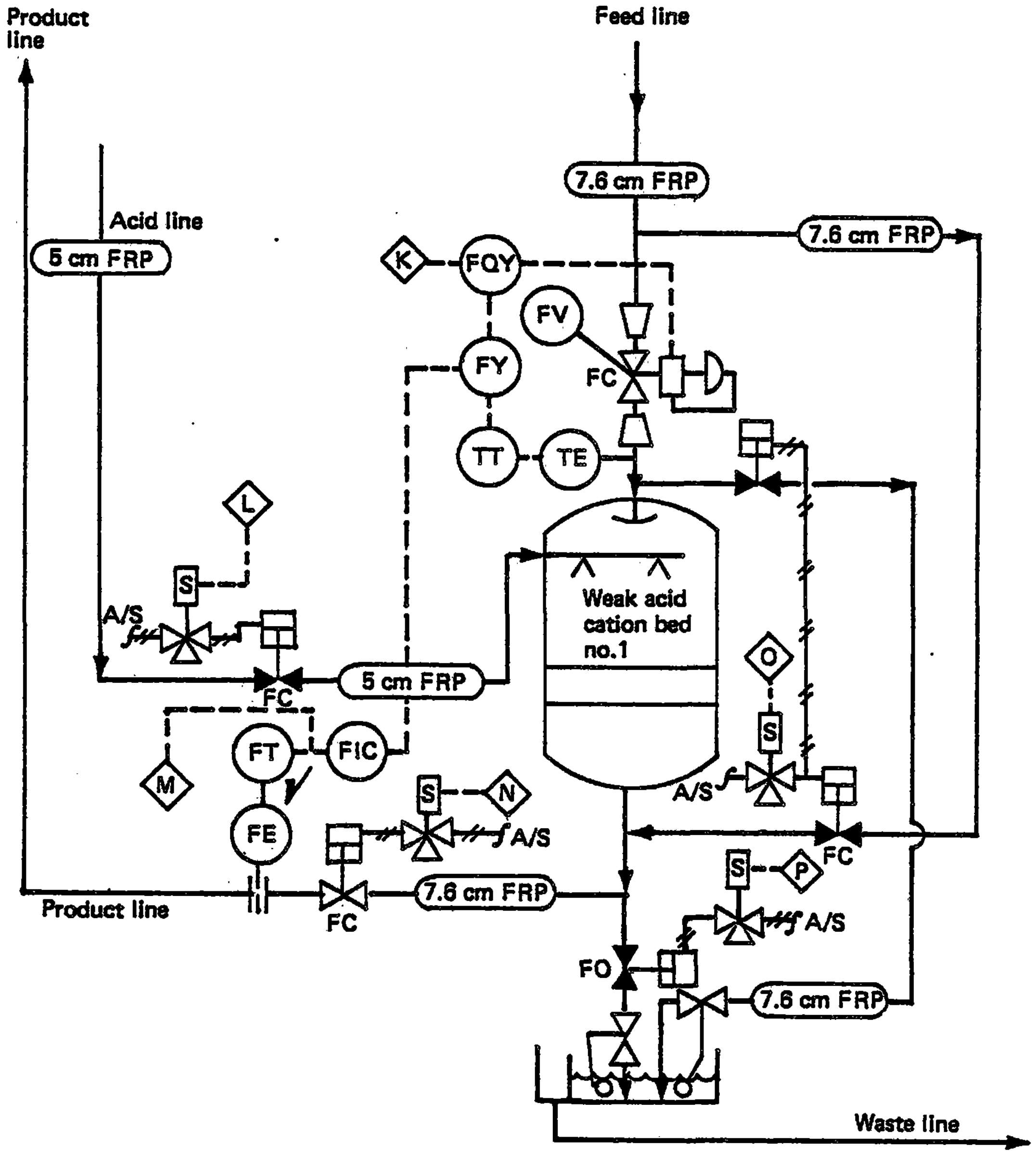


Figure 10-3. Weak Acid Cation Exchange System

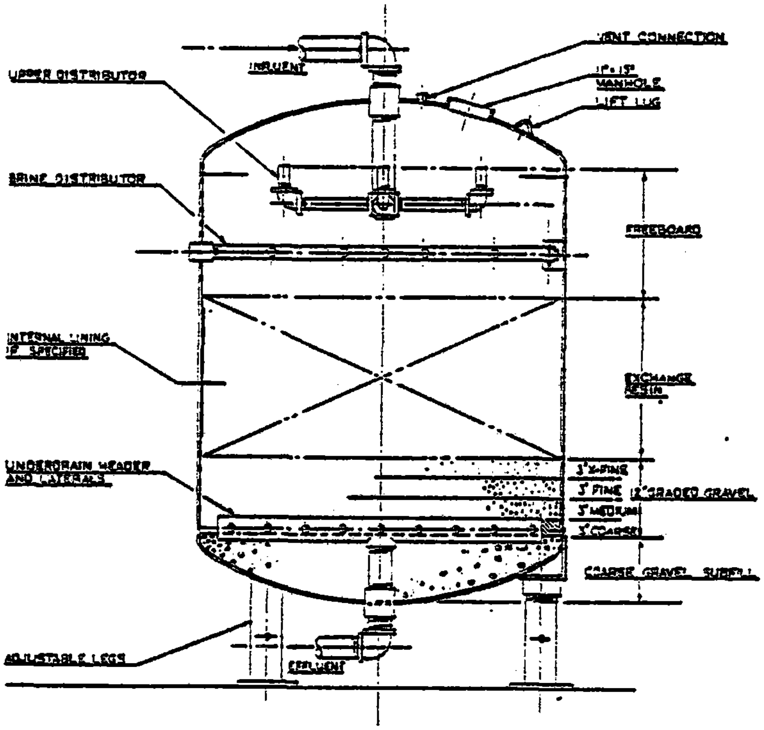


Figure 10-4. Weak Acid Exchange Resin Bed

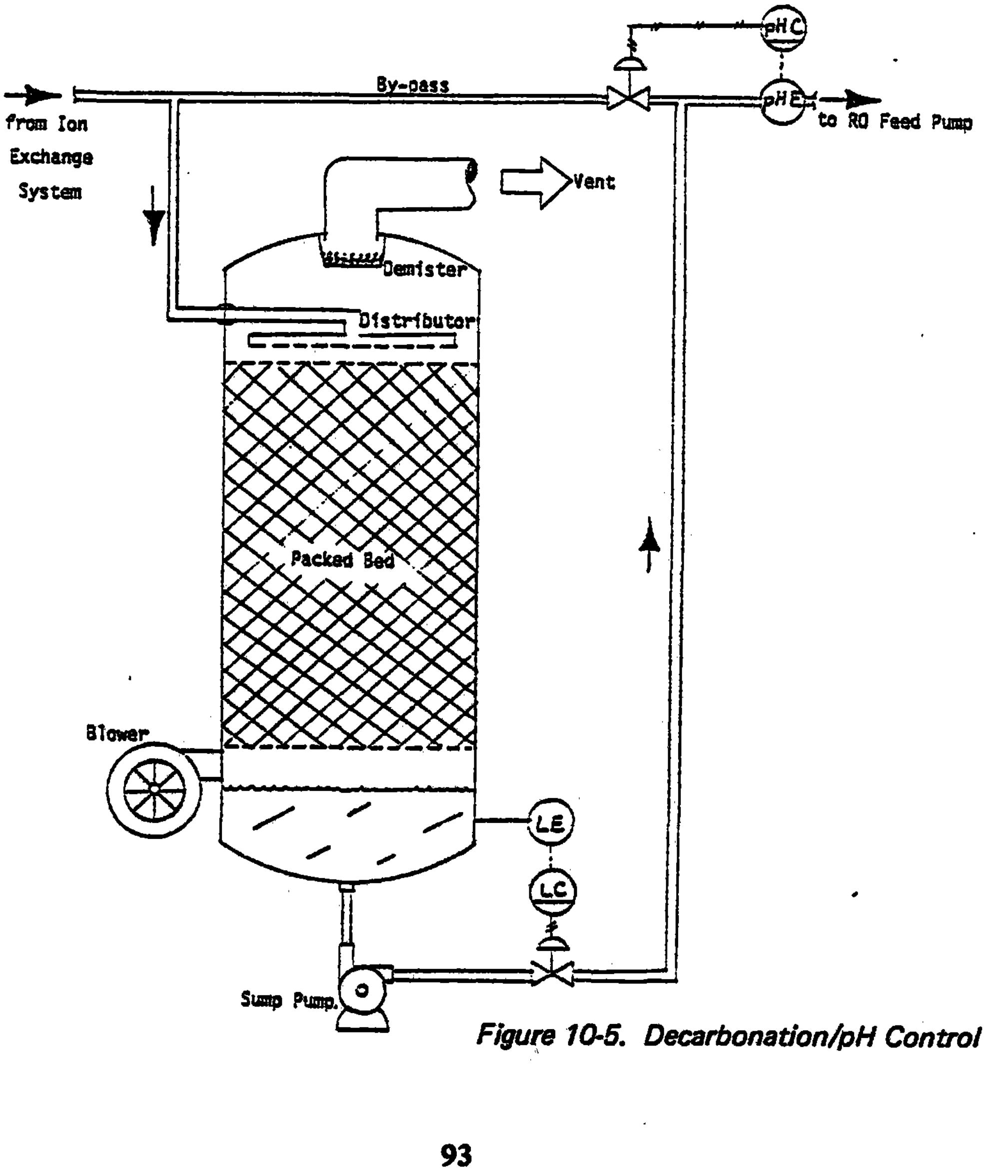


Figure 10-5. Decarbonation/pH Control System

of air from an external blower then sweeps the released carbon dioxide to the vent system. The decarbonator product is collected in the lower section of the unit which serves as surge and feed supply to the RO units. Final pH adjustment is accomplished with untreated WAC effluent via a bypass loop. The specified 5.9 pH feedwater to the RO units is obtained by varying the ratio of the WAC product effluent through the decarbonator and bypass. The bypass flow ratio is estimated at 10% of system capacity. It is automatically controlled by a pH indicating controller downstream of the unit. The unit and control systems are illustrated in Figure 10-5.

The decarbonator is a counter-current packed absorption tower, 1.07 m (3.5 ft) diameter by 3.66 m (12 ft) high overall, with an internal packing height of 2.13 m (7 ft). Packing media is 2.54 cm (1 in) Super Intalox polypropylene material. The decarbonator blower is rated at 0.64 m^3/s at 15.24 cm water pressure. The unit is provided with inlet air filter, differential pressure (across filter) sensors, 1.49 kW (2 hp), 3500 rpm motor and accessories.

11.0 DESALINATION SUBSYSTEM

Desalination for the pilot plant is accomplished by three parallel trains of reverse osmosis units providing a water recovery rate of 75%. The process of reverse osmosis is the rejection of dissolved materials taking place under pressure when the feed solution passes through a semi-permeable membrane. The product flow through the membrane in the reverse osmosis unit is proportional to the applied pressure differential across the membrane. The nominal pressure for this process is 2.76-3.1 MPa (400 -450 psig). The passage of dissolved salts through the membrane is proportional to the concentration differential across the membrane.

Five basic criteria for the selection of the reverse osmosis units were applied against the pilot plant system requirements. They were as follows: capacity in terms of system flow; performance in terms of product composition; stability in terms of operating life, i.e., membrane replacement; economics in the procurement of multitrain RO systems; and operational flexibility and efficiency for utilization of varying solar energy.

11.1 Reverse Osmosis Units

Feedwater from the pretreatment subsystem enters the RO system through an automatically controlled shut-off valve and flows to variable speed positive displacement pump. From the high pressure pump the feedwater flows to the feed inlet connection of the RO module. Each module has been specified to provide a recovery water rate of 0.75. Each RO train includes three RO modules (pressure vessels), each containing six 8600 PA elements in series. The modules are arranged in a 2:1 array. Two liquid streams discharge from each module. The product (permeate) stream is at essentially atmospheric pressure since any back pressure would reduce the net feed pressure which is the driving force controlling module productivity. The discharge pressure is estimated at less than 1.5 atmospheres but is sufficient to direct product to storage or the Rankin municipal system without additional pumping requirements. Reject water leaves the reject outlet at an estimated 2.34 MPa (340 psig) due to an overall pressure drop through the module. Reject water (concentrate) flow rate is controlled by a reject flow control value which maintains sufficient pressure for the module operation and limits the concentration of the feed to minimize precipitation of salts. Each RO train is protected by pressure and flow instrumentation which will shutdown the high pressure pump and isolate the system to protect equipment and insure product water quality. .

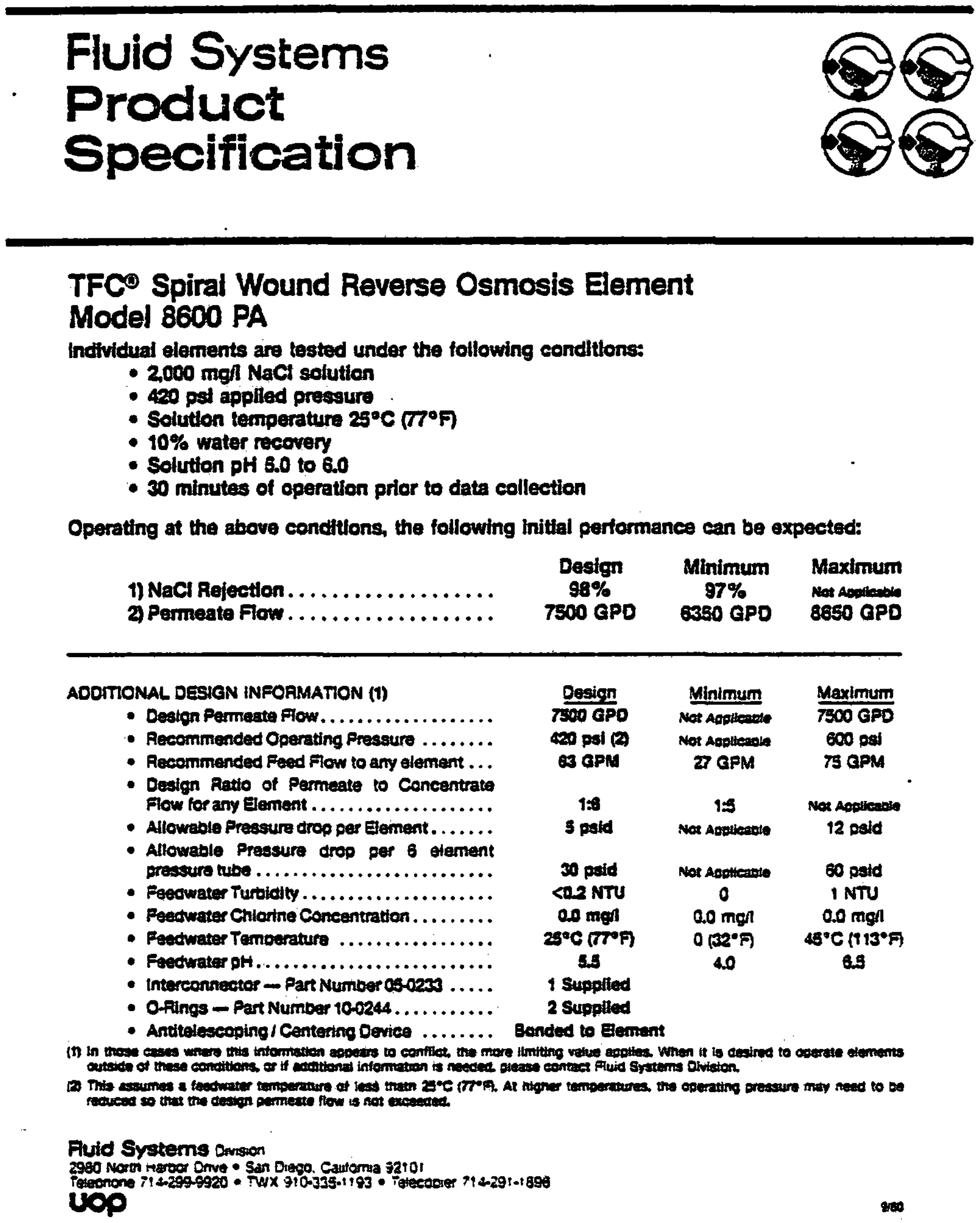
Specific protection for each RO train that would schedule the shutdown of the RO high pressure pump include:

Location	Sensing
Pressure pump suction	Low pressure
RO module feed	High pressure
RO module reject	High differential pressure across membrane
RO module reject	Low flow

The membrane type selected for the RO units is Fluid System's Model 8600 PA, TFC® Spiral Wound Reverse Osmosis Element; the supplier's data for this non-cellulosic element are shown in Figures 11-1 and 11-2. The element operates at high flux (flow) levels and is proven in commercial applications. The expected normal membrane life is three years. This is the same membrane that is specified for the commercial plant.

Performance of the elements in the 2:1 train configuration is shown in Figure 11-3. Each train can be operated down to 60% of its maximum flow rate. The predicted TDS of the permeate water with no blending is 122 ppm which is well within the 500 ppm potable water requirement.

Three parallel RO trains were specified to permit utilization of varying solar power. By combining the variable capability of each train , it is possible to provide a variable production rate that "follows" the available power supply. Figure 11-4 presents the RO production (unblended) for single and multiple train operation.



Fluid Systems Product Specification

TFC® Spiral Wound Reverse Osmosis Element Model 8600 PA

Individual elements are tested under the following conditions:

- 2,000 mg/l NaCl solution
- 420 psi applied pressure
- Solution temperature 25°C (77°F)
- 10% water recovery
- Solution pH 5.0 to 6.0
- 30 minutes of operation prior to data collection

Operating at the above conditions, the following initial performance can be expected:

	Design	Minimum	Maximum
1) NaCl Rejection	98%	97%	Not Applicable
2) Permeate Flow	7500 GPD	6350 GPD	8650 GPD

ADDITIONAL DESIGN INFORMATION (1)	Design	Minimum	Maximum
• Design Permeate Flow	7500 GPD	Not Applicable	7500 GPD
• Recommended Operating Pressure	420 psi (2)	Not Applicable	600 psi
• Recommended Feed Flow to any element	63 GPM	27 GPM	75 GPM
• Design Ratio of Permeate to Concentrate Flow for any Element	1:6	1:5	Not Applicable
• Allowable Pressure drop per Element	5 psid	Not Applicable	12 psid
• Allowable Pressure drop per 6 element pressure tube	30 psid	Not Applicable	60 psid
• Feedwater Turbidity	<0.2 NTU	0	1 NTU
• Feedwater Chlorine Concentration	0.0 mg/l	0.0 mg/l	0.0 mg/l
• Feedwater Temperature	25°C (77°F)	0 (32°F)	45°C (113°F)
• Feedwater pH	5.5	4.0	6.5
• Interconnector — Part Number 05-0233	1 Supplied		
• O-Rings — Part Number 10-0244	2 Supplied		
• Antitelescoping / Centering Device	Bonded to Element		

(1) In those cases where this information appears to conflict, the more limiting value applies. When it is desired to operate elements outside of these conditions, or if additional information is needed, please contact Fluid Systems Division.

(2) This assumes a feedwater temperature of less than 25°C (77°F). At higher temperatures, the operating pressure may need to be reduced so that the design permeate flow is not exceeded.

Fluid Systems Division
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Figure 11-1. TFC Spiral Wound Reverse Osmosis Element Model 8600 PA — Product Specification

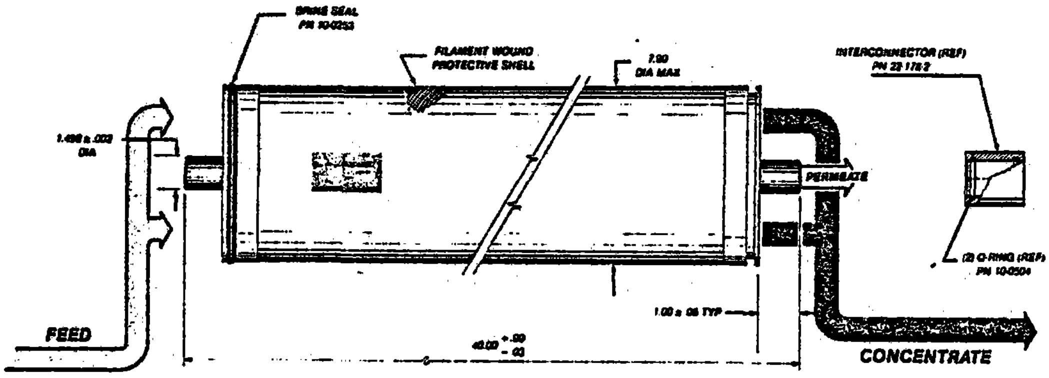


Figure 11-2. TFC Spiral Wound Reverse Osmosis Element — Model 8600 PA

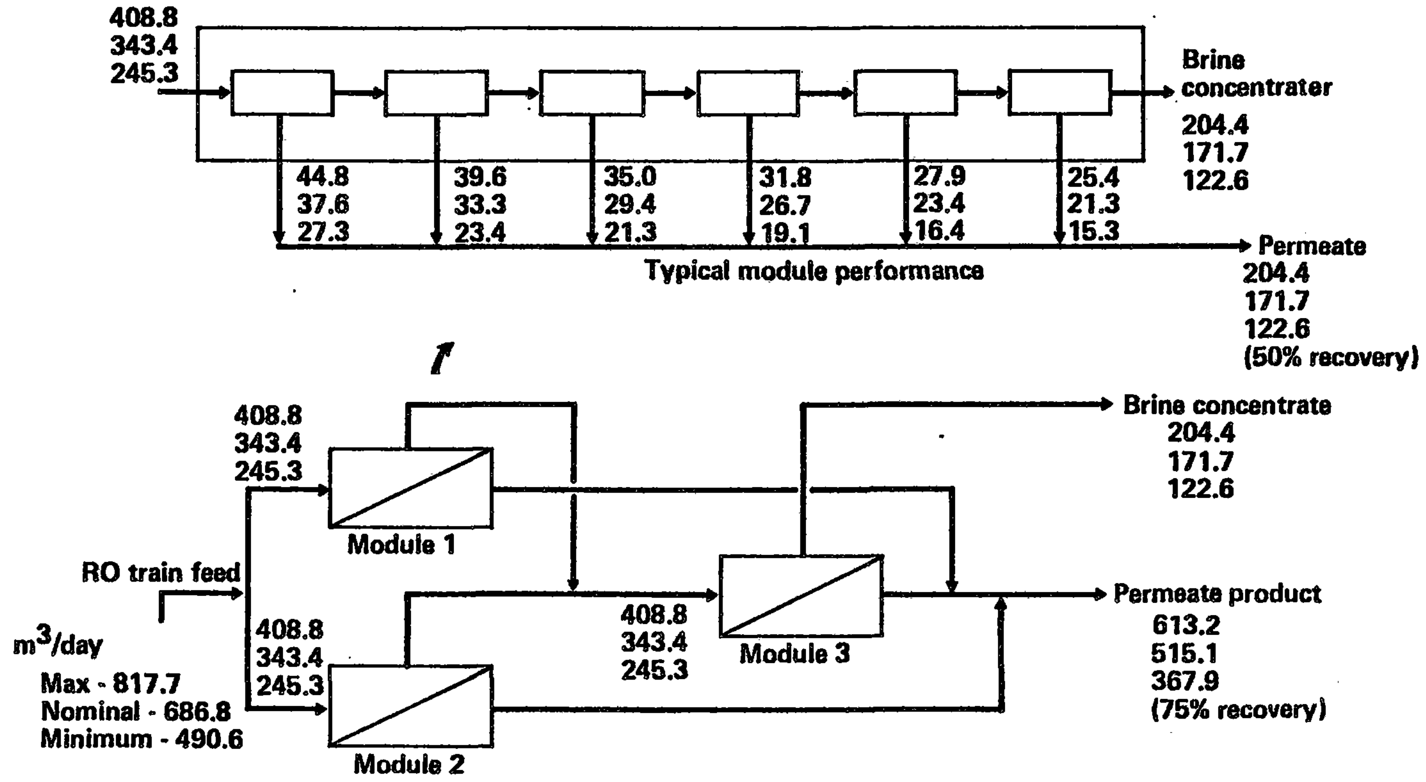


Figure 11-3. Reverse Osmosis Train Performance

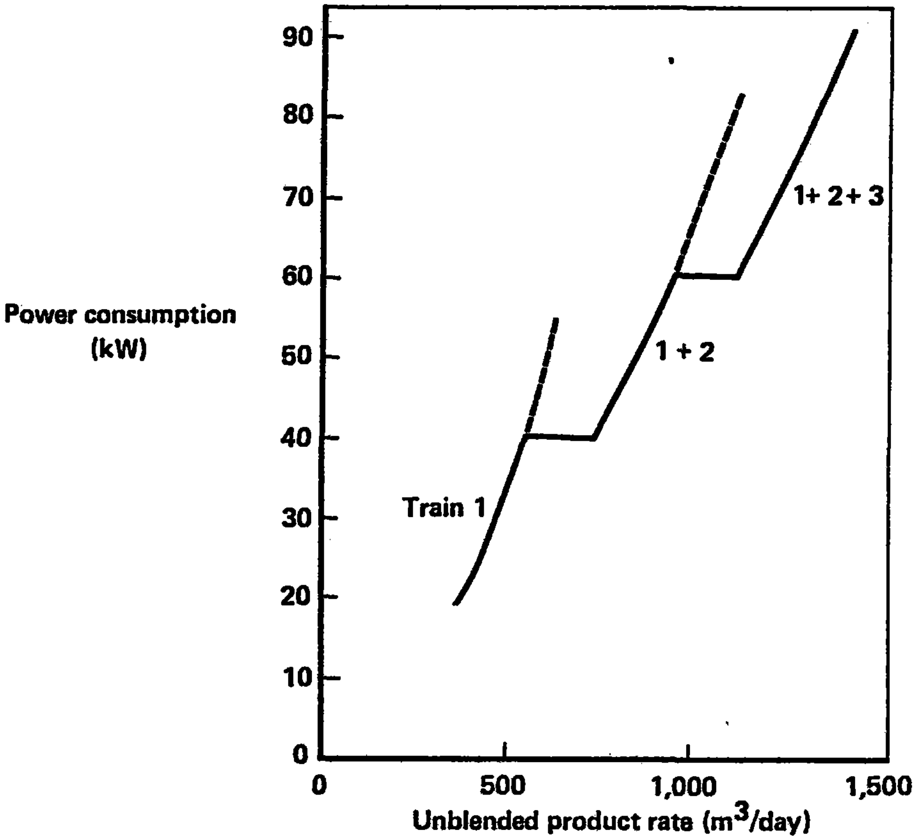


Figure 11-4. Power Consumption Versus Combined Product Water from Combined RO Trains.

The three train design has several features that make it attractive for the pilot plant:

1. The control system will be required to manage two changes in number of operating RO trains (good simulation of the three changes that occur in the commercial plant).

2. All RO trains can be close to or at peak flow during switching of TES unit (similar to the commercial plant).

3. The combined RO peak power requirement is slightly in excess of peak available power (80 kW).

4. Maintenace can be done on an individual RO train with two trains operating.

5. The train design is a good fit with commercially available RO equipment.

Several variations of the train architecture were studied with the results supporting the selected three train design. Water production data for these variations are shown in Figures 11-5 to 11-8. This production data is based on available power computed using the plant performance model and assuming a packed bed TES with 42,500 kg (see Figure 17-32); of the power available for water treatment, 90% is allocated to the RO process and 10% is allocated to feedwater pretreatment.

Figure 11-5 compares the water production from discrete trains (Figure 11-4) to production computed by the plant performance model which analyzes water production as a "smooth" function of available power. The plant performance model offers a reasonably close simulation of integrated water production from discrete trains.

A comparison of two train versus three train is shown in Figure 11-6. The extra train produces a significant amount of water under solar-only conditions; with grid subsidy, the additional production will be substantial.

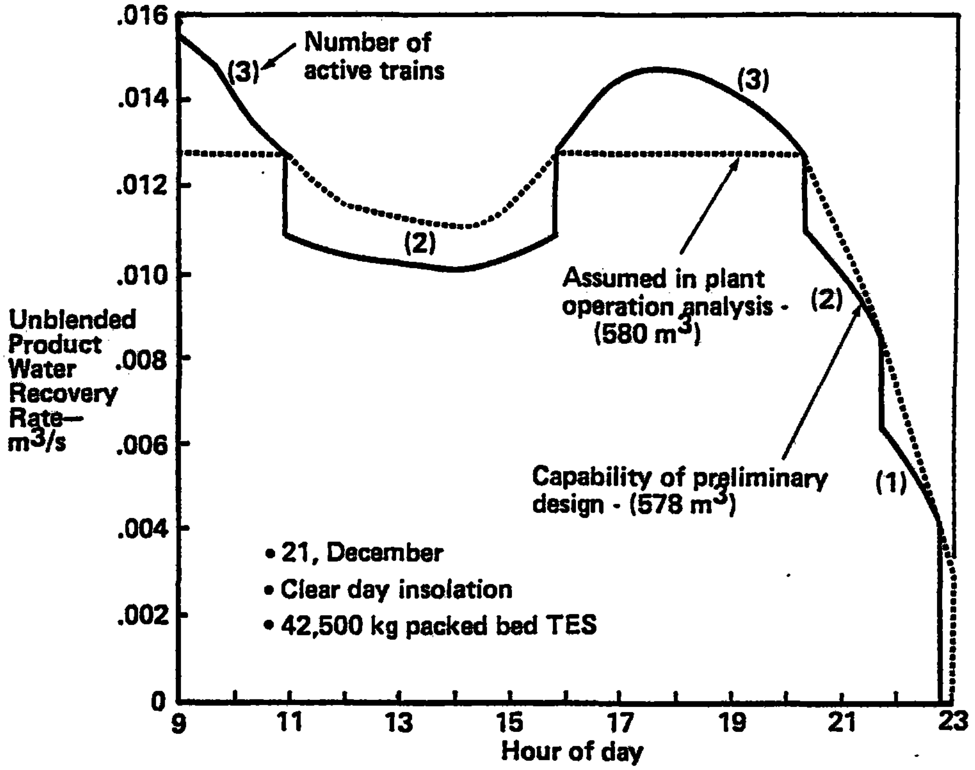


Figure 11-5. Comparison of Desalination Subsystem Performance for Preliminary Design with Plant Operation Analysis

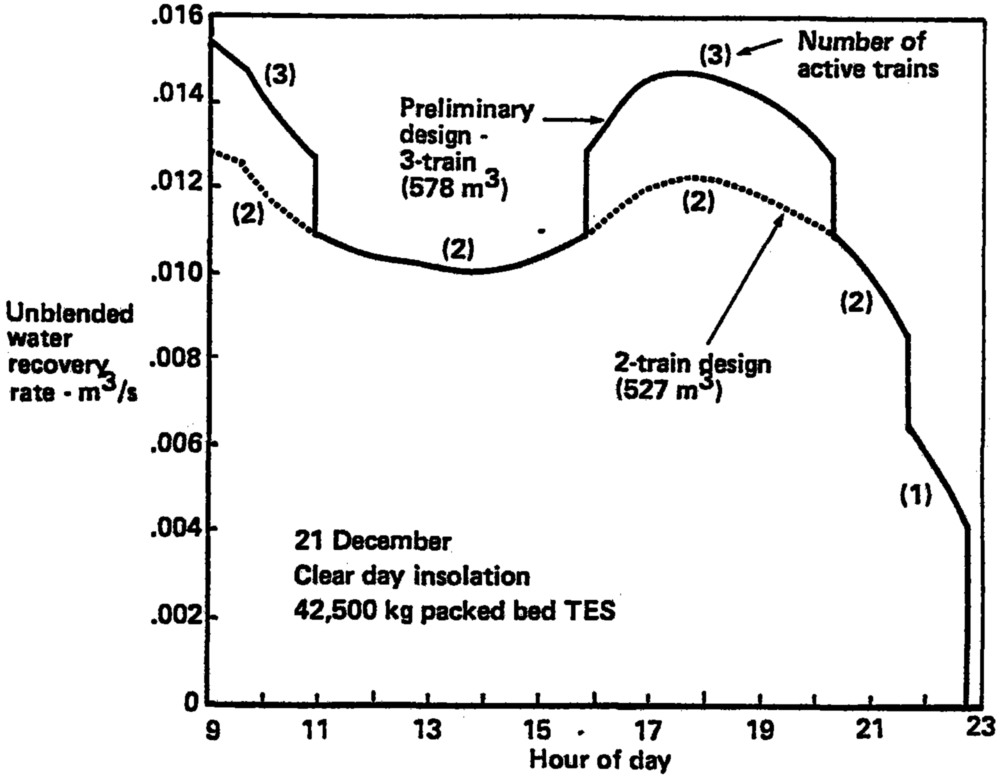


Figure 11-6. Performance Comparison of The 3-Train Preliminary Design With a 2-Train Design

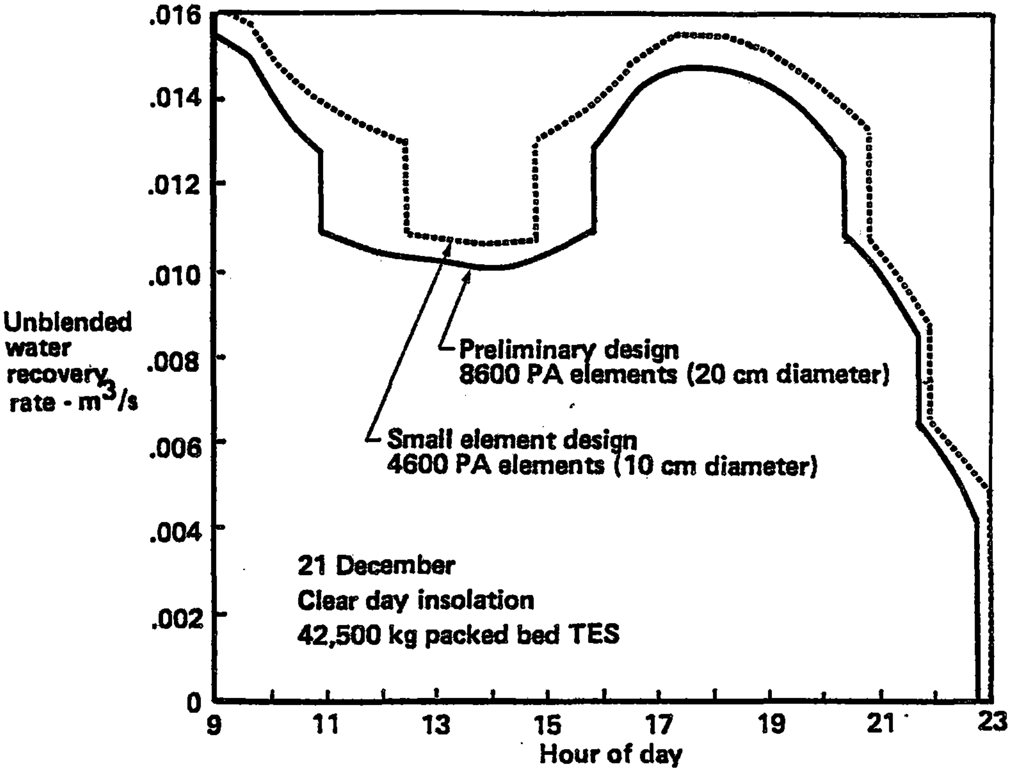


Figure 11-7. Comparison of The Preliminary Design With a Design Using Smaller Elements

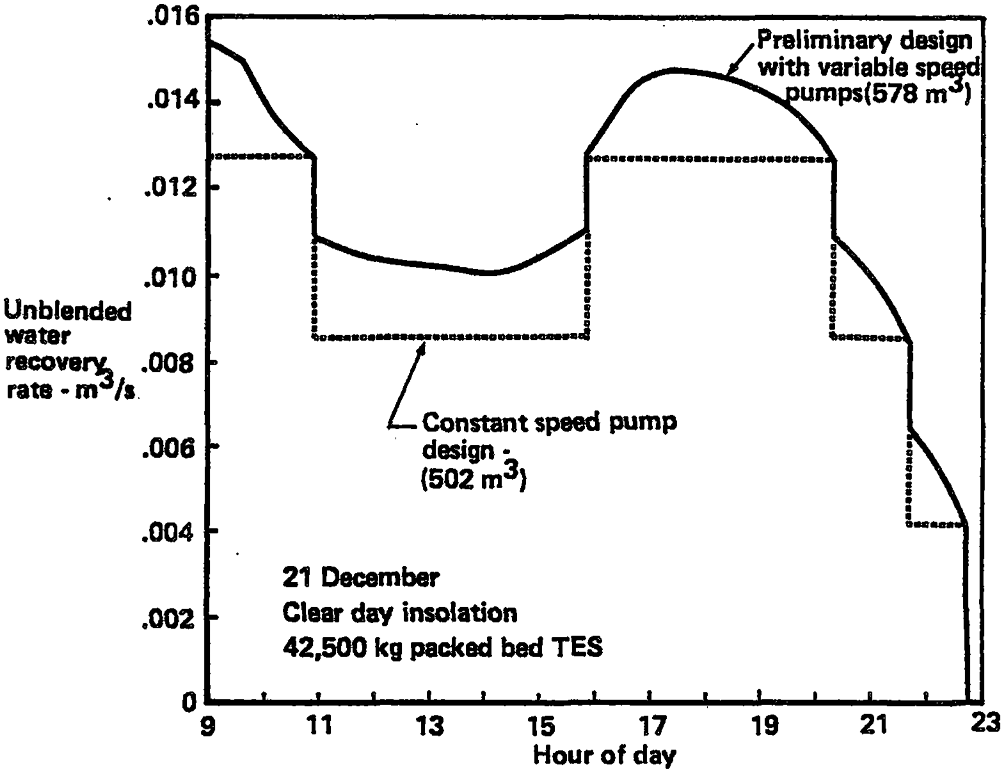


Figure 11-8. Comparison of The Preliminary Design With Variable Speed Pumps to a Constant Speed Pump Design

In Figure 11-7, the performance of a smaller sized element (UOP 4600 PA) is compared to the selected designs. While the smallest element (10 cm diameter) offers some performance advantage, its system cost is significantly higher because of the numerous modules required (the smaller elements would be arranged in 3 parallel trains of 2:1 arrays with a total of 45 modules). Each module would contain six elements in series.

Figure 11-8 shows a comparison between variable and constant speed pumps. The on-off nature of the constant speed pump option results in significantly lower water production. Variable speed operation was not considered in the commercial plant design. However, these comparisons indicate that the power matching capability and additional efficiency would be highly desirable in the commercial plant, and that no significant drawbacks exist.

11.2 Reverse Osmosis Cleaning Systems

Under most operating systems, some degree of membrane fouling will occur requiring a scheduled maintenance cleanout and flush of each permeater. The requirement to initiate the cleanout is the significant increase in pressure drop across the module with resulting decline in productivity and decreased salt rejection. The specific RO train is isolated from the water system and cleanout initiated via a connection in accordance to membrane manufactures specification for chemicals, concentrations flow rates and pressure. Permeators are cleaned in parallel requiring a manual valving change of permeators. A valved crossover connection is provided from the permeate line to direct any contaminated product to waste disposal during the cleanout. Normally the cleanout is specified at a low pressure to minimize product flow. The RO cleaning system for the pilot plant consists of a 1325l (350 gallon) open top tank with chemical mixer, and a distribution pump. The pump has a 381.6 m^3/day (70 gpm) capacity at 10.7m (35 ft) total dynamic head and meets UOP-Fluid Systems requirements. All reject cleanout flows are flushed to the waste sewer.

Each manufacturer of RO systems has its own method of cleaning for the type of membrane and contaminate. The Fluid Systems membranes specified for the pilot plant, TFC Spiral Wound - Model 8600 PA, will require a two step procedure if both acid soluble, acid insoluble and microbiological slimes require removal.

The initial flush is normally computed for acid soluble materials. The chemical used is a 2% citric acid solution adjusted to a pH of 3. The solution is heated to 50°C and circulated for 45 minutes at a flowrate of 190.8m^3/day (35 gpm). The system pressure should be the minimum required to achieve specified flow but in no case should exceed 413.7 kPa (60 psig). Acid insoluble foulants are flushed with a 2% trisodium phosphate - EDTA solution. A 1% formaldehyde solution is used for micro-organisms. Its application is equivalent to the citric acid solution. Following treatment and the discharge of the spent cleaning solution, the cleaning tank will be filled with product water and circulated for 30 minutes to remove all cleaning solutions. Sampling connections are provided ahead of and downstream of the module to permit comparative analysis for foulant constituents and chemical content. The pilot plant RO cleanout system will be used to circulate and fill the permeate units with preservative solution in the event the pilot plant is down for any extended period. The actual interval is subject to the bacteria and mold content of the supply. Since chlorine or chlorine dioxide cannot be used with the PA type of membrane a dilute solution, 1%, formaldehyde will be required for membrane sterilization. This flush will be required under the following conditions:

- RO plant out of service for 5 days or longer (period to be determined by bacteria analysis).

- RO plant out of service for a day or more after treatment with citric acid.

- Product or brine contaminated with micro-organisms.

In the event the RO modules are taken out of service, the formaldehyde solution will be left in the permeators. A thorough flushing of the module bank and piping is received when the plant is returned to service. For a 2.76 MPa (400 psi) flush 1.5 to 2.0 hours is required at 109 m^3/day (20 gpm) with the RP product and reject going to waste.

12.0 WATER STORAGE AND DELIVERY AND WASTE DISPOSAL SUBSYSTEMS

12.1 Water Storage and Delivery Subsystems

Product water from the plant building will be piped to a piping vault that is adjacent to the existing water storage tank. The product water will then be piped into the tank via an existing pipe. this pipe will also be connected in the piping vault to a new water delivery to be installed to Rankin alongside an existing feedwater delivery line. Flow control valves and meters will also be located in the existing piping vault. A new water level sensor will be installed in the tank that will be wired to the master control computer.

12.2 Waste Disposal Subsystem

Brine wastes from the feedwater pretreatment and desalination processes and sanitary wastes from the building facilities will be piped to a new sewer to be installed to Rankin. This sewer line will be laid alongside the existing feedwater and new product water delivery lines. connection of the new sewer and plant lines will be made in the piping vault.

In preliminary discussions with Upton County officials and Esmond-Haner, consulting engineers retained by BEC, it was determined that plant wastes could be disposed to the Rankin sewer system. Esmond-Haner, who also provides engineering services to the Upton County Water District, will be retained to perform an environmental assessment during the detail design phase.

13.0 INSTRUMENTATION AND CONTROLS SUBSYSTEM

The Instrumentation and Controls Subsystem is illustrated in the control room layout, Figure 13-1, and the block diagram shown in Figure 13-2. Plant control functions are distributed among the electric power controls, the heliostat controls, the water treatment process controls, and the master computer. This configuration (1) allows use of commercially available control hardware, (2) minimizes development and procurement costs, and (3) provides independent control and data acquisition capabilities needed during testing and normal services. Each of the distributed control systems will be discussed in detail in the following paragraphs.

13.1 Master Computer System

The master computer system is built around a Digital Equipment Corporation PDP 11/44 computer and interfaces with three multicolor video displays (Cathode Ray Tubes or CRT's), the operator control panel, a printer, data storage devices (dual hard disks and a tape drive), and a system dedicated black and white CRT.

Real-time heliostat field status will be displayed on one of the CRT's, dedicated to this function, in the form of alphanumerics and color graphics. The other two CRT's are utilized for master display of the overall pilot plant operation. Graphical displays will include system overview, particular component information (i.e., receiver, generator, etc.) power production levels, water production rates and inventory, alarm status, etc. Examples of displays are shown in Figures 13-3 and 13-4.

Communication between the operator and the control system is accomplished through the operator control panel shown in Figure 13-5. This panel provides the operator with independent control of either the left or the right video display. Operational mode control is selected by pushbutton and is acknowledged via pushbutton illumination and response of the CRT display. Power source selection is by pushbutton, and can be either total utility, or total solar generation or split bus operation from both the utility and solar sources. Other operator control inputs include heliostats status, turbine start-stop, and emergency heliostat SCRAM.

