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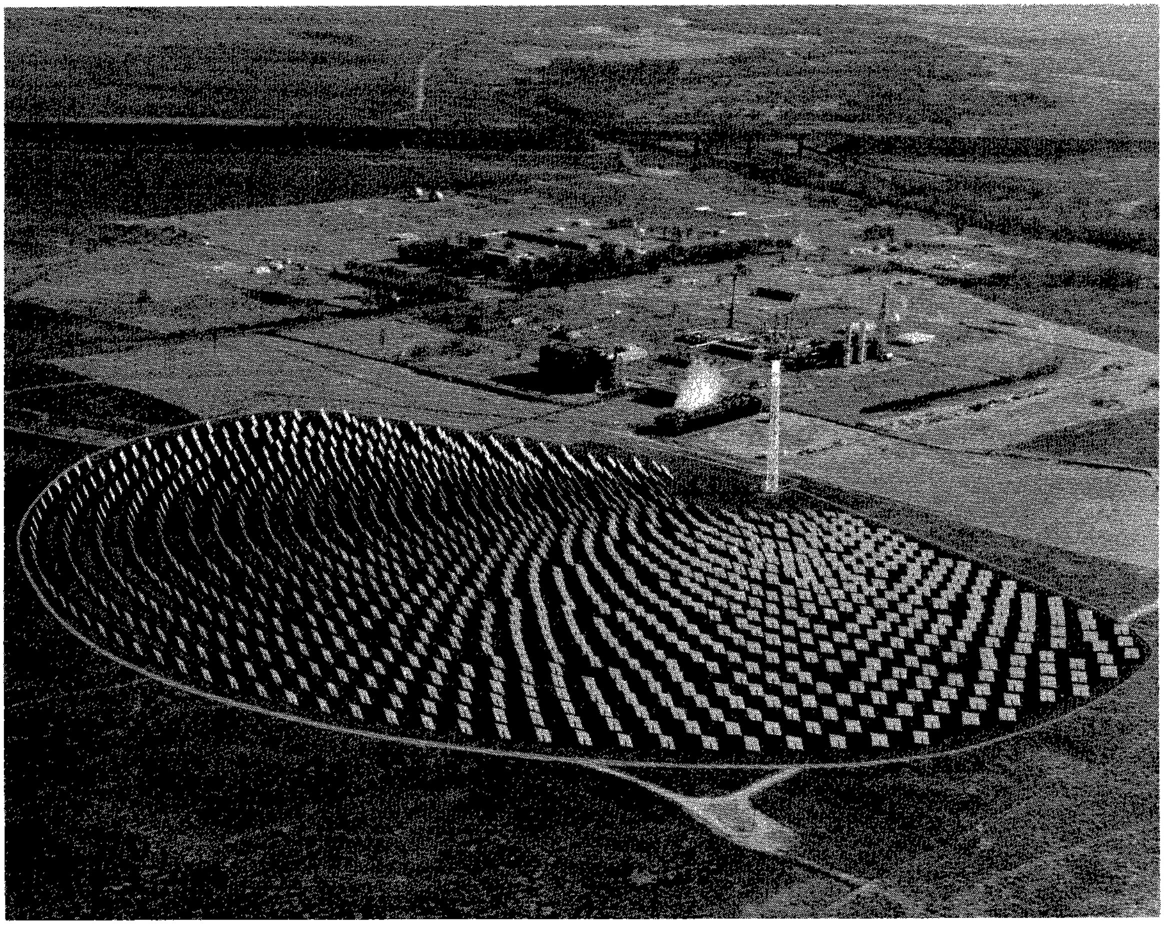
Vol 1

SOLAR COGENERATION FACILITY

CIMARRON RIVER STATION

CENTRAL TELEPHONE & UTILITIES - WESTERN POWER



EXECUTIVE SUMMARY

August 7, 1981

Black & Veatch, Consulting Engineers
Central Telephone & Utilities - Western Power
Babcock & Wilcox Company
Foxboro Company

Department of Energy

Contract No. DE-AC03-81SF 11439

DOE/SF/11439-1/1

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Prepared for

DEPARTMENT OF ENERGY
CONTRACT NO. DE-AC03-81SF 11439

by
BLACK & VEATCH, Consulting Engineers
CENTRAL TELEPHONE & UTILITIES - WESTERN POWER
BABCOCK & WILCOX COMPANY
FOXBORO COMPANY

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PREFACE

This report describes the conceptual design and evaluation of a solar facility addition to a cogeneration plant as part of the Department of Energy (DOE) Solar Cogeneration Program. The DOE San Francisco Operations Office issued Contract Number DE-AC03-81SF 11439 to Black & Veatch (B&V) for this effort, which was performed during the period November 10, 1980 to August 7, 1981. Significant contributions to the project were made by B&V's subcontractors: Central Telephone & Utilities-Western Power, the utility and site owner; the Babcock & Wilcox Company, designer of the solar receiver; and the Foxboro Company, designer of the solar master control system. B&V expresses appreciation for the guidance provided by Mr. Robert W. Hughey, Director of Solar Energy Division and Mr. Keith Rose, Program Manager for the DOE San Francisco Operations Office, and Dr. Al Baker, Technical Advisor for Sandia National Laboratories, Livermore, California.

The report is contained in three volumes: Executive Summary, Final Report and Appendices. The Executive Summary provides a brief overview of the conceptual design, a synopsis of the performance and economic evaluation, and an assessment of the concept from the site owner's perspective. The Final Report contains a more comprehensive description of the work performed on the project; this volume presents the trade studies, conceptual design, system performance, economic analysis, and development plan, as well as a description of the site test program. The Appendices consist of the System Specification and detailed cost estimate data.

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ABSTRACT

As part of their Solar Central Receiver Program, the Department of Energy (DOE) contracted with Black & Veatch (B&V) to develop and evaluate a site-specific conceptual design of a solar central receiver system integrated with an existing cogeneration facility. The cogeneration facility studied is the Central Telephone & Utilities--Western Power (CTU-WP) Cimarron River Station (CRS) located near Liberal, Kansas. The CRS generates electricity for the CTU-WP system and delivers a portion of that electricity and process steam to the National Helium Corporation natural gas processing plant, located adjacent to CRS.

Early in the project, tradeoff studies were performed to establish key system characteristics. As a result of these studies, the use of energy storage was eliminated, the size of the solar facility was established at 37.13 MW_t, and other site-specific features were selected.

The conceptual design addressed critical components and system interfaces. The result is a hybrid solar/fossil central receiver facility which utilizes a collector system of DOE second generation heliostats with a receiver system consisting of an external, water/steam, screen tube receiver located atop a steel support tower. Other solar systems include the receiver piping system, the solar master control system, and the solar auxiliary electric system.

The value of the solar facility to CTU-WP was assessed based on performance, estimated cost, and revenue requirements over its operating life. The solar facility is expected to deliver 15 MWe net electrical output and 3.7 MW_t process steam at the design point and 66 GWh_t during its first year of operation; this translates to an annual fossil fuel displacement of 48,100 barrels of oil equivalent. The cost of the solar facility in July 1, 1980 dollars includes $33.2 million for construction and owner's cost and $136,000 annually for operating and maintenance cost. In the economic analysis, the value of the solar facility to CTU-WP was computed to be 30 per cent. This value increases to 38 per cent for a 50 per cent increase in assumed fossil fuel prices and to 31.7 per cent for an operating life of 14 rather than 15 years.

A development plan was prepared which addresses the durations and sequencing of major activities which will lead from this conceptual design study to an operational facility. These major activities include licensing, test program, detailed design, procurement, construction, checkout and startup, and performance validation. The plan is based on the solar facility beginning operation in 1986.

Finally, B&V and CTU-WP conducted a test program at the CRS site. In this test program, valuable data were collected on direct normal insolation and heliostat mirror contamination.

1.0 EXECUTIVE SUMMARY

1.1 PROJECT SUMMARY

The conceptual design of a solar cogeneration facility at the Central Telephone & Utilities--Western Power (CTU-WP) Cimarron River Station (CRS) represents a logical extension of the DOE Solar Central Receiver Program. Further, the technical developments achieved during the contract period make use of and carry forward current solar central receiver technology. Finally, some critical economic conclusions which were reached on the project make significant contributions to the ultimate success of central receiver applications.

The DOE Solar Central Receiver Program has followed a logical course of research and development (R&D) both in terms of system integration and scale. System integration has progressed from the component level to the system level and ultimately to the integrated facility level. This progression has been built on component design and testing as well as subsystem research experiments; and, it soon may be providing essential design and operating data through the 10 MW_e Pilot Plant near Barstow, California. In a similar manner, the size of solar facilities has steadily increased. Beginning with the 30 kW_t White Sands test facility and 400 kW_t Georgia Tech facility, DOE increased the size of its experimental capabilities with the completion of the 5 MW_t Central Receiver Test Facility. The next step in solar capacity expansion will be operation of the 10 MWe (50 MW_t) Pilot Plant near Barstow, California; this facility is scheduled to be in operation by the end of this year. The final step in the DOE program may be a solar repowering facility. Although CRS does not offer an order of magnitude increase in solar output, it does represent a very attractive, relatively low cost application which will extend the base of knowledge for solar central receiver systems and can be operational by 1986. Further, since CRS is a cogeneration facility, it has relevance for industrial applications beyond the Barstow Pilot Plant.

In terms of technology, the greatest possible use was made of existing design concepts and data; in addition, the state-of-the-art was advanced in a couple of important areas. The tradeoff studies which were conducted early in the project used existing technology to establish the basic system characteristics which are most cost effective for the CRS application. In these studies, the use of energy storage was eliminated, the basic size was established at 15 MWe (about 37 MW_t) and other site-specific characteristics were selected. From this point in the project, the critical components and system interfaces were addressed. The result is a hybrid solar/fossil central receiver facility which utilizes a collector system of DOE second generation heliostats with a receiver system composed of an external, water/steam, screen tube receiver located atop a steel support tower; the other solar systems include a receiver piping system, solar master control system and solar auxiliary electric system. Only minor modifications to the existing facility are needed. The principal advancements in central receiver technology which were made on the project occurred in the design of the solar receiver and in the insolation and mirror contamination test program conducted at the site. The design of the solar receiver was refined to reduce its cost while maintaining high levels of performance. Also, valuable site data were collected on insolation and mirror contamination.

The critical factor facing potential users of solar central receiver systems is economics. This factor was carefully analyzed during the project by addressing three key aspects of the problem: performance, cost and value. By taking advantage of the high efficiency of cogeneration at CRS, the solar facility is expected to deliver 37.13 MW_t at the design point (noon, March 21) and 66 GWh_t during its first year of operation; this translates to an annual fossil fuel displacement of 48,100 barrels of oil equivalent. The capital cost of the solar facility in July 1, 1980 dollars is $33.2 million. Annual operating and maintenance cost in 1980 dollars is estimated to be $136,000. In light of these performance and cost considerations, the value of the solar facility to CTU-WP was determined using the revenue requirements approach. Although this analysis resulted in a relatively low value, 30 per cent of total cost, constructing the solar facility at CRS may still be very attractive because of the relatively low capital cost. In conjunction with this economic analysis, sensitivity studies and a solar incentives analysis were conducted. Results of these investigations indicate that the value of the solar facility is relatively insensitive to increases in projected coal and gas prices, as well as to solar facility life. Of greater significance is the increase in value to CTU-WP if heliostat and receiver costs are reduced through some type of incentive. In addition, the timing of the solar facility addition has a critical impact on its economic value. The solar facility is of greatest value during the early years of its operation; later in its operating life, more coal-fired plants with lower fuel costs are in operation. Thus, delays in construction of solar facilities will result in decreased value to the owners.

