1410

Black & Veatch

FINAL REPORT

VOLUME I

EXECUTIVE SUMMARY

150 KW SOLAR POWERED DEEP WELL IRRIGATION FACILITY

AUGUST 30, 1977

prepared for

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

Albuquerque, New Mexico

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U.S. Energy Research and Development Administration
Reference: Preliminary Design Study for a
150 KW_e Solar Powered Deep Well
Irrigation Facility
(ERDA Contract EG-77-C-04-3916)

August 26, 1977

U.S. Energy Research and Development Administration
Division of Solar Energy
Washington, D. C. 20545

Attention: Mr. J. Weisiger

Gentlemen:

Our Phase I Final Report is submitted in three volumes, as follows:

Volume I, Executive Summary

Volume II, Main Report

Volume III, Supplementary Data

The studies summarized in our Phase I Final Report respond directly to the program objectives of achieving an "economically viable design through reasonably high thermodynamic efficiency" and using "components that are well along the research and development cycle".

The design that is proposed as a result of Phase I meets or exceeds all of the Technical Requirements of the Contract. We believe it is noteworthy that the central receiver concept developed by Black & Veatch during Phase I has the potential of achieving higher working fluid temperatures and, thus, higher thermodynamic efficiencies than any other solar thermal concept. Also, except for the heliostats, all components and fluids of the proposed design have demonstrated reliable long-life operation under similar operating conditions. Even the heliostats are well developed: more than 200 of the type proposed for this project have already been manufactured by Martin-Marietta. This is about twice the number required for a 150 MW_e deep well irrigation unit.

Phase II Project

Our plan for Phase II is intended to include the complete scope of services you have specified for the project. We are very much interested in Phase II and will do our best to make it an outstanding project. In the report and in the oral presentation at Albuquerque, we have explained our philosophy, our engineering system and procedures, and have indicated our approach to providing the required services.

Black & Veatch has extensive engineering and scientific capabilities which we believe uniquely qualify the firm to accomplish all of the necessary design effort, construction management, and operational testing required of the Prime Contractor for implementation of this project. Also, we have considerable experience in the design and construction of projects using similar components and systems. Special capabilities which directly relate to this project include an inhouse group of engineers and scientists working continuously and full time on solar thermal-electric conversion design projects and studies, and a very substantial amount of experience in the design, construction, operation and testing of power plants. Black & Veatch is, in addition, especially well qualified in the area of testing as it applies to solar power systems and components.

We have ample design engineering and construction management manpower to accomplish this project as scheduled. We are looking forward to undertaking this important assignment.

Very truly yours,

BLACK & VEATCH

John K. Kintigh,
Partner

JKK:mcw
Enclosures (Final Report)

cc: P. Grace (5) ALO
R. Alvis (2) Sandia
C. Koskovich (2) ALO

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1.0 FACILITY REQUIREMENTS

1.1 BACKGROUND

Rising energy costs and potential fuel shortages in the United States have greatly affected that portion of our agricultural production which utilizes irrigation. Seeking alternatives to this situation, ERDA/Division of Solar Energy (DSE) has identified the potential for using solar energy to power irrigation systems. The overall objective of the ERDA/DSE Solar Irrigation Program is the development of a viable, economical and practical power source for irrigation pumps.

Black & Veatch, in response to ERDA's request, submitted a proposal and was awarded a contract to study the potential of a small, central receiver system to provide energy for irrigation. B&V proposed to utilize proven processes, technology, and existing equipment to the fullest extent possible.

1.2 PHASE I PROGRAM SCOPE

The scope of work proposed by Black & Veatch during the Phase I contract consisted of six technical tasks with reporting as the seventh task. Tasks 1 and 2 were undertaken to select the most promising thermodynamic cycle system out of three proposed candidate systems. The three systems were the closed Brayton cycle, the open Brayton cycle and the Rankine cycle. In Task 3, a preliminary design for the facility was developed for the system selected as a result of Tasks 1 and 2, the steam turbine Rankine cycle. Task 4 was the analysis of production costs of future systems similar to the one developed in the preliminary design. Task 5 was the development of a program plan for Phase II, and Task 6 was the cost estimate for Phase II. The results of these six tasks are incorporated in this report. Presented are the preliminary design of a viable, potentially economical, deep well irrigation facility, and the Black & Veatch plan whereby the Phase II experimental facility will be operational by 1 January 1979 as specified in the Solar Irrigation Program Plan.

1.3 ORGANIZATION OF THE REPORT

The documentation of the results of work performed in Phase I of the ERDA Solar Powered Deep Well Irrigation Facility program is presented in three volumes: Volume I - Executive Summary, Volume II - Main Report, and Volume III - Supporting Data. Volume I provides a synopsis of the facility requirements, the design features, the experimental and future systems economics, the Phase II plan, and recommendations on action to be taken by ERDA. The main report presents discussions of design development, preliminary design, a detailed Phase II program plan which is fully responsive to ERDA's needs, cost estimate, and production (future) plant solar powered deep well irrigation plant analysis. Volume III contains essential supporting data such as baseline characteristics, system specifications, system analyses, engineering drawings and cost estimating worksheets.

1.4 DESIGN REQUIREMENTS

The overall objective of the program was to develop an economically viable design of a 150 kWe Solar Powered Irrigation Facility with reasonably high thermodynamic efficiency (600 F or higher).

The Phase I Statement of Work, along with subsequent ERDA and Sandia directives, established the design requirements for the irrigation facility. These design requirements include specified system capabilities, a preliminary as well as a site specific data package, the use of existing technology, the meeting of certain environmental conditions, reliability/maintainability/life considerations, and guidelines on capital/energy costs.

DESIGN FEATURES

VOLUME I

2.0 DESIGN FEATURES

2.1 SYSTEMS ANALYSES

The Systems Analyses performed during Phase I are discussed in terms of analytical methods, preliminary systems analyses, and systems analysis/ design optimization.

2.1.1 Analytical Methods

Systems analyses performed in Phase I utilized three computer codes and trade-off study techniques. The computer codes used are the Optical Performance Program, the Facility Performance Program, and the Economic Evaluation Program.

2.1.1.1 Optical Performance Program. The Optical Performance Program (OPP), a Black & Veatch developed code, is used to analyze the performance of central receivers and heliostat fields. Utilizing Monte Carlo techniques, the OPP code provides: (1) single timepoint flux maps; (2) single time-point heliostat field performance; and (3) integrated time average heliostat field performance. The code is capable of handling a variety of receiver configurations; multiple receivers/apertures; a heliostat of any size, shape, reflectivity, focussing strategy, and slope and track error; a heliostat field of any size and shape, and either uniform or nonuniform ground covers. The code accounts for both inter-heliostat shadowing and inter-heliostat blocking.

2.1.1.2 Facility Performance Program. The Facility Performance Program (FPP) was developed to predict the expected net electrical output of a central receiver solar power plant. The expected net output is computed both as a function of time and as an integrated annual value. The FPP code utilizes the output from the OPP code as input and provides output which serves as input to the Economic Evaluation Program. The FPP code predicts the net electrical output by modeling the insolation and the performance of the Collector, Receiver, Steam Generation, and Electrical Generation Systems. The gross energy generated, net energy generated, total purchases from the utility grid, total auxiliary energy requirements, and total irrigation water delivered are computed.

2.1.1.3 Economic Evaluation Program. The Economic Evaluation Program (EEP) was developed to calculate the levelized annual capital and busbar energy costs of a central receiver solar power plant. Computations are based on inputs of net annual electrical output (from FPP), capital investment costs, annual operating and maintenance costs, and the year of plant commercialization. Parameters, such as tax rates, depreciation rates, inflation rate, et cetera, are built into the code but may be altered as desired.

2.1.1.4 Trade-Off Studies. In addition to the preceding codes, trade-off studies, comparing two or more alternatives, were utilized extensively in systems analyses. Comparisons were made on the basis of present worth or annualized total costs. However, in some trade-off studies, factors other than cost, such as operating advantages, reliability, and delivery time, were considered.

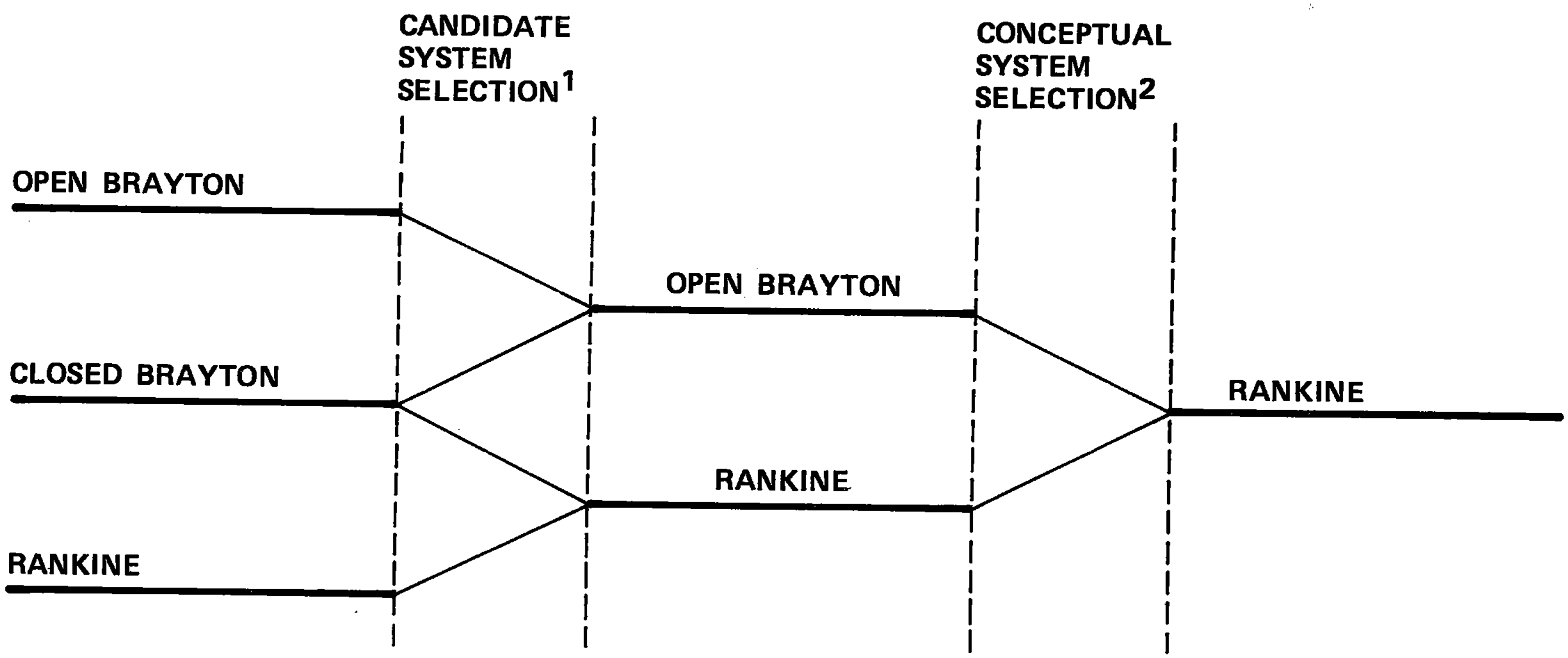
2.1.2 Preliminary Systems Analysis

A preliminary systems analysis was conducted to select the best of three conceptual thermodynamic cycles for the solar powered irrigation facility. This was performed in two steps--candidate system selection and conceptual system selection, as shown in Figure 2-1.

2.1.2.1 Candidate System Selection. Black & Veatch proposed investigating three thermodynamic cycles in Phase I. The three thermodynamic cycles were: (1) an open Brayton cycle which utilized air as the working fluid; (2) a closed Brayton cycle which had an inert gas as the working fluid; and (3) a Rankine cycle using water/steam as the working fluid.

Candidate system selection, involving the elimination of one of the thermodynamic cycles, was straightforward. A search of commercial machinery revealed that no closed Brayton cycle turbine was available in the required size range. Therefore, the two candidate systems selected for further study were: (1) the open Brayton cycle, and (2) the Rankine cycle.

2.1.2.2 Conceptual System Selection. The two candidate systems selected for further investigation in the first part of preliminary systems analyses were compared on the basis of performance and controlability. Conceptual designs of both systems were developed so a meaningful comparison could be made.



[1] THE CLOSED BRAYTON CYCLE WAS REJECTED BECAUSE:

- AN ENGINE IN THE REQUIRED SIZE RANGE WAS NOT COMMERCIALLY AVAILABLE

[2] THE RANKINE CYCLE WITH STORAGE WAS SELECTED BECAUSE:

- GREATER ANNUAL ENERGY
- ALL PROVEN COMPONENTS
- SIMPLE CONTROL SYSTEM

THERMODYNAMIC CYCLE SELECTION

FIGURE 2-1

The open Brayton cycle system conceptual design was constrained by receiver material limitations, types of backup energy systems, and commercially available turbine output characteristics. The maximum receiver outlet air temperature for the open Brayton cycle was determined to be approximately 1500 F, due to material limitations. The backup energy system for the open Brayton cycle utilizes fossil fuels during periods of inadequate insolation. The output characteristics of two prime turbine candidates degraded such that neither developed sufficient power. To overcome this problem, a configuration utilizing a single receiver and multiple, ganged turbines were utilized. However, the sophistication required of the control system appeared to be impractical.

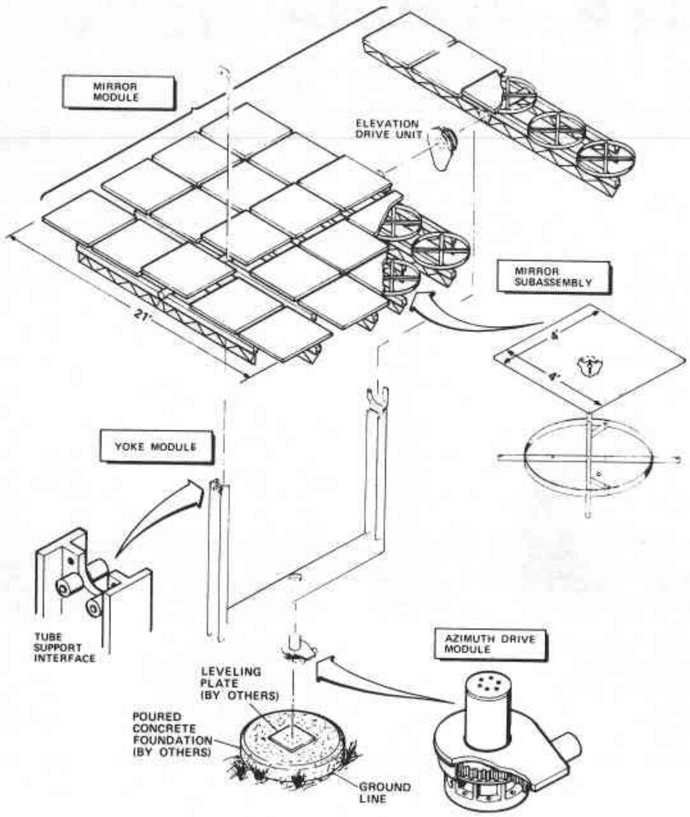
The turbine was selected over the multivane expander and the reciprocating engine as the prime mover for the Rankine cycle. A survey and subsequent analyses of available machinery identified the Terry GAF series, six stage turbine as providing the highest efficiency. The Rankine turbine coupled with a thermal energy storage system offers the advantages of greater net annual energy than the open Brayton cycle, continuous facility operation, simple receiver design, constant net electrical output, and a simple control system.

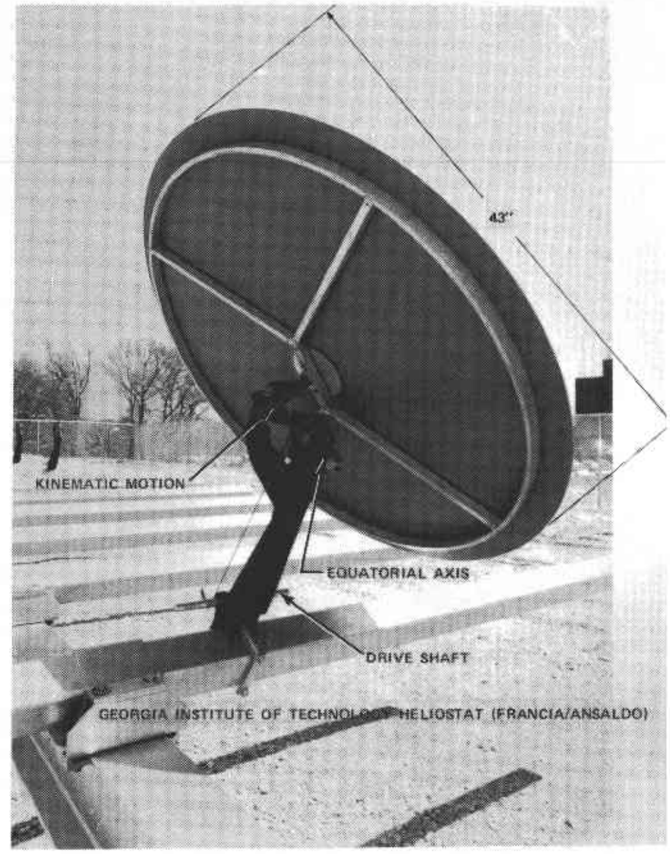
The result of the preliminary systems analysis was the selection of the Rankine cycle using a water/steam turbine combined with thermal energy storage for the system of choice for the preliminary design.

2.1.3 System Analysis/Design Optimization

Systems analyses and design optimizations were conducted on the selected conceptual system. Facility characteristics investigated include the heliostat field configuration, turbine parameters, heat rejection systems, steam generator pinch point, insulation thickness, and equipment arrangement. Systems analyses related to facility performance are discussed in Section 3, Economics.

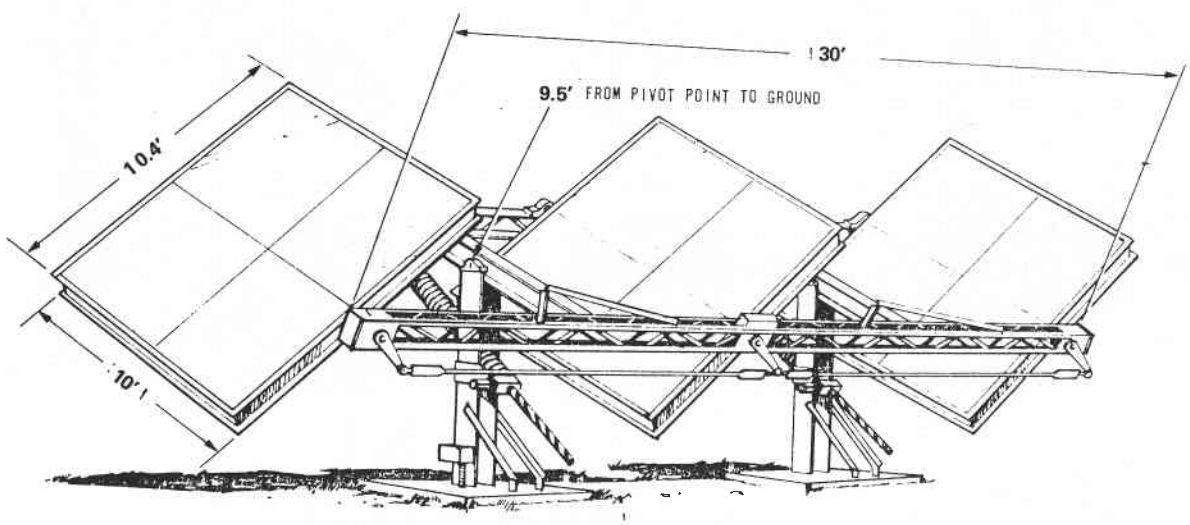
2.1.3.1 Heliostat Field Configuration. The heliostat field was designed for both the kinematic motion heliostat and the Martin Marietta heliostat, shown in Figure 2-2. The Honeywell heliostat was not considered in the field design.





