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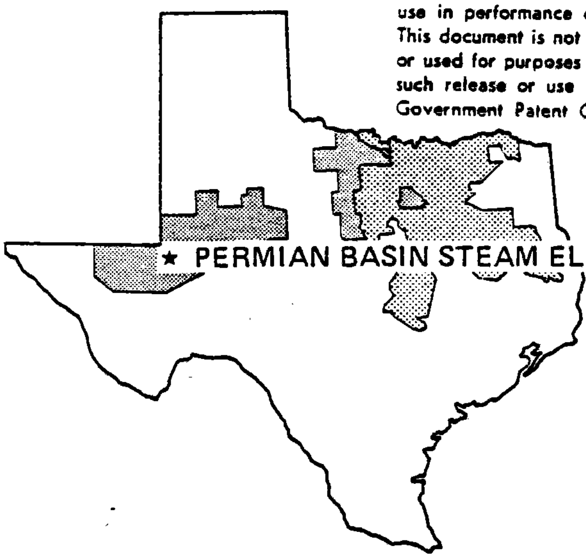
VOL II

SOLAR REPOWERING SYSTEM FOR TEXAS ELECTRIC SERVICE COMPANY PERMIAN BASIN STEAM ELECTRIC STATION UNIT NO.5 FINAL REPORT



VOLUME II
SOLAR REPOWERING CONCEPTUAL DESIGN

Rockwell International
Energy Systems Group

TEXAS ELECTRIC SERVICE COMPANY

35-0109 VOL II

ESG-80-22
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JULY 15, 1980

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~~FINAL REPORT~~
TABLE OF CONTENTS

FINAL REPORT
TABLE OF CONTENTS
(Continued)

FINAL REPORT
TABLE OF CONTENTS
(Continued)

VOLUME III

APPENDICES

APPENDIX A - SYSTEM REQUIREMENTS SPECIFICATION

APPENDIX B - ~~DESIGN DATA SHEETS~~ CONCEPTUAL DESIGN DATA

~~APPENDIX C - COST DATA BACKUP SHEETS~~

PREFACE

This report is submitted by the Rockwell International Energy Systems Group to the Department of Energy under Contract DE-AC03-79SF10607 as final documentation. This final report summarizes the analyses, design, planning, and cost efforts performed between September 27, 1979, and July 15, 1980. The report is submitted in three volumes as follows:

Volume I	Executive Summary
Volume II	Solar Repowering Conceptual Design
Volume III	Appendices

Organizations and personnel contributing to this conceptual design program and to the final report are as follows.

Energy Systems Group - T. H. Springer, Project Manager; T. L. Johnson, Project Engineer; W. W. Willcox, System Engineer; J. Ives, Lead Engineer, Steam Generator Components; S. Lee, Lead Engineer, Master Control Subsystem

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Stearns-Roger Services, Inc. - W. R. Lang, Project Manager; A. W. McKenzie, Principal Author

Title:	Solar Repowering Systems for Texas Electric Service Company, Permian Basin Steam Electric Station Unit 5
Contract Number:	DE-AC03-79SF10607
Contract Amount:	$288,661
Period of Performance:	September 27, 1979, to July 15, 1980
Prime Contractor:	Rockwell International Corporation Energy Systems Group 8900 De Soto Avenue Canoga Park, California 91304
Utility Partner:	Texas Electric Service Company Post Office Box 970 Fort Worth, Texas 17601
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2.0 INTRODUCTION

This report presents the result of a conceptual design study to repower the Texas Electric Service Company (TESCO) Permian Basin Steam Electric Station Unit 5 with an advanced solar central receiver thermal power system using liquid sodium as the heat transport fluid. This repowering application is estimated to replace the burning of natural gas equivalent to 191,000 barrels of oil per year.

The solar central receiver system consists of a receiver absorber surface mounted on a tower which is surrounded by a field of heliostats (mirrors) such as shown in Figure 2-1. As the heliostats track the sun, the solar radiation is reflected by the mirror surface to the receiver on the tower. Solar energy in the form of heat is absorbed by the liquid sodium flowing through the receiver. Liquid sodium is an excellent heat transfer fluid because of its high thermal conductivity, remains liquid for the temperature range of this application, and the sodium technology is well developed. The resulting system advantages from these characteristics of sodium are that the receiver is smaller and lighter in weight, a single-phase fluid simplifies receiver operation, reheat is readily accomplished, and thermal storage is easily incorporated as tanks of liquid sodium. With thermal storage in this manner, complete thermal buffering between the receiver and steam generator is accomplished to minimize the effects of receiver thermal transients. Unit 5 is an intermediate-load plant that employs a reheat steam cycle with a net power output of 115 MWe.

2.1 STUDY OBJECTIVE

The objective of this study as given by the Request for Quote is to develop site specific conceptual designs that (a) provide practical and effective use of solar energy for repowering of electric power plants, (b) have the potential for construction and operation by 1985, (c) make maximum use of existing solar thermal technology, and (d) provide the best possible economics for the overall plant application. A solar repowered plant is one that uses solar energy to partially or completely replace oil or natural gas as an energy source.

Specific tasks directed toward the above objectives include:

1) Preparation of a system requirements specification for this repowering application.
2) Select a site specific repowering configuration based on criteria to optimize performance and minimize capital cost.
3) Perform a conceptual design of the selected configuration in sufficient detail to accomplish performance and capital cost estimates.
4) Develop plant performance estimates based on the conceptual design configuration at the Permian Basin site.
5) Develop plant cost estimates and economic analysis. The plant capital cost estimate using the conceptual design characteristics together with the plant performance estimates and assumptions regarding fuel costs, interest rates, inflation rates, and lifetime, allow economic parameters to be developed to asses the value of the plant.
6) Prepare a development plan to identify the design and instruction phases and activities to attain an operating solar repowered plant by 1985.

2.2 TECHNICAL APPROACH AND UNIT SELECTION

The technical approach which was undertaken to select an optimum solar configuration and optimum unit consists of several design and trade study iterations on a reference design.

The Permian Basin Steam Electric Station Unit 5 was chosen as the best unit on the Texas Electric System for several reasons. There is adequate company-owned land to build a heliostat field for approximately 50-megawatts peak solar-generated electrical power. The land is presently unoccupied with no surface utilization presently in effect or planned for the future. The unit size, 115-megawatts capacity, is large enough to permit repowering with 50 to 60 megawatts and yet operate on the fossil fuel at or above the minimum fossil boiler output of 30 megawatts. The plant site is also the best company-owned site from the standpoint of high-insolation levels. An alternate fuel is needed for the western portion of Texas Electric's service area in order to reduce the dependency of part of the system on natural gas-fired generation.

Several trade studies were completed to provide an optimized design as discussed in 3.0. Various power generation levels, storage capacities, field layouts, and central receiver tower construction methods were studied. Different operating methods were studied to determine the optimum manner to operate the system for different scenarios. The economic assessment for different operating methodologies was determined through use of a Texas Electric economics computer program, as well as the JPL solar economic procedure.

2.3 Site Location

Permian Basin Steam Electric Station is located approximately 6.5 kilometers (4 miles) west of Monahans, Texas, in Ward County (FIGURE 2-2). This location is also 64 kilometers (40 miles) west of Odessa, Texas. The main line right-of-way of the Texas and Pacific Railway adjoins and runs parallel to the southern property line. U. S. Highway Route 80 also runs parallel to the railway and is adjacent to the railway on the south. Interstate Highway 20 is located approximately 0.4 kilometer (0.25 mile) south of U. S. Highway Route 80 at the plant site.

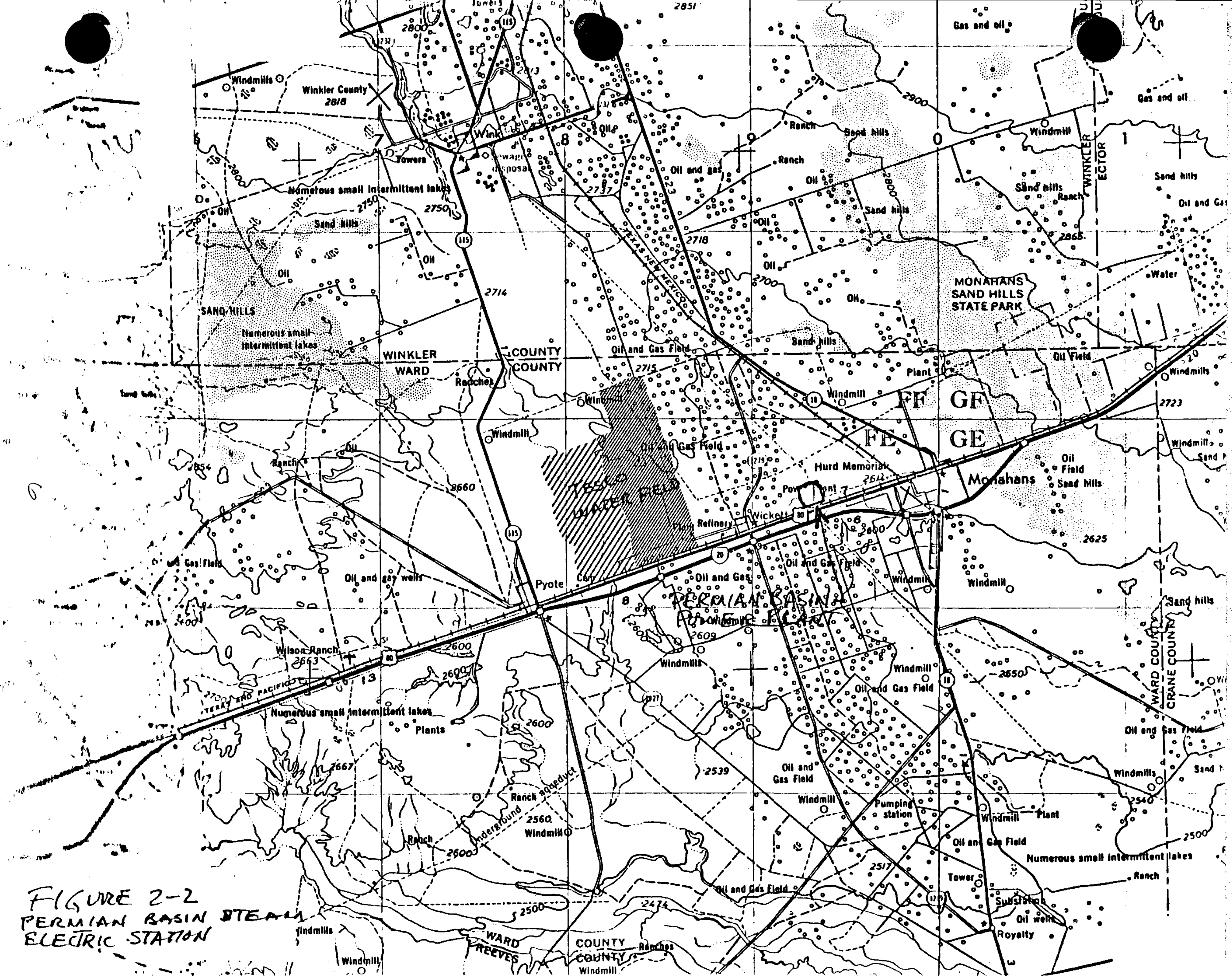

FIGURE 2-2
PERMIAN BASIN STEAM
ELECTRIC STATION

2.4 Site Geography

Most of the land required for the heliostat field is available. The existing power plant occupies the northwest quadrant of Section 100. The entire section of land, 2.59 X 10^6 square meters (640 acres), is owned by Texas Electric Service Company. ~~The entire eastern half of the section is virtually free of obstructions and is available for use to construct the heliostat field~~. The section is shown on the property layout, FIGURE 2-3 Approximately 1.30 X 10^6 square meters (320 acres) are available east of the present plant to locate the solar receiver tower and heliostat field.

The existing power plant is sited on gently sloping terrain. The base of the Unit #5 boiler is at an elevation of 808.79 meters (2653.5 feet) above sea level. The terrain falls from the northwest to southeast at a slope of 1 percent. The existing power plant with its cooling towers, water tanks, oil storage tanks, and switching station structures occupy the northwestern quarter of Section 100. The plant and other installations occupy approximately 6.475 X 10^5 square meters (160 acres).

The elevator of the Unit #6 is a reference point for location of the plant. The reference point is 31° 35' 08" North - Latitude and 102° 57' 41" West - Longitude.

The existing power plant is located on the Pyote series of soils. The Pyote series consists of deep, noncalcareous, sandy soils. These are gently undulating soils on upland plains. They formed in sandy unconsolidated sediment of eolian or alluvial origin. The surface is plane to undulating.

In a representative profile, the upper 0.305 meter (1 foot) of the surface layer is yellowish-red, noncalcareous loamy fine sand. Below this is reddish-brown, noncalcareous loamy sand 0.559 meter (22 inches) thick. The next layer, to a depth of 1.27 meters (50 inches), is reddish-brown, noncalcareous fine

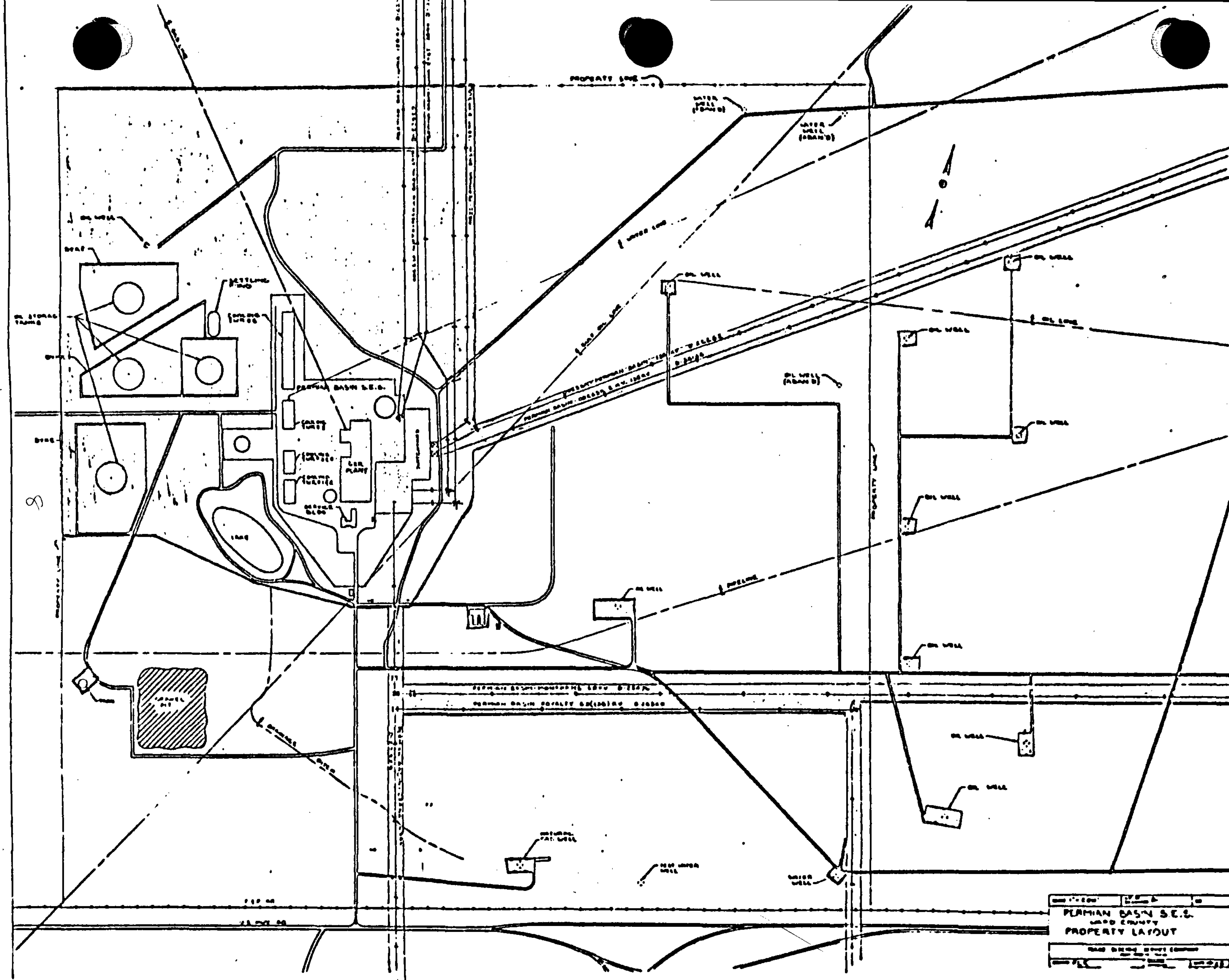

FIGURE 2-3 Permian Basin Property Layout

sandy loam. Yellowish-red fine sandy loam extends to a depth of 1.575 meters (62 inches). The next lower layer, which reaches to a depth of 1.93 meters (76 inches), is pink, calcareous fine sandy loam that contains threads, films, and soft masses of calcium carbonate.

Pyote soils are well drained. Runoff is none to very slow, and permeability is moderately rapid. These soils are free of salts and alkali. Slopes are 1 to 4 per cent.

The hazard of soil blowing is severe on these soils.

The proposed central receiver tower site and heliostat field site are located on the Wickett series of soils. The Wickett series consists of noncalcareous sandy and loamy soils that are moderately deep over indurated caliche. These soils formed in a sandy and loamy eolian mantle over thick beds of caliche that is indurated in the upper part. Slopes range from 1 to 3 per cent. The surface is plane to gently undulating.

In a representative profile, the surface layer is reddish-brown, noncalcareous loamy fine sand about 0.356 meter (14 inches) thick. The next layer is yellowish-red, noncalcareous fine sandy loam about 0.406 meter (16 inches) thick. The underlying material is weakly cemented to indurated caliche that extends to a depth of 0.965 meter (38 inches).

Wickett soils are well drained. Runoff is very slow, and permeability is moderately rapid. These soils are free of salts and alkali.

The caliche under these soils is excellent as a source of roadbuilding material. The hazard of soil blowing is severe on these soils.

2.5 Climate

The weather data station nearest the Permian Basin Plant is located at the Midland-Odessa Regional Airport. This official weather station is 80.46 km (50 miles) to the east of the plant site and is midway between Midland and Odessa, Texas. The climate at the Permian Basin site does differ from that found at the weather station and wherever possible additional data taken at the plant site itself is included. The general weather data pertaining to the Permian Basin area is given in Table 2 - 1. This table includes temperature extremes, precipitation amounts, and average wind data. One should note that in addition to the long term extremes found during 29 years of measurements, the weather data from 1977 and 1978 is also included. As seen from these figures, the general weather at the plant site is fairly mild with hot summers, small annual snowfalls, and low yearly precipitation totals. The wind has reached a maximum of 29.45 m/s (67 mph) in 23 years and the average wind is 4.83 m/s (10.8 mph). The normal yearly precipitation is 0.343 m (13.51 in) with an average of 52 days in the year having precipitation of 2.54 x 10^{-4} m (0.01 in) or more. Temperature extremes have been recorded ranging from 42.8 C (109 F) as the record high to -22.2 C (-8F) as the record low.

In addition to the average wind data given in Table 2 - 1, the wind speed data is broken into monthly peak winds in Table 2 - 2. An examination of the annual precentage frequency of wind at Midland is listed in Figure 2 - 4 by speed groups. The wind speed is between 1.79 m/s (4 mph) and 8.05 m/s (18 mph) for 86% of the time. During 1979 wind direction data was recorded at the Permian Plant site and this is shown in the Wind Roses of Figures 2-5 to 2-6. an easterly to southeasterly wind seems to dominate many of the months.

The collection of direct insolation data at Midland was initiated in the last two years and this data is incomplete. In order to obtain a more complete representation of the insolation characteristics at the Permian Basin site, the data for Abilene, Amarillo, and Midland, Texas plus Roswell, New Mexico were examined. Since direct insolation data is not available at these sites, the percentage possible sun and the percentage sky cover were used. The comparison of this data by month is shown in Table 2 - 3. An average of the percentage possible sun and the percent possible sky cover gives an annual yearly average of 77.4%. Useful solar insolation is considered to be available when the sun is 10^{o} above the horizon. On this basis, there are 3750 hours of possible sunshine per year. Also shown in Table 2 - 4, the mean daily solar radiation at Midland is given in both KWH/m^2 - day and Langleys. Finally, the number of clear hours during the daylight periods is shown for each month in Table 2 - 5. This data was taken at the Permian Basin site during 1979 and shows that 71.2% of the daylight hours were "clear". This data was taken visually by plant operators on an hourly basis.

Direct solar radiation readings are also being taken at the Permian Basin site. A pyreheliometer was set up at the site on March 26, 1980. A pyreheliometer is an instrument that measures the direct solar radiation received on a surface area normal to the sun's rays. The data is being taken as a daily integrated insolation reading and recorded every 10 min on a paper tape from sunrise to sunset. As of this date, 59 days have been recorded. Table 2-6 is a summary of the comparison with the direct readings with the University of Houston insolation model. As weather can fluctuate significantly from year to year, it is not surprising to see some differences. However, the clear day insolation and maximum heat flux showed a very good comparison. The average insolation for the 59 days was 7.00 kW-hr/m^2-day vs 8.00 kW-hr/m^2-day from the U of H model. This represents a 12% reduction. However, a comparison on a monty-by-month basis shows considerable scatter with May being a particularly bad month.

At this time, the U of H model seems to be a reasonable representation. TESCO will continue to take readings, and an effort will be made to correlate with the Midland weather station when its data becomes available. Appendix C contains a listing of the data taken and some sample insolation curves vs time of day.