Stated concisely, the reasons for constructing the solar cogeneration facility at CRS are the following.

- A solar cogeneration facility at CRS is a logical extension of the DOE Solar Central Receiver Program. A solar cogeneration facility can show the potential for solar central receiver systems in both utility and industrial markets. At CRS, the direct normal insolation of 6.1 kW/m^2 day is representative of a large portion of the southwestern U.S., where central receiver systems can operate effectively.
- The hybrid solar/fossil application represents a significant extension of the technology base beyond the Barstow Pilot Plant. In addition, the receiver design is based on Advanced Water/Steam Receiver technology.
- The daily output curve for the CRS solar facility is very similar to the CTU-WP system daily load curve.
- The solar central receiver concept is readily adaptable to repowering the existing CRS gas-fired cogeneration facility. In addition, sufficient land is available for the collector field with no significant environmental impact.
- Addition of the solar facility at CRS requires a relatively low-cost investment.

1.2 INTRODUCTION

The conceptual design and evaluation of a solar facility addition to the Central Telephone & Utilities-Western Power (CTU-WP) Cimarron River Station (CRS) is described in this report. The CRS is a cogeneration facility which generates electricity for the CTU-WP system and delivers process steam to the National Helium Corporation gas processing plant, located adjacent to the CRS. The solar addition would permit, at the design point, a 25 per cent reduction of the gas fuel consumed by the 60 MW_e CRS. The work on this project was performed as part of the Department of Energy's Solar Cogeneration Program. Black & Veatch Consulting Engineers, was the prime contractor; and CTU-WP, Babcock & Wilcox Company (B&W), and Foxboro Company were subcontractors.

The project objective was to develop the best site-specific solar conceptual design that would fulfill the following requirements.

- Provide practical and effective use of solar energy.
- Have the potential for construction and operation by 1986.
- Have the potential for wide commercial application and significant fossil fuel savings.
- Make maximum use of existing solar energy technology.

Project tasks included development of a solar conceptual design, identification of the economic value of the solar addition, and preparation of a development plan to implement the design and construction of the facility. Figure 1.2-1 is an artist's rendering of the conceptual design.

Important criteria for the technical approach and site selection were the use of proven and accepted technology and a plant whose physical condition, age, and usage are compatible with solar cogeneration.

The technical approach selected was a water/steam solar central receiver supplying superheated steam to the CRS turbine. The use of a water/steam receiver permits generation of steam whose pressure and temperature conditions match those currently used in central stations for electric generation, and permits the application of steam generation technology which is mature, reliable, and well-established with potential users. Receiver fluid design criteria are well understood by B&W, a company that

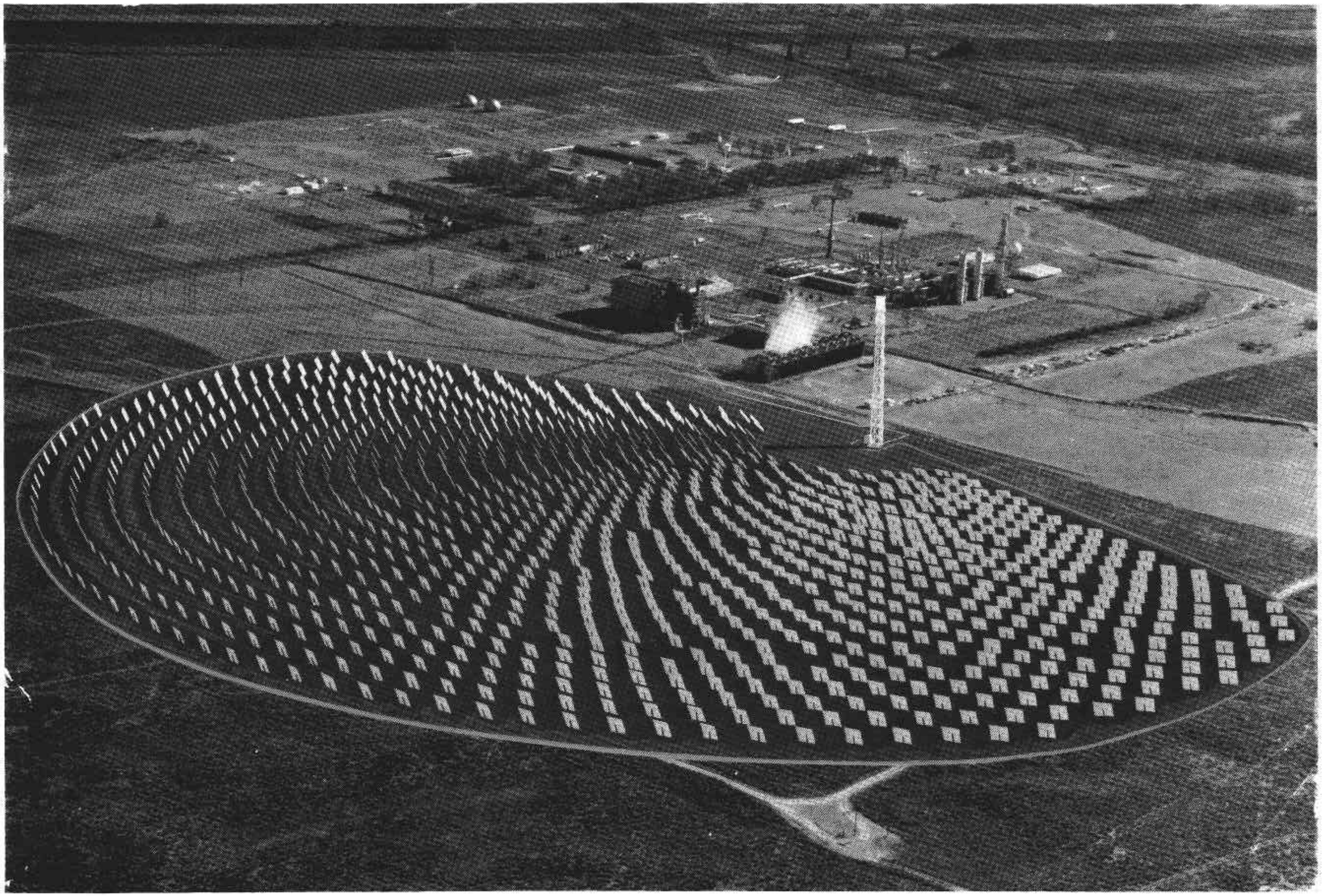


FIGURE I.2-I. ARTIST'S RENDERING OF CONCEPTUAL DESIGN has been designing and building steam generators for 113 years. Furthermore, water chemistry and materials compatibility at the operating conditions of the solar receiver are known, and the risks associated with combining materials to perform in uncertain operating regimes are eliminated.

The selection of CRS as a host cogeneration facility for solar augmentation was influenced by two major factors. First, it is representative of a medium size cogeneration facility with a typical industrial processing plant operating on a 24-hour basis with relatively constant electrical and thermal power demands. Second, due to its location and direct mean daily average insolation of approximately 6.1 kWh/m^2, CRS is representative of a large group of other potential cogeneration facilities.

1.3 FACILITY DESCRIPTION

The Cimarron River Station is located about 18 kilometers (11 miles) northeast of Liberal, Kansas, as shown on Figure 1.3-1. The National Helium Corporation (NHC) natural gas processing plant borders the Cimarron River Station on the south. Primary access to the site is provided by US Highway 54. The station is located on the 162,000 m^2 (40 acre) site currently owned by CTU-WP. National Helium Corporation owns additional land to the north, west, and south of the CTU-WP property. Together, the land presently owned by CTU-WP and NHC would provide for all the land required for the proposed heliostat field, receiver tower, and receiver piping system.

The topography of the site, including the possible heliostat field areas, slopes irregularly to the north. Test borings, performed during the original station design, indicate that the site is underlaid by sandy loam of various grades. The site area contains water wells and underground pipelines, and is traversed by electric transmission lines. The site is located at 37° 10' north latitude and 100° 45' west longitude. The ground elevation of the station is 801.6 meters (2,630 feet) above sea level.

The Cimarron River Station is situated in a region of minor to moderate seismic risk. The site area is classified by the Uniform Building Code (UBC) as Zone 1 of seismic risk for the contiguous United States. The

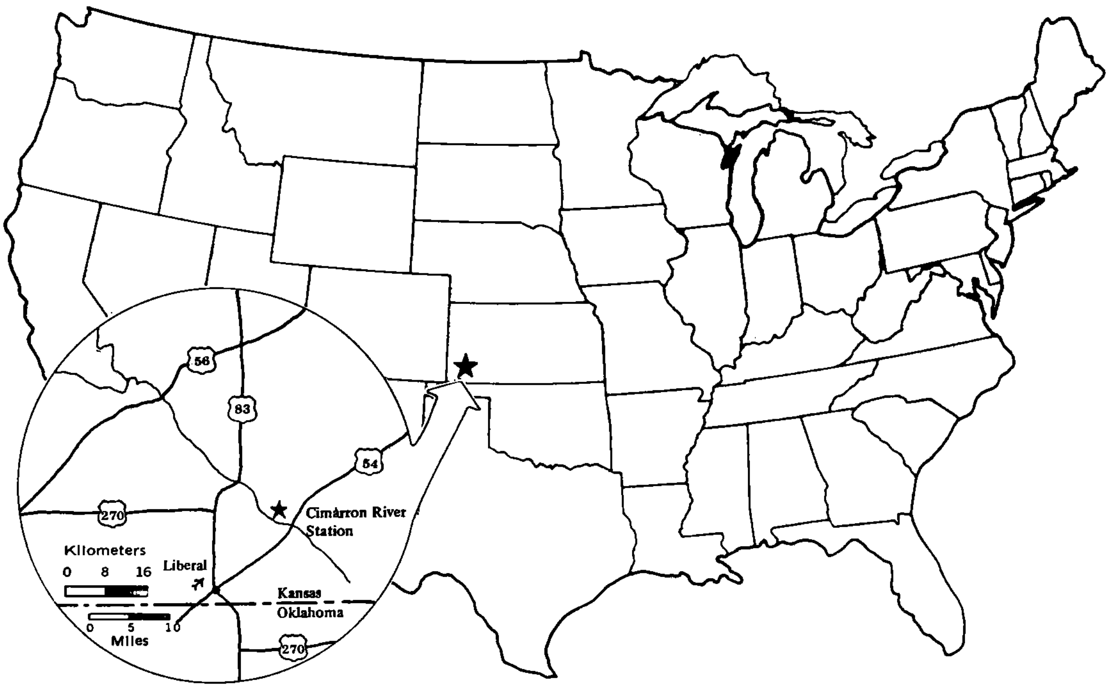


FIGURE I.3-I. CIMARRON RIVER STATION LOCATION

prevailing climate is typical of the Great Plains regions. Summer temperature extremes of about 43 C (110 F) and winter lows around -26 C (-15 F) are not uncommon. Annual precipitation averages about 7.5 cm (19 inches), including about 48.3 cm (18 in) of snowfall.