A) MARTIN MARIETTA HELIOSTAT (SELECTED HELIOSTAT FOR SPDWIF)

B) KINEMATIC MOTION HELIOSTAT (FRANCIA/ANSALDO DESIGN) (DESIGN PLANNED WOULD HAVE USED A 7' DIAMETER MIRROR)



C) HONEYWELL HELIOSTAT

FIGURE COMPARATIVE HELIOSTATS CONSIDERED FOR THE SPDWIF.

FIGURE 2-2

The configuration of the field for the kinematic motion heliostat is circular with the 32.5-meter-high receiver tower located south of center. The configuration has a variable ground cover ratio such that the annual shadow-block efficiency everywhere in the field is .90.

The Martin Marietta heliostat was used to design a 360 degree field and a north field. Neither was optimized; uniform ground cover ratios for both fields were assumed to be 0.5. The 360 degree field using Martin Marietta heliostats produced more net annual energy than either the north field or the kinematic motion heliostat optimized field. Therefore, the circular field with Martin Marietta heliostats surrounding a tower located just south of the field center was selected as the heliostat field configuration for the preliminary design.

2.1.3.2 Turbine Parameters. The turbine parameters analyzed include throttle steam temperature and pressure, turbine speed, and turbine exhaust pressure. The throttle steam temperature of 750 F was selected on the basis of heat transfer salt (HTS) material property considerations. The throttle steam pressure of 350 psig and turbine speed of 5,400 rpm were selected on the basis of interrelated optimization studies. Finally, the turbine exhaust pressure of 1.5 in. Hg absolute was determined on the basis of a cost optimization study.

2.1.3.3 Heat Rejection Source. Two sources were considered for rejecting waste heat in condensing the turbine exhaust steam. The first source is water in a conventional wet cooling tower system. The second source considered is well water which is pumped through the condenser before it enters the irrigation ditch. The two concepts were evaluated with respect to turbine cycle efficiency and total facility cost (both capital and operating).

Well water was selected as the turbine exhaust heat rejection source because the benefits of the increased cycle efficiency of the cooling tower were outweighed by the cost of the tower and the power consumption of the tower fans.

2.1.3.4 Steam Generator Pinch Point. The pinch point of a heat exchanger is that point at which the smallest temperature differential exists between the two working fluids. A detailed analysis on the pinch point was not conducted in the preliminary design phase of the program. The steam generator designer, who has experience with HTS heat exchanger steam generators, believes the 11 F pinch point in the steam generator is near the optimum value.

2.1.3.5 Insulation Thickness. The major function of insulation on plant equipment is the reduction of conductive and convective heat loss. As insulation thickness increases, overall plant efficiency increases. However, overall plant cost also increases. The optimum insulation thickness has been determined for the various tanks, piping, and steam generation equipment in the facility.

2.1.3.6 Equipment Arrangement. The circulating water system, electrical generation system, and steam generation system cannot all be located in the center of the heliostat field due to space restrictions. In order to locate one or more of the systems outside of the heliostat field, additional piping, piping supports, and pumping power are required.

The circulating water and electrical generation systems were located outside the heliostat field, pumping the feedwater to and steam from the steam generation system at the field center. This arrangement was selected on the basis of cost, heliostat shadowing, and ease of operation.

2.1.3.7 Heliostat Selection. Black & Veatch's Phase I proposal was based on the use of simple, relatively inexpensive, ganged, kinematic motion heliostats. Tests conducted during the preliminary design, however, showed that these heliostats did not meet performance specifications. Further, it was evident that there was little chance these deficiencies could be corrected in time for January 1, 1979 facility operation.

Black & Veatch requested quotations from the four leading U.S. manufacturers of central receiver heliostats. Figure 2-3 illustrated the central receiver heliostat selection process. The two quotations received, from Honeywell and Martin Marietta, were compared in terms of performance and cost. Performance considerations include control system design, reflectivity, and slope/track errors. Cost considerations include both capital cost and maintenance.

SOLICITED MANUFACTURERS	QUOTATIONS RECEIVED	HELIOSTAT SELECTED*
• BOEING	• HONEYWELL	• MARTIN MARIETTA
• HONEYWELL	• MARTIN MARIETTA	
• MARTIN MARIETTA		
• McDONNELL DOUGLAS		

*Martin Marietta's heliostats were selected because:

- Existing Production Experience
- No Redesign Required
- Control System Provided

CENTRAL RECEIVER HELIOSTAT SELECTION

FIGURE 2-3

The Martin Marietta heliostat was selected for use by Black & Veatch in Phase II because it had the lowest evaluated cost and offered the important benefit of production experience and extensive full scale testing at the ERDA 5 MW_t Solar Thermal Test Facility at Sandia Albuquerque.

2.2 PRELIMINARY DESIGN

2.2.1 Overall Facility Design

2.2.1.1 Key Factors. The preliminary design of the 150 kWe Solar Powered Deep Well Irrigation Facility, presented in this section, has several important advantages. First, it is simple to operate and simple to maintain.

Second, the design uses thermal storage to operationally separate the collection of solar energy from the generation of electrical energy.

An important feature is that the system can be operated by an automatic control system which eliminates the need for an operator during daily start-up, normal operation, and shutdown.

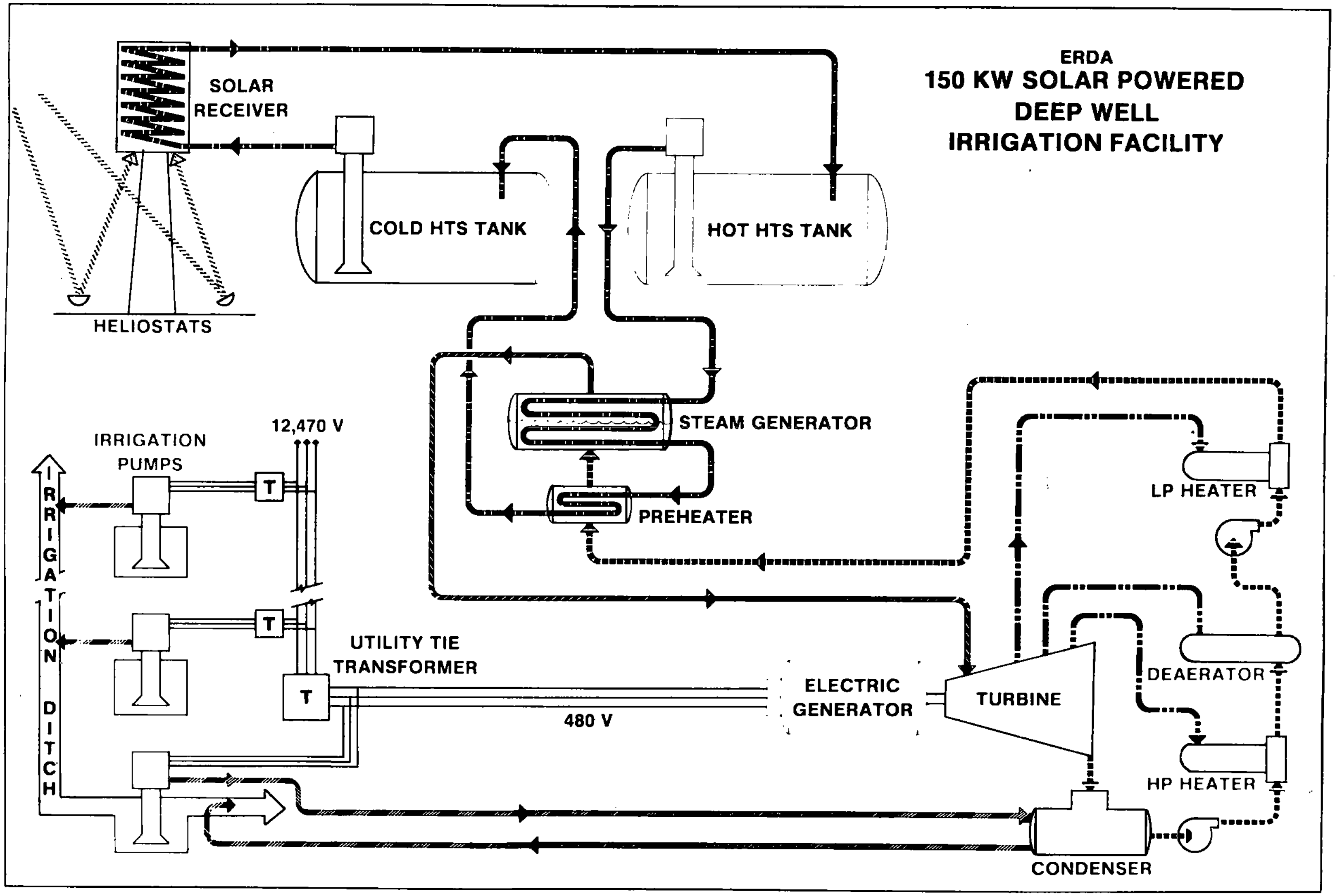
The fourth important advantage of this design is the fact that all important components and fluids are commercially available and are currently in operation under similar conditions.

Another important advantage is that scheduled maintenance is very low, largely because of proven components and a conservative design.

2.2.1.2 Basic Cycle Configuration. Figure 2-4 is a simplified schematic flow diagram of the preliminary design. The basic cycle configuration consists of a solar to thermal conversion process, a thermal storage process, a thermal energy transfer process from a heat transfer salt (HTS) into feedwater and steam, a thermal to mechanical conversion process, a mechanical to electrical conversion process, and an electrical distribution process.

Solar energy is redirected into the aperture of the solar receiver by the heliostats. HTS flows through the receiver tubes absorbing solar/thermal energy.

The HTS heated in the receiver is piped to the hot HTS tank where it is stored. The hot HTS accumulates in the hot HTS tank until sufficient energy is available to begin the thermal to electrical conversion process.



SIMPLIFIED SCHEMATIC FLOW DIAGRAM
150 kW SOLAR POWERED DEEP WELL IRRIGATION FACILITY

FIGURE 2-4

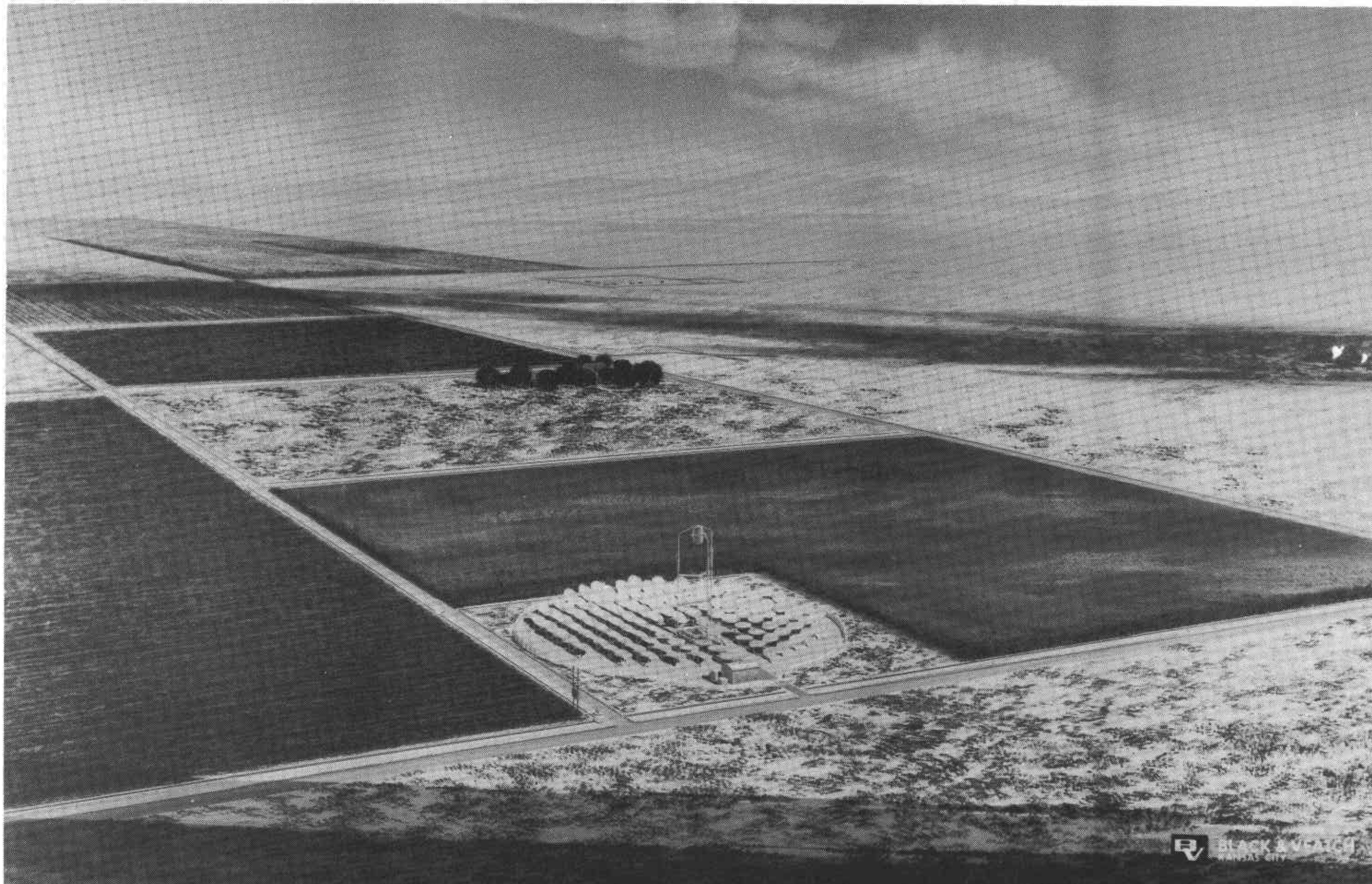
The preheater and steam generator are heat exchangers which transfer thermal energy to the feedwater and steam from the HTS. After passing through the two heat exchangers, the HTS is piped to the cold HTS tank. Feedwater is heated in the preheater, boiled in the lower section of the steam generator, and superheated in the upper section.

The superheated steam leaving the steam generator is piped to the turbine throttle. In the turbine, thermal energy is converted to mechanical shaft energy. The turbine exhaust steam is condensed by diverted irrigation water in the condenser. The condensate is pumped through three stages of regenerative feedwater heating, which improves turbine cycle efficiency, before returning to the preheater and steam generator. The irrigation water leaving the condenser has been raised to 85 F from 80 F and is returned to the irrigation ditch for meeting crop irrigation needs.

The electric generator, which converts mechanical energy to electrical energy, is driven by the turbine through a gear box. The electric power is used to operate the irrigation pump and the facility auxiliary equipment. The utility grid serves as the backup source of energy.

2.2.1.3 Facility Arrangement. Figure 2-5 is an artist's rendering which shows how the Black & Veatch preliminary design would appear on the Dalton Cole farm near Coolidge, Arizona. The proposed location for the solar powered deep well irrigation facility is just north of Kleck Road and east of a farm road near Pump E.

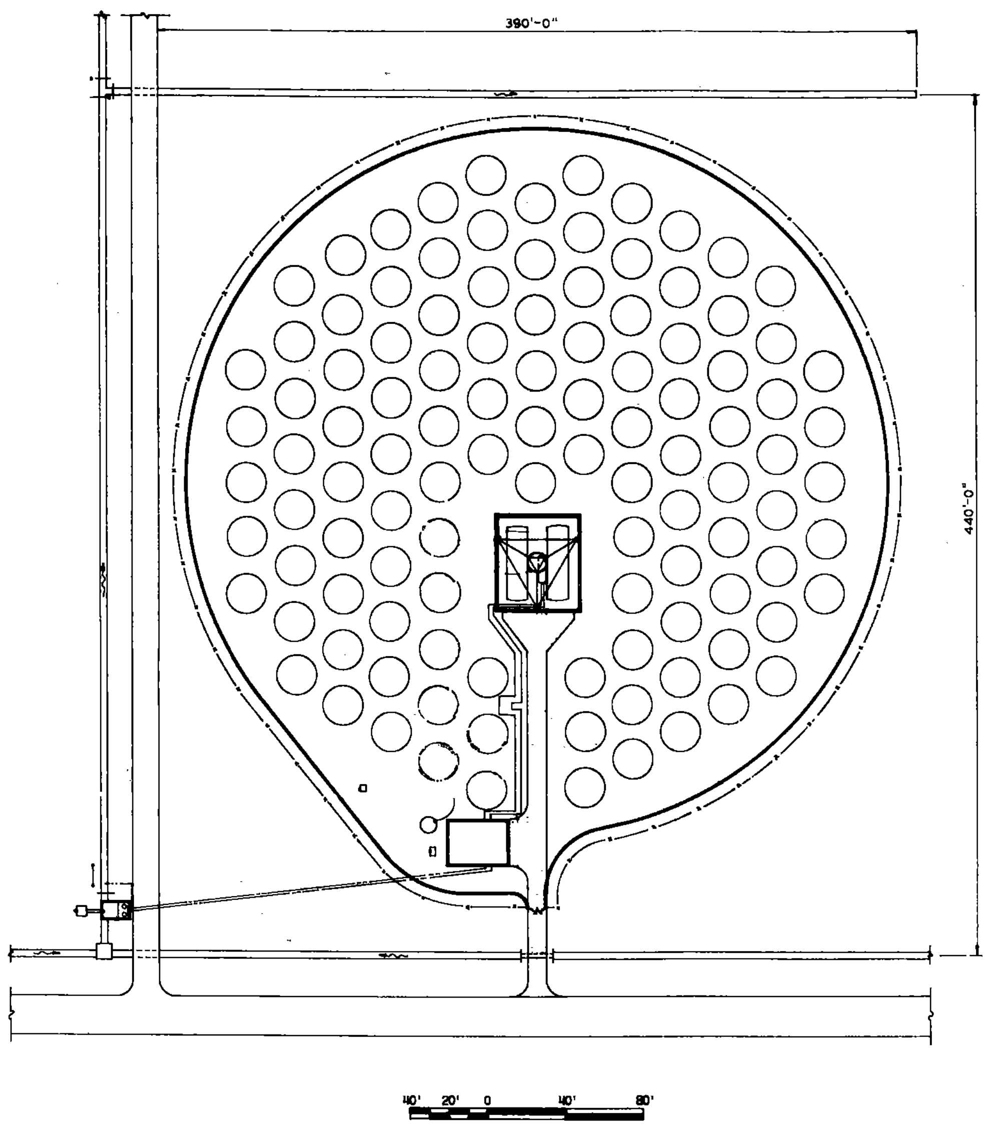
Figure 2-6 is a facility arrangement drawing. Access is provided to the circular heliostat field which surrounds the receiver tower. The concrete foundation which supports the tower forms a pit that is about three feet below grade. This foundation also supports the two HTS tanks located in the depressed section of the tower foundation. The preheater and the steam generator are mounted above the HTS tanks. Feedwater and steam are piped between the steam generation at the base of the tower and the Electrical Generation System (EGS) building south of the heliostat field. The EGS building houses the turbine generator and auxiliaries. A small control room in the EGS building houses the control computer and the control panel. A circulating water (condenser cooling water) intake



ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

SOLAR POWERED DEEP WELL IRRIGATION FACILITY (150 KW)

FIGURE 2-5



FACILITY ARRANGEMENT

FIGURE 2-6

structure is located adjacent to irrigation Pump E. Circulating water is piped underground from the intake structure to the condenser in the EGS building and back to the irrigation ditch where it discharged just downstream of the intake structure and used for irrigation. A new irrigation ditch north of the plant area is provided to supply water to that portion of the field just north of the heliostat field.