Table 2 – 1
Weather Data Pertaining
to the Permian Basin Area

Temperature Extremes:

-Highest of Record (29 Yrs) = 42.7 C (109F)

-Lowest of Record (29 Yrs) =-22.2 C (-8F)

(1978) Annual Average Temperature: 16.8 C (62.6F)

-High = 39.4C (103F) (July 17)

-Low =-10.6C (13F) (Dec. 9)

Total Annual Precipitation: .439 m (17.29 in)

(1977) Annual Average Temperature: 18.7C (65.7F)

-High = 41.1C (106F) (Aug. 23) (+1.8 Departure)

-Low =-13.3 C (8F) (Jan. 10)

Total Annual Precipitation: .174 m (6.84 in)

Precipitation:

-Mean No. of Days With Precipitation 2.54 x 10 -4 m (0.01 in) or more = 52 (29 yrs)

-Snowfall = .09 m (3.5 in)

-Normal Precipitation = .343 m (13.51 in) (30 yrs)

Wind:

-Average = 4.83 m/s (10.8 mph) (23 Yrs)

-Maximum = 29.95 m/s (67 mph) (23 Yrs)

Table 2 - 2
Fastest Wind Speed, Monthly and Annual
Midland, Texas

	m/s	mph		m/s	mph
January	18.3	41	July	12.9	29
February	29.9	67	August	13.4	30
March	21.5	48	September	17.9	40
April	17.0	38	October	14.3	32
May	23.2	52	November	14.3	32
June	25.9	58	December	16.5	37

Annual: 29.9 m/s; 67 mph

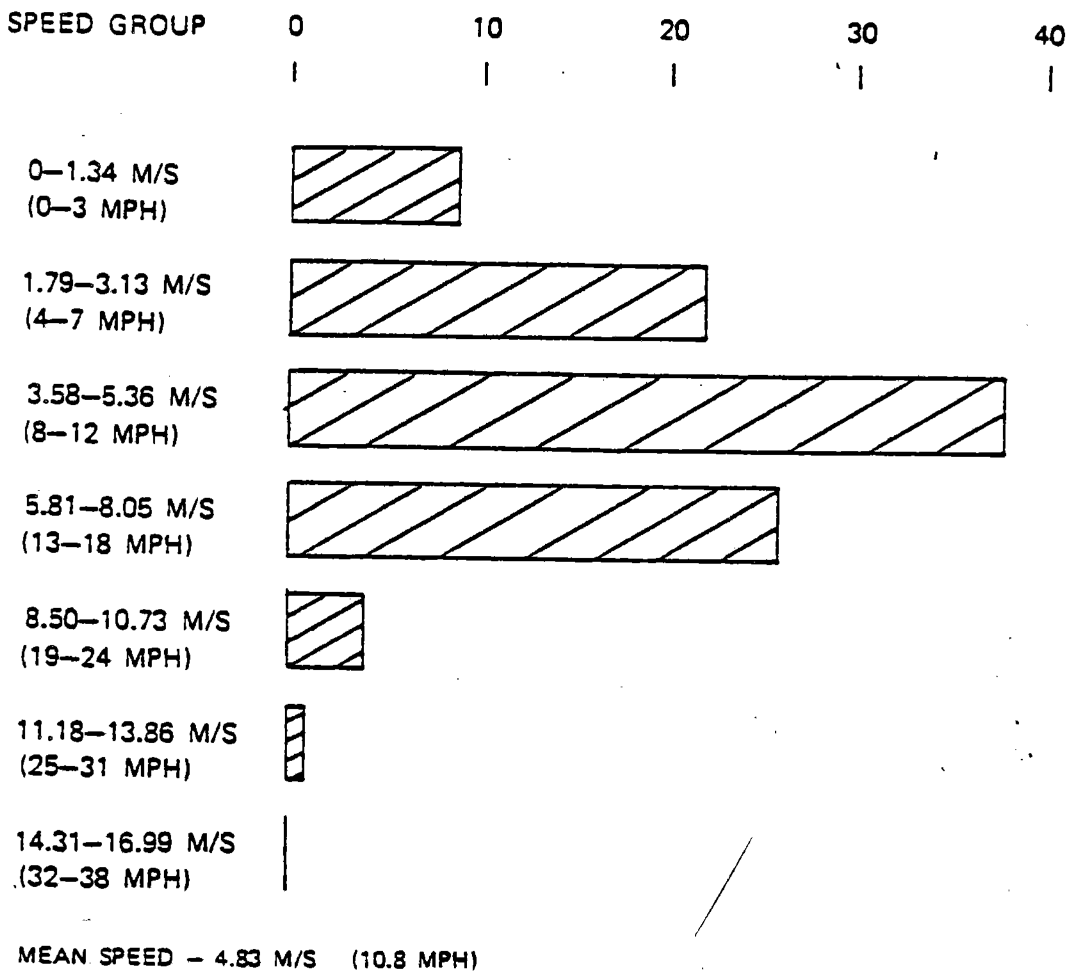

FIGURE 2-4
THE GRAPH OF ANNUAL PERCENTAGE
FREQUENCY OF WIND BY SPEED GROUPS

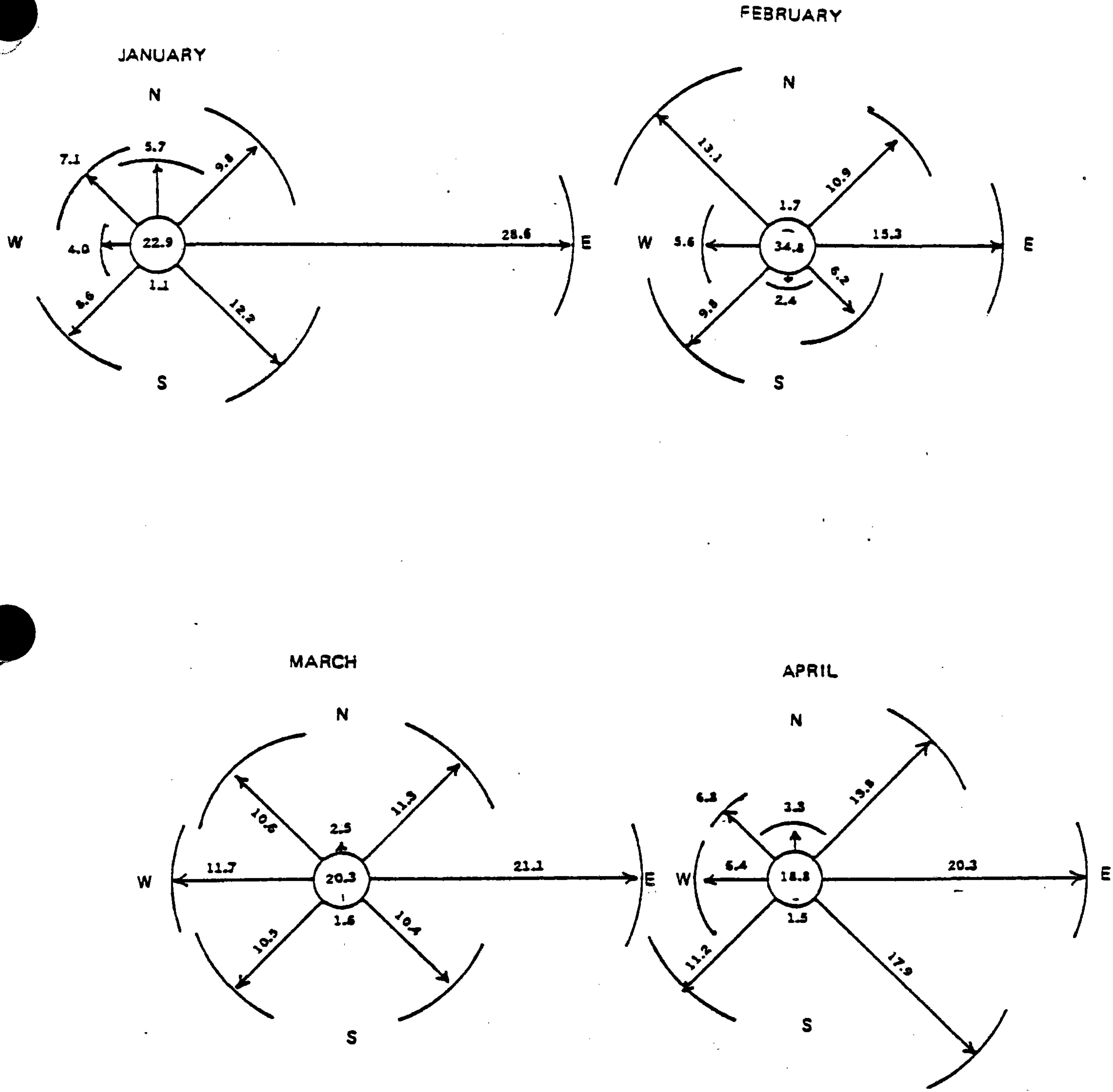

FIGURE 2-4
PERCENTAGE OF TIME WIND BLEW FROM THE
8 COMPASS POINTS DURING JANUARY – APRIL

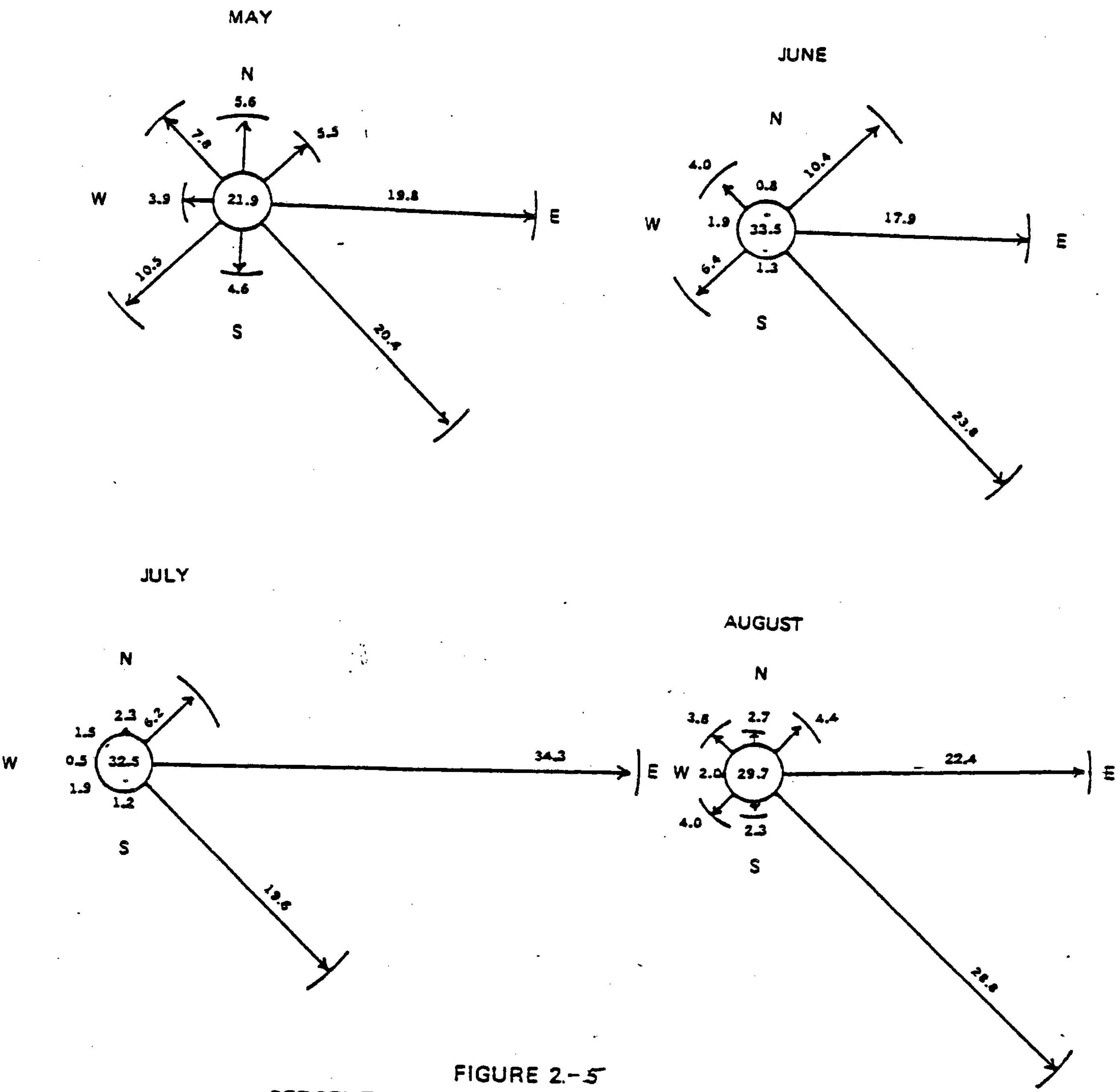

FIGURE 2.-5
PERCENTAGE OF TIME WIND BLEW FROM THE
8 COMPASS POINTS DURING MAY – AUGUST

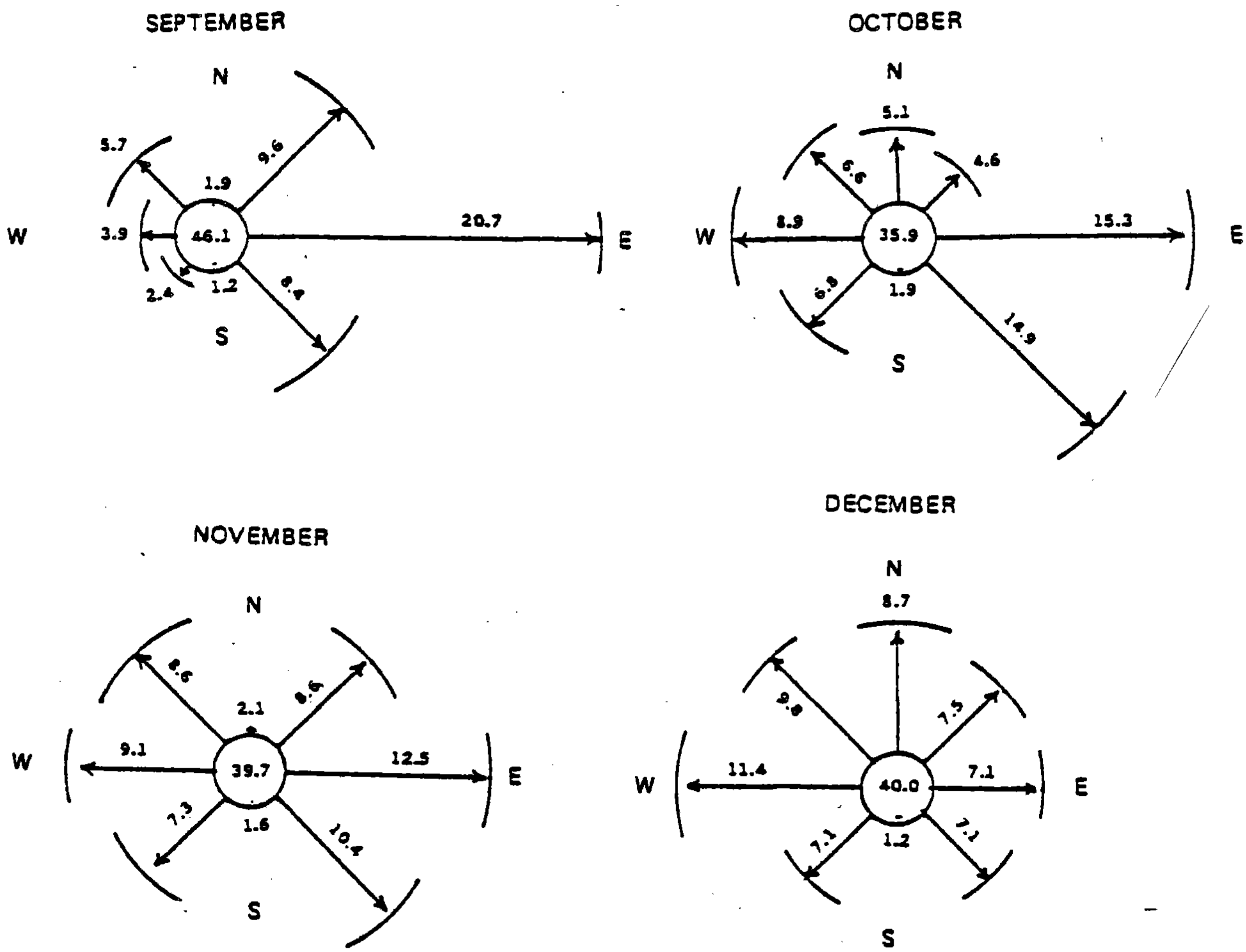

FIGURE 2-6
PRECENTAGE OF TIME WIND BLEW
FROM THE 8 COMPASS POINTS DURING SEPTEMBER – DECEMBER

TABLE 2-.3

PERMIAN BASIN (MONAHANS) INSOLATION CHARACTERISTICS

	J	F	M	A	M	J	J	A	S	O	N	D	Yearly Ave.
% Possible Sun													
Abilene	64	68	73	66	73	86	85	85	73	71	72	66	73
Amarillo	71	71	75	75	75	82	81	81	79	76	76	70	76
Roswell	69	72	75	77	76	80	76	75	74	74	74	69	74
(A) Monahans	68	70	74	73	75	83	80	80	75	74	74	68	74.5
% Sky Cover													
Roswell	41	40	40	38	39	32	36	36	34	33	33	39	37
Midland	54	53	51	49	47	38	46	39	35	36	35	43	44
Monahans	47	47	45	43	43	35	41	38	34	34	34	41	40
(B) $\sin\frac{\pi}{20}$ (1 - % Cover)	74	74	76	78	78	85	80	83	86	86	86	80	80.5
AVERAGE, [(A) + (B)]/2	71	72	75	75	76	84	80	82	80	80	80	74	77.4

TABLE 2-4

MEAN DAILY SOLAR RADIATION
MIDLAND, TEXAS

Month	kWh/m^2-day	Langleys
January	5.29	457
February	6.10	527
March	7.10	613
April	7.66	661
May	8.06	696
June	8.86	765
July	8.09	699
August	7.78	672
September	6.94	599
October	6.26	541
November	5.74	496
December	5.16	449
Annual	6.90	596

Table 2 - 5
Per Cent Clear Hours Observed
Visually at Permian Basin Plant

Month	Per Cent Clear
January	41.6
February	65.1
March	65.2
April	68.6
May	60.5
June	75.0
July	76.1
August	73.4
September	83.3
October	95.3
November	82.1
December	61.6
Year	71.2

TABLE 2-6

DIRECT INSOLATION MEASUREMENTS AT PERMIAN BASIN

	Units	Pyreheliometer	U of H Model*
Clear Day Insolation			
March (3 days)	kWh/m^2-day	9.92	9.96
April (4 days)	kWh/m^2-day	10.46	10.65
May (3 days)	kWh/m^2-day	10.69	11.00
Avg. Day Insolation			
March (6 days)	kWh/m^2-day	8.29	6.99
April (28 days)	kWh/m^2-day	7.60	7.94
May (25 days)	kWh/m^2-day	6.01	8.31
Total Time Period (59 days)	kWh/m^2-day	7.00	8.00
Max. Heat Flux	W/m^2	1032 (Mar 24)	1000

*U of H insolation adjusted for sunrise to sunset.

2.6 Existing Plant Description

Permian Basin Steam Electric Station Unit #5 is utilized as an intermediate - load unit and employs a reheat steam cycle with a net maximum electrical power output of 115.1 megawatts.

Unit #5 is north of Unit 4 at an approximate elevation of 808.8 meters (2653.5 feet). The turbine operating level, 4.9 meters (16 feet) above ground elevation, serves as a base level for all major equipment such as fans, feed-water pumps, feedwater heaters, condensate pumps, switchgear, compressors, etc., and is continuous with the operating level of units 1 through 4. Unit #5 consists of a thermodynamically independent steam generating unit, a turbo-generator, a separate cooling tower, and a water collecting system. A condensate tank is located between the boilers for units #4 and #5. A water treatment plant and demineralizer is located approximately 76.2 meters (250 feet) west of the Unit #5 boiler.

For Unit #5, a Riley Stoker Corporation steam generating pressurized unit burning either natural gas or fuel oil supplies steam to a Westinghouse Electric Corporation turbogenerator with a capacity rating of 115,000 kilowatts. The turbine exhausts from each side into a Westinghouse twin shell 5574 square meters (60,000 square feet) two-pass deaerating type surface condensing plant. Cooling water is supplied by a collecting system from a water well field located west of the plant approximately 11.26 kilometers (7 miles). ~~The water is cooled by recirculating through a Fluor Corporation redwood cooling tower with a capacity of 4.29 cubic meters per second (68,000 gallons per minute).~~

Unit #5 began trial operation on April 19, 1958. The unit was accepted for commercial operation on June 1, 1958.

A concrete basin from the cooling tower has a capacity of 1,402 cubic meters (49,504 cubic feet). Water is normally maintained at a depth of .940

meter (3 feet - 1 inch), for a capacity of 1081 cubic meters (38159 cubic feet or 285,408 gallons) by a weir box overflow and by a leveltrol.

The cooling tower was furnished by Fluor Products Company. It is a six cell double-fan, induced draft Unit ~~cooling tower~~, constructed of California redwood lumber. The tower includes twelve 5.49 meter (18 feet) diameter, 41.6 kilowatt (55.8 bhp) fans with gear reducers. The 44.8 kilowatt (60 hp) motors for the fans were furnished by Westinghouse Electric Corporation. The cooling tower is designed to cool 4.29 cubic meters/second (68,000 gallons/minute) from a temperature of 42.3 deg C (108.2 deg F) to 32.2 deg C (90 deg F) with an entering wet bulb temperature of 24.4 deg C (76 deg F).

Oil suction and return connections supply fuel oil to Unit #5 from the 318 cubic meters (2000 barrels) day oil tank. The oil is pumped to a heater by two DeLaval rotary type fuel oil pumps, designed to pump 7.7×10^{-3} cubic meters/second (122 gallons/minute) of fuel oil. The heater is a horizontal fixed tube sheet type heater designed to heat 7.56 kilograms/second (60,000 pounds (mass)/hour) from 37.8 deg C (100 deg F) to 107.2 deg C (225 deg F), using extraction steam at 191.6 deg C (376.9 deg F) and 1.14×10^{6} Pascals (165 psig). A propane gas system has been installed for igniting the burners when natural gas is not available.

Natural gas is supplied from the regulating station to the boiler. An orifice is supplied in the pipe riser for the combustion control system and for measuring the fuel supplied to Unit #5. The natural gas is supplied to the burners through a 0.305 meter (12 inch) ring header with a 0.152 meter (6 inch) line at each burner. Two 0.076 meter (3 inch) branches supply each burner tube.

Twelve Riley Stoker directional flame burners, combination gas and mechanical atomizing fuel oil, are installed in the boiler. One row of six burners is at the front of the boiler, and a row of six burners is on the same level at the rear of the boiler. Burners include air register vanes with provision for tight shut-off. Remote semi-automatic gas burner control is provided from the Boiler Turbine Generator (BTG) board in the Unit #6 control room. The control system provides open-shut control of the air registers, off-on control of the pilot ignitors, open and closing of gas cocks and the gas stop cocks, remote electronic flame indication for each ignitor and burner, and automatic burner sequence cut-off. Starting is accomplished by means of Riley gas electric ignitors, using natural gas or propane as secondary fuel when firing on fuel oil.

The two forced draft fans were manufactured by American Blower Company. They are driven by Westinghouse Electric Company 522.2 kilowatt (700 hp), 900 rpm, 2300 volt motors. Forced draft fan inlet vanes and outlet dampers are controlled by drive units supplied by Republic Flow Meter Company. Each fan is designed to deliver 72.7 cubic meters/second (154,000 CFM) of air at 43.3 deg C (110 deg F) at a static outlet pressure of 5365.4 Pa (21.6 inches of H_2O) at full load.

The single drum front and rear fired steam generator is designed to deliver 103.9 kilograms/second (825,000 lbm/hour) of steam continuously at 10.7×10^6 Pascals (1550 psig), 540.6 deg C (1005 deg F) steam temperature at the superheater outlet, and reheat 91.7 kilograms/second (728,000 lbm/hour) from 380.6 deg c (717 deg F) to 540.6 deg C (1005 deg F) when supplied with feedwater at 236.7 deg C (458 deg F) firing on gas or oil.

Heating surface of the steam generating unit are:

Boiler water heating surface, excluding water cooled furnace	418 m^2 (4,500 ft^2)
Superheater surface	2,830 m^2 (30,460 ft^2)
Water cooled furnace heating surface	1,008 m^2 (10,846 ft2)

Economizer heating surface	1,734 m^2 (18,660 ft^2)
Reheater surface	2,244 m^2 (24,150 ft^2)
Airheater surface	12,263 m^2 (132,000 ft^2)

The economizer is of the convection type with a continuous tube heating surface consisting of 30 elements in the upper by-pass section and 117 tubes in the lower economizer.

The two airheaters are horizontal flow Ljungstrom types, with ~~They have~~ 6,142 m^2 (66,000 ft^2) of heating surface each, and are rotated by 5.6 kw (7.5 hp) General Electric motors geared to turn at 1.78 rpm.

An automatic combustion control system including controllers, automatic valves, operating units, selector valves, gauges, and other equipment was furnished by Republic Flow Meter Company. The system adjusts fuel supply, air supply, and furnace draft in accordance with metered requirements. A master controller takes steam flow indication from the flow nozzle in the main steam line and translates any change in steam pressure to master loading pressure and supplies this to the fuel and air flow regulators. Boiler air flow is totalized and measured by calibration of the pressure differential across venturis installed in two ducts from the airheater to the boiler windbox. Total air for combustion is controlled by regulators actuating the inlet louvers and outlet dampers on the forced draft fans which receive their impulses from a differential master regulator.

The firing aisle cubicle contains transmitter pressure gauges for drum, feedwater, fuel oil and natural gas supply, and fuel oil and natural gas at burners; transmitters for superheat and reheat temperature; recorders for superheat and reheat temperatures, totalized air flow, oxygen, and combustibles; drum level alarms; steam temperature control relays and purge relay equipment. This cubicle was furnished by Panellit, Incorporated.

Two instrument air compressors complete with an air receiver, after coolers with moisture separators and drain traps were furnished by Chicago Pneumatic Tool Company.

Five extraction feedwater heaters are used on this unit. The heaters were furnished by Westinghouse Electric Corporation. The crossover heater receives steam from the 10th stage of the high pressure turbine. It has a heating surface of 368.4 m^2 (3965 ft^2) and heats 105.6 kilograms/second (838,000 lbs/hour) of feedwater from 191.2 deg C (376.1 deg F) to 236.3 deg C (457.4 deg F) using steam at 3.16×10^6 Pascals (459.3 psia) and enthalpy of 6.56×10^5 Joules/kilogram (1371 BTU/lb). The high pressure heater receives steam from the 17th stage extraction of the reheat section of the turbine and from drains from the crossover heater. It has a heating surface of 345.6 m^2 (3720 ft^2) and heats 105.7 kilograms/second (838,600 lbs/hour) of feedwater from 152.6 deg C (306.7 deg F) to 191.2 deg C (376.1 deg F) using steam at 1.3×10^6 Pascals (189.2 psia) and enthalpy of 6.79×10^5 Joules/kilogram (1420 BTU/lb). The intermediate pressure heater is supplied with steam extracted from the 21st stage of the reheat section of the turbine and drains from the crossover and/or high pressure heaters. It has a heating surface of 221.1 m^2 (2380 ft^2) and heats 86.4 kilograms/second (685,900 lbs/hr) of feedwater from 122.4 deg C (252.3 deg F) to 152.6 deg C (306.7 deg F) using steam at 5.4×10^5 Pascals (78 psia) and enthalpy of 6.33×10^5 Joules/kilogram (1322 BTU/lb). The low intermediate pressure heater is supplied with steam extracted from the 25th stage of the reheat section of the turbine. It has a heating surface of 269.4 m^2 (2900 ft^2) and heats 86.4 kilograms/second (685,900 lbs/hr) of feedwater from 91.1 deg C (195.9 deg F) to 122.4 deg C (252.3 deg F) using steam at 2.5×10^5 Pascals (35.6 psia) and enthalpy of 6.0×10^5 Joules/kilogram (1256 BTU/lb). The low pressure heater is supplied with steam extracted from the 28th stage of the low pressure turbine. It has a heating surface of 409.7 m^2 (4410 ft^2) and heats 86.4 kilograms/second (685,900 lbs/hr) of feedwater from 27 deg C (80.7 deg F) to 91.1 deg C (195.9 deg F) using steam at 8.1 x 10^4 Pascals (11.5 psia) and enthalpy of 5.6 x 10^5 Joules/kilogram (1170 BTU/lb).

For boiler make-up water, a 3.15 x 10^{-3} cubic meter/second (72,000 gallon/day) demineralizer was purchased from Graver Water Conditioning Company. The demineralizer consists of a cation unit, an anion unit, a mixed bed unit, a degasifier, a heating tank, two acid pumps, two caustic pumps, two decationized water transfer pumps, piping, instrumentation, and control panels. The unit is capable of reducing total dissolved solids from 900 parts/million to 500 parts/million and supplying 3.78 x 10^{-3} cubic meter/second (86,400 gallons/day) with an average blowdown of 5.26 x 10^{-4} cubic meters/second (500 gallons/hour).