As shown in Figure I.3-2, the Cimarron River Station cogeneration facility contains three major elements: a natural gas fueled conventional steam power plant (Unit I), a combustion gas turbine (Unit 2), and a natural gas fueled process steam generator. Unit I, which became operational in 1963, utilizes a 44 MWe General Electric tandem compound, double flow, non-reheat turbine generator with design steam inlet conditions of 8.72 MPa (1,265 psia) and 510 C (950 F) and overpressure operating conditions of 9.58 MPa (1,390 psia). The turbine generator is normally operated at the overpressure condition for improved cycle efficiency and has a maximum capability of 60 MWe. The Unit I steam generator was built by Babcock & Wilcox and is a two drum Stirling, natural circulation, pressurized furnace, with a design rating of 192,740 kg/h (425,000 lb/h), 9.06 MPa

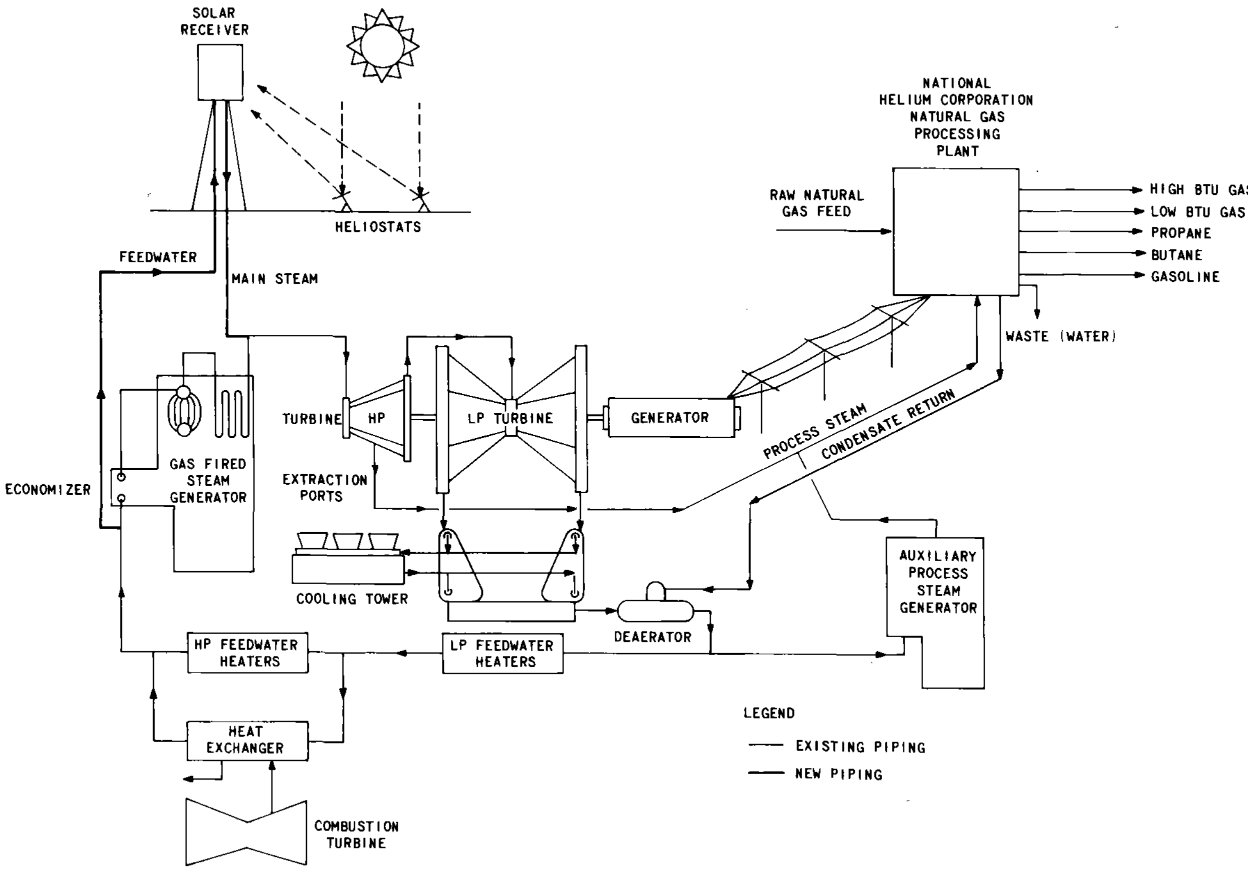


FIGURE 1.3-2. SIMPLIFIED SCHEMATIC OF COGENERATION FACILITY

(1,315 psia), 513 C (955 F) superheated steam. The maximum extended capability is 226,760 kg/h (500,000 lb/h), 9.99 MPa (1,450 psia), 513 C (955 F). The Unit 1 cycle configuration includes five stages of feedwater heating. The steam cycle also employs a horizontal, two pass, surface type condenser and a mechanical draft wet cooling tower. The plant control systems were supplied by the Foxboro Company.

The combustion turbine (Unit 2) is rated at 14 MWe. It is provided with an exhaust heat recovery heat exchanger. When Units 1 and 2 are operating in a combined cycle mode, the Unit 1 high pressure feedwater heaters are taken out of service and feedwater heating is provided by the exhaust heat recovery heat exchanger. The combustion turbine is normally only operated during the summer peaking season in a combined cycle mode with Unit 1.

The process steam generator, built by Babcock & Wilcox, has a design pressure of 1.83 MPa (265 psia) and has a capability of 27,000 kg/h (60,000 lb/h) of steam. This process steam generator is utilized to provide process steam to National Helium Corporation when Unit 1 is shut down.

Service water and makeup water for the circulating water system is provided from five wells located onsite. Cooling tower blowdown is directed to an onsite evaporation pond.

The cogeneration facility provides electricity to the Western Power grid and process steam and electrical energy to the adjacent National Helium Corporation plant. Process steam is taken from the first two extraction ports of the steam turbine through pressure regulating valves to maintain .65 MPa (95 psia) steam for delivery to National Helium Corporation. This steam is desuperheated to 204 C (400 F). The electric energy supplied to NHC may be provided from either the CRS or the Western Power grid. The NHC plant processes natural gas for the Detroit, Michigan area. A refrigeration process is utilized to remove the propane, butane, and gasoline (pentane and greater fractions) products. At the same time, water and carbon dioxide are removed from the gas stream. The refrigeration process used requires both electric and thermal energy in the ratio of approximately 3:1, thermal equivalent.

The solar addition to Unit 1 will take a portion of the feedwater from the discharge of the highest pressure feedwater heater to generate steam in the solar receiver, and will deliver this steam to the turbine through a connection to the existing main steam line. No modifications to the NHC plant, Unit 2 or the process steam generator will be required.

1.4 CONCEPTUAL DESIGN DESCRIPTION

Key design characteristics for the solar facility were determined using trade studies at the outset of the project. Those key characteristics were then used as design specifications for the balance of the conceptual design. The resulting solar cogeneration facility is comprised of five major systems, as shown in Figure 1.4-1. These are the collector system, receiver system, receiver piping system, solar master control system, and solar auxiliary electric system. The five solar systems are fully integrated with the existing fossil energy system to provide:

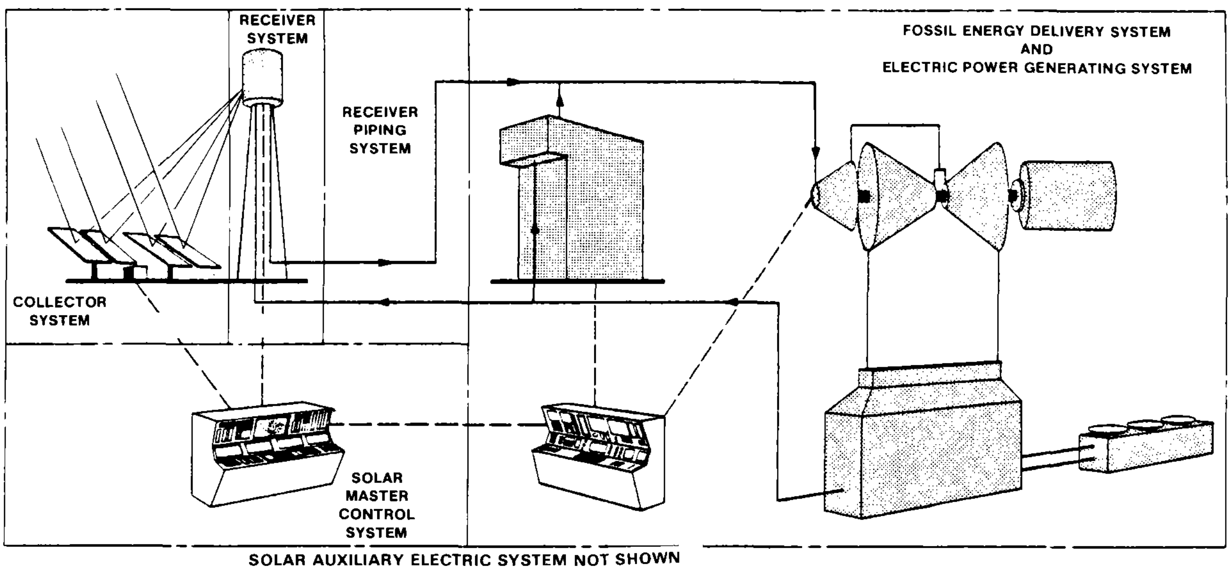


FIGURE 1.4-1. SOLAR COGENERATION FACILITY SCHEMATIC

- Maximum use of solar energy.
- High system reliability.
- System safety for personnel and equipment.
- Simple operation.

The solar cogeneration facility operates in a hybrid mode; the solar and fossil generated steam flows are merged before entering the turbine. At the design point of noon, March 21, the solar facility supplies a net power of 37.13 MW_t with a reference insolation of 950 W/m^2; this corresponds to a net plant output of 15 MW_e electricity and 3.7 MW_t process steam. The functional requirements, design and operating characteristics, site requirements, and performance of each system are described below.

The collector system, based on DOE second generation heliostat specifications, consists of 1,057 heliostats [55,780 m^2 (600,103 ft^2) of reflective area] optimally located on 34 circular arcs centered on and north of the receiver support tower. They occupy an area of 216,000 m^2 (53 acres), which is 848 m (2,782 ft) wide (east-west) and the radius of the outer row of heliostats is 424 m (1,391 ft). As shown in the site arrangement drawing, Figure 1.4-2, the heliostats are located in a staggered radial array, which allows close packing with minimum optical interference. Each heliostat has a unique, fixed aim point selected so as to provide uniform flux on the receiver.