2.2.2 Collector System

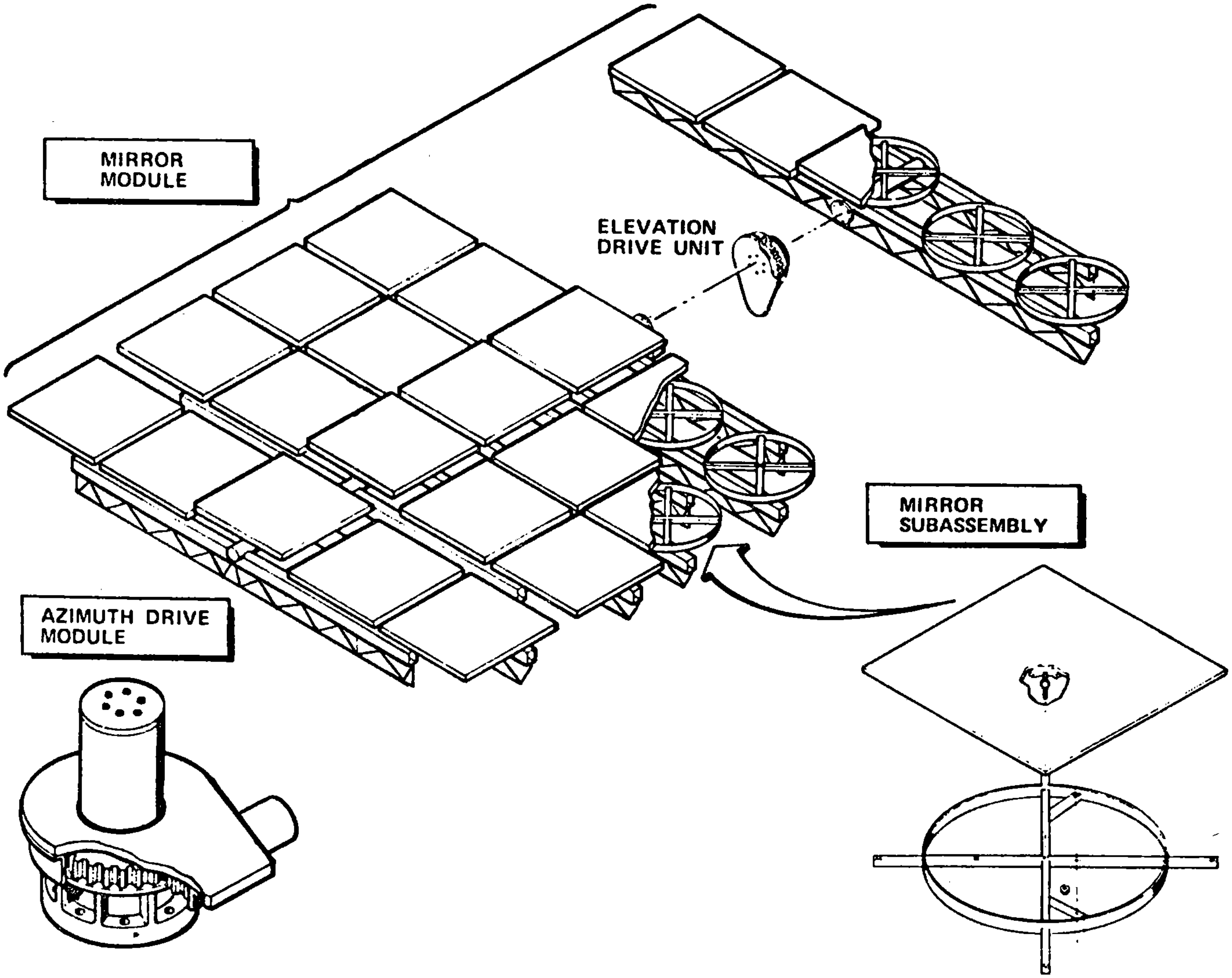
The Collector System intercepts the incident direct insolation and redirects it into the aperture of the solar receiver. The system consists of an array of 100 heliostats, heliostat foundations, the heliostat power and control cables, and the heliostat control system.

The proposed heliostats are manufactured by the Martin Marietta Corporation of Denver, Colorado. The heliostat configuration, shown in Figure 2-7, contains a 5 by 5 array of laminated, second-surface mirrors, each 4 by 4 feet. Each mirror is deformed so that its surface shape is approximately spherical. The mirrors are independently focused to the appropriate slant range for their position in the field. Rotation about both the azimuth and the elevation axes is provided by tandem motors, acting through gear boxes. Each axis is equipped with a step motor (fine track) and an induction motor (slewing). The angular position of a mirror array about each axis of rotation is measured by a 13 bit encoder.

Heliostat foundations are below grade, cast-in-place concrete, reinforced with preassembled steel reinforcing bars. Anchor bolts are integrally cast with the foundations and protrude from the tops to provide means of attaching the heliostats.

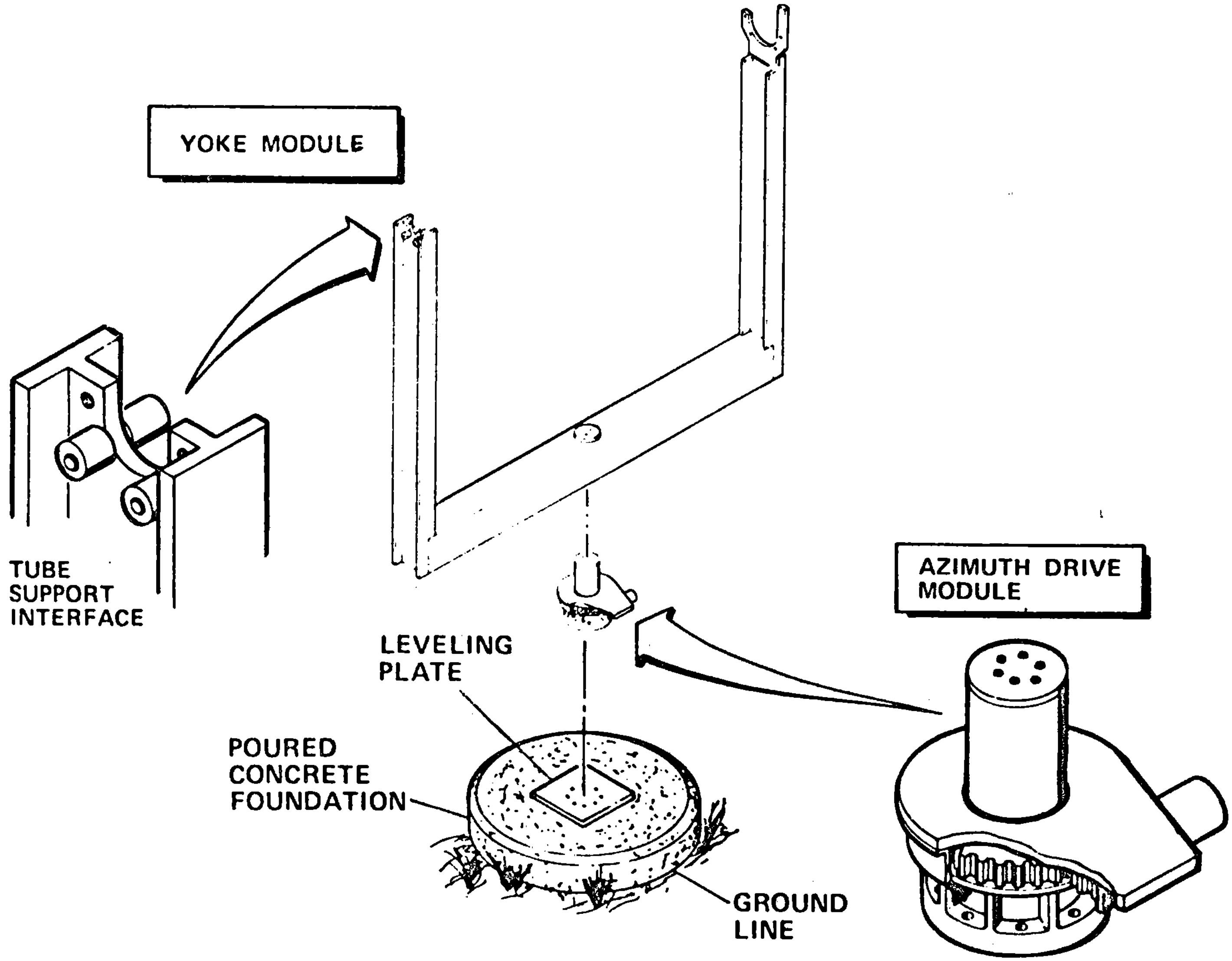
Four cables connect to each heliostat: a power cable, a control cable, a data cable, and a fail-safe cable.

The heliostat array controller (HAC) contains in memory the location of each heliostat, the address code of each heliostat, and the coordinates of the target point for each heliostat. The HAC utilizes the direction cosines of the sun, computed by the solar position calculator, to compute the azimuth and elevation positions for each heliostat appropriate to the mode of operation.



ASSEMBLY-BUILDING OPERATIONS

FIGURE 2-7a



FIELD ASSEMBLY OPERATIONS

FIGURE 2-7b

A heliostat control electronics assembly (HCE) on each heliostat identifies the commands appropriate to the heliostat via the heliostat address code. Each HCE then activates either the step motors (fine track) or slew motors (course track) in accordance with the heliostat command signal to position the heliostats.

The Collector System is capable of assuming one of five operating modes: acquisition, standby, power, shutdown, and emergency shutdown.

The Collector System normally enters the shutdown mode each evening when the solar elevation drops below 10 degrees. Also, shutdown initiates any time the average wind speed exceeds 20 mph or precipitation is detected.

2.2.3 Receiver System

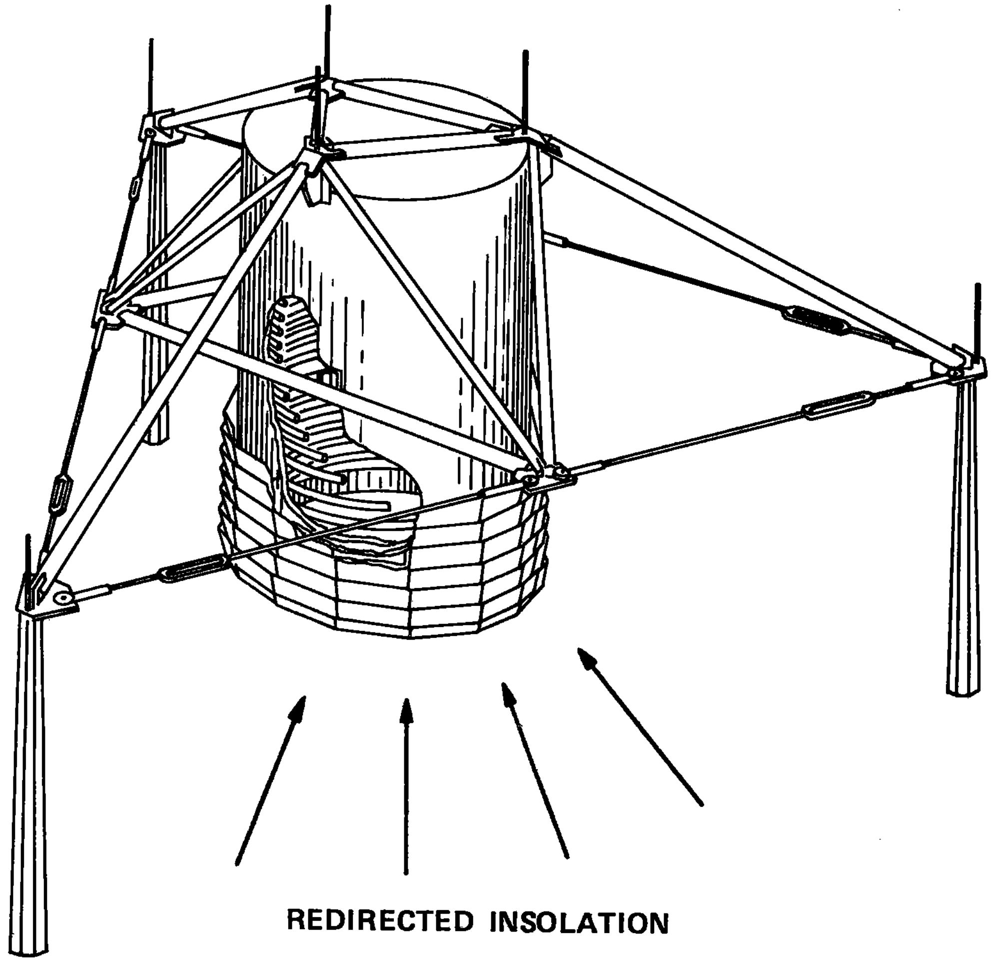
The Receiver System exists to provide thermal energy input to the heat transfer salt (HTS). The major components in the system are the solar receiver, receiver housing, receiver support tower, cold HTS tank, and cold HTS pumps.

The solar receiver, shown in Figures 2-8 and 2-9, serves as a focal point for the solar flux redirected from the heliostat field. This solar energy is transformed by the receiver into thermal energy in the HTS.

The receiver housing is a carbon steel shell of a right circular cylinder geometry with a downward facing circular aperture located on the bottom face. A solar radiation shield covers the lower 1 meter of the housing, protecting the exterior of the structure from stray radiation. The receiver is suspended vertically from three tower support brackets. Wind and seismic loads are absorbed at these brackets and by three lateral restraint brackets located at mid-height of the housing. The housing rigidity is maintained with stiffening rings at the support levels.

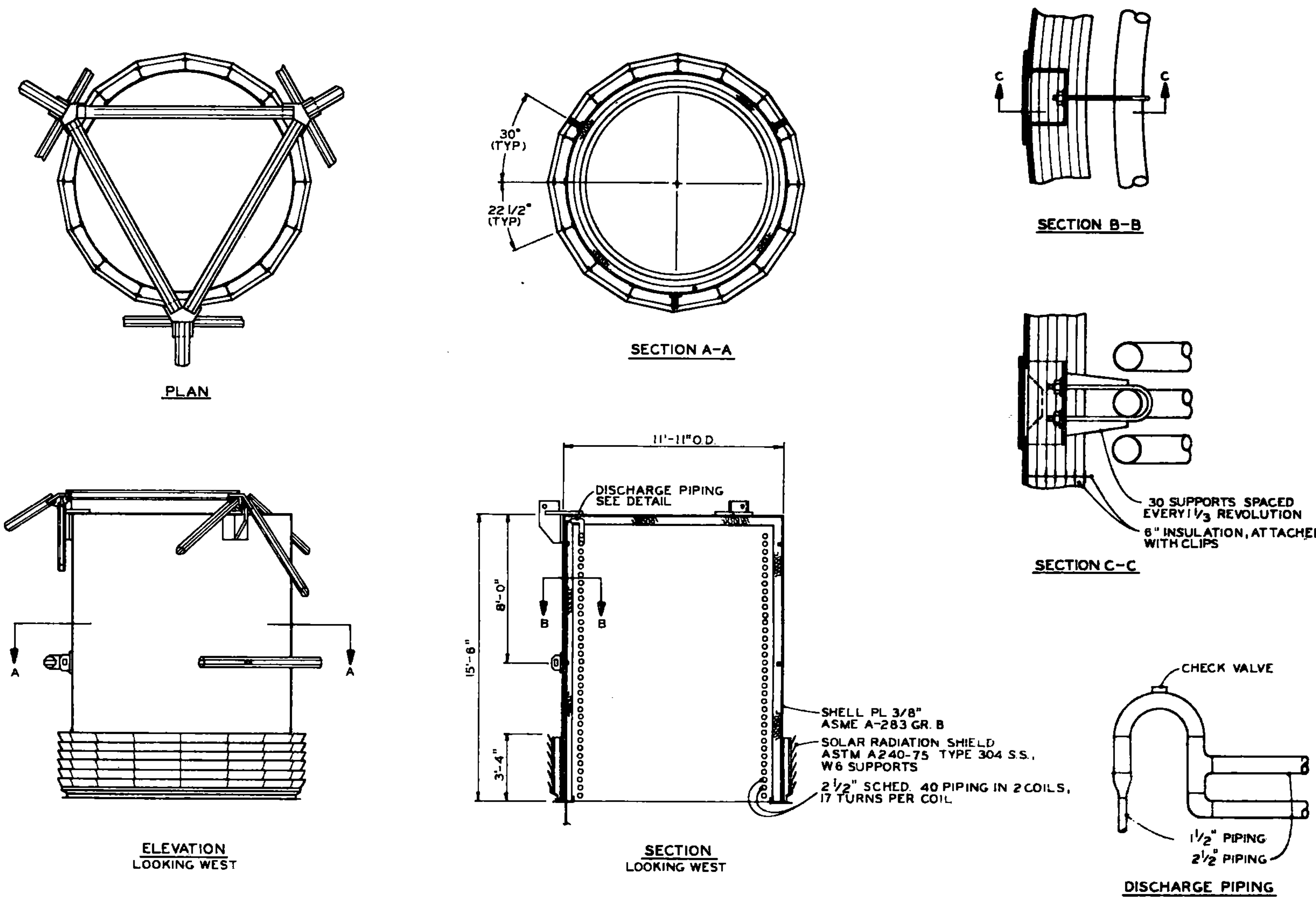
The receiver support tower, illustrated in Figure 2-10, is a braced steel space frame comprised of three vertical legs and a network of bracing and stiffening members. In addition to providing structural support for the solar receiver, the tower supports HTS piping, an anemometer, lightning rods and wiring.

The cold HTS tank, shown in Figure 2-11, serves as a storage vessel for the cold HTS before it is heated in the solar receiver. This tank, which contains electric heaters, is also the vessel used for the initial HTS meltdown.