Three Pacific 0.152 meter (6 inch) SX type BFI, 9-stage boiler feed pumping units are supplied. Each pump is designed to deliver its maximum rated capacity of 59.2 kilograms/second (470,000 lbs/hour) of 160 deg C (320 deg F) feedwater against a discharge head of 1280.2 meters (4200 ft) at an efficiency of 76%. Each pump will supply half the plant capacity of feedwater with one of the three pumps serving as standby. Each pump is driven by a Westinghouse 1.12 megawatt (1500 hp), 2300 volt motor.

Two Goulds Figure 3047F condensate transfer pumps are included in the boiler plant auxiliaries. They are 7.62 x 10-2 meter (3 inch) vertical centrifugal pumps designed to deliver 12.6 kilograms/second (100,000 lbs/hr) of condensate. They are driven by Westinghouse 5.6 kilowatt (7.5 hp), 440 volt, 1800 rpm motors.

The three element automatic feedwater control was furnished by Republic Flow Meter Company. The feedwater valve is designed to pass 118.4 kilograms/

second (940,000 lbs/hr) of water with a pressure drop of approximately 5×10^5 Pascals (75 psi). Changes in steam flow, feedwater flow, or drum level vary the output of compressed air transmitters connected to the master regulator which integrates the three elements to maintain a predetermined water level in the steam drum. Each operating unit and control valve is provided with a means of directly operating the equipment it controls, completely independent of the manual control at the panel board.

Feedwater pretreatment equipment was manufactured by the Milton Ray Company. This equipment consists principally of two pumps to handle 7.3×10^{-6} cubic meter/second (6.9 gallons/hr) each of mono-sodium phosphate, one 3.6×10^{-6} cubic meter/second (3.4 gallons/hr) pump for sodium sulfite solution, a 0.95 cubic meter (250 gallon) mixing tank with agitator for phosphate solution, and a 0.57 cubic meter (150 gallon) mixing tank with agitator for sulfite solution.

The turbogenerator with complete accessories was furnished by Westinghouse Electric Corporation. The turbine is a tandem compound double side exhaust 3600 rpm reheat condensing type with guaranteed rating 100 megawatt when supplied with steam at 10×10^6 Pascals (1450 psig), 537.8 deg C (1000 deg F), 537.8 deg C (1000 deg F) reheat with 11,820 Pascals (3.5 inches Hg) average back pressure and full five stage extraction of steam for feedwater heating and 3% evaporated make-up. The maximum expected throttle flow is 104.6 kilograms/second (830,000 lbs/hr), which is expected to produce approximately 118.5 megawatts at 5065.9 Pascals (1.5 inches Hg) back pressure. The turbine, hydrogen seal oil equipment, lube oil equipment starting panel and other appurtenances are of weatherproof outdoor construction with housing being provided over the high pressure turbine and a walk-in housing being provided for the exciter.

The inner cooled type generator has a nominal rating of 135,240 KVA at 310,345 Pascals (45 psig H_2), 0.85 power factor, 3600 rpm, 13,800 volt, 3 phase, 60 cycle, and 147,000 KVA with 413,793 Pascals (60 psi) hydrogen. A gear connected 700 KW, 250 volt, 897 rpm exciter is provided.

A condensing plant complete with auxiliaries was furnished by Westinghouse Electric Corporation. The condenser is a 5574.1 m^2 (60,000 ft ^{2}), 2 pass, twin shell, deaerating type surface condensing plant. The condensing plant is designed to maintain a back pressure of 11,753 Pascals (3.48 inches Hg) absolute at a duty of 172,919 watts (590,000 BTU/hr) when supplied with 4.1 cubic meters /second (65,000 gallons/minute) of 35 deg C (95 deg F) circulating water. The shells are rigidly connected to the turbine side exhaust piece. Incoming drains and makeup are introduced to baffles which permit deaerating of the water. Released gases are withdrawn by the steam jet air ejector.

Two vertical circulating water pumps were furnished by Westinghouse. Each pump is designed to deliver 2.1 cubic meter/second (33,500 gallons/minute) at 35 deg C (95 deg F) with an efficiency of 84%. The pumps are driven by Westinghouse 596.8 kilowatt (800 hp), 2300 volt, 514 rpm motors.

The condenser also includes three vertical pit type condensate pumps, each designed to deliver 59.2 kilogram/second (470,000 lb/hr) of condensate at 26.7 deg C (80 deg F).

A twin element two-stage steam jet air ejector with combined inter and after condenser is included as part of the condenser. Also included is one hogging ejector designed to create a vacuum in the condensers when starting up, two automatic drain traps for after condenser, and one air leakage meter.

The lubricating oil system is supplied by a 0.063 cubic meter/second (1000 gallons/minute) main oil pump driven by the main turbine shaft and one 0.028 cubic meter/second (450 gallons/minute) auxiliary oil pump driven by a

440 volt motor. There are two 17 cubic meter/second (135,000 lb/hr) turning gear oil pumps, one driven by a 440 volt AC motor and one driven by a 125 volt DC motor. These are mounted in a 11.4 cubic meter (3000 gallon) oil reservoir.

Two Goulds cooling water pumps are included. They are horizontal single stage double suction centrifugal pumps designed to deliver 0.126 cubic meters/sec (2000 gallons/minute) of water against a total head of 41.1 meters (135 feet). They are driven by Westinghouse 93.25 kilowatt (125 hp), 440 volt, 1800 rpm motors. These pumps take suction from a 3.6 cubic meter (950 gallons) cooling water tank and discharge through a cooling water heat exchanger. It cools 22 kilograms/second (175,000 lbs/hr) of condensate from 41.7 deg C (107 deg F) to 32.2 deg C (90 deg F). Makeup water for the cooling tower absorbs the heat from the cooling water in the heat exchanger.

2.7 Existing Plant Performance Summary

Permian Basin Plant Unit #5 was designed and constructed as a base load unit and placed in commercial operation on June 1, 1958. At that time, the size of the unit was correct for its consideration as a base load unit. With the addition of Permian Basin Unit #6 in 1974 and the construction of several large lignite-fired units in the eastern part of the state, the Unit #5 is no longer considered to be a base load unit.

Unit #5 was designed as a base load unit, so it cannot be economically operated as a peaking unit. The unit is used continuously during the summer peaks and also during periods of overhaul for the other, larger, units in the western part of the state.

Unit #5 operated a larger percentage of the time during 1979 than in the past few years because Unit #6 was being repaired during an extended outage. Unit #5 operated 6,663 hours during 1979 for a total net output of 377,311,000 kwh. This is an equivalent 3,278 hours at full load, or 37.42% of the time. The unit's 6,663 hours is 76.06% of the time.

Unit #5 had 5 planned outages and 3 forced outages. Those outages are as shown in Table ~~2.7.1~~ 2-6.

Table 2 - 6

Scheduled and Unscheduled Outages for Permian Basin Unit #5 - 1979

Planned Outages

1. Overhaul	302.0 hours
2. Cleaning	8.9 hours
3. Overhaul	652.5 hours
4. Feedwater heater leak	31.3 hours
5. Cleaning	10.9 hours
Total	1 005.6 hours

Table 2-6 (cont'd)
Forced Outage

1. Boiler casing	30.2 hours
2. Condenser vacuum	3.6 hours
3. Condenser vacuum	2.6 hours
Total	36.4 hours
Reserve (Economy)	1 055 hours

Forced outages in 1979 accounted for approximately 0.5% of the time the unit was available for duty.

Table 2-7 includes the total plant investment and operation and maintenance (O&M) costs since 1958, when Unit #5 was placed in service. As can be seen, in 1974, when Unit #6 was placed in service; the additional O&M cost is approximately 1% of the additional net investment. The increase in O&M cost each year from 1974 through 1979 has been at a rate of 7.5%, while the increase in the Consumer Price Index has been at a rate of 8.1% during those years. The O&M cost in 1978 was excessive due to a cooling tower collapse.

As can be seen from the preceding paragraph, the rate of increase of the O&M cost is approximately the same as the general inflation rate. Due to this fact, the rate of increase of O&M costs is assumed to be equivalent to the general inflation rate during the life of the solar repowered unit. The O&M cost is also assumed to begin at 1% of the plant investment. If the solar repowering project is not pursued, the O&M costs for the Permian Basin Plant are expected to increase from the current 3.19% at an annual rate equivalent to the genral rate of inflation.

Table 2-7

Permian Basin Plant

Year	Net Investment	O&M Cost	Per Cent (O&M ÷ Net Investment)	CPI*
1958	19,320,879.76	395,748.10	2.05	86.6
1959	19,326,557.84	473,187.32	2.45	87.3
1960	19,344,366.72	562,765.06	2.91	88.7
1961	19,345,593.79	465,523.98	2.41	89.6
1962	19,386,741.62	511,496.53	2.64	90.6
1963	19,392,794.68	606,074.18	3.13	91.7
1964	19,434,366.66	650,864.62	3.35	92.9
1965	19,435,843.79	593,809.03	3.06	94.5
1966	19,456,119.04	637,720.12	3.28	97.2
1967	19,535,844.51	597,212.96	3.06	100.0
1968	19,557,918.67	652,903.57	3.34	104.2
1969	19,590,067.60	745,274.55	3.80	109.8
1970	19,594,462.14	777,307.84	3.97	116.3
1971	19,633,694.05	890,239.33	4.53	121.3
1972	19,666,961.20	902,670.67	4.59	125.3
1973	66,524,990.88	1,128,302.35	1.70	133.1
1974	69,654,908.24	1,545,971.51	2.22	147.1
1975	69,794,498.89	1,594,025.42	2.28	161.2
1976	70,065,857.89	1,605,830.82	2.29	170.5
1977	70,249,022.97	1,703,841.47	2.43	181.5
1978	70,317,941.75	2,635,032.02	3.75	195.4
1979	75,876,785.53	2,419,927.49	3.19	217.4

*Department of Labor, Consumer Price Index U.S. City Average

2.8 PROJECT ORGANIZATION

In order to meet the program objectives most effectively, Texas Electric Service Company (TESCO) and Energy Systems Group (ESG) formed a team of organizations including McDonnell Douglas Astronautics (MDAC), University of Houston (U of H), and Stearns-Roger (SR), as shown in Figure 2-7. In combination, the team incorporates all of the necessary background, experience, and skills to complete all aspects of the program.

ESG is the prime contractor for the conceptual design phase at the request of TESCO and is directly responsible for the storage subsystems, the system integration, and the receiver subsystem--the latter including the receiver, the sodium pump, the steam generator, and associated components and piping. In addition, ESG has prime responsibility for meeting all of the major technical, schedule, and budgetary milestones.

As a subcontractor in the work for this proposal, TESCO has responsibility for current plant data, operations studies, and performance evaluations, determination of permits and licenses required, environmental data and economic assessments.

Stearns-Roger Engineering has the responsibility for civil and structural design and cost studies, tower design, storage tank design, steam system modifications, and control room modifications.

McDonnell Douglas Astronautics Company provides heliostat data, collector field performance and cost summaries and collector field control, power, and operating mode requirements.

The University of Houston Energy Laboratory provided the Collector Field Optimization Studies to determine collector field size and shape, tower height, and receiver size to satisfy both receiver and land constraints.

ESG-79-16P, Vol 1

5-2

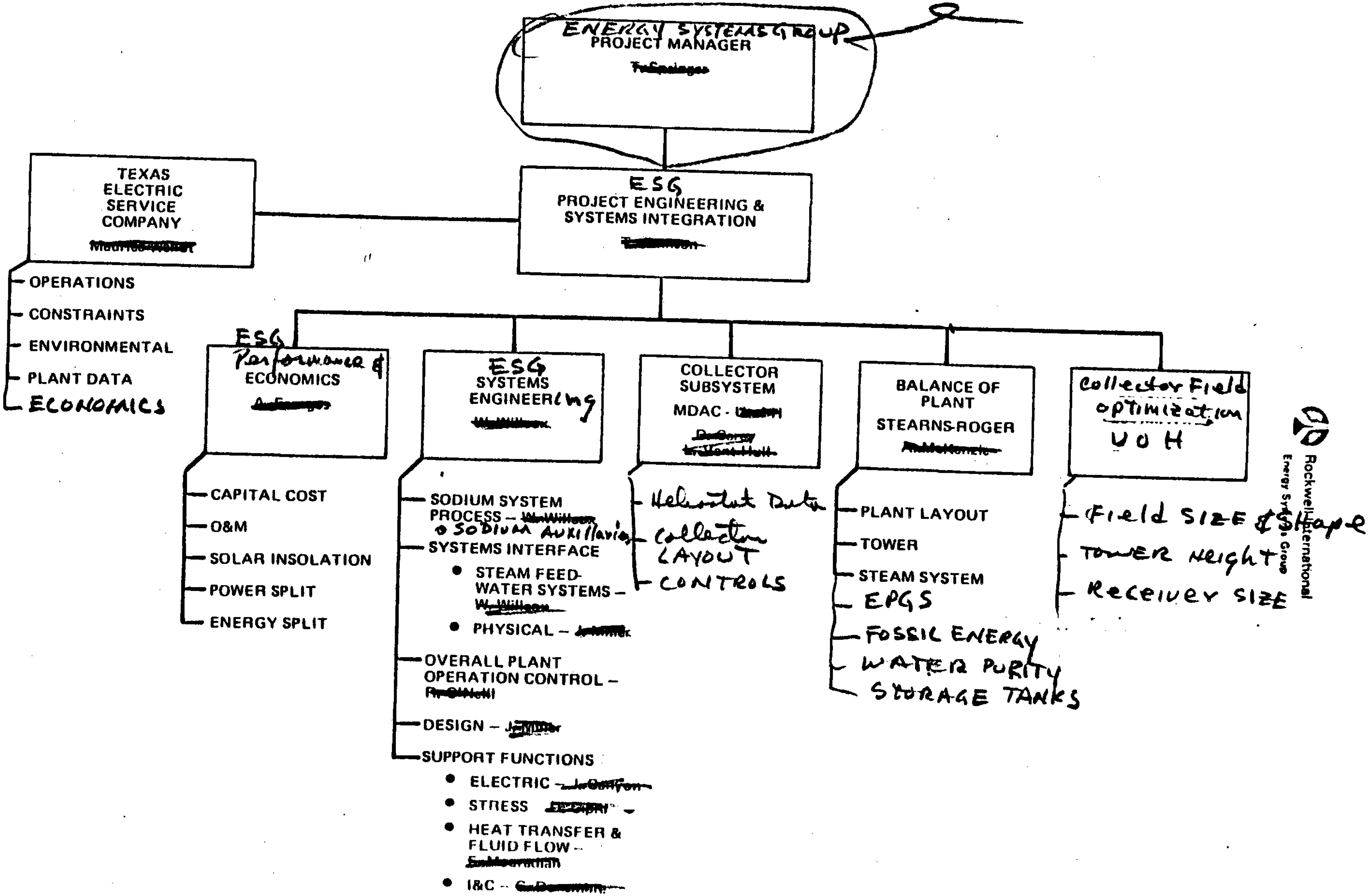

Figure ~~5-1~~ 2-7. Project Organization

Rockwell International
Energy Systems Group

2.9 FINAL REPORT ORGANIZATION

The final report is presented in three volumes:

Volume I, Executive Summary
Volume II, Solar Repowering Conceptual Design
volume III, Appendices
- A. System Requirements Specification
- B. Conceptual Design Data Including Cost Data

Volume I contains a summary and overview of the material contained in Volumes II and III in Sections 1.0 through 1.7. Section 1.8 is the Site Owner's Assessment of the study results and assessment of the repowering project's worth of TESCO in terms of economics, fuel savings, operational characteristics, institutional and regulatory considerations.

Volume II includes discussions, evaluations, and results of the conceptual design studies accomplished in Task 2 through 6: The task descriptions are as follows:

Task 1, System Requirements Specification
Task 2, Selection of the Site-Specific System Configuration
Task 3, Plant Conceptual Design
Task 4, Plant Performance Estimates
Task 5, Plant Cost Estimates and Economic Analysis
Task 6, Development Plan
Task 7, Program Plan and Management

The tasks are not identified specifically in the sections of Volume II, but all of the data results developed are included.

The results of Task 1 are contained in Volume III as Appendix A. The extensive design and cost data developed during this study are presented in Appendix B of Volume III as Design Data Sheets and the Detail Cost Account Work Sheets. The significant design data parameters are presented in Section 5.0 of this volume for each of the six subsystems. The six subsystems are presented in the order as defined in the System Requirements Specification: collector, receiver, master control, fossil energy, energy storage, electric power generating. Cost data is summarized in Section 4.6, also by subsystems.

3.0 SELECTION OF PREFERRED SYSTEM

The preferred system selection process consisted of a series of system level trade studies and analyses complemented by engineering judgement decisions designed to tailor the final conceptual design to fit TESCO's system and unit operating philosophies and procedures. The specific trade studies and analyses performed are outlined in Section 3.1 and reported in detail in Sections 3.2 and 3.4.

3.1 TRADE STUDIES

Table 3-1 shows the major trade studies accomplished in this study. Also shown are the assumptions made, the parameter range studied, and the selection criteria used. The requirements for a minimum solar fraction of 20% was specified in the System Requirements Specification (2-1). Other criteria used included the following: preference by TESCO to site the repowered system on currently owned TESCO property, the use of proven components, and subsystem and component size that would allow ready extrapolation to commercial-scale plants with a size of at least 100 MWe.

Some of the system and subsystem characteristics adapted herein are based on previous trade studies in the Advanced Central Receiver and the Solar Hybrid Programs.[3-1, 3-2] These characteristics have been reevaluated and are considered to apply to this repowering study because of the similarity of the process systems and requirements. In particular, the following selections are included based on the previous study results:

- Steam generator arrangement with evaporator, superheat and reheat units
- External receiver
- Single tower
- Mechanical pumps
- Pressure reducing device
- Tower pipe routine

TABLE 3-1

PERMIAN BASIN NO. 5

Trade Study List

ITEM	ASSUMPTIONS	PARAMETER RANGE	SELECTION CRITERIA
SYSTEM LEVEL			
Solar Power Level	Minimum Fossil Turndown 33%	Minimum* to 115 MWe	Land availability Minimum solar fraction 20% Technology to permit 1985 ops. Fuel savings Minimum capital costs Minimum BBEC
Storage Capacity	All sodium storage	0 to 6 hours	Same as above
System Configuration	Collector field to east of plant; two-tank storage system	Four arrangements of hot and cold storage tanks	Maximum capital cost Maintainability and safety Control dead time and process logs. Heat losses.
RECEIVER SUBSYSTEM			
Tower Design	1985 Technology Seismic Zone 1 Wind speeds to 90 mph	Reinforced concrete vs steel construction	Acceptable deflection and resonance Minimum capital cost
STORAGE SUBSYSTEM			
Tank Configuration	1985 Technology	Spherical tanks - right circular cylinders	Minimum capital costs

*Power level must satisfy requirement for solar fraction minimum of 20%.

715-A.75/sjh

TABLE 3-1

PERMIAN BASIN NO. 5

Trade Study List
(Continued)

ITEM	ASSUMPTIONS	PARAMETER RANGE	SELECTION CRITERIA
COLLECTOR SUBSYSTEM			
Field Size and Configuration Tower Height	Site and land acquisition constraints. Heliostat costs, tower cost model, U. of H. computer model	Surround field - displaced field, field voids	Maximum flux 1.5 MW/m^2 Minimum capital costs; also minimum land acquisition North/south panel power ratio <4

Liquid sodium storage system using hot and cold storage tanks
Passive receiver protection system
Sodium process temperature difference of 306°C (550°F)

The reasons for the selection of sodium as the heat transfer fluid are given in 3.3. Tower design has been studied extensively on several previous programs with results favoring the concrete design for the heights involved. However, for the current study with the reduced seismic requirements in Texas (Zone 2) and the shorter tower as compared to the previous studies, a comparison of several tower designs was made. This comparison is presented in detail in Section 5.2.

The purpose of the trade study is to select the receiver tower configuration which results in the most cost-effective design meeting the design criteria while utilizing accepted construction practice. Three tower configurations were compared:

1) Reinforced concrete
2) Conventional steel
3) Tubular steel

This study includes the structural dynamic analysis and costing for the various receiver towers and founcations only; tower design, engineering, accessories and appurtenances are considered a stand-off and are not included.

A comparison of deflections, accelerations, and shears for both wind and seismic design conditions was determined for each tower configuration. The lateral displacement for the operational wind 13.4 m/s (30 mph) is very low for all towers. Wind governs both the steel and concrete tower designs. Also, the results show an increase of 50% above ground acceleration (0.15 g) for the maximum seismic acceleration at the top of the tower for the steel towers, with the corresponding value for the concrete tower being slightly less than ground acceleration. At the centroid of the receiver, however, the maximum seismic accelerations for the steel towers are considerably reduced, while increasing for the concrete tower owing to the stiffness of the concrete tower.

The foundations for all the towers were assumed to be of the mat type with the top of the mat at grade elevation.

Some savings in foundation cost, particularly for the steel towers, could result from burying the mat below grade elevation.

Although the tower cost analyses were performed for a specific tower height and receiver mass, it is believed that a change in tower height of ±10% would not significantly affect the results or final selection of the tower configuration.

The table below shows the cost comparison for the three towers. Both steel towers are lower in cost than the concrete towers. The conventional steel tower is the selected design.

TOWER COST COMPARISON
119 m (390 ft) TOWERS
(1980 DOLLARS)

	Concrete	Conventional Steel	Tubular Steel
Direct Field Cost	770,000	475,600	504,100
Indirect Field Cost	43,100	109,200	94,700
Total Field Cost	813,100	584,800	598,800
% Over Base	+39.4	Base	+2.39

Notes:

1. Cost estimate is for tower and foundation only. Tower design engineering, accessories and appurtenances are not included.
2. Labor rates for Monahans, Texas.

The storage tank study, reported in detail in Section 5.5 compared spherical tanks with right circular cylindrical tanks.

The storage system contains a hot storage tank constructed of 304 stainless steel operating at 1100°F and a cold storage tank of carbon steel at 550°F. Based on the initial design (60 MWe with 3 h of storage capacity), a tank volume of 201,000 ft^3 is required. For the current design point (50 MWe with 1 h of storage capacity), the tank volume is 56,000 ft^3.

Chicago Bridge and Iron (CB&I) Company supplied engineering comments regarding flat-bottomed tank and spherical tank designs. For the hot tank, CB&I recommended a spherical tank design. The sphere is supported from an equitorial girder of rolled or forged section, with support legs hinged at the base to permit free thermal expansion of the tank. Based on the soil conditions at Permian Basin, a ring or "donut" type concrete foundation would be used.

The cold tank design can be either a cylindrical or spherical tank configuration. The spherical tank design is considered to be much more expensive by a factor of 4.

A comparison of a single spherical tank vs two spherical tanks showed the two tanks to cost only about 2% more (bare tanks only). When isulation, interconnecting piping, stairways, and other accessories are included, the cost difference is substantially greater.

A single cylindrical tank design is selected for this repowering application.

The collector field optimization study is presented in Section 5.1.

The collector field studies are conducted by the University of Houston are based on use of the MDAC Second Generation Heliostat. This heliostat is a noninverting type with a surface area of 56.42 m^2.

The plot plan of Figure 1-3 shows the space available for locating collector field to the east half of the section of land owned by TESCO. The studies of collector field size and shape included the following:

1) Idealized symmetrical surround field (Field 1)
2) Surround field with exclusion areas buy no boundary trim (Field 2)
3) Surround field with exclusion areas with boundary trim (Field 3)
4) Enhanched sourthern field to improve flux distribution (Field 4)

Field 3 would not require the purchase of additional land by TESCO, and the field would fit within the section currently owned by TESCO. The exclusion areas within the field area (Figure 1-3) allows for the power line corridors and the oil wells.

The following table shows the lowest figure of merit for the idealized collector field, as would be expected. The figure of merit increasing slightly as exclusion areas are added, as boundary trim is imposed, and for the enhanced southern field, Field 4. Field 4 reduces the receiver north-panel-to-south-panel power ratio to 2.5 as compared to 8 for Field 2. Field 3 is acceptable with a ratio of about 4.

TESCO REPOWERING COLLECTOR FIELD STUDY

Case	Power MWt	Tower Ht, m	Mirror Area Km^2	Field Area Km^2 (AC)	Figure of Merit $/MWh	Annual Energy 10^3 MWh
1. Idealized	160	120	0.253	1.067 (264)	257.6	354.61
2. No Boundary Trim	160	120	0.256	1.135 (280)	259.4	350.87
3. Boundary Trim	160	120	0.270	1.106 (273.3)	265.6	354.66
4. Enhanced South	160	120	0.264	1.076	263.36	357.57

The comparison of Fields 2 and 3 of above table shows that the figure of merit increases by 2.4% with the addition of boundary trim. While TESCO will negotiate with the property owner to the east, the option does exist to place the entire collector field on TESCO property. A comparison of Fields 2 and 4 shows the effect of modifying the flux distribution around the receiver so as to reduce the maximum temperature gradient across any one panel. This is represented by reducing the north-panel-to-south-panel power ratio. Flux distributions are discussed fully in Section 5.1. The figure of merit for Field 4 is increased by 1.5% over that for Field 2. Field 4 is the selected field for the conceptual design. The small cost penalty is accepted in order to simplify the receiver design considerations for this early design.