The receiver system converts solar energy into steam thermal energy; this system consists of an external receiver and its support tower. An artist's rendering of the receiver is provided in Figure 1.4-3. The external receiver offers a simpler design, smaller size, and lighter weight than a cavity receiver; and the efficiency of this external receiver design is only slightly lower than that of a cavity receiver. Pumped circulation was selected to permit the maximum freedom for transitions between operating modes; extensive thermohydraulic analyses of the receiver design show excellent performance under transient conditions. The use of commercial materials and fabrication procedures further assures reliability, low maintenance, and safety. As shown in Figure 1.4-4, the heat absorbing surface is configured as an 8 panel, 210 degree sector of a right circular cylinder

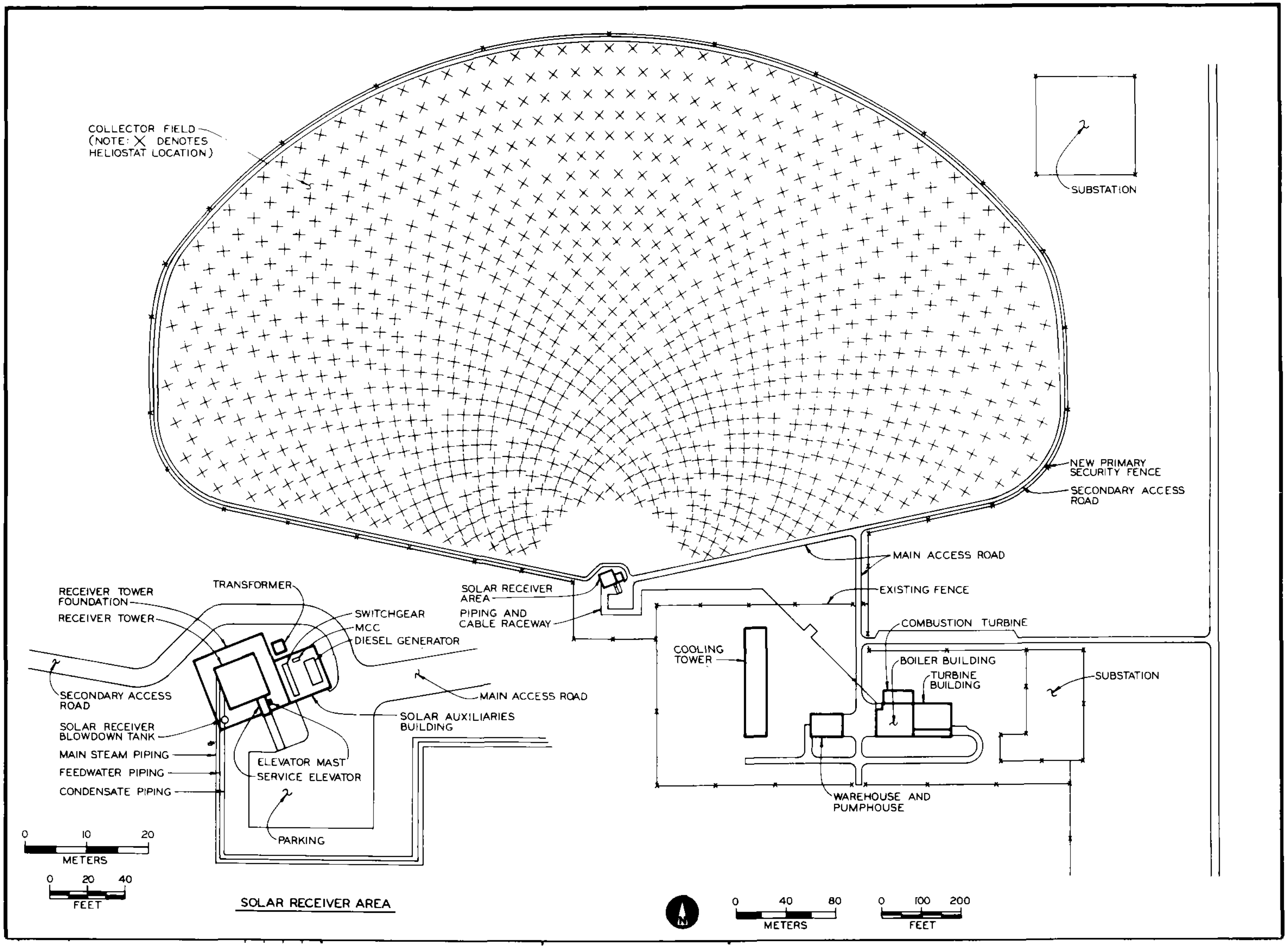


FIGURE I.4-2. SITE ARRANGEMENT

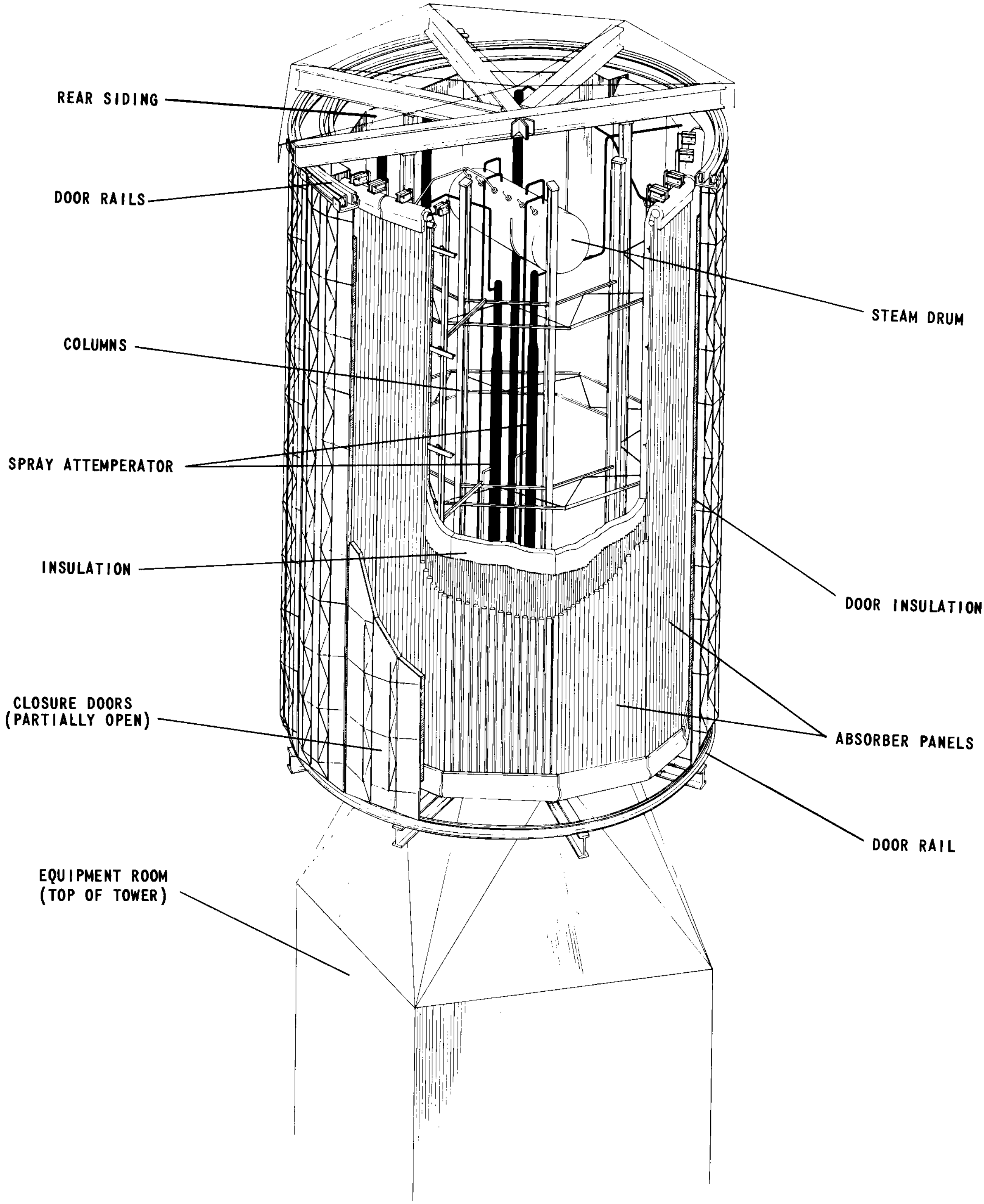


FIGURE I.4-3. RECEIVER ARTIST'S RENDERING

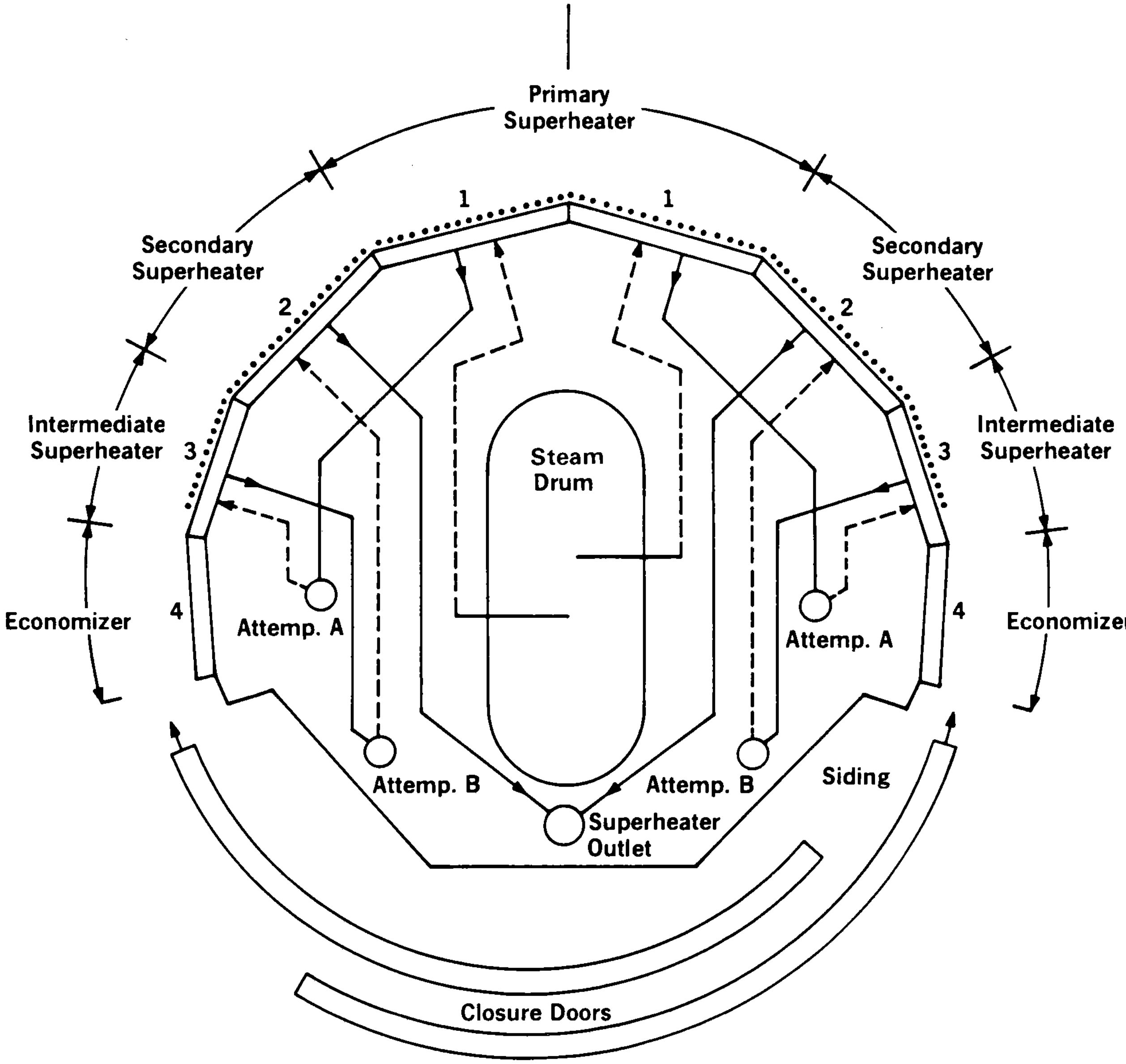


FIGURE I.4-4. EXTERNAL RECEIVER SCHEMATIC centered at 84 m (276 ft) above grade level. The cylinder is 6.71 m (22 ft) in diameter and 9.45 m (31 ft) high, with two concentric heat absorbing surfaces. The inner surface has 6 panels which comprise the superheater surface; the outer surface forms a protective screen in front of the superheater and comprises the evaporator (boiler) surface; the economizer has 2 panels, one located at either side of the superheater panel array. The south 150 degree sector of the receiver cylinder, which does not contain heat transfer surfaces, provides the storage region for two 110 degree closure doors, which are used to reduce heat loss during shutdown. Superheater temperature control is accomplished through spray attemperation. The receiver has its own control system which interfaces with the solar master control system.