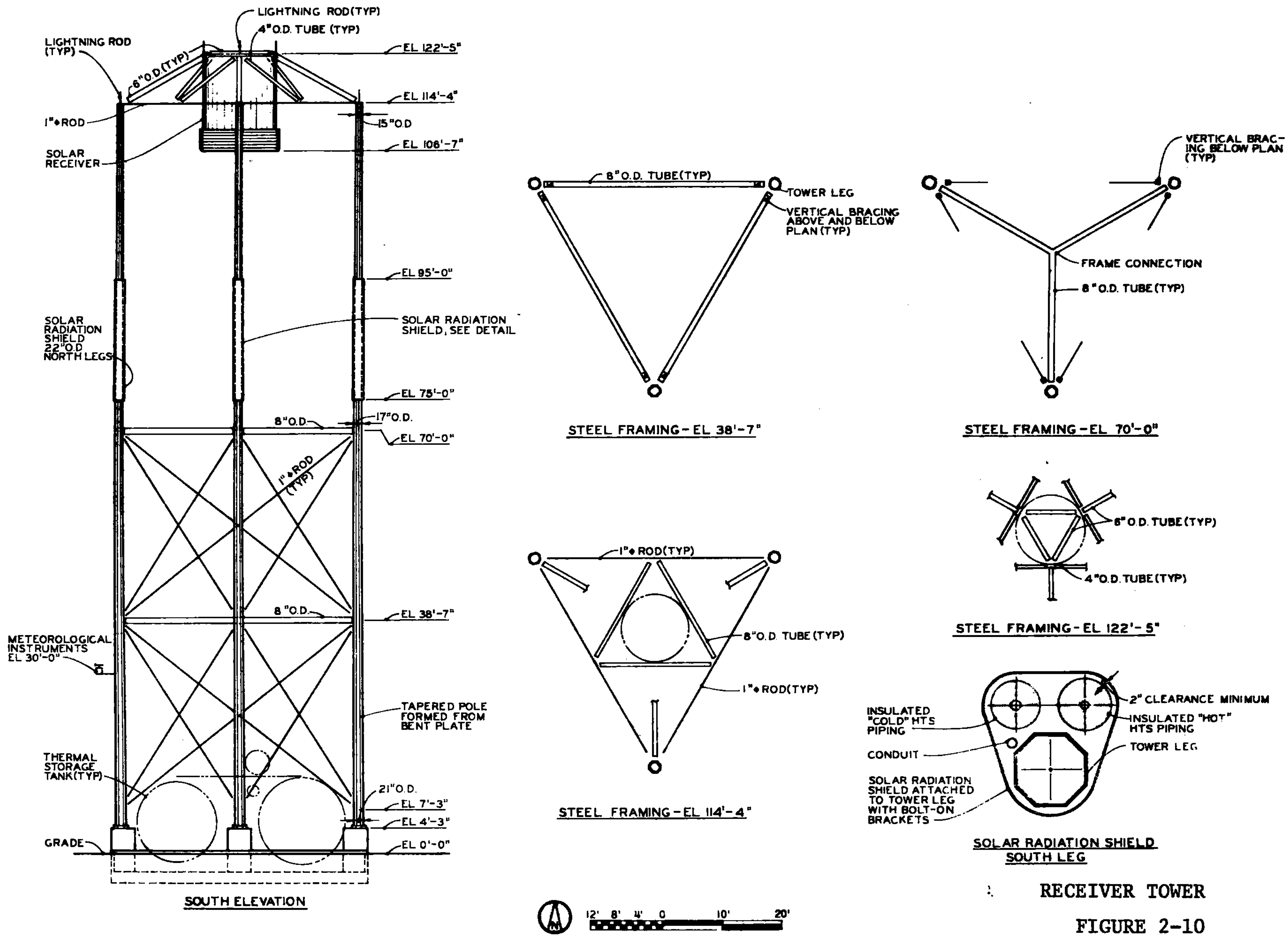
SOLAR RECEIVER AND SUPPORT STRUCTURE

FIGURE 2-8



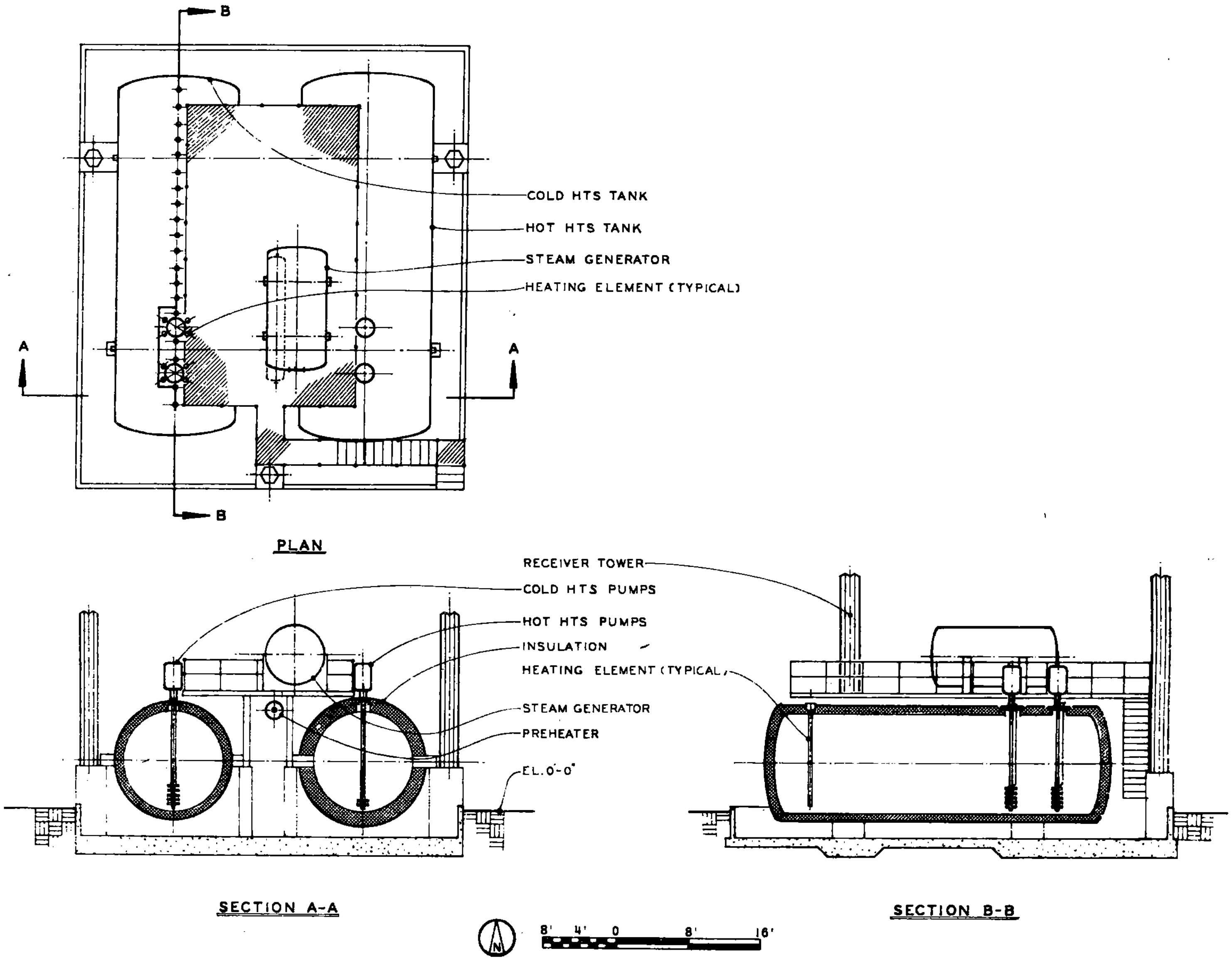
SOLAR RECEIVER

FIGURE 2-9



RECEIVER TOWER

FIGURE 2-10



STEAM GENERATION AREA ARRANGEMENT

FIGURE 2-11

The cold HTS pumps, shown in Figure 2-11 take suction from the cold HTS tank and pump HTS through the solar receiver to the hot HTS tank. Each cold HTS pump is a 5-stage, vertical, submerged, sleeve-bearing pump with a variable speed V-belt motor drive.

2.2.4 Steam Generation System

The functions of the Steam Generation System are: (1) to store the thermal energy collected by the Receiver System until required by the Electrical Generation System, and (2) to generate steam from the stored thermal energy for the Electrical Generation System. The major components of the system, shown in Figure 2-11, are the steam generator, the preheater, the hot HTS tank, the hot HTS pumps, and the HTS.

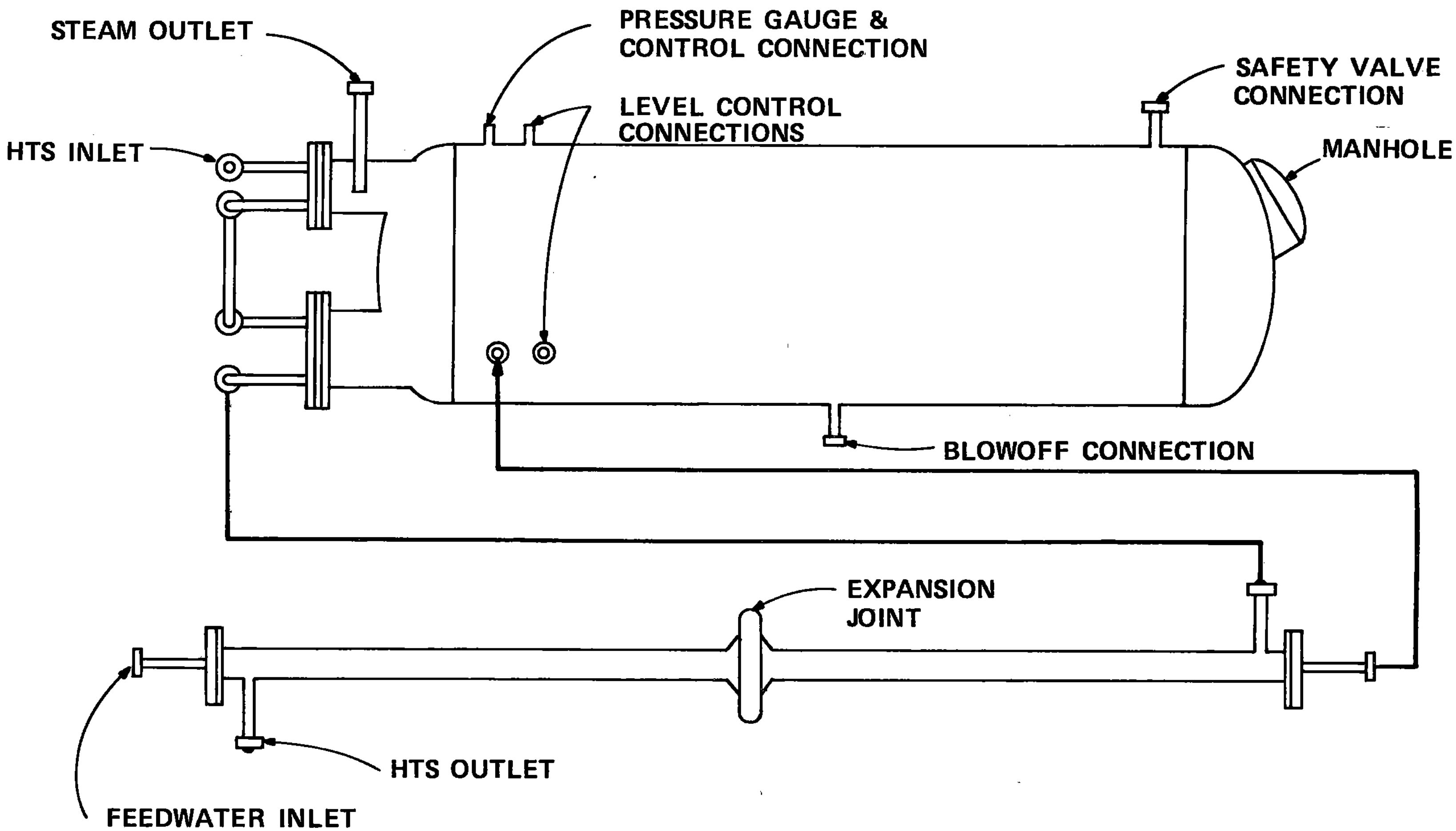
The steam generator is a shell and tube heat exchanger that is divided into two sections--the boiler and the superheater. In the lower section, feedwater in the shell is boiled by HTS flowing through U-tubes. The saturated steam rises into the upper section where it is superheated. The 800 F HTS entering the U-tubes in this section provides the final heating.

The preheater, located in series with the steam generator, is a counterflow shell and tube heat exchanger. The feedwater flows through low-finned tubes and the HTS flows through the shell. A drawing of the steam generator and preheater is shown in Figure 2-12.

The hot HTS tank serves as a storage vessel for the hot HTS before usage in the steam generator and preheater.

The hot HTS pumps take suction from the hot HTS tanks and pump HTS through the steam generator and preheater to the cold tank. Each hot HTS pump is a 2-stage, vertical, submerged, sleeve-bearing pump with a variable speed V-belt motor drive.

HTS is a eutectic mixture of inorganic salts having a melting point of 288 F and is suitable for use up to 1,100 F. The mixture is composed of 40 per cent sodium nitrite, 7 per cent sodium nitrate, and 53 per cent potassium nitrate. HTS is chemically very stable to 850 F. There is, however, a small amount of thermal decomposition of the nitrite over long periods.



STEAM GENERATOR AND PREHEATER

FIGURE 2-12

Under normal operation, the facility control system automatically regulates the HTS flow through the steam generator and preheater, thereby keeping the outlet steam conditions constant. This is accomplished by varying the hot HTS pump speed. In addition, water level in the steam generator is monitored and maintained at a constant level by varying the pump stroke on the feedwater pumps.

During diurnal shutdown, steam is required to maintain deaerator pressure, seal the turbine, and blanket the feedwater heaters for corrosion protection. For extended shutdown, nitrogen blanketing of the heaters, steam generator, and preheater is provided.

2.2.5 Electrical Generation System

The Electrical Generation System (EGS) converts thermal energy in the superheated steam supplied by the steam generator into electrical energy.

The turbine, shown in Figure 2-13, is a 5400 rpm, nonreheat, condensing, top exhaust, single shell machine designed for operation at any back pressure from 1 in. Hg absolute to atmospheric pressure. The turbine drives an 1800 rpm (60 cycle) generator through a speed reducing gear.

Turbine exhaust steam is condensed in the condenser by irrigation water. After it passes through the condenser tubes, the irrigation water is returned to the ditch to meet crop needs.

Turbine extraction steam is supplied to three regenerative feedwater heaters to increase the cycle efficiency. A heat balance is shown in Figure 2-14.

The turbine generator is designed to operate continuously on steam supplied by the steam generator, or to be sealed during diurnal shutdown for corrosion protection. The arrangement of equipment in the EGS building is shown in Figure 2-15.

2.2.6 Electrical System

The Electrical System delivers 150 kWe net electrical power to the irrigation pump and supplies electrical power to auxiliary equipment. A utility tie provides power for auxiliary power required for start-up and shutdown, and is available when the facility is not in operation. The Electrical System also provides lightning protection and a grounding

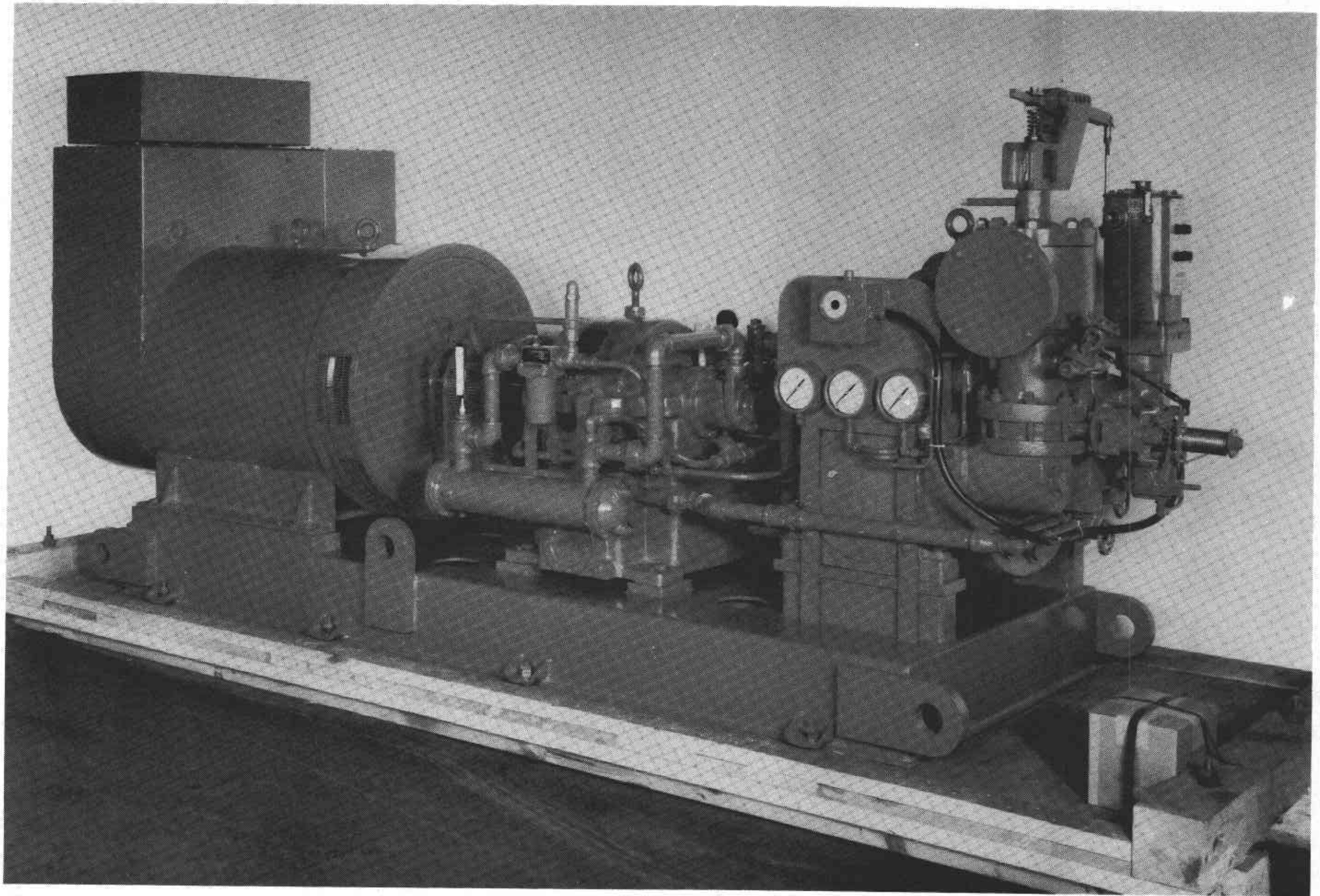
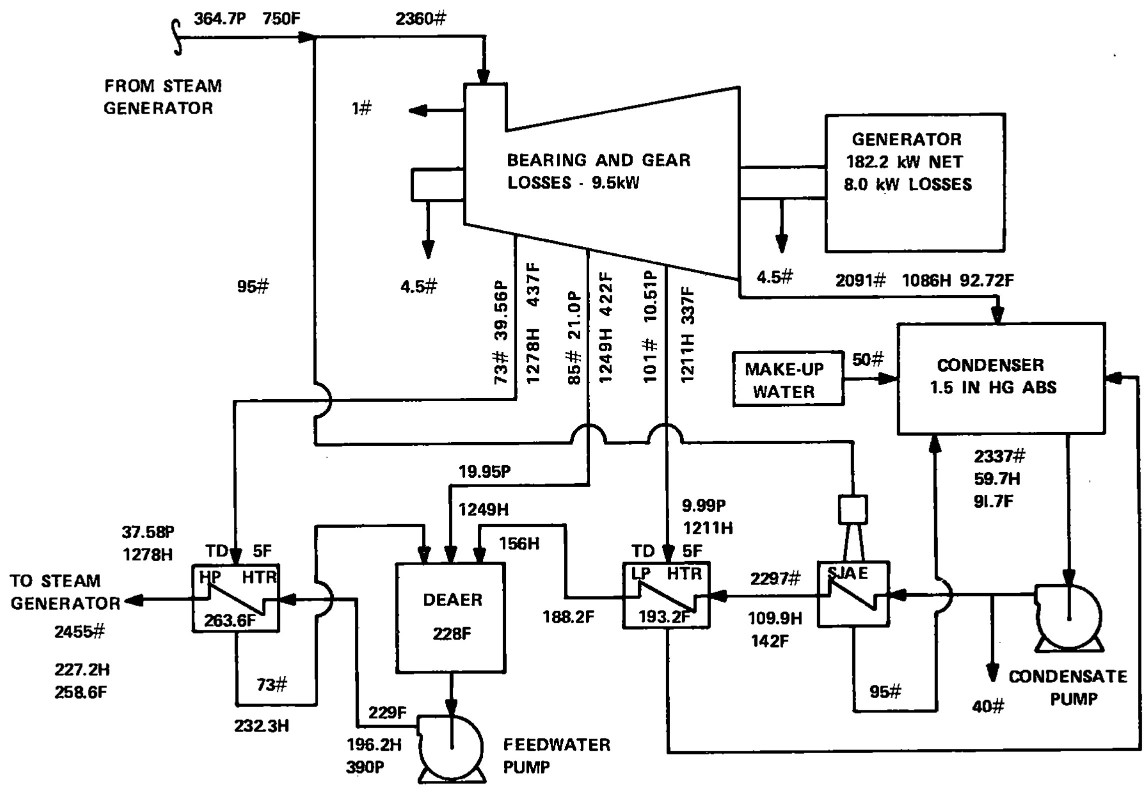