3.2 SYSTEM SIZE

3.2.1 Introduction

Solar repowering of the Permian Basin Unit 5 plant will require the addition of: a collector field of two axis, tracking heliostats; a tower located in the field; a receiver on top of the tower; a sodium circulation system; a set of sodium-to-water steam generators (evaporator superheater and reheater); a storage system; a master control system; various pieces of ancillary equipment; and existing plant interfaces.

A process flow diagram showing the relationship of these systems and components to one another is shown in Figure 3-1.

Two of the fundamental selections to be made early in the conceptual design phase include the fraction of original plant capacity repowered, or solar power rating, and the thermal storage capacity. The determination of these two parameters is sufficient to initiate a complete plant design. These two parameters are related to each other in that a given receiver/collector field combination is capable of theoretically supporting an infinite combination of solar power ratings and storage capacities. The solar power rating is represented by the steam generator output.

There is an inverse relationship between steam generator size and storage capacity for a given receiver peak output. The fraction of each MWht of solar energy used directly or from storage is determined from the relative magnitude of these two parameters.

The purpose of this parametric analysis was to select the solar-rated steam generator power level and the storage system capacity at the solar-rated power level suitable for repowering TESCO's Permian Basin Unit 5. These parameters formed the basis of other ongoing trade studies as well as a revised baseline design.

SOLAR REPOWERING FLOW DIAGRAM
PERMIAN BASIN - UNIT NO. 5 TESCO

COMBINED MODE

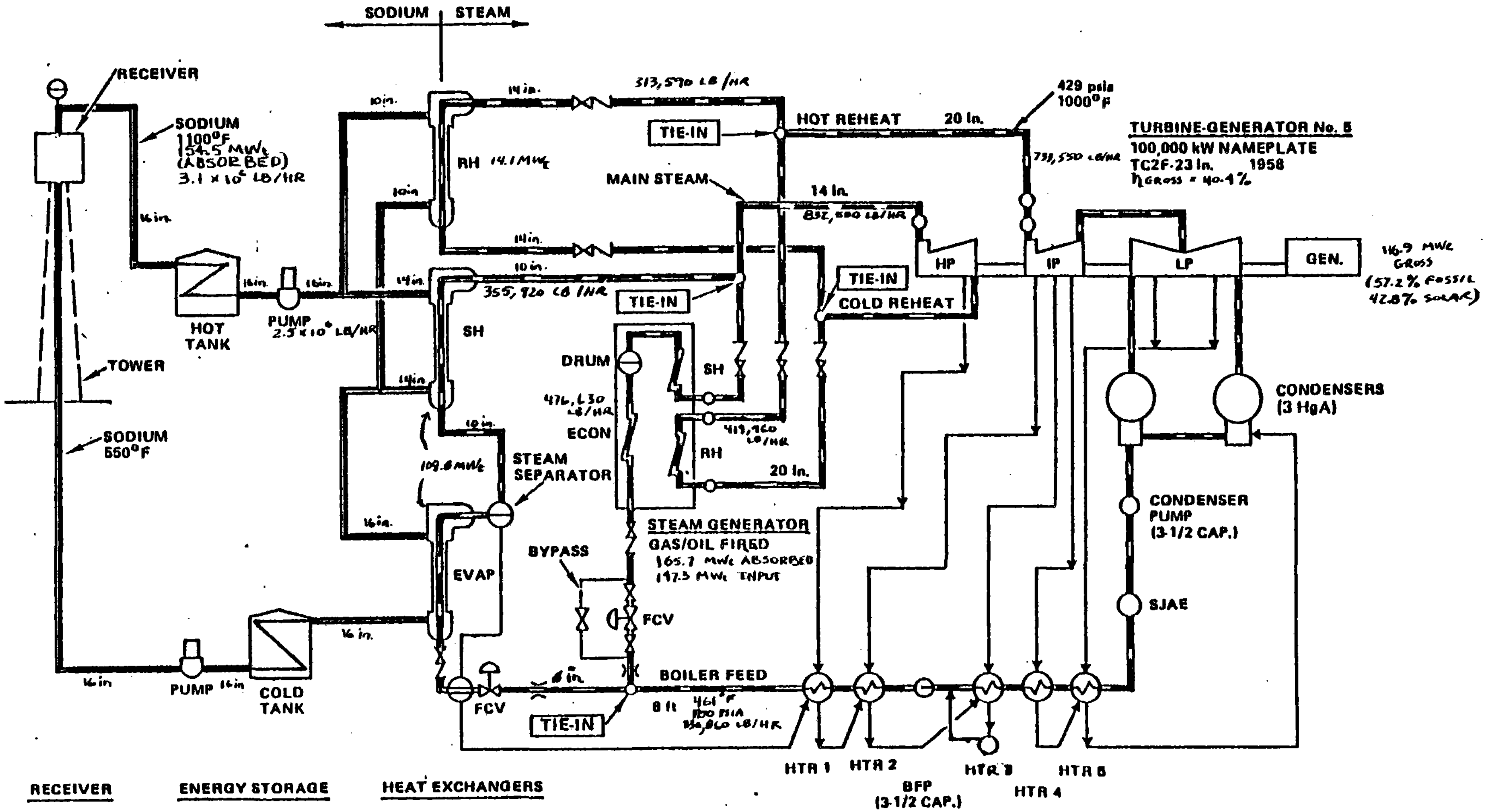

Figure 3-1

3.2.2 Design Basis for Comparison Study

As shown in Figure 3-1, the steam generators and existing boiler will be configured for parallel flow operation. Several operating modes, involving solar and nonsolar operation between 0 and 100% of plant output, can be postulated for this configuration. In a combined operating mode, the boiler cannot operate at a power less than its minimum turndown and, consequently, the solar steam generator cannot supply more than 100% minus this turndown. However, operation in a solar-only mode is possible and, for this reason, solar steam generator ratings equivalent to 100% of turbine ratings have been considered in this study.

The sodium inlet temperature to the solar steam generator is currently fixed at 593^{o}C (1100^{o}F), and the temperature drop (ΔT) across the steam generator is maintained at 306^{o}C (550^{o}F), which establishes the steam generator outlet sodium temperature at 550^{o}F. The nominal sodium outlet temperature of the receiver, 593^{o}C (1100^{o}F), and the ΔT of 306^{o}C (550^{o}F were established as the optimum design points as a result of previous solar design studies.[3-1, 3-2] Based on the foregoing, the solar and nonsolar systems, connected in parallel, are designed to furnish steam to the turbine at a nominally constant temperature of 538^{o}C (1000^{o}F), the existing plant design temperature.

Variations in the solar receiver thermal energy output, because of dinural and meteorological conditions, will be buffered by the storage system. The degree of buffering will depend upon the storage system capacity.

The combination of the fossil boiler, steam generator, and storage system will provide electrical output demanded of the plant, expected to range between 0 and 115 Mwe gross. During combined mode operations, as the receiver output drops, the level of sodium in the storage system hot tank will fall corresponding to a rise in the level of the cold tank. At some predetermined hot tank level, the fossil boiler will begin to increase its output as the steam generator output drops. At some specified minimum hot tank level, the steam generator sodium flow will be secured and the fossil boiler will provide the entire plant heating requirements.

The point of departure for this study is the baseline design identified in the proposal.[(3-4)] This baseline specified a repowered level of 60 MWe gross and a storage capacity of 3 hours at full repowered capacity. In this study, repowered capacities as low as 30 and as high as 115 MWe gross were considered in conjunction with storage capacities in the range of 0 to 6 hours full repowered capacity.

3.2.3 Parameters of Interest and Assumptions

The technical trade assumptions used in this study are listed in Table 3-2. The economic assumptions are shown in Table 3-3.

TABLE 3-2

TRADE ASSUMPTIONS

1.	Plant Gross Rating	115 MWe
2.	Boiler/Steam-Generator Configuration	Parallel
3.	Plant Capacity Factor	49%*
4.	Boiler Desirable Minimum Turndown	33%
5.	Boiler Fuel Source	Natural Gas or No. 5 Fuel Oil
6.	Baseline Annual Energy Solar Energy Available	203,040 MWhe†
7.	Minimum Solar Fraction	20%§
8.	Gross Cycle Heat Rate, Peak Power	8458

*Based on recent plant operating history, tentative
†Based on proposal, Reference 3-4
§Based on contractual requirement

3.2.4 Methodology

Four representative solar repowering capabilities were selected from the scope established in Section 3.2.2. These included 30, 60, 90, and 115 MWe gross output. Concurrently, four representative storage system capacities were selected.

TABLE 3-3

ECONOMIC ASSUMPTIONS

Economic Life	25 Years
Reference Year	1980
Year of Start of Commercial Operation	1985
Construction Period	4 Years
After Tax Cost of Capital	10%
Income Tax Rate	50% (Investment Tax Credit = 4%)
Annual Insurance/Other Taxes	0.0225
Depreciation Method	SOYD*
Depreciation Life	20 Years
Fixed Charge Rate	17.38%†
General Escalation Rate	8%
Capital Escalation Rate	8%
O&M Escalation Rate	8%
Fuel Escalation Rate	10%
1985 O&M Cost	1% of Capital Cost and 10% of Fuel Cost
1980 Heliostat Cost	$230/M^2$
1980 Natural Gas Cost	$2.63/MMBtu

*Sum of the year's digits
†Derived from values on this table

They were 0, 1, 3, and 6 hours of full repowered operation. Note that for all but one repowered level (115 MWe) full repowered operation does not correspond to full plant operation. This gives a plant design for each of the elements of the matrix shown in Table 3-4. Also shown in Table 3-4 is the estimated annual solar output in equivalent MWhe gross. Using the elements of this matrix in combination with full power output and an assumed plant capacity factor of 49%, a solar fraction for each plant was calculated and is plotted in Figure 3-2.

TABLE 3-4

TRADE STUDY PARAMETERS - SOLAR ANNUAL MWHE

Repowered Capacity (MWe, gross)	Storage System Capacity Full Repowered Operating Hours			
	0	1	3	6
30	66,353	81,614	101,520	127,398
60	132,706	163,228	203,040	254,795
90	199,059	244,842	304,560	382,193
115	254,353	312,854	389,160	488,358

Using the repowered capacity, a constant assumed plant heat rate, the relation between storage system size and solar multiple shown in Figure 3-3* and the receiver ΔT, an approximate plant design was generated for each element in the trade study matrix. For purposes of this study, the solar multiple is defined as the peak receiver output divided by the peak steam generator power required.

A programmable HP 97 desk-top calculator was used to generate the plant parameters for each point in the design matrix. This program uses simple relations and algorithms developed during the Advanced Central Receiver[3-1] and Hybrid[3-2] programs to predict, as a function of solar multiple and plant solar power, the plant parameters shown in Table 3-5. Also shown in Table 3-5 is a sample output of the program for the baseline plant.

Using the output data of this program as input and a second HP 97 program, a capital cost was generated for each plant design. This program incorporates capital cost algorithms also developed during the ACR and Hybrid programs. A sample output is shown in Table 3-6 along with an explanation of the output. The output of this program is in 1978 dollars x 10^6. These estimates were updated to 1980 dollars using a short-term escalation rate of 10%/year to more accurately simulate recent capital escalation rate trends than the more optimistic 8% rate assumed for long-range economic studies.

*Using the average daily energy curve

SOLAR FRACTION vs. SOLAR POWER

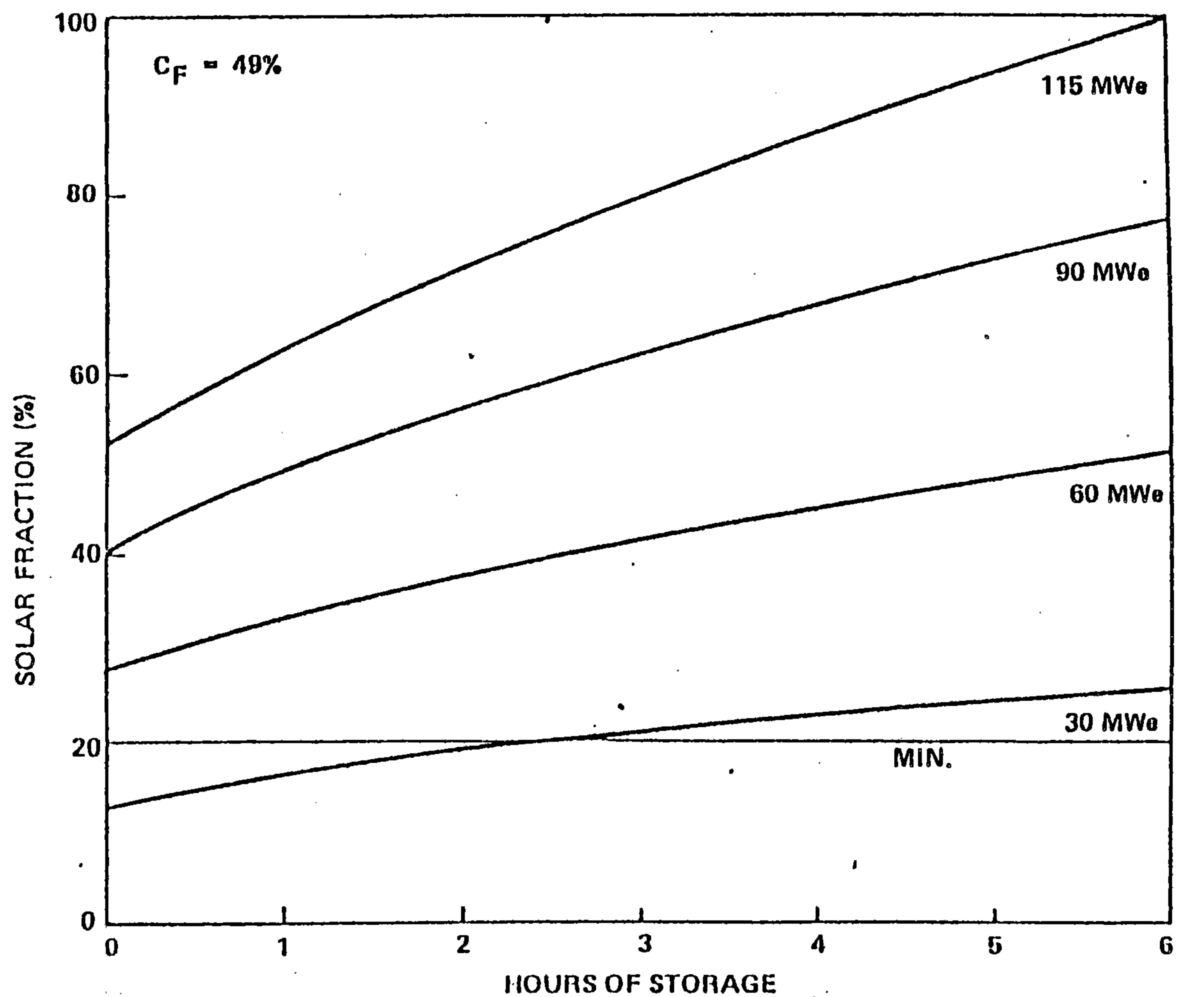

Figure 3-2

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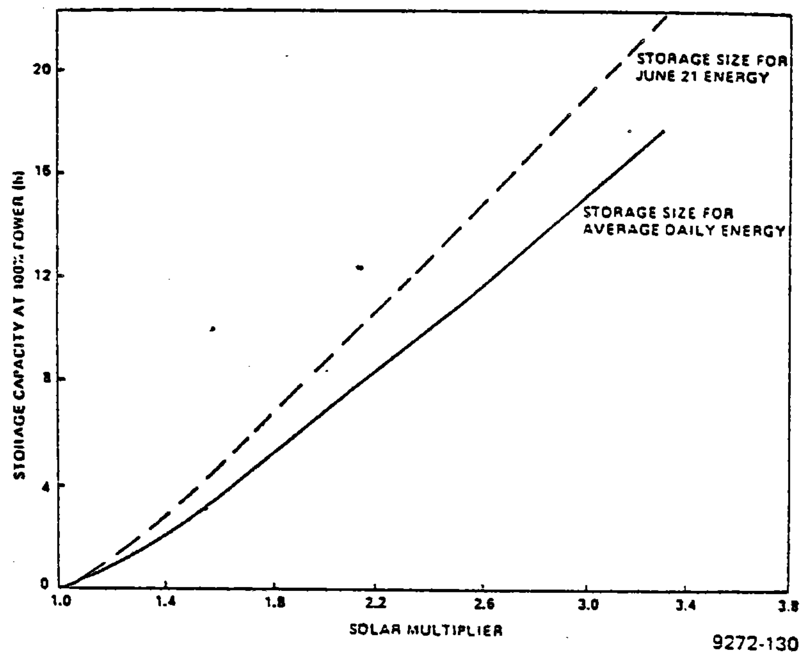

3-3

Figure 4. Storage Capacity Versus Solar Multiplier

PERMIAN BASIN, UNIT 5 PV [illegible] SODIUM/SOLAR REPOWERING

60 MWe Gross Conceptual Design Parameters

11/8/79

PLANT SIZING AND DESIGN PARAMETERS	HOURS OF STORAGE 0	1	3	6
Electric Power- MWe	[illegible] ***	[illegible] ***	[illegible] ***	[illegible] ***
Heat Rate-Btu/kw-hr	[illegible] ***	[illegible] ***	[illegible] ***	[illegible] ***
Solar Multiple	[illegible] ***	1.2750 ***	[illegible] ***	[illegible] ***
Plant Cycle Temp Diff.-°F	[illegible] ***	550.0000 ***	[illegible] ***	[illegible] ***
Hours of Storage	[illegible] ***	1.0000 ***	[illegible] ***	[illegible] ***
Plant Cycle Efficiency	[illegible] ***	0.4035 ***	[illegible] ***	[illegible] ***
Nominal Thermal Power-Pt MWt	[illegible] ***	148.6987 ***	[illegible] ***	[illegible] ***
Maximum Thermal Power-MWt	[illegible] ***	182.8954 ***	[illegible] ***	[illegible] ***
Receiver Centerline Height-meters	[illegible] ***	114.9196 ***	133.0581 ***	[illegible] ***
Tower Height-HT -meters	[illegible] ***	98.2851 ***	109.2177 ***	[illegible] ***
Hours of Storage	0.0000 ***	1.0000 ***	3.0000 ***	[illegible] ***
Thermal Energy Stored-MWt-hrs	0.0000 ***	148.6987 ***	446.0961 ***	[illegible] ***
Pounds of Sodium in Storage	0.0000 ***	3025342.855 ***	[illegible] ***	[illegible] ***
Collector Field Efficiency	[illegible] ***	[illegible] ***	[illegible] ***	[illegible] ***
Collector Packing Efficiency	[illegible] ***	0.3665 ***	[illegible] ***	[illegible] ***
Mirror Area-square meters	[illegible] ***	[illegible] ***	[illegible] ***	[illegible] ***
Field Area-square meters	[illegible] ***	[illegible] ***	1545149.154 ***	[illegible] ***
Field Area-acres	[illegible] ***	294.9430 ***	[illegible] ***	[illegible] ***
Site Area-square meters	[illegible] ***	[illegible] ***	[illegible] ***	[illegible] ***
Field Pipe Diameter-inches	[illegible] ***	17.6076 ***	[illegible] ***	[illegible] ***
LF-key field dimension-meters	[illegible] ***	623.3959 ***	[illegible] ***	[illegible] ***
MF-field piping sodium weight-lbs	[illegible] ***	759951.0822 ***	[illegible] ***	[illegible] ***
Plant/Tower Pipe Diameter-inches	[illegible] ***	16.3587 ***	[illegible] ***	[illegible] ***
Lp+t-plant&tower piping length-meters	[illegible] ***	297.1462 ***	[illegible] ***	[illegible] ***
MP-sodium weight in plant piping-lbs	[illegible] ***	324297.3341 ***	[illegible] ***	[illegible] ***
Sodium in Receiver Subsystem-MR-lbs	[illegible] ***	[illegible] ***	[illegible] ***	[illegible] ***
Piping Thermal Loss- MWt	[illegible] ***	[illegible] ***	[illegible] ***	[illegible] ***
Thermal Storage Heat Loss-MWt	[illegible] ***	0.2065 ***	[illegible] ***	[illegible] ***

Figure 5 3-4

PERMIAN BASIN, UNIT No. 5

60 MWe Plant Solar/Sodium Repowering COSTS in MILLIONS *

	Hours of Storage			
	0	1	3	6
COLLECTOR SUBSYSTEM	[illegible] ***	61.10834 ***	[illegible] ***	[illegible] ***
Receiver	[illegible] ***	4.41433 ***	[illegible] ***	[illegible] ***
Piping	[illegible] ***	3.99474 ***	[illegible] ***	[illegible] ***
Sodium	[illegible] ***	0.79576 ***	[illegible] ***	[illegible] ***
Tower	[illegible] ***	1.26653 ***	[illegible] ***	[illegible] ***
Steam Generator	[illegible] ***	3.42054 ***	[illegible] ***	[illegible] ***
RECEIVER SUBSYSTEM	[illegible] ***	[illegible] ***	[illegible] ***	[illegible] ***
Containment	[illegible] ***	1.66930 ***	[illegible] ***	[illegible] ***
Pump	[illegible] ***	1.19760 ***	[illegible] ***	1.19760 ***
Media-sodium	0.00000 ***	1.31014 ***	[illegible] ***	[illegible] ***
THERMAL STORAGE SUBSYSTEM	1.19760 ***	4.07754 ***	[illegible] ***	[illegible] ***
Site	0.25714 ***	0.72126 ***	[illegible] ***	[illegible] ***
Structures	0.69714 ***	[illegible] ***	[illegible] ***	[illegible] ***
Connection	0.70000 ***	0.36200 ***	[illegible] ***	[illegible] ***
Master Control	0.47000 ***	0.47000 ***	[illegible] ***	0.47000 ***
MISCELLANEOUS & EPGS	1.72037 ***	1.78840 ***	[illegible] ***	[illegible] ***
SUBTOTAL	[illegible] ***	[illegible] ***	[illegible] ***	[illegible] ***
DISTRIBUTABLES & INDIRECT @ 5%	[illegible] ***	[illegible] ***	[illegible] ***	[illegible] ***
CONTINGENCY @10%	[illegible] ***	9.45611 ***	[illegible] ***	[illegible] ***
PRELIMINARY & FINAL DESIGN	[illegible] ***	[illegible] ***	[illegible] ***	[illegible] ***
GRAND TOTAL	[illegible] ***	[illegible] ***	[illegible] ***	[illegible] ***
TOTAL IN 1980 $	97.34150	119.65203	149.04337	187.43029

* 1978 $, $190./M² COLLECTOR COST

Figure ~~6~~ 9.1 3-5

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Page 17

A third HP 97 program, based on the assumed economic parameters and the JPL methodology,(3-5) was used to transform the plant capital cost, capacity factor, heat rate, and fuel cost into levelized busbar energy costs.

From the system design points, land availability and component requirements were also generated. Fuel savings as a function of solar repowering level and storage capacity were determined as part of the economic studies. Consequently, graphical representations of all of the selection criteria were determined for all of the design points in the Matrix of Table 3-4. They are presented and discussed in Sections 3.2.5 and 3.2.6.

3.2.5 Results

Capital costs, in 1980 dollars, plotted as a function of solar power level and storage capacity, are shown in Figure 3-4. The capital costs ranged between $\$50 \times 10^6$ and $\$350 \times 10^6$. Capital costs increased with solar power levels and storage capacity.

Levelized busbar energy costs, plotted as a function of solar power level and storage capacity for $\$230/M^2$ (1980 dollars) heliostats and $\$65/M^2$ heliostats* (1978 dollars) are shown in Figure 3-5. Two disparate trends were observed. For $\$230/M^2$ heliostats, $\overline{BBEC}$ increased with solar power level and storage capacity. However, for $\$65/M^2$ heliostats, $\overline{BBEC}$ decreased, slightly, with solar power level while still increasing with storage capacity. Clearly, at $\$230/M^2$ heliostat costs, energy derived from the sun is more expensive than that derived from relatively inexpensive natural gas at $2.63/MMBtu, a representative comparison cost.

A cross plot of Figure 3-5 (shown in Figure 3-6) showing $\overline{BBEC}$ as a function of plant capacity factor, solar plant size, and hours of storage for repowered <u>plants operating in a stand-alone mode</u> reinforces this observation. This conclusion is in direct conflict with the trends observed for stand-alone and hybrid plants(3-1, 3-2) which both showed decreasing $\overline{BBEC}$ with increasing capacity

*The purpose of including $\$65/M^2$ heliostats is to avoid seriously biasing the study with the relatively high ($\$230/M^2$) heliostat costs and to examine the sensitivity of the trends observed to heliostat costs.