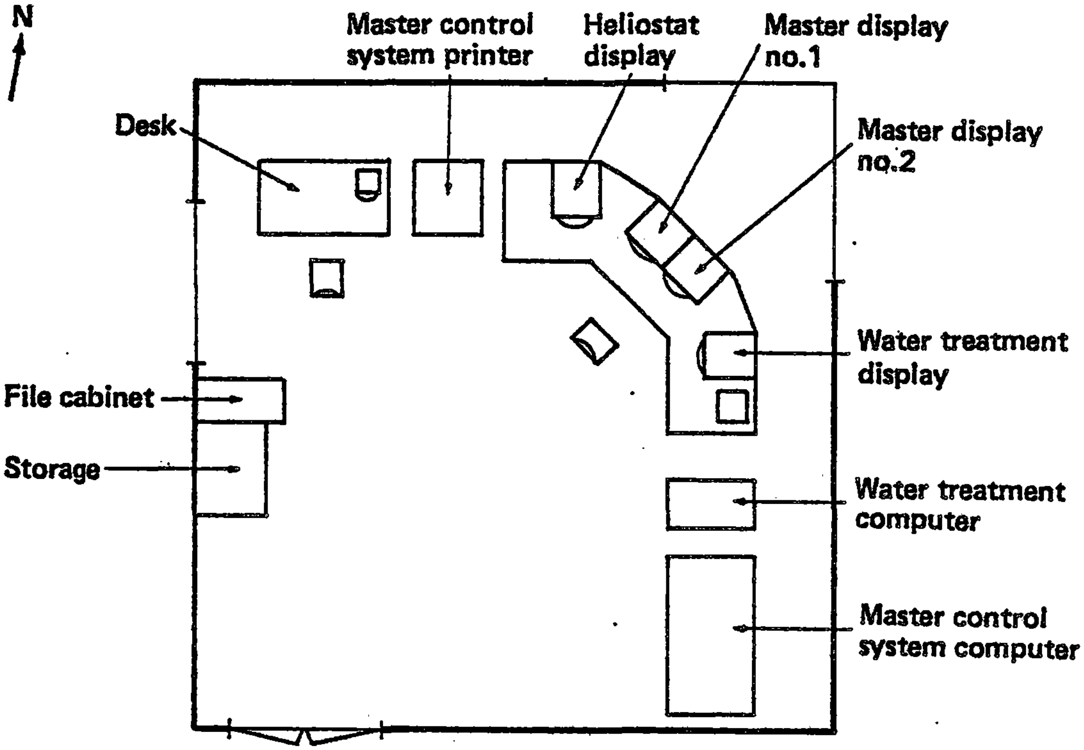


Figure 13-1. Control Room Layout

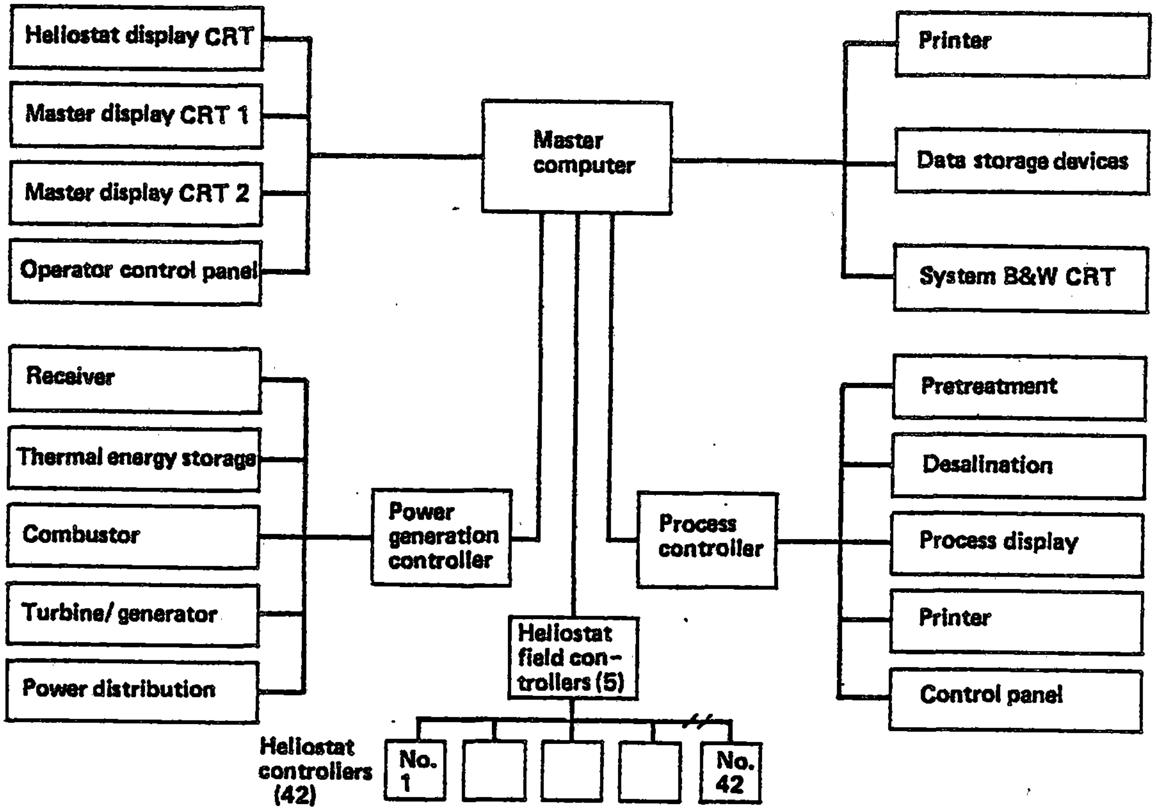
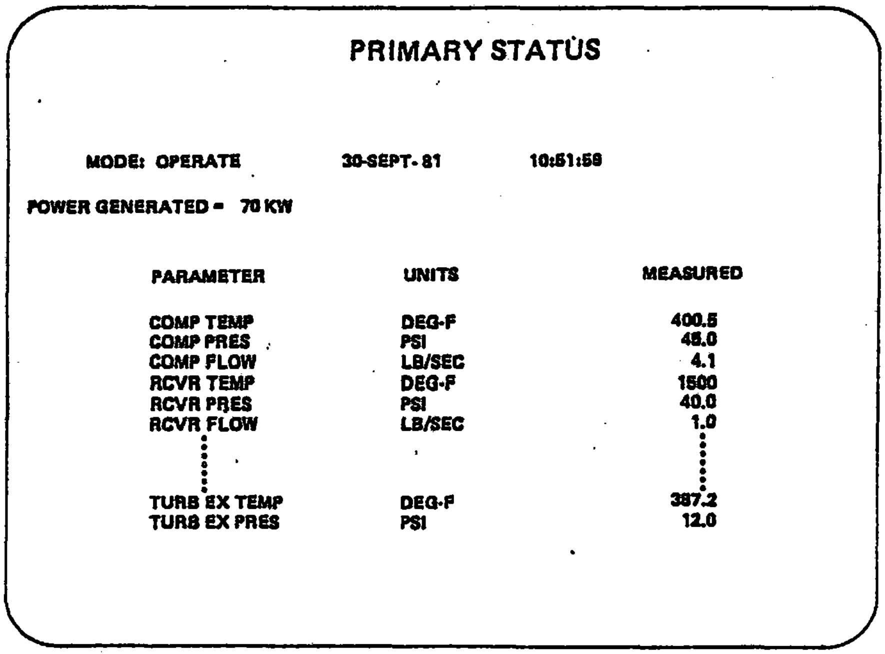


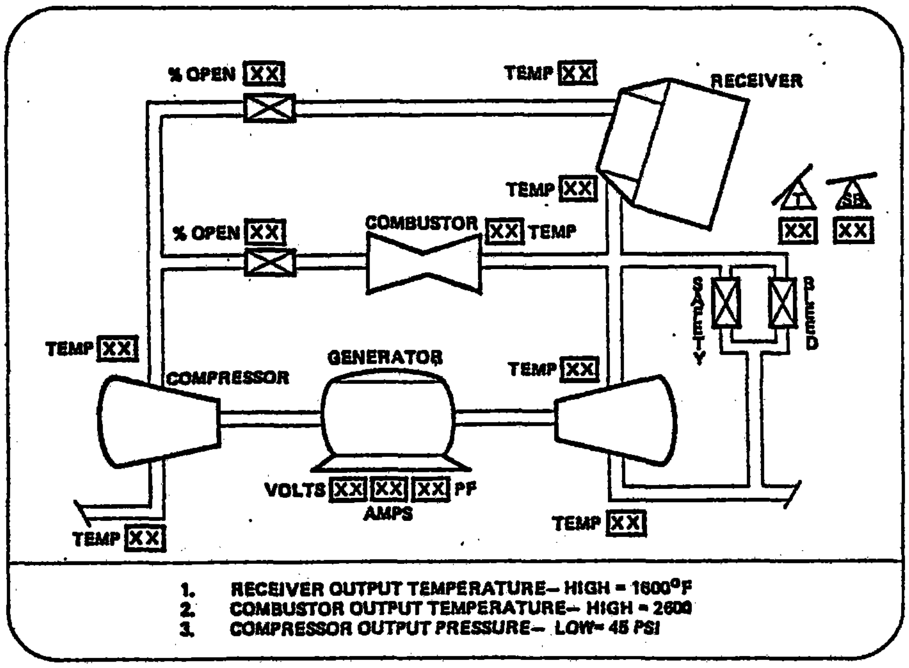
Figure 13-2. Plant Control System Block Diagram



```
                        PRIMARY STATUS


   MODE:  OPERATE          30-SEPT- 81        10:51:58

POWER GENERATED =   70 KW


        PARAMETER              UNITS                   MEASURED

        COMP TEMP              DEG-F                    400.5
        COMP PRES              PSI                       45.0
        COMP FLOW              LB/SEC                     4.1
        RCVR TEMP              DEG-F                     1500
        RCVR PRES              PSI                       40.0
        RCVR FLOW              LB/SEC                     1.0
            :                                              :
            :                                              :
        TURB EX TEMP           DEG-F                    387.2
        TURB EX PRES           PSI                       12.0
```

Example from FSE Program

Figure 13-3. Master Control System Color Status Display



1. RECEIVER OUTPUT TEMPERATURE– HIGH = 1600°F
2. COMBUSTOR OUTPUT TEMPERATURE– HIGH = 2600
3. COMPRESSOR OUTPUT PRESSURE– LOW= 45 PSI

Figure 13-4. Master Control System Color Graphic Display

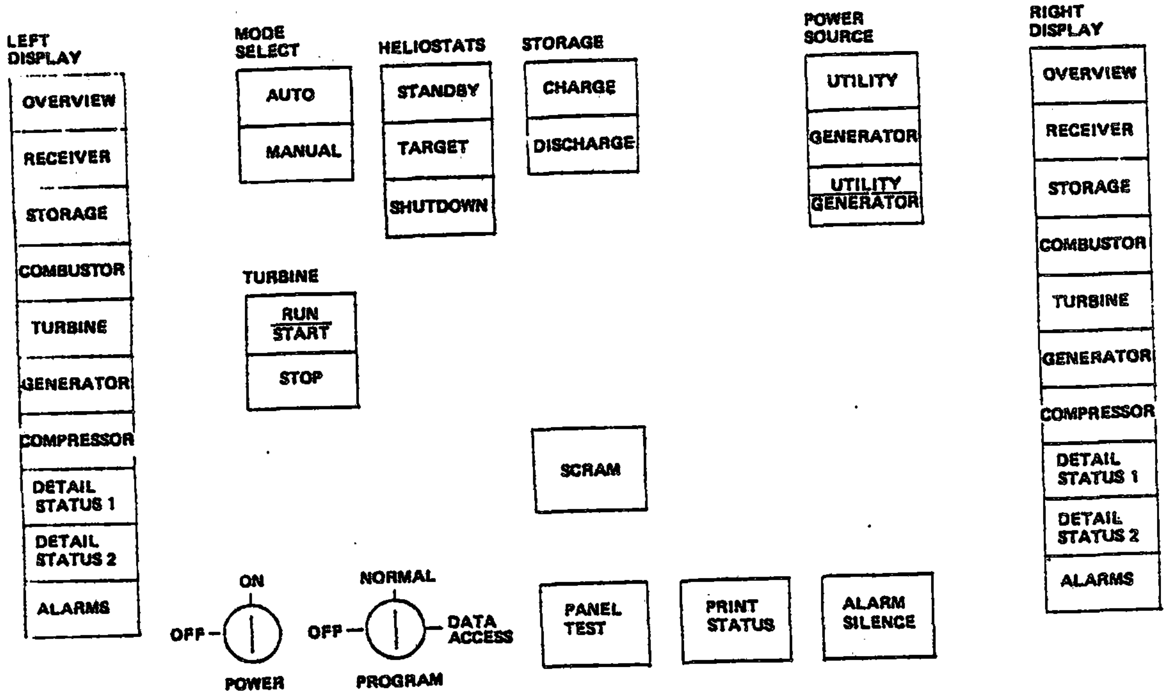


Figure 13-5. Power Generation Operator Control Panel – BEC Configuration

The master control system operation is separated into three functional groups: coordinate subsystem activity, predict plant performance, and provide operator interface for power generation:

Coordination of system activity for water treatment involves production management, by adjustment of the water production rate proportional to the solar power available. Also, equipment maintenance scheduling is required and must be brought to the attention of the operator.

Power generation is coordinated by setpoint control to the electric power generation system controller for the various operating points as a function of plant status. Heliostat coordination activities include performing the ephemeris calculations and heliostat mode control.

Prediction of plant performance is based on the knowledge of current weather inputs and insolation levels along with the expected water demand and water reserves. Based on these inputs a best estimate for time of power source switchover can be determined and automatically transferred. Further, based on current solar day knowledge and expected weather a best estimate of startup time for the next period of operation can be made.

The operator will obtain displays of operating status and data of the heliostat field and power generation systems. Requests for displays on the three multicolor CRT's will be input through the operator control panel.

The PDP 11/44 master control system baseline computer has a dual hard disk memory of 28 megabytes. Included with this system is a VT100 black and white CRT terminal for system programming and monitoring. The master control computer will be interfaced to data acquisition subsystem hardware: Magnetic tape drive and a DEC LA120 keyboard/printer.

Selection of this system was based on the high reliability experienced in BEC's previous usage of DEC's equipment, the low cost to performance ratio, and the flexible realtime operating system software developed by DEC. BEC has considerable experience with similar DEC systems, which provides confidence in a successful control system development.

13.2 Water Treatment Process Control System

The water treatment process control system components are the process controllers, the process display CRT, the dedicated water treatment process printer and the operator control panel. This process control system was developed by Rosemount, a large manufacturer of process system, and is the Rosemount Diogenes™ system. Components of this system are the Model 25 video display station, analog input/output modules, process backup units, and the discrete input/output modules, shown in Figure 13-6.

This system was selected because it is fully developed and because it has manual operation backup capability. The Diogenes system is tested and proven and has been utilized extensively in industry for various commercial operations. This system has the capability that, if the process controller fails, the backup units hold the present operating setpoints and can be switched over to run as a manually operated station. Thus, water production will continue even in the event of a failure of the process controller.

System interface with the operator is through the video display, with three levels or pages of alphanumeric and graphical display being presented. The highest level of display is the system operational overview, the second level of display is the group page which can be considered a subset of the previous level and the third is the component level where individual parameters can be monitored. Selection of a display level is made by the operator though the operation control panel by simple push-button selection. All operator inputs for process control, such as valves open/close and pumps on/off, and control loop tuning while the water treatment system is operational are made through the operator control console.

13.3 Heliostat Control System

The heliostat control system is a three-tier heirarchy control system. The three tiers of control are the heliostat array control, the heliostat field control, and the heliostat control, as shown in Figure 13-7.

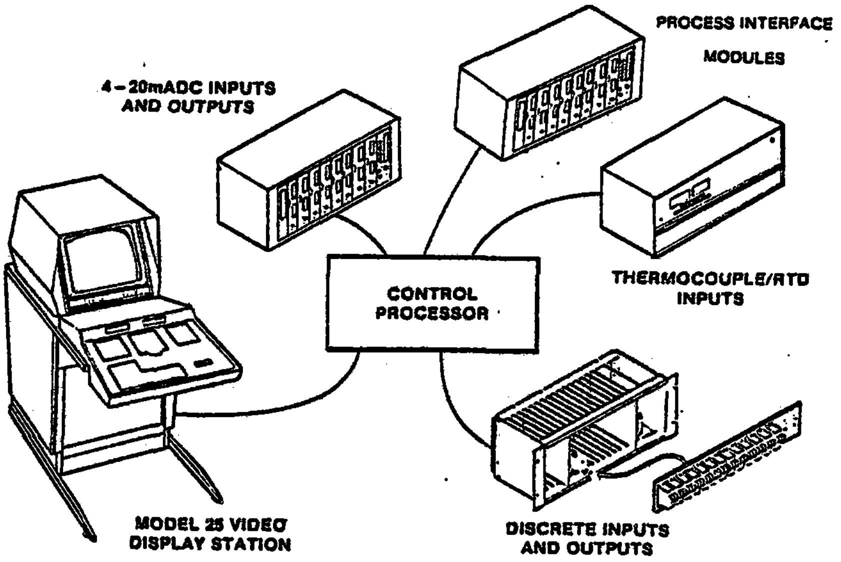


Figure 13-6. Water Treatment Process Control System Rosemount Configuration

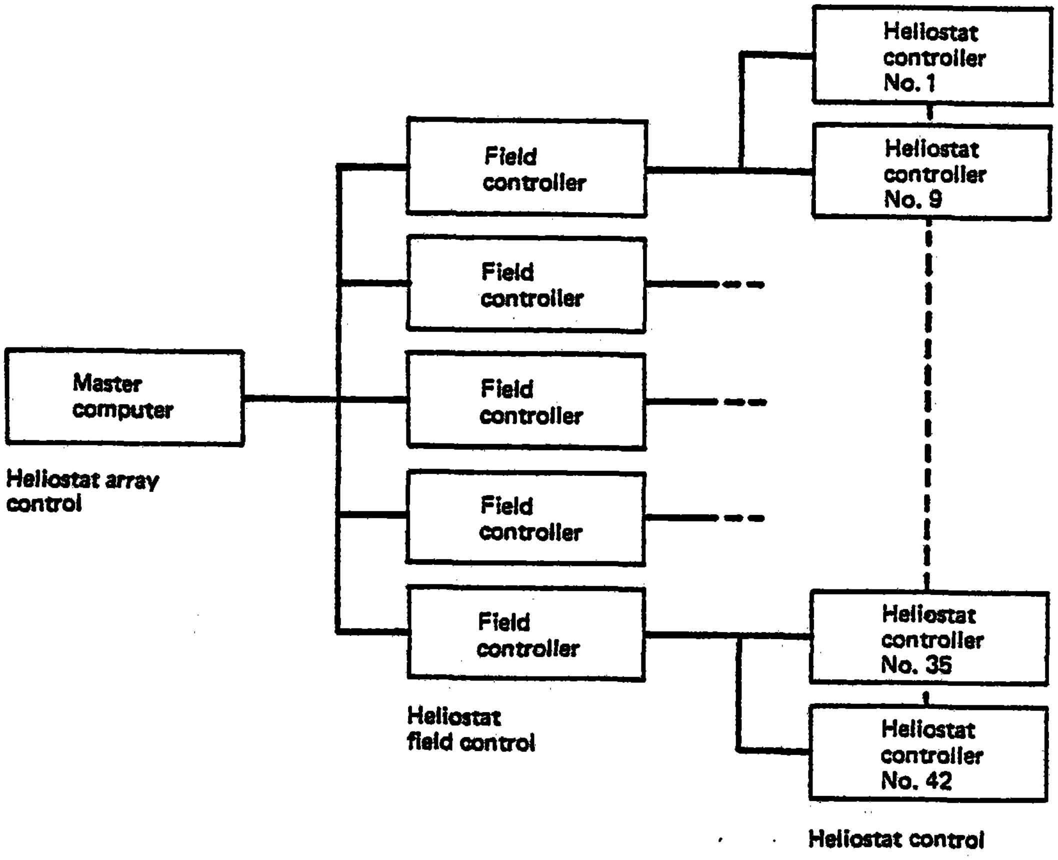


Figure 13-7. Heliostat Control System Functional Diagram

The heliostat array control determines the field controller assignments based on the time of day, which field is operational, and which group of heliostats will give the highest performance. In addition, the array controller must generate the graphical field display and perform the operator interface functions for requests such as addition or deletion of heliostats. Solar position calculations and the required communications to the field controllers are other functions of the array controller. The heliostat array control functions will be implemented as software within the master control computer due to the limited size of the heliostat field and associated computation.

The field controller functions include heliostat priority assignments, based on energy requirements, position calculations, and generation of pointing commands, for each heliostat to be at standby or on target as well as the required communications to each heliostat. The field controller configuration was selected to be of a segmented fail-safe design arrangement as compared to a redundant backup fail-operational configuration. This configuration was chosen because it is the most cost effective.

The heliostat controller provides directional control and motor on/off commands. The controller also performs gimbal limit interlock functions and the required closed loop communication for closed loop positional control. The heliostat controller has been designed for fail-safe operation which includes automatic shutdown positioning in the event of loss of communication.

The heliostat field controller and heliostat controller configurations are based on a Texas Instruments TMS 9995 microprocessor chip, as shown in Figures 13-8 and 13-9. The heliostat controller is a second generation design which is currently being operationally tested. These tests will prove the design concept and life cycle performance.

13.4 Electric Power Generation Control

The electric power generation (EPGS) control system interfaces with the receiver, the thermal energy storage unit, the combustor, the turbine generator set, and the switch gear for power distribution. The power generation controller is purchased as part of the turbine generator package from Solar Turbines International (STI). Development of this system is being done under an EPRI contract for the Full System Experiment (FSE).

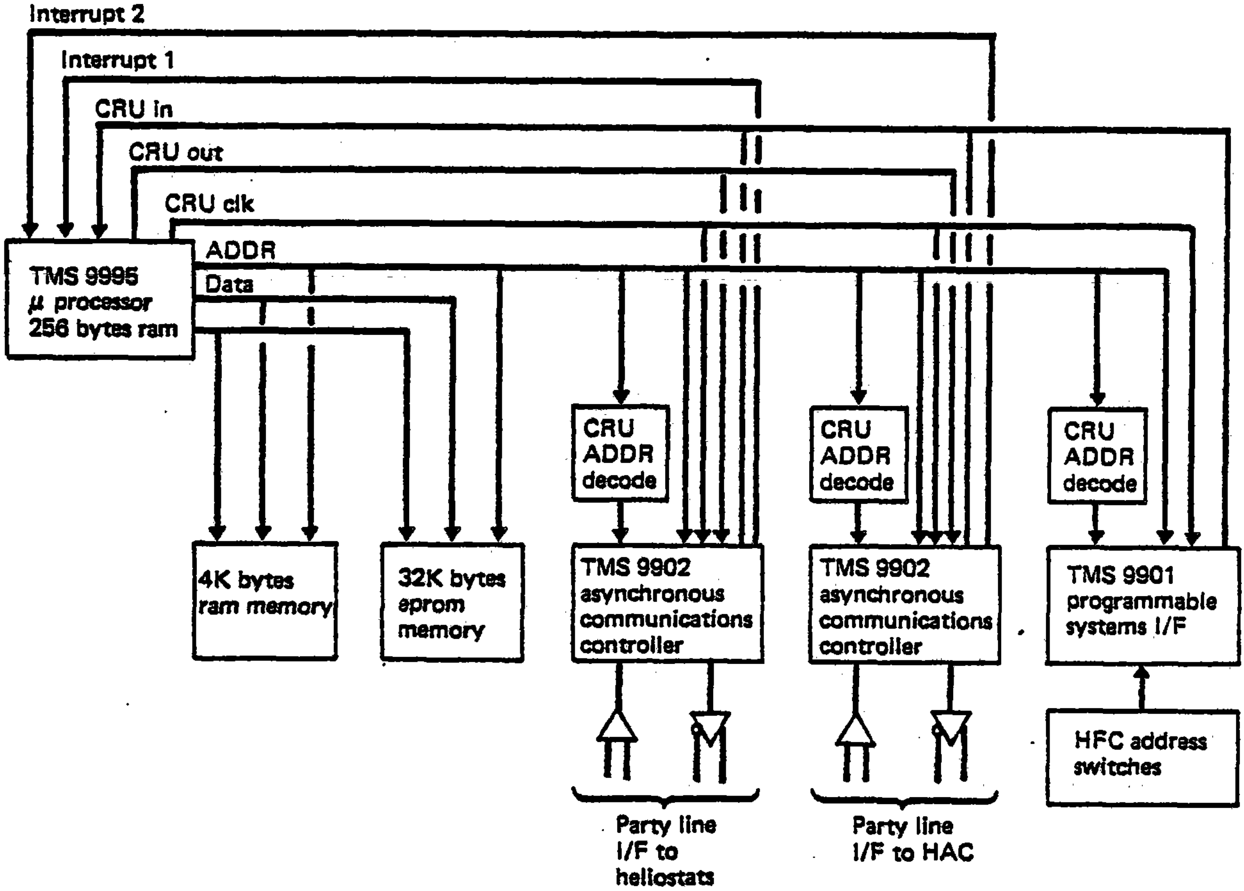


Figure 13-8. Field Controller BEC Configuration

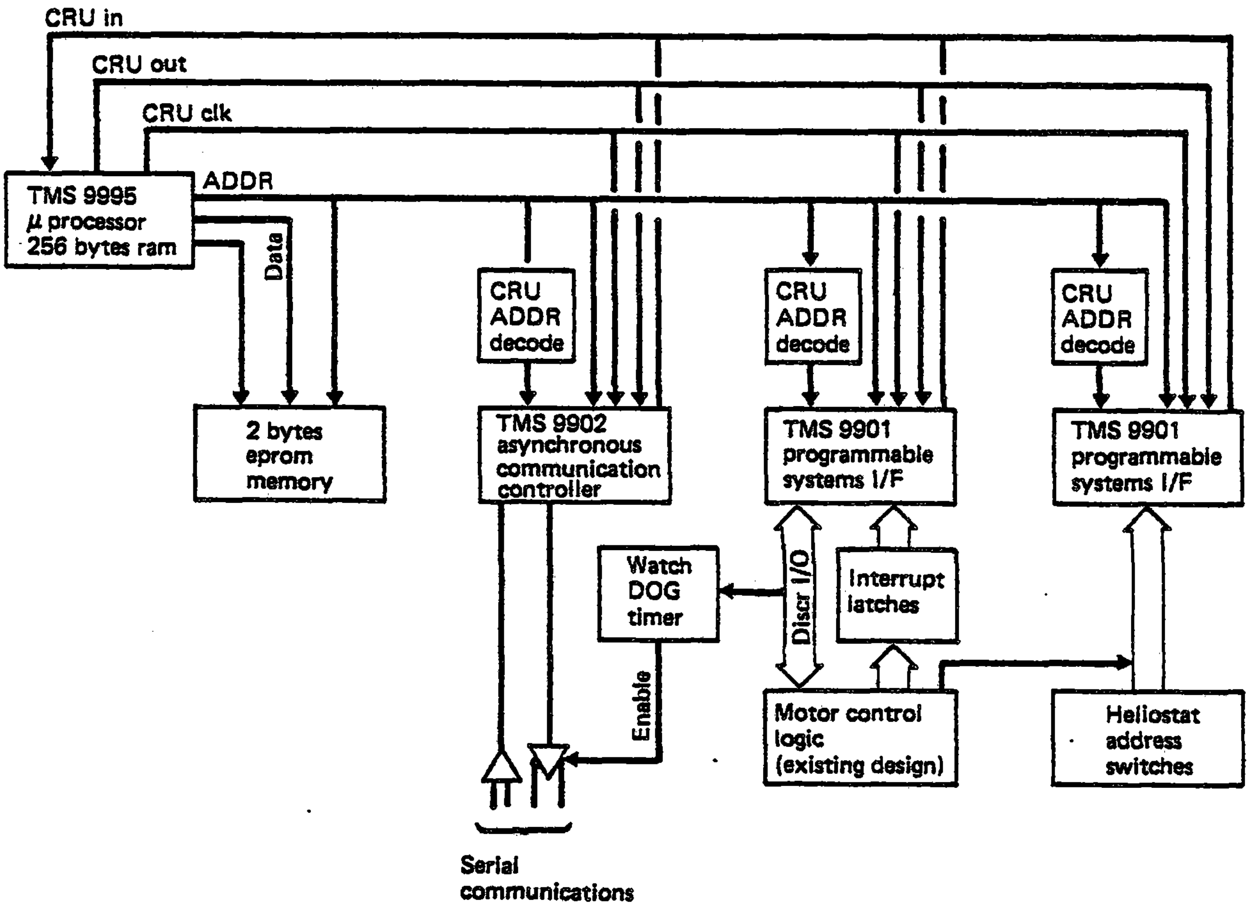


Figure 13-9. Heliostat Controller BEC Configuration

A functional diagram of the EPGS controller is given in Figure 13-10. Component functions will be controlled throughout all the operational modes listed in Table 13-1. A detailed description of operation for each operational mode, including flow diagrams, will be generated during the detailed design phase.

The EPGS controller shown in Figure 13-11 is a multiple microprocessor based design, based on the INTELL 8085 microprocessor chip, and is a single board computer. As shown in the figure, the primary microprocessor controls and monitors the power generation elements of the EPGS and the secondary microprocessor is utilized for serial transmission control with the master control computer.

In addition to the electric power generation control, the EPGS controller will control the switchgear equipment, as required for electric power distribution.

13.5 Instrumentation

The preliminary instrumentation requirements are shown for the Electric Power Generation System and the Water Treatment systems in Figures 13-12 and 13-13, respectively. Further, a preliminary instrumentation list is given in Table 13-2 which shows the item and its intended use. Refer to RCC drawing 171-M4-1 in the Appendix for instrumentation associated with the water treatment subsystems.

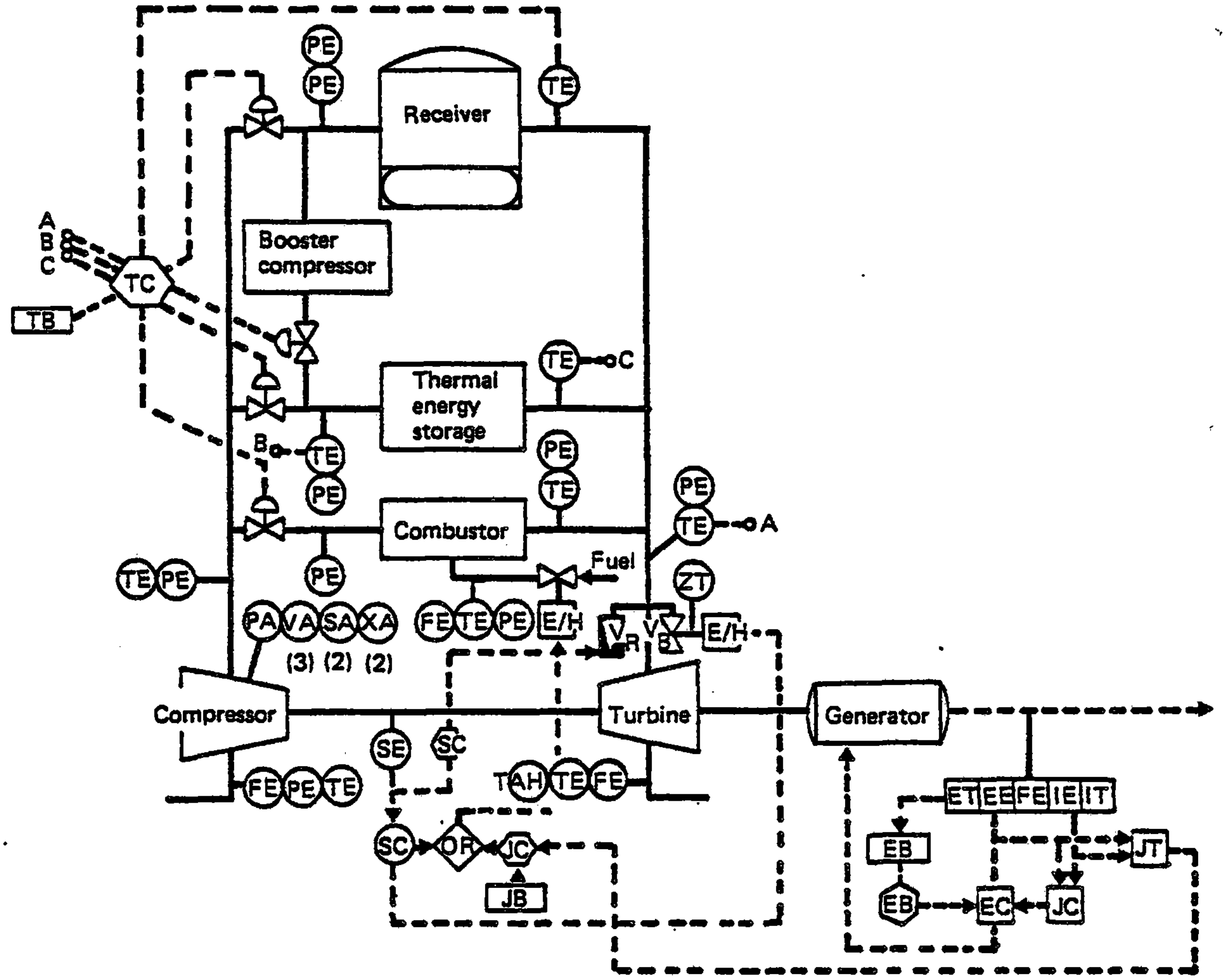


Figure 13-10. Electric Power Generation System Functional Diagram

Table 13-1. Plant Solar Operating Modes

- Starting
- Starting to TES transition
- TES discharge to receiver transition
- Receiver
- Receiver + TES charging transition
- Receiver + TES charging
- Receiver + TES charging turnoff transition
- Receiver
- Receiver + TES discharge transition
- TES discharge
- Shutdown
- Emergency shutdown

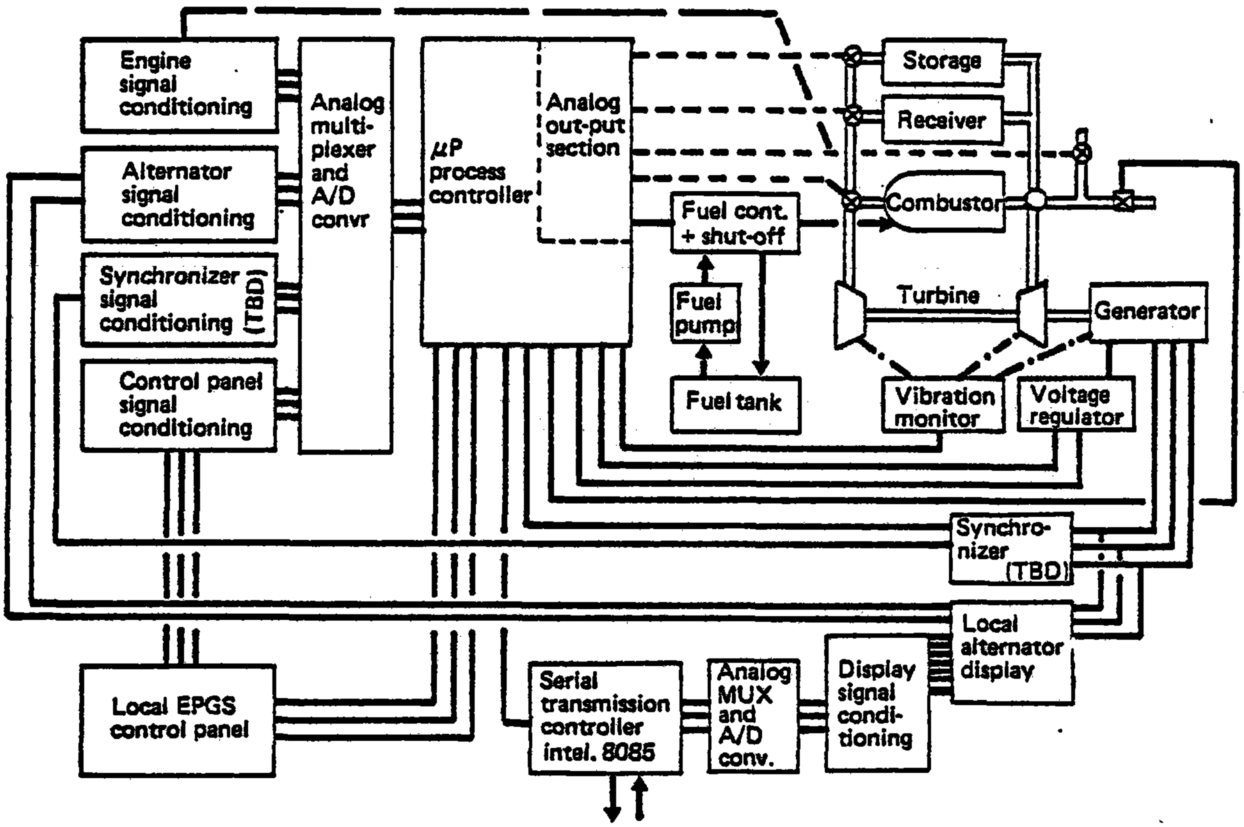


Figure 13-11. Electric Power Generation System Controller

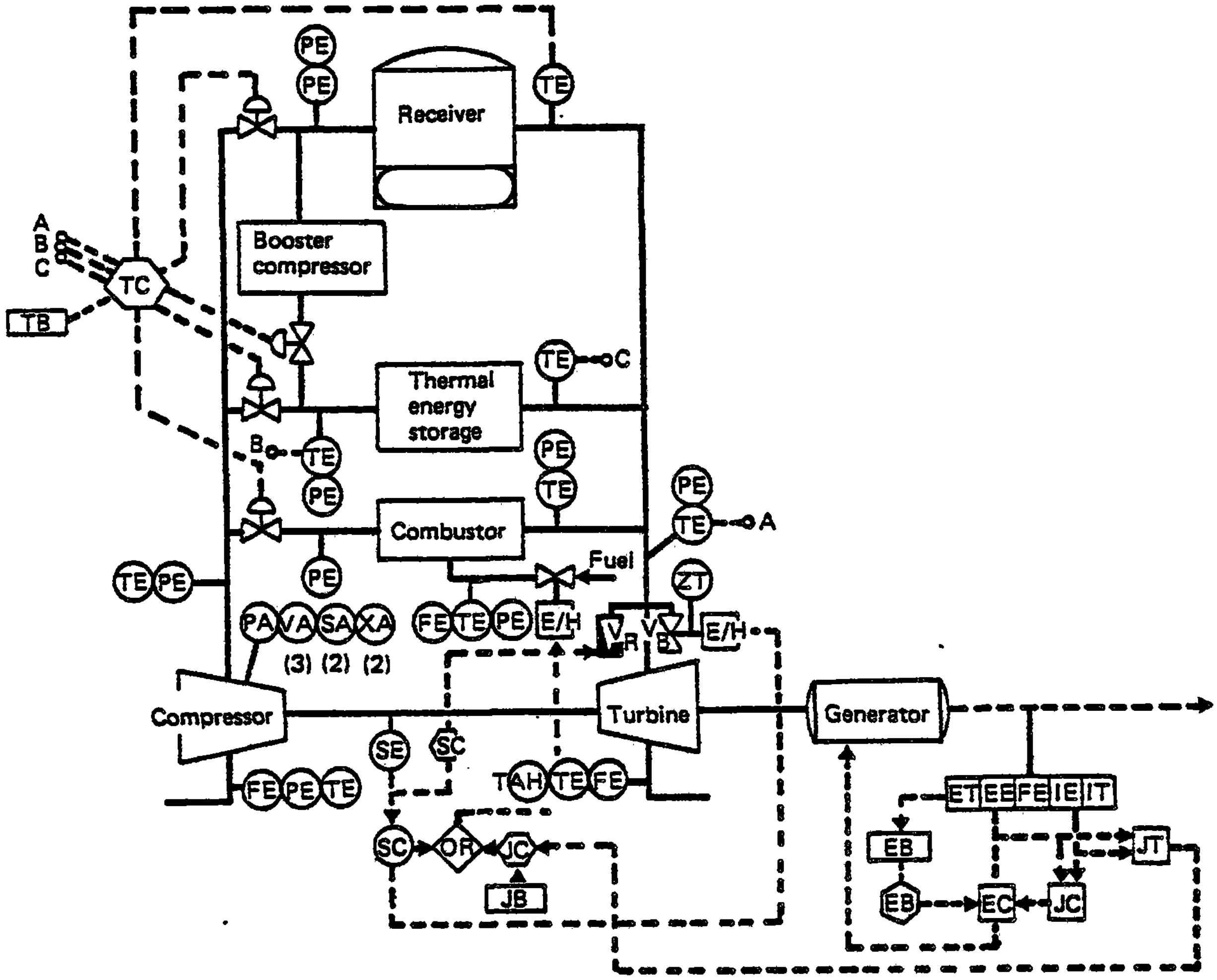


Figure 13-12. Electric Power Generation System Functional Diagram

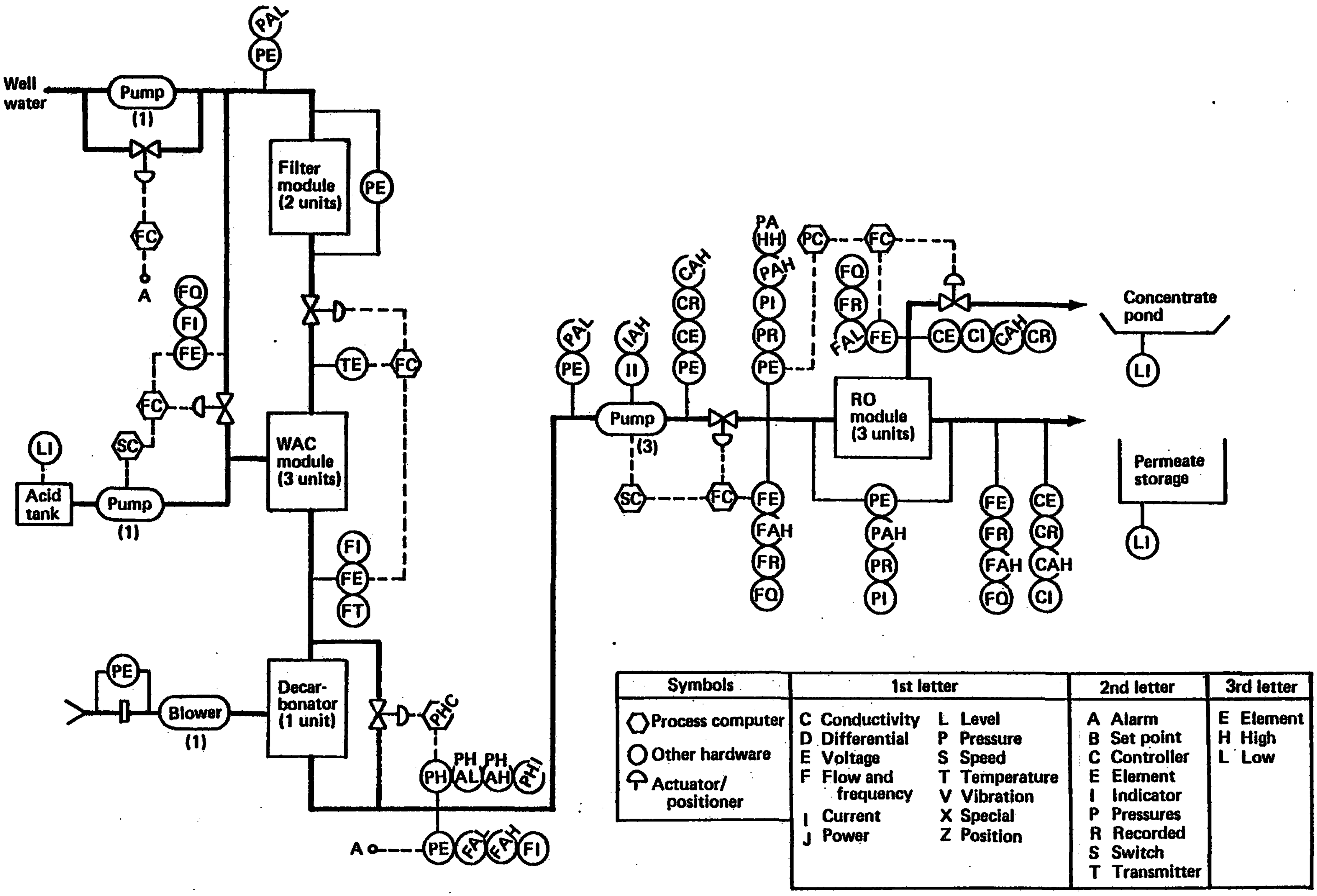


Figure 13-13. Water Treatment Process Control Functional Diagram

Table 13-2. Measured, Controlled and Alarmed Process Parameters

Power Generation	Display	Control	Alarm
Compressor			
Measurements			
Inlet flow	M		
Inlet pressure	M		
Inlet temperature	M		
Outlet pressure	M		
Outlet temperature	M		
Discretes			
Speed high		D	
Speed low		D	
Vibration high (3)		D	L
Overchank		D	H
Charger failure			F
Combustor			
Measurements			
Inlet pressure	M		
Outlet pressure	M		
Outlet pressure	M		
Fuel flow	M/T		
Fuel temperature	M		H
Fuel pressure	M		L
Thermal Energy Storage			
Measurements			
Inlet temperature	M	C	L
Outlet temperature	M	C	L/H
Outlet pressure	M/R		
Receiver			
Measurements			
Inlet flow	M/R		
Inlet pressure	M/R		
Outlet temperature	M/R	C	H

Table 13-2 continued

	Display	Control	Alarm
Turbine			
Measurements			
Inlet pressure	M/R		
Inlet temperature	M/R	C	L/H
Outlet flow	M		
Outlet temperature	M/R		H
Bypass valve position		C	
Shaft speed	M	C	L/H
Generator			
Measurements			
Output voltage (3)	M	C	L/H
Output current (3)	M	C	H
Output frequency	M		
Water Treatment			
Feed Pump			
Measurements			
Outlet pressure	M		L
Filters (2)			
Measurements			
Inlet/outlet diff. pressure	M		
WACS (3)			
Measurements			
Inlet temperature	M	C	
Outlet flow	M	C	
Acid System			
Measurements			
Acid tank level	M		
Dilution water flow	M/T	C	

Table 13-2 continued

	Display	Control	Alarm
Carbonator			
Measurements			
Outlet flow	M		L/H
Outlet pH	M	C	L/H
RO Pumps			
Measurements			
Inlet pressure	M		L
Outlet pressure	M		
Outlet conductivity	M/R		H
Motor current	M		H
RO Module			
Measurements			
Inlet pressure	M	C	H/HH
Inlet flow	M/T	C	H
Inlet/permeate diff. press.	M		H
Permeate flow	M/T		H
Permeate conductivity	M		H
Concetrate flow	M/T		L
Concetrate conductivity	M		H
Miscellaneous			
Permeate storage level	M		

Functions:
M = Monitor
R = Record
T = Totalize
C = Continuous
L = Low
H = High
D = Discrete
F = Failure

14.0 DATA ACQUISITION SUBSYSTEM

The data acquisition subsystem will be designed to interface with the master control computer and to acquire and record the process parameters identified previously in Section 13.5. Actual data acquisition and preliminary data processing will be performed by the peripheral controllers: electric power generation controller, heliostat array controller and the water treatment controller. Also, data will be manually input to the master control computer by the operators. The data will be processed by the master computer and then transmitted to a data storage device or printer. An operator log system will be maintained and coordinated with processed data. In addition to the data defined in Section 13.5, the following data will be recorded:

Insolation level
Energy production rate
Feedwater supply rate and cumulative volume
Pretreatment rate and cumulative volume
Pretreatment waste rate and cumulative volume
Desalination product-water rate and cumulative volume
Desalination waste rate and cumulative volume
Potable water tank storage level
Potable water feed rate to Rankin and cumulative volume
Status of energy storage system
Ambient conditions; temperature, wind speed and direction, and relative humidity
Comments as to problems, repairs made, work to be done, storage tank levels, reasons for units off line, etc.

15.0 SITE AND FACILITIES

15.1 Site Description

The pilot plant site is 0.8 km north of the city of Rankin, Texas, on State Highway 349. As shown in Figure 15-1, Rankin is located in the western part of Texas in an area that is semi-arid. Rankin is the county seat of Upton County and has a population of 1300. The city and surrounding area obtains potable water from the Upton County Water District which is managed by the Upton County Board of Commissioners. The site is deeded to the Water District and is legally described as being in Section 23, Block B, HE & WT Railroad Company survey. The site has an area of 4.05×10^4 m^2 (10 acres) and has rectangular dimensions of 125 m (410.5 ft) by 323 m (1061 ft). The site is located at 101.93°W longitude, 31.93°N latitude and 579 m (1900 ft) altitude.

Figures 15-2 and 15-3 are photographs of the site; a site plan showing existing features and topography is included in the appendix. Esmond-Haner, an A&E firm in Odessa, Texas, performed the site survey and prepared the site plan for BEC. This site is nearly level accept for a depression in the northeast corner (beyond the helisotat field). Soil conditions are classified as hard: outcropping cap rock (fractured limestone) with scattered thin soil cover. Vegetation consists of low-lying grass and brush.

Existing facilities that will be retained and modified for the pilot plant are:

1136 m^3 (300,000 gal) water storage tank
Operating water well
Pump house
Below-surface vault containing water line connections and pressure controller
1036 m (3400 ft) underground 25.4 cm (10 in) water line to Rankin via easement owned by Upton County Water District

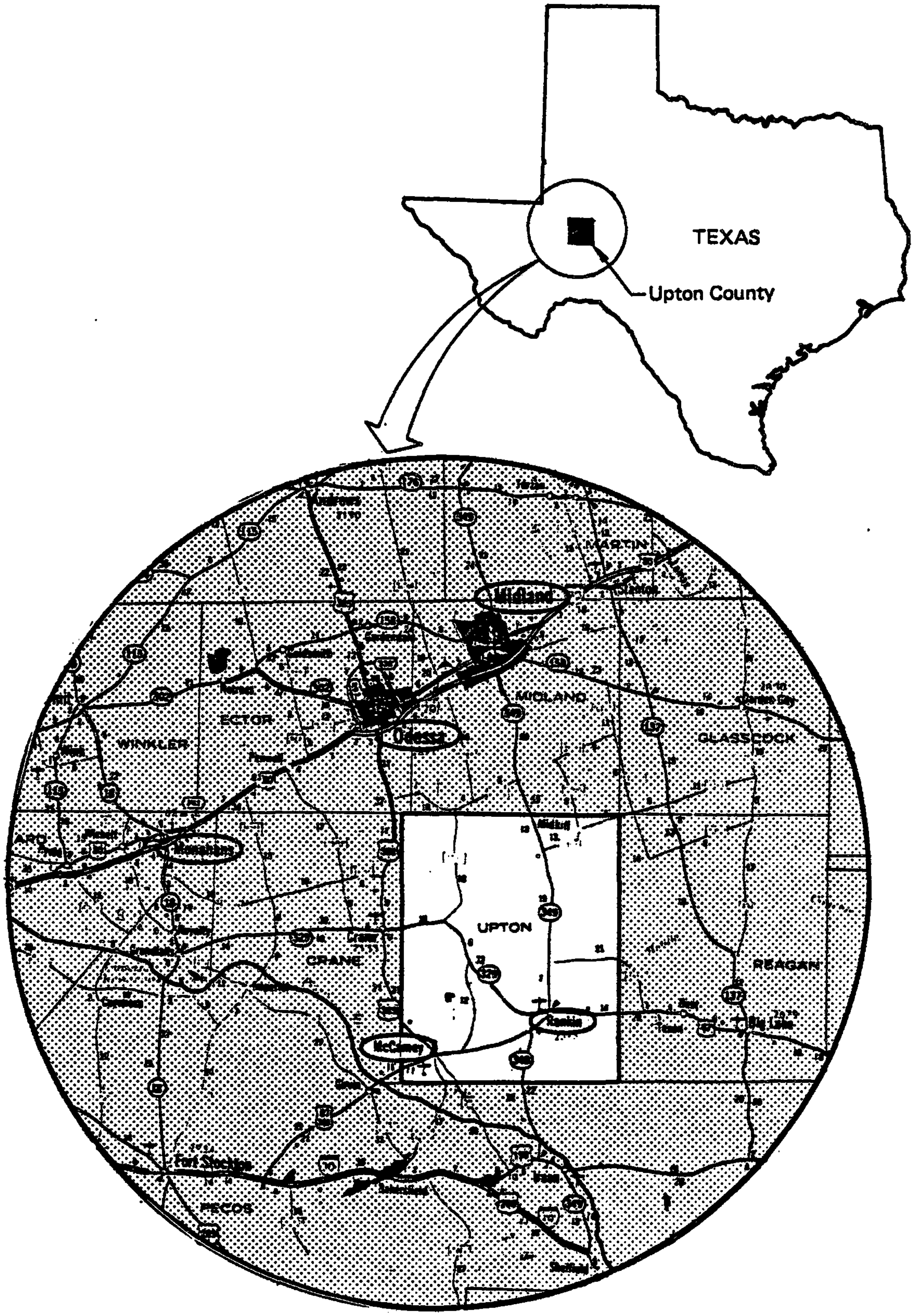


Figure 15-1. Location of Rankin—Selected Site for Pilot Plant

Figure 15-2. View from Top of Tank Towards Future Heliostat Field

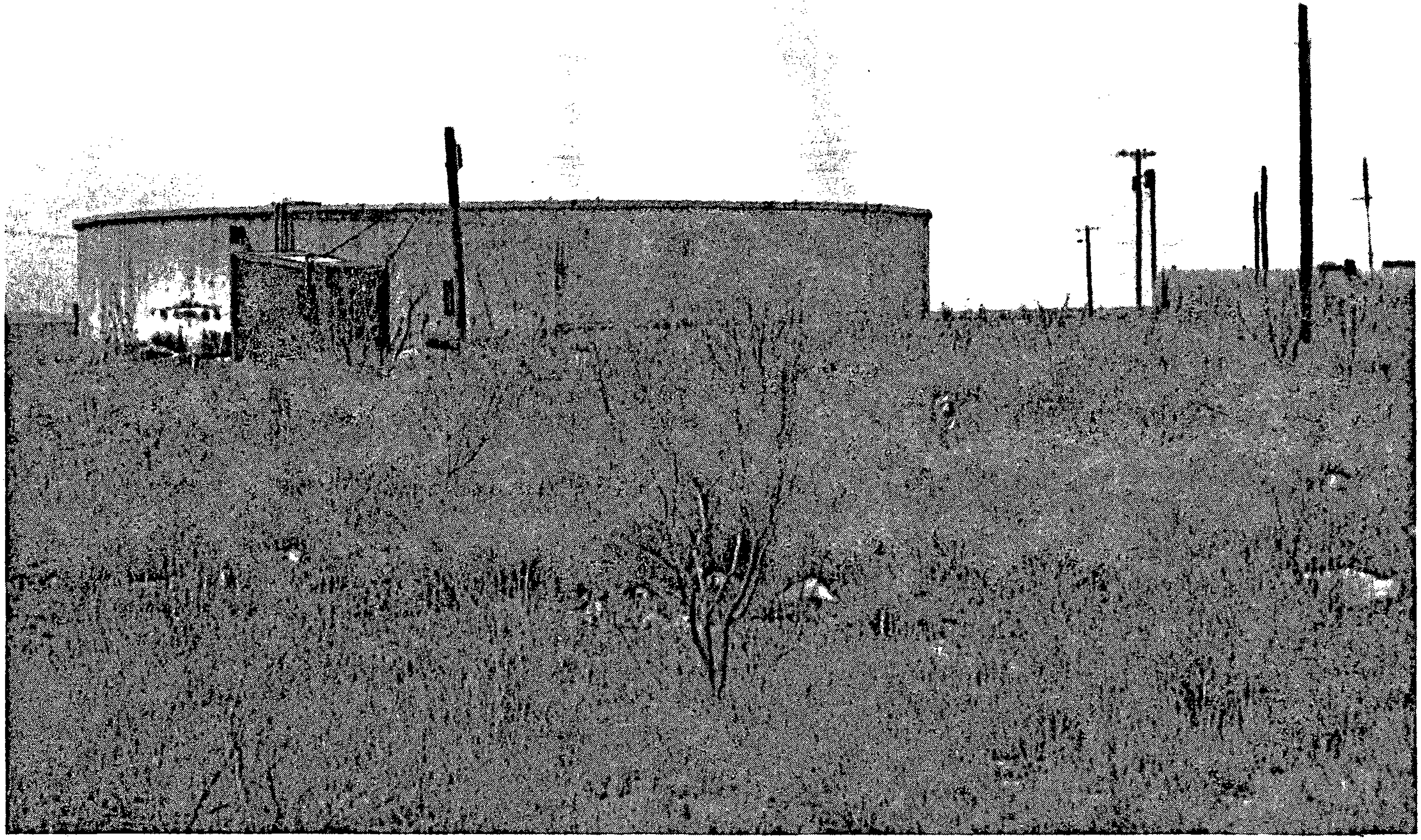


Figure 15-3. Existing Water Supply Tank

Utilities that are available at or near the site are:

Utility	Supplier
Natural gas	Rankin Gas Company (city owned)
Electricity 480V 3 phase 4 wire	West Texas Utilities
Telephone	Southwestern Bell Telephone

Located north of the property is an oil field maintenance business which has buildings and equipment yards. (Esmond-Haner performed engineering services for construction of this facility). Southwest of the property, next to the highway, is a residence. These adjoining properties and facilities have little if any impact on the pilot plant.