The receiver tower is a steel structure, rising 74.4 m (244 ft) above grade, and tapering from 7.32 m (24 ft) in width at the base to 4.27 m (14 ft) in width at the top. The tower will consist of four support legs of bolted structural steel construction, with x-bracing to provide resistance to lateral loads. An equipment room is located in the top section of the tower to house control panels, chemical feed, and other required equipment. Tower accessories include an elevator, aircraft obstruction lighting, caged ladder, and communication and ventilation systems.

The receiver piping system provides the piping interface between the solar receiver and the existing fossil energy system. The system transports feedwater to the receiver from the fossil system, and high energy steam from the receiver to its interface with the fossil system. It also provides blowdown and drain lines for the receiver. The system consists of piping, pumps, tanks, vents, valves, water chemistry equipment, and control elements.

The Solar Master Control System (SMCS) coordinates the operations of the collector, receiver, receiver piping and solar auxiliary electric systems to ensure safe and proper operation of the entire integrated cogeneration plant. The SMCS also receives appropriate status and data input information from the existing plant control systems. The SMCS operates at the highest level in the control hierarchy as shown on Figure 1.4-5. The SMCS

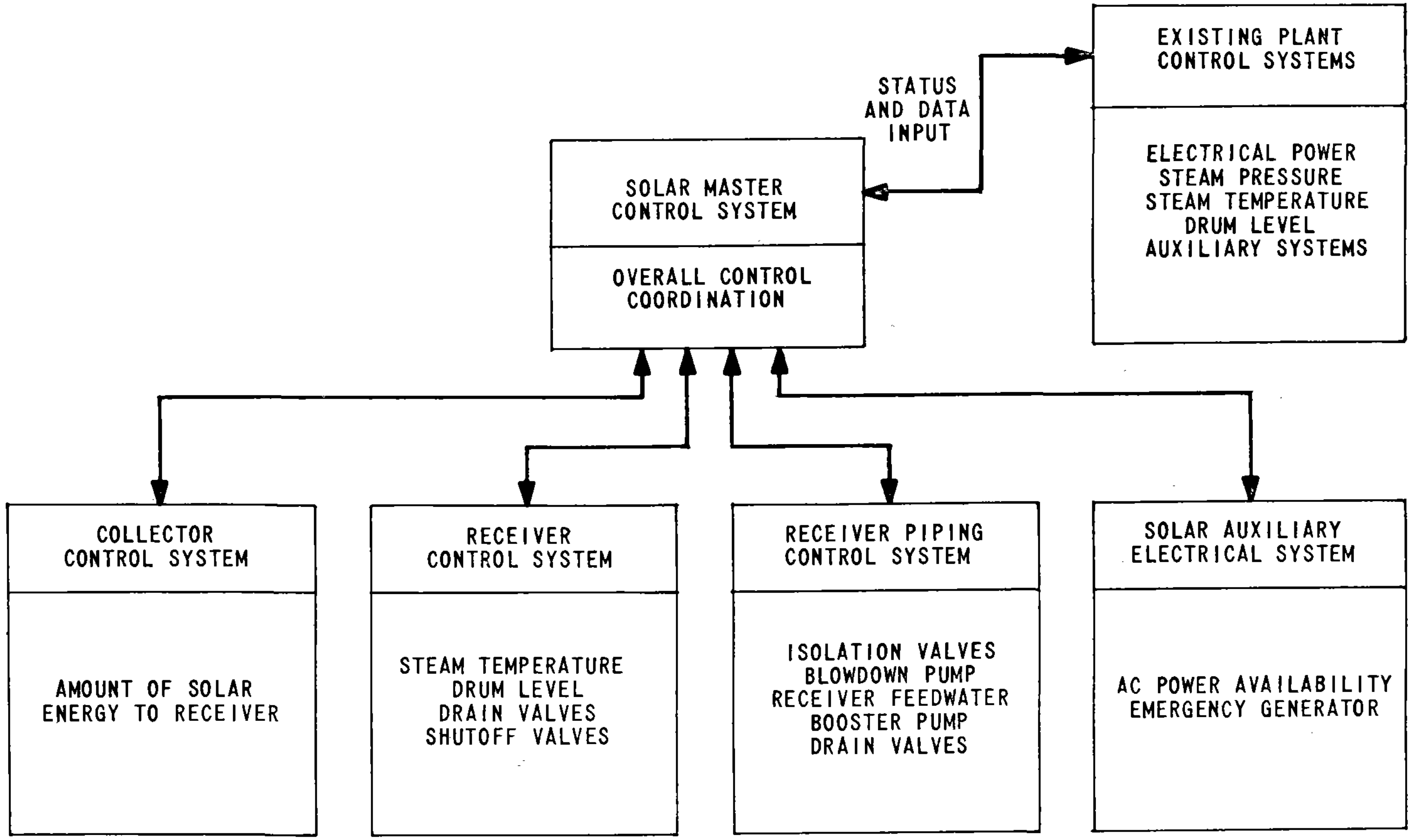


FIGURE I.4-5. CONTROL SYSTEM HIERARCHY

issues commands to the control systems at the lower level of this hierarchy and receives feedback status information from these control systems. The SMCS provides the capability for automatic start-up, normal operation, and shutdown of the collector, receiver, and receiver piping systems. The SMCS also issues emergency shutdown commands. In addition, this system serves as a centralized data acquisition system which monitors, analyzes, and displays all critical solar system and subsystem parameters.

The Solar Auxiliary Electric System provides electrical power to all solar facility auxiliary loads. The auxiliary loads are defined as electrical loads required by the various solar systems during shutdown, start-up, and normal operating modes of the solar facility. Two categories of electrical power are required: normal ac power and uninterruptible ac power. Normal ac power is used to supply power to collector, receiver, and receiver piping system electrical loads, as well as miscellaneous electrical loads such as lighting, heating, ventilation and air conditioning. Uninterruptible ac power is used to supply power to the solar master control system computers and other critical control and instrumentation, where an interruption of power for even a few cycles cannot be tolerated.

Key features of the conceptual design are presented in Table I-I.

I.5 SOLAR FACILITY PERFORMANCE

The performance of the conceptual design was determined through simulation modeling of the solar cogeneration facility. Individual characteristics and performances of the collector, receiver, receiver piping, solar master control, and auxiliary systems provided the inputs to the Solar Thermal Electric Plant Performance Evaluator (STEPPE) simulation program. The collector system performance model is part of OPTICS, Black & Veatch proprietary software, developed for central receiver collector/receiver systems. This engineer/computer interactive set of programs is used for design optimization. These simulations were used with a weather effect-

TABLE I-I. CONCEPTUAL DESIGN SUMMARY

Key Feature	Description
1. Prime Contractor:	Black & Veatch, Consulting Engineers, Kansas City, Missouri.
2. Major Subcontractors:	Central Telephone & Utilities-Western Power, Great Bend, Kansas. Babcock & Wilcox Company, Alliance, Ohio. Foxboro Company, Foxboro, Mass.
3. Site Location	Cimarron River Station, Liberal, Kansas.
4. Facility Characteristics:	
a. Year of Commercial Operation	1963 (Unit 1); 1967 (Unit 2)
b. Turbine Type	General Electric tandem compound, double flow, non-reheat condensing turbine rated at 44 MWe (60 MWe at overpressure).
c. Turbine Inlet Temperature and Pressure	
--rated conditions	510 C (950 F)/8.72 MPa (1,265 psia)
--overpressure conditions	510 C (950 F)/9.58 MPa (1,390 psia)
d. Turbine Exhaust Steam Pressure	38.1 mm (1.5 in) Hg absolute
e. Process Fluid	Steam
f. Process Fluid Temperature and Pressure	204 C (400 F)/550 kPa (95 psia)
5. Design Point:	Noon, March 21
6. Receiver:	
a. Receiver Fluid	Water/steam
b. Configuration	External, absorber 210-degree sector of 6.71 m (22 ft) diameter by 9.45 m (31 ft) high cylinder with closure doors.
c. Type	Drum with pumped circulation
d. Elements	Economizer, boiler, superheater
e. Output Fluid Temperature	520 C (968 F)
f. Output Fluid Pressure	11.07 MPa (1605 psia)

TABLE I-1 (Continued). CONCEPTUAL DESIGN SUMMARY

Key Feature	Description
7. Collector Field:	
a. Number of Heliostats	1057
b. Reflective Area Per Heliostat	52.77 m^2 (568 ft^2)
c. Cost Installed	$215/$m^2$
d. Type of Heliostat	DOE Second generation
e. Field Configuration	North, 156 degree sector
f. Total Reflective Area	55,780 m^2 (600,103 ft^2)
g. Total Collector Field Area	222,000 m^2 (55 acres)
8. Storage:	None
9. Capital Cost	
a. Total Capital Cost: 1980 dollars including all capital, startup, and checkout cost but excluding O&M (based on installed heliostat cost of $215/$m^2$)	$33,241,168
b. Total Capital Cost: 1980 dollars using installed heliostat cost of $260/$m^2$	$36,684,289
10. Construction Time	2 years
11. Solar Facility Contribution at Design Point (based on turbine valves wide open, overpressure operation):	
a. Receiver Output	37.13 MW_t
b. Electrical Power, net	15 MWe
c. Mechanical Power	0
d. Process Power	3.7 MW_t
12. Solar Facility Contribution, Annual (based on plant load model)	
a. Receiver Output	66 GWht
b. Electrical Energy	20.0 GWhe
c. Mechanical Energy	0
d. Process Energy	13.5 GWht

TABLE I-I (Continued). CONCEPTUAL DESIGN SUMMARY

Key Feature	Description
13. Solar Fraction:	
a. Design Point	0.247
b. Annual	0.102
14. Annual Fossil Energy Saved	48,100 barrels of oil equivalent
15. Type of Fuel Displaced:	Natural gas and coal
16. Ratio of $\frac{\text{Annual Energy Produced}}{\text{Total Mirror Area}}$:	1.18 $\frac{\text{MWht}}{m^2}$
17. Ratio of $\frac{\text{Capital Cost (1980 dollars)}}{\text{Annual Fuel Displaced}}$	$\frac{\$406.87}{\text{MWht}}$
18. Site Insolation (direct normal):	
a. Design Point	950 W/m^2
b. Annual daily average	6.1 kWh/m^2 day
c. Source	"On the Nature and Distribution of Solar Radiation", March 1978 HCP/72552-01
d. Site Measurements	Started January 15, 1981, will continue for one year
19. Cogeneration Utilization Efficiency*	41.0%

*Defined by $\frac{\text{MWhe} + \text{MWht}}{\text{MWh}}$

Where: MWhe is net useful electrical energy
MWht is net useful thermal energy
MWh is total energy input to the facility (fuel plus solar energy incident on the receiver) using annual energy in megawatt-hours

modified ASHRAE* clear air model of the direct insolation to calculate net annual thermal energy produced by the solar facility for electric power generation and process steam generation.