PLANT SIZE AND STORAGE TRADE STUDY

CAPITAL COST VS. SOLAR POWER RATING AND STORAGE CAPACITY

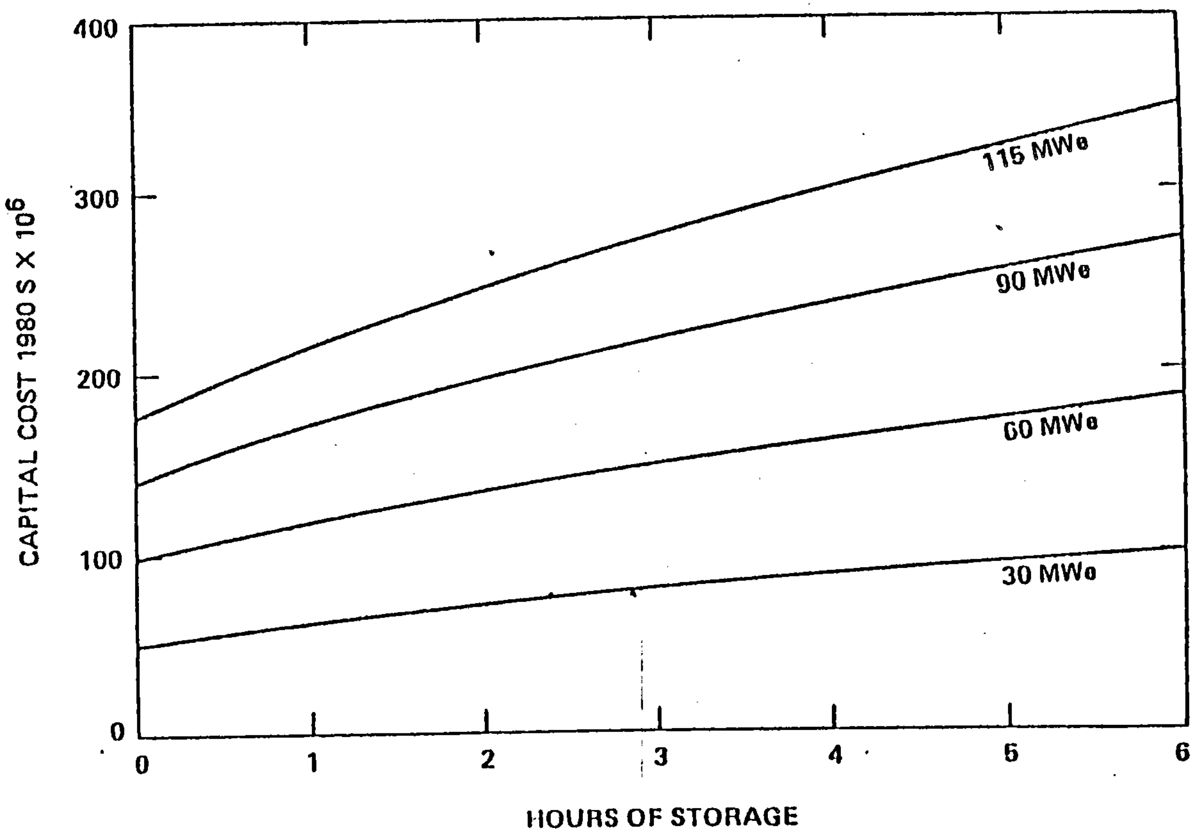

Figure 3-6

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Page. 19

PERMIAN BASIN UNIT NO.5 $\overline{BBEC}$ vs. SOLAR PLANT CAPACITY AND STORAGE CAPACITY

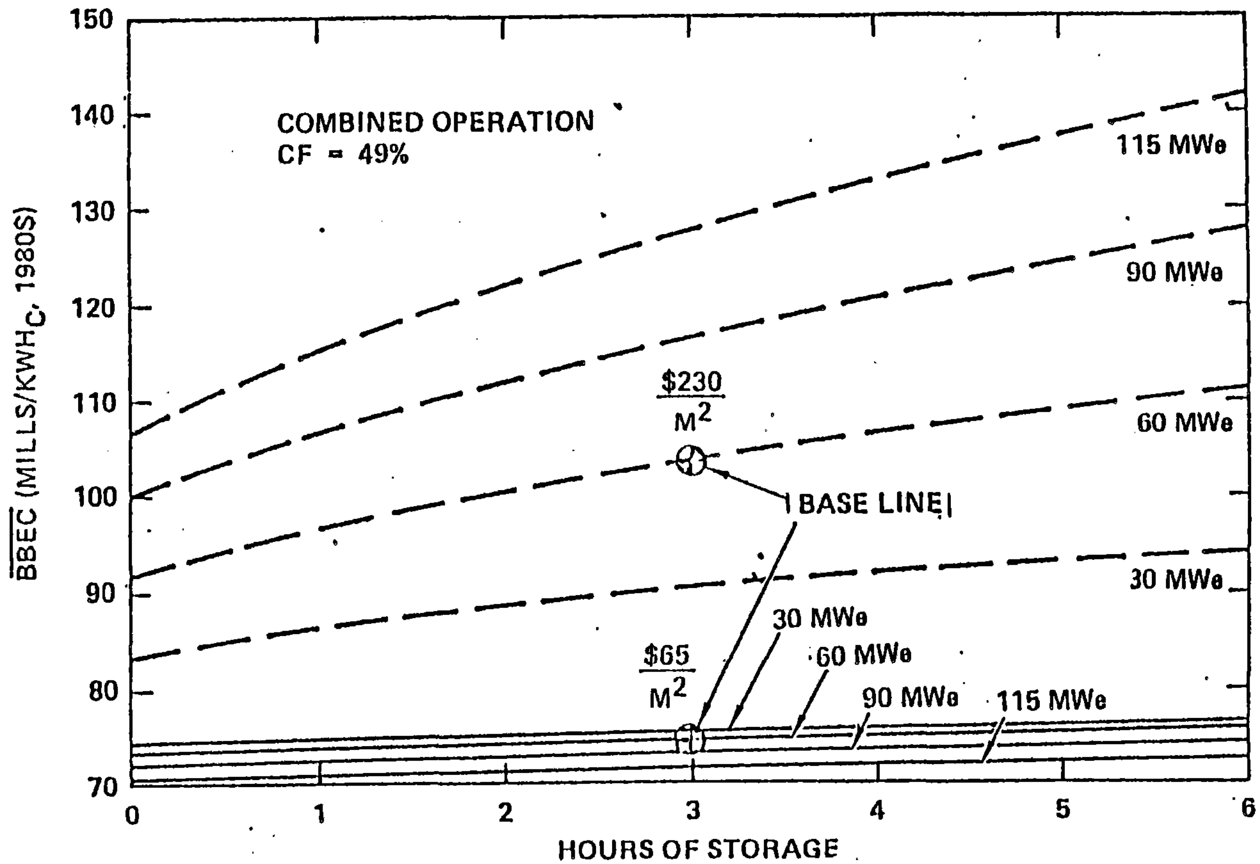
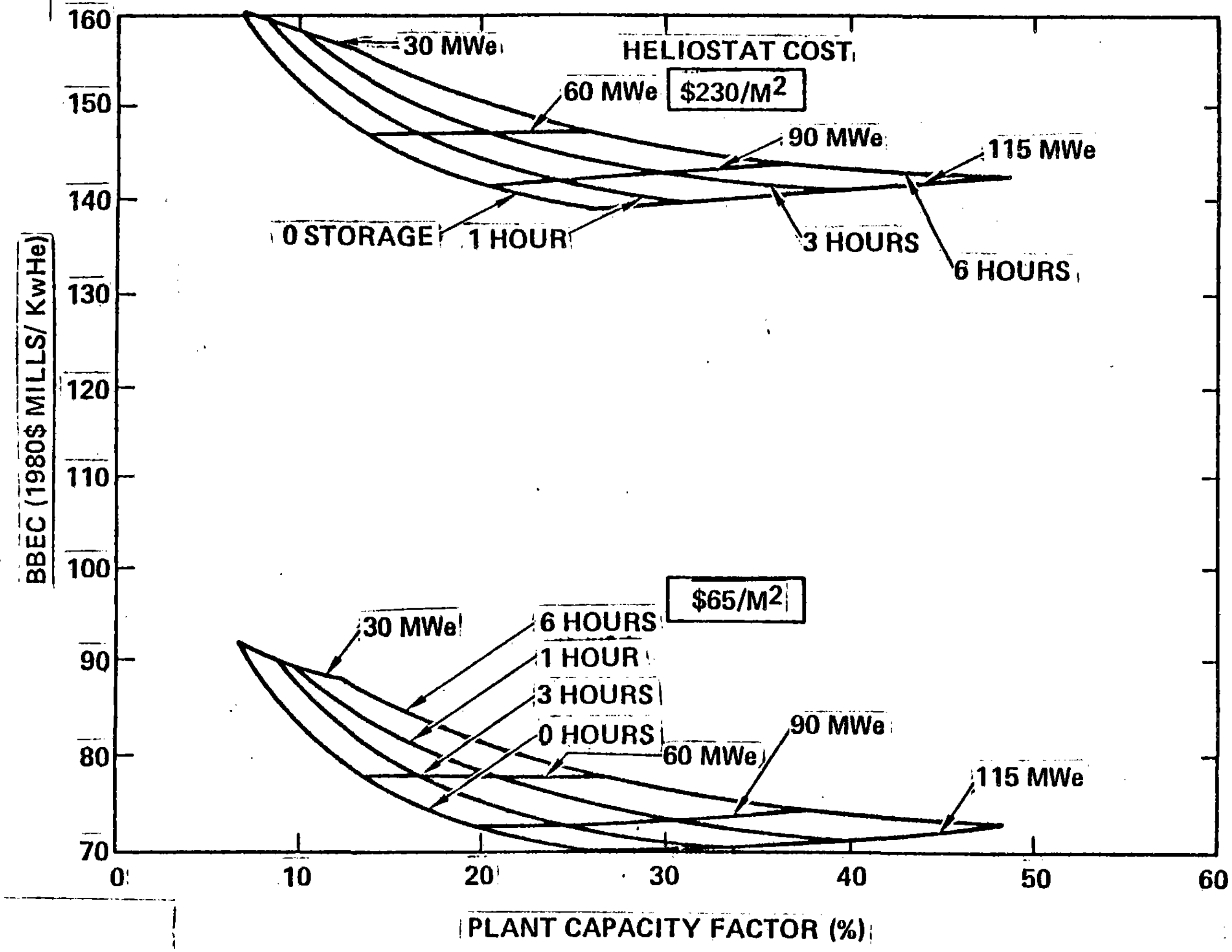


Figure (8) 3-7

PERMIAN BASIN UNIT No. 5 -BBEC VS. PLANT CF

SOLAR ONLY



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factor. The curves for 30 MWe in Figure 3-6 are perplexing in that they alone show the expected trend.

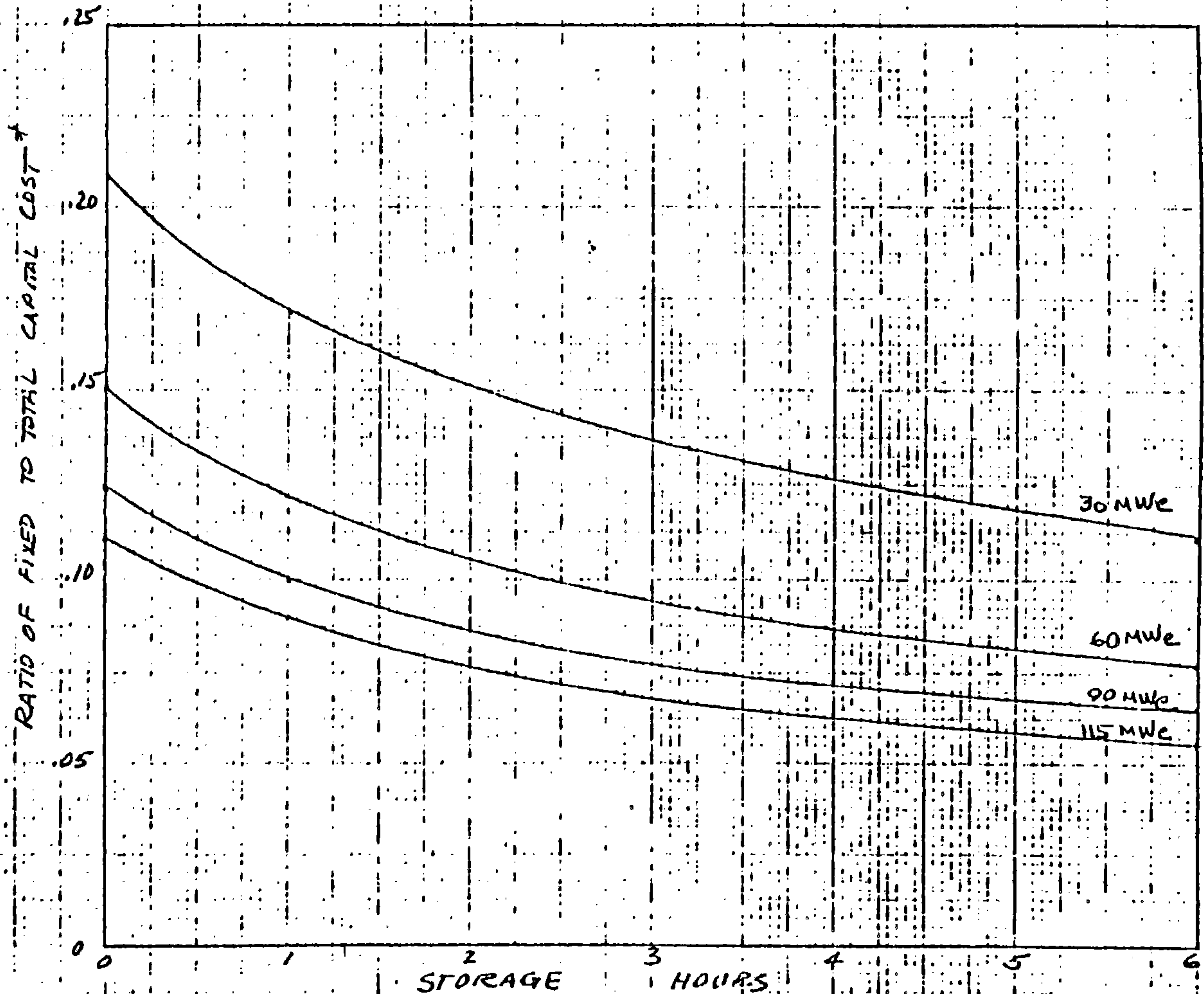
The explanation of this result is contained within the breakdown of capital costs and the derivative, with respect to storage capacity, of the $\overline{\text{BBEC}}$. In the case of stand-alone plants, this derivative indicates that the % change in $\overline{\text{BBEC}}$ (slope) is equal to the difference between the % change in annualized cost and the % change in annually generated electricity. For stand-alone plants, the annualized cost can be expressed solely in terms of capital cost when the O&M costs are estimated as a fraction of capital costs. Capital costs consist of the sum of relatively fixed costs and storage variable costs. The derivative of capital costs is given in Equation 3-1:

$$\frac{\text{d Capital Cost}}{\text{Capital Cost}} = \frac{\text{Constant x d Storage Costs}}{\text{Fixed Costs + Storage Costs}} \qquad (3\text{-}1)$$

Clearly, a small fixed cost relative to total costs implies that the derivative is sensitive to storage coupled costs. A highly sensitive capital cost derivative with respect to the annual energy derivative results in the positive slopes observed. This is the case in repowered plants where a large portion of the fixed costs come "free" (i.e., EPGS and existing equipment). In light of these phenomena, the observed trend of increasing $\overline{\text{BBEC}}$ with storage is not surprising after all.

However, the expected trend, observed in the 30 MWe curve, is now apparently at odds with the above explanation. Even this can be explained in terms of fixed cost fraction. Figure 3-7 shows the ratio of fixed to total capital cost as a function of solar power rating and storage capacity. At all storage capacities, this ratio is significantly greater for the 30 MWe system. Consequently, it can be concluded that the high fixed costs of this system make its derivative relatively insensitive and its costs decrease with increasing storage capacity.

Figure 3-8 shows the estimate of land area requirements, in acres, as a function of solar power storage capacity. Superimposed on Figure 3-8 are lines showing the land available in the east half of the TESCO property and the total available land area (see Figure 2-1).



PERMIAN BASIN UNIT No5
RATIO OF FIXED TO TOTAL CAPITAL COST

Figure (10) 3-1

SOLAR POWER RATING VS LAND AREA AND STORAGE CAPACITY

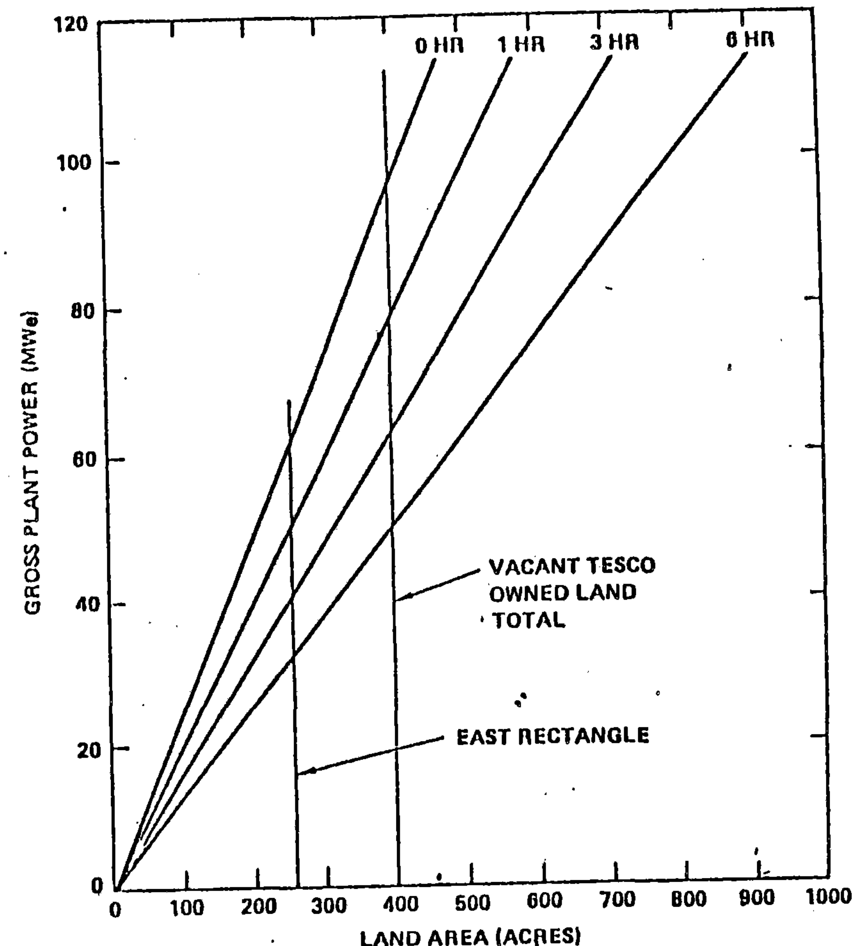


Figure (11) 3-10

The major sodium components of a solar-repowered system are the sodium pumps, steam generator units, valves, and receiver.

Figure 3-9 shows the sizes of some of these components as a function of thermal power. The top graph of Figure 3-9 shows the steam generator components as a function of total steam generator power. Also shown is the size of available once-through evaporator-superheaters of the hockeystick type (the baseline design). The largest separate steam generator units of this type expected to be available* by 1985 include: 115 MWt evaporators and 90 MWt superheaters. These experience values are superimposed on Figure 3-9 and indicate that steam generator arrangements using single units would allow repowering to a level of 238 MWt. It is, of course, feasible to use multiple steam generator units in parallel to attain higher thermal power levels. Consequently, the available steam generator components do not represent a limit to repowered plant power level.

The second graph of Figure 3-9 shows the required receiver pump characteristics as a function of receiver peak power. Superimposed on the head and power curves are the design points for various types of operating pumps. The pump for the CRBRP has a sodium flow capability of 33,000 gpm which is "off-scale" of the center figure of Figure 3-9. Pump experience is satisfactory, particularly with regard to flow rate and horsepower for the range of repowered plan size being considered herein. Developed head is not considered to be limiting. The current sodium pumps have head capability satisfactory for reactor applications. Single-stage sodium pumps can develop up to 900 ft of head before tip speed limitations are encountered. Hence, head capability for the receiver pump for a commercial-sized plant can be provided.

The pipe and valve size curve in Figure 3-9 shows adequate experience for repowering applications as well as for commercial-sized plants and does not represent a technology limit.

Since the receiver has no counterpart in the sodium-cooled reactor program, except the fossil-fueled sodium heater, the receiver requires a development

*This is the size of the units being <u>built</u> for Clinch River Breeder Reactor Plant.

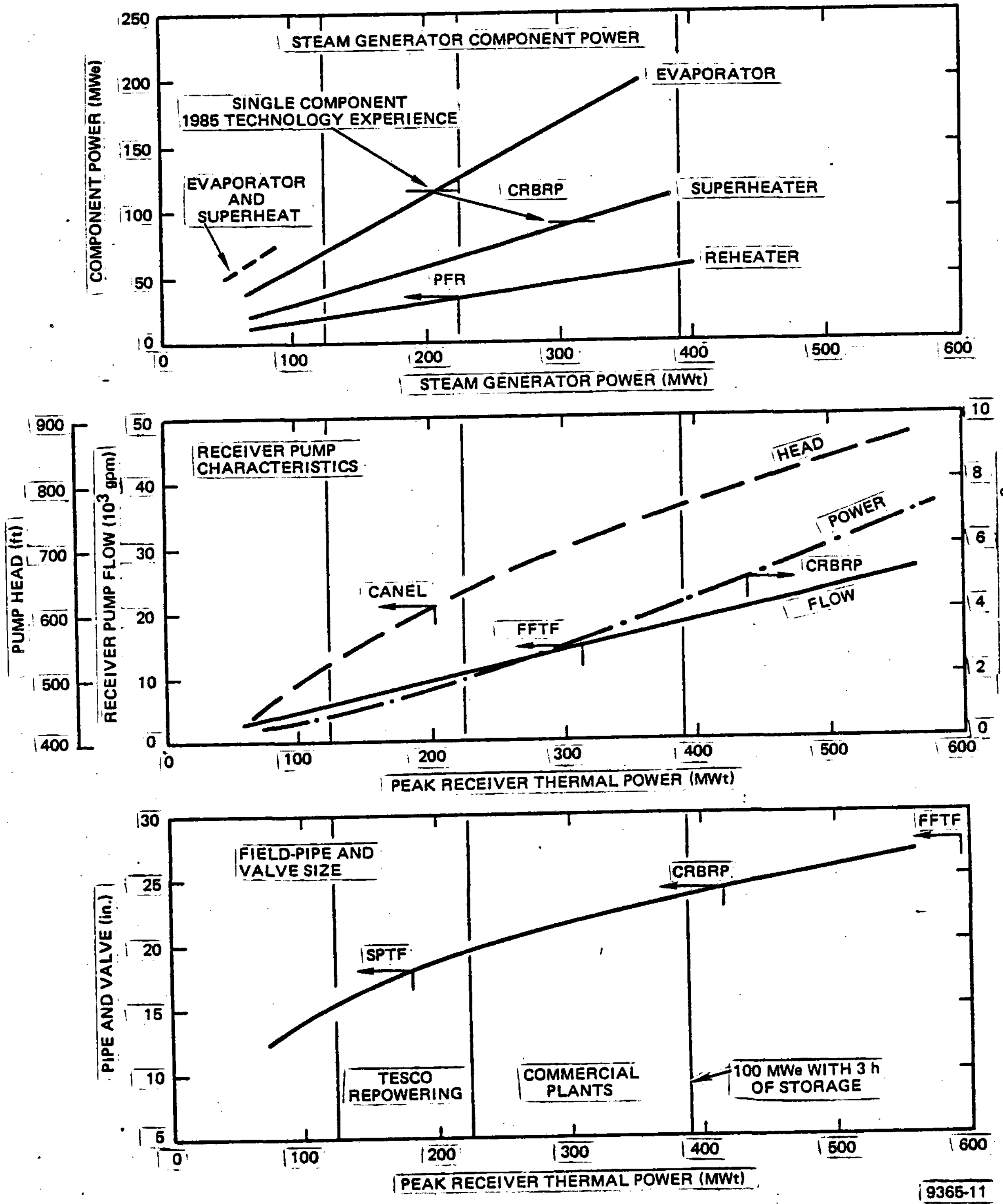


Figure 3-11 COMPONENT SIZES

effort. It is expected that ongoing sodium receiver panel tests at power levels in the neighborhood of 10% of the power required in the study will verify the analytic techniques required to successfully design and fabricate the receivers required for this repower application.

There are no limitations on the plant repowered solar capacity or storage system capability due to component availability.