FIGURE 2-13

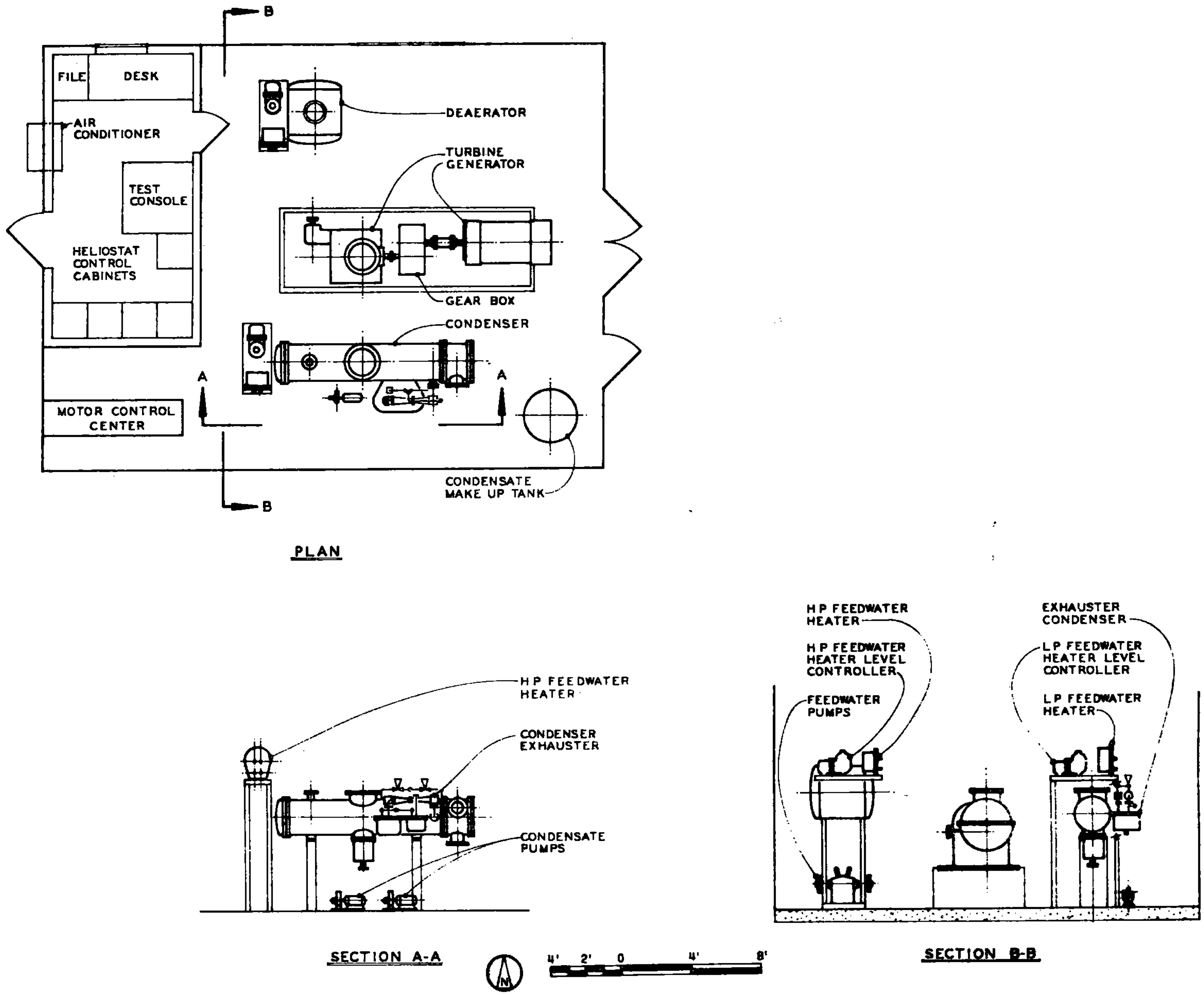
TERRY CORPORATION
Model GAF 6-Stage Turbine Generator
Skid-Mounted with Gearbox



$$\text{GROSS TURBINE HEAT RATE} = \frac{2455\,(1392 - 227.2)}{182.2} = 15{,}695\ \frac{\text{Btu}}{\text{kW-hr}}$$

HEAT BALANCE

FIGURE 2-14



EGS BUILDING ARRANGEMENT

FIGURE 2-15

network for the facility. A one-line diagram of the Electrical System is shown in Figure 2-16.

2.2.7 Control System

The basic functions of the Control System are to:

(1) Provide automatic operation of the facility with minimum operator attention.

(2) Maintain reliable facility operation and performance.

(3) Allow flexibility in facility operating strategy to match the widely varying solar conditions.

(4) Collect and record facility operating parameter data.

(5) Protect facility equipment from catastrophic failure or severe damage due to component or subsystem malfunction.

The control system developed for the preliminary design is based on the following assumptions.

(1) All available solar energy, as allowed by the quantity of heat transfer salt (HTS), is utilized.

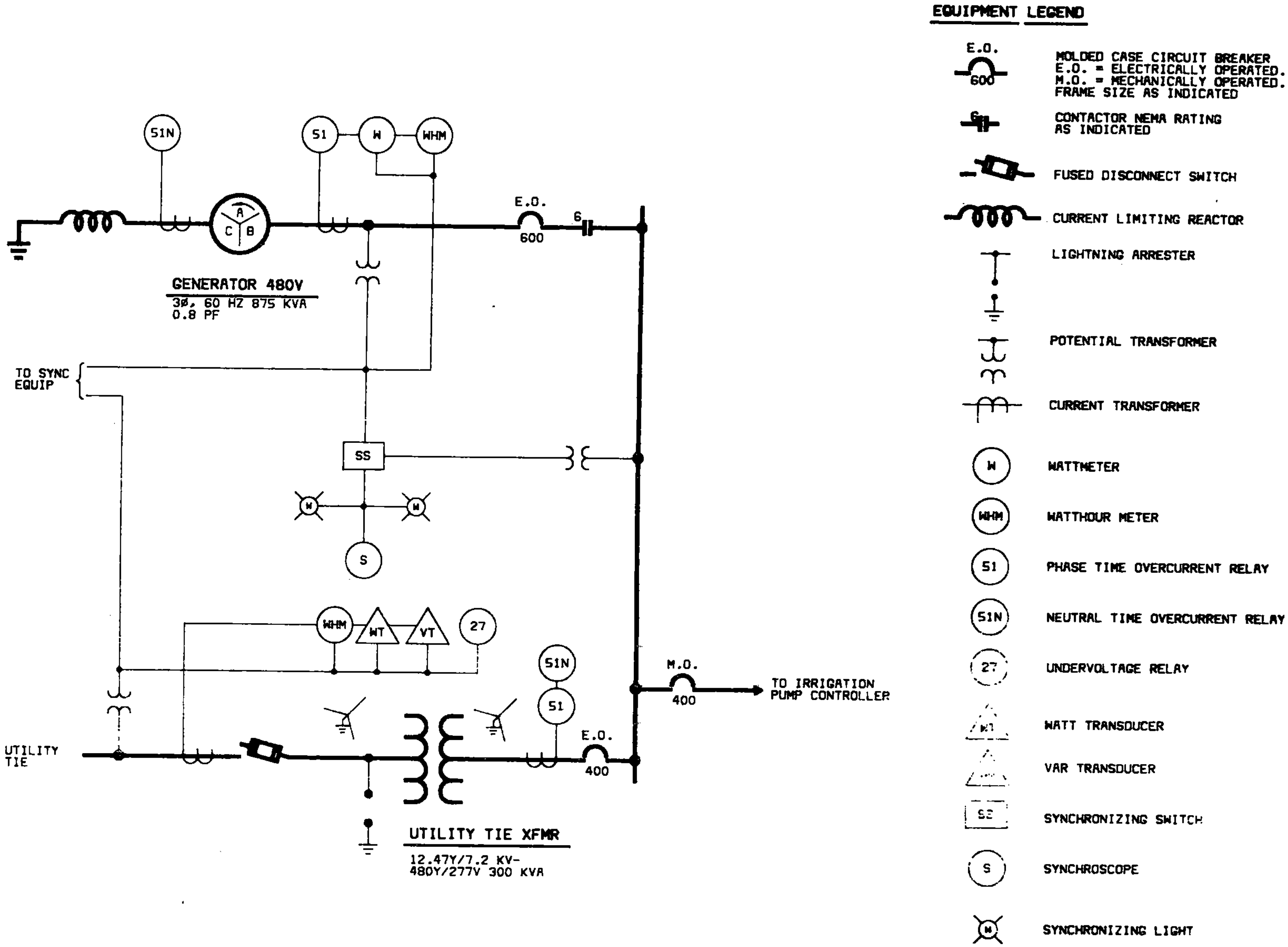
(2) Excessive start-ups and shutdowns are eliminated to the extent possible.

(3) Normal operation is at full load.

(4) The control system is to protect facility equipment from harmful extremes of certain process parameters.

(5) Start-up, shutdown, and normal operation are fully automated requiring no operator intervention.

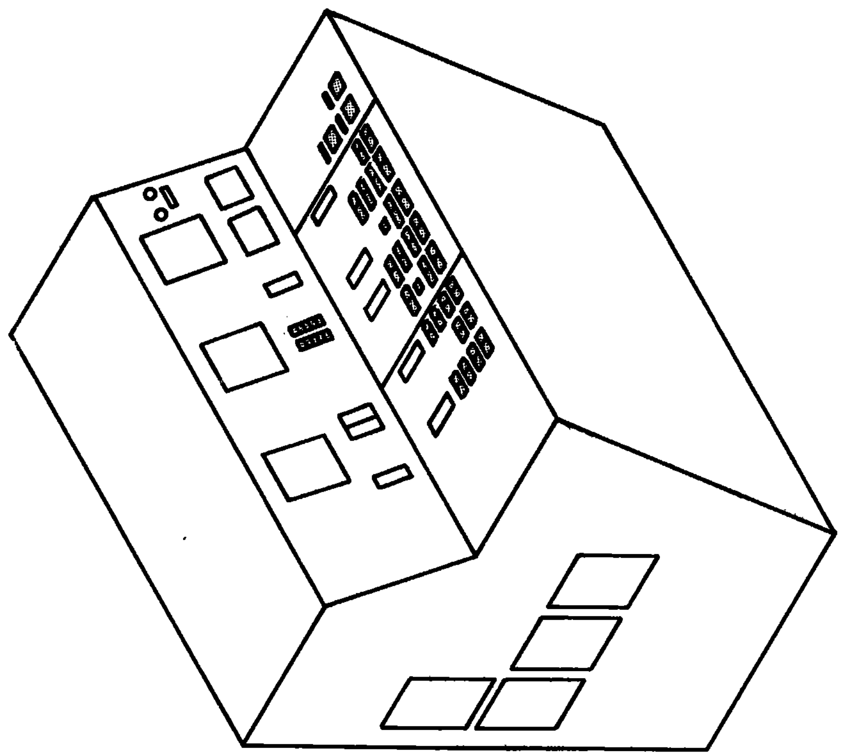
The control system consists of both modulating and digital controls. The modulating controls regulate HTS flow and collection and feedwater flow to the steam generator. Minor modulating controls are used to perform isolated control functions. The digital controls provide overall master control which determines when a start-up is required or can be made, starts pumps and places the analog control loops in service, places systems in service in the proper sequence, runs the turbine up, and puts the generator on line. The digital control also monitors all parameters during operation and initiates an automatic shutdown when a parameter exceeds safe limits.



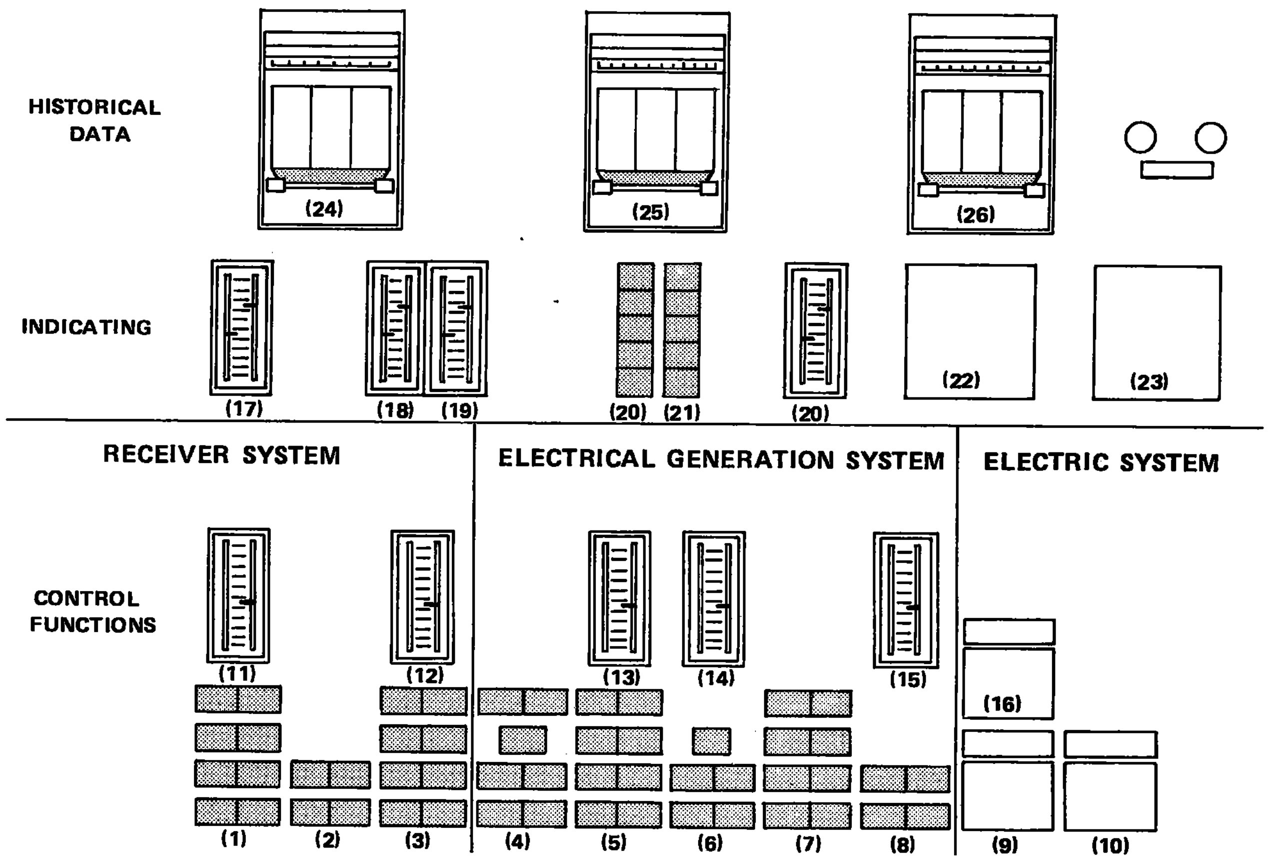
MAIN ELECTRIC SYSTEM

FIGURE 2-16

The control room, located in the EGS building and shown in Figure 2-15, houses the control console. The console and its panel arrangement are shown in Figures 2-17 and 2-18.



CONTROL CONSOLE
FIGURE 2-17



CONTROL CONSOLE PANEL ARRANGEMENT

FIGURE 2-18

ECONOMICS

VOLUME I

3.0 ECONOMICS

3.1 INTRODUCTION

The cost estimates and performance calculations presented in this section provide a summary of the following: baseline cost for the Coolidge Facility, potential cost reductions from the baseline cost achievable in Phase II, performance estimates for the Phase II facility, estimates of the future cost of electric energy with a central, and receiver design solar powered deep well irrigation facility.

3.2 COST ESTIMATES

Cost estimates on presented in terms of the estimating procedures used, the baseline cost estimate, and cost modifications.

3.2.1 Estimating Procedure

The cost estimates presented herein are based upon the following:

(1) Costs are for a facility to be located on the Dalton Cole farm, Coolidge, Arizona, with no cost for land included.

(2) Equipment costs shown are total installed costs.

(3) Costs summarized are escalated in accordance with the Phase II project schedule for operation January 1, 1979.

(4) Each line item is based on current design information. Some items are based on vendor quotations that have been checked against costs for similar items from recent Black & Veatch projects; other items are based on recently contracted costs. The price basis varies throughout the estimate.

(5) Labor costs are based on recently experienced manhour data. The wage rates used for the estimate are for the Phoenix, Arizona area.

(6) A contingency allowance of 5 per cent is included. A diligent effort has been exercised to include a cost for all items of facility design, to price each item according to the best available design information, and to obtain a realistic price for all items.

Adherence to this procedure eliminates the need for a high contingency figure. No other adjustment factors or hidden contingency costs are included in the estimate.

The methodology used to prepare the estimate is characterized by the following:

(1) Current design data for all items to be estimated are obtained.

(2) Quantity takeoffs are prepared from the design data, as required, to estimate costs. A master list of plant components (punch list) provides the means to eliminate omissions.

(3) All takeoffs, unit prices, price projections, and mathematical manipulations, such as escalating July 1, 1977 costs to incurred cost on dates as needed for January 1, 1979 operation, are carefully checked.

3.2.2 Baseline Costs

A cost estimate has been made on the preliminary design prepared in Phase I and described in Section 2 of Volume II. This cost estimate is referred to as the baseline cost estimate as some modified cost estimates were made using this as a baseline. The baseline cost estimate is summarized in Table 3-1.

3.2.3 Cost Modifications

Table 3-2 presents cost modifications requested by ERDA. For clarity, the format of the original cost breakdown is followed. The baseline costs are listed in the center column. From the baseline costs were subtracted those costs peculiar to the first unit and those costs associated with the operations and test program. The remainder was characterized as recurring costs. The left column presents only the recurring costs as they were reported at the oral presentation. The right column reflects costs reductions which may be achievable in Phase II detailed design. In each case, Black & Veatch's fixed fee for the CPFF contract extension covering Phase II effort is not included. Black & Veatch has taken a conservative position in presenting the baseline and modified costs.

TABLE 3-1. PRELIMINARY COST ESTIMATE SUMMARY FOR PHASE II

CBS	Element Description	Escalated Costs for Jan. 1, 1979 Comm. Oper. ($1,000)		
		Level 2	Level 1	Level 0
	Total Power Plant			4,080
4100	Yard Work		41	
4103	EGS Building		15	
4104	Circulating Water Intake Structure		3	
4105	Tower Foundation & Steam Generation Pit		35	
4190	Solar Plant Equipment		3,141	
4190.1	Collector Equipment	2,414		
4190.2	Receiver & Tower Unit	174		
4190.3	Thermal Storage	502		
4190.4	Steam Generator	51		
4300	Turbine Plant Equipment		338	
4300.1	Turbine Generator	146		
4300.2	Turbine Installation	21		
4300.3	Heat Rejection System	37		
4300.4	Condensing Systems	44		
4300.5	Feedwater Heating Systems	75		
4300.6	Water Treatment & Storage Tanks	15		
4401	Electric Plant Equipment		54	
4402	Plant Master Control Equipment		92	
4500	Miscellaneous Plant Equipment		36	
8000	Distributables		131	
8300	Contingency at 5 Per Cent		194	

TABLE 3-2. COST MODIFICATONS (All costs shown are in thousands of dollars.)

CBS[a]	Element Description	Baseline Design: Recurring Cost Only	Baseline Design: Total Costs	Modified Design: Total Costs
4190.1	Collector System	2,709[b]	3,008	2,845[e]
4190.3	Thermal Storage	502	502	345
4190.31	Thermal Storage Tanks	249	249	171[f]
4190.32	Piping	49	49	49
4190.33	Salt Material	119	119	82[f]
4190.34	Salt Pumps	85	85	43[g]
4300.1	Turbine Generator	131[c]	146	146
4500.1	Meteorological Station	2[d]	12	12
	Subtotal	3,344	3,668	3,348
	Balance of Plant	218	218	218
		3,562	3,886	3,566
	Contingency 5%	178	194	178
	Total Plant Cost[h]	3,740	4,080	3,744
	Engineering Services Without Fee	422	755	755
	Total Cost Without Fee	4,162	4,835	4,499

[a] CBS = Cost Breakdown Structure.

[b] $299,000 nonrecurring cost per Martin Marietta Corporation.

[c] $15,000 nonrecurring cost per Terry Corporation.

[d] $10,000 nonrecurring cost only anemometer needed.

[e] 90 Keliostats equivalent to 91% reflectivity and 4,000 M^2 area @ 75% reflectivity.