A typical operating profile for CRS during the summer months is shown on Figure I.5-I. Specific information on facility performance may be found in the design point and annual average efficiency stair steps, Figures I.5-2 and I.5-3. At the design point the solar to thermal energy conversion efficiency is 70.0 per cent, with solar contributing 24.7 per cent of the power requirement of both electric generation and process steam. On an average annual basis, solar would satisfy 10.2 per cent of the CRS process steam and electric generation requirements, thereby displacing natural gas equivalent to 48,100 barrels of oil annually.

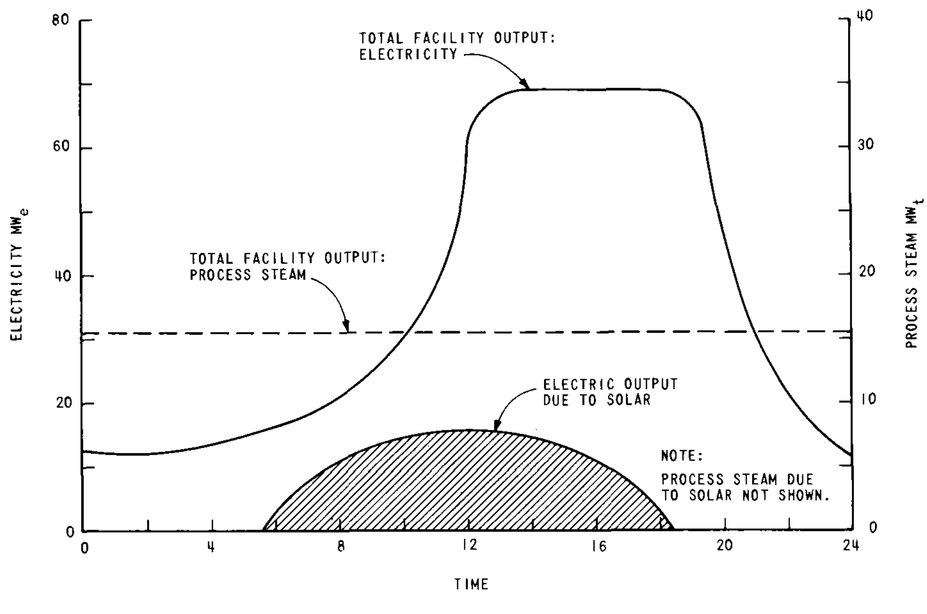


FIGURE I.5-I. TYPICAL OPERATING PROFILE FOR CRS

*American Society of Heating, Refrigerating and Air Conditioning Engineers.

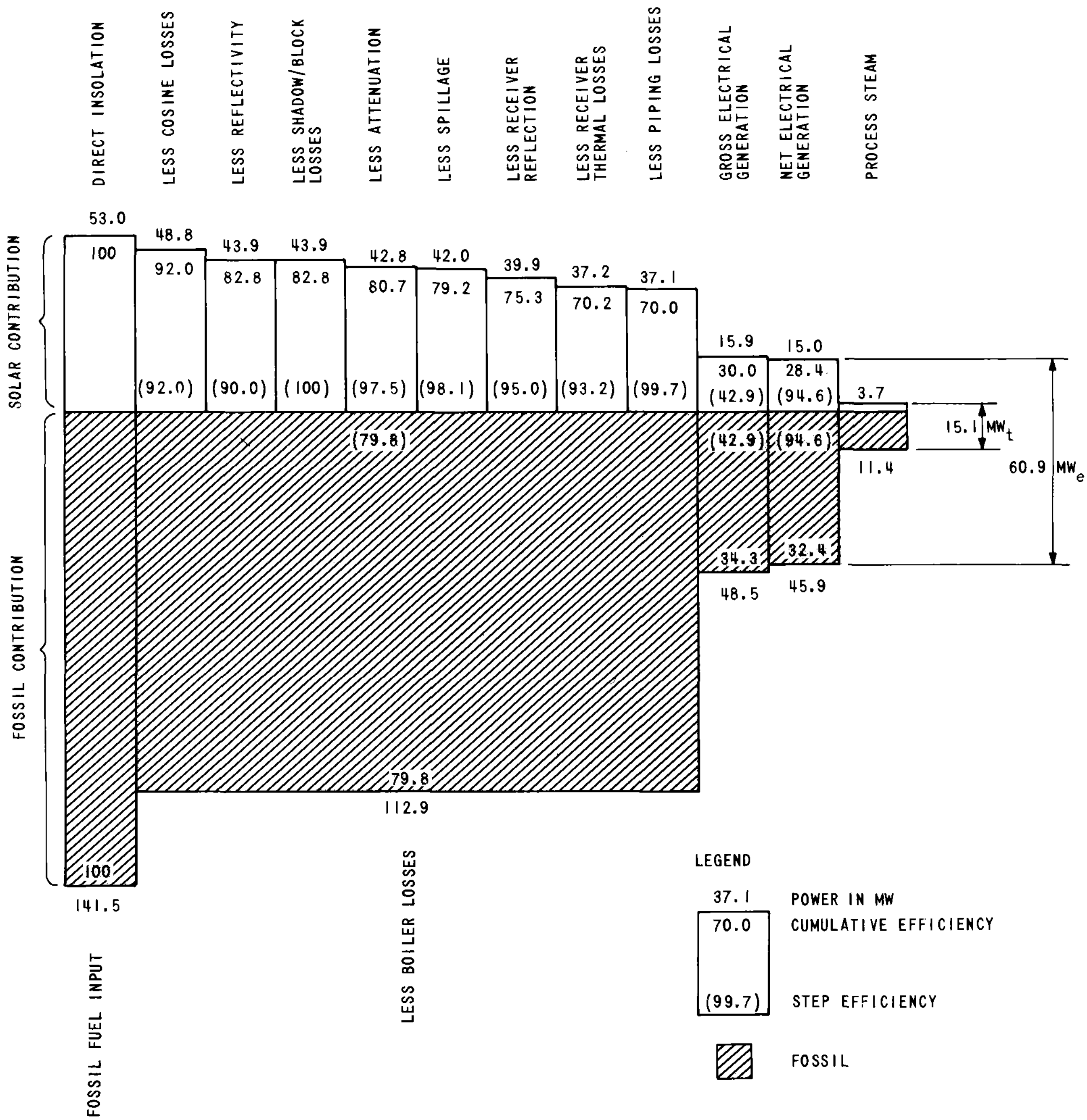


FIGURE 1.5-2. EFFICIENCY STAIRSTEP AT RATED CAPABILITY FOR MARCH 21, NOON

1.6 ECONOMIC ANALYSIS

The economic evaluation of solar repowering CRS was based on the following considerations.

- Construction cost estimate.
- Owner's cost.

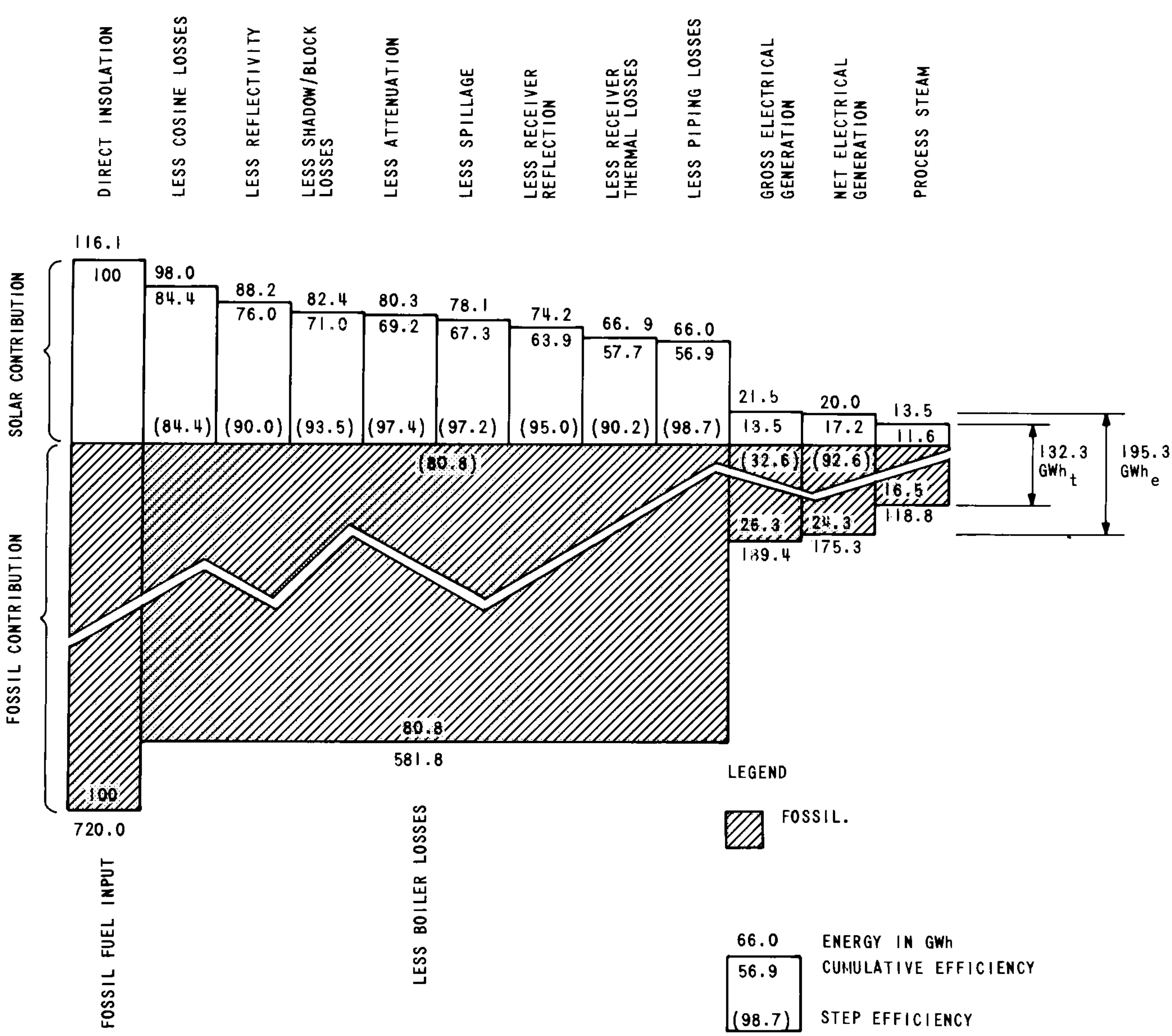
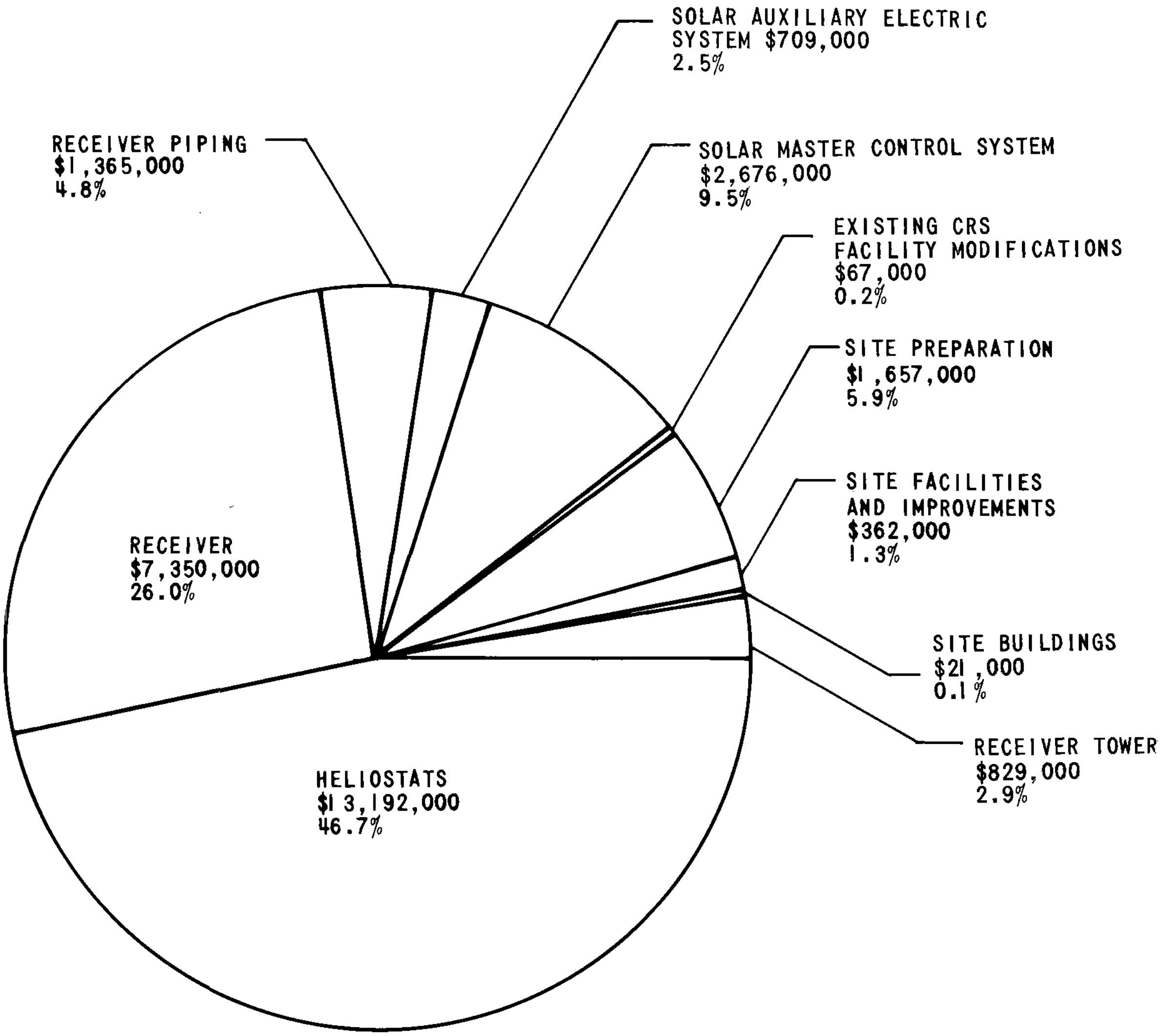