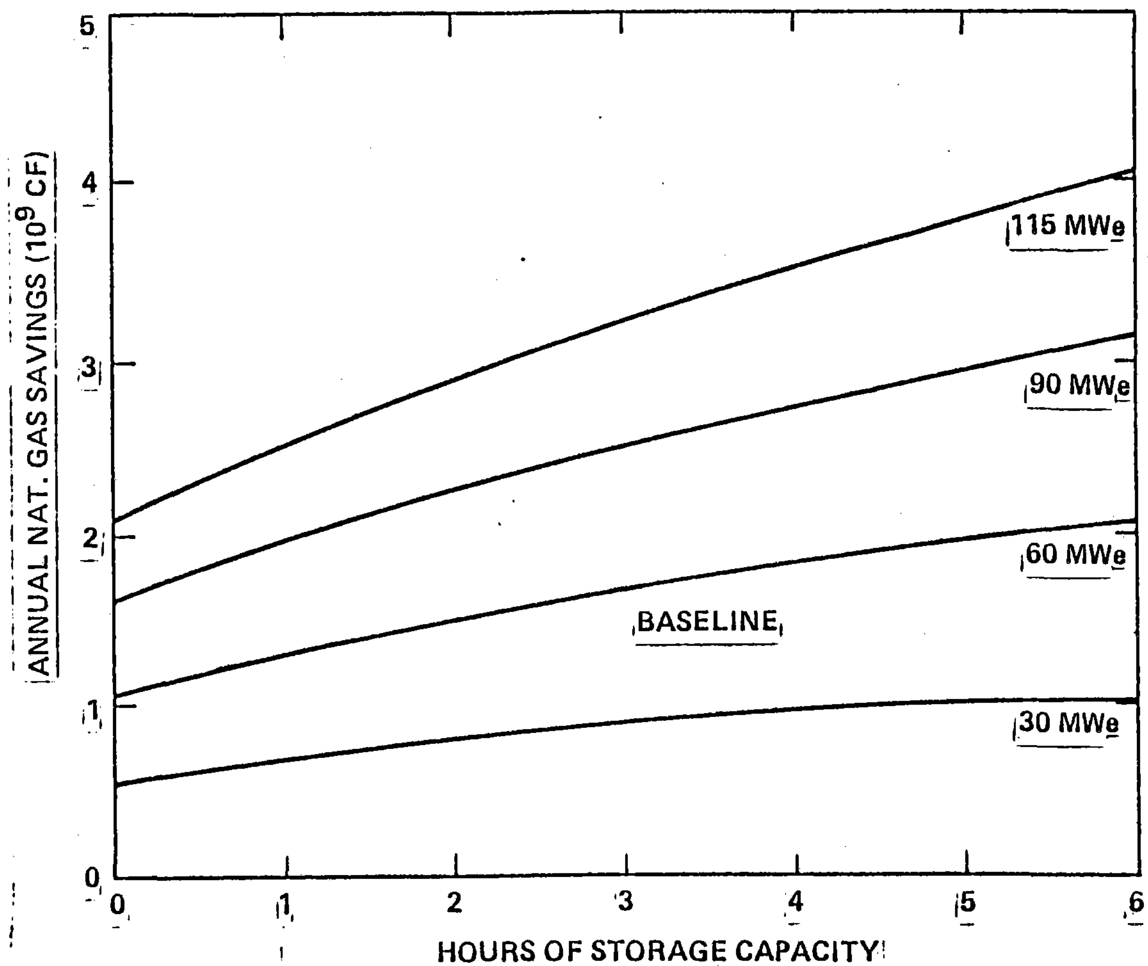
Figures 3-10 and 3-11 show the gas savings and equivalent oil savings attributable to solar repowering as a function of solar repowered capacity and storage capability.

3.2.6 Selection of Solar Plant Output and Storage Capacity

Based on the total land area available, the baseline design would easily fit the selection criteria. However, the utility has expressed an interest in utilizing only the east half of the available section, equivalent to 250 unencumbered acres. This reduces the receiver peak power considerably. Furthermore, the addition of storage was found to be cost ineffective, when compared to gas at $\$2.63/10^6$ Btu, above solar plant powers of 30-40 MWe. The utility has also found that this system best fits their generating load profile when operated as an essentially stand-alone plant. All of these have a tendency to reduce the receiver peak power and storage time. However, operating the plant in a stand-alone mode introduces a technical requirement for storage to supply heat during boiler cold startup, system cold starts, and transient cloud covers. These storage requirements are not expected to exceed 1 hour. Consequently, the selected system is the largest 1-hour system capable of fitting a 250-acre collector field area. Figure 3-8 shows this to be a 50-MWe, gross, solar power level.

By operating the steam generators at reduced power, additional storage operating duration can be obtained. For example, with the steam generators providing a 24 MWe of gross plant output, the operating duration from storage of the selected configuration would be increased to about 2 hours. Furthermore, by selecting steam generators with increased capacity, higher thermal power output from the solar is possible by increasing the flowrate from the storage tanks.

PERMIAN BASIN UNIT No. 5 ANNUAL GAS SAVINGS VS. SOLAR CAPACITY AND STORAGE CAPACITY



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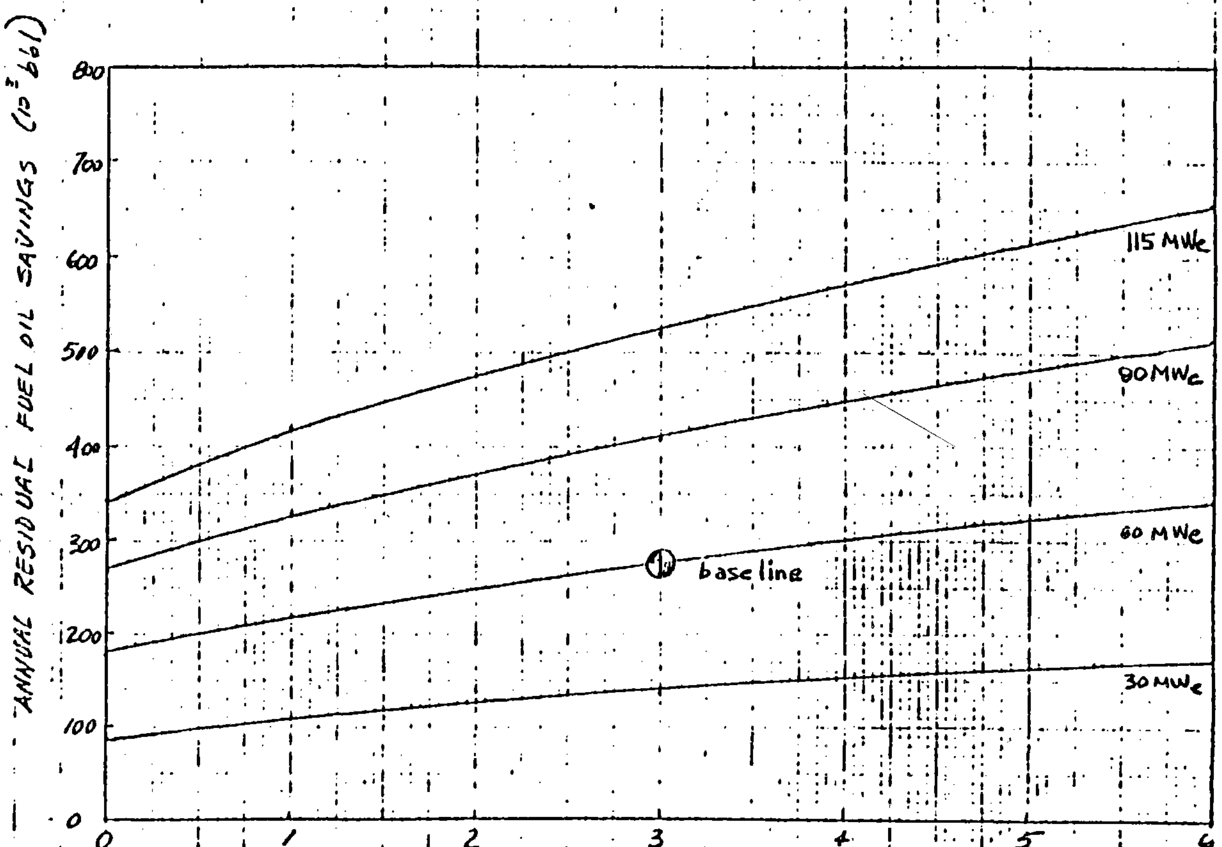


Figure 13 3-1
PERMIAN BASIN UNIT No 5
ANNUAL OIL SAVINGS vs SOLAR CAPACITY AND STORAGE CAPACITY

These operating options greatly enhance the commercialization potential of the system since only a modest extrapolation in component size is required from this repowering application to a commercial-size plant at 100 MWe.

Operated as a stand-alone plant with an allowance for a 5% fossil fuel capacity factor, the 13.5% capacity factor will give this plant a 73% solar fraction. This fraction exceeds the contractually required 20% by a wide margin, satisfying the solar fraction selection criteria.

As seen in Section 3.2.5, there are no limitations on this plant configuration from a component availability standpoint.

The fuel savings, capital cost, and $\overline{\text{BBEC}}$ selection criteria or goals have been somewhat compromised by the selection of the 50-MWe, 1-hour configuration. However, within the limitations of land availability, the capital costs and $\overline{\text{BBEC}}$ have been minimized.

For convenience of comparison, Table 3-7 summarizes the comparison of the alternatives.

Due to the small fixed costs, storage capacity is not of obvious economic benefit. However, the design must include some storage for buffering and to demonstrate the thermal storage concept.

The capital worth discussion of Figure 3-6, in Table 3-7, leads to a solar fraction of 28% for a typical current capacity factor of 49%. If the plant is operated in a predominantly stand-alone mode, as preferred by TESCO, the solar fraction would increase to 73%, with an overall plant capacity factor of 18.5%.

The interrelation of the capital worth limit and the storage selection of 1 hour gives a solar plant rating of about 50 MWe. This plant also is expected to just fill the east half of TESCO's available land.

TABLE 3-7

COMPARISON OF ALTERNATIVES

Figure	Use - Title	Trends	Comments or Conclusions
3-2	Solar fraction as a function of storage capacity C_F = 49%	Highest solar fraction with largest solar plant rating and storage capacity	Solar fraction must be greater than 20%. Power level must be greater than 45 MWe with zero storage or 30 MWe with 3-h storage.
3-4	Capital cost as a function of storage capacity	Increasing cost with solar plant rating and storage capacity	Shows cost trade between solar plant rating and storage capacity. TESCO identifies capital cost worth ~$100M. Size range is from 30 MWe for solar with 6-h storage to 60 MWe solar with no storage.
3-5	$\overline{\text{BBEC}}$ versus storage capacity for both \$280/m² and \$65/m² heliostats C_F = 49%	The higher cost mirrors are appropriate for the first repowering application. Minimum $\overline{\text{BBEC}}$ is for low solar power rating and storage capacity.	The high heliostat cost in comparison with fuel costs at \$2.63/MMBtu indicates that solar is not economic for the first solar repowering application.
3-6	$\overline{\text{BBEC}}$ for solar plant only operations various capacity factors	$\overline{\text{BBEC}}$ decreases for larger plant size and minimum storage capacity for both heliostat costs. Sensitivity of $\overline{\text{BBEC}}$ to storage capacity is small.	The 115-MWe solar plant rating with minimum storage capacity for buffering gives minimum $\overline{\text{BBEC}}$.
3-8	Land area required as a function of solar plant rating	Limit lines show area available (vacant) on TESCO-owned property	TESCO prefers limiting the collector field to east 1/2-section (250 acres). Solar plant size is thus limited to 63 MWe with no storage to 33 MWe with 6 h of storage.
3-10	Fuel saving as a function of solar power rating and storage capacity	Maximum savings are attained for the maximum power rating and storage capacity	The 115-MWe solar plant rating with 6 h of storage gives the maximum savings.

3.2.7 Conclusions

As a result of these trade studies, it was concluded that at solar power levels above 30-40 MWe, storage is not obviously cost effective in repowered systems utilizing $230/M^2 heliostats and $2.63/10^{6}Btu natural gas. It was also concluded that a 50-MWe solar power level in conjunction with 1 hour of storage best fits all the selection criteria for Permian Basin Unit 5 repowering.

3.3 TECHNOLOGY

The selection of sodium as the receiver heat transfer fluid was made at the time the teaming agreement with TESCO was accomplished with their full concurrence. The advantages of sodium are given below.

The sodium system can operate at temperatures of 593^{o}C (1100^{o}F) or more and generate steam at 538^{o}C (1000^{o}F) or higher. Hence, the steam conditions of 538^{o}C (1000^{o}F) for the Permian Basin plant are readily satisfied. The thermal storage system is designed to operate at the same high temperatures so that during operation from storage, steam conditions are unchanged. The storage system provides a smooth transition between solar and nonsolar operation. Other advantages of a sodium-cooled system, as compared to other systems, are as follows:

1) Good Heat Transfer — Liquid sodium has a heat transfer coefficient that is several times that of high-pressure steam, molten salt, or air. Thus, sodium systems can accept high heat fluxes [up to 0.14 MW/ft^2 (1.5 MW/m^2)] that the other systems often cannot. In view of the irregular and uncertain heat fluxes that can occur on or in a receiver, it is important to have a very high heat transfer capability.
2) Single-Phase, Dense Coolant — Sodium coolant remains as a dense liquid throughout the process. Water flashes to steam in the

receiver in a manner that is sensitive to the heat flux pattern. Instabilities could develop in the water-steam flow. Air has the disadvantage of having a relatively low density.

3) Low-Pressure Coolant — Sodium pressure in the receiver or heater is expected to be 1.5×10^5 to 3.5×10^5 Pa (22 to 50 psi). Steam is expected to be in the range of 10 to 17 MPa (1450 to 2500 psi). High pressures in the receiver or heater tubes add to an already difficult design problem.

4) Sodium Reheat — Reheat can be used in sodium systems but not necessarily with water, as the latter would have to be returned to the receiver as steam or a segregated nonsolar boiler design would have to be developed. Reheat increases system efficiency and lengthens turbine life. Efficiency increases up to 5%, directly and indirectly related to this phenomenon, may be realized.

5) Sodium Thermal Storage — Neither water nor gas is suitable for storage of sensible heat at the temperatures under consideration here. Sodium can be used directly in thermal storage systems, a feature that leads to design simplification and maintaining design performance when operating off storage. There would be no degradation in performance relative to operating directly from either the receiver or storage.

6) Receiver Size Reduced — Because of the excellent heat transport capabilities of sodium, a much higher heat flux [up to 1.5 MW/m^2 (0.14 MW/ft^2)] can be tolerated on the receiver. This factor permits a substantial reduction in the size of the receiver and, hence, a less expensive and lighter component. Some reduction in the costs of the tower also ensues from this fact.

7) Thermal Gradients Reduced — In general, receiver tubes are heated only on one side, a condition that creates substantial circumferential thermal stresses. Since sodium has a thermal conductivity ~100 times greater than that of pressurized steam,

these gradients will be significantly reduced. Similarly, the thermal gradients encountered along the length of the tube in the water-steam system can be reduced when a sodium coolant is used.

8) Tube Fouling Eliminated — Sodium does not form a boiler scale or coating, which tends to reduce heat transfer capability, as do water-steam and possibly molten salt systems.

9) High Component Availability — All of the required sodium components have been built and extensively tested, except the receiver. It is expected that sodium receiver tests completed in the near future at the Central Receiver Test Facility would have a direct bearing on the repowered receiver because the designs are similar.

3.4 SYSTEM CONFIGURATION

A study was completed which compared the configuration candidates for the heat transport system. As a substudy, the piping size for each configuration was also selected. The selection criteria included: lowest equivalent total capital cost, maintainability, safety, and minimization of plant parasitic losses. The capital costs and parasitic losses were evaluated quantitatively. The maintainability and safety criteria were evaluated qualitatively.

A process flow diagram of the plant is shown in Figure 3-1.

The primary objective of this study was to select the location of the hot and cold tanks. A secondary objective was to select the piping size for the final configuration.

The configuration candidates are illustrated in Figure 3-12. For purposes of this study, it was assumed that the required hot and cold pumps would be located close to their respective tanks, thus eliminating potential NPSH problems with these pumps. Consequently, there are four possible configurations. In Configuration A, as shown in Figure 3-12A, both tanks are located adjacent to the receiver tower, inside the collector-field exclusion radius. Configuration B

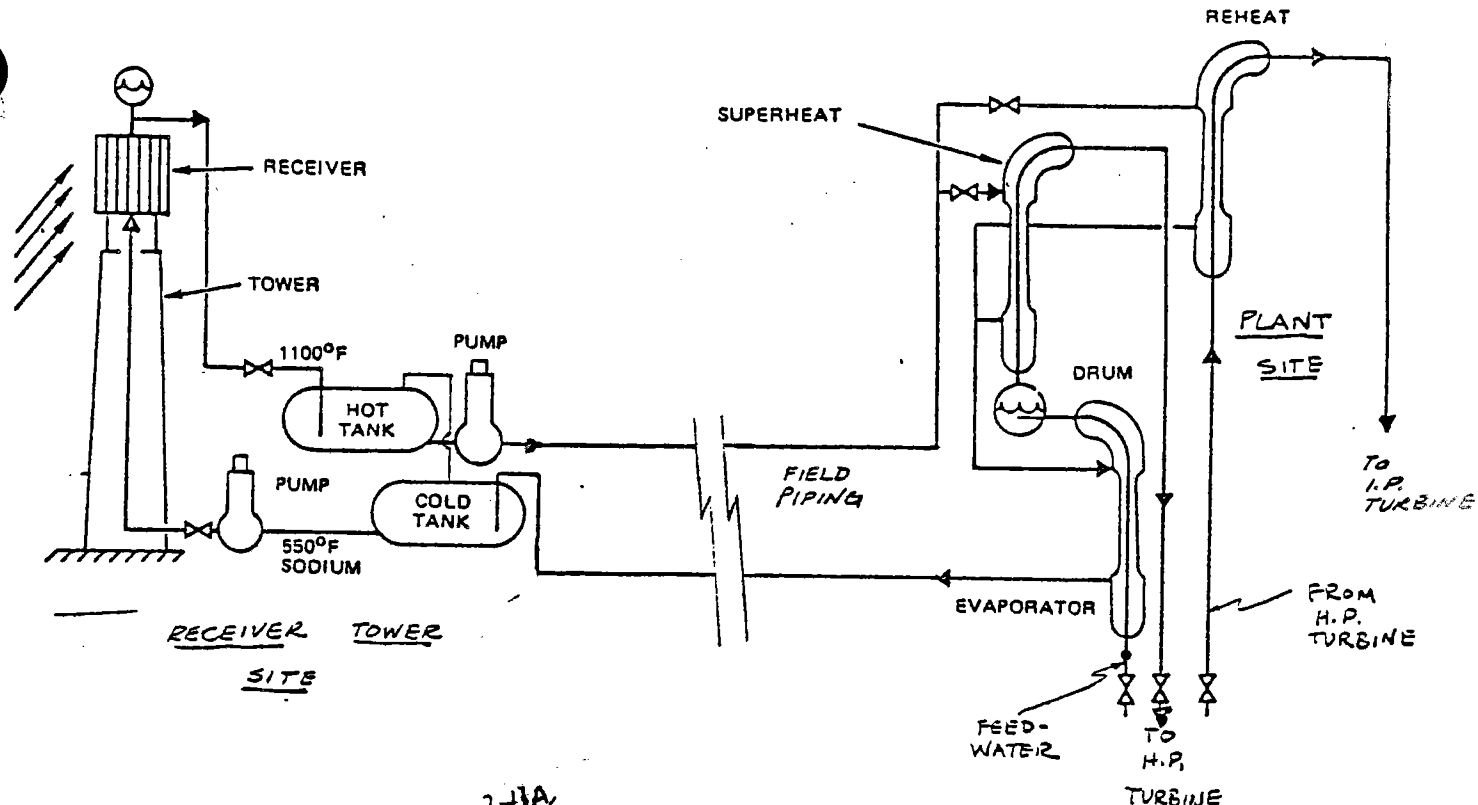


FIGURE 3-13A - CONFIGURATION A
STORAGE TANKS IN FIELD

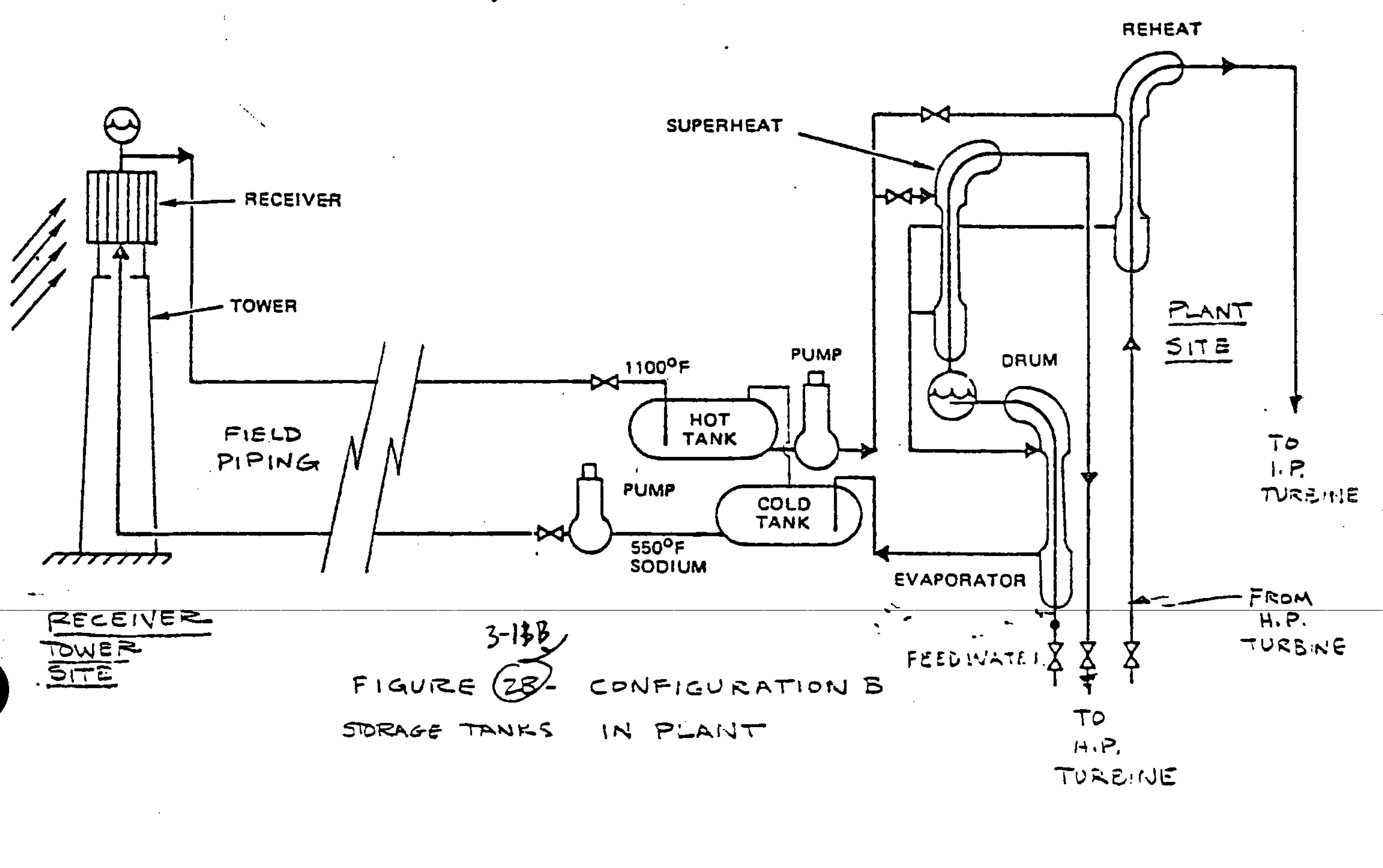
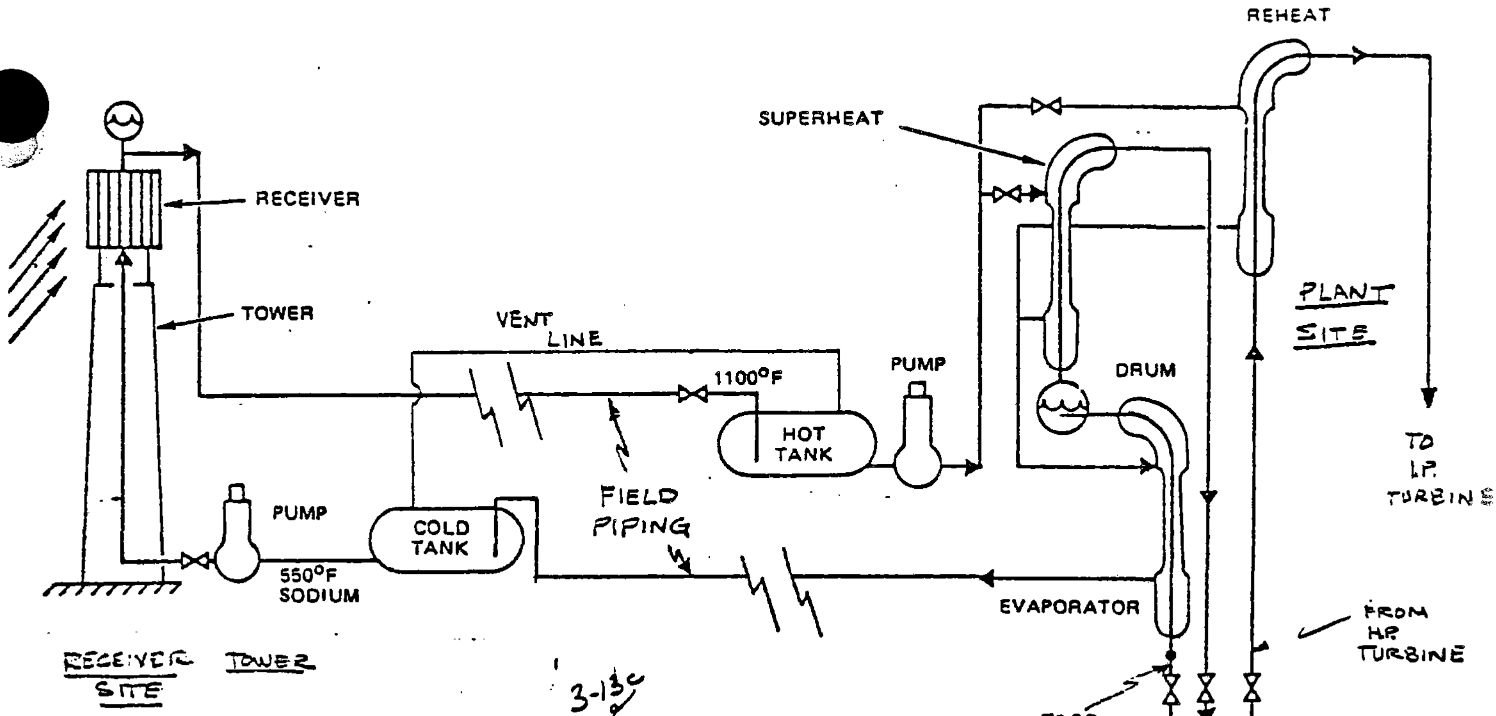
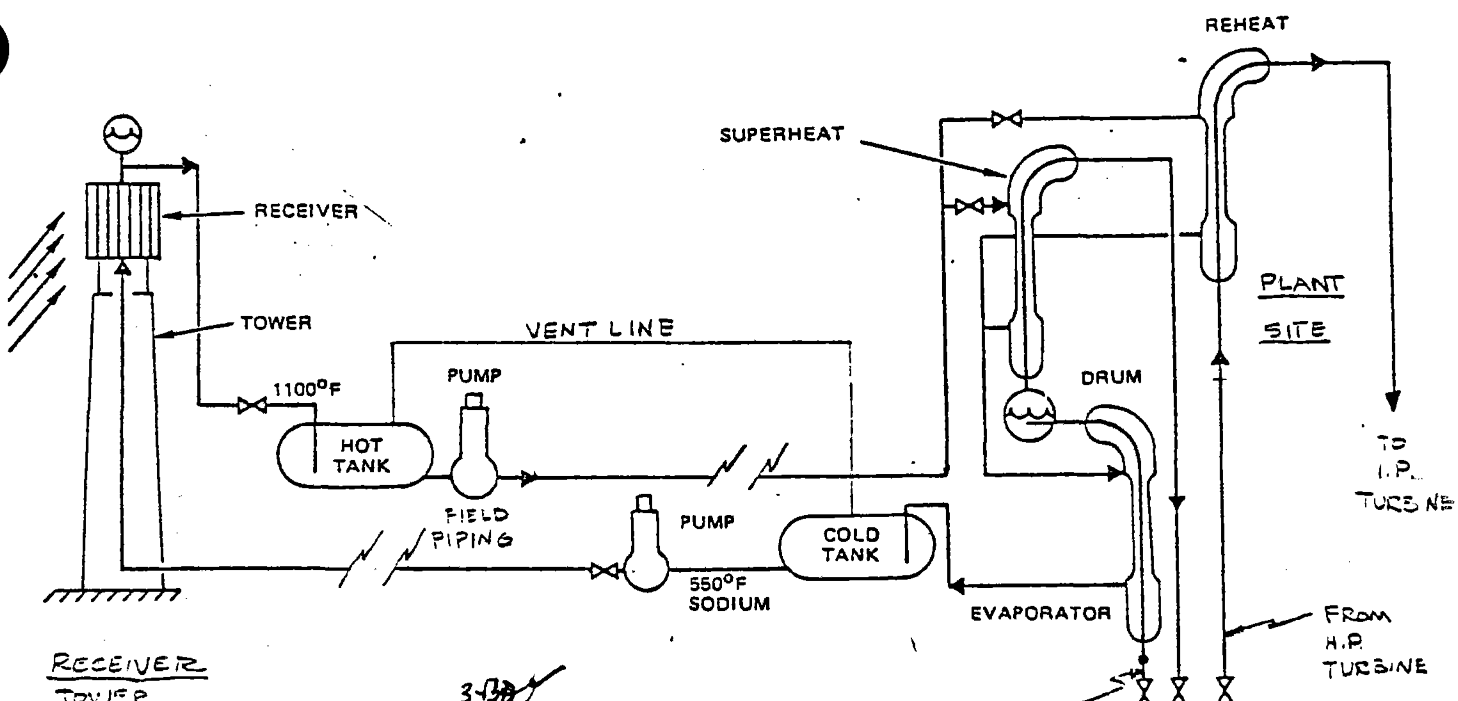