15.2 Plant Building

The building planned for the pilot plant is a pre-engineered insulated metal type which is available from local contractors. BEC Drawing 277-10360 shows the building's general features and allocation of floor space. The building is divided into a high bay area for water treatment and equipment and a low bay area for a control room and office facilities. Floor areas are 204 m^2 (2200 sq ft) for high bay, 93 m^2 (1000 sq ft) for low bay, and 297 m^2 (3200 sq ft) total area. Components and contents of the building are:

Foundation
Building Structure (Pre-Engineered)
Control Room with Raised Floor
Office/Meeting Room
Water Treatment Room
Mechanical/Electrical Room
Lavatory
Entry
Water Quality Laboratory Bench
Maintenance Bench
Supplies Storage

Fire Protection System
Electrical Power
Lighting
Air Conditioning/Heating
Sanitary Sewer
Brine Concentrate/Ion Exchange Softening Waste Floor Drains
Telephone
Plumbing

15.3 Site Work

Routine site preparations will be required for the pilot plant. Minor grading will be done to clear bush, make construction driveways, prepare for the building driveway/parking paving and to remove soil where concrete foundations will be poured. Boring machines will be used to drill holes for heliostat pedestals, tower support caissons, thermal energy storage support caissons, and power poles, and fences. Trenches for cables, piping and foundation slabs will be prepared using trenching machines. Trenching will also be done in the easement leading to Rankin alongside the existing water line where the previous backfill is soft (this easement is rocky and was blasted previously). A new product water lines and a sewer line (to be used for brine waste disposal into the Rankin sewer system) will be installed alongside the existing water line which will become a feedwater line.

16.0 OPERATIONS AND MAINTENANCE

16.1 General

After construction, and acceptance testing, BEC plans to operate and maintain the pilot plant for a period of 18 months This operation and maintenance period will consist of short-term and long-term tests for the purpose of performance evaluation, development of data for commercial plant design, and development of pilot plant operating strategies for subsequent operation by Upton County Water District.

During operation and maintenance, the pilot plant will be operated in a dispatch mode. Test activities will receive precedence. Maintenance will be performed in the same manner as for an operating utility (in those instances where contract maintenance is recommended during utility operation, it will also be used during the operations and maintenance period).

16.2 Plant Operation

The pilot plant approximates a dispatch-type, commercial solar powered water desalination system. Such a plant would be operated less than 24 h/d, but could be expected to be dispatched every day. The functions to be performed by the system to accomplish the dispatch are shown in Figure 16-1.

For small scale stand alone water desalination plants, one expects diurnal and seasonal variations in water use. Based on estimated consumption in 1980, Rankin's seasonal variation in average daily consumption is shown in Figure 16-2. No data are available to show diurnal (e.g., hourly) demand variation. This consumption includes curtailable watering of a golf course and football field. The golf course consumption occurs upstream from the pilot plant so the net potable water required by Rankin peaks at about 1200 m^3/day. The turndown capability of the pilot plant provides a range of output from about 212 -1270 m^3/day which provides a reasonable approximation to Rankin's demand.

The expected operational sequence (disregarding any special or planned testing) would be as shown in Table 16-1. An example of a dispatch for June

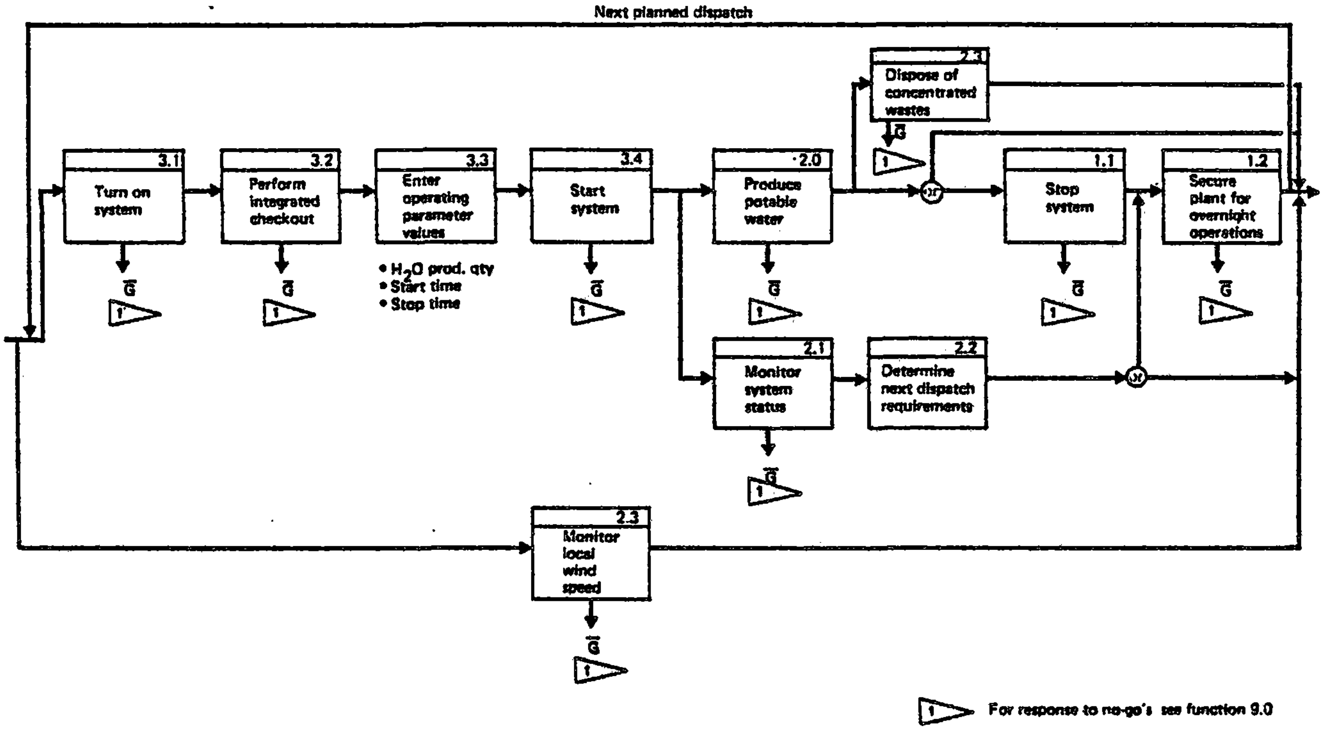
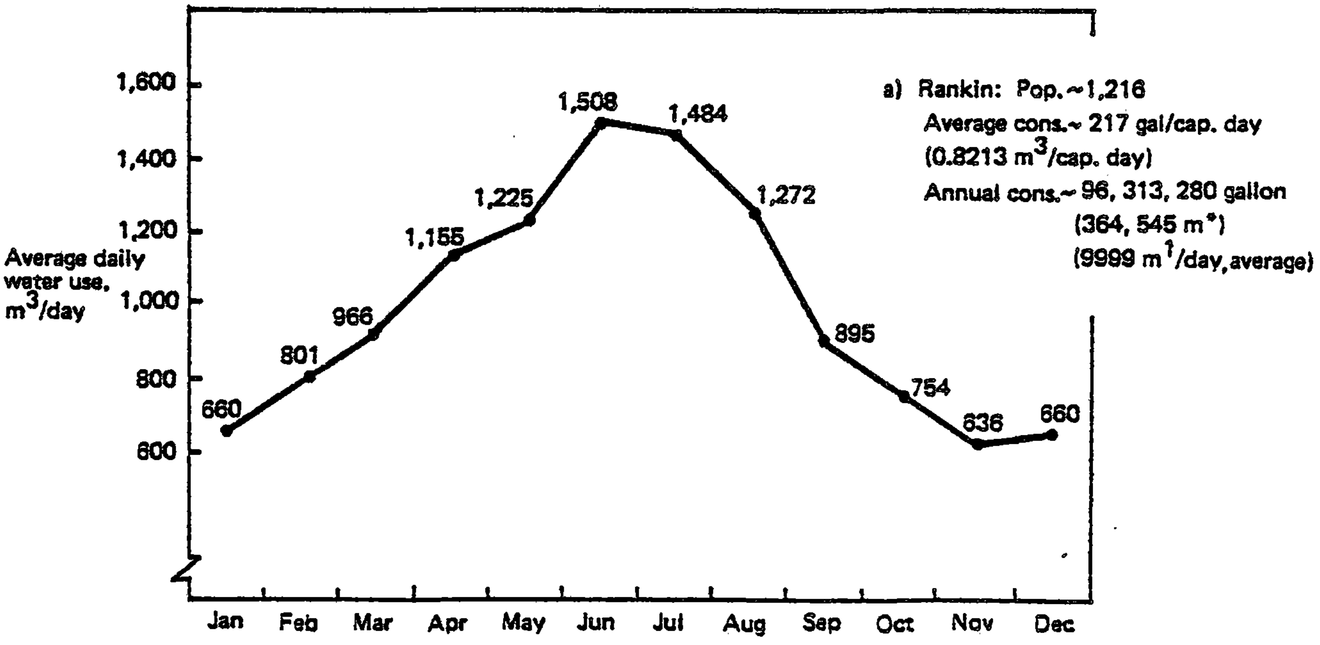


Figure 16-1. System Dispatch Functions



Source: Table 2.1.1-2. and Figure 2.1.1-4. of technical proposal, volume 1, page 14; and derived

Figure 16-2. Estimated Variation in Average Daily Water Use, Rankin, Texas, 1980

Table 16-1. *Expected Daily Operations*

- First shift operations
  - Initialize system
  - Review readiness for dispatch
  - Start system
  - Produce water as required*
- Second shift operations
  - Review water production status
  - Shutdown plant**
- Third shift operations**
  - Review water production status
  - Shutdown plant**

*May include shutdown of collector
** Depending on water demand

Table 16-2. *Operating Sequence for June 15th Dispatch*

Time	Event/action (Over-night shutdown)
0630	Turn on system
	Perform integrated checkout
	Initialize all subsystems
	Start turbine
	Transition turbine to tess heat
	Power up collector, bring to standby
0700	Begin receiver heatup
	Transition from tess to solar heat
0730	Turn on water subsystem, produce at variable rates
	Store/extract thermal energy
1800	Transition from solar to tess heat, shut down collector/receiver
0100	Shut down water subsystem
0130	Shut down plant

16 might be as shown in Table 16-2. In the dispatch shown in Table 16-2, only two shifts of water production were planned. Depending on water demand, a third shift could be added with water production from the external electric utility power.

Based on 1978 insolation data for the Midland, Texas and the plant performance model described in Section 17, the expected pilot plant subsystem utilization for a typical year is summarized in Table 16-3.

16.3 Plant Availability

The pilot plant system requirements specification (paragraph 3.2.1 of S277-10243-1) establishes the availability requirements. During the detail design phase, these requirements will be allocated to each subsystem. However, it is possible to make some availability estimates based on the pilot plant preliminary design.

To estimate system availability, the following models are used:

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

where MTBF is the mean time between failures of the system, subsystem or component, and MTTR is the mean time to repair the same system, subsystem or component.

Reliability is evaluated using the expression:

$$\text{Reliability} = e^{-\lambda t} \quad ,$$

which is based on the Poisson probability mass function. The assumption is made that all qualifications for a Poisson process are satisfied.

In order to evaluate the pilot plant availability, initial estimates of the underlying failure rates were made. The sources of the estimates for the major subsystems are shown in Table 16-4. The resulting operating and non-operating MTBF's and associated MTTR's are summarized in Table 16-5.

Table 16-3. Expected Pilot Plant Subsystem Utilization

Subsystem or segment	Expected yearly number of hours*		
	Operating	Non-operating	Starts/other
Solar energy segment			
Collector			
Heliostat gimbal/mtrs	2690	6076	–
Controllers	8766	–	–
Receiver	2560	6206	262
Heat transport compressor	1900	6866	–
Thermal storage segment	3910	4856	–
Electric power generation segment	4610	4156	262
Electric power distribution segment	8766	–	–
Water desalination segment	6310	2456	**
Master control and communication			
Wind sens./TM-DTE rcvr	8766	–	–
Main computer	8766	–	–

* Based on 1978 insolation

** Assumes no water produced on cloudy days

Table 16-4. Sources of Reliability Information

Item	Sources
Turbo-generator set	• Solar Turbines Int. data
Solar energy segment	• Boeing experience analysis center • Previous BEC studies (heliostat, ACR, etc.) • Engineering judgement • MIL-HNDBK-217B
Water desalination segment	• Engineering judgement • General literature • MIL-HNDBK-217B
Electric power dist. segment	• Electric power system reliability texts • General literature • Proceedings of elect. power industry reliability conferences • MIL-HNDBK-217B
Master control/comm. segment	• MIL-HNDBK-217B • Engineering judgement

The reliability and maintainability values shown in Table 16-5 were used to calculate estimates for the specified values in paragraph 3.2.1 of S277-10243-1. The estimates were developed based on simplified (serial) reliability and availability models according to the matrix shown in Table 16-6.

In Table 16-6, the subsystems which must function properly (or be available) to satisfy the specified values, are identified by an 'X' in the matrix. Using this matrix, the simplified models discussed above, and the MTBF and MTTR estimates listed in Table 16-5, the reliability and availability estimates for the pilot plant functions were developed; they are summarized in Table 16-7.

16.4 Maintenance Plan

Pilot plant maintenance will be conducted such that compliance with the requirements of System Specification S277-10243-1, paragraphs 3.2.1.7 and 3.2.4 can be verified.

During Phase 2B, BEC will perform maintenance supported by some contracted maintenance. Water utility personnel will be trained during Phase 3. Systematic transfer of maintenance responsibilities will take place so the utility can accept full responsibility at the conclusion of Phase 3.

Overall Maintenance Concept

After construction, pilot plant maintenance consists of scheduled and unscheduled actions to maintain the plant in an operational condition. BEC will establish a pilot plant repair capability consistent with the requirement of System Specification S277-10243-1 and with the intended support concepts to be implemented by the Upton County Water Utility.

As currently planned, BEC will perform scheduled and unscheduled maintenance on all pilot plant equipment, except for the turbine generator set. Maintenance on this item will be subcontracted to a firm in the general locale

Table 16-5. Pilot Plant Reliability and Maintainability Values

SUBSYSTEM SEGMENT	NUMBER PER	UNIT MTBF, HOURS		MTTR, HRS.	REPAIRABILITY		REMARKS
		OPERATING	NON-OPERATIING		REPAIR-ABLE	NON-REPAIR-ABLE	
COLLECTOR SUBSYSTEM							
HELIOSTAT	42	14,124	-	3.4	X		
FIELD CONTROLLERS	5	50,000	-	4.0	X		REPAIR IN PLACE
TIME/DATE RECEIVER	1	80,000	-	1.0	X		REMOVE/REPLACE
WIND SENSORS	1 SET	35,000	-	3.0	X		
DATA DIST. LINK	1 SET	150,000	-	16.0	X		FIELD REPAIR
POWER DIST. SYSTEM	1 SET	100,000	-	8.0	X		FIELD REPAIR
RECEIVER SUBSYSTEM							
TOWER	1	876,000	-	24.0	X		
RECEIVER	1	4,000	50,000	120.0	X		8 HR AVG. C-D
HEAT TRANSPORT SUBSYS.							
PIPES AND VALVES	1 SET	30,000	50,000	24.0	X		EX.RP;16 HR C-D
AIR COMPRESSOR	1	8,000	25,000	96.0	X		
THERMAL ENERGY STORAGE							
STORAGE TANKS/MEDIA	1	200,000	400,000	192.0	X		
ELECTRIC POWER GEN.							
MAIN TURBO-GEN.	1	4,285	10,000	96.0	X		
ELECTRIC POWER DIST.							
480 TRANSFORMERS	4	200,000	-	8.0	X		REMOVE/REPLACE
POWER SWITCHING	1 SET	125,000	-	6.0	X		
PLANT PWR. DIST.	1 SET	150,000	-	4.0	X		
WATER DESAL SEGMENT.							
FEEDWATER SUBSYSTEM	1 SET	25,000	50,000	12.0	X		
DESAL UNITS	3	10,000	30,000	4.0	X		
PERMEATE SUB.	1 SET	30,000	60,000	6.0	X		
WASTE TRMTN SUB.	1 SET	15,000	30,000	12.0	X		
MASTER CONTROL SEGMENT	1	3,778		16.0	X		
MASTER COMPUTER	1	60,000	-	8.0	X		
PROCESS COMPUTER	1	60,000	-	8.0	X		
DISPLAYS	3	40,000	-	4.0	X		
PRINTERS	2	35,000	-	12.0	X		
DATA STORAGE	1	60,000	-	4.0	X		
CONTROLLERS	2	50,000	-	5.0	X		
MISC. INTERCON.	1 SET	50,000	-	2.0	X		
DATA FINALS	1 SET	80,000	-	4.0	X		
SOFTWARE	1 SET	100,000	-	8.0	X		
INSTRUMENTATION	1	25,000	75,000	4.0	X		
MAINT. RESOURCE SEG.							
MAINT. SYS. EQUIP.	1 SET	7,000	30,000	24.0	X		
PERSONNEL SEGMENT							
OPERATORS	4	5,600	-	1.0	X		
MAINTENANCE	4	4,000	-	1.0	X		
STRUCTURE AND SITE							
AIR CONDITIONING	1	10,000	-	8.0	X		

Table 16-6. Reliability and Availability Matrix

Function	System elements required to perform function													Required values
	SES			TESS	EPGS	EPDS	WDS				MCCS	MRS	EDAS	
	Collector	Receiver	HTS				FWS	WTS	PWS	WTS				
3.2.1.1 Start (3.2.3.1)	–	–	–	–	X	X	–	–	–	–	X	–	–	R=0.95
Transitions (3.2.3.2)	–													
3.2.1.2 LHF to TESS	–	–	X	X	X	X	–	–	–	–	X	–	–	R=0.95
3.2.1.3 TESS to solar	X	X	X	X	X	X	–	–	–	–	X	–	–	R=0.95
3.2.1.8 Solar to TESS	X	X	X	X	X	X	X	X	X	X	X	–	–	R=0.95
3.2.1.9a TESS to ext.	–	–	X	X	X	X	X	X	X	X	X	–	–	R=0.95
3.2.1.9b Ext. to solar	X	X	X			X	X	X	X	X	X	–	–	R=0.95
3.2.1.3 Generate 60Hz (3.2.3.3)	X	X	X	X	X	X	–	–	–	–	X	X	–	A=0.85
3.2.1.6 Product H_2O (3.2.3.3)	X	X	X	X	X	X	X	X	X	X	X	X	–	A=0.85
3.2.1.10a Shutdown normal (3.2.3.4)	–	–	X	X	X	X	–	–	–	–	X	–	–	R=0.94
3.2.1.10b Shutdown emerg. (3.2.3.4)	X	X	X	X	X	X	X	X	X	X	X	–	–	R=0.99

Table 16-7. Preliminary Reliability and Availability Estimates

Function	Requirement		Preliminary prediction
	Type	Value	
Start	R	$\geqslant 0.95$	0.99912
Transitions	R	$\geqslant 0.95$	
• LHF to TES			0.99944
• TES to solar			0.99860
• Solar to TES			0.99855
• TES to ext. pwr			0.99939
• Ext. pwr to solar			0.99866
Generate 60 Hz	A	$\geqslant 0.85$	0.95214
Produce H_2O			0.95062
Shutdown	R	$\geqslant 0.99$	
• Normal			0.99944
• Emergency			0.99916

'R' - reliability; 'A' - availibility

that is fully qualified to perform scheduled maintenance and unscheduled major repair. Minor unscheduled maintenance on the turbine generator set will be performed by BEC.

The scheduled maintenance on the pilot plant equipment is summarized in Table 16-8. Unscheduled maintenance will rely heavily on the fault detection/annunciation capability built into the plant hardware and master control software. The general concept to be employed is shown in Figure 16-3.

The number of unscheduled maintenance demands/year has been estimated from reliability estimates from the commercial solar powered desalination system. The MTBF and MTTR values used in this analysis are as previously shown in Table 16-5. The MTBF values are used in conjunction with the estimated operating times shown in Table 16-3 to compute the expected maintenance demands.

Because not all maintenance demands can be predicted from equipment failure rates, factors have been used for each subsystem to adjust the "theoretical" demand rates to maintenance planning rates. The MTBF's, factors, operating times, and expected maintenance demands are summarized in Table 16-9.

During periods of extended cloudiness (2 or more consecutive overcast days), certain maintenance actions must be performed on the RO units; these are summarized in Table 16-10.

16.5 Operation and Maintenance Costs

Because of the preliminary status of the pilot plant design, it is not possible to develop an accurate ownership cost estimate. However, by making some simplifying assumptions, a very tentative estimate can be determined.

Assuming that the plant is to be operated 365 d/y, the pilot plant could require the (incremental) personnel shown in Table 16-11. It should be recognized that the personnel requirements are based on the assumption that some support is available from the existing water utility. In addition, it is assumed that heliostat cleaning will be accomplished by natural weather phenomena.

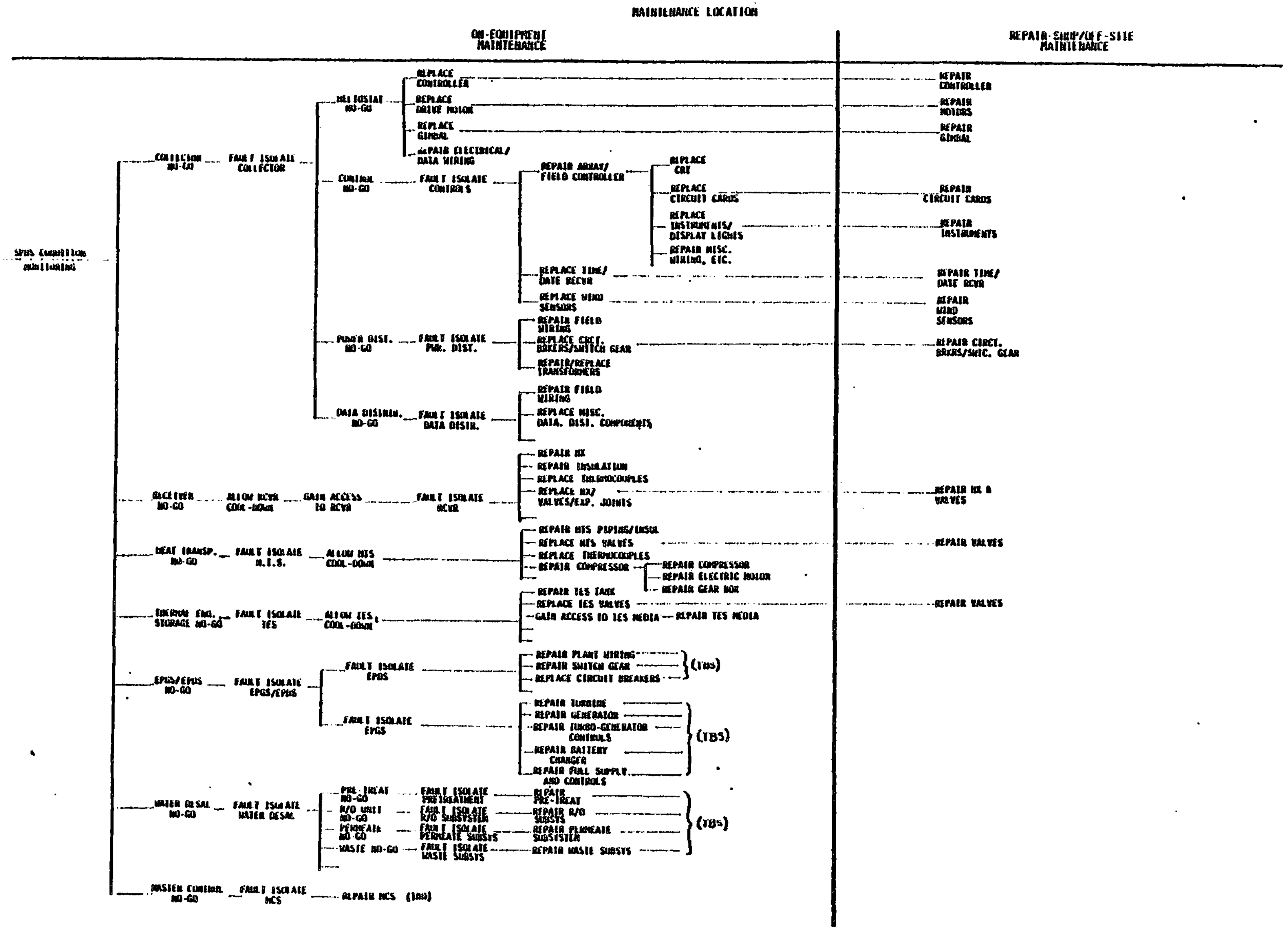


Figure 16-3. Unscheduled Maintenance Concept

Table 16-8. Scheduled Maintenance Requirements

Subsystem/End Item	Primary Maintenance	Interval
Collector	Inspect Heliostat Gimbals	Yearly
Receiver	Inspect Insulation Refurbish Insulation	1800 Hot Hours ~ 10 Years
Heat Transport	Inspect Pipes/Insulation Lubricate Compressor	Semi-Annually Every 2 Years
EPGS	Lubricate Bearings; check voltage/ frequency regulators; hot section suspection	3600 Hours
	Turbine Overhall	36,000 Hours
Water Desalination	Check/Maintain Pumps Replace Membranes Calibration/Standardization	Daily Every 3 Years Monthly

Table 16-9. Estimated Maintenance Demands

SUBSYSTEM/SEGMENT	QUANTITY/ SYSTEM	FAILURE RATE X 10^{-6}		OPERATING FACTOR	HOURS		MAINTENANCE REMARKS		TOTAL DEMANDS YEAR	SUB TOTALS
		OPERATING	NON-OPERATING		OPERATING	NON-OPERATING	OPERATING	NON-OPERATING		
SOLAR ENERGY SEGMENT										
COLLECTOR SUBSYSTEM										
HELIOSTAT	42	70.8		1.1	8766		28.67		28.67	
FIELD CONTROLLERS	5	20.0	-	1.2	8766	-	1.05	-	1.05	
TIME/DATE RECEIVER	1	13.0	-	1.1	8766	-	0.12	-	0.12	
WIND SENSORS	1 SET	29.0	-	1.2	8766	-	0.30	-	0.30	
DATA LINK	1 SET	7.0	-	1.3	8766	-	0.08	-	0.08	
POWER DISTRIBUTION	1 SET	10.0	-	1.2	8766	-	0.11	-	0.11	30.32
RECEIVER SUBSYSTEM										
TOWER	1	1.0	-	1.1	8766	-	0.01	-	0.01	
RECEIVER ASSEMBLY	1	250.0	20.0	1.4	2560	6206	0.90	0.12	1.02	1.03
HEAT TRANSPORT SUBSYS.										
PIPES/VALVES	1 SET	33.0	20.0	1.3	4610	4156	0.20	0.08	0.28	
COMPRESSOR	1	125.0	40.0	1.3	1900	6866	0.31	0.27	0.58	0.86
THERMAL ENERGY STORAGE										
TANK ASSY. W/STOR. MED.	1	5.0	2.5	1.4	3910	4856	0.03	0.01	0.04	0.04
ELECTRIC POWER GEN.										
TURBO-GEN. SET	1	233.0	100.0	1.2	4610	4156	1.29	0.42	1.71	1.71
ELECTRIC POWER DIST.										
TRANSFORMERS	4	5.0	-	1.2	8766	-	0.21	-	0.21	
POWER SWITCHING	1 SET	8.0	-	1.2	8766	-	0.08	-	0.08	
POWER WIRING	1 SET	7.0	-	1.2	8766	-	0.07	-	0.07	0.36
WATER DESALINATION										
FEEDWATER SUBSYS.	1 SET	40.0	20.0	1.2	6310	2456	0.30	0.05	0.35	
WATER TREAT. SUB.	3	100.0	33.3	1.4	6310	2456	2.65	0.25	2.89	
POTABLE WATER SUB.	1 SET	33.3	16.7	1.2	6310	2456	0.25	0.04	0.29	
WATER DISPOSAL	1 SET	66.7	33.3	1.3	6310	2456	0.55	0.08	0.63	4.16
MASTER CONTROL/COMM.										
MCCS EQUIPMENT	1 SET	264.7		1.3	8766	-	3.02	-	3.02	
INST. AIR SYSTEM	1	40.0	13.3	1.2	6310	2456	0.30	0.03	0.34	3.36
MAINTENANCE RESOURCE										
MAINT. SUPT. EQUIP.	1 SET	142.9	33.3	1.3	3000	5766	0.56	0.19	0.75	0.75
STRUCTURES & SITE										
HVAC	1	100.0		1.1	8766	-	0.96	-	0.96	
MISC. SYSTEMS	1 SET	50.0		1.1	8766	-	0.48	-	0.48	1.44
								TOTALS	44.05	

Table 16-10. RO Maintenance During Extended Cloudiness

Number of consecutive overcast days	Maintenance action	Maintenance accomplished
Up to 14 days	Inject dilute formaldehyde in RO modules	Manually
More than 14	Flush with permeate; remove; store membranes in cool place	Manually

Table 16-11. Preliminary Direct Personnel Requirements

Type personnel	Title	Number required on shift			Total*
		1st	2nd	3rd	
Operations	Operator	1	1	1	4**
	Supply/clerical	(1/8)***	–	–	(1/8)***
	Lab. technician	(1/8)***	–	–	(1/8)***
Maintenance	Electro/mech.	2	–	–	2
	Totals	3	1	1	6

* Assumes 24 hour/day operation

** Fourth operator required for scheduling flexibility

*** '( )' : Indicates support required from existing utility personnel

Based on the personnel identified in Table 16-11, a preliminary ownership cost estimate in constant 1981 dollars was developed; it is summarized in Table 16-12.

Table 16-12. *Preliminary Operation and Maintenance Cost Estimates*

Cost account		Amount/year (constant 1981 $'s)		
Number	Description			
5300	Ownership cost			
5310	Operations costs			
5310.1	Personnel			$125,111.00
5310.2	Operating supplies			43,956.00
5310.3	Utilities			1,979.00
			Subtotal	$171,046.00
5320	Maintenance costs			
5320.1	Personnel			$ 50,488.00
5320.2	Maintenance materials			29,250.00
5320.3	Turbine maintenance contract			12,150.00
			Subtotal	$100,888.00
		Total		$271,934.00

17.0 PLANT PERFORMANCE ANALYSIS

This section describes the system level performance analysis of the selected solar desalination plant configuration. First, the general purpose system analysis computer code is briefly described. The available site ambient data is then summarized. Evaluations of the site solar resource character and availability are also presented. The solar and water production design points are discussed. Finally, data from an hour-by-hour yearly analysis of plant performance are summarized.

17.1 Plant Performance Model

Functions of the System Analysis Model

The functions of the solar desalination system analysis model (DESAL) are illustrated in Figure 17-1. The model has been devised as a flexible tool to be utilized throughout the solar desalination program. DESAL is a quasi-steady state model of the various components of the selected solar desalination plant. The model assumes the plant will proceed from one steady state point to another. This is accurate for slowly changing events where the minimum time increment is approximately 0.25 hours. For transient events less than 15 minutes time constant, the transient performance of the receiver/turbine/field is likely to be significant and not adequately represented in DESAL.

One of DESAL's great utilities is in exploring the effects of large numbers of potential system configurations and operating philosophies. Data for many combinations can be gathered quickly and inexpensively, allowing the system analyst to study the major operation parameters without becoming bogged down in extensive, tedious hand calculations.

Another important model usage is in the area of annual performance predictions with hour-by-hour data. This allows verification of subsystem component sizes and permits an accurate assessment of plant outages and startup requirements.

Functions

- Provide system performance for various system level configurations
- Provide subsystem design point operating conditions
- Provide annual performance predictions with hour-by-hour data
- Provide a tool for evaluation of various operating strategies

Figure 17-1. Performance Model Update

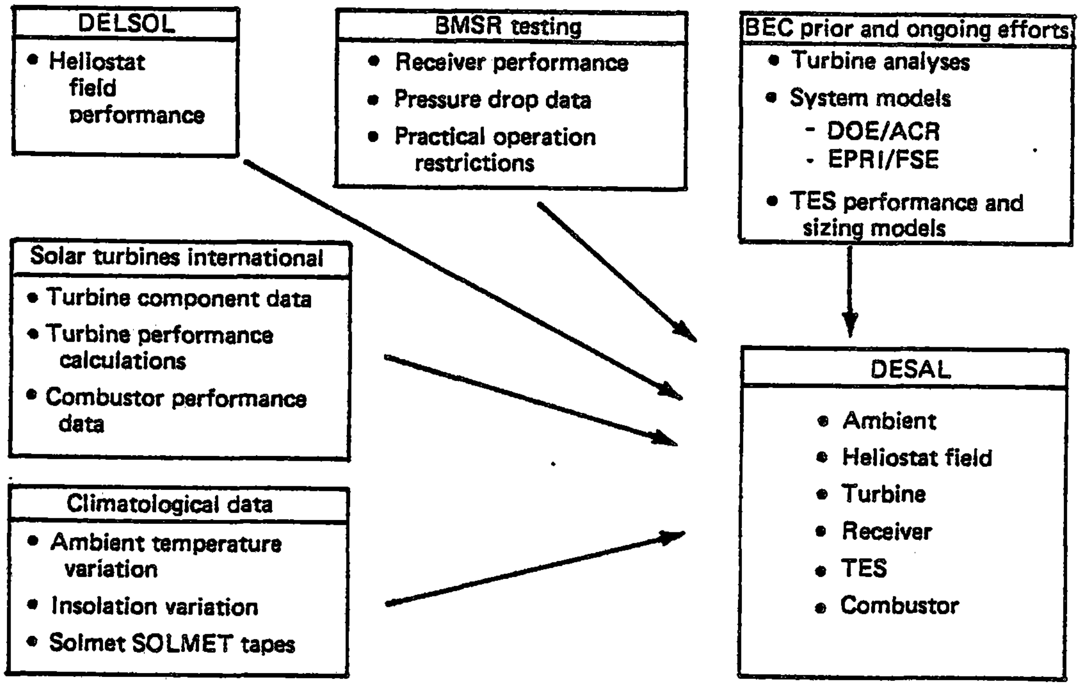


Figure 17-2. Data Sources

Data Sources

Figure 17-2 illustrates the data sources for this computer model. Climatological data used in the DESAL code are broken into two categories, clear day and annual hour-by-hour. The clear day data were generated to represent a cloudless day for each month of the year. Insolation values were generated for Rankin, Texas using Allen's clear air model [6]. Ambient temperature profiles were chosen to represent the 30-year average for each month. Annual hour-by-hour insolation and ambient temperature data were obtained from 1978-1979 SOLMET data for Midland-Odessa, Texas. The hour-by-hour data is more fully described in a following section on weather data.

Solar Turbines International (STI) provided turbine component data, the turbine performance calculation method, and combustor performance data. Heliostat field performance was obtained with the DELSOL computer code. This field data consisted of the field efficiency multiplied by the mirror area as a function of solar hour for the 21st day of each month of the year. Performance on other days was interpolated from these 12 days' data. Data from the BEC/EPRI BMSR testing program (EPRI Research Project 377-3) were used as a basis for estimating receiver performance and pressure drop. A system analysis model (FSESAM) developed for the BEC/EPRI Full System Experiment program provided a base upon which the DESAL model was constructed. Plant/thermal energy storage analytical tools developed under previous BEC programs were adopted for DESAL use to produce both a solar hybrid and a storage integrated plant analysis capability. DESAL was also greatly benefited by ongoing parallel system analysis model development at Boeing. The information from these data sources were combined into a consistent calculation methodology resulting in the final DESAL program.

Model Capabilities and Limitations

The basic capabilities of the DESAL model are summarized in Figure 17-3. DESAL was written in FORTRAN on the Boeing Computer Services CDC 6600 System. The basic limitation in the use of the DESAL model is due to the quasi-steady state model. As stated before, the model assumes slowly varying ambient conditions, allowing the solar subsystems to equilibrate to a new steady state. For rapid transients e.g. time constants on the order of several

- FORTRAN language
- Ambient
    - Ambient temperature
        - 30 year average (12 days0)
        - 1978 actual hour-by-hour data
    - Insolation
    - Clear day profile (12 days)
        - 1978 actual hour-byp-hour data
- Heliostat field performance
    - Clear day, diurnal data (12 days)
    - Annual data interpolated
- Turbine
    - STI - Titan
    - STI - Spartan
    - Garrett 831 - 800 (partial)
    - STI - Centaur
    - STI - Saturn
- Receiver
    - BMSR
    - Desal receiver
- TES
    - Sensible heat
    - Latent heat
- Cycle
    - Simple cycle
    - Recuperated cycle
    - Steam bottoming cycle
- Operation
    - Maximum solar
        - Constant turbine inlet temperature
        - Constant electric output (hybrid solar mode only)
        - Minimum solar-receiver flowrate
        - Charge TES
        - Parallel receiver/TES only
        - Discharge TES only
        - Fossil only

Figure 17-3. "Desal" Capabilities

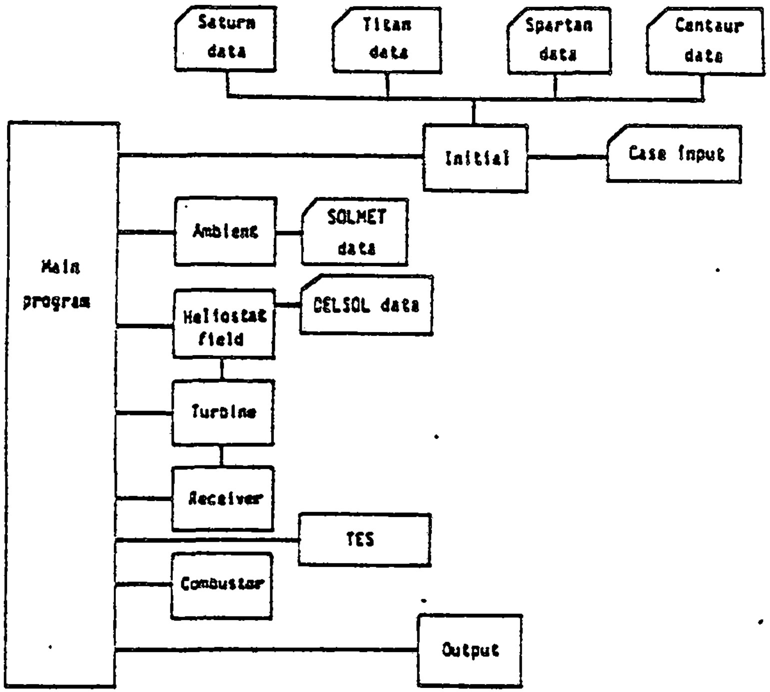


Figure 17-4. "Desal" Organization

minutes or less, the capacitive effects of the various solar components must be analyzed in a truly dynamic system model. Presently, the DESAL model is "resistive" in nature, containing "capacitance" only in the TES subsystem.

Model Organization

The organization of DESAL is illustrated in Figure 17-4. Subsystem performance is based on subroutine submodels. A main or executor program sequentially calls each subroutine as needed.

Model Operating Strategies

The DESAL model operating strategies are illustrated in Figure 17-5. This list is not exhaustive in all of the operation modes that a solar desalination plant of this type could expect. The purpose of the list is to summarize the major operating strategies of the model. As new operating methods and refinements are developed, they can be added to the model.

The major current operating strategy is to maintain at all times the turbine inlet temperature as high as possible but not above the design value. A corollary of this strategy is that the model attempts to operate the plant to produce as much electricity as possible at a given instant. No anticipatory logic is included. This results in some situations where the model may not produce the best long term plant performance. As an example, consider a mostly cloudy day that has usable direct insolation becoming available late in the operation day, e.g. an hour before the minimum solar elevation angle (10°). The model would attempt to start up the plant to capture that energy, whereas a plant operator would probably evaluate the nearness of the minimum elevation angle time and choose not to start the turbine. It is expected that using a nonanticipatory logic will produce conservative plant performance, actual performance being greater. Anticipatory logic should allow an increase in long term plant performance and a reduction in required plant starts.

Solar input control strategy is influenced by a number of factors. Potential solar input above the design value for maximum solar flux could result in a turning away some of the heliostats (e.g., a very clear solar noon insolation condition. This maximum solar input condition coincides with the maximum

- Maintain turbine inlet temperature as close to design value as possible
    - Solar only
    - Solar and TES in parallel
    - TES only
- Produce as much electricity as possible at all times
    - No anticipatory logic
- Limits on solar input
    - Design values
    - Receiver subsystem pressure drop
    - TES pump power consumption
    - Minimum receiver mass flow

Figure 17-5. "Desal" Model Current – Operating Strategies receiver pressure drop and TES pump power consumption at the plant design point. If the maximum receiver pressure drop and/or TES pump power consumption limits are encountered at lower solar input conditions, adjustments in the heliostat field are also made. As the minimum desirable pressure drop level is passed, additional heliostats are added, if available, to boost solar input and hence receiver thermal output. At the minimum receiver mass flow, the heat transfer capability of the receiver heat exchanger panels reaches a level where further receiver operation becomes unrealistic, and the heliostat field is shut down.

17.2 Solar Resource Analysis

The performance of a given solar plant is obviously affected by the ambient environment at the site for which it is intended. This section summarizes the various analyses performed on ambient data available for or typical of the solar desalination plant site. The basic data sources are described as well as conclusions available from statistical analyses of those data. The solar energy density (kW_t-hr/m^2-day) or "solar resource" available at the site is presented. Finally, the site solar availability derived from long term data and hour-by-hour measurements is discussed.

Weather Data

Weather data for the Rankin-McCamey, Texas solar desalination plant site are adequately represented by National Oceanic and Atmospheric Administration (NOAA) data for Midland-Odessa, 50 miles to the north, which was utilized extensively for the plant performance analysis.

As indicated earlier in the discussion of the DESAL model data sources, weather data is broken into two broad categories: hour-by-hour data and long-term, i.e. "30-year", average data. The hour-by-hour data is useful for estimating detailed performance characteristics such as plant outage times, startup requirements, and TES utilization. The long-term data is used to size the plant components and predict the long term performance and economics.

The following subsections present the data sources for the hour-by-hour and long-term data.

SOLMET Data

A SOLMET data tape for Midland-Odessa, Texas was purchased from NOAA. This data tape provided hour-by-hour ambient data from January 1, 1978 to June 30, 1979. The specific ambient data of interest to the plant performance analysis were the ambient temperature and direct insolation. A separate file or tape was created containing ambient temperature and insolation data. The separate tape would represent an actual hour-by-hour record of ambient temperature and insolation representative of the variations expected at the site.

An analysis of the SOLMET data revealed that the ambient temperature data were complete for each hour of the year (8760 data points) and could be transferred directly to the separate file. However, the direct insolation data revealed gaps for January and February, 1978 and January, 1979. In order to produce a representative year's insolation variation, February, 1979 insolation data were substituted in the February slots. March through December data were taken directly from March through December, 1978 SOLMET data. January insolation data was taken symmetric about the winter solstice, i.e. Day 1 data taken same as Day 308, Day 2 as 307, etc. For the remainder of the plant performance analysis discussion, the separate file data thus formed is referred to as the "1978 Midland" data.

30-Year Average Data

Long term or "30-year" average temperature data for Midland-Odessa, Texas are presented in Table 17-1.

Table 17-1. Midland-Odessa, Texas Normal Ambient Temperature Data (1941-1970)

Month	Daily Maximum (°C)	Daily Minimum (°C)	Monthly Average (°C)
J	14.6	-1.1	6.8
F	17.1	+1.2	9.1
M	21.1	4.3	12.7
A	26.5	10.0	18.3
M	30.6	14.8	22.7
J	34.1	19.7	26.9
J	34.2	21.1	28.3
A	35.0	20.9	28.0
S	31.4	17.3	23.3
O	26.6	11.7	18.0
N	20.1	4.3	12.2
D	15.9	0.1	6.9
Year	25.7	10.4	18.1

Long term direct insolation data for Midland-Odessa are not directly available. Long term total insolation (direct plus diffuse) data for Midland-Odessa are presented in Table 17-2. The average long term yearly average direct insolation energy density or "solar resource" for Midland-Odessa, Texas has been estimated as 6.00 kW_t-hr/m^2-day.

Clear day insolation data for the 21st of each month of the year were generated for the selected solar desalination site using Allen's clear air model [6]. The insolation profiles are presented in Figure 17-6.

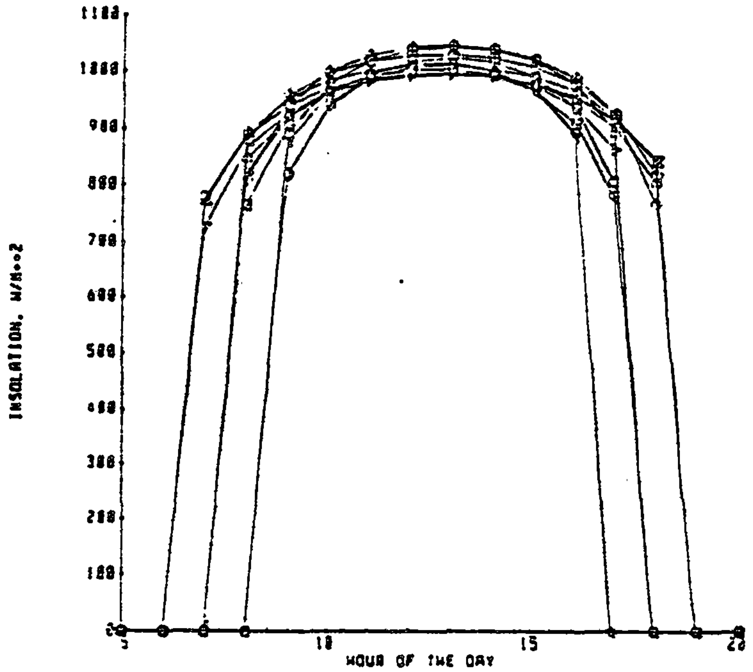


Figure 17-6. Clear Day Insolation Profiles

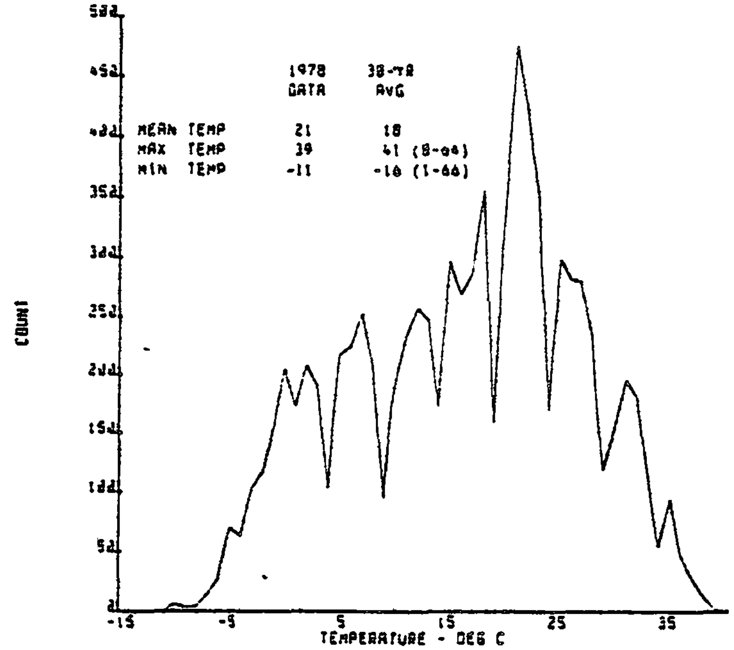


Figure 17-7. Ambient Temperature Histogram, Midland, Texas, 1978

Table 17-2. Midland-Odessa, Texas Total Insolation Data

Month	Average Daily Total Solar Energy Density (kW_t-hr/m^2-day)
J	3.35
F	4.20
M	5.47
A	6.39
M	6.99
J	7.19
J	7.61
A	6.56
S	5.76
O	4.71
N	3.63
D	3.36
Year	5.44

Ambient Temperature Data Results

By analyzing the 1978 Midland data, a histogram of the ambient temperature was constructed as shown in Figure 17-7. Presented are the number of occurrences in the 1978 Midland data year that a particular ambient temperature was encountered.