FIGURE 1.5-3. ANNUAL AVERAGE ENERGY STAIRSTEP

- Operating and maintenance cost estimate.
- Western Power fuel cost projections.
- Western Power economic criteria.

The construction cost estimate, $28,227,000 in July 1, 1980 dollars, is based on the conceptual design of the solar facility systems, site improvements/facilities, and modifications to the existing CRS facility. The capital cost of each system and its fraction of the total cost are given in Figure 1.6-1. Heliostat costs are estimated to be $\$215/m^2$. A contingency of 10 per cent is added to each cost element. Owner's cost, in July 1, 1980 dollars, is



TOTAL COST $28,227,000 (1980 DOLLARS)

FIGURE 1.6-1. CONSTRUCTION COST ESTIMATE

projected to be $5,014,943. The owner's cost consists primarily of AFUDC (allowance for funds used during construction) and taxes. The estimate of annual operating and maintenance cost is $135,610, expressed in July 1, 1980 dollars; this cost is allocated to major accounts as shown in Figure 1.6-2. The fuel cost and projected escalation rates are given in Table 1-2. In addition, the financial parameters used in the economic analysis are presented in Table 1-3.

The methodology for calculating the value of the solar facility to Western Power was based upon standard utility long range generation expansion planning procedures and criteria. It involves analyzing revenue

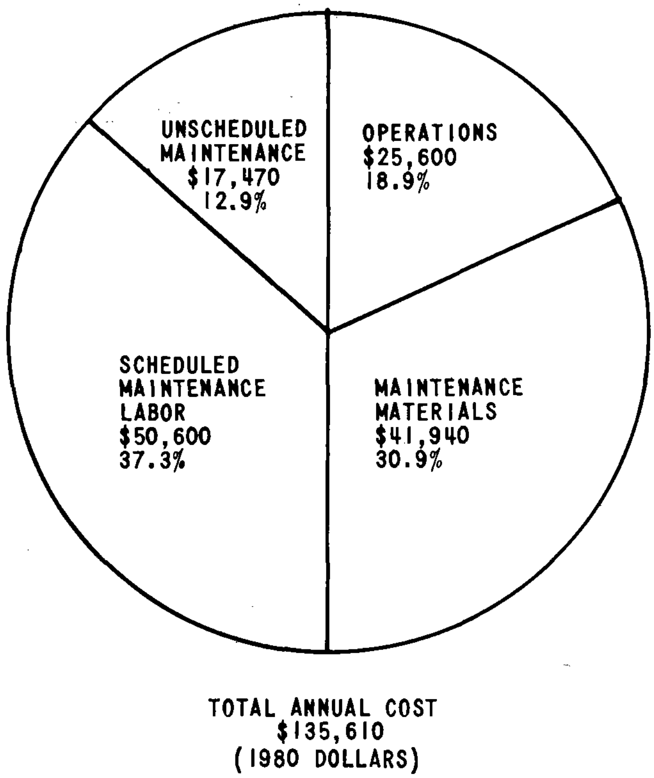


FIGURE 1.6-2. OPERATING AND MAINTENANCE COST ESTIMATE

requirements of the investment, the investment related costs, and the operating costs. The analysis yields cumulative present worth of comparative revenue requirements and identifies savings by comparing the solar plan with the no-solar base plan.

The value to Western Power of the solar facility addition at CRS is explicitly defined as the additional investment that Western Power could incur for the solar facility without increasing the system's revenue requirements. The value of the solar facility is due to operating and capacity addition cost savings. With the addition of the solar facility, the economic lifetime of CRS can be extended from December 1993 to December 2000.

TABLE I-2. FUEL COST PROJECTIONS

Fuel	1980 Cost ($/MBtu)	Escalation Rate (Per Cent)
Natural Gas	1.86	--
1981	--	14.5
1982	--	13.4
1983-1990	--	12.0
1991-2000	--	11.0
Coal	1.10	--
1981	--	12.2
1982	--	10.7
1983	--	10.1
1984-1985	--	10.0
1986-1990	--	9.0
1991-1995	--	8.0
1996-2000	--	7.0

The 7-year extension could allow the deferral of 60 MW_e of new quick start combustion turbine capacity on the Western Power system, required to meet the system spinning reserve requirement.

The analysis began with establishing the alternate generation expansion plans. Then, each plan was simulated using the Black & Veatch economic dispatch system simulation computer model; this model was adapted to the Western Power system. The simulation produced annual production costs which were combined to yield the total annual comparative revenue requirement. Comparison of revenue requirements for the fifteen year evaluation period is the basis for determining the value to Western Power of the solar facility. These comparisons were made using Western Power's economic criteria.

TABLE I-3. FINANCIAL PARAMETERS

Factor	Per Cent
Discount Rate	13.45
Investment Tax Credit	11.0
AFUDC Rate	13.0
Property Tax Rate	1.45
Insurance Rate	0.22
General Inflation Rate	
1981	10.2
1982	8.7
1983-1990	8.0
1991-2000	7.0
Combined Federal and State Income Tax Rate	49.645
Fixed Charge Rate	
Solar	17.50
Combustion Turbine	16.27
Pulverized Coal	15.43

The long term operation of NHC is dependent on gas industry economics and future availability of natural gas feedstocks. Since uncertainties surround both of these factors, the economic analysis addressed two "limiting" cases: one in which NHC continues to operate through the year 2000, and one in which NHC is not operating beyond 1985. The results of the value determination for these two cases are summarized in Table I-4. For each case, Table I-4 shows the value due to capacity savings and operating savings in 1986 discounted dollars. In both cases, the capacity savings are due to the deferral of combustion turbine capacity and the operating cost savings accrue because the solar facility reduced total system fuel requirements.

TABLE 1-4. VALUE OF CRS SOLAR FACILITY

	NHC Case	No-NHC Case
Total Capacity Savings*	13.46	13.46
Total Fuel and O&M Savings*	4.30	4.40
Total Solar Facility Revenue Savings*	17.76	17.86
Solar Facility Cost*	59.46	59.46
Value of Solar Facility	29.9%	30.0%

*Values indicated are expressed in millions of dollars discounted to 1986.

Table 1-4 shows that the value to Western Power of solar repowering is about 30 per cent of the solar facility cost. This value results primarily from incurring higher system fixed charges beginning in 1986 for no increase in system generating capability. Further, the addition of solar to CRS extends the natural gas fueled operation of CRS through 2000 under the solar plan; whereas, under the no-solar (base) plan, CRS is retired January 1, 1994, and the Western Power system generation requirements are then mostly supplied by coal fueled generation. Therefore, there is greater natural gas consumption under the solar plan beginning in 1994; the cost of this increased natural gas consumption in later years almost totally offsets the system fuel cost savings which accrued in 1986 through 1993. Because of the increased fixed charges in early years and the lack of significant cummulative fuel cost savings, only a limited capital expenditure would be cost effective within the utility economic evaluation framework.

Sensitivity analyses were performed to identify the effect on value to Western Power of three factors.

- Fossil fuel prices
- Solar facility life
- Solar components costs

The sensitivity analyses results, shown in Figure I.6-3, support the basic conclusion of the economic analysis, and indicate that the value of the solar facility is largely insensitive to the factors studied.

I.7 DEVELOPMENT PLAN

The development plan addresses the major activities, financial requirements, and organizational issues which will lead from the conceptual design study to an operational facility. In keeping with the project objectives, the plan is based on the solar facility beginning operation in 1986.

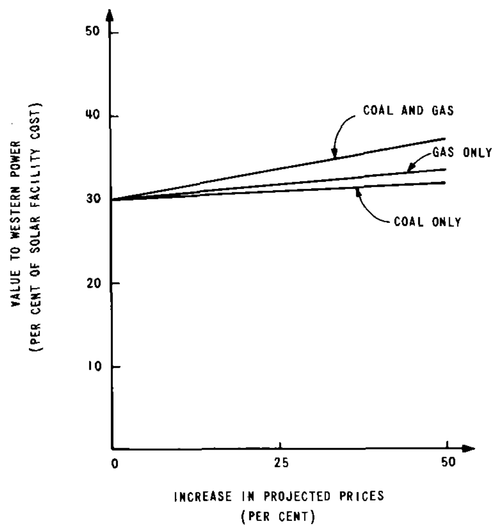
The major activities in the development plan include licensing, test program, detailed design, procurement, construction, checkout and startup, and performance validation; no Subsystem Research Experiment is required. These activities, their durations, and sequencing, along with critical project milestones, are shown on the Major Milestones Schedule in Figure I.7-I. This schedule was prepared using a detailed Critical Path Method of scheduling.