FIGURE 3-13B - CONFIGURATION B
STORAGE TANKS IN PLANT



3-13c

FIGURE 2C - CONFIGURATION C
SPLIT STORAGE TANK LOCATION



3-13D

FIGURE 2D - CONFIGURATION D
SPLIT STORAGE TANK LOCATION

(Figure 3-12B) located both tanks adjacent to the plant. Configuration C (Figure 3-12C) has a hot tank next to the plant and the cold tank in the field. Configuration D (Figure 3-12D) reverses the location of the hot and cold tanks as compared to Configuration C.

3.4.1 Methodology

For each configuration, a study was conducted to select the optimum supply and return line sizes. For the required flow and temperature Reynolds numbers, friction presure drops per foot, hydraulic pumping power required per foot, heat losses per foot were calculated for a range of probable pipe sizes using the straightforward hydraulic formulas from Crane.[3-6] The sodium film coefficient was determined from the Seban-Shimazaki[3-7] correlation. In all cases, the outside film coefficient was taken to be 2 Btu/hr-ft^2-$^\circ$F, which accounted for free and forced convection as well as radiation heat losses. Insulation manufacturer's recommendations for insulation thickness were accepted and adopted resulting in 6 in. of calcium silicate for all the pipe sizes of interest.

From the foregoing estimates of pressure drop, heat loss, and pumping power, estimates of total equivalent capital cost were developed. This cost consists of the sum of the capital cost of the pipe, the equivalent capital cost of the revenue lost due to heat losses through the pipe wall, and the equivalent capital cost of the required pumping power. The equivalent capital saving due to viscous heating was also considered but was not significant. The capital cost of the pipe includes the pipe, supports, insulation, trace heating, and installation labor. Table 3-8 shows these costs for carbon and stainless steel pipe in the sizes of interest. In all cases, standard wall pipe was utilized. The number of trusses required to keep the pipe 20 ft off the ground were the same regardless of pipe size and were, therefore, neglected in this study. Once the total equivalent capital cost per foot of pipe was obtained, a size selection was made based solely on minimum cost.

TABLE 3-8

PIPING CAPITAL COSTS.

Pipe	Std. Stainless Steel 1100°F	Pipe	No. 257 Supports	Insulation	Trace Heaters	Labor	Total
8	5 1/2 in.	$ 74.00	$12.00	$ 50.00	$25.00	$ 70.00	$ 231.00
10	5 1/2 in.	$135.00	$15.00	$ 57.00	$41.00	$ 88.00	$ 336.00
12	6 in.	$166.00	$13.00	$ 61.00	$41.00	$120.00	$ 401.00
14	6 in.	$183.00	$13.00	$ 69.00	$41.00	$130.00	$ 436.00
16	6 in.	$210.00	$12.00	$ 72.00	$41.00	$144.00	$ 479.00
18	6 in.	$236.00	$11.00	$ 92.00	$41.00	$153.00	$ 533.00
20	6 in	$263.00	$11.00	$102.00	$41.00	$165.00	$ 583.00
24	6 in.	$317.00	$11.00	$115.00	$41.00	$212.00	$ 696.00
30	6 in.	$542.00	$11.00	$234.00	$41.00	$272.00	$1,100.00
	Carbon Steel ASTM A-53 Std. Wall 550°F						
8	5 1/2 in.	$ 18.00	$ 9.00	$ 50.00	$25.00	$ 62.00	$ 164.00
10	5 1/2 in.	$ 25.00	$12.00	$ 57.00	$41.00	$ 80.00	$ 215.00
12	6 in.	$ 31.00	$10.00	$ 61.00	$41.00	$107.00	$ 250.00
14	6 in.	$ 36.00	$10.00	$ 69.00	$41.00	$119.00	$ 275.00
16	6 in.	$ 41.00	$ 9.00	$ 72.00	$41.00	$131.00	$ 294.00
18	6 in.	$ 48.00	$ 8.00	$ 92.00	$41.00	$139.00	$ 328.00
20	6 in.	$ 53.00	$ 8.00	$102.00	$41.00	$149.00	$ 353.00
24	6 in.	$ 63.00	$ 8.00	$115.00	$41.00	$181.00	$ 408.00
30	6 in.	$108.00	$ 8.00	$234.00	$41.00	$245.00	$ 636.00

After selecting line sizes for each configuration, a configuration comparison cost was generated. The total equivalent capital cost of a given configuration consisted of the capital cost of the supply, return and vent lines, and the capital cost of the hot and cold pump. The capital cost of each pump was based on $605 (1980)/hydraulic horsepower. Horsepower requirements were derived from estimates of head and flow for each configuration. The capital cost of vent lines was based on 10-in. stainless steel pipe.

Finally, the relative maintainability and safety of each configuration were based on engineering judgment.

3.4.2 Results

The results of the piping study are tabulated in Table 3-9. The results of the configuration cost comparison study are shown in Table 3-10. A relative evaluation of the intangibles is shown in Table 3-11.

TABLE 3-11

SUBJECTIVE EVALUATION OF INTANGIBLE CRITERIA*

Configuration	A	B	C	D
Maintainability	4	1	2	3
Safety	1	4	3	2

*Ranked in order of desirability

3.4.3 Discussion of Results

In the following discussion, the supply lines and the cold storage tank operate at a temperature of 288°C (550°F) and use carbon steel (CS). The return lines and the hot storage tank are at 593°C (1100°F) and are made of stainless steel (SS). Based on the total equivalent capital cost (Table 3-9), the selected nominal line size for Configurations A and C supply lines is 14 in. The total equivalent capital cost of this CS line is $487.33/ft. The selected line size for Configurations A and D return lines is 12 in.

TABLE 3-9

SOLAR REPOWERING OF TEXAS ELECTRIC SERVICE COMPANY,
PERMIAN BASIN, UNIT 5
SODIUM FIELD PIPING COMPARISON

Configuration/ Line	Flow (lbm/ sec)	Temp °F	Candidate Nominal Pipe Size (in.)	ΔP/ft (psi)	Hydraulic HP/ft	Heat Loss* ft (Btu/h)	Capital Cost† ft (1980 $)	Equivalent Capital Cost/ft Heat Loss (1980 $)	Equivalent Capital Cost/ft Viscous Heat (1980 $)	Equivalent Capital Cost/ft Pump Power (1980 $)	Equivalent Capital Cost/ft Total (1980 $)	Selected Pipe
A and C/Supply	722.4	550	12 CS	.0220	.0755	226.1	250	142	-38	137	491	
			14 CS	.0132	.0435	243.0	275	153	-23	82	487	X
			16 CS	.0064	.0220	267.6	294	169	-11	40	492	
			18 CS	.0034	.0117	292.9	328	185	-6	21	528	
A and D/Return	722.4	1100	10 SS	.0601	.2251	533.7	336	336	-113	407	966	
			12 SS	.0235	.0880	568.8	401	358	-44	159	874	X
			14 SS	.0141	.0528	608.9	436	384	-27	96	889	
			16 SS	.0068	.0255	672.8	479	424	-13	46	936	
B and D/Supply	900.9	550	12 CS	.0337	.1443	226.1	250	142	-55	198	535	
			14 CS	.0204	.0873	243.0	275	153	-33	120	515	
			16 CS	.0098	.0420	267.6	294	169	-16	58	504	X
			18 CS	.0052	.0223	292.2	328	185	-9	31	535	
B and C/Return	900.9	1100	14 SS	.0216	.1007	608.9	436	384	-38	10**	792	
			16 SS	.0109	.0509	672.8	479	424	-19	0	884	X
			18 SS	.0056	.0262	736.2	533	464	-10	0	987	
			20 SS	.0032	.0149	799.5	583	504	-6	0	1081	

* 6 in. of $CaSiO_3$ insulation
**Requires extra booster pump, not accounted for in total cost

TABLE 3-10

SOLAR REPOWERING OF TEXAS ELECTRIC SERVICE COMPANY,
PERMIAN BASIN, UNIT 5
HEAT TRANSPORT SYSTEM CONFIGURATION COMPARISON

1980 $ x 10^6

Configuration/ Field Pipe Equivalent Length (ft)	Supply Pipe Nominal Size (in.)	Return Line Nominal Size (in.)	Hot Pump Required Head (ft, Na)	Cold Pump Required Head (ft, Na)	Equivalent Capital Cost Supply Line	Equivalent Capital Cost Return Line	Capital Cost Hot Pump	Capital Cost Cold Pump	Capital Cost Vent Line	Total Equivalent Capital Cost	Selected Configuration
A/5080 (Conventional field)*	14	12	681	410	2.476	4.442	.537	.403	.054	7.912	
B/5080	16	16	163	540	2.562	4.488	.129	.531	.054	7.764	X
C/5080	14	16	338	410	2.476	4.448	.266	.403	1.707	9.300	
D/5080	16	12	506	540	2.562	4.442	.399	.531	1.707	9.641	
A/4483 (Rectangular Field)*	14	12	621	410	2.185	3.920	.490	.403	.054	7.052	
B/4483	16	16	163	525	2.261	3.961	.129	.516	.054	6.921	X
C/4483	14	16	318	410	2.185	3.961	.251	.403	1.506	8.306	
D/4483	16	12	466	525	2.261	3.920	.367	.516	1.506	8.570	

*Piping Run Distance: Conventional Field = 3387 ft
Rectangular Field = 2989 ft

This SS line has a cost of $874.41/ft. The selected size of the Configurations B and D supply lines is 16 in. The cost is $504.36/ft. The optimum size of Configurations B and C return lines is 16 in. with a cost of $883.56/ft. In all cases except the last, the selection was straightforward. In the case of Configurations B and C return lines, lines of 16 in. and greater require only the available head of the receiver tower. Fourteen inch and smaller lines require an additional booster pump to accommodate higher friction losses. It is felt that such a pump could not be purchased for the difference in per foot equivalent capital cost, hence, the selection of the apparently more expensive 16-in. pipe in this case.

Based only on a comparison of the equivalent capital cost of each configuration, shown graphically in Figure 3-13, the optimum configuration appears to be Configuration B.* However, the margin of superiority is less than 2%. Consequently, it is useful to consider criteria to which it would be difficult to assign an economic value at the conceptual design level.

Table 3-11 shows a subjective, relative evaluation of maintainability and safety. The maintainability ratings are based on the premise that the further away a component is from the maintenance facility, the longer the time will be for any maintenance procedure. Consequently, close-in component configurations have greater availability and maintainability. The relative safety ratings are based on the common perception that large amounts of liquid sodium in proximity to the plant are less desirable than storage tanks located away from the plant and near the tower. Consequently, the maintainability criteria and safety criteria have a tendency to balance one another.

Finally, it should be noted that TESCO has expressed a strong interest in housing all the sodium circulation and heat transfer equipment in one location, close to the plant, to facilitate operation and maintenance activities.

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*At the time of this study, a final decision on a symmetric or rectangular layout has not been made; hence, two configuration studies are listed in Table 3-10, see Figure 3-14.

HEAT TRANSPORT SYSTEM CONFIGURATION COMPARISON

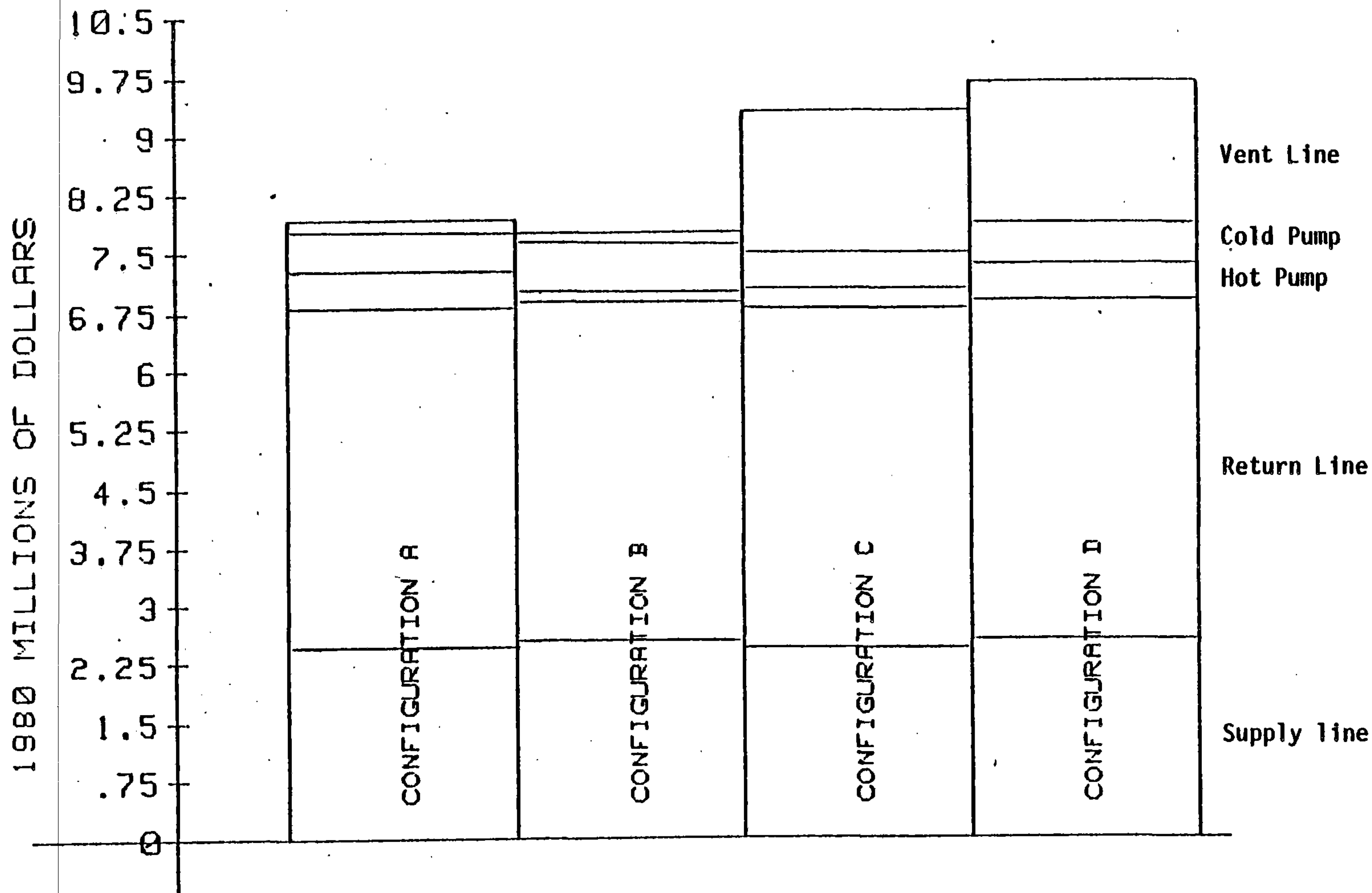

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FIGURE 3-14

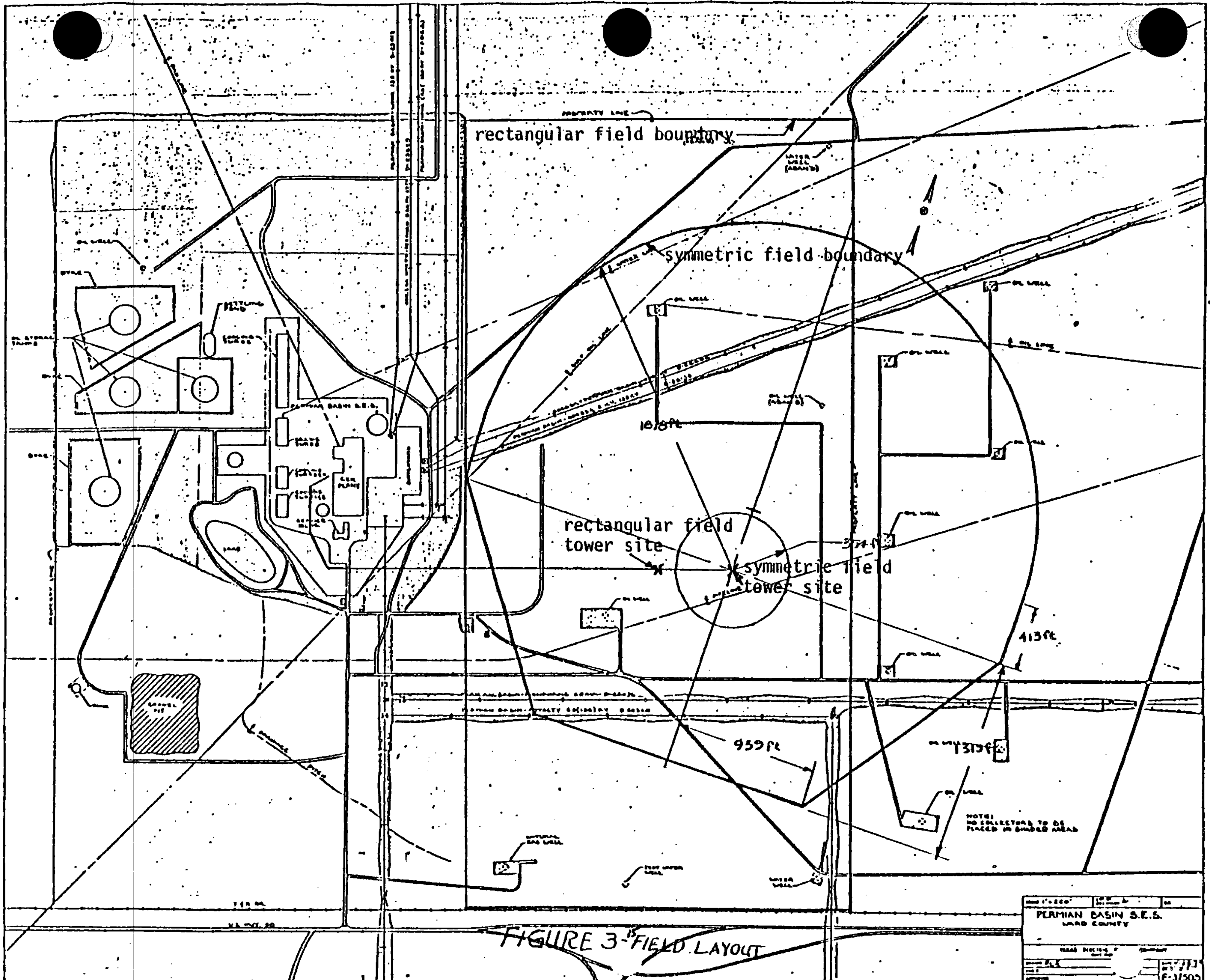


FIGURE 3 - FIELD LAYOUT

3.4.4 Conclusion

Based on a comparison of the economic and intangible attributes of each configuration, it appears that Configuration B is the optimum heat transport system arrangement.

3.4.5 Multiple Towers

In response to a request by TESCO, a second brief study was completed which compared the capital costs of achieving the required original baseline receiver power using various multi-tower configurations all on TESCO-owned property. In all, three multi-tower field configurations in addition to the single tower baseline design were generated and capital cost estimated for each. These configurations included one two-tower model with approximately equal collector field areas, one two-tower model with unequal collector fields, and one three-tower model with approximately equal fields, illustrated in Figures 3-15 through 3-17, respectively. Table 3-12 shows a summary of the results of this study.