Insolation Data Results

The maximum daily insolation level for each day of the year is presented in Figure 17-8. As can be seen, several periods of the year had no direct insolation indicating periods of extended cloudiness. An insolation histogram is shown in Figure 17-9. The fractional sum of the insolation distribution for the 1978 Midland data is presented in Figure 17-10. Of the time that direct insolation is available, 95% of the occurrences were at 940 W/m^2 and below, although insolation levels as high as 1030 W/m^2 were encountered occassionally. Also, 75% of the direct insolation occurrences were between 150 and 940 W/m^2.

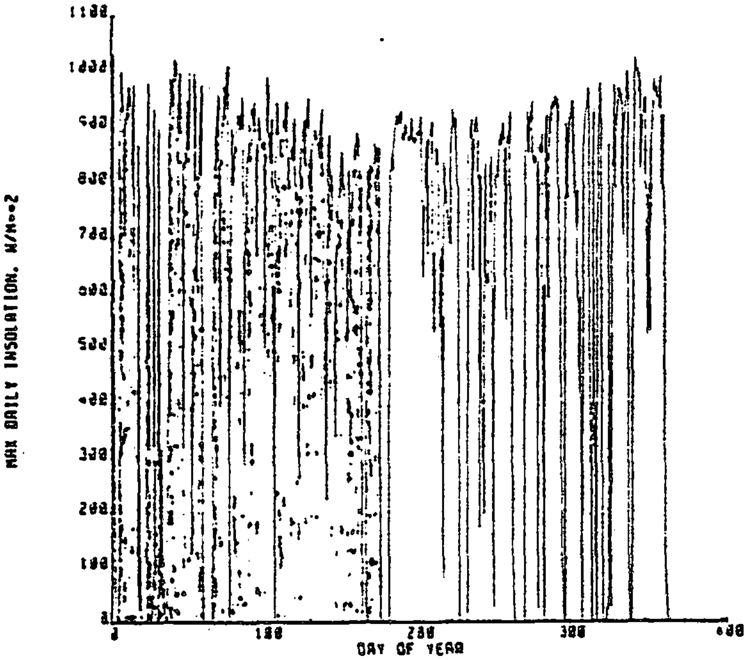


Figure 17-8. Maximum Daily Insolation Yearly Distribution

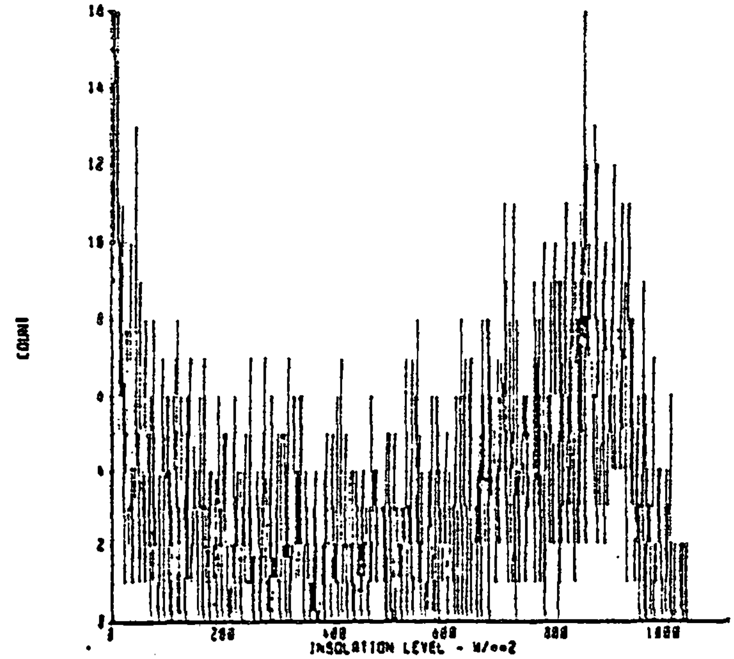


Figure 17-9. Insolation Histogram, Midland, Texas, 1978

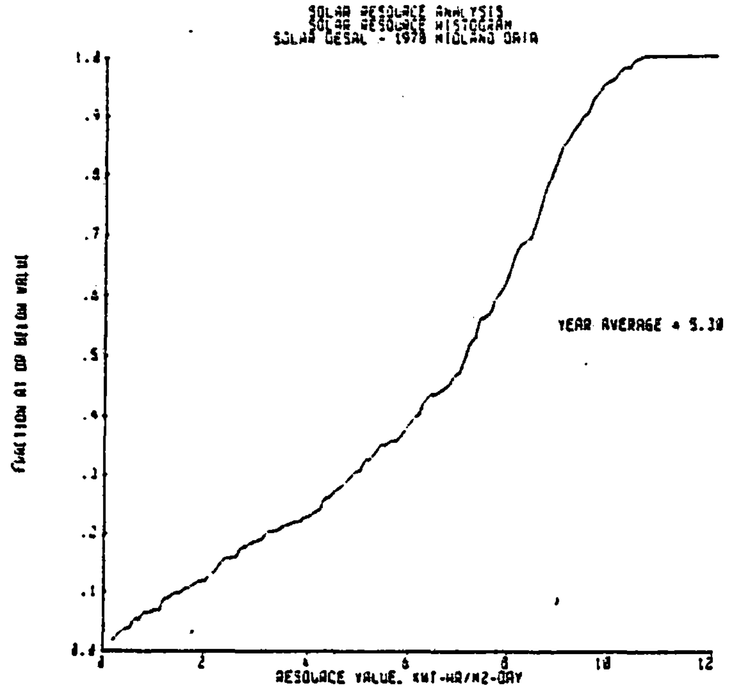


Figure 17-10. Insolation Fractional Distribution

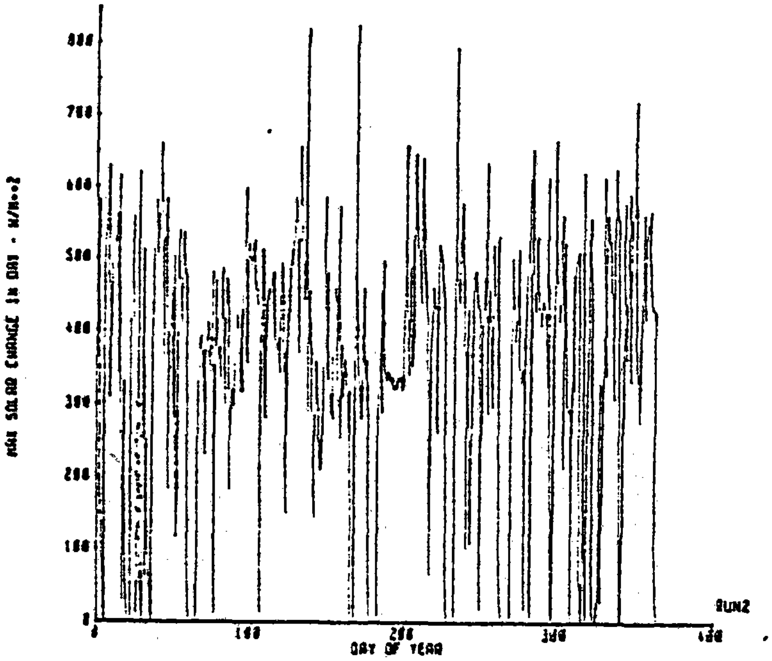


Figure 17-11. Maximum Solar Insolation Change per Day

The hour-by-hour solar variability is studied by calculating the change in insolation level from one hour to another. Figure 17-11 presents the maximum hourly insolation change for each day of the year. Figure 17-12 presents the spectrum of insolation changes as a function of their frequency of occurrence. The change distribution is nearly symmetric with "off-loading" changes (loss of insolation) as high as 900 W/m^2 and "on-loading" changes (gain of insolation) as high as 800 W/m^2. Considering the general concerns about thermal shock and thermal cycling in solar receivers, such solar change data should be useful in the pilot plant receiver design. For instance, Figure 17-12 suggests that rates of change are usually moderate and rarely approach the "black cloud" worst case condition.

Site Resource Data Results

The solar power density or insolation level in W/m^2 directly affects the sizing of the solar receiver and flow components. However, the TES system performance is influenced more by the energy density or "solar resource". This solar resource is generally expressed in terms of kW$_t$-hr/m^2-day. The long term solar resource data were discussed earlier. The day-by-day resource from the 1978 Midland data is presented in Figure 17-13. These data further demonstrate that there were several periods of extended cloudiness in the 1978 year data. A histogram of the solar resource data is presented in Figure 17-14. A significant number of occurrences were at 7.0 kW$_t$-hr/m^2 and above. The fractional distribution of the resource shown in Figure 17-15 demonstrates that although the yearly average resource value is 5.30 kW$_t$-hr/m^2, the mean value is 7.0 kW$_t$-hr/m^2. The mean includes only days that had direct normal insolation whereas the average includes all days.

It is obvious than one hour at 1000 W/m^2 contributes to the daily solar resource value 5 times the effect of an hour at 200 W/m^2. Figure 17-16 presents the insolation fractional distribution based on power and energy. These data demonstrate that although 75% of all the occurrences of insolation fall between 150 -940 W/m^2, that same 150 -940 W/m^2 range accounts for 90% of all the energy potentially available at the site. Furthermore, plant operation at less than 150 W/m^2 or greater than 940 W/m^2 is relatively unimportant because only small amounts of potential solar input energy are actually available at those insolation levels. These conclusions give some

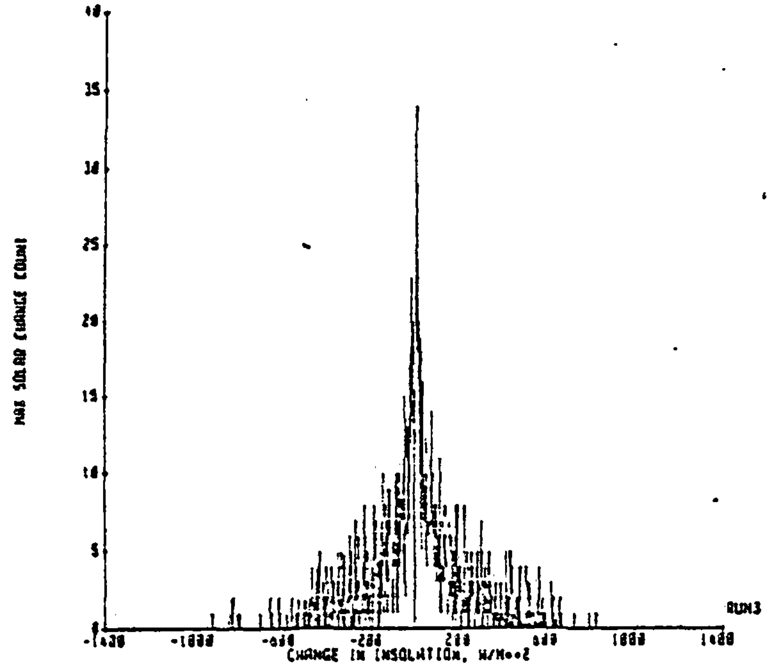


Figure 17-12. Insolation Change Distribution

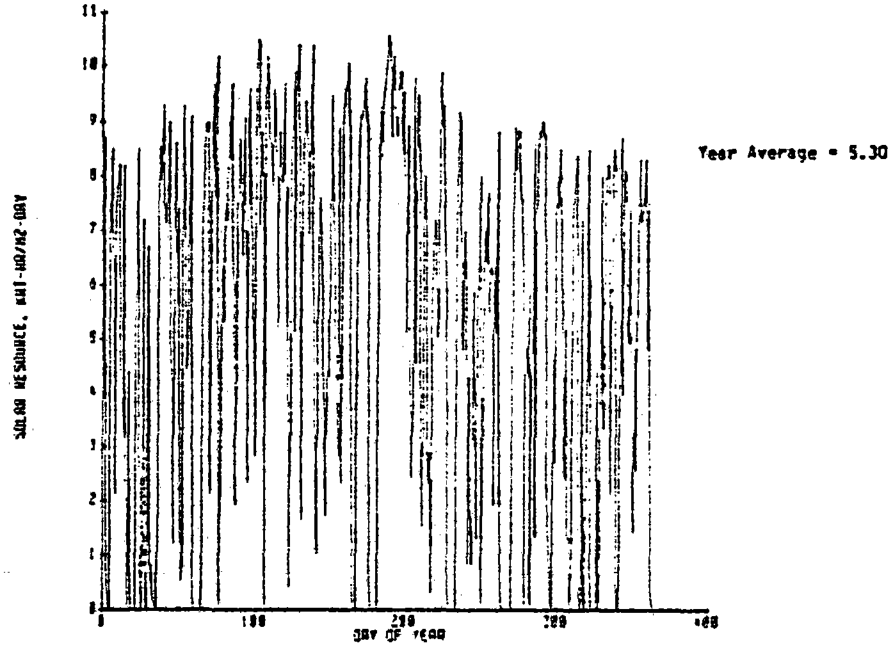


Figure 17-13. Solar Resource Yearly Distribution

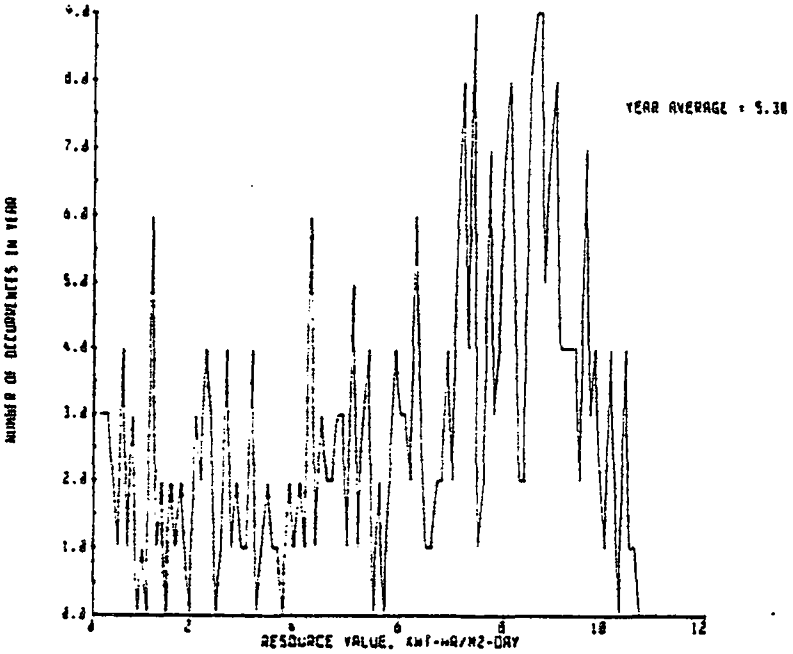


Figure 17-14. Solar Resource Histogram

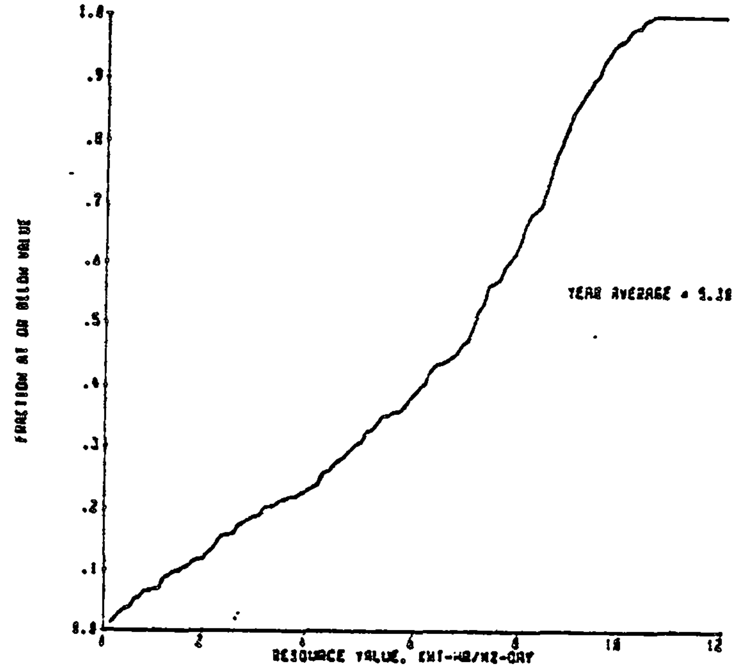
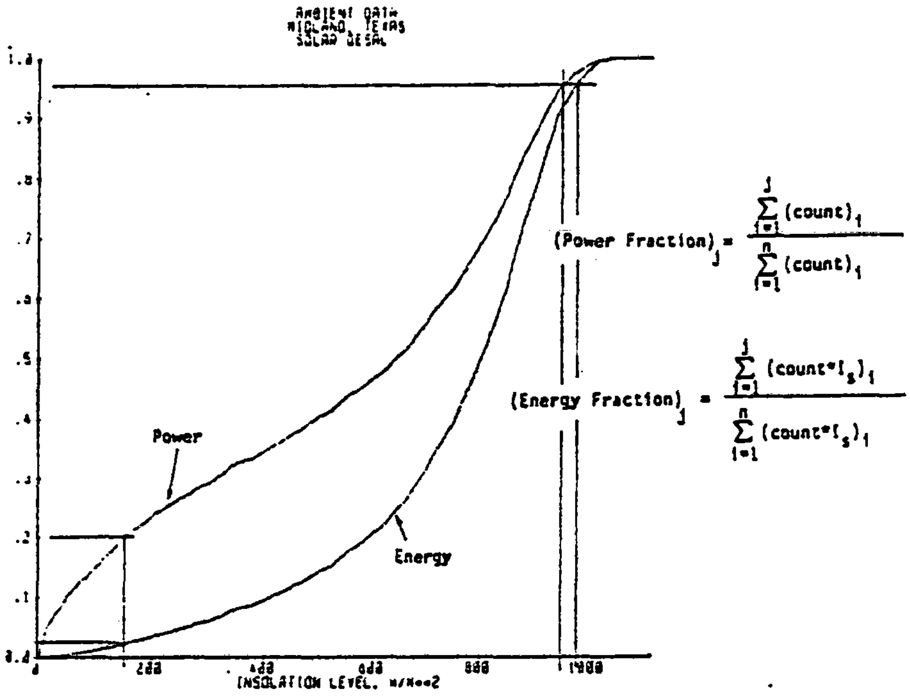


Figure 17-15. Solar Resource Fractional Distribution



$$(\text{Power Fraction})_j = \frac{\sum_{i=1}^{j} (\text{count})_i}{\sum_{i=1}^{n} (\text{count})_i}$$

$$(\text{Energy Fraction})_j = \frac{\sum_{i=1}^{j} (\text{count}*I_s)_i}{\sum_{i=1}^{n} (\text{count}*I_s)_i}$$

Figure 17-16. Insolation Fractional Power and Energy Distribtuion

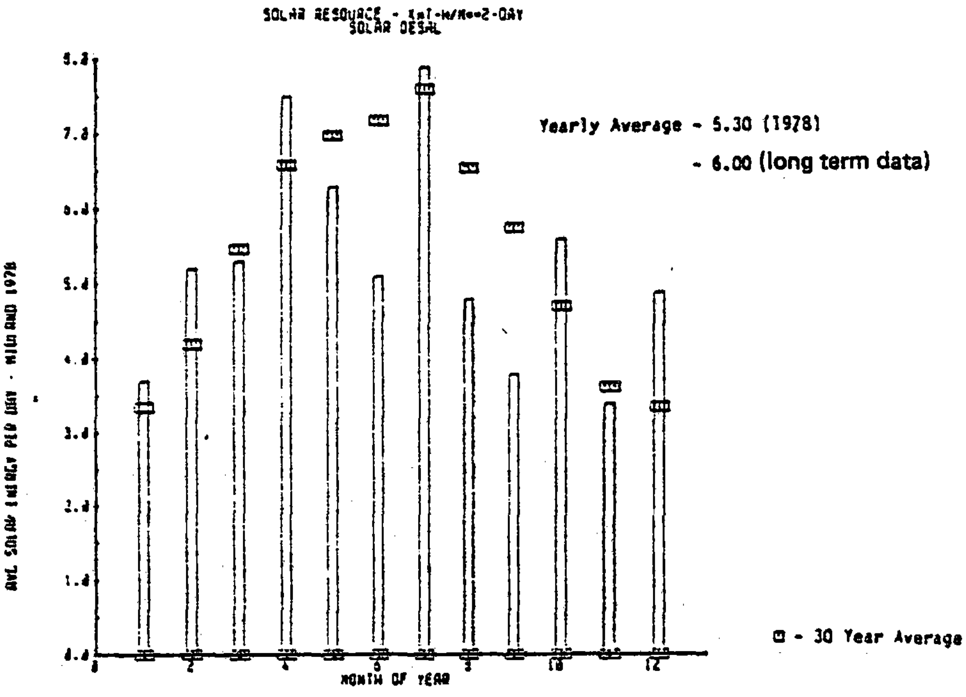


Figure 17-17. Monthly Average Solar Resource Distribution

guidance in plant operation strategy. At some minimum insolation level at the heliostat field design point efficiency, the solar input to the receiver will be at a minimum allowable level. This minimum allowable solar input level results from consideration of the heat transfer capability of the heat exchanger panels at low mass flows. The minimum flow condition for the solar desalination receiver occurs at roughly 150 W/m^2. The data shown in Figure 17-16 indicates that the annual performance penalty of not operating the receiver at levels below 150 W/m^2 is small.

On the other side, requiring the receiver to operate at the maximum expected insolation levels also imposes a receiver design capability that on an annual basis is fully utilized only occassionally. The strategy chosen for the solar desalination plant is to turn away heliostats for those relatively rare conditions when the field efficiency and insolation level are high and the TES is simultaneously nearly fully charged.

The monthly average solar resource derived from the 1978 Midland data is presented in Figure 17-17. Also presented are the 30-year average total solar resource (direct and diffuse) data. Although the data do not compare directly, their month-by-month distributions indicate that the 1978 data had more month-by-month variation in solar resource than would be expected in the long term.

Solar Availability Analysis and Results

The solar availability is an important concern in sizing the TES subsystem. An analysis was performed to determine the most likely amounts of time that solar insolation would not be available. Figure 17-18 illustrates the process utilized. The number and length of occurrences of solar outage (below 150 W/m^2) were tallied for each hour of the year. The resulting data is displayed in Figure 17-19. By analyzing all hours of the year, outage caused by both cloudiness and nighttime are counted. Figure 17-19 shows a peak near 1-2 hours and another at 12-13 hours. It is expected that the 12-13 hour peak is caused largely by nighttime outage, whereas the 1-2 hour peak by cloudiness. Solar outages as large as 210 hours were experienced. However, 323, or 91.3%, out of the total 353 solar outage hours were at or below 24 hours. These data indicate that storage times on the order of 24-48 hours would be most appropriate.

- Histogram
- Fractional Occurrences

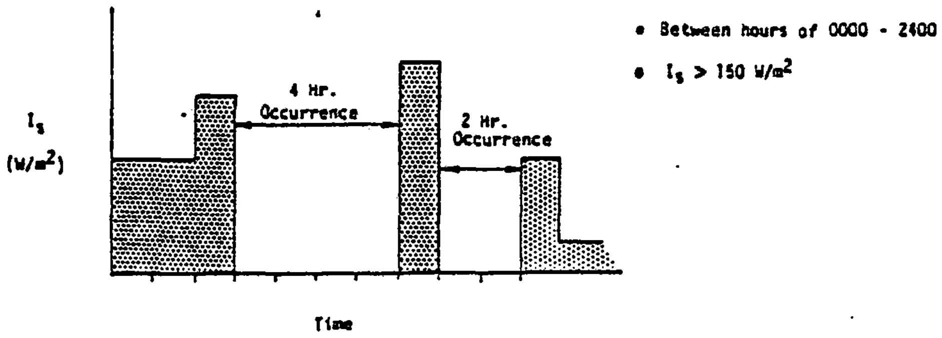
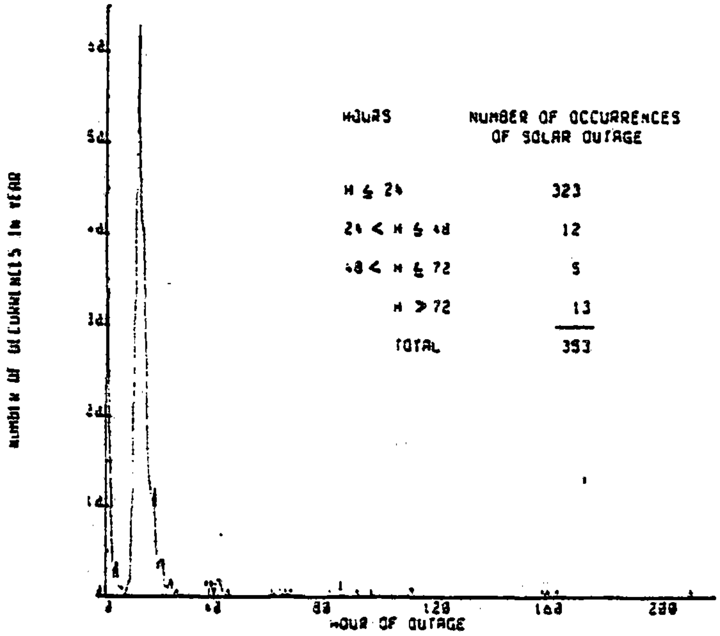


Figure 17-18. Solar Availability Analysis Schematic



HOURS	NUMBER OF OCCURRENCES OF SOLAR OUTAGE
H ≤ 24	323
24 < H ≤ 48	12
48 < H ≤ 72	5
H > 72	13
TOTAL	353

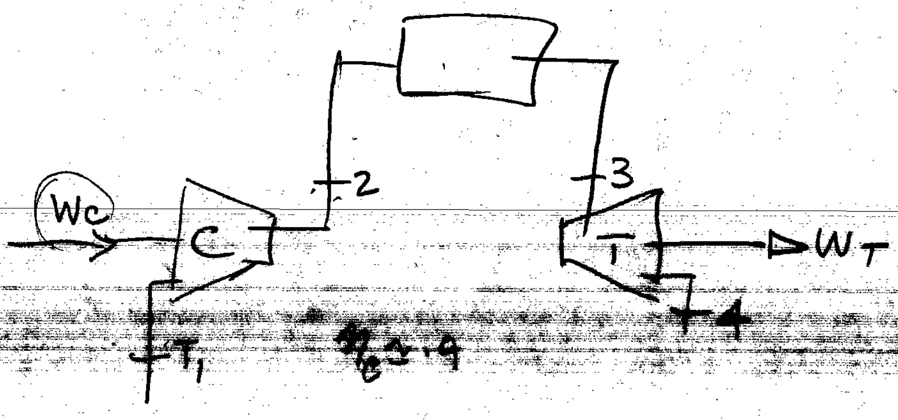
Figure 17-19. Solar Availability Analysis Results

As an attempt to filter out the cloudiness effects from the nighttime effects, the average solar hours per clear day were calculated for each month of the year. The direct insolation data for each month was analyzed for the hours of potential solar operation. The number of hours of no insolation and for insolation at or below 150 W/m^2 were tallied for each month. The resulting data are presented in Table 17-3. As indicated, 1115 hours out of a potential 3777 were lost due to non-available insolation. This indicates a 70% "weather factor" from the 1978 Midland data. The long term "weather factor" for Midland is 75%.

17.3 Solar Plant Design Point

As discussed in the Task 3 report, the design point chosen for the commercial solar desalination plant is solar noon, winter solstice. Also, results from the annual performance for the commercial plant indicated the minimum water production occurring in the winter months. Assuming the pilot plant annual performance follows a similar minimum winter performance pattern, the winter solstice, solar noon condition was chosen for the heliostat field design point condition. As in the commercial plant, 940 W/m^2 was chosen as the design insolation level.

The receiver design point must accommodate the maximum receiver mass flow rate. At this mass flow the receiver subsystem pressure drop would be the highest. For a given peak solar input level, the maximum receiver mass flow occurs when the temperature difference across the receiver is a minimum. For a given maximum receiver outlet gas temperature, the maximum mass flow occurs at maximum receiver inlet temperature. The maximum receiver inlet temperature occurs when the TES subsystem is nearly fully charged. Therefore, the solar subsystem design point occurs at solar noon, winter solstice for the TES approaching the fully charged condition. This condition is illustrated in Figure 17-20. The turbine generator produces 78.8 kW$_e$ with 40 kW$_e$ consumed in the TES compressor. The TES configuration used for the design point (and the following plant performance analyses) is 94,090 kg of brick. Performance of packed bed TES, which is the preferred design configuration (see Section 7.1), is described later in Section 17.7.



$W_c = \dfrac{\dot m c_p (T_2 - T_1)}{\eta_c}$ $W_T = \eta_T \dot m c_p (T_3 - T_4)$

$W_{net} = W_T - W_c = \dot m c_p \left[\eta_T (T_3 - T_4) - \dfrac{(T_2 - T_1)}{\eta_c} \right]$

$T_3 - T_4 = 816 - 569 = 247°C$

$\dot m = 0.83$ kg/sec

$T_2 - T_1 = 181$

$c_p = 1004.836$ J/kg°K

try $\eta_c = \eta_T = 0.90$ J/sec°K

$W_n = \overset{834.01}{0.83(1004.836)} \left[\overset{222.30}{0.90(247)} - \overset{201.11}{\dfrac{(181)}{0.90}} \right]^{21.19}$

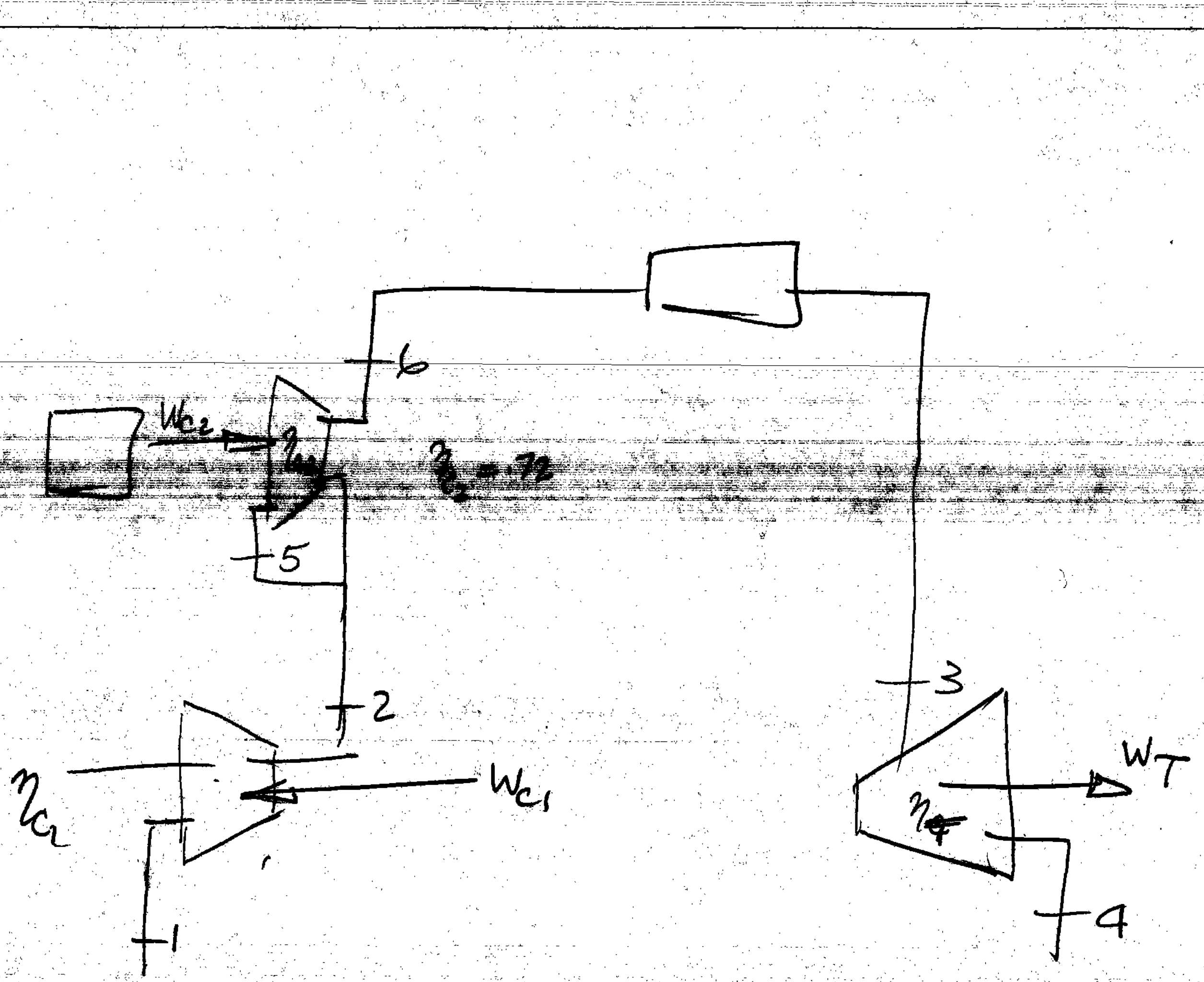
$= $ ~~[illegible] kW~~ $=$ ~~[illegible] Btu~~ $= 17.671\ kW_m$

$\eta_c = \eta_t = 1.00$ $P_2/P_1 = \dfrac{3765}{924} = 4.07$ $P_3/P_4 = \dfrac{3392}{924} = 3.67$

$\eta_t = 1 - \dfrac{1}{\pi^{\frac{\gamma - 1}{\gamma}}} = .32$ ✓

$\pi = 3.87$

$\gamma = 1.4$



$$W_n = W_T - W_{C_1} - W_{C_2}$$

$$W_{C_1} = .83(1004.836)(194-13) = 150.95\ kW_m$$

$$W_T = .83(1004.836)(816-\overset{247}{569}) = 206.00\ kW_m$$

$$W_{net}\Big)_{max} = 55.04\ kW_m$$

.105 net

$$(P_2/P_1) = 4$$

$$\boxed{T_2/T_1 = (P_2/P_1)^{\frac{k-1}{k}}} = 1.4853$$

$$T_1 = 13°C = 286 =$$

$$T_2 = 424.79 = 151.8°C$$

$$T_3/T_4\Big)_{max} = 1.449$$

Table 17-3. Solar Availability Results – "1978 Midland" Data

Month	Average solar hour per clear day	Potential solar hours per month	Hours* $I_S=0$	Days with No I_S	Days with kW_t-h 0.1 m^2
Jan	8.44	262	138	8	9
Feb	9.36	262	64	2	2
Mar	10.41	332	83	7	7
Apr	11.40	342	31	1	1
May	12.10	375	38	0	0
Jun	12.36	371	176	9	9
Jul	12.10	357	19	0	0
Aug	11.04	353	128	6	6
Sep	10.41	312	145	7	7
Oct	9.36	390	72	2	3
Nov	8.44	353	142	6	9
Dec	8.06	250	79	3	4

* During daylight period

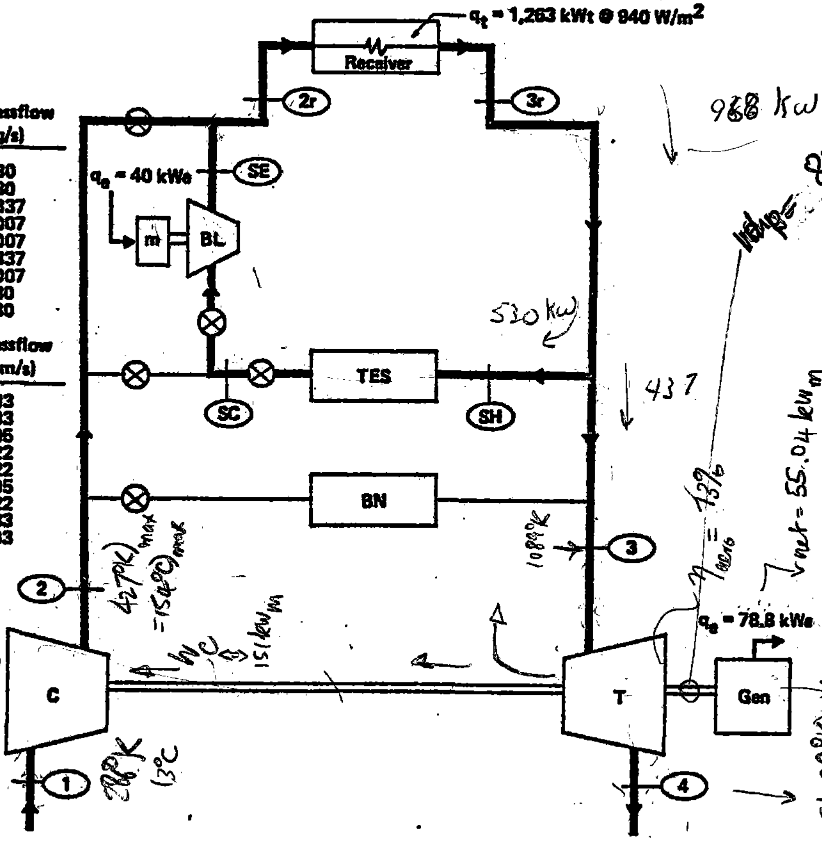
1,007 (375 - 357) 1004.836 = 18,213

Point	Temperature (°C)	Pressure (kPa)	Massflow (kg/s)
1	13	92.4	.830
2	194	376.5	.830
2r	292	375.1	1.837
SC	357	317.2	1.007
SE	375	375.1	1.007
3r	816	339.2	1.837
SH	816	339.2	1.007
3	816	339.2	.830
4	569	92.4	.830

(154)max

478 min

Point	Temperature (°F)	Pressure (psia)	Massflow (lbm/s)
1	56	13.4	1.83
2	382	54.6	1.83
2r	559	54.4	4.05
SC	676	46.0	2.22
SE	708	54.4	2.22
3r	1,500	49.2	4.05
SH	1,500	49.2	2.22
3	1,500	49.2	1.83
4	1,053	13.4	1.83



988 kW

W_{mp} = 82.06 kW_m ⇒ 78.8 kWe

96.6% η_{me}

From pg 82

530 kW

437

1089 K

$\eta_{turbine}$ = 73%

W_{net} = 55.04 kW_m

$W_n = W_T - W_C$

751.09 K
478.09 °C

206.0 kW

427 K)max
=154 °C)max

W_C ⇔ 151 kW_m

288 K
13 °C

.830 (816 - 569) 1004.836 = 206 kW

kg/sec · °C   J/kg °C

Figure 17-20. Solar Desalination Pilot Plant Design Point

1,837 x (816 - 292) 1004.836 = 968 kW

.83 (194 - 13) 1004.836   150 986

1,007/1,837 x 968

System pressure losses are always a concern for gas turbines. Table 17-4 presents the design point system pressure loss budget for the solar desalination pilot plant. The data are expressed in terms of a percentage of compressor outlet pressure. The air supply and heat exchange piping were physically sized to produce a large majority of the pressure loss across the heat exchanger turbing. This was done for two reasons: (1) the large pressure drop provides better forced convective heat transfer; and (2) tube-to-tube massflow imbalances are minimized. A total maximum pressure loss of 10% from compressor outlet to turbine inlet was assumed. Pressure losses in excess of 10% could lead to compressor "surge" and subsequent damage to the turbomachinery. Out of the 10% budget, 0.92% has been maintained as a margin for inaccuracies in pressure loss estimated.

17.4 Water Production Design Point

The water production design point is defined as the amount of water that can be produced when the power supply is 70 kW. Tihs amount of power is available at noon on the winter solstice and is the maximum amount of power allocated to the water treatment plant. Figure 17-21 shows the flow rate and the concentrations of water streams when the power supply is 70 kW. Since the RO permeate is predicted to be 122 ppm of dissolved salts, and the required treated water purity to be less than 500 ppm, blending of the RO permeate with the feedwater is provided. The blending gives a higher water production rate at no additional energy consumption, while keeping the treated water concentration below the required 500 ppm. The blend by-pass flow, as well as losses and waste flows are all shown on Figure 17-21. When the plant operates below its design point, the flowrates on Figure 17-21 will be proportional to each other, and the concentrations will be unchanged.

Table 17-5 shows the concentration of each stream shown on Figure 17-21. The chemical constituent concentrations were defined as follows (is not adjusted for electro-neutraility balance):

Raw Feed	Water sample analysis (3-81) of Rankin, Texas well water.
RO Feed	Analysis of commercial weak acid cation units.

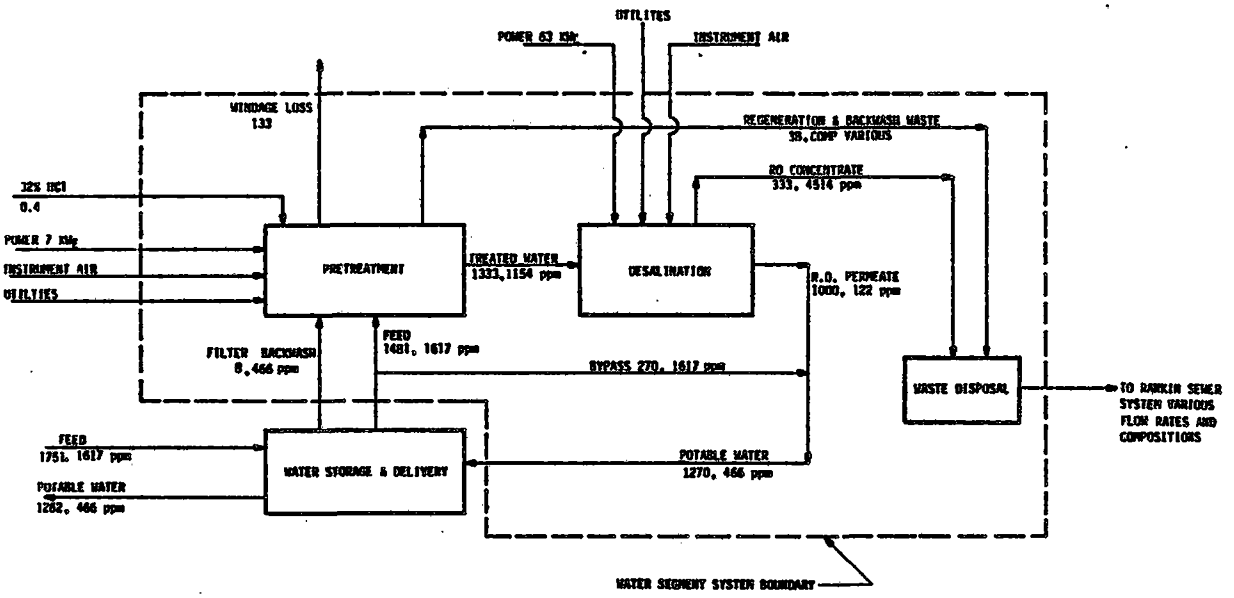
Table 17-4. System Pressure Loss Budget

(Percent of compressor outlet pressure = 376.5 kPa)

Inlet	
Riser	0.09%
Manifold	0.14%
Control valve	1.00%
Header	0.07%
H/X tubes	7.00%
Outlet	
Header	0.20%
Manifold	0.26%
Downcomer	0.18%
Interconnect piping	0.14%
Margin	0.92%
Total	10.00%

Table 17-5. Water System Chemistry - Pilot Plant

	Raw Feed	R.O. Feed	Predicted Reject	Predicted Permeate	Predicted Product (Blend)
Calcium (Ca)	174	70	272	4.0	40
Magnesium (Mg)	113	112	424	7.0	30
Sodium (Na^+)	160	160	483	23	52
Potassium (K^+)	0	0	0	0	0
Iron (Fe)	0.1	0.1	0.1	0.1	0.1
Manganese (Mn)	.05	.05	.05	.05	.05
Bicarbonate (HCO_3^-)	330	12	14	10	78
Carbonate (CO_3^-)	0	0	0	0	0
Chloride (Cl^-)	146	146	537	15	43
Sulfate ($SO_4^=$)	698	697	2601	56	193
Nitrate (NO_3^-)	34	34	155	4.0	28
Phosphate ($PO_4^=$)	0	0	0	0	0
Flouride (F^-)	20	2.0	2.0	2.0	2.0
Silica (SiO_2)	7.2	7		1.0	
TDS	1617	1154	4514	122	466
pH	7.4	5.9	5.6	7.0	6.95



- ALL FLOW RATES IN M^3/DAY
- 24 HOUR OPERATION AT DESIGN POINT ASSUMED
- DESIGN POINT (MAX.) FLOWS
- ALL COMPOSITIONS IN mg/l AS IONS

Figure 17-21. Design Day Data

Predicted Permeate Predicted Reject	Analysis of commercial RO units.
Predicted Product (Blend)	Mass balance on each component (from Raw Feed and Predicted Permeate streams).

17.5 Clear Day Performance

Performance data for a clear winter solstice day are presented in Figures 17-22 to 17-24. Tables 17-6 and 17-7 summarize data for winter, spring, summer and fall clear days. Figure 17-22 presents the massflow through the turbine, receiver and thermal energy storage subsystems as a function of the time of day (standard local time). Operation begins at 0900, the receiver massflow following the insolation profile. Thermal energy storage charging begins at 1000 and continues until 1600. Direct solar operation ceases and thermal energy storage discharge begins at 1700. Thermal energy storage discharges until 2400 whereupon the plant is shutdown.

Figure 17-23 shows the plant electrical production and consumption as a function of time of day. Thermal energy storage charging is noted by the block of power devoted to the blower. After thermal energy storage blower and plant parasitics are subtracted, the net power is supplied to the RO system for water production. The power consumption for all three modules at full production rate is 70 kWe. This occurs early in the plant operation where ambient temperature and pressure losses are low, allowing additional electrical production. The minimum RO electrical consumption occurs where only one RO module is operating at 1/2 capacity. This condition defines the thermal energy storage "empty" condition at 2400 hours. Figure 17-24 presents the water production data for the clear day operation. Full production capacity rate of 1272 m^3/hr is provided at 0900 hours. The total cumulative water production ~~for the~~ day is 530 m^3. ?

Table 17-6 presents summarized performance data for clear spring, summer, fall and winter days. Presented are water production, operational hours, and electrical production and consumption. The spring day performance is best owing to the relatively low ambient temperatures, high insolation levels (clearer sky), moderate length of solar day, and moderately high heliostat field efficiencies.