[f] 11 MWH Thermal storage as 16 MWH Baseline design.

[g] Redundant pumps for HTS deleted.

[h] Total Plant Cost excludes prime contractor, construction management, office and field engineering and the 9 month test program costs.

3.3 PHASE II FACILITY PERFORMANCE AND COST EVALUATION

Phase II facility performance and cost evaluation is discussed for facility size and operating strategy, facility performance, baseline facility energy cost, and re-evaluation.

3.3.1 Facility Size and Operating Strategy

Two items must be known before the facility performance and cost can be evaluated. These items are (1) definition of the facility size, and (2) definition of the facility operating strategy. The minimum facility size is determined by generating capacity of 150 kWe net electrical output at noon June 21 when the direct normal insolation is 600 watts per square meter. This criterion requires approximately 2,500 square meters of collector area. The maximum size criterion is related to a maximum of 3,600 kilowatt-hours on the peak demand day.

Further, all energy produced by a facility has uniform value, i.e. electric energy could, in effect, be "stored" in the utility grid. Thus, solar-generated energy supplied does not need to match the irrigation demand, evaluation is based on the cost of electricity generated.

Detailed cost studies using the above criterion showed water storage is not economical. These studies also showed that it is more economical to install a control system which provides completely automatic start-up and shutdown than it is to employ coasting or to hire manpower for manual start-up. Coasting refers to the operation of the electrical generation system when it produces just enough power to supply internal facility requirements (no net electrical output).

The facility operating strategy is established as follows.

(1) The Collector and Receiver Systems are in operation whenever adequate insolation is available and the system has the capacity to accept the solar power.

(2) The Electrical Generation System automatically starts when hot thermal storage reaches a pre-defined level.

(3) Enough water to cool the condenser is pumped at all times while the Electrical Generation System is in operation.

(4) The Electrical Generation System continues to operate until thermal storage is depleted to a preset level.

(5) The utility grid supplies energy for auxiliary equipment for start-up, for shutdown and for periods when the electrical generation system is not operating.

3.3.2 Facility Performance

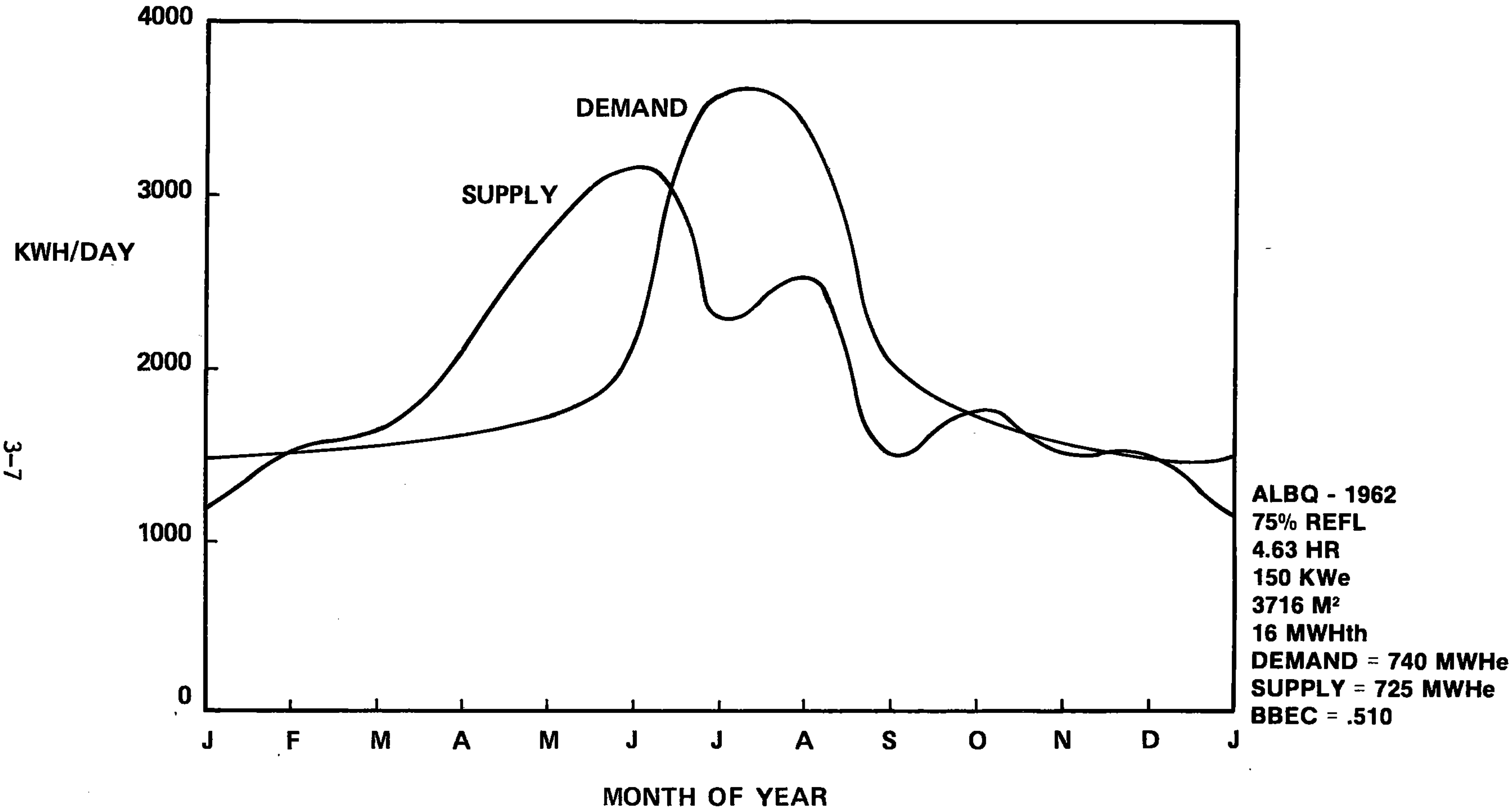
ERDA specified that the design be evaluated using 100 per cent and 90 per cent of the insolation levels contained in the 1962 Albuquerque weather tape. The Facility Performance Program (FPP) simulation for the baseline facility using these data yields the supply-demand curve of Figure 3-1. Results of another simulation, using "adjusted" mean daily direct normal insolation to match the monthly mean values reported by Sandia publication SAND 76-0411 for Phoenix, Arizona, is shown in Figure 3-2. The smoother supply curve based on adjusted mean insolation has 8.5 per cent higher annual solar-generated energy than that obtained using the unadjusted 1962 Albuquerque data. This method of adjustment yields results nearer to the average annual energy expected from the facility in Coolidge.

3.3.3 Baseline Facility Energy Cost

ERDA directed that the facility be sized such that the incremental cost of energy equals the cost of utility supplied energy on a levelized annual cost basis. In order to determine the appropriate facility size, the combinations of storage capacity and collector area of the system having the incremental levelized busbar energy costs matching utility values had to be identified.

Figure 3-3 presents the marginal energy cost for combinations of heliostat area and storage capacity. The facility size is determined when the marginal cost equals the utility grid cost. This facility, with 4,000 square meters of collector area and 11 megawatt-hours (thermal) storage capacity, is used in the remainder of the evaluation. The cost differential between the baseline plant (3720 M^2 heliostats and 16 MWH storage) and this optimal facility is less than $600.

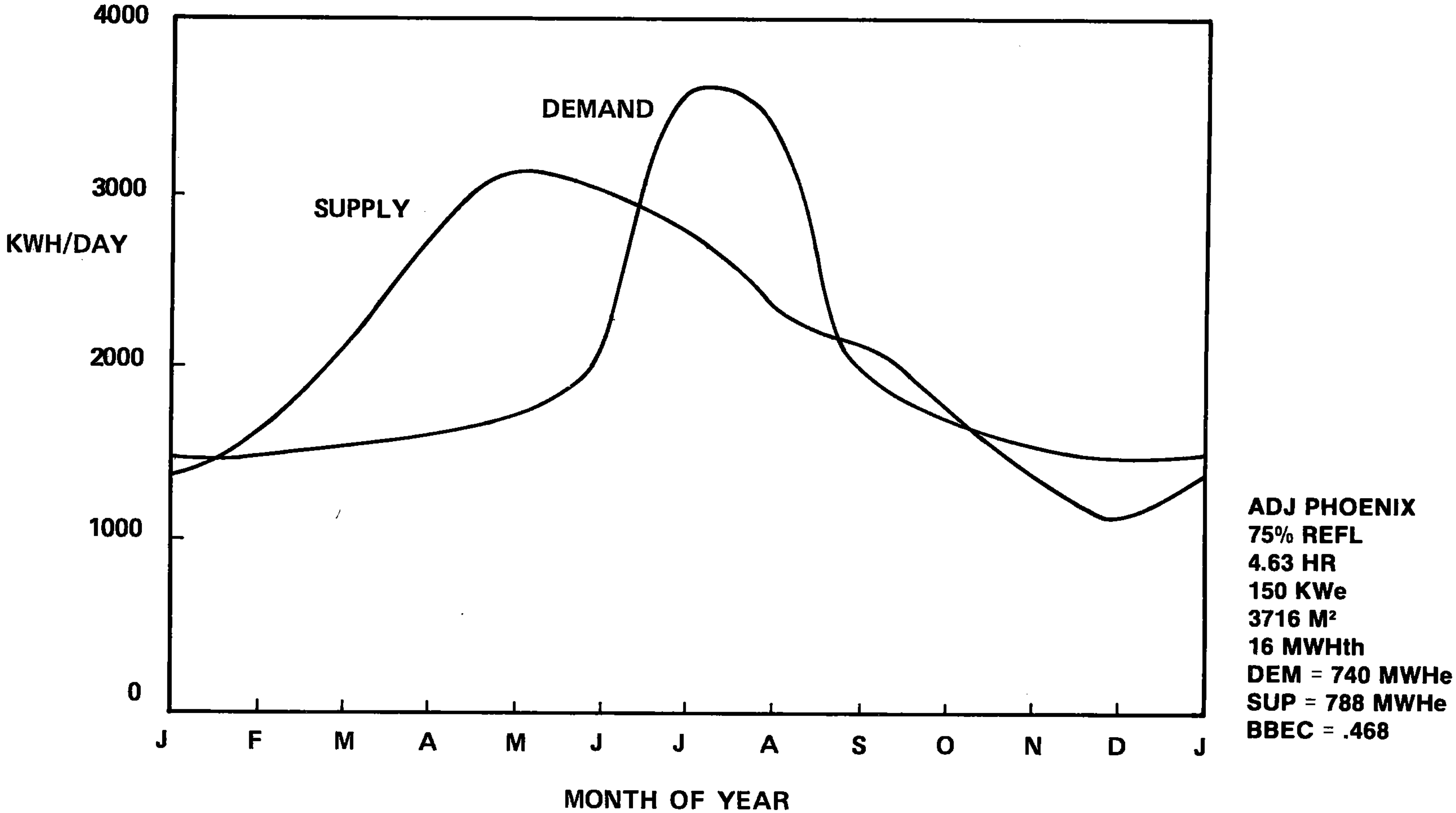
Figure 3-4 shows the supply-demand curve for a facility with 4,000 square meters of collector area. The annual energy of 820 megawatt-hours



SUPPLY AND DEMAND

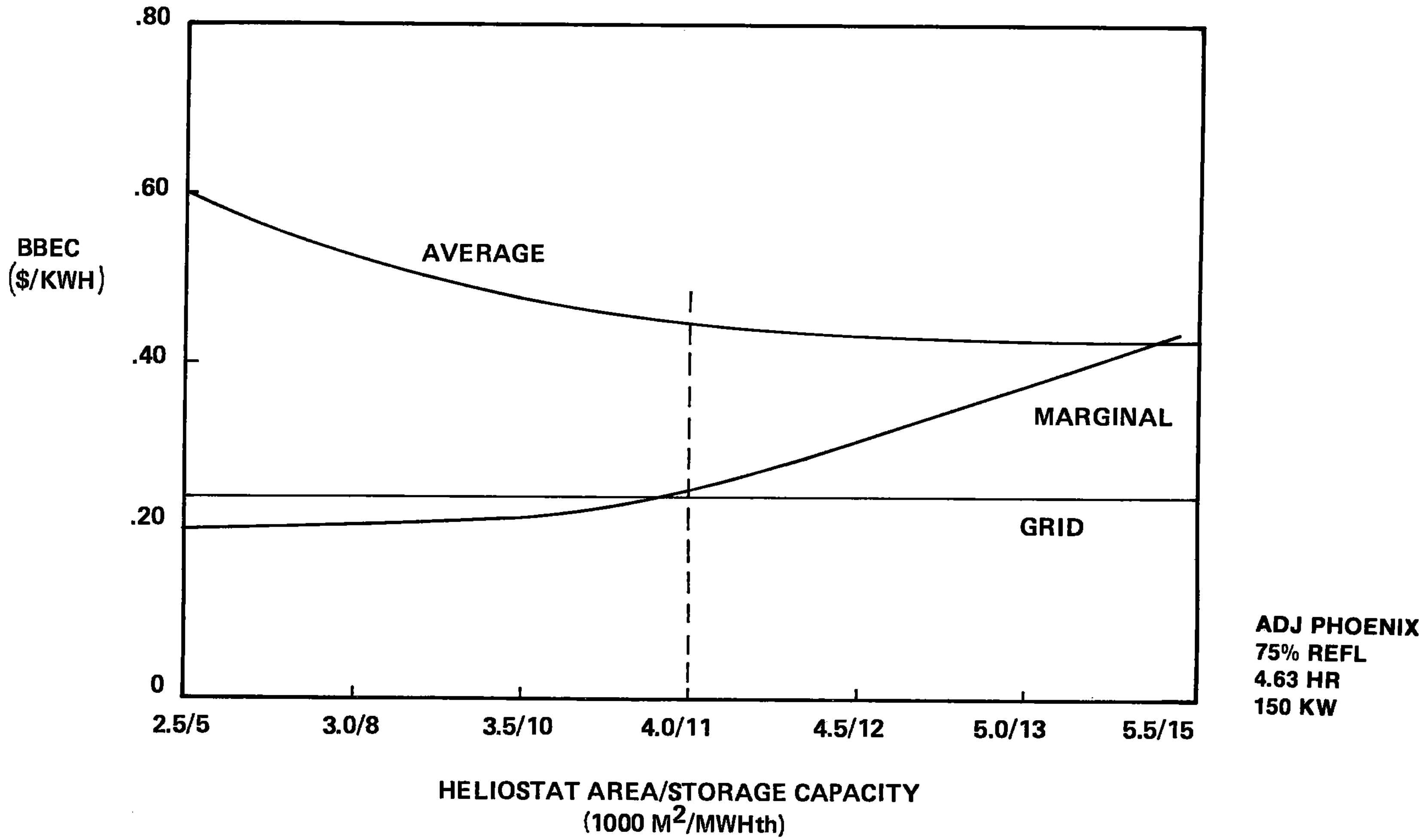
ALBUQUERQUE UNADJUSTED

FIGURE 3-1



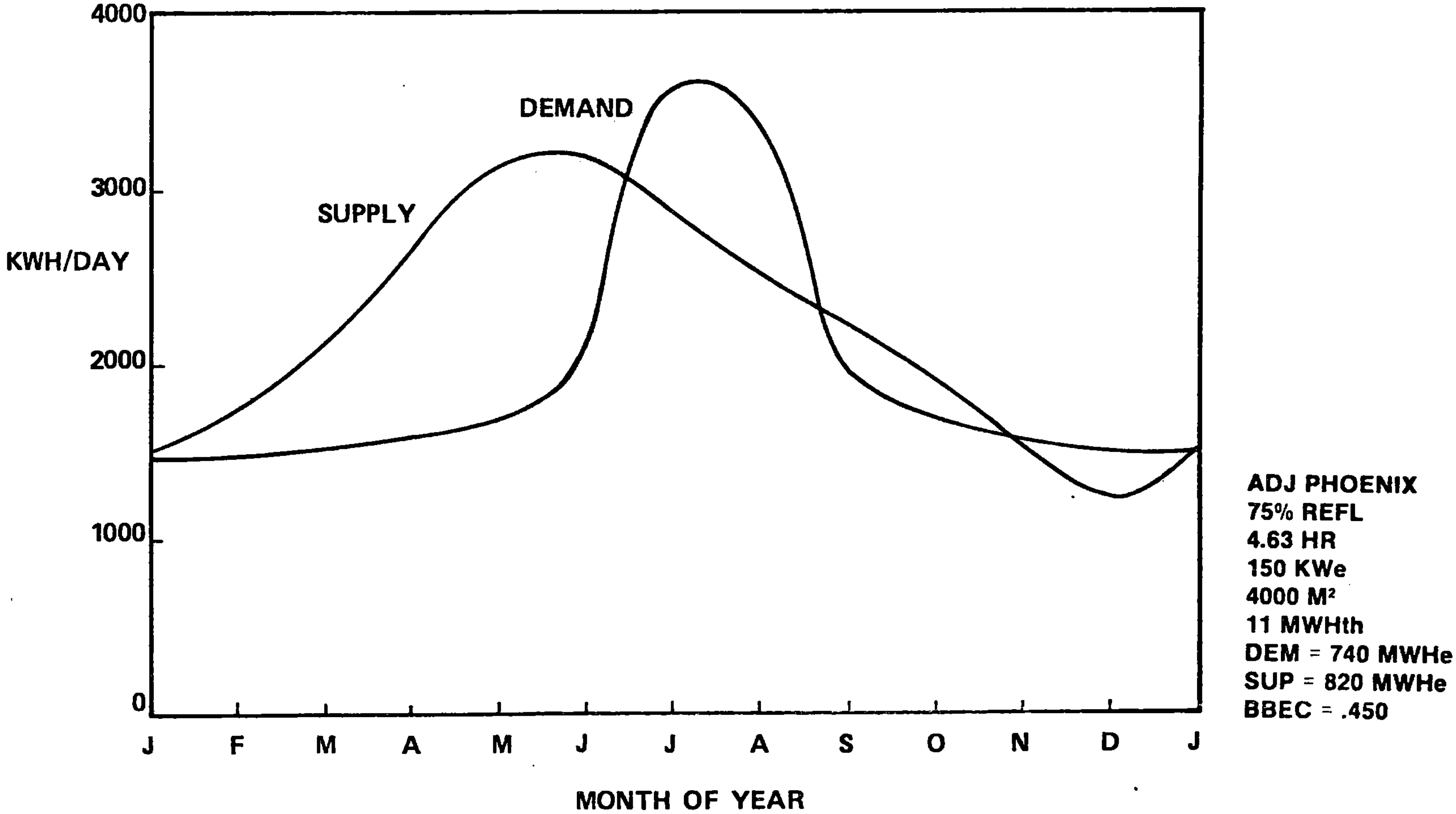
SUPPLY AND DEMAND PHOENIX ADJUSTED

FIGURE 3-2



BUSBAR ENERGY COST VS PLANT SIZE

FIGURE 3-3



SUPPLY AND DEMAND
4000 M^2 OF COLLECTOR AREA
FIGURE 3-4

electric exceeds the baseline plant by 4 per cent and exceeds the demand by 11 per cent. The levelized busbar energy cost of this plant is $0.450 per kilowatt-hour (1978 dollars) compared with $0.468 per kilowatt-hour for the baseline plant.

3.3.4 Re-evaluation

Since most of the equipment in the baseline facility is used below its designed capacity, the power rating of the facility could be increased with negligible increases in cost. A simulation of facility performance based on 200 kWe net output shows that the busbar energy cost could be reduced to $0.394 kWh (1978 dollars). This amounts to a 12 per cent reduction in energy cost compared to that of a facility designed for 150 kWe net output. The 200 kWe facility does have a greater capital cost, however, as it contains 5000 square meters of heliostats and 14 MWH of thermal storage capacity.

Black & Veatch developed the 150 kWe baseline facility on the basis of a very conservative design philosophy. The baseline design does permit additional perturbations on the design elements which may lead to lower levelized busbar energy costs. These variations, will be examined in the Phase II program.