The financial requirements of the solar cogeneration facility are illustrated in the cash flow plan, Table I-5. This plan shows the relationship between the cost estimate and the development plan schedule. The schedule identifies the periods in which each of the major activities takes place. The material, labor, and indirect costs associated with each activity are then apportioned over those periods; from this schedule of cash outlays,

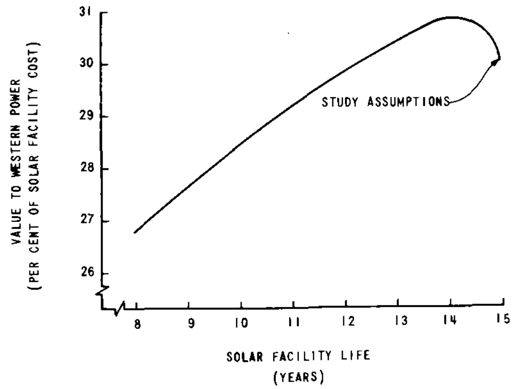
TABLE I-5. CASH FLOW PLAN

	1982	1983	1984	1985	1986
Calendar Year	643,018	3,839,862	9,194,017	19,564,271	--
Fiscal Year	444,397	3,078,517	7,855,479	16,971,707	4,891,068

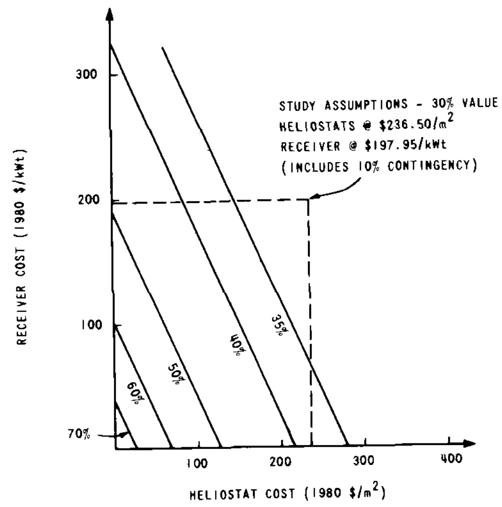
Total Construction and Owner's Cost--$33,241,168 (7/1/80 Dollars)



EFFECT OF FUEL PRICES ON VALUE OF CRS SOLAR REPOWERING



EFFECT OF SOLAR FACILITY LIFE ON VALUE OF CRS SOLAR REPOWERING



EFFECT OF SOLAR COMPONENT COSTS ON VALUE OF CRS SOLAR REPOWERING

FIGURE I.6-3. SENSITIVITY ANALYSIS

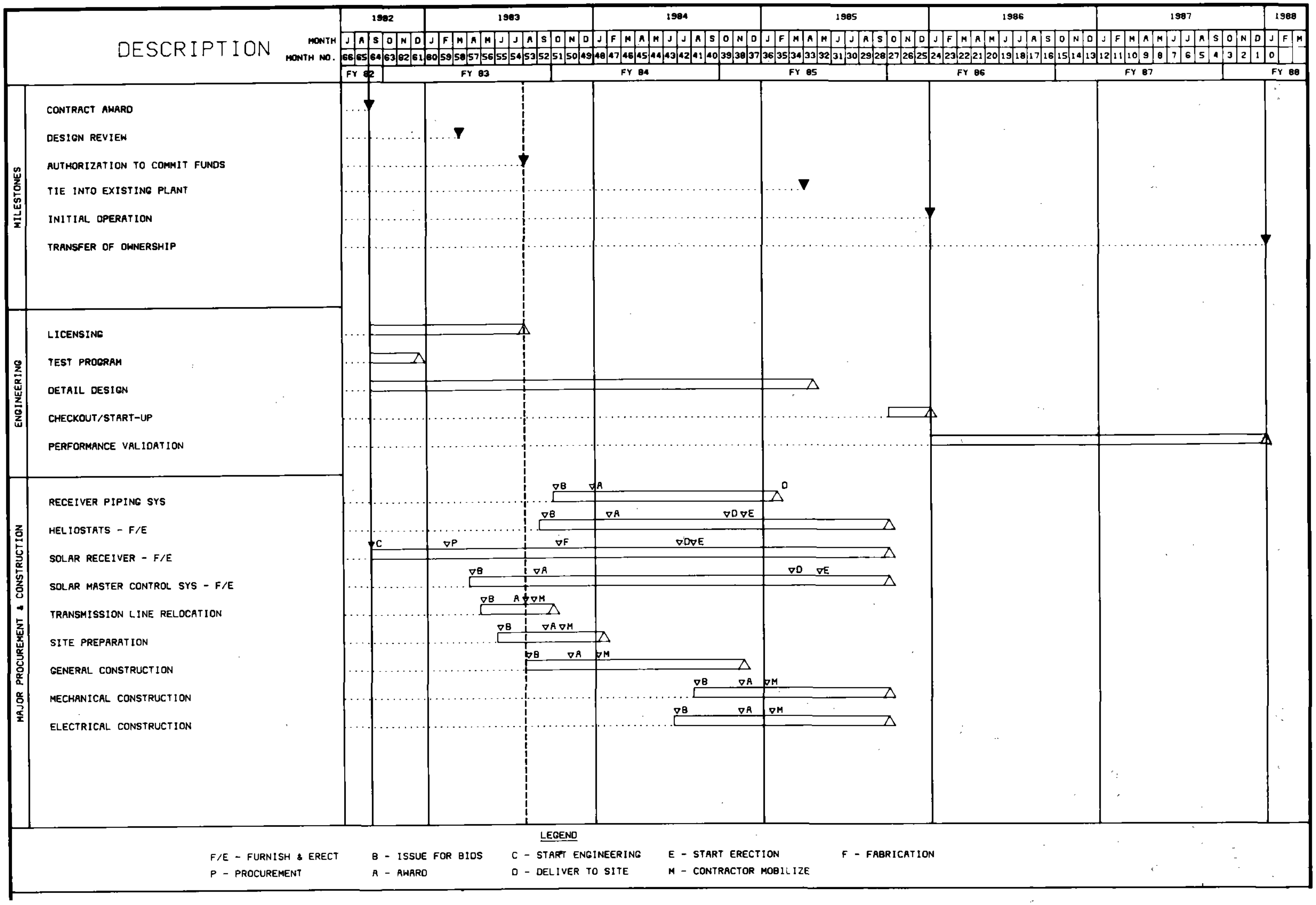


FIGURE I.7-I. MAJOR MILESTONES SCHEDULE

the AFUDC* costs are computed and the total cash flow requirements determined.

The roles of key participants in the development plan activities are a combination of traditional power industry working relationships and unique arrangement necessitated by the experimental nature of the solar cogeneration facility. The working relationships among Western Power, Black & Veatch, Babcock & Wilcox and other equipment suppliers and contractors will essentially follow conventional power industry practice. That is, Western Power will serve as owner and operator of the solar facility. Black & Veatch will provide design and project management services to Western Power; these services will include engineering, procurement, and construction management. Babcock & Wilcox will be the supplier of the solar receiver and make any needed modifications to the existing fossil boiler. Other equipment suppliers and construction contractors will fill their traditional roles.

The involvement of DOE in the development plan requires a few adjustments to the conventional working relationships. As the major investor, DOE will share decision-making responsibilities with Western Power; in this unique working agreement, Western Power will be the prime contractor to DOE. In addition to its typical role, Black & Veatch will serve as a subcontractor to Western Power and provide project management services for the Western Power contract with DOE. In order to meet the 1986 operational date, the solar receiver, along with estimates of its performance, will be furnished sole source by Babcock & Wilcox. This arrangement is necessary because of the lead times associated with detailed design of the receiver, procurement of receiver materials, fabrication of receiver panels, and erection of the receiver at the site. Other equipment and construction contracts will be procured on a fixed price, competitive bid basis to minimize cost.

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*Allowance for Funds Used During Construction.

1.8 SITE OWNER'S ASSESSMENT

Western Power is predominantly a gas burning utility, with oil as a secondary fuel; therefore, the oil embargo and severe gas curtailments of the mid-1970's have had a major influence on the system. This, along with the enactment of the Fuel Use Act of 1978 and the country's continued dependence on foreign oil, are indicators that other sources of energy must be developed.

Because gas and oil are depleting and expensive resources, the option of converting Western Power generating units to coal was reviewed. Use of coal at the Cimarron River Station would involve major reconstruction of the existing plant; but, the major deterrent to coal use is the fact that the existing plant is a 60 MW unit, which is far too small for economic coal conversion. The emission control equipment needed to meet environmental requirements and coal handling facilities for this size unit are just not an economic alternative.

Confronted with limited fuel options, the idea of solar energy stands out as an alternative energy source. For our application, it has several major advantages. First, the daily output curve of a solar plant is much like the system daily load curve. Secondly, it can be constructed faster and in smaller increments than a coal-fired plant. Third, it is readily adaptable to retrofit existing gas-fired facilities, shifting the source of energy from currently limited gas to infinite solar.

At the present time, relative cost appears to be the major disadvantage. Current solar capital requirements are not competitive with that required to build comparable coal-fired systems. The difference must be considered in planning actions despite the ultimate advantage of sparing finite fossil fuels and helping prepare for new avenues of energy supply. Western Power is hopeful that a cost sharing arrangement will be provided for supportive funds necessary to balance our cost and further develop solar energy.

The second solar problem is the loss of output caused by cloud interruptions. The operating problems caused by solar interruptions can be solved with an existing unit. One of the trade studies for this project considered potential storage systems. In all cases, the addition of storage only increased the lifetime cost and the complexity of the system. Western Power feels that parallel operation, at least in the development stages, provides a more flexible, more reliable and less expensive system. It should hold the most potential for economic solar applications in the near term.

The Western Power Cimarron River Station is in the heart of the high plains. It is surrounded by pastures, located in the Cimarron River Valley, 18 kilometers (11 miles) northeast of Liberal, along with two other major industrial complexes: National Helium Corporation and Panhandle Eastern Pipe Line Company. This remote location, along with its rolling landscape, is truly ideal for solar application. It has good access for construction and for the many interested visitors that the facility will attract.

The high plains area of western Kansas lends itself as an appropriate location for use of solar energy. Direct normal annual average insolation is approximately 6.1 kW/ m^2 day. The terrain is open and has vast areas that are basically unproductive. The installation of a large collector field will not significantly affect the local ecology, scenic attractions or other land uses. Due to the fact that solar power emits no pollutants, this project will not affect local air or water quality.

This conceptual design study has gone into considerable detail, examining the possibility of supplementing our Cimarron River Station's fuel supply with solar. The end result is a water/steam receiver system that parallels the existing gas-fired boiler. One of our major requirements in the beginning of the study was that the system must have very high reliability and assured performance. We feel that this system meets that requirement and is operable, reliable and a significant demonstration of solar potential.

Every effort has been made to design a system that is simple and cost effective. The water/steam technology has been well proven and, in Western's opinion, has the highest probability of being built on schedule and within budget. The simple design has helped reduce the risk of failure and of poor performance which would be very detrimental to the solar concept. Basic utility industry design will greatly simplify operator training, reduce operating problems and provide operation safety.

Western Power believes that realistic costs have been used and system benefits have been fairly assessed in the economic analysis. Even though the analysis does not show solar to be cost competitive, it should be noted that this is an R&D facility and, by continual systems improvements and volume production, the cost of solar could become competitive with oil or gas generation in the foreseeable future.

Western Power is enthusiastic about the study results. It is a system that will work; it will provide a creditable demonstration of the potential of solar energy; and it will make major advancements to solar technology and assist the commercialization of solar subsystems, thereby, improving solar's economic competitiveness.