- 21 Dec, Clear day insolation
- Average ambient temperature profile

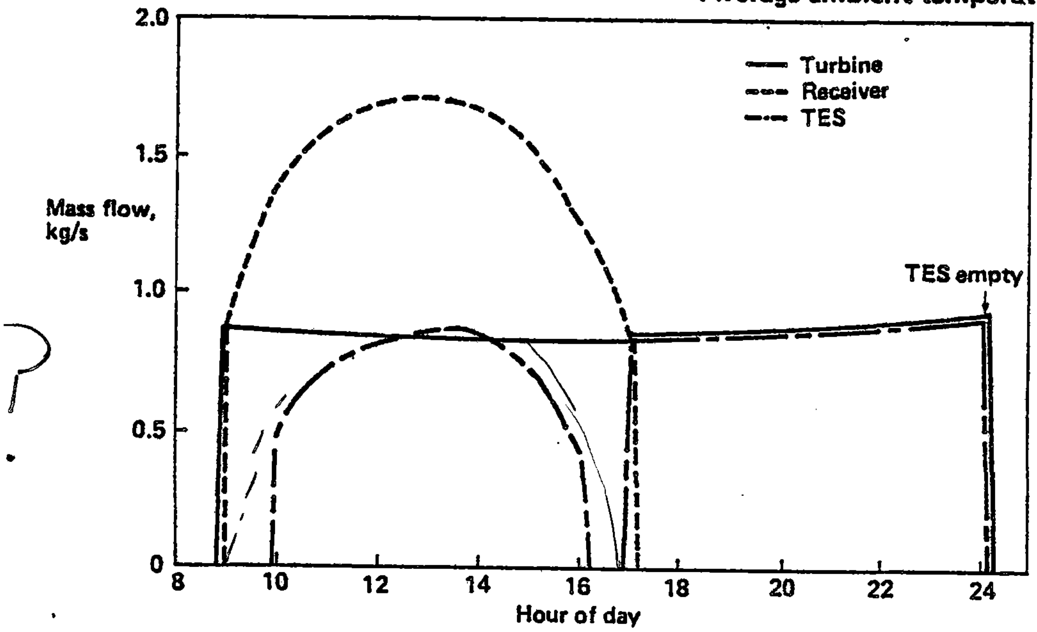


Figure 17-22. Design Day Data

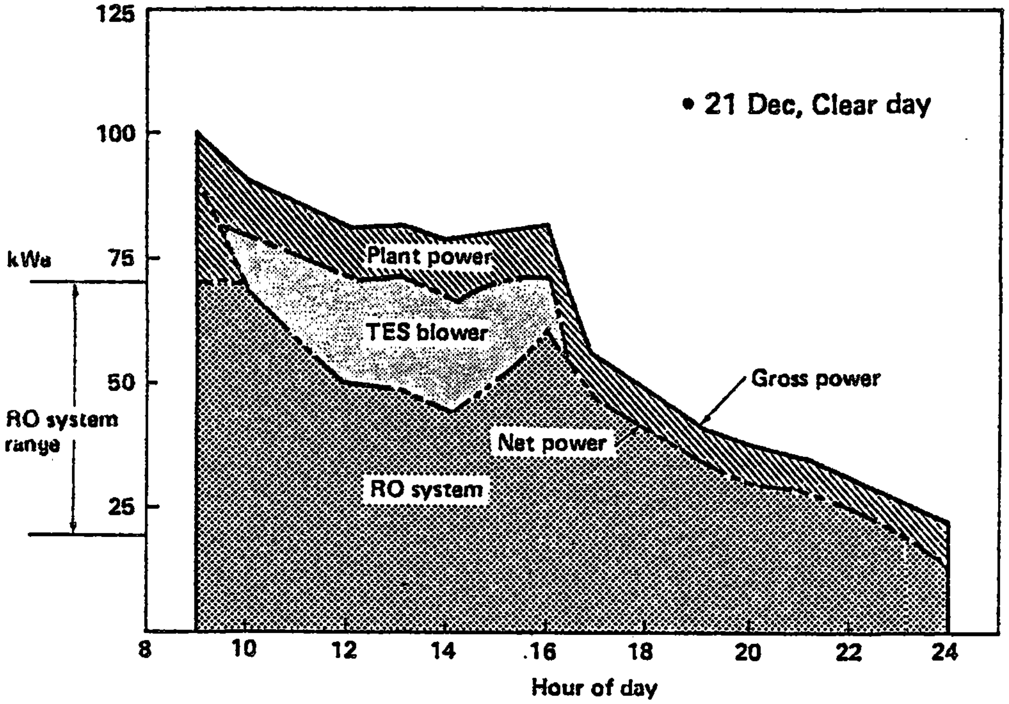


Figure 17-23. Design Day Data – Electrical Production

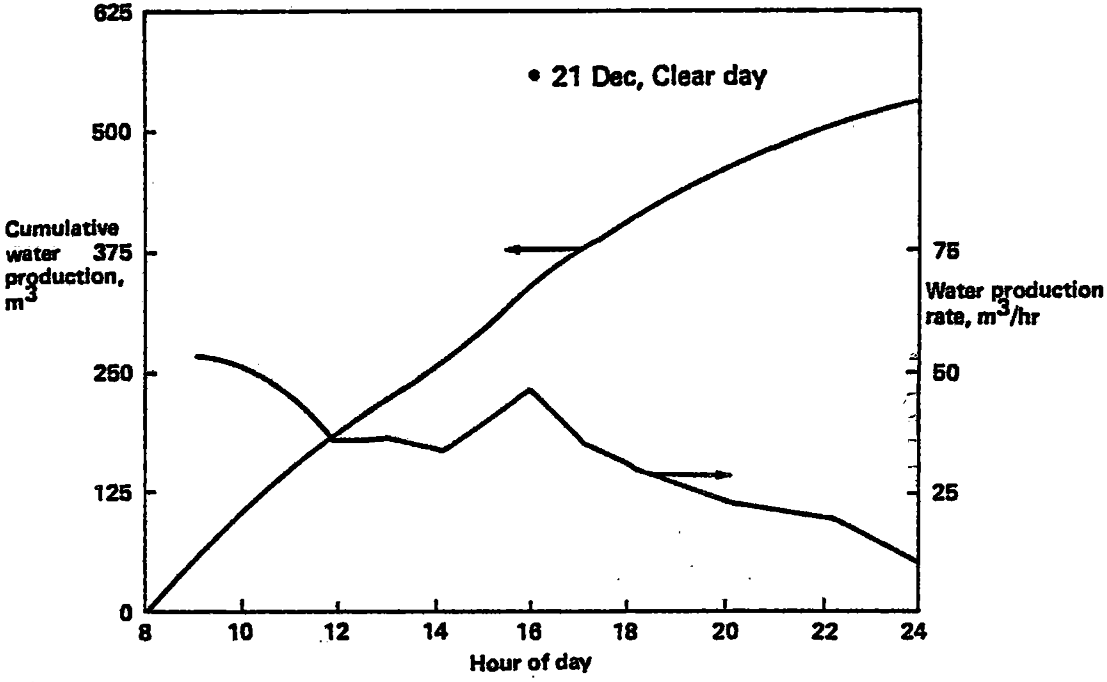


Figure 17-24. Design Day Data — Water Production

Table 17-6. Solar DESAL Pilot Plant Clear Day Performance

Day	Solar-only operation/solar electrical busbar					Additional parasitic power from grid (kW$_e$-hr)
	Gross electrical production, kW$_e$-hr	Process electricity consumption, kW$_e$-hr	Parasitics			
			Heliostat field, kW$_e$-hr	TES pump, kW$_e$-hr	Plant power, kW$_e$-hr	
Winter	985	704	79	122	80	1,132
Spring	1,143	831	91	131	90	1,122
Summer	872	601	95	91	85	1,127
Fall	903	569	87	152	95	1,117

17.6 Annual Performance Data

The solar desalination plant system analysis model (DESAL) was used to investigate the hour-by-hour performance for the selected plant configuration. The following subsections present the results from that analysis.

Correction of "1978 Midland" Insolation Data to Long-Term Average

As discussed earlier in Section 17.2, the long term solar resource for the Rankin, Texas site should be about 6.00 kW_t-hr/m^2. The "1978 Midland" data yields a 5.30 kW_t-hr/m^2 solar resource value, or about 13% below the 6.00 value. Two options are available to correct 1978 Midland data to reflect the long term behavior: 1) multiply the water production estimates from the 1978 data by 1.13, or 2) multiply the individual instantaneous insolation values by 1.13. Neither of these options are entirely satisfactory. The first option essentially stretches the solar operation day when in fact the thermal energy storage may become fully charged, and the additional energy would not be available. In the second option, both clear and cloudy day insolation levels are increased. In order to assess the effects of which option to use, January 1978 data were repeated for the pilot and commercial plants using both options. The results are presented in Table 17-7. The effect is small, about 3.2% difference in water production. Since the second option produces conservative performance, the pilot plant performance data presented in the following subsections is based on the second option.

Table 17-7. Correction of Insolation Data

	Water Production for January 1978 (m^3)	
Plant	$1.13*I_s$	1.13*Yr
Pilot	8256	8530
Commerical (updated)	145000	140400

Monthly and Yearly Performance Predictions

Tables 17-8 to 17-12 summarize the monthly and yearly performance results using the 1978 Midland ambient data as defined in Sections 17.2 and 17.6.

Table 17-8. Solar DESAL Pilot Plant Annual Performance – Factored 1978 Midland Data

Month	Water production (m^3) •	Operation time (hr)			Insolation (MW_th)			RCR heat absorption (MW_th)
		Total	Direct solar	TES	Collector field	Max. avail. input at RCR	Actual input at RCR	
Jan	8,256	217	126	91	228.6	152.0	151.7	126.4
Feb	10,270	270	164	106	293.7	185.6	184.9	154.0
Mar	9,564	308	180	128	333.7	199.2	198.6	165.4
Apr	11,348	402	234	168	453.1	252.6	252.0	209.9
May	8,416	283	187	96	396.5	204.4	203.7	169.7
Jun	6,748	225	154	71	310.0	152.8	152.4	126.9
Jul	10,141	393	244	149	496.8	249.5	248.9	207.3
Aug	6,721	236	155	81	298.0	162.6	161.7	134.7
Sep	5,764	286	207	79	233.3	135.8	131.2	109.3
Oct	10,094	348	197	151	350.7	215.7	215.2	179.3
Nov	6,388	195	112	83	205.7	131.8	131.4	109.5
Dec	11,030	311	170	132	306.9	202.4	201.9	168.2
Year	104,740	3,474	2,139	1,335	3907.0	2244.4	2233.6	1860.6

- Adjustment for 30 year average
  104,740 x 0.85 = 88,929m^3
  (Factored "1978 data")x (Plant availability estimate)

Table 17-9. Solar Desalination Pilot Plant Annual Performance – Factored 1978 Midland Data

Month	Solar-only operation/solar electrical busbar					Additional parasitic grid power for dormant plant (kW_e-hr)
	Gross electrical production (kW_e-hr)	Process electricity consumption (kW_e-hr)	Parasitics			
			Heliostat field (kW_e-hr)	TES pump (kW_e-hr)	Solar portion of plant power (kW_e-hr)	
Jan	15,362	10,921	1,786	1,570	1,085	36,983
Feb	18,848	13,585	2,113	1,800	1,350	32,869
Mar	18,020	12,651	1,783	2,046	1,540	36,851
Apr	21,800	15,012	2,233	2,545	2,010	34,998
May	15,724	11,133	1,755	1,421	1,415	37,429
Jun	12,412	8,926	1,403	958	1,125	36,334
Jul	19,823	13,415	2,290	2,153	1,965	36,418
Aug	12,657	8,891	1,402	1,184	1,180	37,647
Sep	11,134	7,625	816	1,263	1,430	36,504
Oct	19,566	13,356	1,962	2,508	1,740	36,551
Nov	11,906	8,446	1,081	1,404	975	36,479
Dec	19,945	14,587	1,603	2,200	1,555	36,938
Year	197,197	138,548	20,227	21,052	17,370	436,001

Table 17-10. Solar DESAL Pilot Plant Annual Performance —Factored 1978 Midland Data

Month	Total water production (m^3)	Raw feedwater requirements (m^3)	Evaporation (m^3)	Sewage flow (m^3)	Blend flow (m^3)	Permeate flow (m^3)
Jan	8,256	11,311	892	2,163	1,759	6,497
Feb	10,270	14,670	1,109	2,691	2,188	8,082
Mar	9,564	13,103	1,053	2,506	2,037	7,527
Apr	11,348	15,547	1,226	2,973	2,417	8,931
May	8,416	11,530	909	2,205	1,793	6,623
Jun	6,748	9,245	729	1,768	1,437	5,311
Jul	10,141	13,893	1,095	2,657	2,160	7,981
Aug	6,721	9,208	726	1,761	1,432	5,289
Sep	5,764	7,897	623	1,510	1,228	4,536
Oct	10,094	13,829	1.090	2,645	2,150	7,944
Nov	6,388	8,752	890	1,674	1,361	5,027
Dec	11,030	15,111	1,191	2,890	2,349	8,681
Year	104,740	143,494	11,312	27,442	22,310	82,430

Table 17-11. DESAL Pilot Plant Component Start-up Estimates

- Factored 1978 Midland data
- No anticipatory capabilities

Month	EPGS	Heliostat field	Receiver	TES unit	TES blower
Jan	20	19	19	35	19
Feb	23	24	24	44	18
Mar	25	26	26	45	24
Apr	29	30	30	59	31
May	31	33	33	50	26
June	22	24	24	32	17
July	31	36	36	56	29
Aug	26	32	32	36	21
Sept	23	26	26	32	21
Oct	19	30	30	49	28
Nov	17	21	21	29	16
Dec	27	27	27	48	25
Year	303	328	328	515	275

Table 17-12. DESAL Pilot Plant Component Operational Hours Estimates

- Factored 1978 Midland data
- No anticipatory capabilities

Month	EPGS	Heliostat field	Receiver	TES unit	TES blower
J	217	131	131	188	87
F	270	173	173	234	99
M	308	194	194	267	114
A	402	262	262	349	155
M	283	228	228	220	103
J	225	185	185	164	82
J	393	284	284	322	151
A	236	187	187	174	77
S	286	147	147	162	73
O	348	203	203	304	135
N	195	123	165	123	75
D	311	184	184	278	118
Year	3,474	2,301	2,301	2,827	1,269

These data are for solar only operation, i.e, the effects of backup grid power consumption have not been included (see Section 17.6). The data also considers only the solar availability as contained in the hour-by-hour insolation data.

The data must be corrected to account for plant availability (plant outages due to scheduled and unscheduled maintenance, etc.). As discussed in Section 16.3, the expected plant availability is 0.85. The expected year water production is then 104,740 x 0.85 = 88,929 m^3 or 244 m^3/day, within the 100 - 400 m^3/day SERI goal.

The electrical power production and consumption data of Table 17-9 are based on the electrical power budget allocations shown in Table 17-13. These data are split into two groups, the power consumers that would normally be required to be supported by the solar plant and those balance of plant consumers to be supplied from grid power. Minimum and maximum values are also shown.

Table 17-13. Power Generation Consumption Budget

Component	Power (kW_e) Supplied by Solar Generation Max	Min	Supplied by Grid Max	Min
Heliostats	6	2		
Feedwater Pretreatment	7	7		
RO Modules	63	11		
TES Blower	40	20 or 0		
Power Generation & Heliostat Control Computers	1	1		
Miscellaneous	4	4		
Balance of Plant				
. Security equipment			4	1
. Tower			1	1
. Master computer			4	2
. Plant building			50	25

Table 17-10 presents the water production flow breakdown. The total water production is composed of the sum of the blend and permeate flows. The raw feedwater requirements is composed of the sum of evaporation, sewage, blend and permeate flows.

Table 17-11 presents the startup estimates for the solar system components. The TES blower starts only when TES charging commences. The TES unit starts whenever massflow begins through the medium (charging starts plus discharging starts). The heliostat and receiver are assumed to start whenever usable solar energy becomes available regardless of when that usable energy occurs. A plant operator may be able to reduce heliostat field and receiver start/stops by anticipating the ambient data conditions (incoming weather patterns, closeness of sunset, etc.). Since some days have no solar input, the number of EPGS starts is less than one per day.

Representative Hourly Performance Data

Figures 17-25 to 17-28 illustrate results from the plant performance system analysis model for four days in April. Figure 17-25 presents the daily insolation profile. April 14 is seen to be a relatively clear day followed by an intermittent insolation day representative of the passage of several cloud banks. April 16 contained no direct insolation indicating complete cloud cover. Finally, April 17 is another clear day. The resulting plant component mass flows are illustrated in Figure 17-26. The turbine mass flow is seen to be nearly constant, affected only by ambient temperature variations. The receiver mass flow follows approximately the available insolation. The TES mass flow illustrates first charging with excess receiver heat absorption and equal to turbine mass flow during TES discharge. Figure 17-27 presents the TES hot and cold fluid temperatures and the turbine inlet temperature. The TES hot fluid temperature is equal to the turbine inlet temperature. During TES discharge, the cold TES fluid temperature is equal to the main compressor exit temperature. The TES energy level variation is presented in Figure 17-17. The TES energy level is measured relative to a uniform 15.6°C medium temperature. The charging/discharging behavior is clearly evident. The TES system does not become fully charged as discussed in Section 7.0. The TES system carries the plant for about 7-8 hours after sunset.

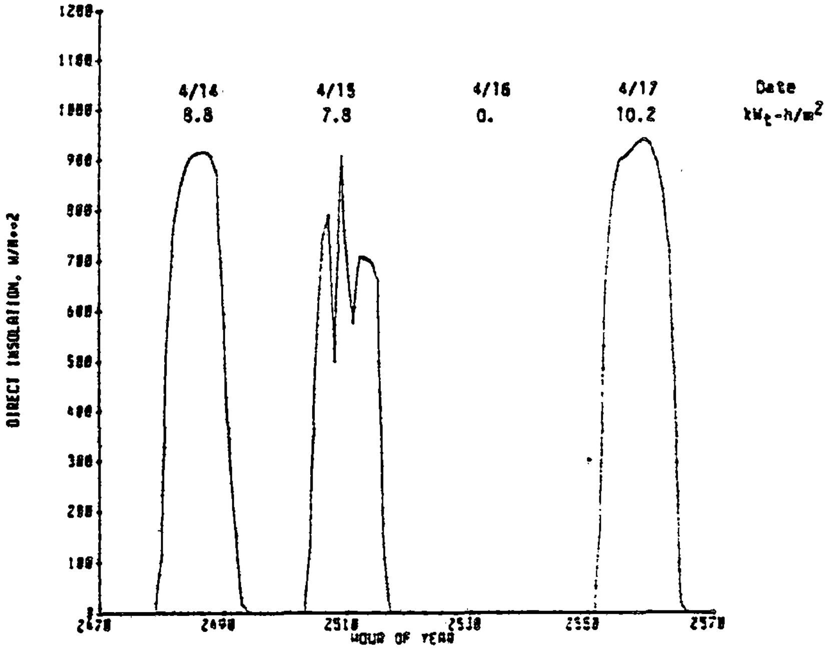


Figure 17-25. Insolation Profiles for April 14-17

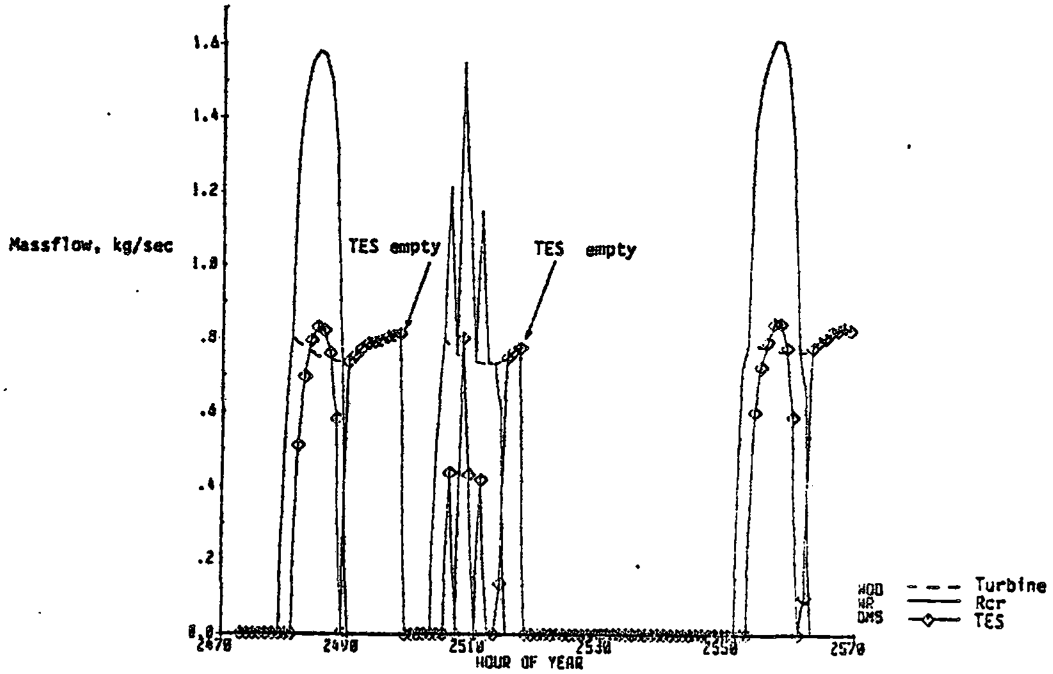


Figure 17-26. DESAL Pilot Plant Performance Yearly Analysis Day 104 to 107 — 1978 Data

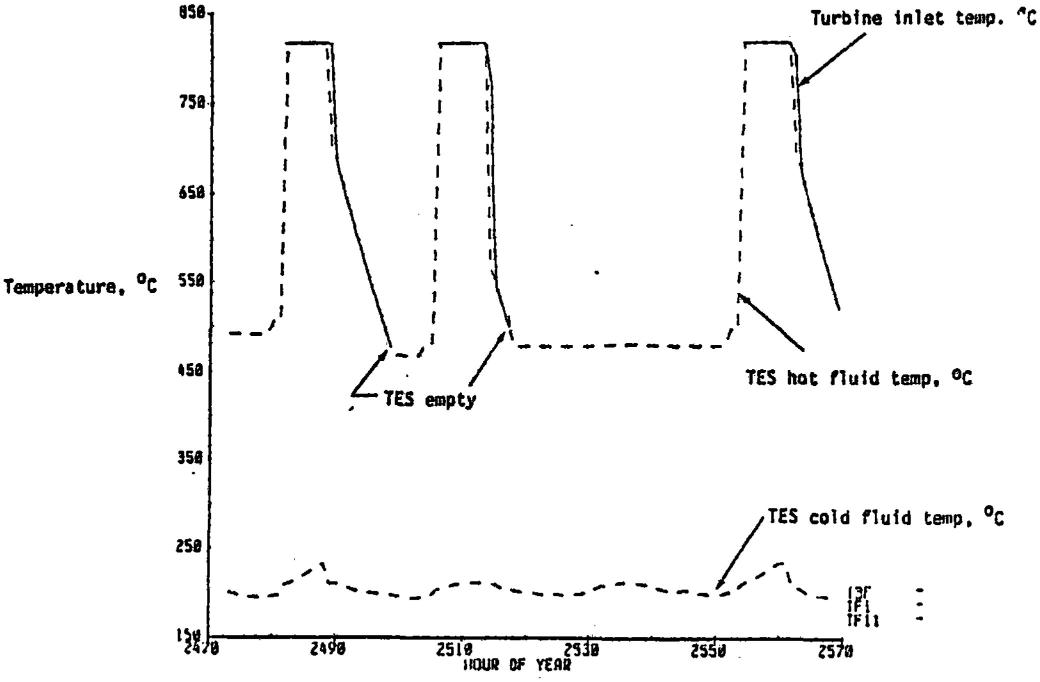


Figure 17-27. DESAL Pilot Plant Performance Yearly Analysis — Day 104 to 107 — 1978 Data

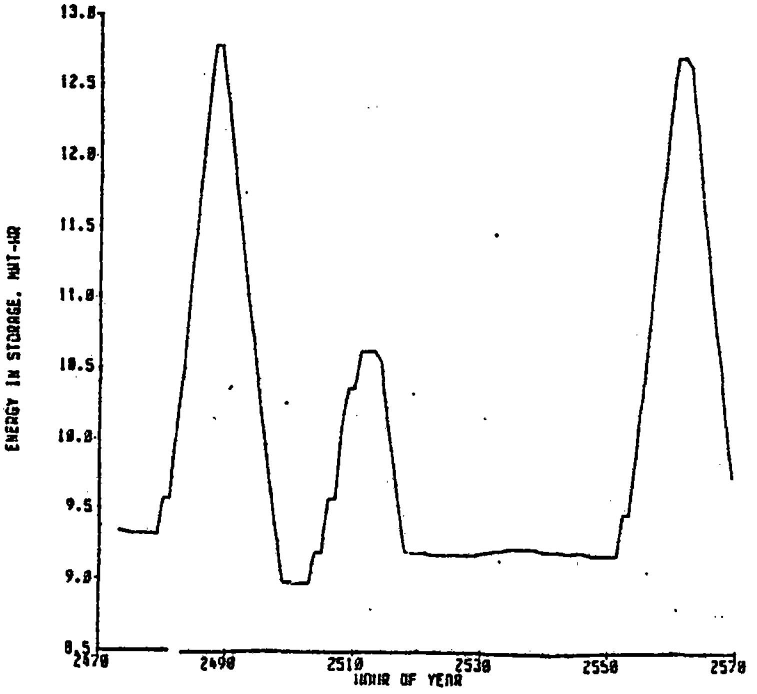


Figure 17-28. DESAL Pilot Plant Performance Yearly Analysis Day 104 to 107 — 1978 Data

Backup Grid Power Connection

When solar power (direct or stored) is not available, grid power can be used to produce water. The switchgear described in Section 8.2 can accomplish the transition from one power mode to another by synchronizing the solar generated electricity with the grid for a short period (less than 30 seconds). Table 17-14 (a duplicate of Table 1-1) shows the plant's water production for the separate power modes. Note that the electrical power requirement shown in Table 17-14 includes grid power needed for miscellaneous facilities (listed in Table 17-13) during both solar and grid powered water production. The water production shown is for 100% plant availability; for 85% availability, total annual water production is predicted to be 327163 m^3.

Should the site owner choose to backup the solar generated electricity with additional purchased grid power, the reverse osmosis modules could be operated continuously at peak water production capacity (1270 m^3/day). The switchgear design, as described in Section 8.2, is capable of managing this dual solar/grid mode with minor design revisions and different control software. The system analysis data already developed allows an estimate of the total purchased grid power required to exercise this option. Table 17-15 presents clear day production data for combined solar/grid operation. The total water production capability approaches the Rankin summer peak consumption of about 1300 m^3/day. The winter Rankin consumption of about 600 m^3/day is seen to be possible with only modest amounts of grid power.

Table 17-16 presents the effects of backup grid power connection on the annual plant water production. For an additional annual grid purchase of 474,700 kW-hr from the grid (above that required for a solar-only dormant plant), an additional 358,810 m^3 of water is produced, at 85% plant availability, total water production is predicted to be 394,000 m^3/year. This value compares with the yearly Rankin consumption of about 200,000 m^3/year of potable water.

Solar Desalination Pilot Plant Efficiency Train

Figure 17-29 presents the solar desalination pilot plant efficiency train for design point and annual operation. Figure 17-30 provides additional details on the annual performance data.

Table 17-14. DESAL Pilot Plant Annual Performance Data—Factored 1978 Midland Data

Month	Solar only operation		Grid connection			Total water (m^3)
	Water production (m^3)	Hours of operation	Water production (m^3)	Hours of operation	Power requirement (kWe-hr)	
Jan	8,256	217	27,931	527	36,890	36,187
Feb	10,270	270	21,306	402	28,140	31,576
Mar	9,564	308	23,108	436	30,520	32,672
Apr	11,348	402	16,854	318	22,260	28,202
May	8,416	283	24,433	461	32,270	32,849
Jun	6,748	225	26,235	495	34,650	32,983
Jul	10,141	393	18,603	351	24,570	28,744
Aug	6,721	236	26,924	508	35,560	33,646
Sep	5,764	286	23,002	434	30,380	28,766
Oct	10,094	348	20,988	396	27,720	31,082
Nov	6,388	195	27,825	525	36,750	34,213
Dec	11,030	311	22,949	433	30,310	33,979
Year	104,740	3,474	280,158	5,286	370,020	384,898

Table 17-15. Clear Day Data with Combined Solar/Grid Operation

Day	Solar contribution		Grid connection for maximum production		Total water production, m^3
	Water production, m^3	Operation, hrs	Water production, m^3	Total power (kW_e-hr)	
Spring	628	18	642	1,971	1,270
Summer	457	17	813	2,206	1,270
Fall	435	19	835	2,228	1,270
Winter	530	16	740	2,108	1,270

Table 17-16. DESAL Pilot Plant Annual Performance Data with Combined Solar/Grid Operation—Factored 1978 Midland Data

Month	Solar contribution		Grid connection for maximum production		Total water m^3
	Water production (m^3)	Hours of operation	Water production (m^3)	Power requirement (kWe-hr)	
Jan	8,256	217	31,114	78,142	39,370
Feb	10,270	270	25,290	66,324	35,560
Mar	9,564	308	29,806	76,280	39,370
Apr	11,348	402	26,752	70,386	38,100
May	8,416	283	30,954	78,376	39,370
Jun	6,748	225	31,352	77,808	38,100
Jul	10,141	393	29,229	75,083	39,370
Aug	6,721	236	32,649	80,836	39,370
Sep	5,764	286	32 336	79,279	38,100
Oct	10,094	348	29,276	75,275	39,370
Nov	6,388	195	31,712	78,433	38,100
Dec	11,030	311	28,340	74,431	39,370
Year	104,740	3,474	358,810	910,653	463,550

Page 167 TES Massflow 1.007 kg/s

EPGS .83 kg/s

1008

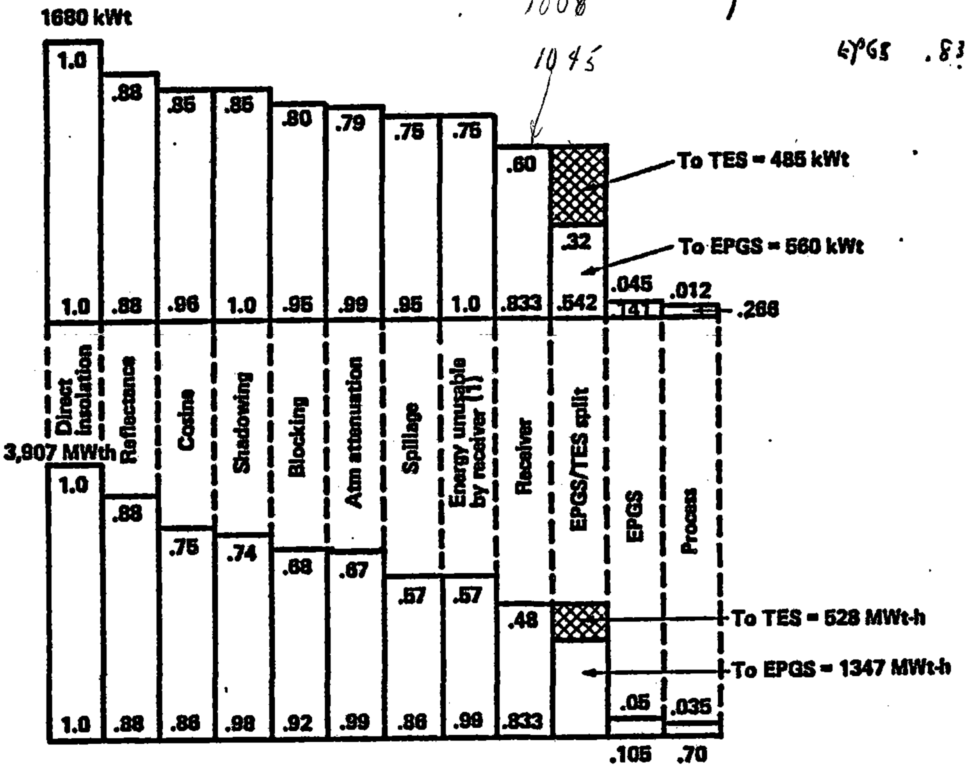
1045

Design point

- Solar noon
- Winter solstice
- 940 W/m^2
- TES near fully charged condition
- Max receiver flow
- Max pressure drop
- T_{amb} = 13°C
- $T_{turb\ in}$ = 816°C

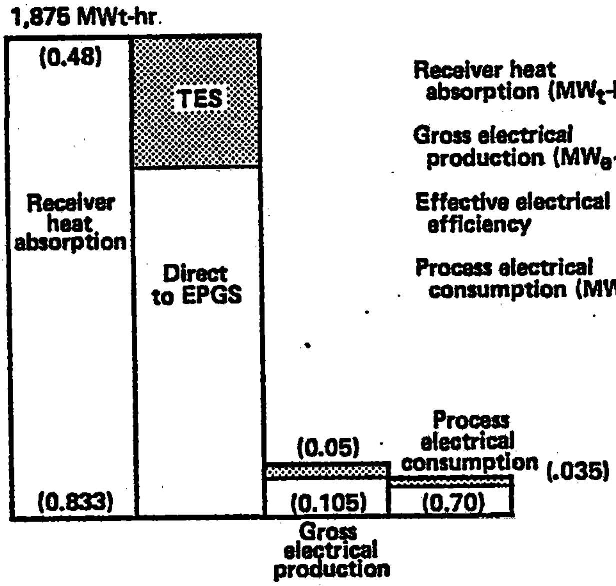
Annual

- 1978 Midland data corrected to long term average
- Collector field data weighted to hours of operation



(1) Energy below minimum receiver massflow condition, no heliostats are turned away

Figure 17-29. DESAL Pilot Plant Efficiency Train



	TES	Direct solar	Total
Receiver heat absorption (MW_t-h)	528	1,347	1,875
Gross electrical production (MW_e-h)	43	154	197
Effective electrical efficiency	.081	0.114	0.105
Process electrical consumption (MW_e-h)	30	108	138

Figure 17-30. DESAL Pilot Plant Annual Performance — Efficiency Train Details

17.7 Clear Day Performance for TES Design Variations

The preceeding plant performance analyses were performed for a brick refractory horizontal TES design, which was presented at the Preliminary Design Review (PDR) [3]. After the review, the TES design was changed to a vertical packed bed (alumina pebbles) and also a more efficient booster compressor was selected. The DESAL system performance model was then used to compare clear day performance of the TES designs. Initial results indicated the baseline medium mass of 94,090 kg is excessive for both brick and packed bed media (the medium could not be fully charged resulting in low round-trip efficiency). Subsequent analyses defined a packed bed mass (42,500 kg) that maximized clear day water production as shown in Table 17-16. Program schedule constraints did not allow a refined packed bed TES optimization nor revision of the design dimensions given in Section 7.1 (to be done during detailed design). But the following results of this initial study do indicate that the size of the packed bed TES presented in Section 7.1 can be significantly reduced.

Two causes were identified for the less than hoped for TES performance using the baseline PDR brick design. Those two causes were the inefficient TES booster compressor and TES medium mass not optimized to the solar system. The baseline PDR brick TES utilized only about 3300 kW-hr of its 7300 kW-hr expected capacity. The baseline PDR booster compressor efficiency varied from 65% at full flow to 35% at minimum flow. This efficiency was changed to a 72% value expected from more efficient compressors, while maintaining the baseline TES design medium mass. Table 17-16 (variation 1) shows this to be a beneficial effect, lowering TES pump power requirements but there is a relatively small effect on the total water production.

The second TES variation has a reduced brick medium size with the mass of 42,500 kg. This change produced a more substantial change in the total water produced, indicating TES performance much more sensitive in the pilot plant to TES mass/plant optimization rather than booster compressor efficiency.

The third TES variation shown in Table 17-16 is for a packed bed configuration of 42,500 kg. The total water production increased substantially, indicating 28% more water production over the PDR baseline for 1/2 the TES medium mass.

Table 17-16. Solar Desal Pilot Plant Performance for TES Design Variations

21 December, Clear Day

TES Variation Number	TES Medium Type	TES Medium Mass (kg)	TES Booster Compressor Efficiency (%)	Water Production (m^3)	Operation Time (hr)			Gross Electrical Production (kW-hr)	Process Electricity Consumption (kW-hr)	TES Booster Compressor Consumption (kW-hr)
					Total	Direct Solar	TES			
Baseline	Brick	94,090	≤ 65	530	16	8	8	985	704	122
1	Brick	94,090	72	544	15	8	7	939	723	80
2	Brick	42,500	72	606	15	8	7	1038	805	96
3	Packed Bed	42,500	72	681	15	8	7	1161	904	64
4	Packed Bed	26,590	72	669	14+	8	6+	1152	888	67

The enormously increased heat transfer surface area significantly sharpened the thermocline, thus allowing much better TES discharge performance.

The final TES variation was a TES medium mass at 26,590 kg or 28% of the PDR design mass. The performance variation 4 is slightly less than for variation 3. Until a cost versus performance trade is performed during detailed design, the 42,500 kg packed bed design, variation 3, is recommended for the pilot plant.

Figures 17-22, 23, 24 and Table 17-6 present massflow, electrical production, and water production for the baseline PDR brick TES design. Figures 17-31, 32, and 33 present analogous data for the 42,500 kg packed bed TES design. Substantial improvement is noted in electrical production, the RO system operates at maximum capacity for 7 hours out of 15. This is a result of the final charged state at 1600 hours approaching the fully charged capacity (see Figure 7-4). Figures 17-34 and 35 present similar data for the 26,590 kg packed bed design. The corresponding thermocline data (Figure 7-5) show TES utilization greater for the smaller mass although water production and operation time suffer slightly.

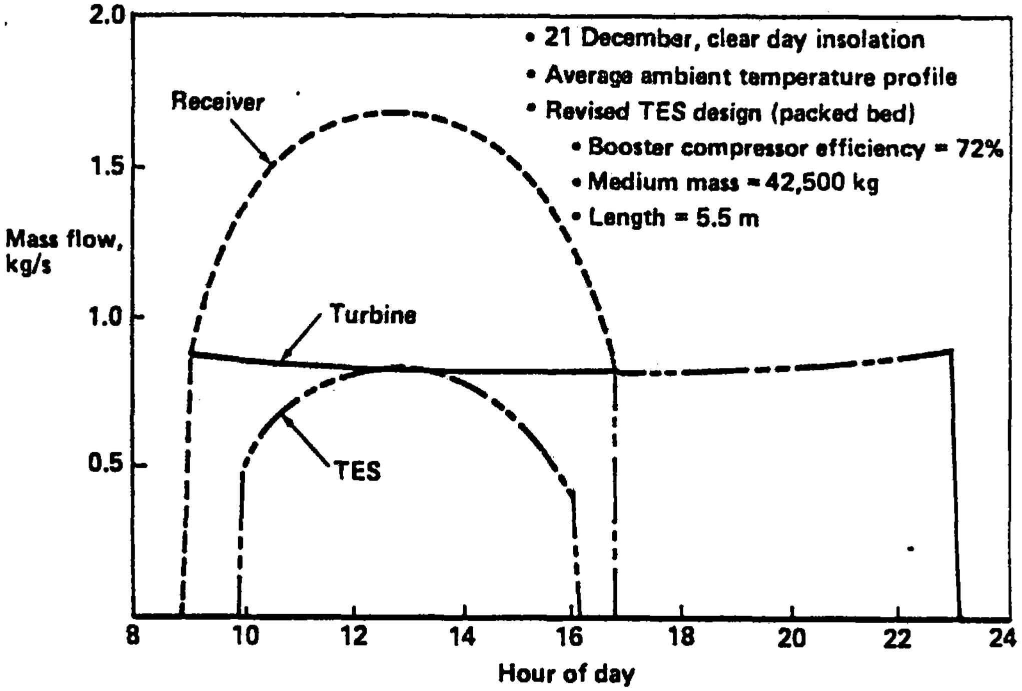


Figure 17-31. Design Day Mass Flows

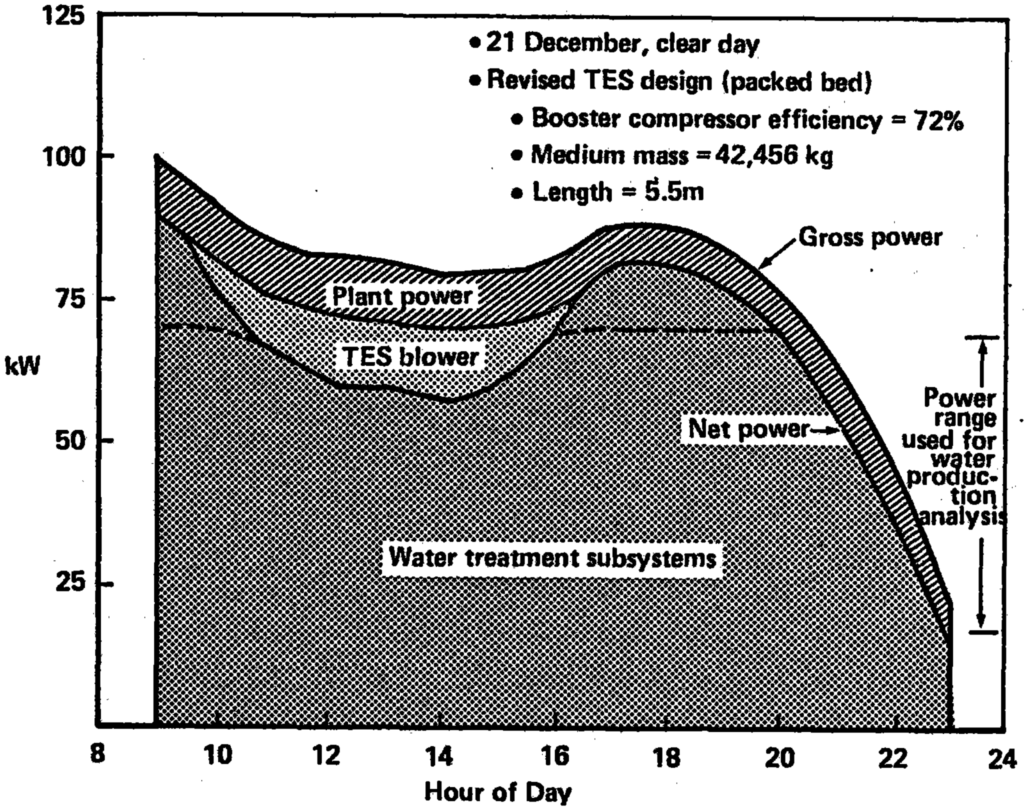


Figure 17-32. Design Day Electrical Production

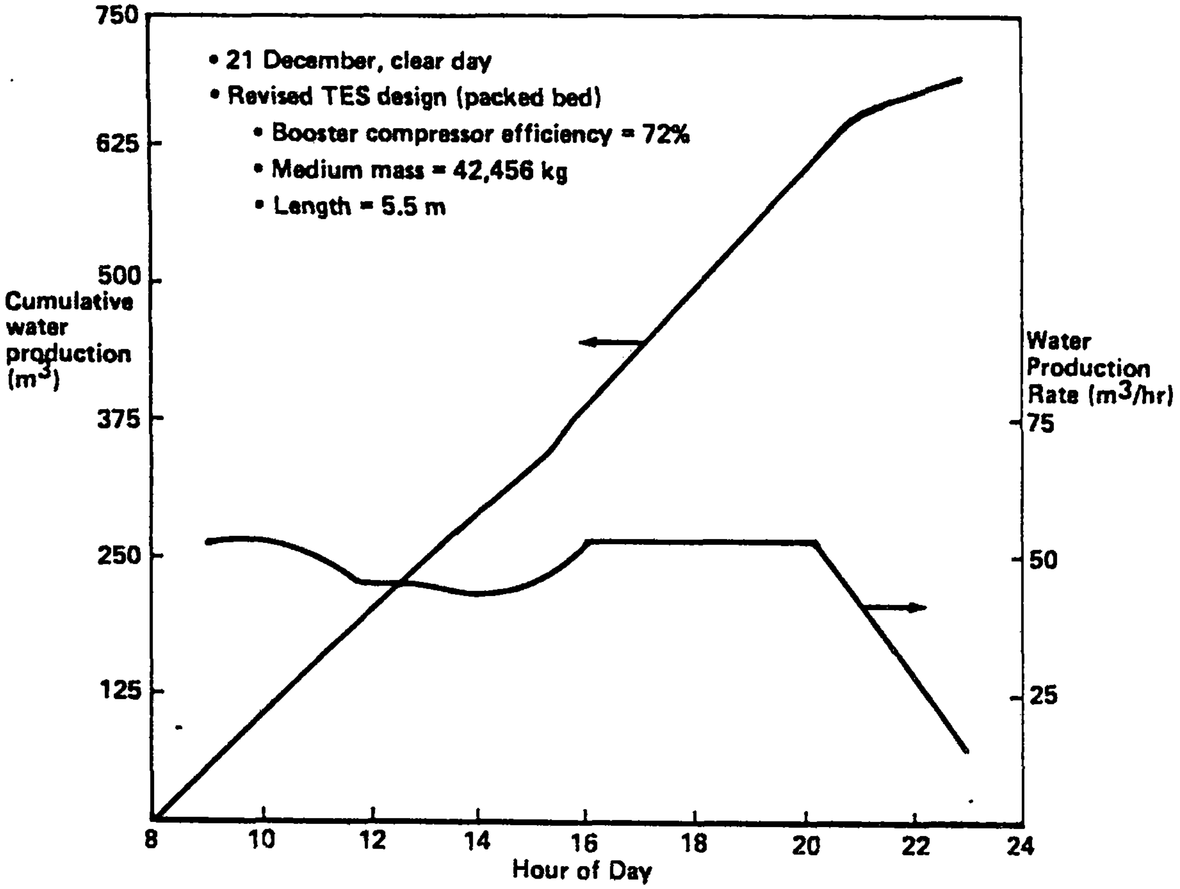


Figure 17-33. Design Day Water Production

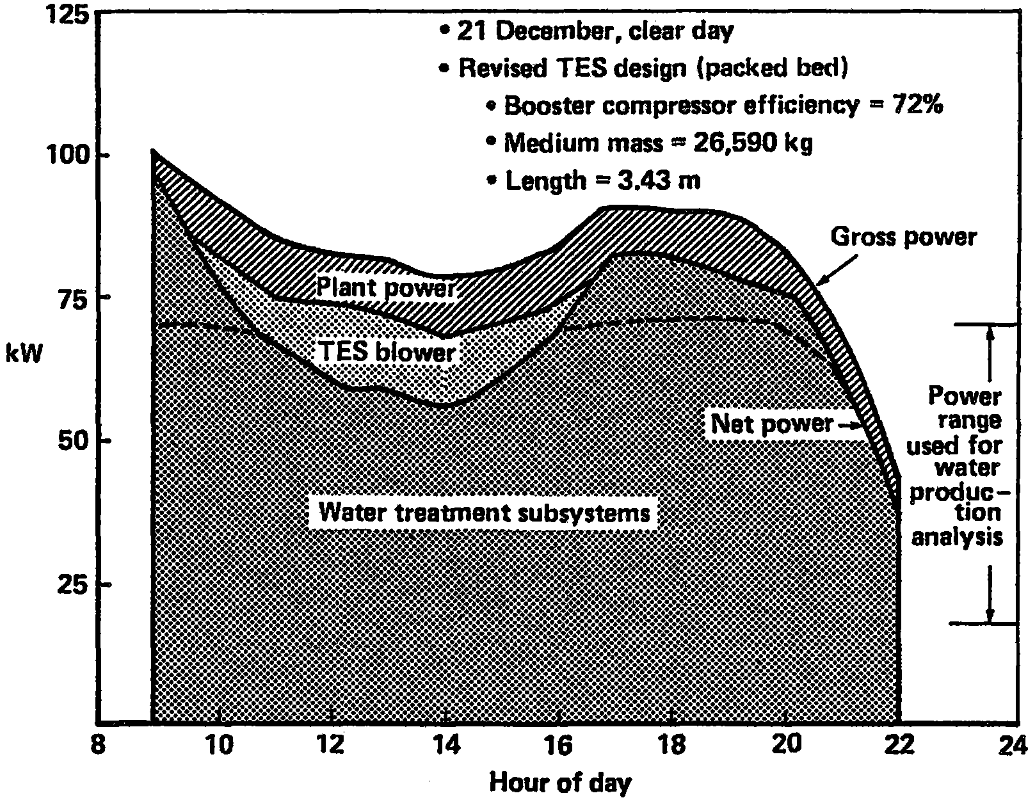


Figure 17-34. Design Day Electrical Production

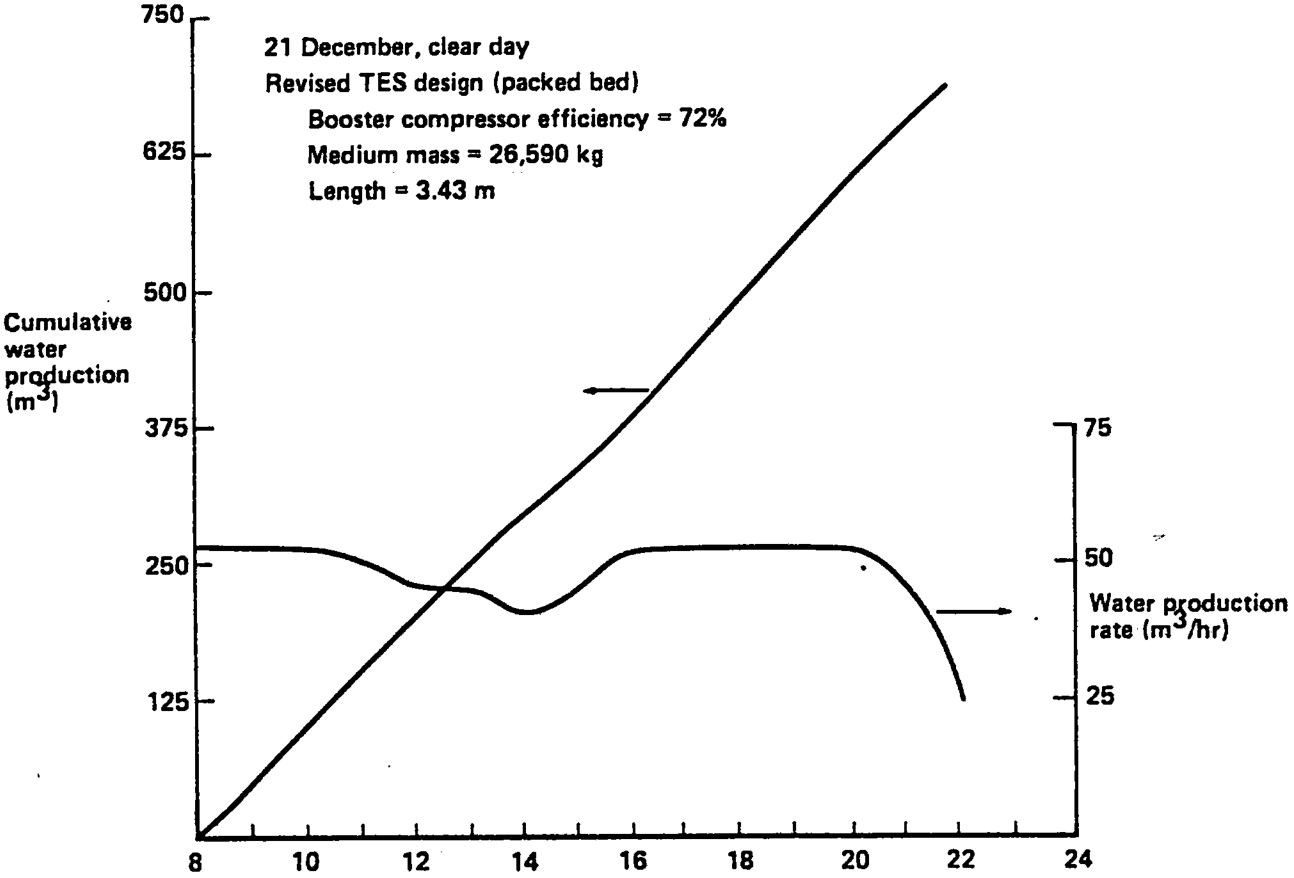


Figure 17-35. Design Day Water Production

18.0 TEST PLANS

The objective of the pilot plant test program is to demonstrate the adequacy of the design and hardware to meet the specification requirements. To satisfy this objective:

a) The test program will be planned as an integrated program to ensure that all hardware that must be tested is tested, and that no unnecessary tests are performed.

b) Test requirements and test procedures will be developed independently and cross-checked.

c) Rigid test controls will be maintained to prevent damage to equipment, to ensure that the tested configuration is the approved configuration, and to ensure that test records reflect the objectives of each test.