3.4 FUTURE PLANT PERFORMANCE AND COST EVALUATION

Future plant performance and cost evaluation is presented as performance projections, cost projections, production schedule, and performance and cost analyses.

3.4.1 Performance Projections

Two areas stand out as having potential for future performance improvements: the heliostat reflectivity and the prime mover efficiency. Martin Marietta projects that with low-iron (0.05 per cent) glass, they can achieve reflectivities of 91 per cent, a 20 per cent improvement over the 75 per cent reflectivity they guarantee as available for the experimental facility.

A turbine heat rate of 3.7 kWt per kWe should be achievable for a turbine designed specifically for this solar application. Such a heat rate is a 25 per cent improvement over the 4.63 value used in the Phase II facility but still does not meet the heat rate that is currently attained in larger turbines. Multivane expanders have demonstrated that heat rates below 3.7 kWt per kWe are possible for small machines. Another prime mover considered for possible use with central receiver systems is the Sterling engine, which has also demonstrated remarkable efficiencies in small applications.*

A heat rate of 3.7 kilowatt thermal per kilowatt electric and a reflectivity of 91 per cent are used in the performance analyses of future (production) plants which follow.

3.4.2 Cost Projections

Two methods are employed to establish cost projections: manufacturer contact and learning curve.

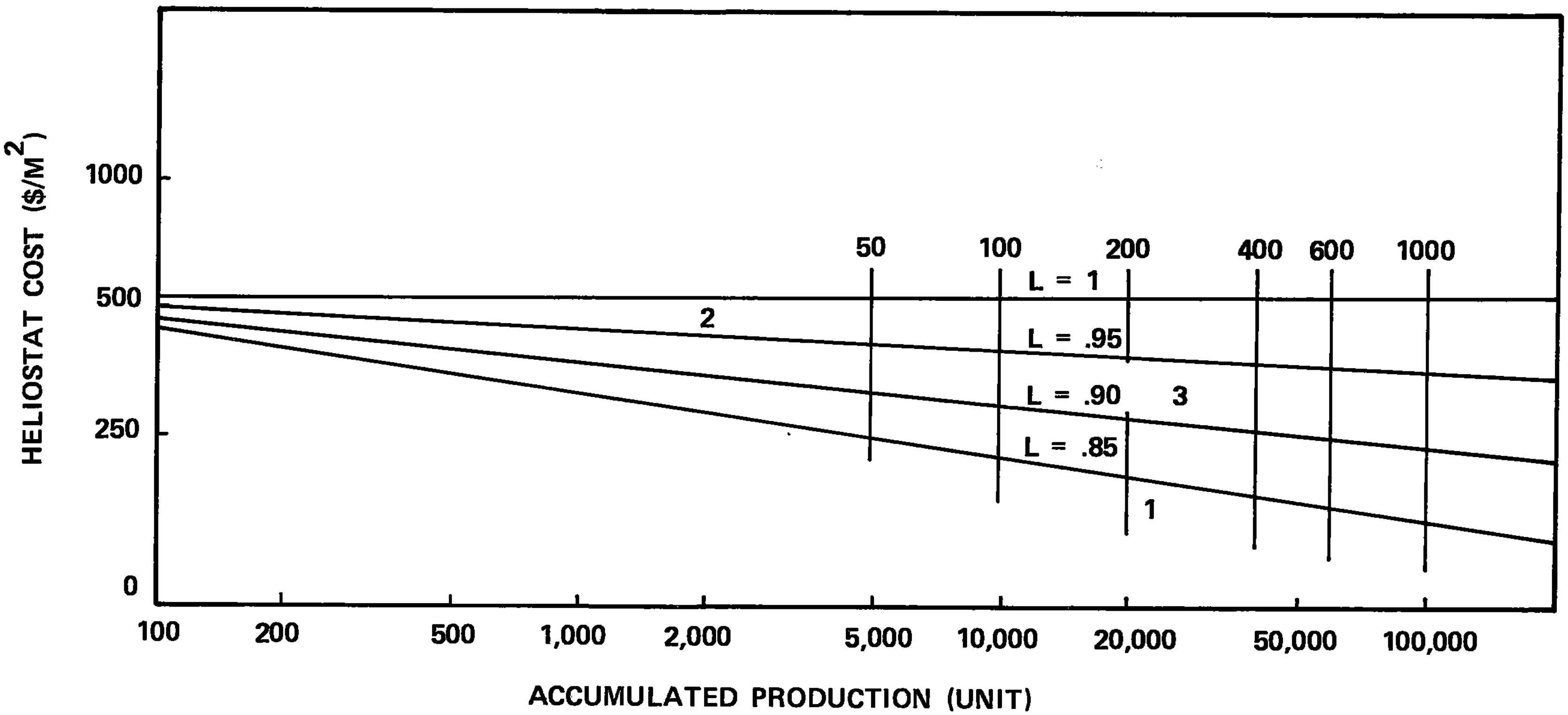
The manufacturers of the larger facility components, with the exception of heliostats, were contacted and asked to evaluate large production runs and to estimate the associated future cost reductions. Their estimates are summarized in Table 3-3.

TABLE 3-3. MANUFACTURER-ESTIMATED COST REDUCTIONS FOR "PRODUCTION" UNITS

Component	Cost Reduction from Baseline Cost
Prime Mover	35%
Receiver	17%
Steam Generator	10%
Storage Tanks	7%
Heat Transfer Salt	23%

To project the cost of heliostats, a widely accepted technique known as the learning curve was utilized. Four learning curves are shown in Figure 3-5. With L=1, no price reduction is projected; as L decreases in magnitude to 0.95, 0.90, and 0.85, the projected cost per square meter of

*ERG, Inc. is projecting heat rates of 2.0 for 1,400 F hydrogen as a working fluid.



(1) MARTIN MARIETTA - COMMERCIAL ($176./M^2)
(2) HONEYWELL - PILOT PLANT (487./m^2)
(3) HONEYWELL - COMMERCIAL (340./M^2

FUTURE FACILITY COST PROJECTION
OF HELIOSTAT COST BY
LEARNING CURVE ACCUMULATED FACILITIES

FIGURE 3-5

heliostat drops correspondingly. The points numbered 1, 2, and 3 on the figure were obtained from heliostat manufacturers and represent their estimates of the future cost of heliostats.

In the analyses that follow, the 0.95 learning curve is utilized.

3.4.3 Production Schedule

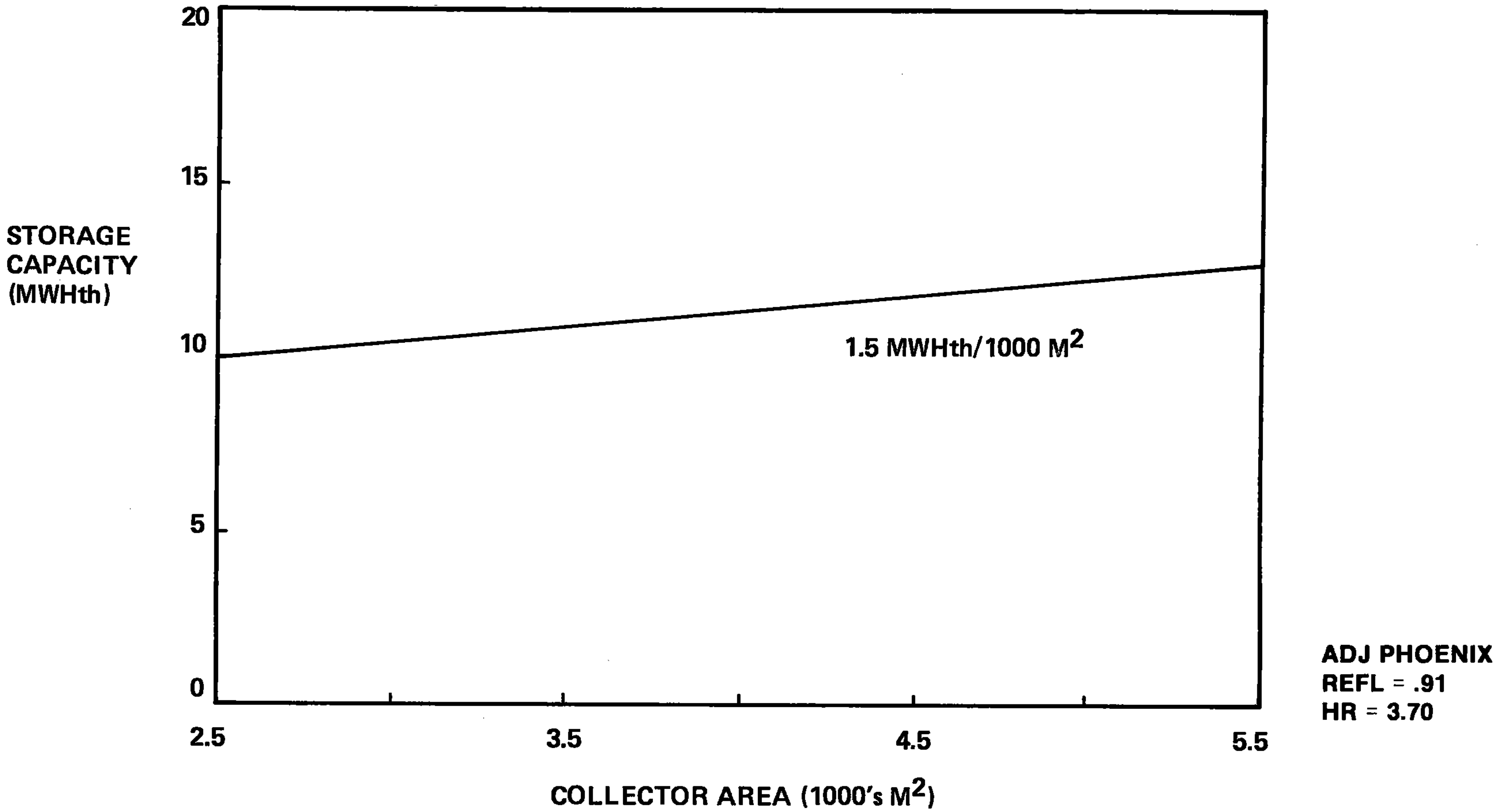
A production schedule must be assumed to analyze performance and busbar energy cost for time points in the future. The production schedule that was assumed has the first fifty solar powered irrigation facilities produced in 1982 and a growth rate of 50 per cent per year. Based on these assumptions, the 1000th facility would be built in 1987.

3.4.4 Performance and Cost Analyses

The baseline design provides a reference for evaluating design modifications and their associated cost modifications. The annual performance was computed for facilities with varying storage capacity, collector area, and plant power rating. The results provided in Figure 3-6 show the relationship between optimum storage size and collector area. Parametric analysis showed this relationship is insensitive to the year of commercialization, learning curve value and the facility power rating.

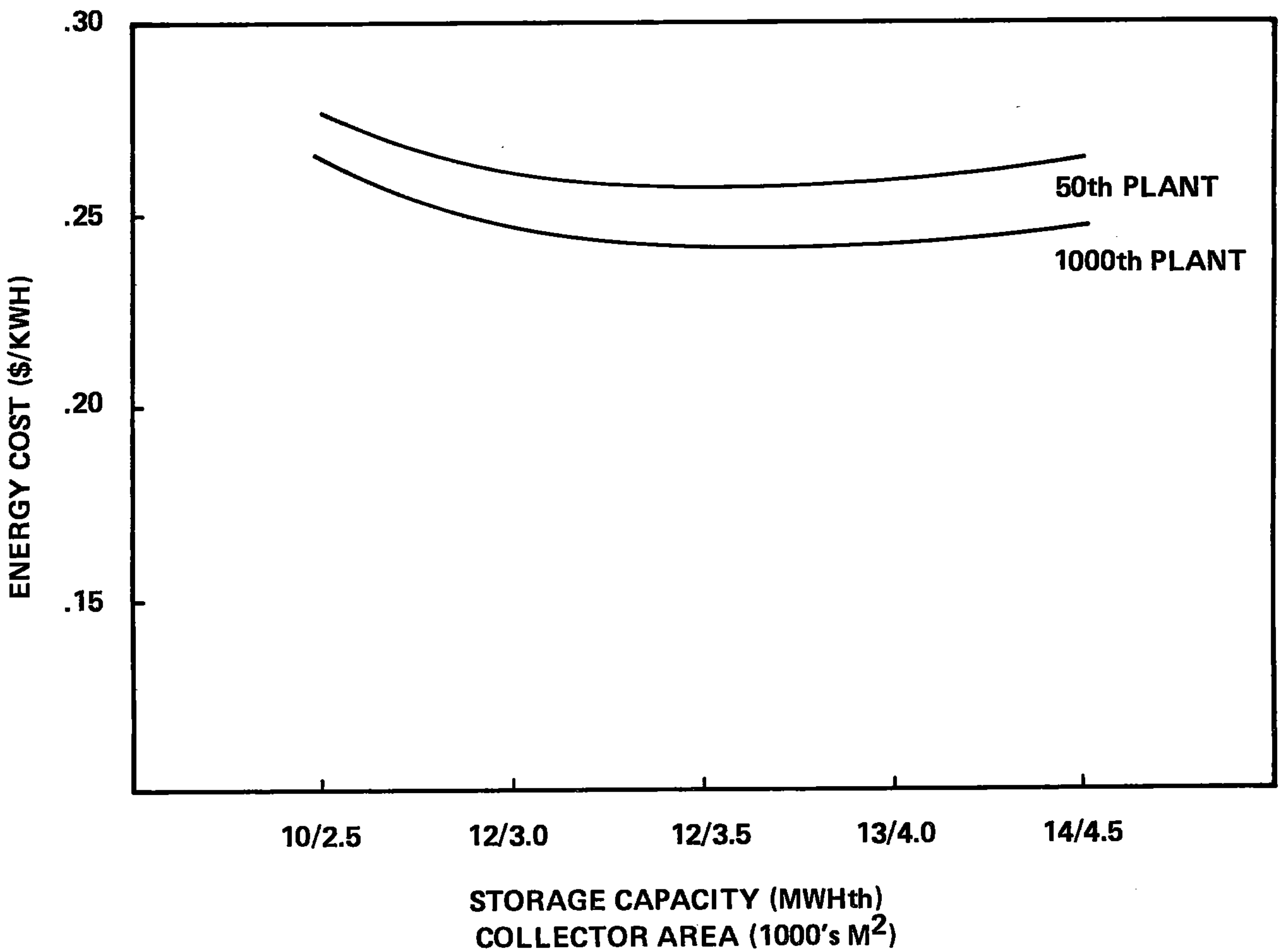
Levelized busbar energy cost for (L = 0.95) is plotted against collector area (with corresponding optimum storage size) for the 150 kWe plant (Figure 3-7). The levelized busbar energy costs for the 50th facility, produced in 1982, and the 1000th facility, produced in 1987 show that optimum facility size is insensitive to year of commercialization. The optimum 150 kWe facility, when compared to the optimum experimental facility has significantly smaller heliostat mirror area (3,500 square meters), has a much lower busbar energy cost, ($0.257 per kilowatt-hour), and produces more of the annual irrigation energy demand (134 per cent).

Figure 3-8 compares the effects that different learning curve assumptions have on the economical evaluation. The levelized busbar energy cost is plotted for the 50th, 100th, 200th, 400th, 600th, and 1000th solar powered irrigation facility, assuming learning curves of L = 1.0, 0.95, 0.90, and 0.85. With no heliostat price reduction whatsoever, i.e., L = 1.0, the facilities become economical with the 200th unit, produced



FUTURE FACILITY OPTIMUM STORAGE
CAPACITY VS COLLECTOR AREA

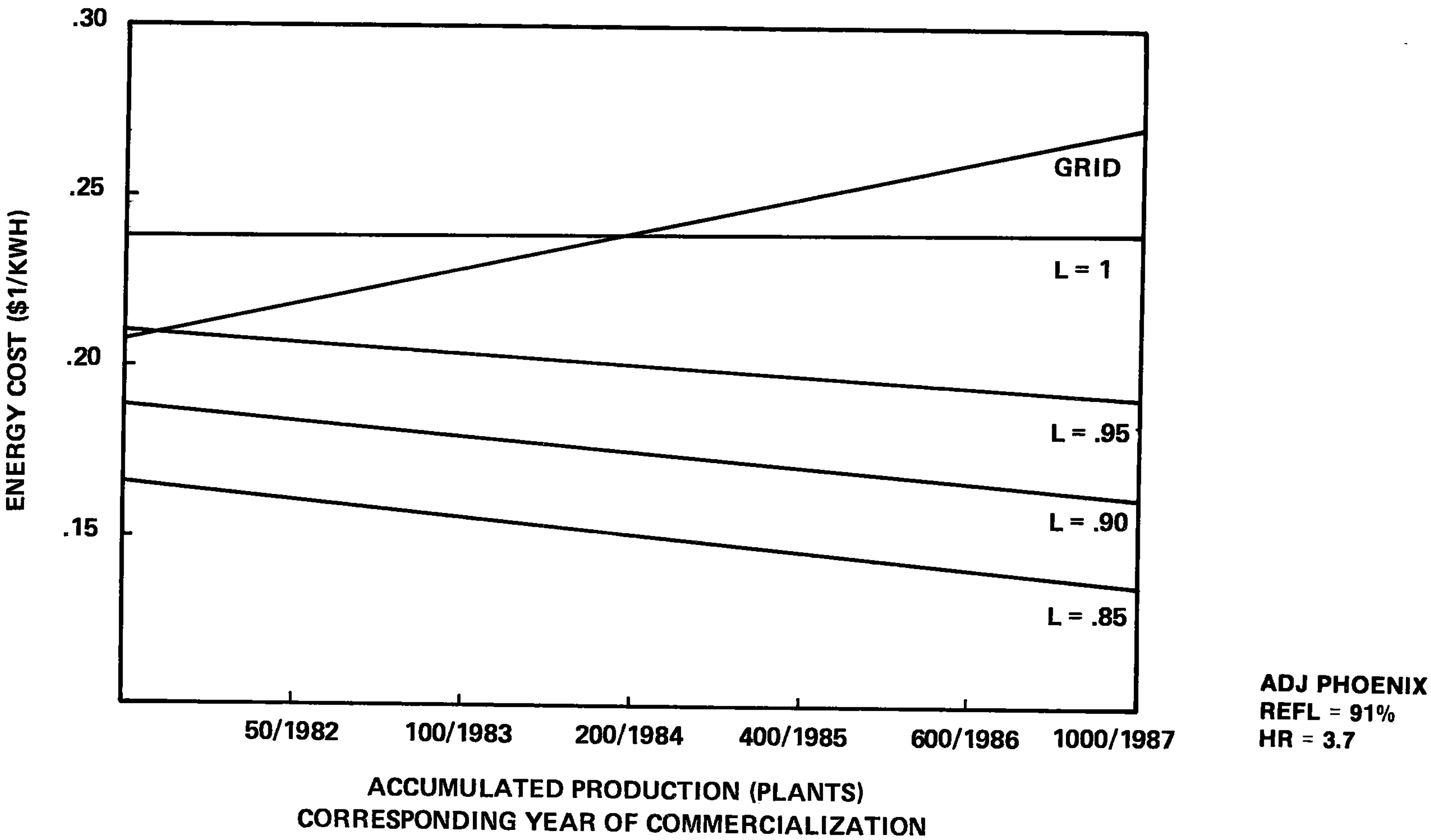
FIGURE 3-6



ADJ PHOENIX
REFL = 91%
HR = 3.7
L = .95

FUTURE FACILITY LEVELIZED BUSBAR
ENERGY COST VS COLLECTOR STORAGE
SIZE 150 KWe RATING

FIGURE 3-7



FUTURE FACILITY LEVELIZED BUSBAR ENERGY COST
OF OPTIMUM FACILITY VS TIME 150 KWe RATING

FIGURE 3-8

in 1984. With lower learning curves, facilities are economical when they are produced.

For a 200 kWe "rated" facility the optimum facility has 4,500 square meters of heliostats and 14 megawatt-hours of thermal storage capacity. Accepting the conservative L = 0.95 learning curve the levelized busbar energy cost of the 50th plant is $0.225 per kilowatt-hour, well below projected utility grid costs.

PHASE II PLAN

VOLUME I

4.0 PHASE II PROGRAM PLAN

4.1 GENERAL

Phase I of the 150 kWe Solar Powered Deep Well Irrigation Facility, Preliminary Design Studies requires presentation of a program plan for the execution of Phase II: development of the detailed design, construction of the facility, and operation and evaluation of the facility for a nine month period. The program plan developed by Black & Veatch, summarized in this section, is discussed in detail in Volume II, Section 3, Program Plan for Phase II.

4.2 BASIC APPROACH

The basic approach employed to develop the plan is the same as is used in all Black & Veatch projects. The project goals, the client's needs and Black & Veatch's competence form the basis for delineations of responsibilities between the client and Black & Veatch. The ERDA goal is to have an experimental 150 kWe Solar Powered Deep Well Irrigation Facility designed, constructed and operated as part of the overall ERDA/DSE Solar irrigation program. ERDA prefers to have the facility delivered as an operating unit. Black & Veatch desires to be fully responsive to this need. Black & Veatch has the engineering resources needed and will assume full responsibility for the design, procurement and construction of the plant.

The plan will integrate the engineering, procurement and construction activities. These activities are divided into project management; engineering assignments; procurement packages, including specifications for the construction contracts involved; and field construction management, field engineering and inspection. The engineering will be performed in the office to the greatest extent possible to minimize the costs and inefficiencies associated with "designing-in-the-field".

B&V will continue its responsiveness to ERDA's requirements and formalize the basic relationships by preparing procedures applying to the project.

4.3 FUNCTIONS DESCRIBED IN THE PLAN

In Volume II there is a discussion of the master work plan for the project and how resources will be assigned to carry out that plan. A project organization is defined (see Figure 4-1).

The means for carrying out cost control are defined in the plan. Prospective cost control will use both continuously updated cost estimates and comparisons of actual expenditure rates to planned expenditure rates. Retrospective cost control comparing actual expenditures to planned expenditures also will be used.

A section on schedule control discusses the computerized Critical Path Method schedules and how they are amended as to maintain the critical milestone dates. The section on scheduling in Volume II contains excerpts of the master schedule for key items. (See Figure 4-2, Schedule for Major Components.)

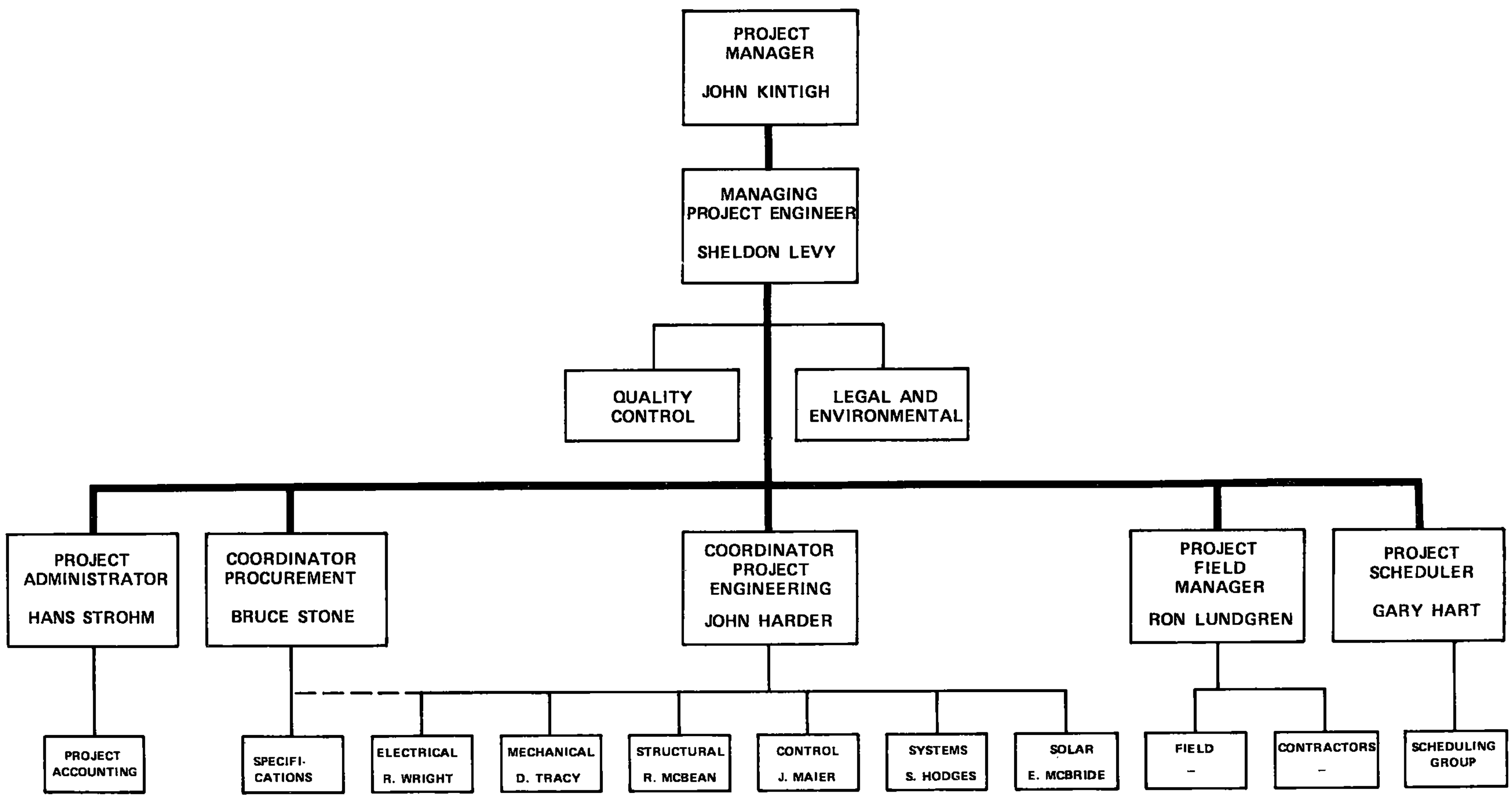
The Quality Assurance program emphasizes how the Quality Assurance program is tailored to the project requirements. A point of departure for this tailoring is Black & Veatch developed procedures for fossil fuel power plant projects.

The engineering function of the plan describes optimization studies, design guidance documentation, detailed design, Engineering Drawings, review of manufacturer's drawings, and conforming engineering drawings to construction records. Examples are given of such work. Detailed engineering procedures to guide the execution of this work are part of Black & Veatch's Engineering System.

The procurement portion of the plan contains a list of long lead time items, a preliminary list of procurement packages, and a proposed list of sole source procurement items. A manufacturing plan is provided for the heliostats as well as a list of Government Furnished Equipment (GFE) needed for the assembly of the heliostats.

Another major section of the plan deals with construction. The plan describes how Black & Veatch will provide Construction Management and Field Engineering work. A schedule for construction is shown in Figure 4-3. Also shown on the same figure is a schedule for the assigment of field engineers.

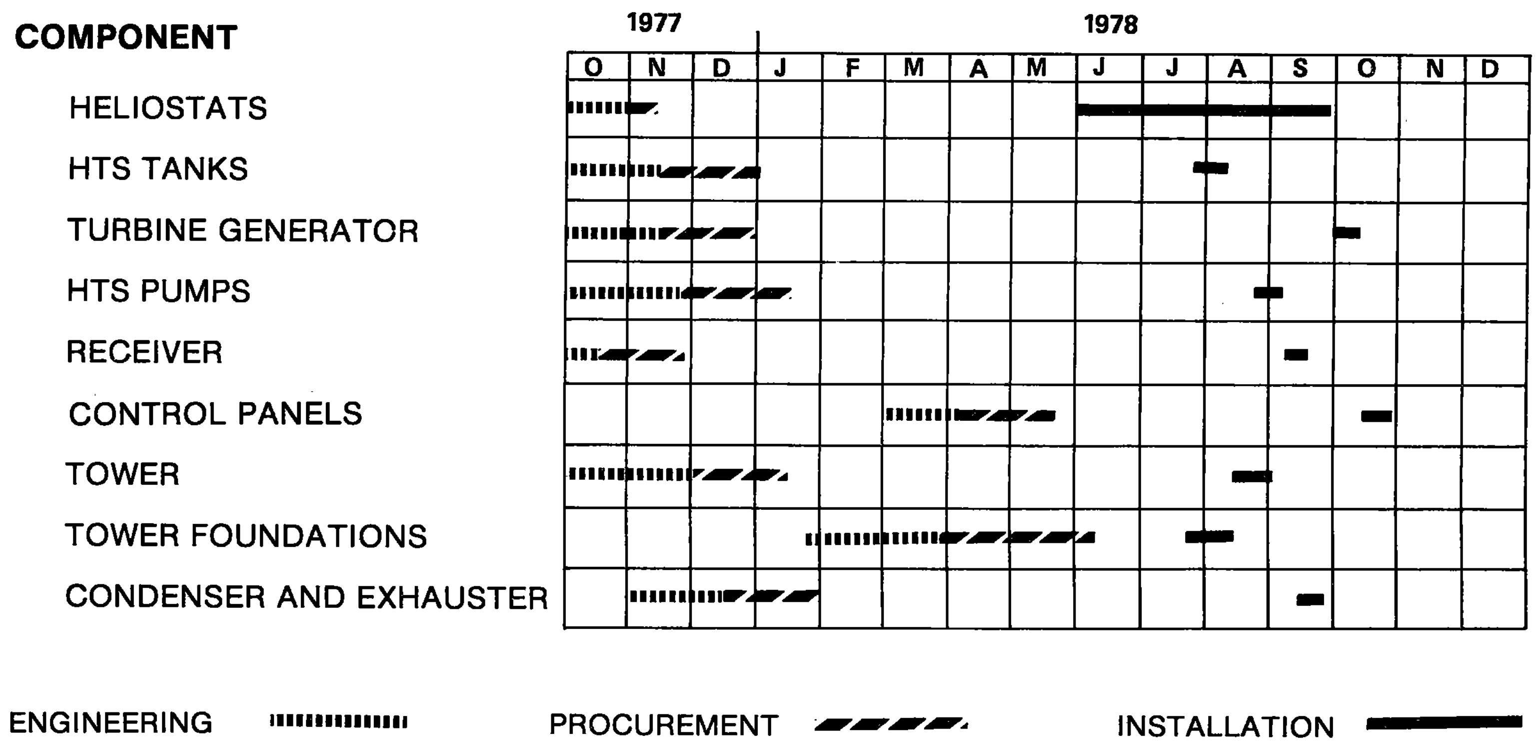
ORGANIZATION CHART



ORGANIZATION CHART

FIGURE 4-1

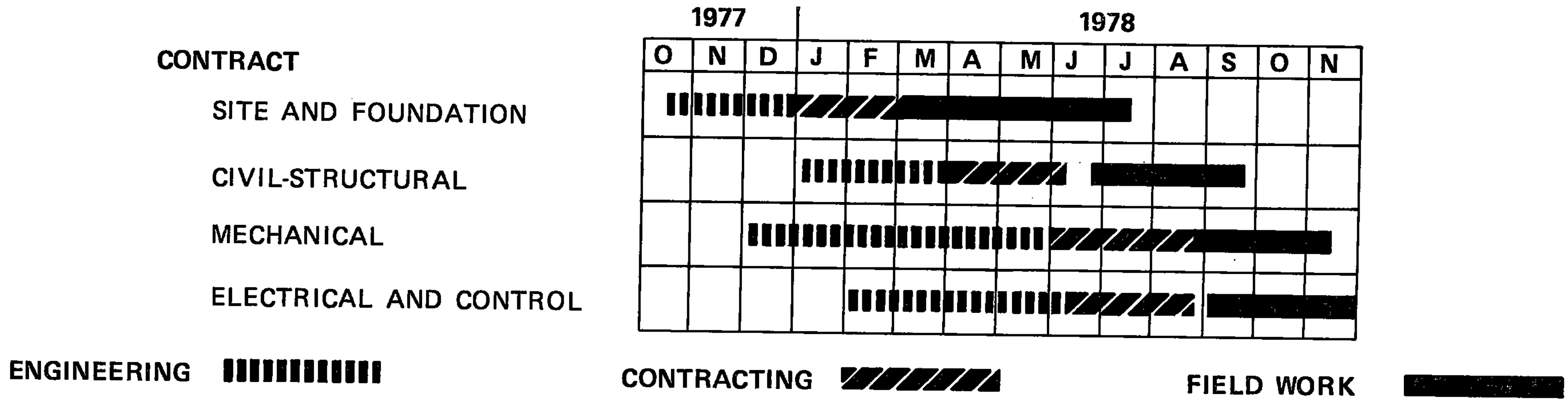
SCHEDULE FOR MAJOR COMPONENTS



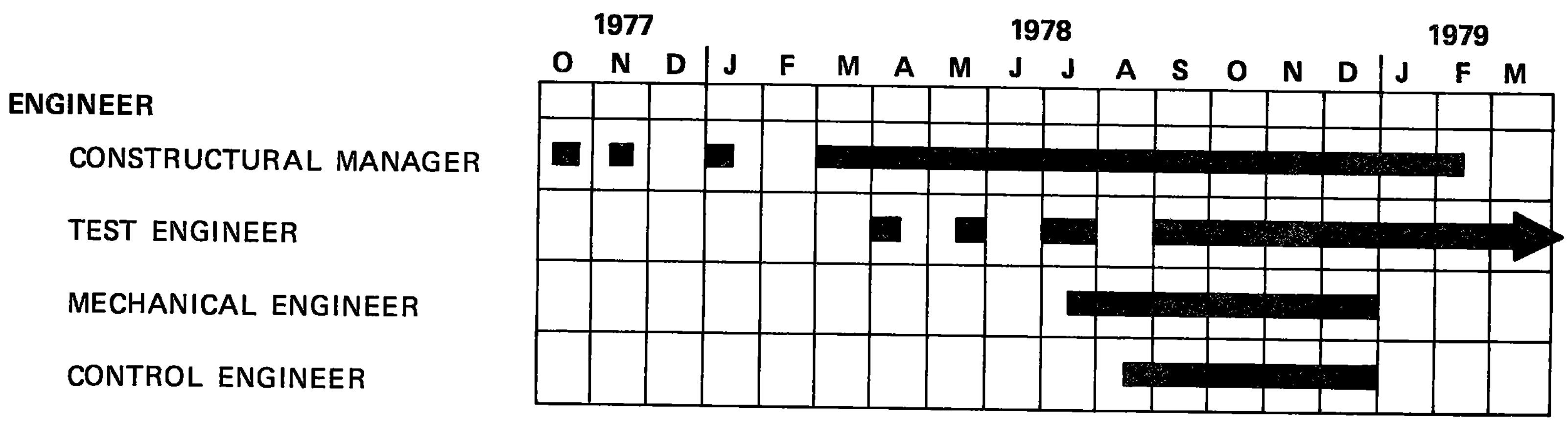
SCHEDULE FOR MAJOR COMPONENTS

FIGURE 4-2

ON-SITE CONSTRUCTION AND EQUIPMENT INSTALLATION



FIELD ENGINEER ASSIGNMENT SCHEDULE



SCHEDULE FOR CONSTRUCTION

FIGURE 4-3

The plan for Facility Checkout actually begins with the shop testing of key components at the manufacturer's shop. The testing continues on the construction site with the construction testing of equipment, then testing subsystems in preoperational tests and finally the initial operational testing of the entire facility. Once the facility has been checked out, the plan further provides for the nine month period of operation and testing to evaluate performance, viability, and develop insight for operating a solar powered deep well irrigation system. The detailed definition of the tests and test procedures are part of the Phase II work effort.

4.4 EXPERIENCE

Black & Veatch offers ERDA for the Phase II program expertise and practical experience in designing power plants. This experience includes coal, gas, and oil fired power plants, and nuclear power plants. Black & Veatch also has extensive solar energy experience, particularly on solar thermal central reciever systems.

In addition to its design competence, Black & Veatch offers and provides many other services for its clients pertinent to the Phase II program. These services include procurement, construction management, field engineering, and plant checkout and testing.

As power plants have grown larger, more complex, and sophisticated their control systems have become more important. The fully automatic operation of the Black & Veatch design for Phase II will use a direct digital control system. Black & Veatch pioneered the use of direct digital control systems in coal fired power plants.

The experience of Black & Veatch combined with the experience of the manufacturers proposed for Phase II provides ERDA with the necessary resources for successful implementation of the program. Martin Marrieta Corporation is currently the most experienced heliostat builder in the United States. The Terry Corporation is a well known and accepted builder of steam turbines in the size range specified. The Bethlehem Corporation is an acknowledged leader in the design and building of Heat Transfer Salt (HTS) systems. Lawrence Pump Company equipment has attained industry-wide acceptance in pumping application for HTS systems. A combination of Black & Veatch engineering, a simple design concept, proven components, experienced manufacturers and the project management of Black & Veatch to execute a well thought out plan will yield a successful and timely completion of the 150 kWe Solar Powered Deep Well Irrigation Facility.

RECOMMENDED ACTION

VOLUME I

5.0 RECOMMENDED ACTION

5.1 IMPORTANCE OF TIMELY ACTIONS

The ERDA/DSE Solar Irrigation Program directly recognizes the importance of agriculture and, especially, its irrigation needs within the national energy/economic milieu. The amount of energy consumed by irrigation is a significant and growing contributor to the national "energy deficit." Crops produced with the aid of irrigation are an increasingly important part of all farm sales throughout the United States. In the western states, the agriculture economy literally depends on irrigation.

The formulation of the ERDA/DES Solar Irrigation Program recognizes that agriculture exports are of the same order of magnitude, in economic terms, as petroleum imports. Irrigation, which is an important basis of the agricultural productivity that provides the export commodities, is also a significant user of energy, and thus one of the important contributors to the demand for petroleum imports. As a consequence of this interrelationship, if solar energy could be used to replace the requirement for fossil fuel energy for irrigation pumping, agricultural productivity could be sustained and the nation's international balance of payments could be improved.

It is worth noting that high insolation and large needs for irrigation go hand-in-hand. That is, those areas of the country where irrigation is practiced most extensively are areas of abundant sunshine. Thus, from a technical and economic viewpoint, the concept of solar powered irrigation is favored. It can be seen that three of the goals of the ERDA/DSE Solar Irrigation Program (1) to determine if solar energy can economically replace fossil energy for irrigation pumping, (2) to demonstrate the performance of solar powered irrigation systems, and (3) to implement the commercialization of those systems, are extremely timely.

5.2 RECOMMENDATIONS

5.2.1 ERDA Should Proceed with Phase II

The promise of solar energy has often been overstated, but the Black & Veatch Preliminary Design Studies indicate that the proposed Phase I Preliminary Design has the technical and economic potential that is necessary for commercialization.

5.2.2 The Phase II Schedule Should be Maintained

Incremental cost savings for Phase II associated with postponements for "new features" are offset by escalating costs of other equipment and may result in the loss of an entire growing season's experience. The latter item delays the potentially large savings which would occur when the significant market potential of solar powered deep well irrigation equipment is accepted by equipment manufacturers, and they respond by offering appropriately improved products.

5.2.3 ERDA Should Maintain Awareness of Central Receiver Systems

The central system, albeit presently costly because of heliostats, offers the best opportunities for the most effective conversion of the collected solar energy into mechanical (electrical) energy. Three areas that show great promise for cost reductions or greater efficiency are the learing curve cost reductions associated with heliostat production for the 10 MWe Pilot Plant, the ERDA low cost heliostat program, and the new highly efficient high temperature engines (Sterling engine with 1,400 F H_2). All of these items are specific to the central receiver type system.