Testing of the pilot plant will be performed in four general categories: engineering development; receiving; integration and checkout; demonstration and acceptance. Plans for these tests will be developed during Phases 2A and 2B as indicated in Table 18-1. A preliminary list of specific tests and their sequencing is presented in Appendix B.

In the engineering development test category, the significant test activities will be in the following areas:

- Site soil investigation
- Focused reflector panel development
- Focused heliostat beam quality
- Receiver insulation thermal capability
- Hx tube heat - pressure cycling
- TES materials thermal properties
- Gas turbine combustor
- Feedwater quality
- Control system software

Table 18-1. Test Planning

Phase	Prime activity	Test planning	Tests
1	Preliminary design	Preliminary test plans	None
2A	Detailed design	Test requirements Functional and integration Test plans and procedures Acceptance test plan Operations plan	Engineering development tests
2B	Equipment procurement		Receiving tests
	Construction		Component and subassembly functional integration tests
	Checkout		Subsystem and plant checkout tests
	Performance evaluation	Performance evaluation plan	Short-term operational tests Long-term operational tests Demonstrations and simulations Acceptance tests

Table 18-2. Receiving Tests

- Functional tests of purchased equipment to verify that performance meets specifications
  - Heliostat gimbals
  - Turbine-generator set
  - Transformers and swtichgear
  - Air compressor
  - Booster-compressor
  - Pumps
  - Skid-mounted water treatment equipment
  - Control system components
- Structural proof tests of pressure vessels and welded assemblies
  - HX panels
  - TES unit pressure vessel

These tests will be performed during Phase 2A to support the detailed design. In several areas - receiver insulation, gas turbine, and control software - testing is being performed on the BEC/EPRI Full System Experiment program that will reduce the extent of pilot plant planned tests.

During Phase 2B, receiving tests will be performed on manufactured equipment to verify compliance with performance specifications and governing codes. These tests will be in addition to quality assurance activities and are summarized in Table 18-2.

Integration and checkout testing will be conducted in Phase 2B on installed equipment and subsystems as summarized in Table 18-3.

After construction is complete, the pilot plant will be operated as a simulated commercial plant and tested to demonstrate its usefulness as a water plant to Upton County. These tests are categorized in Tables 18-4 and 5.

Testing will be conducted with formal acceptance tests that will certify that the pilot plant is in full operational status and complies with all specification requirements.

Table 18-3. Integration and Checkout Tests

- Heliostat focusing and alignment, field performance
- Receiver flow trim, pressure drop, thermal performance
- Energy storage flow, pressure drop, charge-discharge characteristics
- Energy delivery - operation on fossil, utility, solar TES, and combined
- Water treatment subsystems - insolation capability, performance characteristics
- Control subassemblies and subsystem checkout
    - Software
    - Interaction with controlled/measured equipment
    - Interaction with all subsystems operating

Table 18-4. Performance Evaluation Tests — Commercial Plant Simulation

Demonstrate that the pilot plant performs its functions as designed and can be operated by a utility as a water plant

- System functions and operating modes
    - Startup
    - Produce water - solar, stored solar, utility power
    - Shutdown
- Mode transitions
    - Smooth transition between operating modes
- Emergency shutdown
- Operator aids
    - Integrated checkout
    - Fault detection
    - Displays
    - Computation
    - Severe wind monitoring

Table 18-5. Performance Evaluation and Acceptance Tests — Pilot Plant Operations

Demonstrate features of commercial plant performance by simulations with the pilot plant

- **Commercial plant energy storage capacity**
  - **Simulate 2nd and 3rd TES unit storage and discharge**
    - **Operate turbine generator on fossil fuel during storage period**
    - **Discharge pilot plant TES at end of storage period**
- **Simulate continuous standalone solar operation**
  - **Reduced TES discharge flow rate and water production**
  - **Supplemental energy from fossil fuel combustor**

19.0 REFERENCES

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7. Coulson, J. M. et al Unit Operations, 3rd Edition, "Flow of Fluids through Granular Beds and Packed Columns," Pergamon Press, Chemical Eng'g. Series, Vol. II, New York, 1978 pp 125-171.

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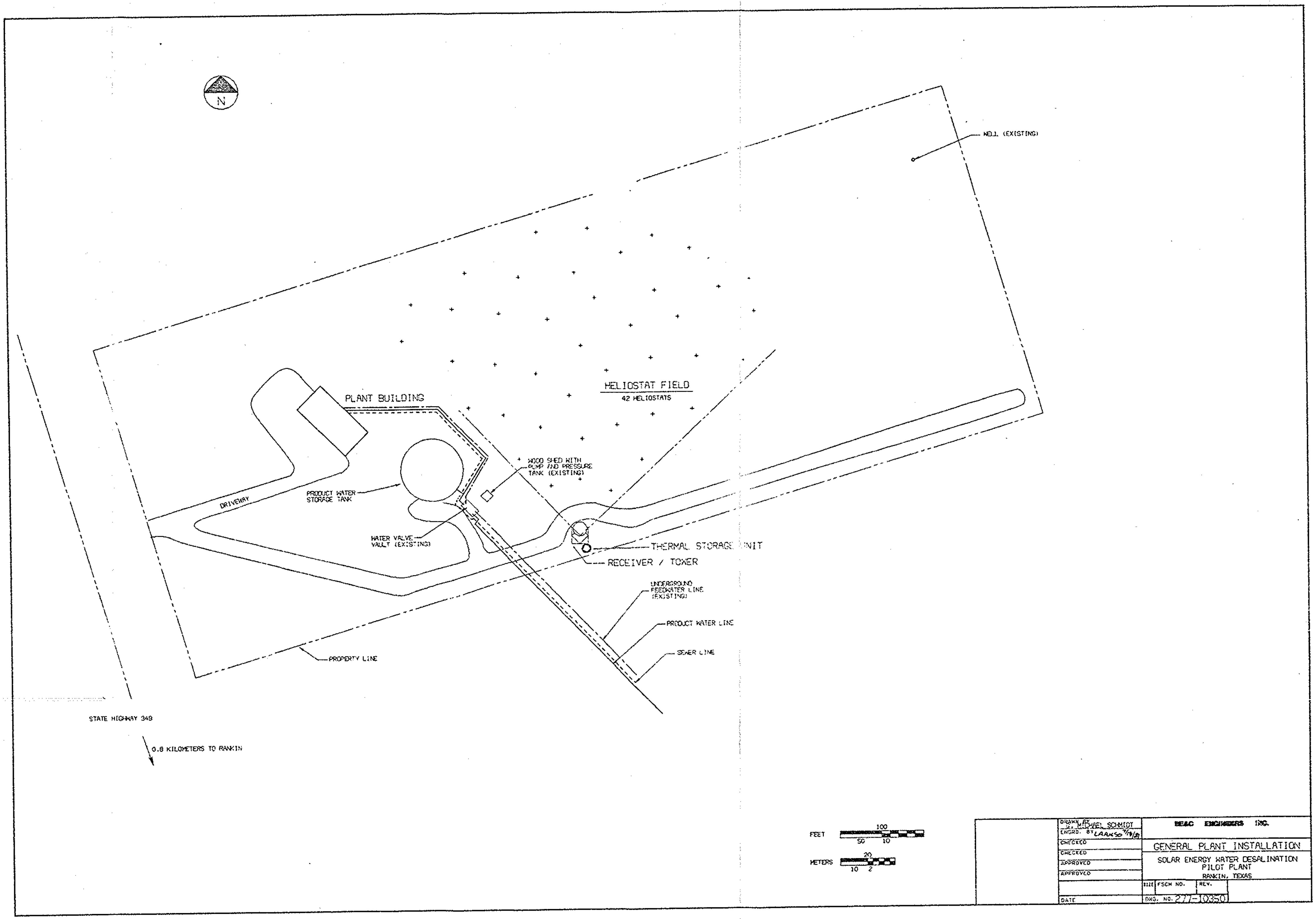
Drawing No.	Title	WBS Reference No.	Drawing Issue Preliminary Design	Revision
	PILOT PLANT	5500		
277-10350	General Pilot Plant Installation	5500	5/27/81	7/13/81
277-10351	Solar Subsystems Installation	5500	5/27/81	7/13/81
277-10352	Plant Control Line Installation	5500	5/27/81	
277-10353	Plant Instrumentation Installation	5500	5/27/81	
277-10354	Plant Electrical Power Distribution Installation	5500	5/27/81	
	Water Subsytem Interfaces (RCC drawing 171-G2-1)	5500	5/27/81	
	PLANT SITE	5400		
	Site Plan (Esmond-Haner Drawing Project No. E-H 32368)	5410	5/27/81	
	FACILITIES AND ENCLOSURES SUBSYSTEM	5510		
277-10360	Building Plan	5511	5/27/81	7/13/81
	SOLAR ENERGY COLLECTION SUBSYSTEM	5520		
277-10365	Heliostat Field Coordinates	5521	5/27/81	
277-10366	Heliostat Installation (BEC Drawing 277-10115)	5521	5/27/81	

DESIGN DRAWING LIST cont'd

Drawing No.	Title	WBS Reference No.	Drawing Issue	
			Preliminary Design	Revision
277-10390	Receiver Assembly Drawing	5522	5/27/81	
277-10397	Tower Design	5523	5/28/81	
277-10400	Interconnect Piping Assembly	5524	5/28/81	
	ENERGY STORAGE SUBSYSTEM	5530		
277-10405	Thermal Energy Storage Unit Assembly	5531	5/28/81	7/7/81 (Reissue)
	ENERGY DELIVERY SUBSYSTEM	5535		
	90 kW Turbine-Generator Set Installation (Alturdyne Drawing 713-13086)	5536	3/4/81	
	FEEDWATER PRETREATMENT SUBSYSTEM	5500		
	and			
	DESALINATION SUBSYSTEM	5860		
	Process Flow Schematic (RCC Drawing 171-M3-1)	5550/5560	5/20/81	
	Process and Instrumentation Drawing (RCC Drawing 171-M4-1)	5550/5560	5/27/81	
	Building Footprint of Desalination Equip. (RCC Drawing 171-A3-1)	5550/5560	5/27/81	



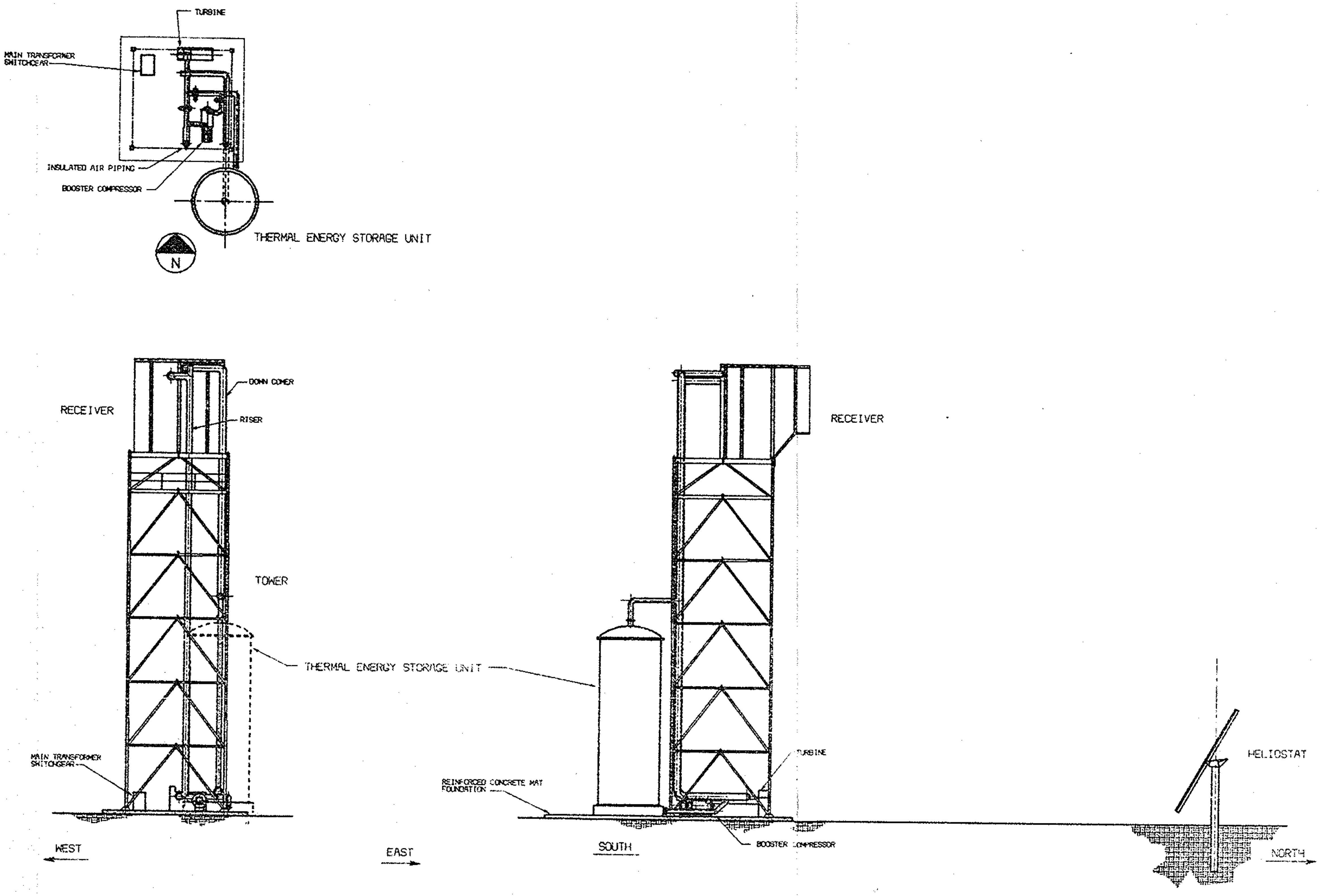
DRAWN BY G. MICHAEL SCHMIDT
ENGRD. BY LAAKSO 7/19/81
CHECKED
CHECKED
APPROVED
APPROVED
DATE

BE&C ENGINEERS INC.

GENERAL PLANT INSTALLATION

SOLAR ENERGY WATER DESALINATION
PILOT PLANT
RANKIN, TEXAS

SIZE | FSCM NO. | REV.
DWG. NO. 277-10350



INCHES 200 100 20

METERS 5 2 1

DRAWN BY J. MICHAEL SCHMIDT
ENGRD. BY LAAKSO 7/17/8
CHECKED
CHECKED
APPROVED
APPROVED
DATE

[illegible] INC.

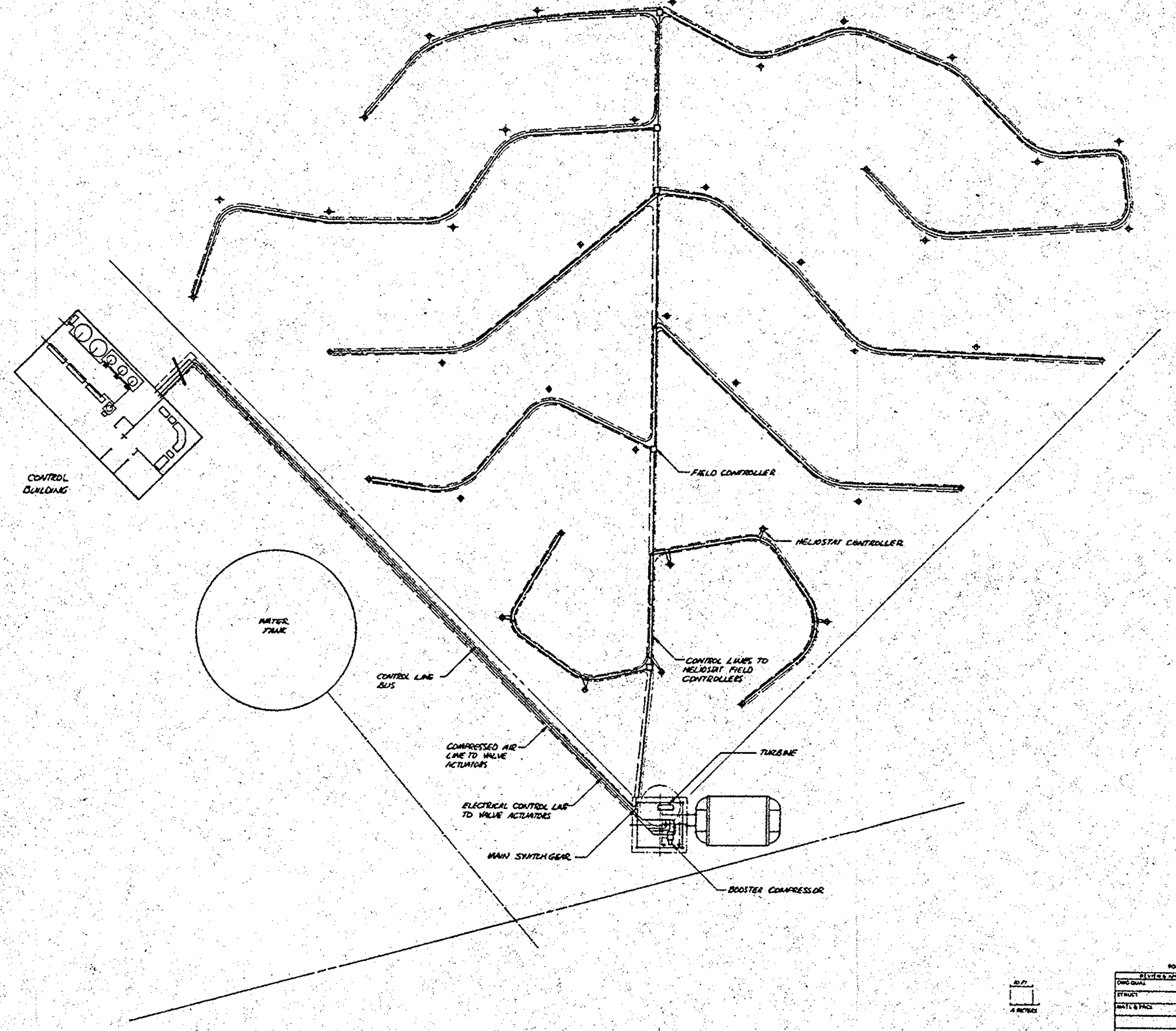
SOLAR SUBSYSTEMS INSTALLATION

SOLAR ENERGY WATER DESALINATION
PILOT PLANT

SIZE | FSCM NO. | REV.
DWG. NO. 277-10351

REVISION

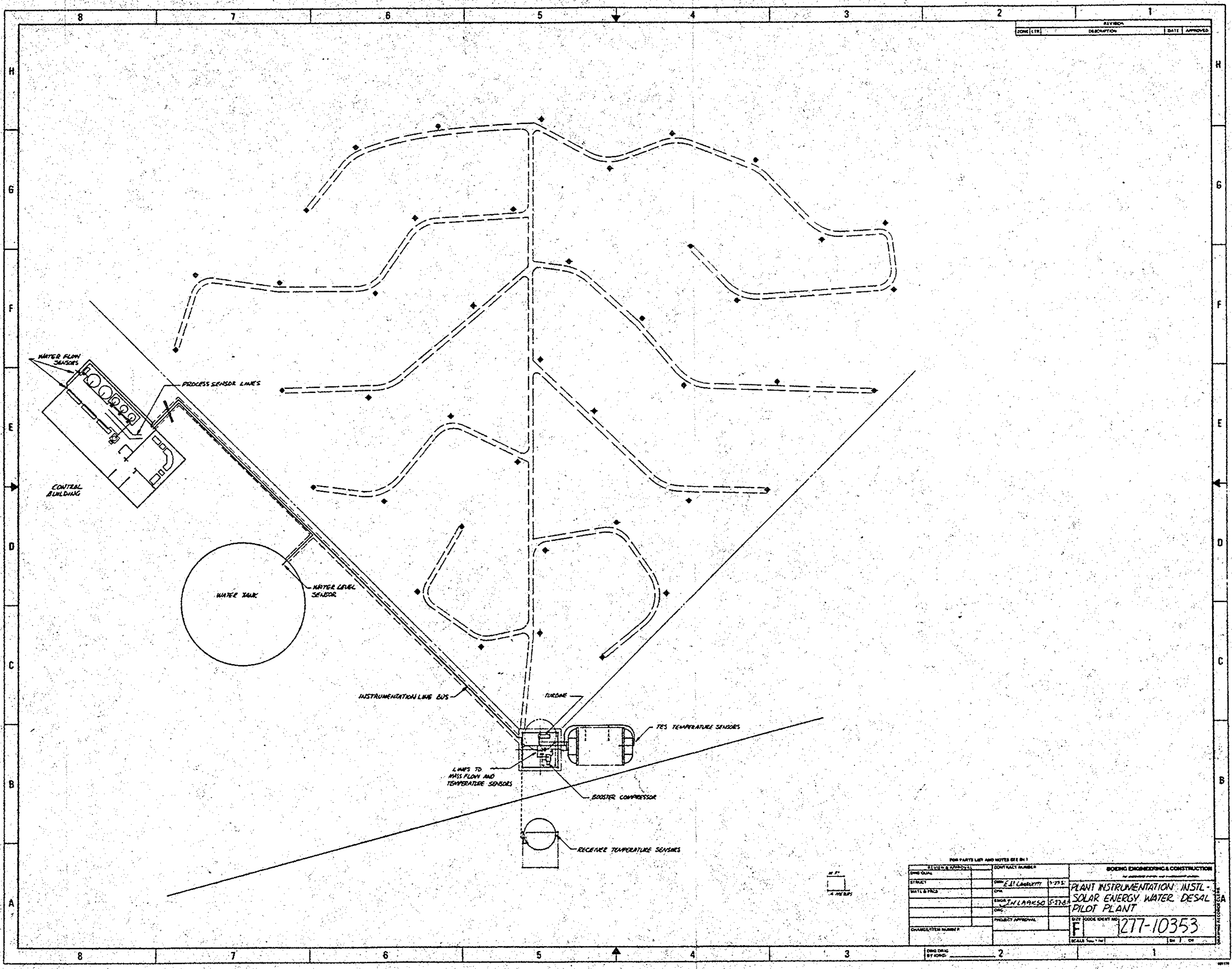
ZONE	LTR	DESCRIPTION	DATE	APPROVED



FOR PARTS LIST AND NOTES SEE SH 1

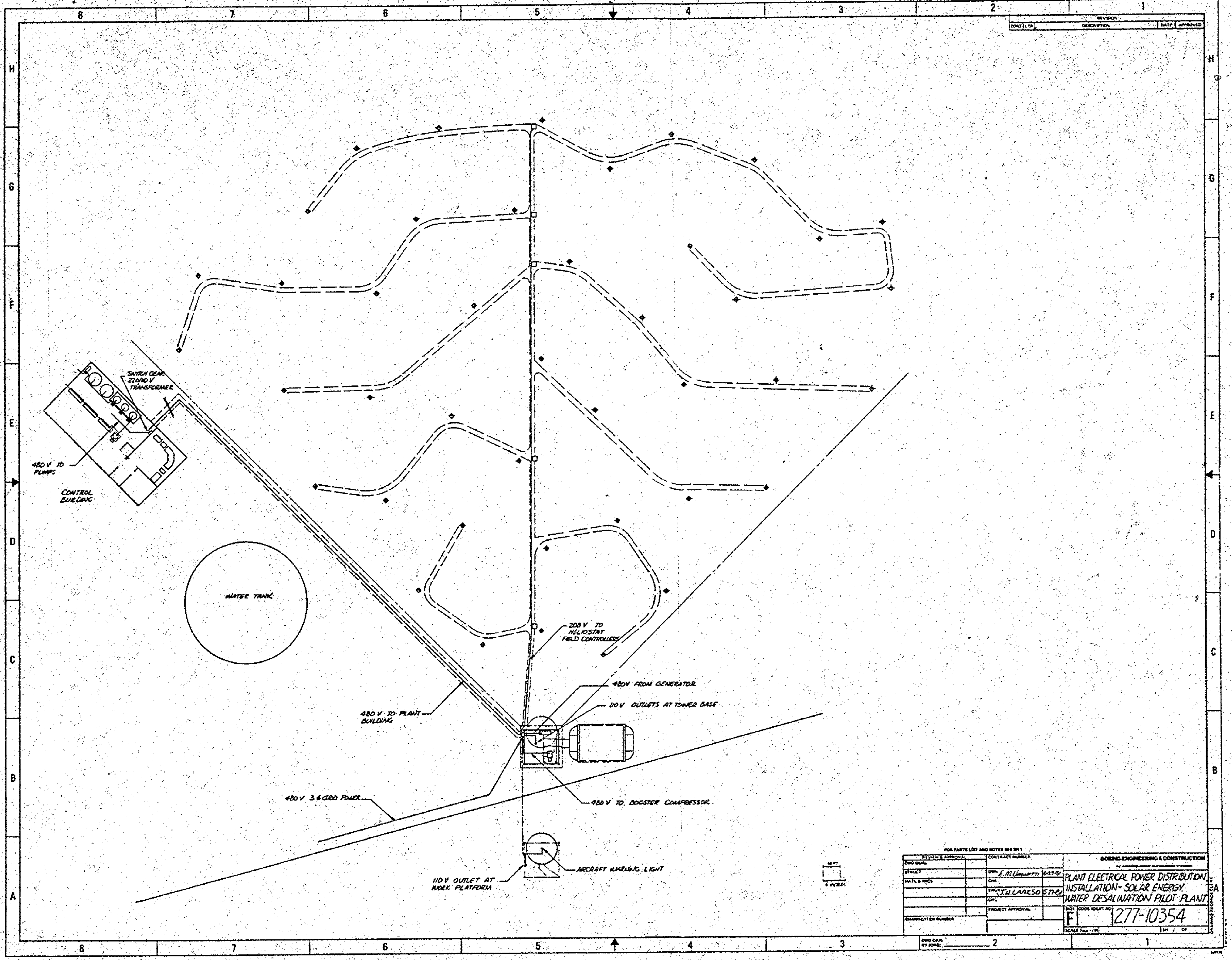
REVIEW & APPROVAL		CONTRACT NUMBER		BOEING ENGINEERING & CONSTRUCTION
DWG QUAL				
STRUCT		DRN E.K. Lindsorm	[illegible]	PLANT CONROL LINE INSTALLATION
MATL & PACK		CHK		SOLAR ENERGY WATER DESALINATON A
		ENGR J.H. LAAKSO	[illegible]	PILOT PLANT
		ORG		
		PROJECT APPROVAL		SIZE F CODE IDENT NO 277-10352
CHANGE/ITEM NUMBER				SCALE [illegible] SH 1 OF 1

ORIG DWG BY (ORG) ______



PLANT INSTRUMENTATION INSTL -
SOLAR ENERGY WATER DESAL
PILOT PLANT

277-10353



FOR PARTS LIST AND NOTES SEE SH 1

REVIEW & APPROVAL		CONTRACT NUMBER	
DWG QUAL			
STRUCT		DWN E.M. Unwerth	6-27-8[illegible]
MAT'L & PRCS		CHK	
		ENGR J.H. LARESO	5-27-8[illegible]
		OPC	
		PROJECT APPROVAL	
CHANGE/ITEM NUMBER			

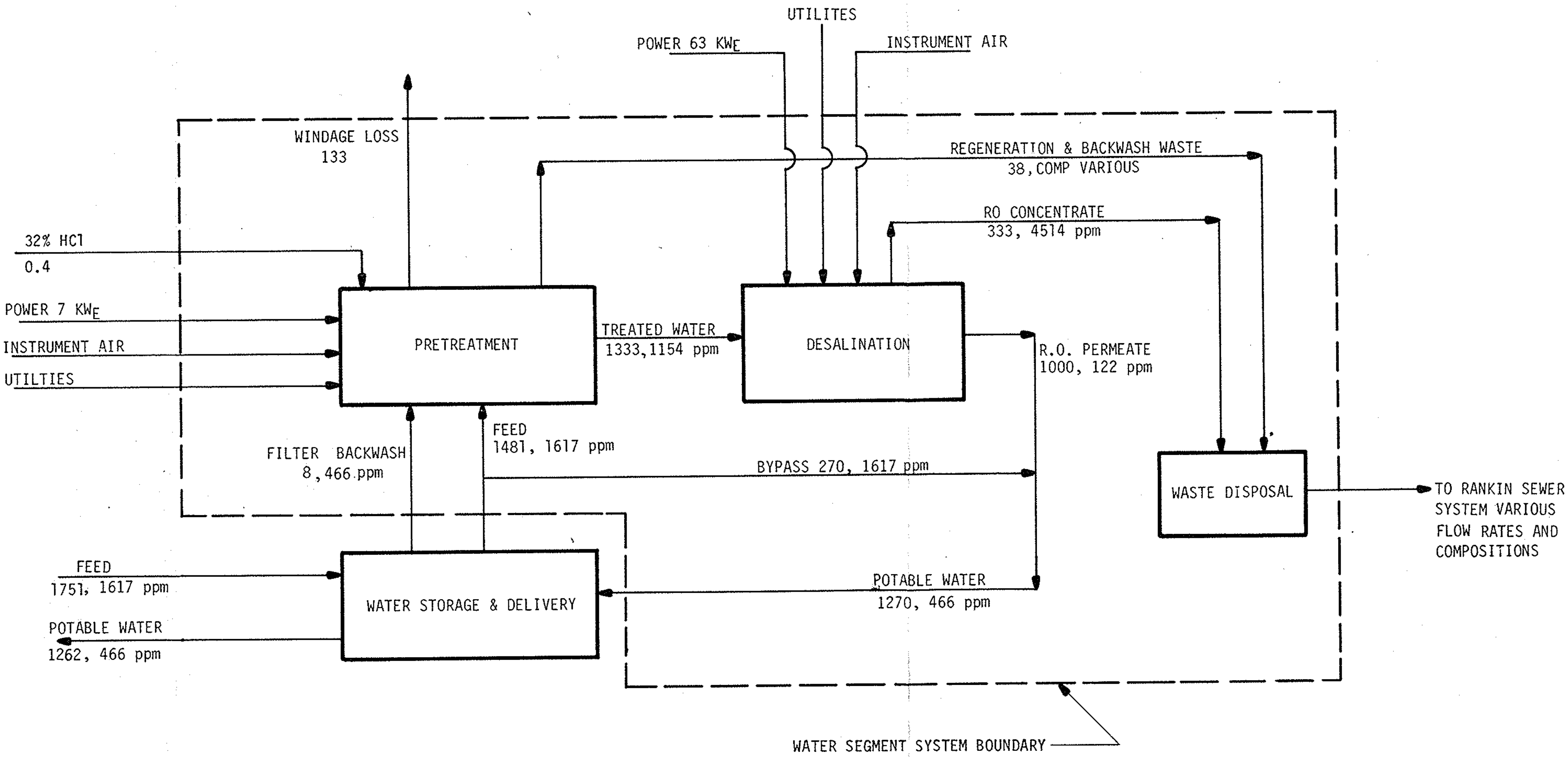
BOEING ENGINEERING & CONSTRUCTION

PLANT ELECTRICAL POWER DISTRIBUTION
INSTALLATION - SOLAR ENERGY
WATER DESALINATION PILOT PLANT

SIZE F | CODE IDENT NO | 277-10354

SCALE | SH 1 OF

DWG ORIG BY ENGR: ______



- ALL FLOW RATES IN M^3/DAY
- 24 HOUR OPERATION AT DESIGN POINT ASSUMED
- DESIGN POINT (MAX.) FLOWS
- ALL COMPOSITIONS IN mg/l AS IONS

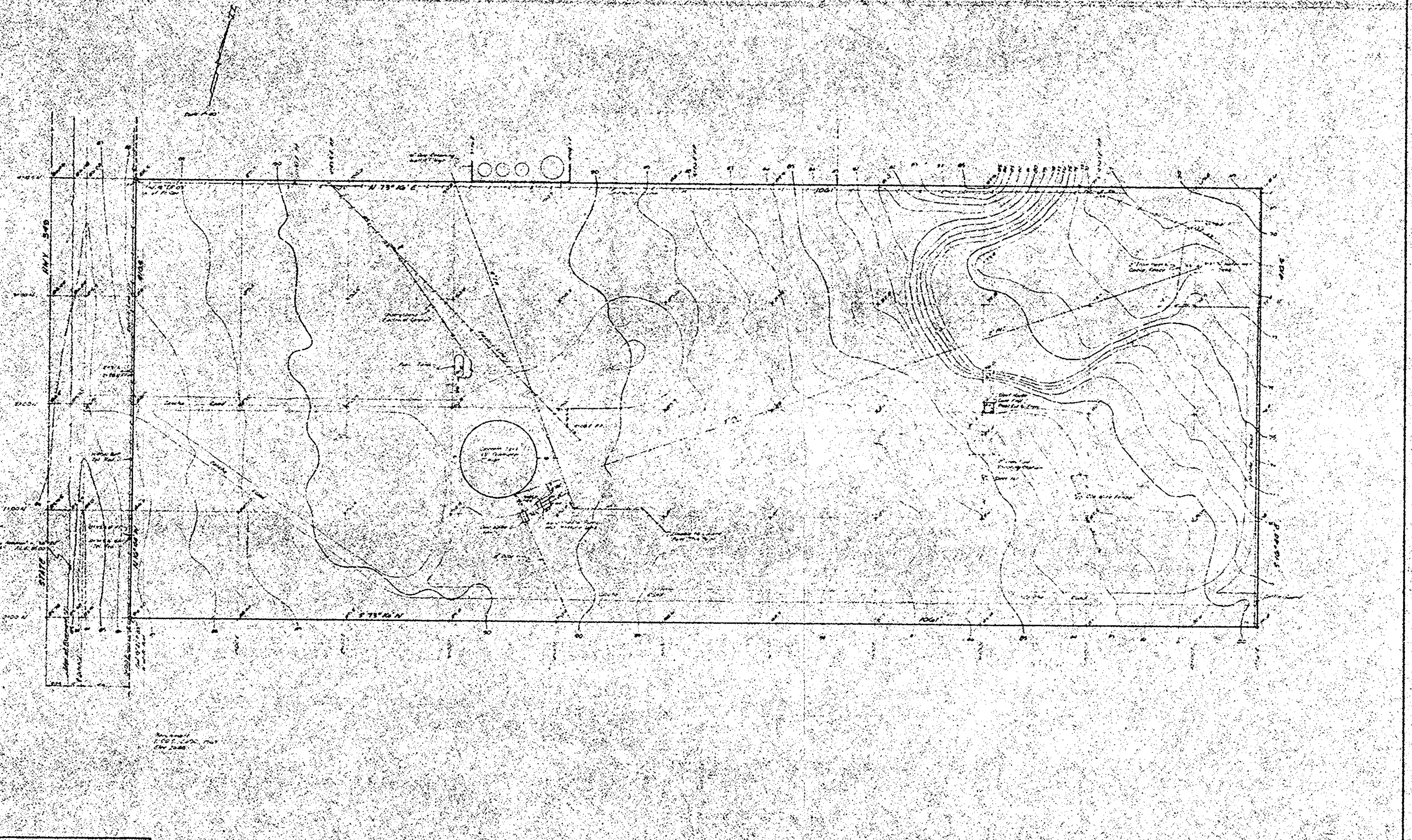
LTR	REVISIONS	BY	CHK	APP	DATE
A	Excluded Water Storage & Delivery			[illegible]	[illegible]
	Subsystem. Added bypass to sewer			[illegible]	[illegible]
	system. Added acid usage.			[illegible]	[illegible]
	Changed Filter Backwash to 8,466 ppm				
	Change Feed to 1507, 1617 ppm				
	Change Potable Water to 1262,466				

DR ROGER ROTH
CHK J. Dalon
APP 5/01/81

RESOURCES CONSERVATION CO.

WATER SYBSYSTEM INTERFACES
SOLAR ENERGY WATER DESALINATION PLANT
RANKIN, TEXAS

171-G2-1 REV. A
SCALE
SHEET 1 of 1



PROJECT NUMBER

APPROVED

Designed By
Drawn By
Traced By
Checked By
Approved By

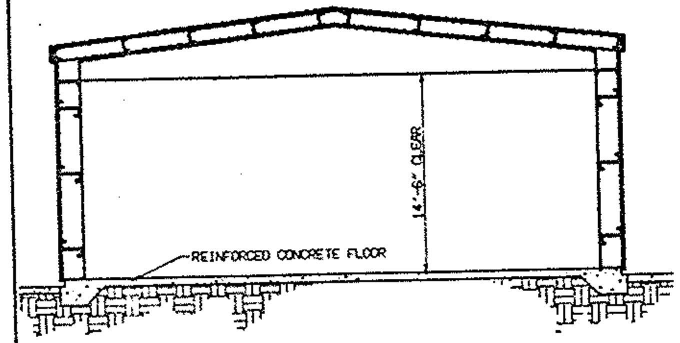
SOLAR ENERGY WATER
DESALINATION SYSTEM
RANKIN, TEXAS

ESMOND-HANER, INC.
ENGINEERS PLANNERS SURVEYORS

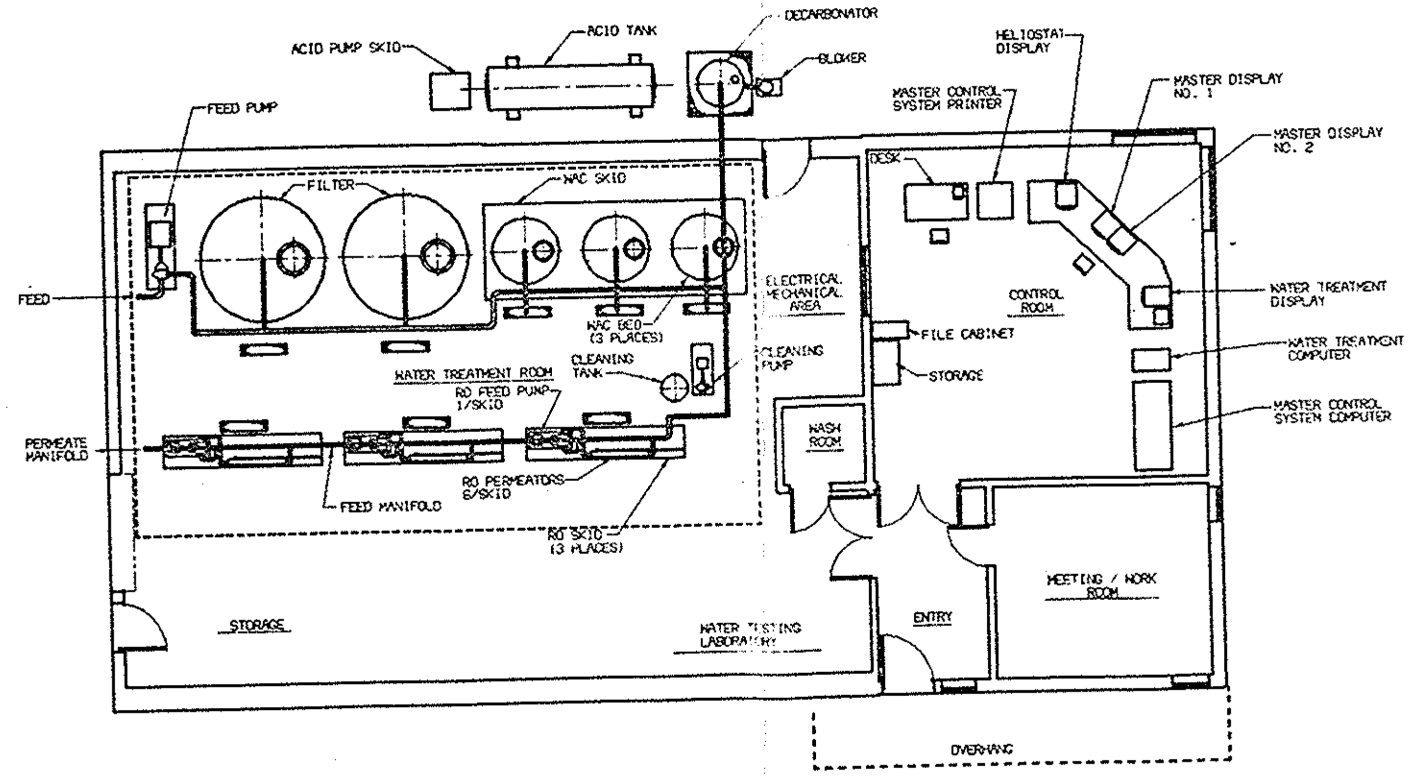
PILOT PLANT SITE PLAN

E-H 32368

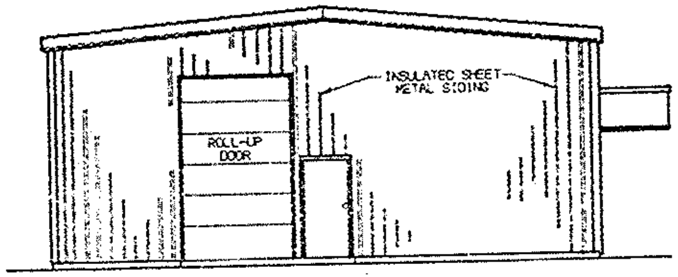
DATE SHEET 1 OF 1



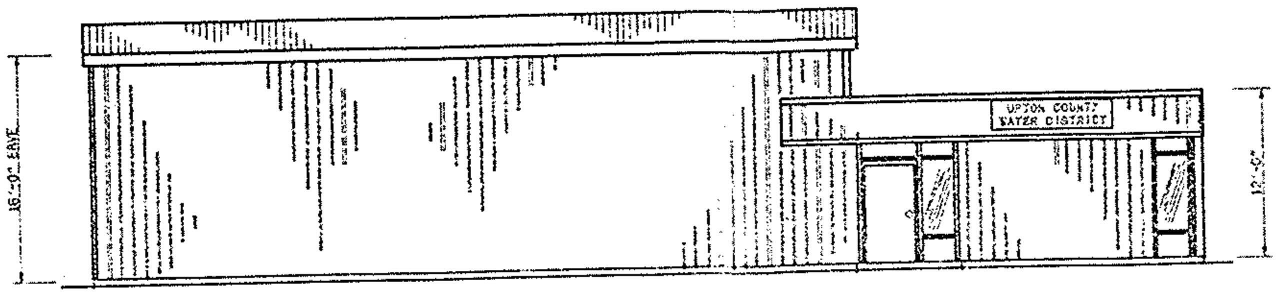
HIGH BAY SECTION



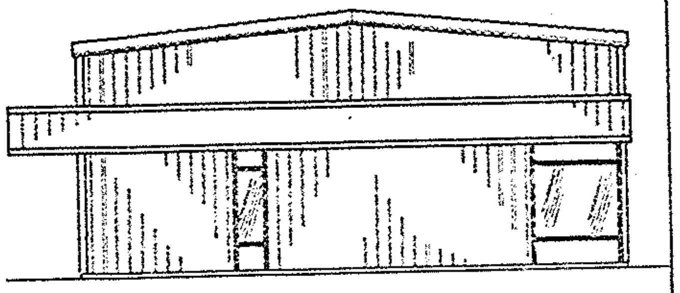
FLOOR PLAN



WEST ELEVATION



SOUTH ELEVATION



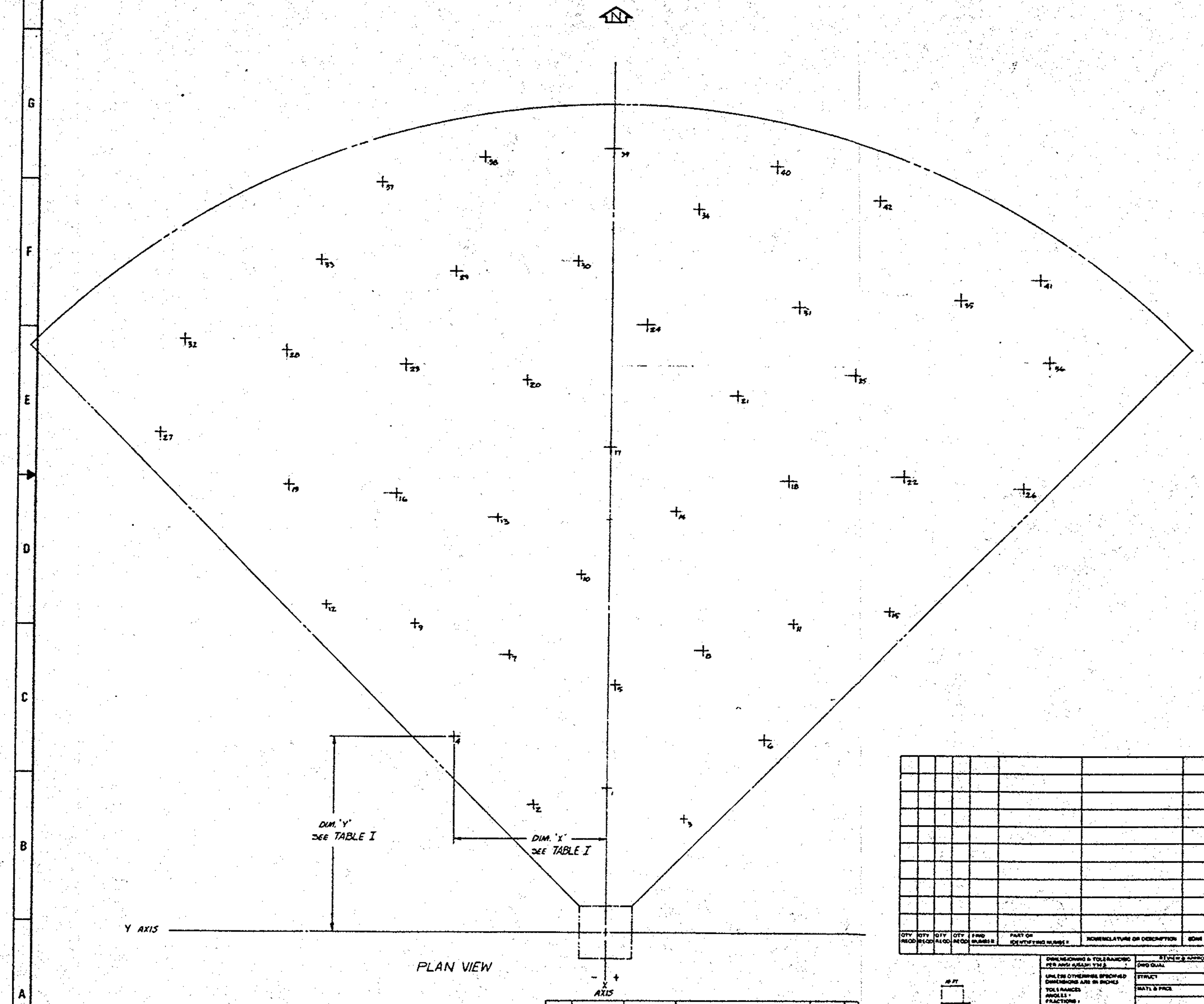
EAST ELEVATION

PRE-ENGINEERED METAL BUILDING

TOTAL FLOOR AREA	3200 SQ/FT	297 SQ/M
HIGH BAY	2200 SQ/FT	204 SQ/M
OFFICE BAY	1000 SQ/FT	93 SQ/M

SCALE: FEET 10 5 1
METRIC 5 2 1

DRAWN BY G. MICHAEL SCHMIDT	BE&C ENGINEERS INC.
ENGRD. BY ZAAKSO 7/13/91	
CHECKED	BUILDING PLAN
CHECKED	SOLAR ENERGY WATER DESALINATION PILOT PLANT
APPROVED	
APPROVED	
	SIZE FSCM NO. REV.
DATE	DWG. NO. 277-10360



PLAN VIEW

TABLE I

NO.	DIM. X	DIM. Y	NO.	DIM. X	DIM. Y
1	0	21.00	23	-30.00	82.50
2	-10.70	18.50	24	5.10	88.25
3	11.30	16.50	25	36.60	81.00
4	-22.40	28.40	26	60.90	64.70
5	1.50	36.00	27	-65.00	72.50
6	22.80	28.10	28	-47.50	84.38
7	-14.40	40.30	29	-22.80	95.90
8	13.80	41.00	30	-5.00	97.50
9	-28.30	49.80	31	27.90	93.90
10	-4.10	52.00	32	-62.50	85.00
11	26.90	44.90	33	-42.50	97.50
12	-41.75	47.50	34	12.50	105.00
13	-16.30	60.30	35	51.00	92.00
14	9.70	61.20	36	64.00	83.00
15	44.10	46.80	37	-33.75	108.75
16	-31.25	63.75	38	-18.75	112.50
17	0	70.50	39	0	113.75
18	26.00	65.70	40	23.75	111.25
19	-46.85	65.00	41	62.50	95.00
20	-12.20	80.20	42	39.00	106.50
21	18.40	78.00			
22	43.00	66.30			

DIMENSIONS ARE IN METERS

10 FT
4 METERS

PART OF IDENTIFYING NUMBER | NOMENCLATURE OR DESCRIPTION | ZONE | MATERIAL AND SPECIFICATION | CODE IDENT NO. | FINISH | REV LTR

PARTS LIST

DIMENSIONING & TOLERANCING PER ANSI Y14.5

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES
ANGLES ±
FRACTIONS ±
DECIMALS .XX ±
DECIMALS .XXX ±

REVIEW & APPROVAL
DWG QUAL
STRUCT
MATL & PROC
CHANGE/LETTER NUMBER

CONTRACT NUMBER
DRN E. M. [illegible] 5-20-81
CHK
ENGR T. H. LARKS[illegible] 5-27-81
ORG
PROJECT APPROVAL

BOEING ENGINEERING & CONSTRUCTION

HELIOSTAT FIELD COORDINATES
SOLAR ENERGY WATER
DESALINATION PILOT PLANT

SIZE F | CODE IDENT NO. | 277-10365

SCALE [illegible] | SH 1 OF

PART NUMBER | NEXT ASSY | USED ON | EFFECTIVITY | DWN BY NUMBER | REV LTR
APPLICATION

STI-10782 SH 1

277-10115

NOTES

1. HELIOSTAT ASSEMBLY INSTALLATION AND ALIGNMENT SHALL BE PER BEC DOCUMENT D277-10196-1.

2 COMMERCIAL ITEM

3 FOR 3 PHASE POWER, ROUTE TO SOURCE.

4 FOR CABLE (SEE 277-10126), ROUTE TO COMPUTER LOCATION.

REV STATUS SH	LTR
1	A
2	B

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	ADDED ITEMS 8 THRU 14 & NOTES 3 & 4	2/24/80	OR LWD

QTY REQD -1	FIND NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	REV LTR
AR	14	3/4" AL CONDUIT	ALUMINUM CONDUIT, RIGID 3/4 DIA		ANY COMMERCIAL SOURCE	A
1	13	233	BUSHING, PLASTIC		THOMAS & BETTS (OR EQUIV.)	A
2	12	1277	CONDUIT CLAMP		THOMAS & BETTS (OR EQUIV)	A
2	11	01-01004	1/4" MASONRY LAG ANCHOR		DIAMOND (OR EQUIV)	A
4	10	EMS-A-CO	EXTERIOR CABLE TIE (EPOXY)		PANDUIT	A
1	9	CT20	CABLE TAP		THOMAS & BETTS (OR EQUIV.	A
1	8		SWITCH BOX			A
9	7	2	WASHER		3/4 I.D. × .090 PLAIN, FLAT, ASTM A325 STL	
9	6	2	BOLT		3/4-10UNC-2A × 2 1/4 LONG ASTM A325	
1	5	277-10126-1	CONTROL SYSTEM ASSEMBLY			
1	4	531149-01	GIMBAL-ACTUATOR ASSY		FORD AEROSPACE & COMMUNICATIONS CORP. WESTERN DEVELOPMENT LABORATORIES DIV. PALO ALTO, CALIFORNIA 94303	
1	3	277-10123-1	PEDESTAL INSTALLATION			
1	2	277-10116-6	REFLECTOR INSTALLATION			
—	1	-1	HELIOSTAT INSTALLATION			

PARTS LIST

UNITS: INCHES

FASTENER CODES

PART NUMBER	NEXT ASSY	USED ON	EFFECTIVITY	DWG SH NUMBER	REV LTR
-1	—		PROTOTYPE MOD 277-1	1 & 2	

APPLICATION

DIMENSIONING & TOLERANCING PER ANSI Y14.5
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES: ANGLES ±
DECIMALS .XX ±
DECIMALS .XXX ±

DRN E.M. Urbanetti 4-29-80
CHK 5-21-80
ENGR 5-30-80
PROJECT APPROVAL 6-1-80

BOEING ENGINEERING & CONSTRUCTION

HELIOSTAT INSTALLATION—
2ND GENERATION HELIOSTAT
MOD 277-1

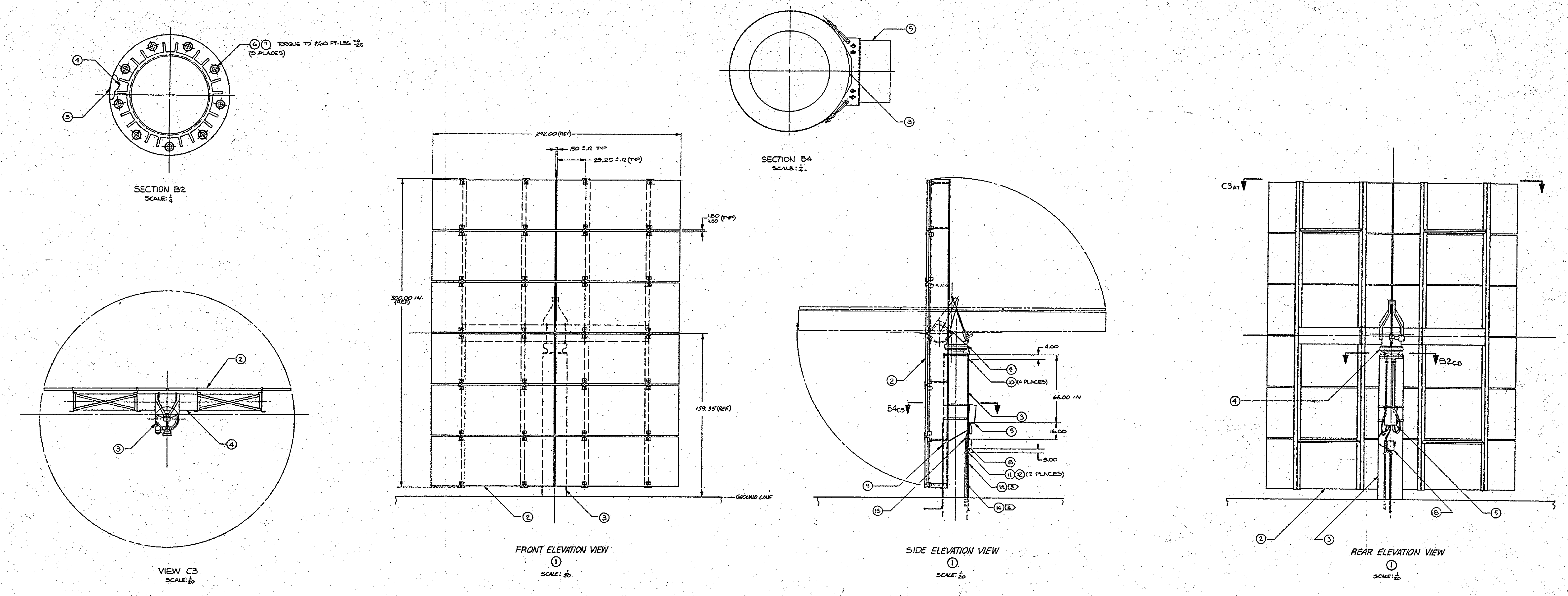
SIZE J
277-10115

SH 1 OF 2

DWG ORIG. BY (ORG) K-6130

277-10115 A

ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	(a) REAR ELEVATION VIEW: ADDED SECT. INDICATOR B2CB ADDED ⑤ (b) SIDE ELEVATION VIEW: ADDED ⑤ & 66.00 DIM. ADDED SECT. INDICATOR B4CS. (c) FRONT VIEW ELEVATION: ADDED (REF) TO 242.00 & 300.00 ADDED .50, 29.25 & 1.00/1.00 DIM. (d) ZN CB, ADDED VIEW B2. (e) ZN C5 ADDED VIEW B4.	5-22-80 5-30-80 6-9-80	DWN: [illegible]
	B	ADDED ⑥ THRU ⑭	8/12/80	[illegible]



UNITS: INCHES

SEE SHEET 1 FOR PARTS LIST AND NOTES

REVIEW & APPROVAL		CONTRACT NUMBER	
DWG QUAL			
STRUCT		DRN E. M. Ubasken	2-4-80
MAT'L & PROC		CHK [illegible]	5-5-80
		ENGR [illegible]	5-5-80
		ORG	
CHANGE/ITEM NUMBER		PROJECT APPROVAL [illegible]	[illegible]

BOEING ENGINEERING & CONSTRUCTION

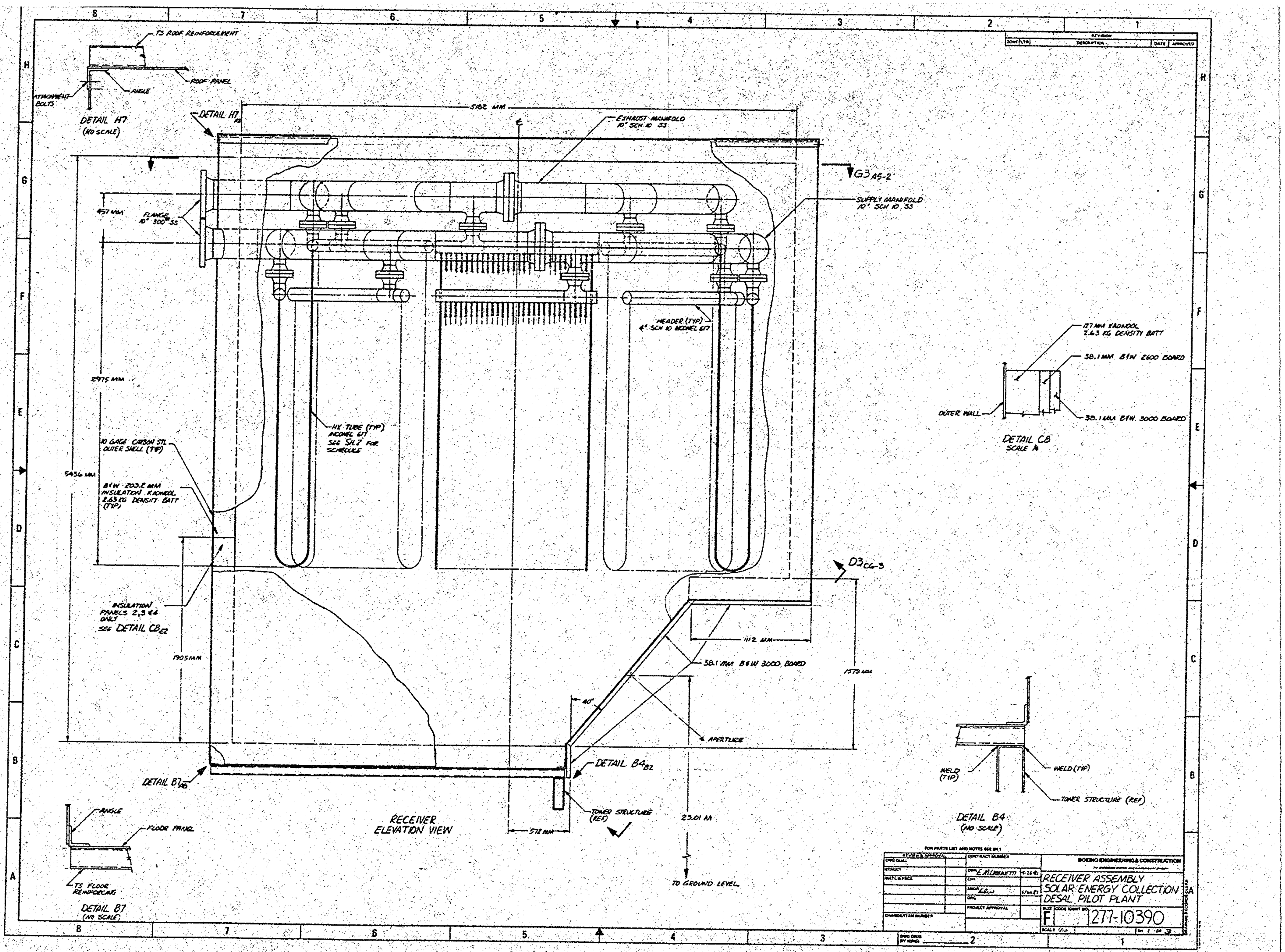
HELIOSTAT INSTALLATION–
2ND GENERATION HELIOSTAT
MOD 277-1

SIZE J CODE IDENT NO. 277-10115

SCALE NOTED SH 2

DWG ORIG BY ENGR K-6130

277-10115 A2



FOR PARTS LIST AND NOTES SEE SH 1

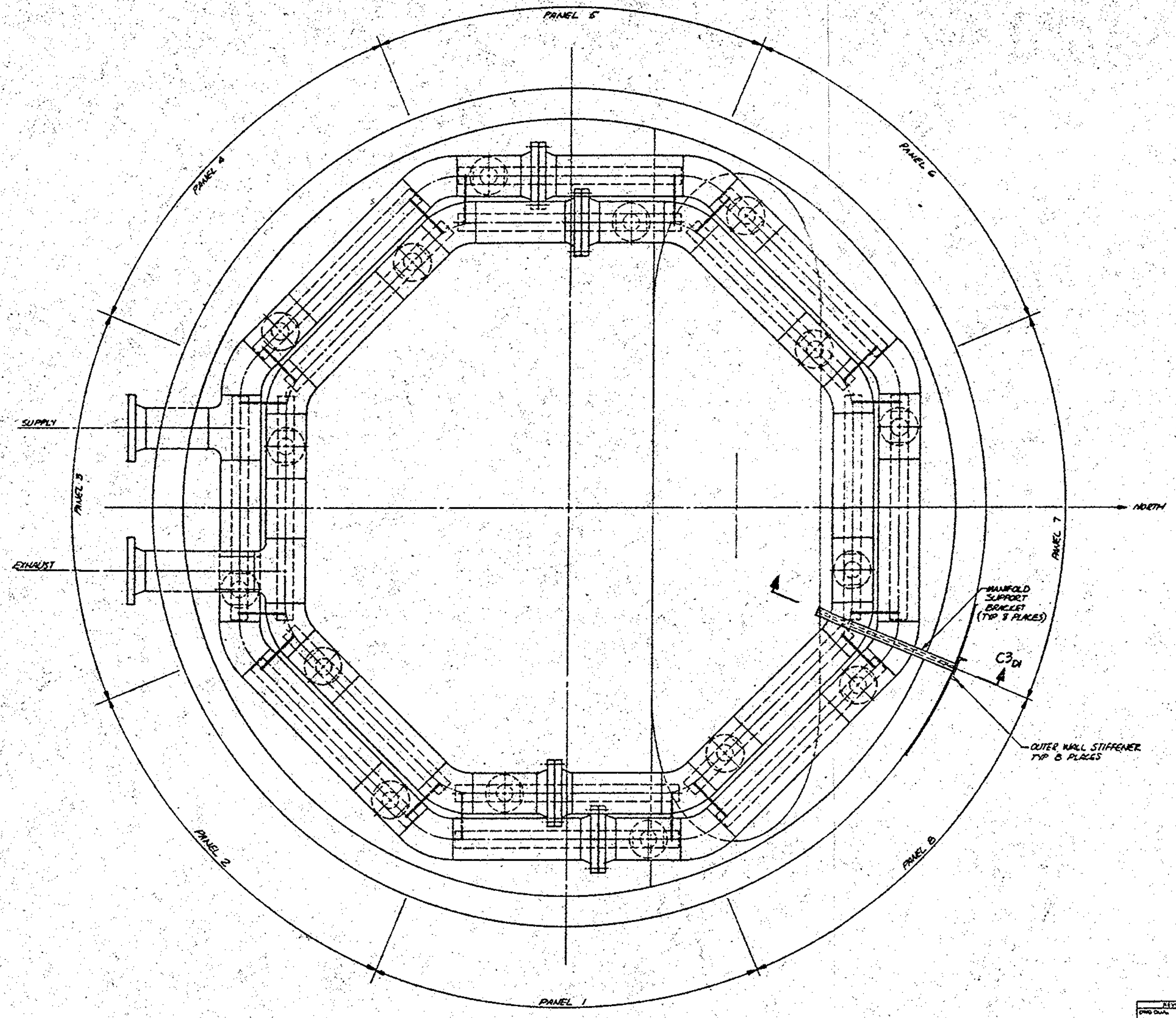
REVIEW & APPROVAL		CONTRACT NUMBER	
DRG QUAL			
STRUCT		DRN E.M.URBALETTI	4-26-81
MATL & PROC		CHK	
		ENGR	
		DRG	
		PROJECT APPROVAL	
CHANGE/LITTER NUMBER			

BOEING ENGINEERING & CONSTRUCTION

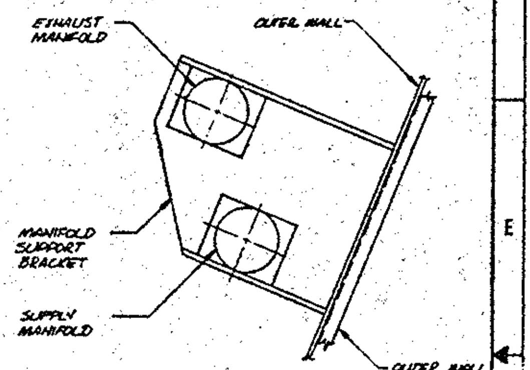
RECEIVER ASSEMBLY
SOLAR ENERGY COLLECTION
DESAL PILOT PLANT

SIZE F
CODE IDENT NO
1277-10390
SCALE 1/10
SH 1 OF 3

REVISION				
ZONE	LTR	DESCRIPTION	DATE	APPROVED



SECTION G3-1



SECTION C3
TYP 8 PLACES
(NO SCALE)

HEAT EXCHANGER TUBE SCHEDULE

PANEL	O.D. (MM)	WALL THICKNESS MM	℄ SPACING MM	NO/PANEL
1	12.7	0.89	48.5	30
2	14.68	0.89	52.1	28
3	14.68	0.89	48.5	30
4	14.68	0.89	52.1	28
5	12.7	0.89	48.5	30
6	12.7	0.89	48.5	30
7	12.7	0.89	48.5	30
8	12.7	0.89	48.5	30

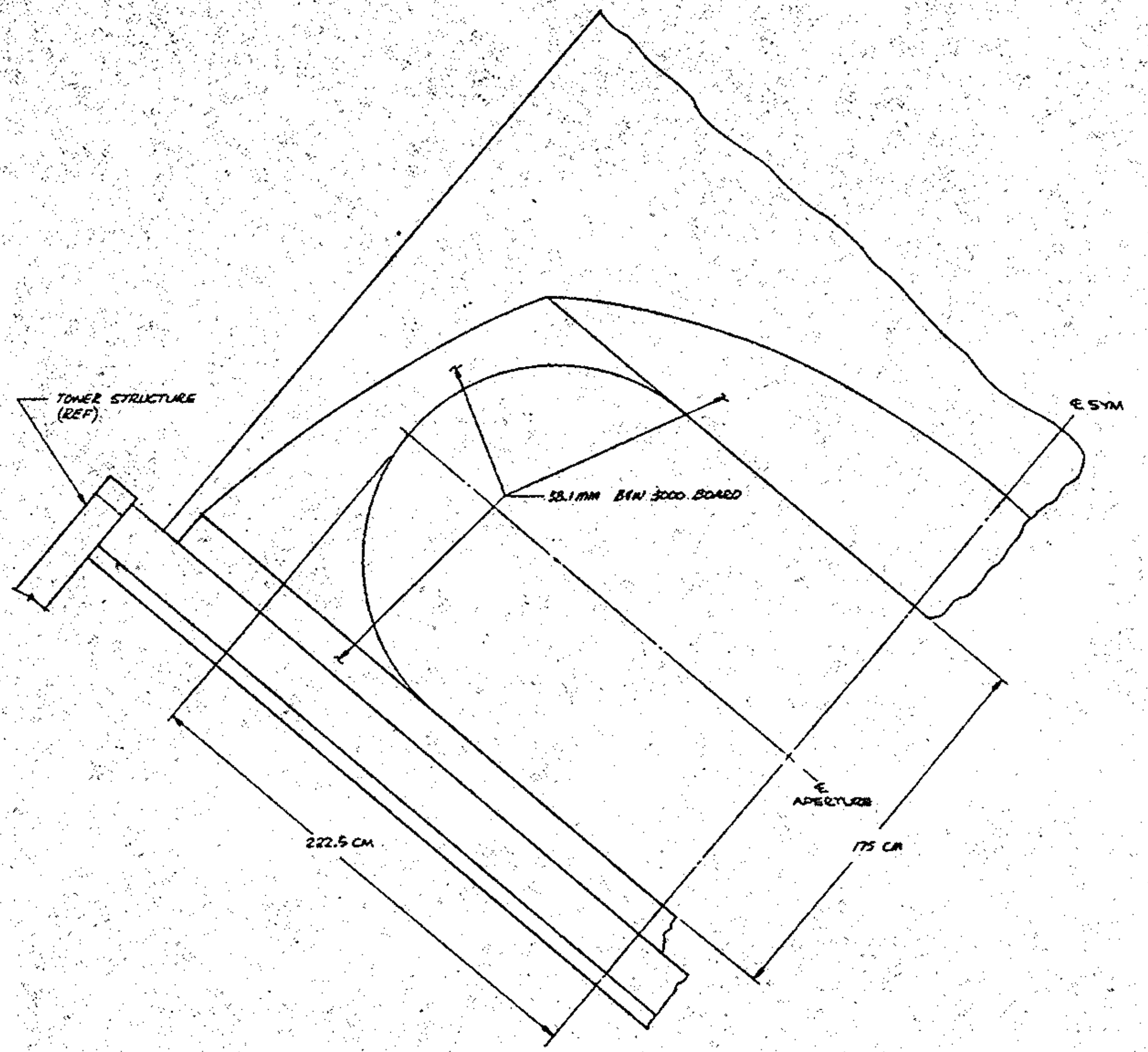
FOR PARTS LIST AND NOTES SEE SH 1

BOEING ENGINEERING & CONSTRUCTION

RECEIVER ASSEMBLY
SOLAR ENERGY COLLECTION
DESAL PILOT PLANT

SIZE F
277-10390
SCALE 1/10
SH 2 OF 3

REVISION				
ZONE	LTR	DESCRIPTION	DATE	APPROVED



VIEW D3-1

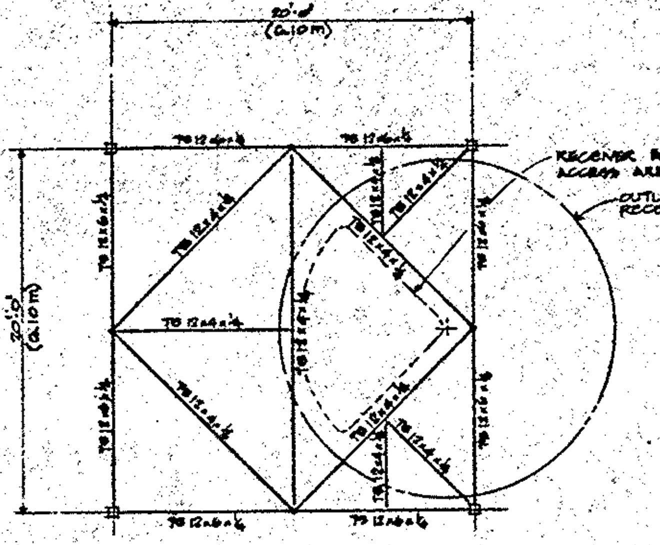
FOR PARTS LIST AND NOTES SEE SH 1

ANALYSIS & APPROVAL		CONTRACT NUMBER		BOEING ENGINEERING & CONSTRUCTION
DWG QUAL				
STRUCT		DWN E.M.Lammett	5-14-81	RECEIVER ASSEMBLY SOLAR ENERGY COLLECTION DESAL PILOT PLANT
MATL & PROC		CHK		
		ENGR Hw	6/2/81	
		ORG		
		PROJECT APPROVAL		SIZE F CODE IDENT NO 1277-10390
CHANGE/ITEM NUMBER				SCALE 1/10 SH 3 OF 3

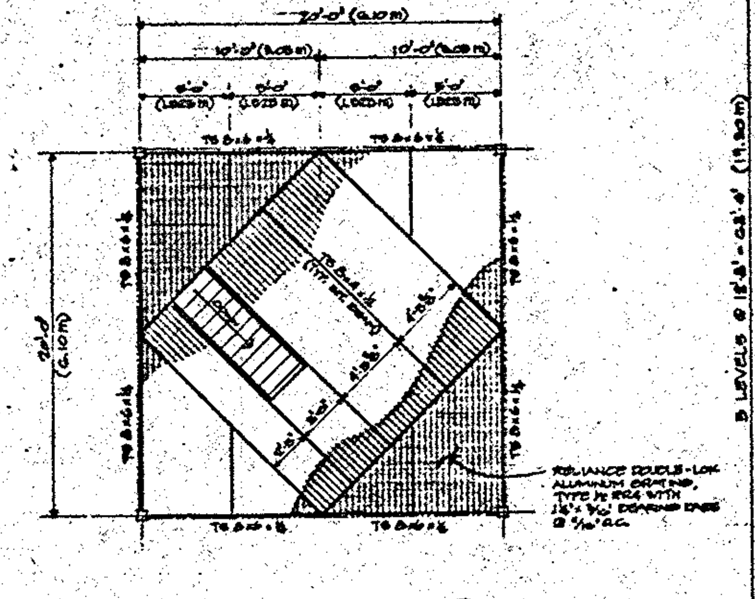
DWG ORIG BY (ORG) ____________

REVISIONS

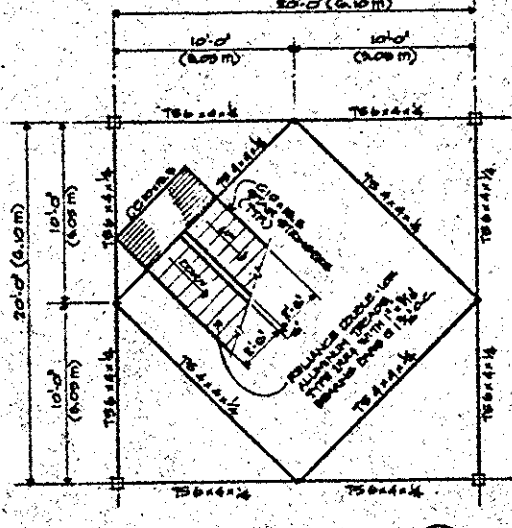
REV | DESCRIPTION | DATE | APPROVED



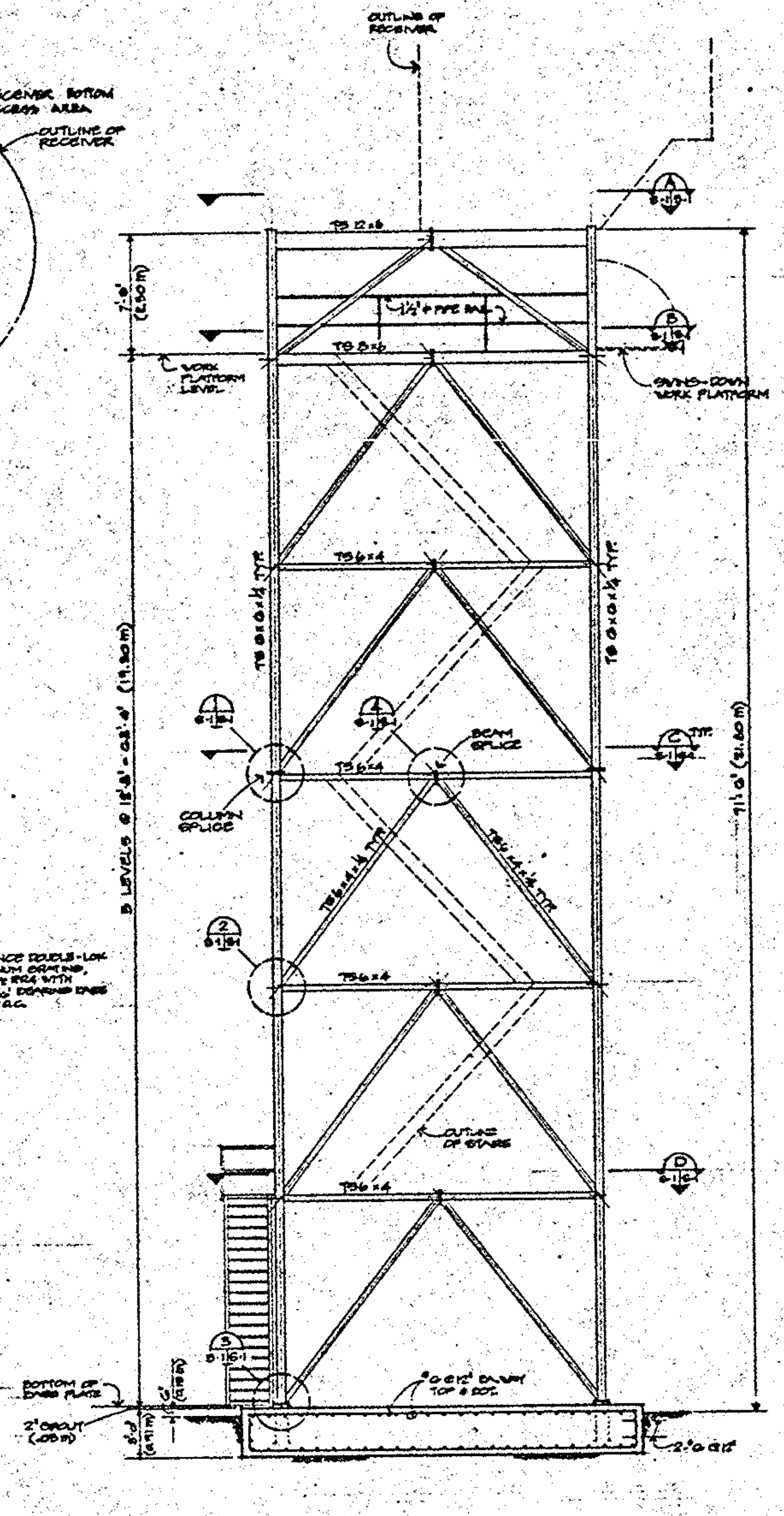
PLAN SECTION (A) S-1 S-1
¼"=1'-0"



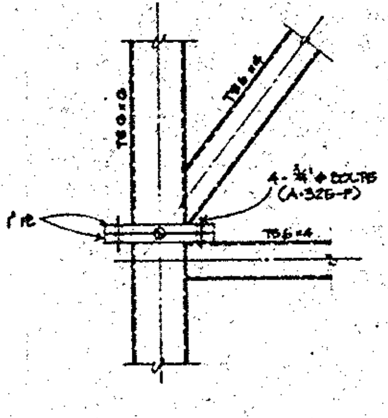
PLAN SECTION (B) S-1 S-1
¼"=1'-0"



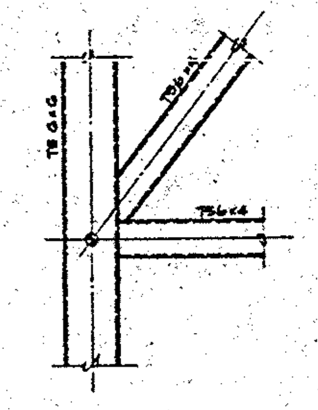
PLAN SECTION (C) S-1 S-1
¼"=1'-0"



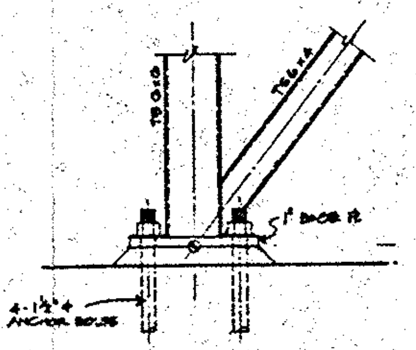
TYPICAL ELEVATION
¼"=1'-0"



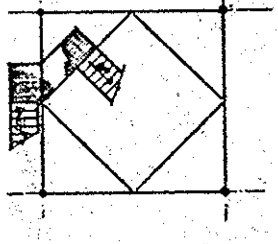
DETAIL (1) S-1 S-1



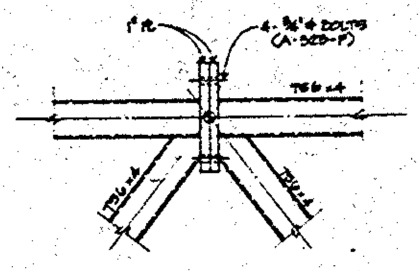
DETAIL (2) S-1 S-1
1½"=1'-0"



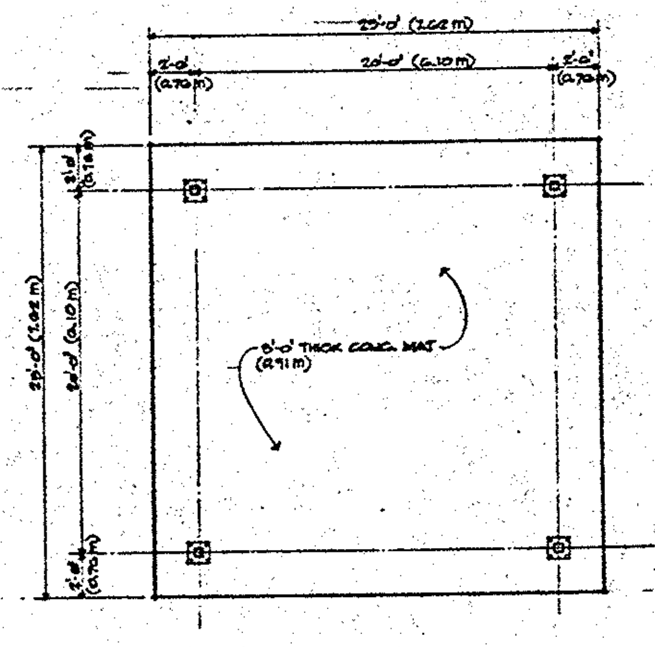
DETAIL (3) S-1 S-1
1½"=1'-0"



PLAN SECTION (D) S-1 S-1



DETAIL (4) S-1 S-1
1½"=1'-0"



FOUNDATION PLAN
¼"=1'-0"

NOTES:

1. Structural shapes and plates shall be ASTM-A36. Structural tubes shall be ASTM-A500, Grade B.
2. Surface preparation for painting shall consist of rust and scale removal by commercial sandblasting.
3. All steel members shall be given one coat of Chem-Prime universal metal primer, an intermediate coat of Encoline high build epoxy, and a finish coat of Endura-Shield polyurethane enamel, all manufactured by TNEMEC Co., Inc.
4. All bolts for primary members shall be high strength ASTM-A325 with friction type connections.

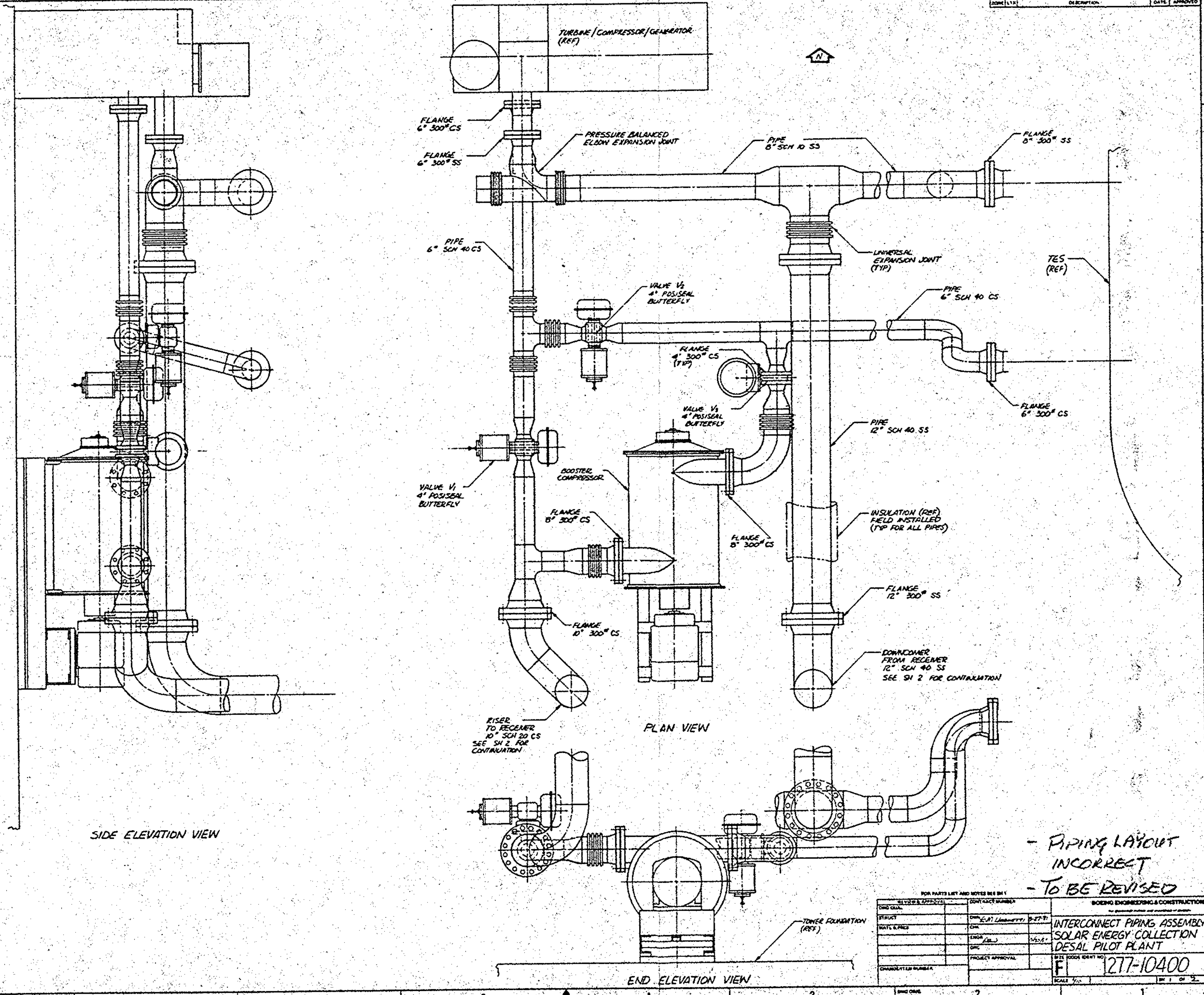
   All anchor bolts shall be ASTM-A307.
5. Concrete shall develop a minimum f'c = 4000 psi at 28 days.
6. Reinforcing steel shall be ASTM-A615, Grade 60.

PRELIMINARY - NOT FOR CONSTRUCTION

DRAWN BY M. CARRICK
ENGRD. BY V. MOOR
CHECKED
CHECKED
APPROVED
APPROVED
SCALE: AS NOTED
DATE 15 MAY, 1981

BE&C ENGINEERS INC.
SOLAR DESAL TOWER
BEC SOLAR ENERGY SYSTEMS
SEATTLE WASHINGTON
SIZE F FSCM NO 328 REV
DWG NO 277-(039)

S-1



- PIPING LAYOUT INCORRECT
- TO BE REVISED

FOR PARTS LIST AND NOTES SEE SH 1

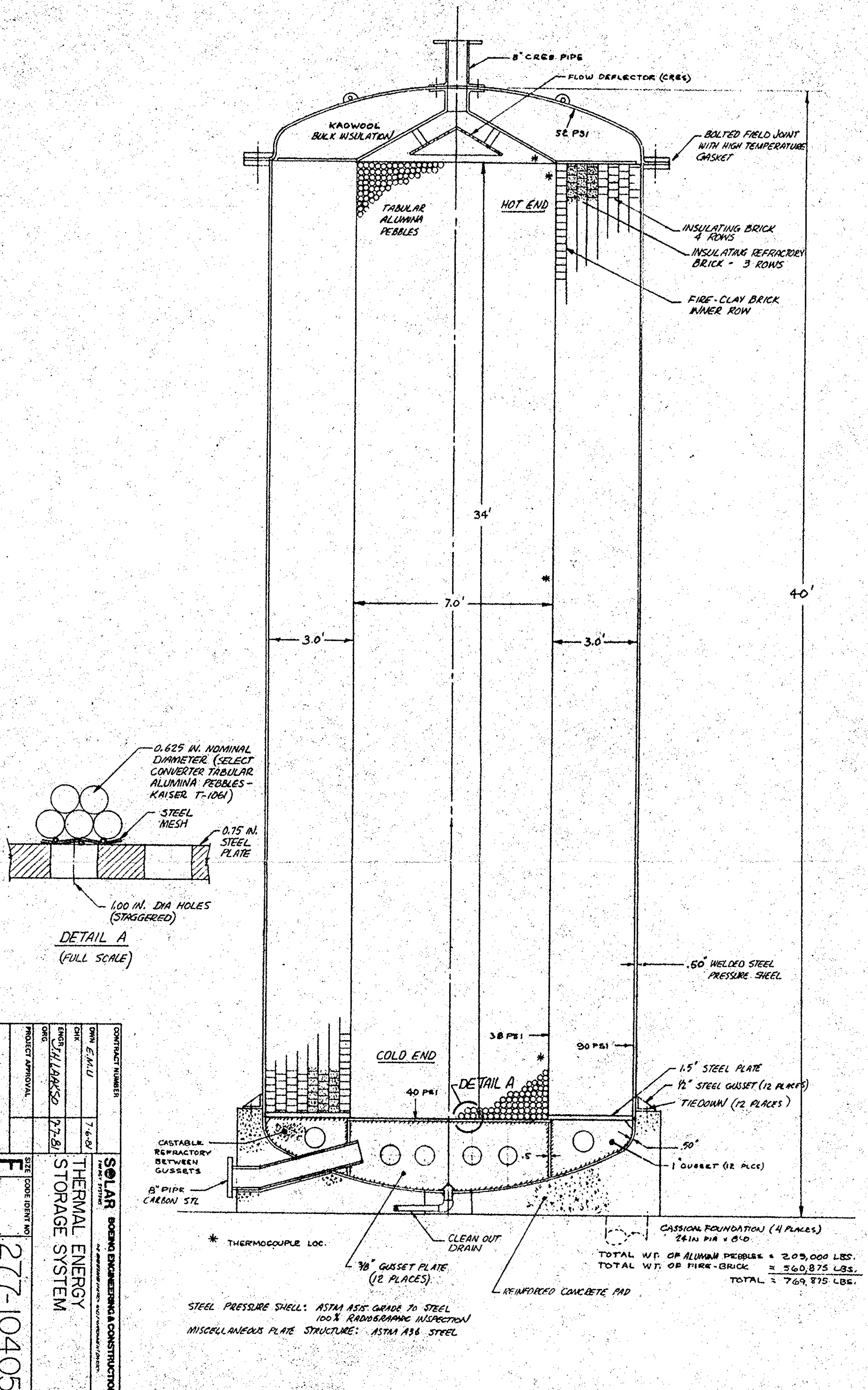
REVIEW & APPROVAL		CONTRACT NUMBER	
DWG QUAL		DWN E.M. Unmanetti	3-27-81
STRUCT		CHK	
MATL & PROC		ENGR	
		GRP	
		PROJECT APPROVAL	
CHANGE/TITLE NUMBER			

BOEING ENGINEERING & CONSTRUCTION

INTERCONNECT PIPING ASSEMBLY
SOLAR ENERGY COLLECTION
DESAL PILOT PLANT

SIZE F
CODE IDENT NO
277-10400
SCALE 1/10
SH 1 OF 2

DWG ORIG BY (ORG)



TOTAL WT. OF ALUMINA PEBBLES = 209,000 LBS.
TOTAL WT. OF FIRE-BRICK = 560,875 LBS.
TOTAL = 769,875 LBS.

STEEL PRESSURE SHELL: ASTM A515 GRADE 70 STEEL
100% RADIOGRAPHIC INSPECTION
MISCELLANEOUS PLATE STRUCTURE: ASTM A36 STEEL

CONTRACT NUMBER
DWN E.M.U 7-6-81
CHK
ENGR J.H. LAAKSO 7-7-81
ORG
PROJECT APPROVAL

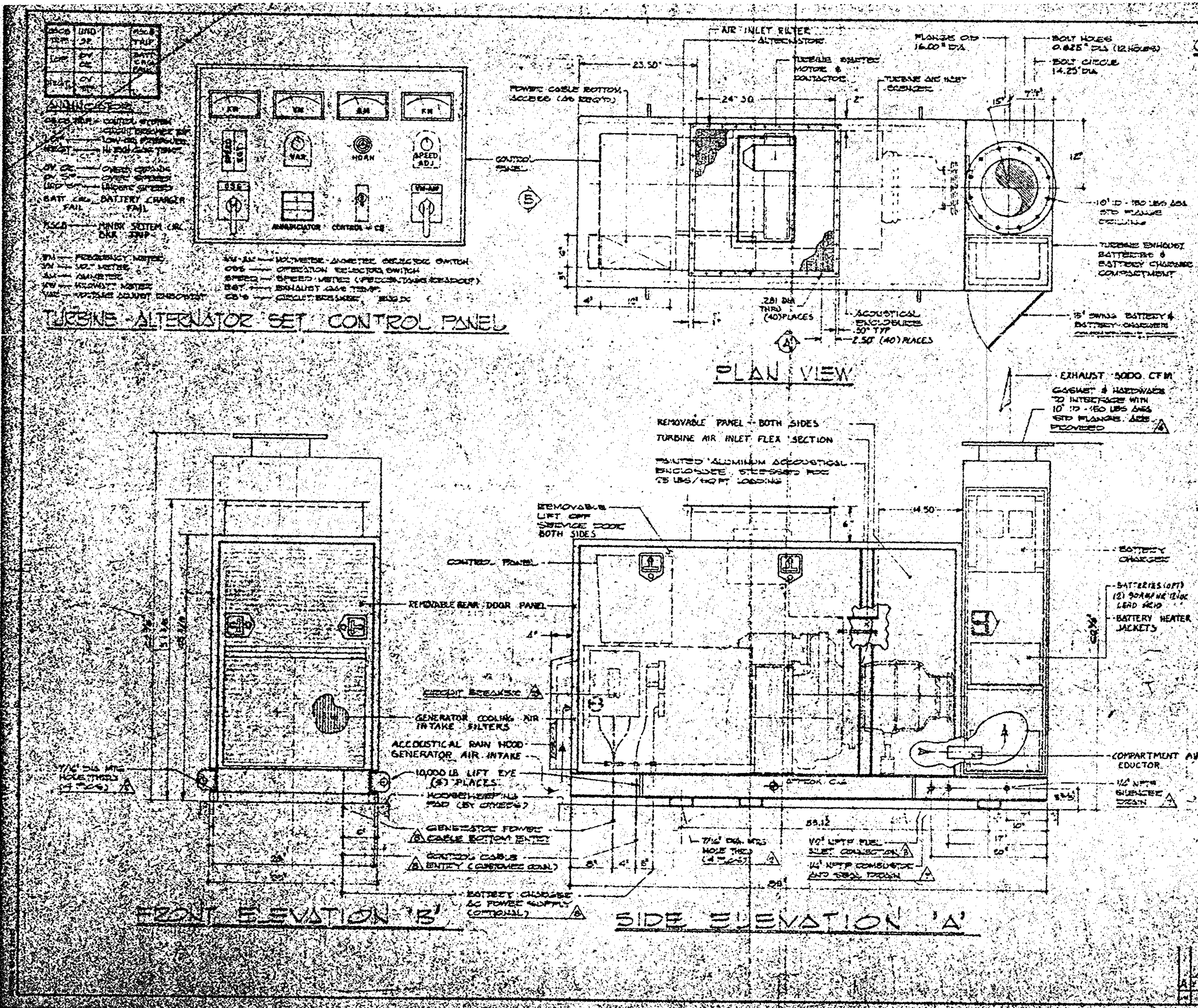
SOLAR ENERGY SYSTEMS
BOEING ENGINEERING & CONSTRUCTION

THERMAL ENERGY
STORAGE SYSTEM

SIZE F
CODE IDENT NO.
277-10405
SCALE 1" = 20' REISSUED 7-7-81
SH 1 OF 1

DRAWING RECORDS CLERK

REVISION
SYM
DESCRIPTION



GENERAL NOTES:

1. ESTIMATED BASIC WEIGHTS:
   - TURBINE & GEARBOX — [illegible] LBS
   - GENERATOR — 1000 LBS
   - SILENCERS — 800 LBS
   - BATTERY & CHARGER EACH ASSY — 200 LBS
   - CONTROLS, SKID, MISC — 400 LBS
   - ENCLOSURE — 800 LBS
   - TOTAL — [illegible] LBS

2. ANCHOR SKID TO FLOOR W/ CONCRETE ANCHOR BOLTS OR "DOG DOWNS" DIRECT TO FIN. FLOOR OR HOUSEKEEPING PAD WHICH SHOULD BE REASONABLY FLAT AND LEVEL WITHIN ±1/16" TO RETAIN INTER CONNECTION LOCATION.

3. FUEL SHALL BE DIESEL NO2, KEROSENE, OR JP-4 TYPE FUEL, @ A MAX. HEAD OF MINUS 15 FT. (TO [illegible]) INCLUDING LINE LOSSES. SUPPLY LINE SHOULD BE [illegible] WITH [illegible] BASED ON A FLOW OF [illegible]. PROVIDE MANUAL SHUT-OFF VALVE TO TURBINE [illegible]

4. THE TURBINE EXHAUST GAS TEMPERATURE IS [illegible] AND ADEQUATE DISCHARGE CLEARANCE SHOULD BE PROVIDED, INSULATE EXHAUST DUCT W/ [illegible] CALCIUM SILICATE. DUCT SHOULD BE SIZED [illegible] PRESSURE LOSS, FLANGE LOADING NOT TO EXCEED [illegible], INTERCONNECTING BELLOWS NOT [illegible]

5. TURBINE COMBUSTION AIR REQUIREMENT [illegible] AND GENERATOR COOLING AIR [illegible] OF 60 °F [illegible]. PACKAGE HEAT REJECTION IS APPROX. [illegible]

6. AIR INTAKE — THE AREA AROUND THE AIR INTAKE MUST BE FREE OF FOREIGN [illegible]

7. PROVIDE DRIP DRAIN PAN FOR COMBUSTOR [illegible] DRAIN, AND SILENCER DRAIN.

8. A CONDUIT ENTRY IS PROVIDED [illegible] CONDUIT, & 1" DC CONTROL WIRING CONDUIT [illegible] 1/2" AC POWER INPUT WIRING CONDUIT FOR A [illegible] BATTERY CHARGER (REFER TO ELECTRIC INTERCONN. [illegible]) CUSTOMER TO SPECIFY TOP OR BOTTOM ENTRANCE.

9. SET MAY BE MOVED BY FORK LIFT [illegible] UNDER SKID BASE OR LIFTED VIA CABLES WITH SPREADER BARS.

10. POWER CONNECTIONS ARE MADE THRU THE [illegible] AND POWER CONNECTION BOX (AS SHOWN) TO THE [illegible] OF THE CIRCUIT BREAKER. LUGS ARE PROVIDED FOR [illegible] OR 350 MCM INSUL. TYPE [illegible] CABLES.

11. FUEL SHALL CONTAIN LESS THAN [illegible] FREE WATER PER GALLON AT AN AMBIENT TEMPERATURE OF 80°F. THERE SHALL [illegible] LESS THAN 1 GRAM PER GALLON OF SEDIMENT [illegible] CONTAMINANTS. 90% OF THE [illegible] SHALL BE LESS THAN 6 MICRONS IN SIZE.

12. LUBE OIL
    - MIL-L-7808 OR MIL-L-23699 OR
    - BRAYCO 778, [illegible]

13. ELECTRICAL SYSTEM 24VDC CONNECTED AT THE [illegible] TERMINALS. DO NOT ALLOW VOLTAGE TO DROP BELOW [illegible] STARTER 1800 AMPS IN RUSH, 300 AMPS [illegible] STARTER SOLENOID, 31 AMPS [illegible]

ALTURDYNE

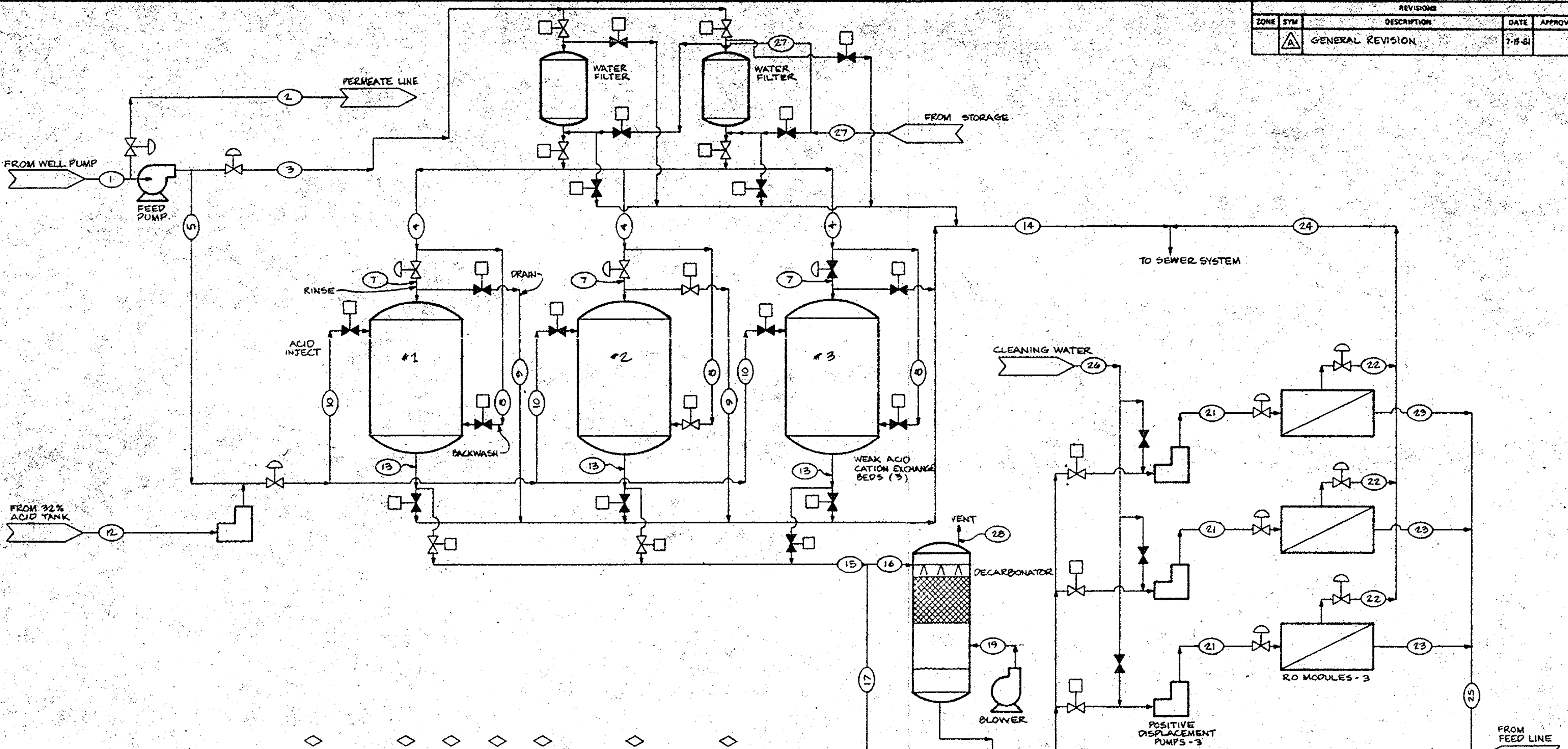
713

62515 | D

TURBINE GENERATOR INSTALLATION DETAILS

713-1308

REVISIONS				
ZONE	SYM	DESCRIPTION	DATE	APPROVED
	△A	GENERAL REVISION	7-15-81	



STREAM NO.	①	②	③	④	⑤ ◇		⑦ ◇	⑧ ◇	⑨ ◇	⑩ ◇		⑫ ◇	⑬	⑭ ◇	⑮
DESCRIPTION	SYSTEM FEED	BYPASS	FEED	BED FEED	REGEN. WATER		RINSE	BACK-WASH	DRAIN	ACID INJECTION (REGEN.)		32% ACID	PRETREATED WATER	WASTE	TOTAL WAC OUTPUT
FLOW - GPM	321	45	276	138	34 (25 MIN.)		145 (15 MIN.)	85 (10 MIN.)	4025 GAL/DAY	40 (29 MIN.)		5.6 (25 MIN.)	138	12,170 GAL./DAY	275
T.D.S. AS $CaCO_3$	2412	2412	2412	2412	2412		2412	2412							
STREAM NO.	⑯	⑰	⑱	⑲	⑳	㉑	㉒	㉓	㉔	㉕	㉖ ◇	㉗ ◇	㉘	㉙	
DESCRIPTION	DECARB FEED	DECARB BY-PASS	DECARB PROD.	AIR TO BLOWER	R.O. FEED	INDIVIDUAL R.O. FEED	INDIVIDUAL R.O. REJECT	INDIVIDUAL R.O. PERMEATE	TOTAL REJECT	TOTAL PERMEATE	R.O. WASH	FILTER BACKWASH	LOSS	POTABLE WATER	
FLOW - GPM	245	30	220	350 CFM	246	82	21	61	63	184		6085 GAL/DAY	28	229	
T.D.S. AS $CaCO_3$	1874	2412	1874	N/A	1874	1874	5800	180	5800	180	180				

NOTES
1. ◇ DENOTES INTERMITTENT FLOWS.
2. ALL FLOWS ARE DESIGN POINT (FULL CAPACITY FLOWS) DURING NORMAL OPERATION.
3. TOTAL ENERGY CONSUMPTION AT DESIGN POINT IS 70 KW_E.
4. FOR DAILY AVERAGE FLOWS, PLANT PERFORMANCE FLOWS, USE DWG 171-G2-1, WATER SYSTEM INTERFACES.

Resources Conservation Co.

ITEM NO.	QTY	DESCRIPTION	MATERIAL

Unless otherwise specified dimensions are in inches.
Tolerances:
Angles ±
Decimals ±
Fractions ±

H. WILSON
DR
CHK
5-20-81
PROJ ENGR
APP

SOLAR ENERGY WATER DESALINATION PILOT PLANT
RANKIN, TEXAS

PROCESS FLOW SCHEMATIC

171-M3-1

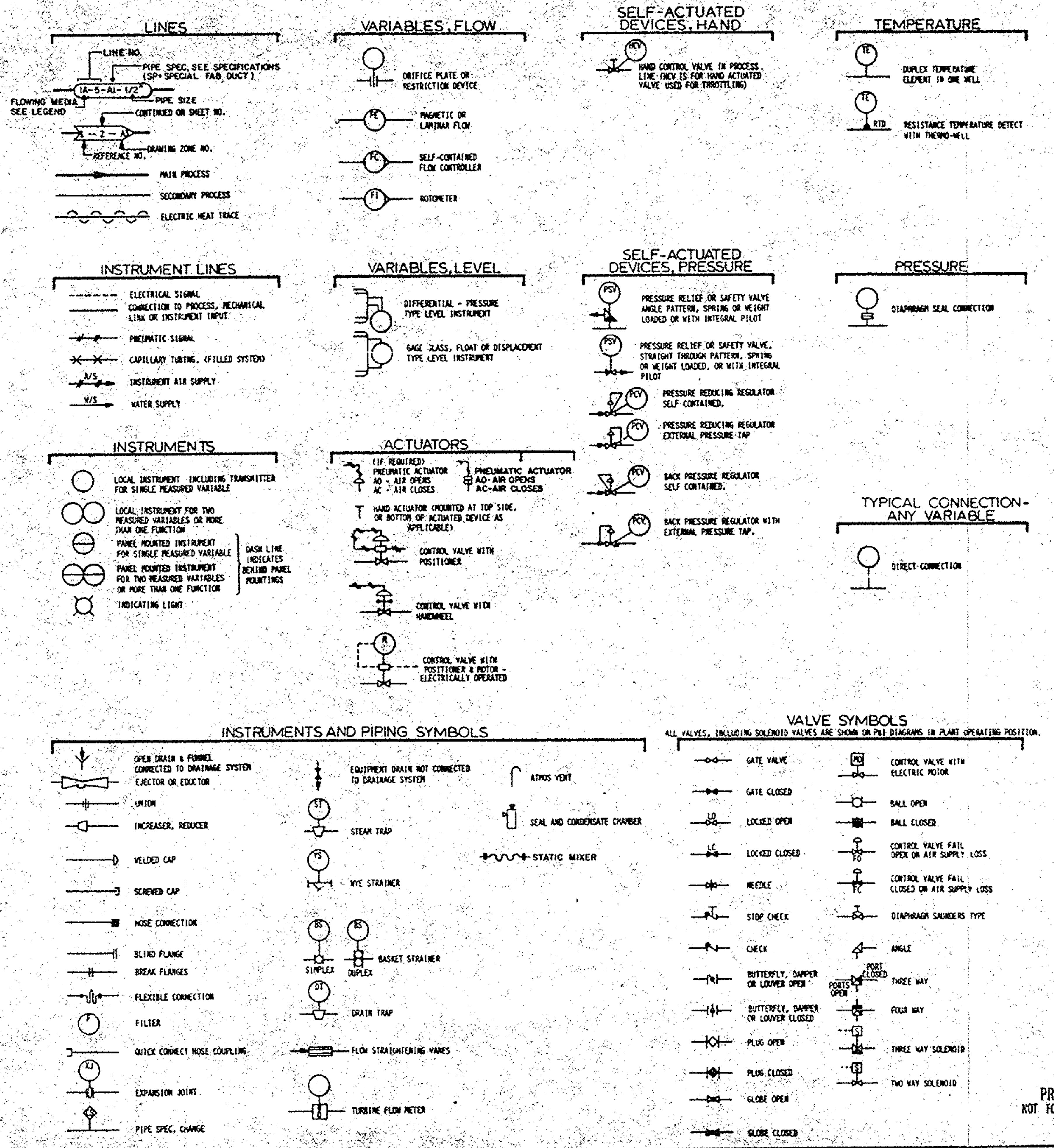
REV △A

SCALE NONE

SHEET 1 OF 1

K-20191 REV 10-79

REVISIONS				
ZONE	SYM	DESCRIPTION	DATE	APPROVED



MISCELLANEOUS

* FURNISHED WITH ASSOCIATED EQUIPMENT

F.D. FLOOR DRAINAGE SYSTEM

V. VENTED TO ATMOSPHERE

N.O. NORMALLY OPEN

N.C. NORMALLY CLOSED

LOGIC INTERFACES

SYMBOL	FUNCTION
E	SETS AMOUNT OF WELL WATER BYPASSED TO PLANT.
F	~~SETS AMOUNT OF FEED TO BE TREATED.~~
G	STARTS BACK FLUSH/RINSE SEQUENCE OPENS/CLOSES TWO VALVES.
J	CLOSE/OPENS TWO VALVES FOR SET AMOUNT OF TIME.
I	CLOSE/OPENS DRAIN VALVE.
H	CLOSE/OPENS PRODUCT VALVE.
K	STARTS REGENERATION SEQUENCE.
O	CLOSE/OPENS TWO VALVES
Q	STARTS ACID FEED SEQUENCE.
L	CLOSE/OPENS ACID VALVE.
P	CLOSE/OPENS DRAIN VALVE.
M	CLOSE/OPENS FEED CONTROL VALVE.
N	CLOSE/OPENS PRODUCT VALVE.
A	OPENS/CLOSES RO FEED VALVE.
B	CURRECNT DRAW FROM MOTOR RO.
C	SPEED CONTROL TO MOTOR (RO).
D	OPENS/CLOSES FEED TO PERMEATORS

FLOWING MEDIA LEGEND
(SEE "LINES" UPPER LEFT)

AS:	AUXILIARY STEAM
CC:	CHEMICAL CLEANING
~~SC:~~	~~STEAM CONDENSATE~~
CF:	CHEMICAL FEED
CL:	CHLORINE
DR:	DRAIN
DW:	DEAERATED WATER
EC:	EVAPORATOR CONCENTRATE
EP:	EVAPORATOR PRODUCT
ER:	EVAPORATOR RECIRCULATION
EV:	EVAPORATOR VAPOR
FE:	FEED
FIW:	FILTERED WATER
HS:	SULFURIC ACID
HW:	HOT WATER
IA:	INSTRUMENT AIR
LO:	LUBE OIL
PW:	POTABLE WATER
RP:	R/O PERMEATE
RR:	R/O REJECT
SA:	SERVICE AIR
SEW:	SEAL WATER
SP:	SAMPLE PORT
SW:	SERVICE WATER
TW:	TREATED WATER
VT:	VENT
WW:	WASTEWATER

GENERAL NOTES

1. ALL INSTRUMENTATION SYMBOLS AND IDENTIFICATION ARE PER THE INSTRUMENT SOCIETY OF AMERICA (I.S.A.) STANDARD-LATEST REVISION - ANSI Y32.20 - 1975

PRELIMINARY
NOT FOR CONSTRUCTION

Resources Conservation Co.

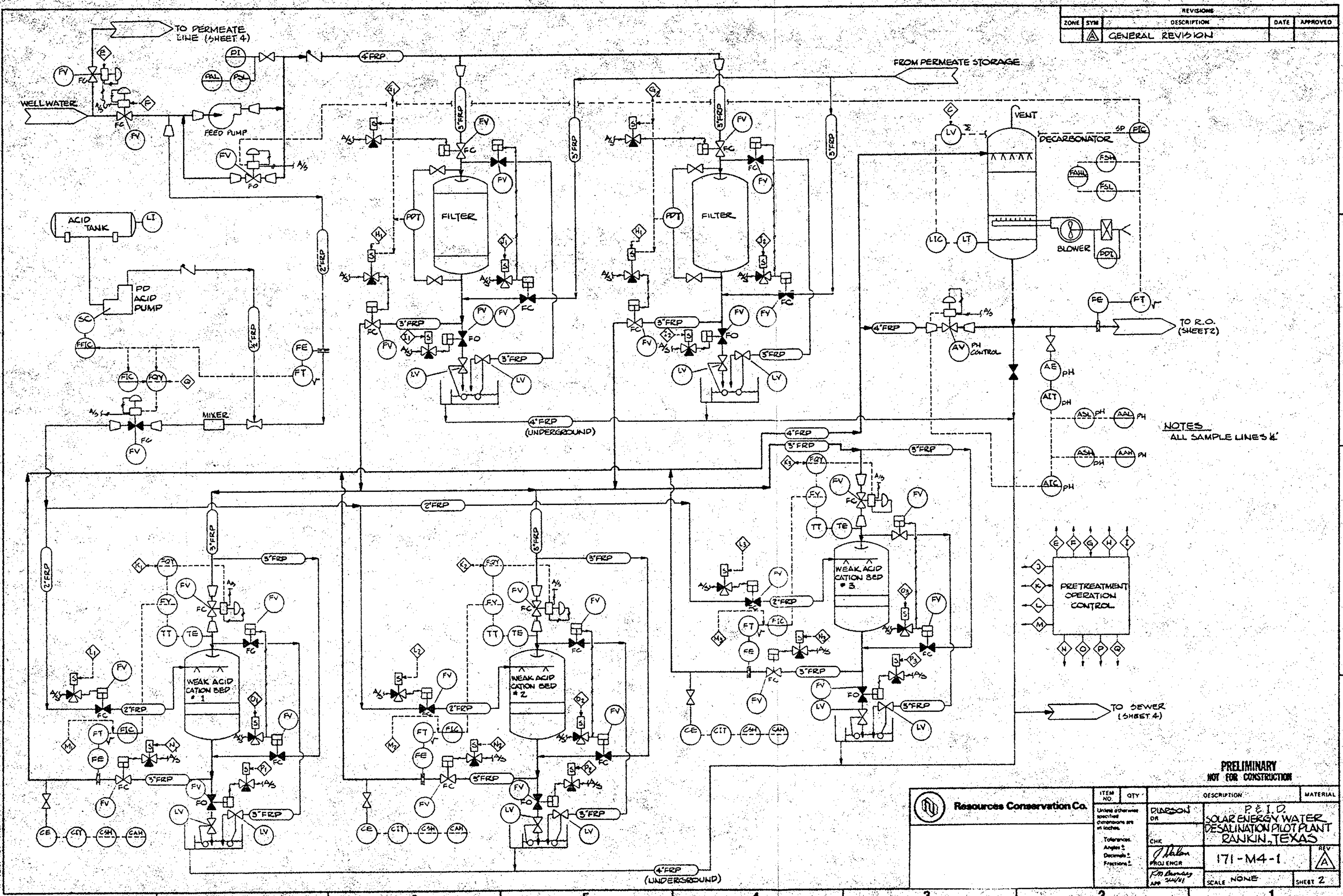
ITEM NO	QTY	DESCRIPTION	MATERIAL

Unless otherwise specified dimensions are in inches
Tolerances
Angles ±
Decimals ±
Fractions ±

DR. ——
CHK.
7-14-8
PROJ ENGR
APP

P & I.D. LEGEND
SOLAR ENERGY WATER
DESALINATION PILOT PLANT
RANKIN, TEXAS

171-M4-1
REV. A
SCALE —→
SHEET 1 OF 4



NOTES
ALL SAMPLE LINES ¼"

REVISIONS				
ZONE	SYM	DESCRIPTION	DATE	APPROVED
	△A	GENERAL REVISION		

PRELIMINARY
NOT FOR CONSTRUCTION

Resources Conservation Co.

ITEM NO.	QTY	DESCRIPTION	MATERIAL

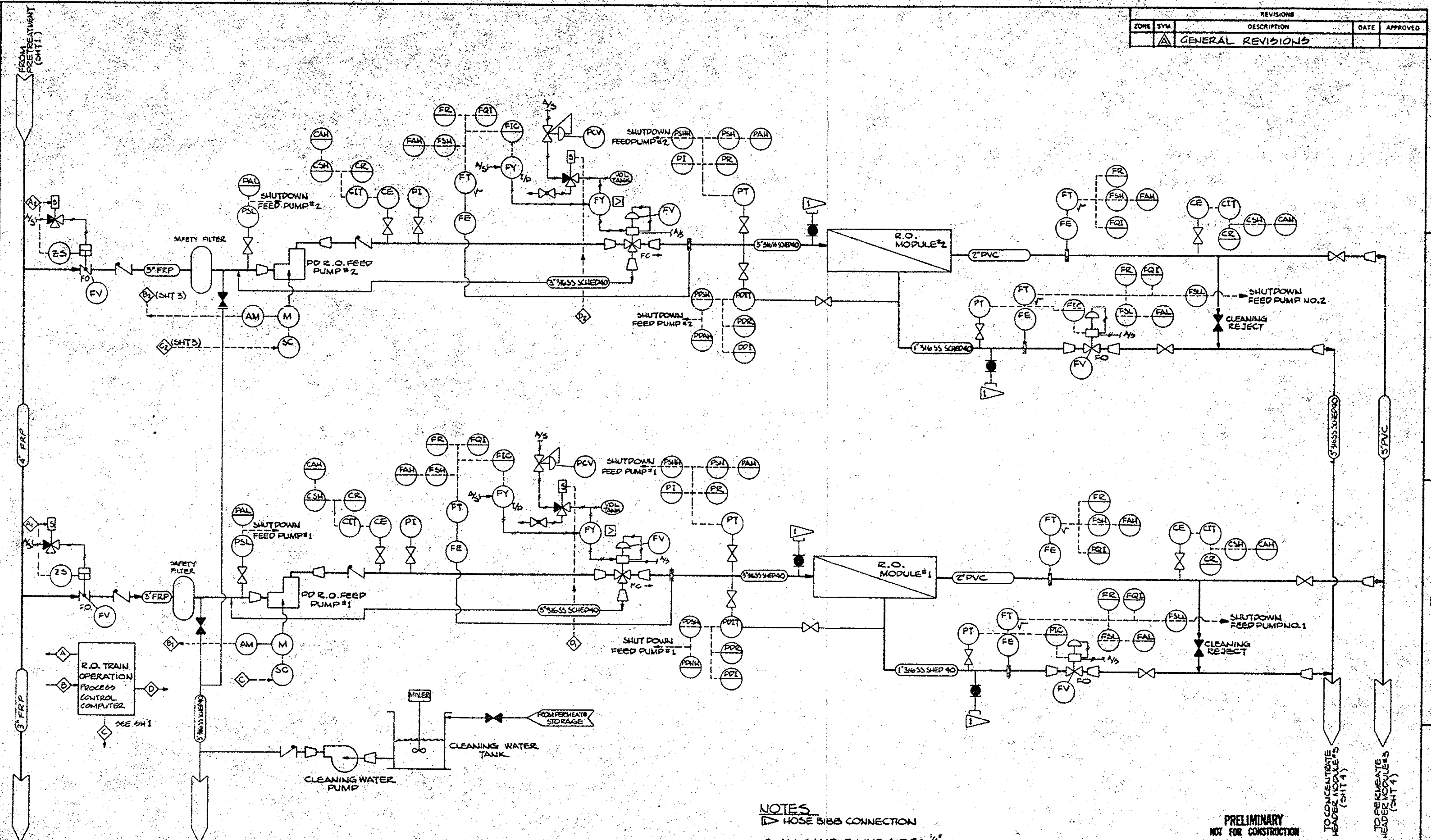
Unless otherwise specified dimensions are in inches.
Tolerances.
Angles ±
Decimals ±
Fractions ±

DIARSON
DR
CHK
J Dalon
PROJ ENGR
K M Barnes 2/4/81
APP

P & I.D.
SOLAR ENERGY WATER
DESALINATION PILOT PLANT
RANKIN, TEXAS

171-M4-1
REV △A
SCALE NONE
SHEET 2

REVISIONS				
ZONE	SYM	DESCRIPTION	DATE	APPROVED
	A	GENERAL REVISIONS		



NOTES

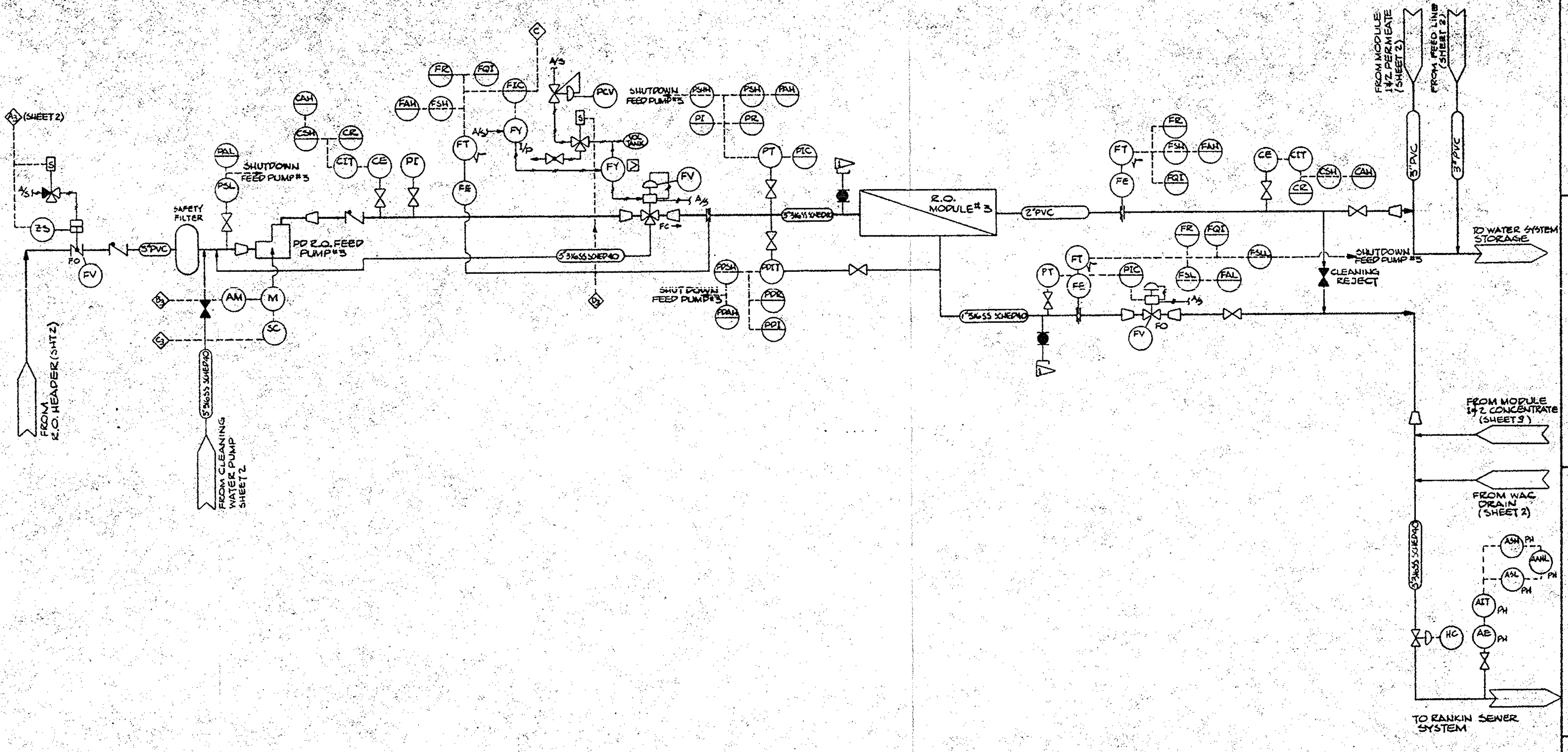
1. ▷ HOSE BIBB CONNECTION
2. ALL SAMPLE LINE SIZES ¼"

PRELIMINARY
NOT FOR CONSTRUCTION

Resources Conservation Co.

ITEM NO.	QTY	DESCRIPTION		MATERIAL
Unless otherwise specified dimensions are in inches. Tolerances: Angles ± Decimals ± Fractions ±		D. LARSON DR	P.&I.D. SOLAR ENERGY WATER DESALINATION PILOT PLANT RANKIN, TEXAS	
		CHK		
		J. Dalan PROJ ENGR	171-M4-1	REV A
		KM Bomar APP	SCALE NONE	SHEET 3

REVISIONS				
ZONE	SYM	DESCRIPTION	DATE	APPROVED
	A	GENERAL REVISION		



NOTES
1. ▷ HOSE BIB CONNECTION
2. ALL SAMPLE LINE SIZES ¼"

PRELIMINARY
NOT FOR CONSTRUCTION

Resources Conservation Co.

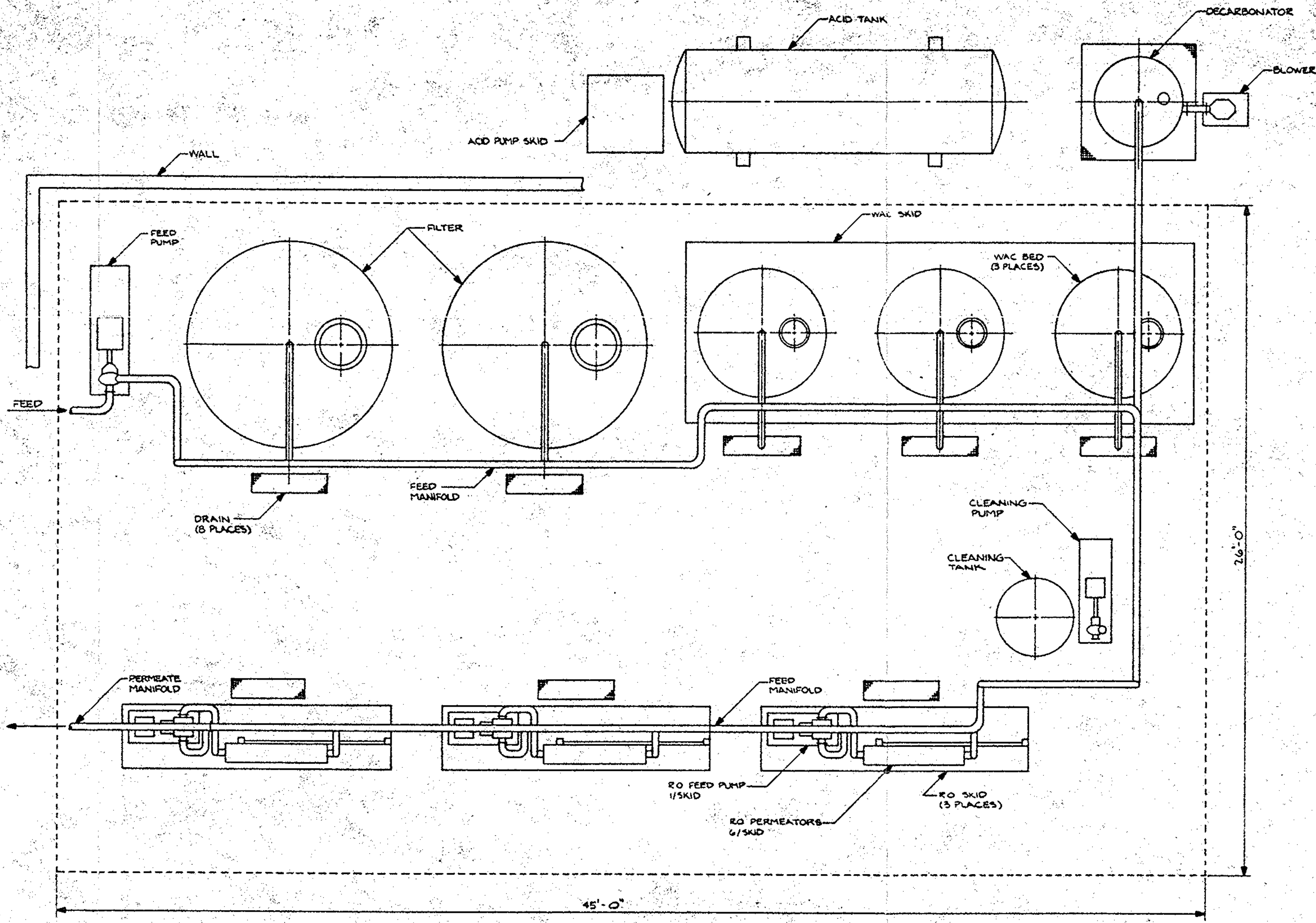
ITEM NO.	QTY	DESCRIPTION	MATERIAL

Unless otherwise specified dimensions are in inches.
Tolerances:
Angles ±
Decimals ±
Fractions ±

D. LARSON
DR
CHK
J. Dalan
PROJ ENGR
C.M. Gonzalez 12-4-?
APP

P.&I.D.
SOLAR ENERGY WATER
DESALINATION PILOT PLANT
RANKIN, TEXAS

171-M4-1
REV A
SCALE NONE
SHEET 4



PLAN
1/2" = 1'-0"

LTR	REVISIONS	BY	CHK	APP	DATE	LTR	REVISIONS	BY	CHK	APP	DATE
A	MOVED ACID TANK CLOSER TO WAC, MOVED ACID SKID OUTSIDE, MOVED DECARBONATOR OUTSIDE.										

STAMP

Unless otherwise specified dimensions are in inches
Tolerances:
Angles ± 1/2°
Under 12" = ± 1/16"
12" to 48" = ± 1/8"
Over 48" = ± 1/4"

ENG RECORD	DRAWING STATUS		
C. OWEN DRAWN	ISSUED		DATE
CHECKED	PRELIMINARY FOR COMMENTS AND/OR APPROVAL		
CHECKED	APPROVED FOR CONSTRUCTION		
PROJ ENGR J Dalon	REVISED AND APPROVED FOR CONSTRUCTION		
Ken Ramsey 6/9/81 APPROVED	NOT APPROVED FOR CONSTRUCTION UNLESS SIGNED AND DATED		

BUILDING FOOTPRINT OF
DESALINATION EQUIPMENT

SOLAR ENERGY
WATER DESALINATION PILOT PLANT
RANKIN, TEXAS

SCALE NOTED

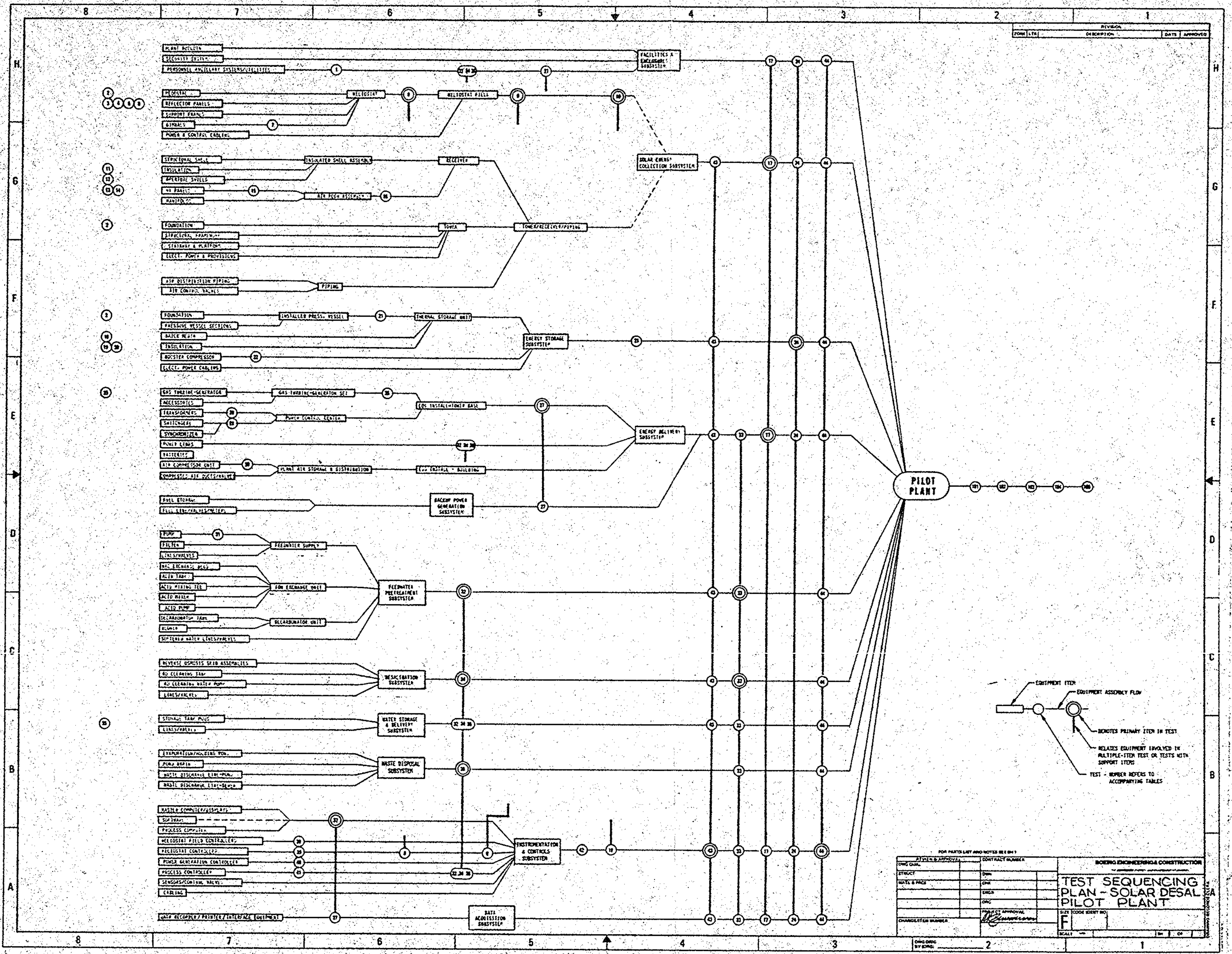
RESOURCES CONSERVATION CO.

DWG NO. 171-A3-1
SHEET NO. 1 OF 1
REV A

APPENDIX B

TEST SEQUENCING DIAGRAM

TEST PLANS



FOR PARTS LIST AND NOTES SEE SH 1

BOEING ENGINEERING & CONSTRUCTION

TEST SEQUENCING PLAN - SOLAR DESAL PILOT PLANT

SIZE F

PRELIMINARY TEST PLANS

					Category				Type			Assembly Level				
No.	WBS	Item	Test Purpose	Test Method	Engineering Dev	Acceptance	Integration & C/O	Demonstration	Environmental	Structural	Functional	Material	Component	Subassembly	Subsystem	System
	5510	Facilities and Enclosures Subsystem														
1.	5513	Utility Power Provisions	Determine power quality	Monitor, record voltage variation	●						●					
	5520	Solar Energy Collection Subsystem														
2.	5521	Heliostat Pedestals	Determine site soil characteristics.	Test borings at selected locations on site.	●				●							
3.	5521	Heliostat Reflector Panels	Verify panel focusing.	Laser ray trace optical scan.	●						●		●			
4.	5521	Heliostat Reflector Panels	Verify panel reflectance.	Bidirectional reflectometer measurements.	●						●		●			
5.	5521	Heliostat Reflector Panels	Verify panel strength.	Static loading in test lab.	●					●			●			
6.	5521	Heliostat Reflector Panels	Verify panel hail resistance.	Ice ball impact.	●					●			●			
7.	5521	Heliostat Gimbals	Verify performance meets specifications.	Determine stiffness, backlash, power consumption of selected units. Perform bench functional tests on all units.		●					●		●			
8.	5521	Heliostat	Verify panel canting and focusing design.	a) Beam quality measurements at CRTF using focused reflector panels on currently installed prototype. b) Abbreviated test at pilot plant site.	●		●				● ●			● ●		
9.	5521	Heliostat	Adjust and check panel canting and focusing on all heliostats.	Manual heliostat alignment using heliostat controller. Go-no-go reflected image on tower-mounted calibration panel.			●				●			●		
10.	5521	Heliostat Field	Alignment of heliostats with control system.	Determine reference position of encoders with reflected image aligned on target.			●				●			●		
(17)	5521	Heliostat Field	Verify heliostat field performance in conjunction with receiver test 17.	Monitor tracking, spillage, insolation levels, etc. to correlate with receiver performance.			●				●			●		
11.	5522	Receiver Insulation	Establish receiver insulation incident flux and temperature capability and life.	Real or simulated concentrated solar exposure of insulation blanket segments. (Depending on insulation material and design details, requirement may be satisfied by FSE program.)	●				●			●	●			
12.	5522	Receiver Aperture Shield	Establish receiver aperture shield incident flux and temperature capability and life.	Real or simulated concentrated solar exposure of aperture segment. (Depending on design details, requirement may be satisfied by FSE program.)	●				●			●	●			
13.	5522	Heat Exchanger Panel Material	Verify material properties of the material purchases.	Tensile, stiffness, fracture tests on machined specimens.		●				●		●				
14.	5522	Heat Exchanger Panel	Verify structural design adequacy.	Radiant heat and pressure cycling test of single Hx tube.	●				●	●			●			
15.	5522	Hx Panel	Verify a) structural integrity and b) flow characteristics of each Hx panel.	a) Hydrostatic proof test b) Pressure drop measurement at reference air flow condition.			● ●			●	●		● ●			
16.	5522	Receiver Air Flow Assembly	Verify leak free assembly and trim flow distribution.	Cold flow test.			●				●			●		
17.	5522	Receiver	Measure and evaluate receiver thermal performance.	Using heliostat field, EDS, ICS, and DAS, operate receiver at increasing increments of energy input. Monitor temperatures, flow pressure drops. Inspect between incremental tests. Use grid to consume electric power produced.			●				●			●		

PRELIMINARY TEST PLANS

					Category				Type			Assembly Level				
No.	WBS	Item	Test Purpose	Test Method	Engineering Dev	Acceptance	Integration & C/O	Demonstration	Environmental	Structural	Functional	Material	Component	Subassembly	Subsystem	System
	5530	Energy Storage Subsystem														
(2)	5531	Thermal Storage Unit Foundation	Sames as 2. above.													
18.	5531	Brick Media	Determine thermal properties.	Materials lab standard method.	●				●			●				
19.	5531	Insulation	Determine thermal properties.	Materials lab standard method.	●				●			●				
20.	5531	Insulation	Verify structural adequacy of load bearing insulation.	Compression test at design temperatures.	●					●		●				
21.	5531	Installed Pressure Vessel	Verify structural integrity, leak-free assembly.	Hydrostatic proof test.		●				●			●			
22.	5532	Booster Compressor	Perform functional acceptance test, verify performance characteristics.	Bench test operation, measurement of efficiency, power consumption.			●				●		●			
23.	5530	Energy Storage Subsystem	Evaluate assembled subsystem flow characteristics.	Measure pressure drops through subsystem using ambient air input to the TES unit.			●				●				●	
24.	5530	Energy Storage Subsystem	Verify ESS performance.	Using the SECS, EDS, ICS, and DAS, operate the Energy Storage Subsystem through a complete thermal energy charging, storage, and discharging cycle. Monitor and evaluate storage media, air, compressor temperatures; air flow rates and pressures, insulation and shell temperatures.			●				●				●	
	5535	Energy Delivery Subsystem														
25.	5536	Gas-Turbine Combustor	Evaluate performance with modifications for solar applications.	Gas turbine operation with modified combustor and additional combustor to simulate solar. (Test can be deleted by using FSE trim combustor.)	●						●		●			
26.	5536	Turbine-Generator Set	Verify set performs per specifications.	Bench test operation on fossil fuel.			●				●		●			
27.	5535	Turbine Generator Set	Verify performance of installed unit.	Operate on fossil fuel, generate power into grid.			●				●			●		
28.	5537	Transformers	Verify performance of purchased unit.	Bench test.		●					●		●			
29.	5537	Switchgear	Verify performance of purchased unit.	Bench test.		●					●		●			
30.	5538	Air Compressor Unit	Verify performance of purchased unit.	Bench test.		●					●		●			
(17)	5535	Energy Delivery Subsystem	Verify EDS performance in solar mode.	Monitor turbine, power generation performance during receiver test 17.			●				●				●	
	5540	Backup Power Generation Subsystem														
	5550	Feedwater Pretreatment Subsystem														
31.	5552	Feedwater Pump	Verify performance of purchased unit.	Bench test.		●					●		●			
32.	5550	Feedwater Pretreatment Subsystem	Verify insolation capability during filter backwash and WAC regeneration.	Perform WAC regeneration sequence using process controller. Verify value positions through sequence.			●				●				●	
33.	5550	Feedwater Pretreatment Subsystem	Verify water desalination segment production performance.	Using utility power and ICS, operate Feedwater Pretreatment and Desalination Subsystems to verify rates, capacity, and quality.			●				●				●	

PRELIMINARY TEST PLANS

No.	WBS	Item	Test Purpose	Test Method	Category				Type			Assembly Level				
					Engineering Dev	Acceptance	Integration & C/O	Demonstration	Environmental	Structural	Functional	Material	Component	Subassembly	Subsytem	System
	5560	Water Desalination Subsystem														
34.	5560	Water Desalination Subsystem	Verify isolation capability during RO units chemical flush.	Perform chemical flush sequences using process controller. Verify valve position through sequence.			●				●				●	
(33)	5560	Water Desalination Subsystem	Combined test with 5550. See 33 above.													
	5570	Water Storage and Delivery Subsystem														
35.		Water	Determine feedwater characteristics.	Water lab test performed periodically to determine constituents in Rankin feedwater.	●		●	●	●							
	5575	Waste Disposal Subsystem														
36.	5575	Waste Disposal Subsystem	Verify waste discharge to pond or sewer as selected.	Observe in conjunction with tests 32 and 34.			●			●					●	
	5580	Instrumentation and Controls Subsystem														
37.	5581 5582 5584	Master Computer and Displays Computer Software Process Computer	Checkout and verify computers and software performance.	Bench test.	●	●	●				●			●		
38.	5585	Heliostat Field Controllers	Verify functional performance.	Bench test.		●					●		●			
39.	5585	Heliostat Controllers	Verify functional performance.	Bench test.		●					●		●			
40.	5586	Power Generation Controller	Verify functional performance.	Bench test.		●					●		●			
41	5583	Process Controller	Verify functional performance.	Bench test.		●					●		●			
42.	5580	Instrumentation and Controls Subsystem	Verify performance of installed subsystem.	Perform all ICS functions, interacting with controllers within the subsystem.			●				●				●	
43	5580	Instrumentation and Controls Subsystem	Verify performance of installed subsystem and proper interaction with all measured/controlled subsystems.	Perform all ICS functions, interacting with controlled/measured equipment.			●				●				●	
44.	5580 (and all)	Instrumentation and Controls Subsystem	Verify functional performance of the pilot plant as controlled by the ICS.	Perform all ICS functions, interacting with and operating all controlled/measured subsystems.			●				●				●	

PRELIMINARY TEST PLANS

FORMAL DEMONSTRATION TESTS - PILOT PLANT OPERATION

No.	WBS	Item	Test Purpose	Test Method	Category				Type			Assembly Level				
					Engineering Dev	Acceptance	Integration & C/O	Demonstration	Environmental	Structural	Functional	Material	Component	Subassembly	Subsystem	System
	5500	Pilot Plant														
101			Demonstrate system functions and operating modes.	Operate plant to produce potable water, sequencing through startup, production, and shutdown. Operating at least 15 hours continuously on directs or stored solar energy.				●			●					●
102			Demonstrate system capability to operate in required modes and to perform the transition between modes.	During the operation in test 101 or in additional tests, operate the plant in all modes and through all mode transitions.				●			●					●
103			Demonstrate system capability for emergency shutdown.	Simulate an emergency shutdown.				●			●					●
104			Demonstrate secondary performance characteristics of the plant, including integrated checkout, fault detection and identification, displays, operating profile computation, and severe wind monitoring.	Perform or simulate these functions during operations described above.				●			●					●

PRELIMINARY TEST PLANS

FORMAL DEMONSTRATION TESTS - COMMERCIAL PLANT SIMULATION

No.	WBS	Item	Test Purpose	Test Method	Category				Type			Assembly Level				
					Engineering Dev	Acceptance	Integration & C/O	Demonstration	Environmental	Structural	Functional	Material	Component	Subassembly	Subsystem	System
	5500	Pilot Plant														
			Demonstrate simulated commercial plant operation where the pilot plant normal operation differs from the commercial plant.													
105			Simulate commercial plant thermal storage capacity.	Commercial plant discharges 3 TES units one at a time. Simulate second and third unit discharge by operating plant on fossil fuel to simulate first unit and first and second units discharge time. Continue to operate plant on TES only until the TES unit is fully discharged.				●			●					●