TABLE 3-12
MULTIPLE FIELD TRADE STUDY RESULTS
AND COMPARISON SUMMARY

Case No.	Number of Towers	Land Area (acres)	Horizontal Run (M)	Tower Diameter (in.)	1978 $ x 10^6 Capital Cost	Tower Height (M)
0	1	379	760	20	138.0	117
1	2	181	644	15	140.4	79
		217	531	16		86
2	2	256	660	17	139.8	92
		142	330	14		72
3	3	142	330	14	150.1	72
		128	740	13		68
		128	708	13		68

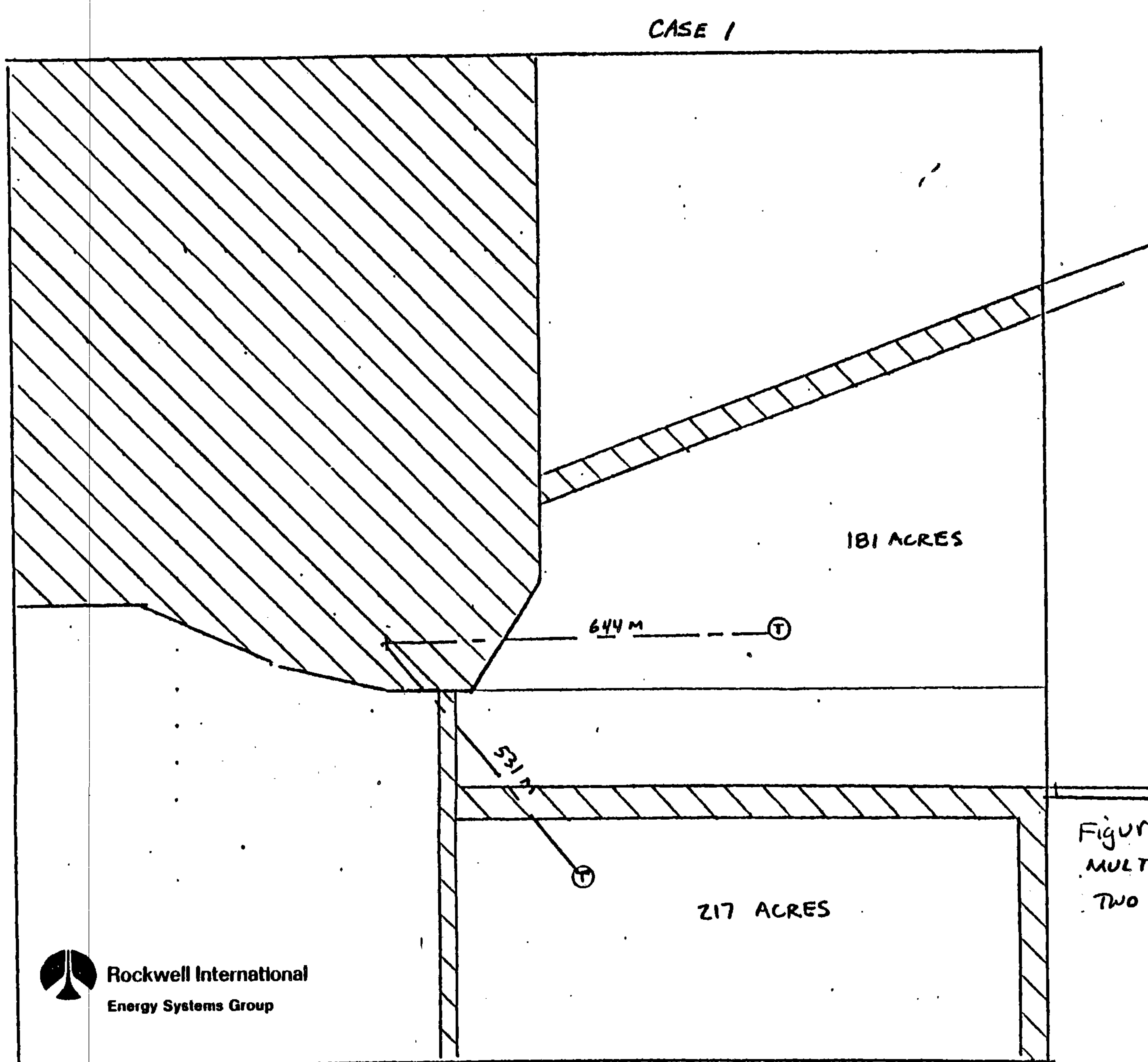
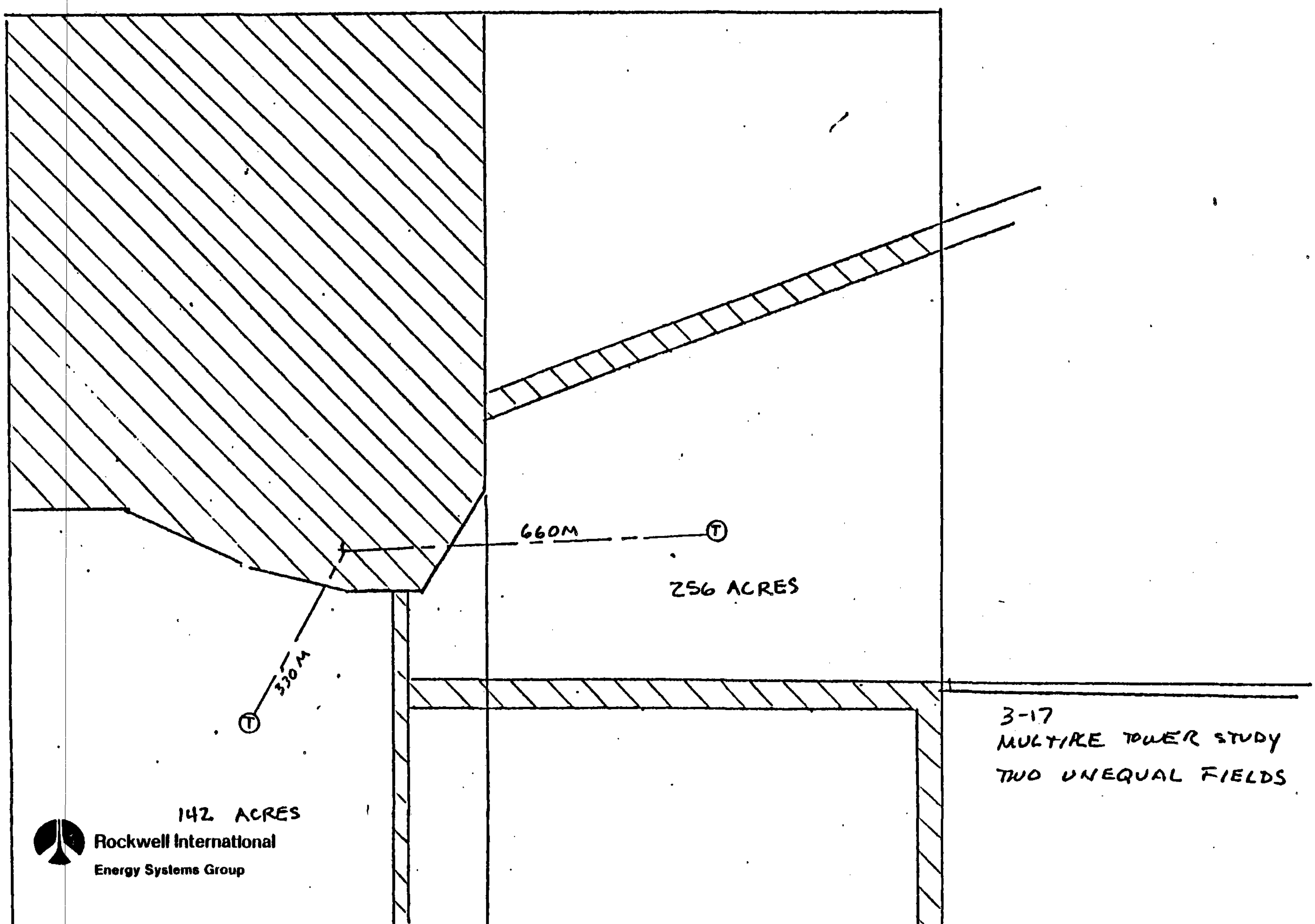


Figure 3-16
MULTIPLE TOWER STUDY
TWO EQUAL FIELDS

CASE 2



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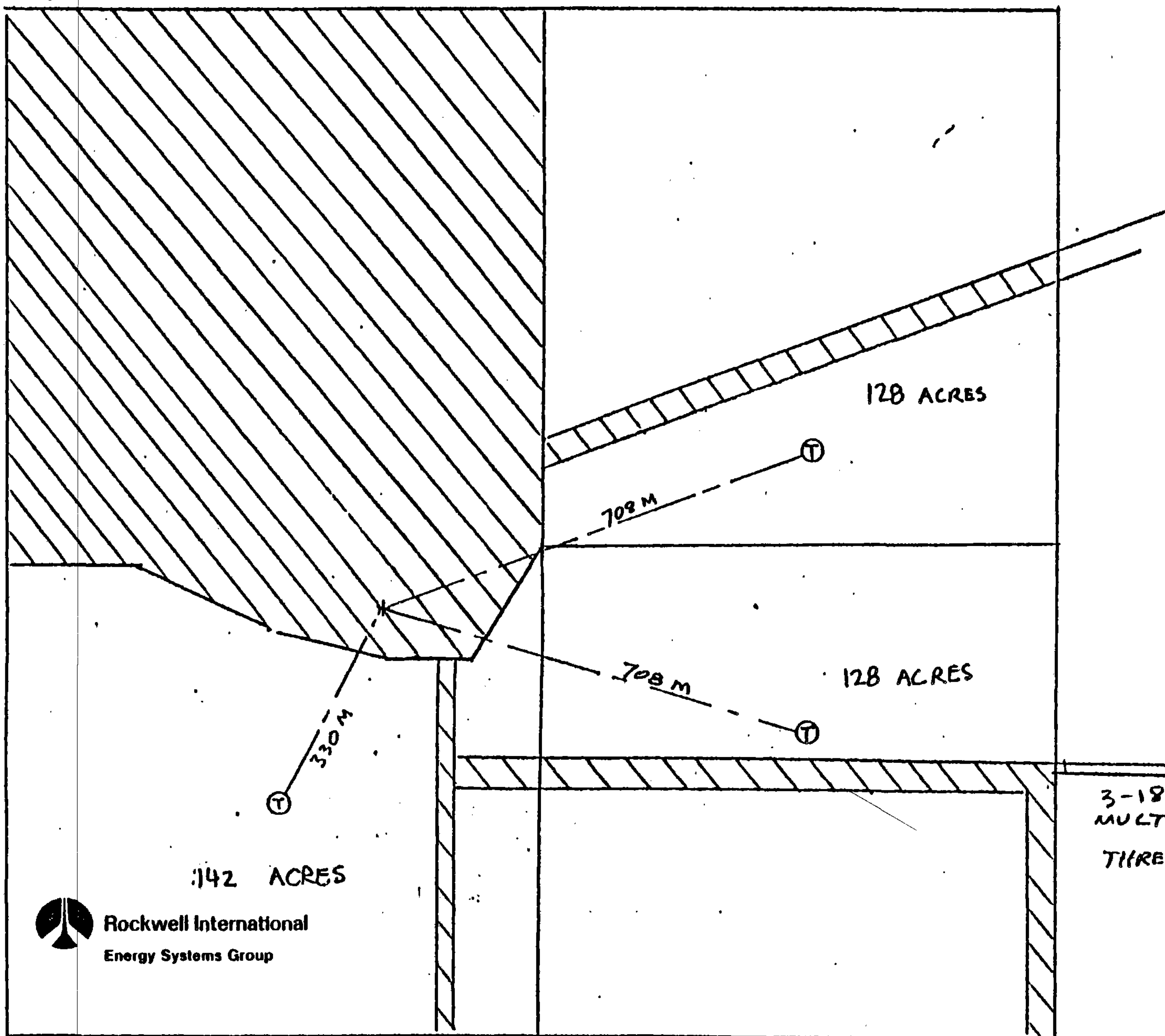
3-17
MULTIPLE TOWER STUDY
TWO UNEQUAL FIELDS

CASE 3



3-18
MULTIPLE TOWER STUDY
THREE FIELDS

In all cases, the capital costs of the multi-tower models exceeded the single-tower costs. Even in Case 2, the equal area two-tower model, where the cost difference is small, no account was taken of field inefficiencies due to nonidealized rectangular field layouts, and the cost estimate is thereby adjudged to be on the low side. It was concluded that the single-tower field configuration should be retained.

4.0 CONCEPTUAL DESIGN

The following section includes information on a system-level which addresses: the system description, functional requirements, design and operation characteristics, site requirements, system performance, capital cost, operating and maintenance considerations, system safety, environmental impact and institutional and regulatory considerations. Conceptual design information on a subsystem-level is included in section 5.

4.1 SYSTEM DESCRIPTION

The solar repowered plant system for Permian Basin, Unit 5, consists of a new solar generated steam source coupled to an exsisting fossil-fueled steam electric generating plant. Coupling of the new and exsisting plants is conceptually achieved through the use of thermal storage which acts as a buffer or capacitance between the two heat sources and allows solar steam generation during periods of low-level or nonexsistant solar insolation.

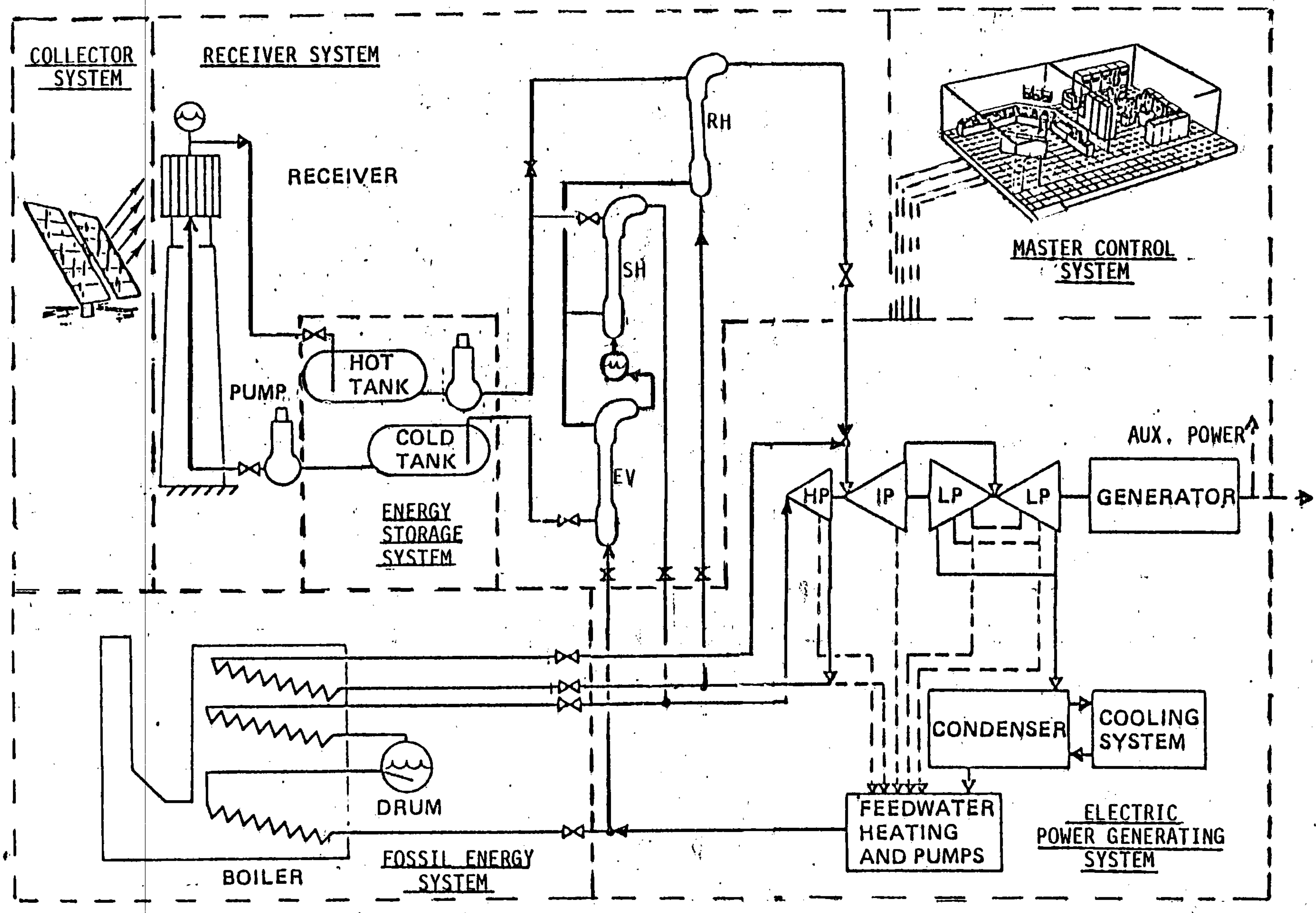
For the purposes of the repowered conceptual design project, the repowered system consists of the following major elements:

- Site
- Site Facilities
- Collector Subsystem
- Receiver Subsystem
- Master Control Subsystem
- Fossil Energy Subsystem
- Energy Storage Subsystem
- Electric Power Generating Subsystem
- Specialized Equipment
- Subsystem Interlationships

4.1.1 The functional interconnections and configuration of these subsystems is illustrated in Figure 4-1, a subsystem identification and simplified process flow diagram. Detailed descriptions of each subsystem are located in Section 5.

4.1.2 System Level Interfaces

The top level system interfaces include: physical interconnections in the feedwater, mainstream, cold reheat, and hot reheat water/steam lines, integration of operating controls, and instrumentation and auxiliary power supply to new plant elements.



1-1

Sub System Identification and Process Flow Diagram

4.1.3 System Level Process Description

The solar system is sized such that with a solar multiple of 1.23 enough excess energy is provided at equinox to permit operation of the plant from storage alone at 50 MWe for 1 h. The receiver is of the external type, 10.6 m in diameter by 13.5 m high and is located on top of a 110-m tower. The solar system configuration is based on the work accomplished on the advanced central receiver and the hybrid studies. The flow configuration, which was developed in these studies, is as follows: Liquid sodium is pumped at 550^{o}F to the top of the tower and through the receiver, from which it exits at a temperature of about 1100^{o}F. The hot sodium coming from the receiver is allowed to flow through a pressure reducing device and then into a hot storage tank, which can contain 2.6×10^{6} lb of sodium when full -- enough sodium to permit operation for a period of 1 h with no solar insolation. The sodium is pumped by a second pump from the hot storage tank through a set of three steam generator units (an evaporator, a superheater, and a reheater) and then into a cold storage tank. From this tank, which is approximately the same size as the hot tank, the sodium is again pumped to the top of the tower, thus completing the circuit. The steam produced by the solar fired steam generators compliments the steam produced by the exsisting unit boiler. The steam sources are configured in parallel. With this configuration, the hot storage tank provides complete buffering between the steam generator units and the receiver, such that temperature transitents at the receiver due to clouds are isolated from the solar steam generator units. This allows the design of the steam generator units to be simplified. The collector subsystem consists of a surround field containing 4610 heliostats on an area of 280 acres. This design was selected to give a significant solar fraction of 28% and a solar power level such that the power level for the fossil system, including a small control margin, would not be less than 30%. The solar system will be operated to maximize the use of solar energy. Load-following variations will be either provided by the fossil system, the storage system, or by other units on the grid in order to maximize the plant flexibility and, consequently, the plant value to the site user.

A preliminary detailed process and instrumentation diagram is shown in Figure 4.1-2

The exsisting fossil-fueled steam electric system consists of a conventional natural gas-fired recirculating boiler producing superheated and reheated steam at 1000^{O}F, 1516 and 417 psia, respectively, coupled to a tandem compound, double-side exhaust, 3600 rpm reheat, condensing-type steam turbine with a nameplate rating of 120.8 MWe, gross, and a gross heat rate of 8457 Btu/kWh. The nominal turbine back pressure is 2.0 in. of Hg. The condenser is cooled by water from forced draft cooling tower which is located west of the power plant. The unit employs five feedwater heaters and three water pumps, each pump having a 50% capacity (one standby). A detailed description of exsisting plant elements is located in Section 2.6.

4.2 FUNCTIONAL REQUIREMENTS

4.2.1 System Design Life

Two system design lifes are contemplated for this plant, 7 and 25 years. If no exemption can be obtained by TESCO the the Fuel Use Act, then the 7-year life would be mandated by the 1992 natural gas cutoff date indicated in the act and the 1985 startup date. If an exemption can be obtained, it is expected that the turbine would be the plant life limiting component. In that case, the life would be 25 years.

Twenty-five years has been selected for the design plant life as it is assumed that relief from the fuel act can be obtained for solar repower plants.

4.2.2 System Performance Requirements

The general system level performance requirements are summarized in Table 4.2-1. These requirements are distilled from N10025, "System Requirements Specification for Repowering of Permian Basin, Unit No. 5, Texas Electric Service

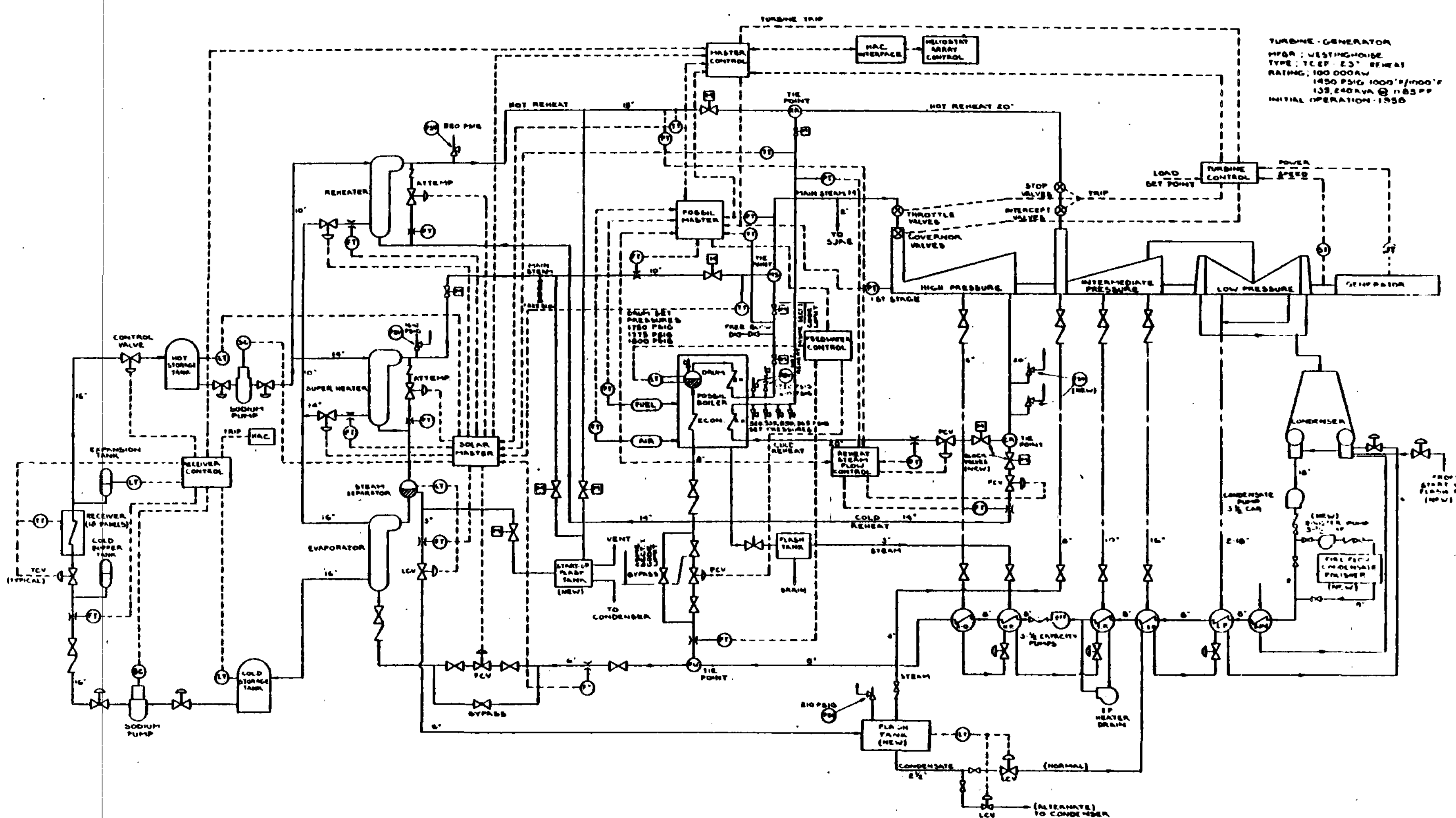


Figure 4.1-2

SOLAR REPOWERING STUDY
PERMIAN BASIN S.E.S.
UNIT 5 P&I DIAGRAM

TEXAS ELECTRIC SERVICE COMPANY

Company," Issue B, as modified to reflect the results of system level selection trade studies documented in Section 3. A copy of this specification is included as Appendix A of this report. The system requirements identify nominal values for plant life, solar power level, solar multiplier and storage duration at 100% rated power.

TABLE 4.2-1

PERMIAN BASIN UNIT NO. 5
SOLAR REPOWERING SYSTEM REQUIREMENTS

Solar Power Levels	
During Receiver Operation (MWe, gross)	50
Operation Exclusively from Thermal Storage (MWe, gross)	50
Solar Multiple (SM)	1.23
Storage Capacity at Rated Power (h)	1.0
Minimum Temperature °C (°F)	-23 (-10)
Maximum Temperature °C (°F)	45 (110)
Maximum Operating Wind (Including Gusts)* M/S (mph)	13.3 (30)
Maximum Survival Wind (Including Gusts)* M/S (mph)	40 (90)
Seismic Environment	Zone 2**
Survival Earthquake Horizontal and Vertical (g) Acceleration	0.15
Availability (Exclusive of Sunshine)	0.9
Lifetime (Years)	25
Maximum Dust Level Wind Speed M/S (mph)	18 (45)
Maximum Static Snow Load Pa (lb/ft^2)	96 (2)
Maximum Snow Deposition Weight m (in.)/24 h	0.1 (4)
Average Annual Rainfall mm (in.)	400 (16)
Maximum 24-h Rainfall mm (in.)	100 (4)
Maximum Ice Deposit mm (in.)	25 (1)
Hail Maximum Diameter mm (in.)	25 (1)
Hail Specific Gravity	0.9
Hail Maximum Terminal Velocity M/S (fps)	23 (75)

*At a reference height of 10 m (32.8 ft)
**Not near a great fault

4.2.3 Design Point

The design point for which the system will be required to meet the performance requirements is summarized in Table 4.2-2. The design point is also taken from Appendix A.

TABLE 4.2-2

PERMIAN BASIN UNIT NO. 5
SOLAR REPOWERING DESIGN POINT

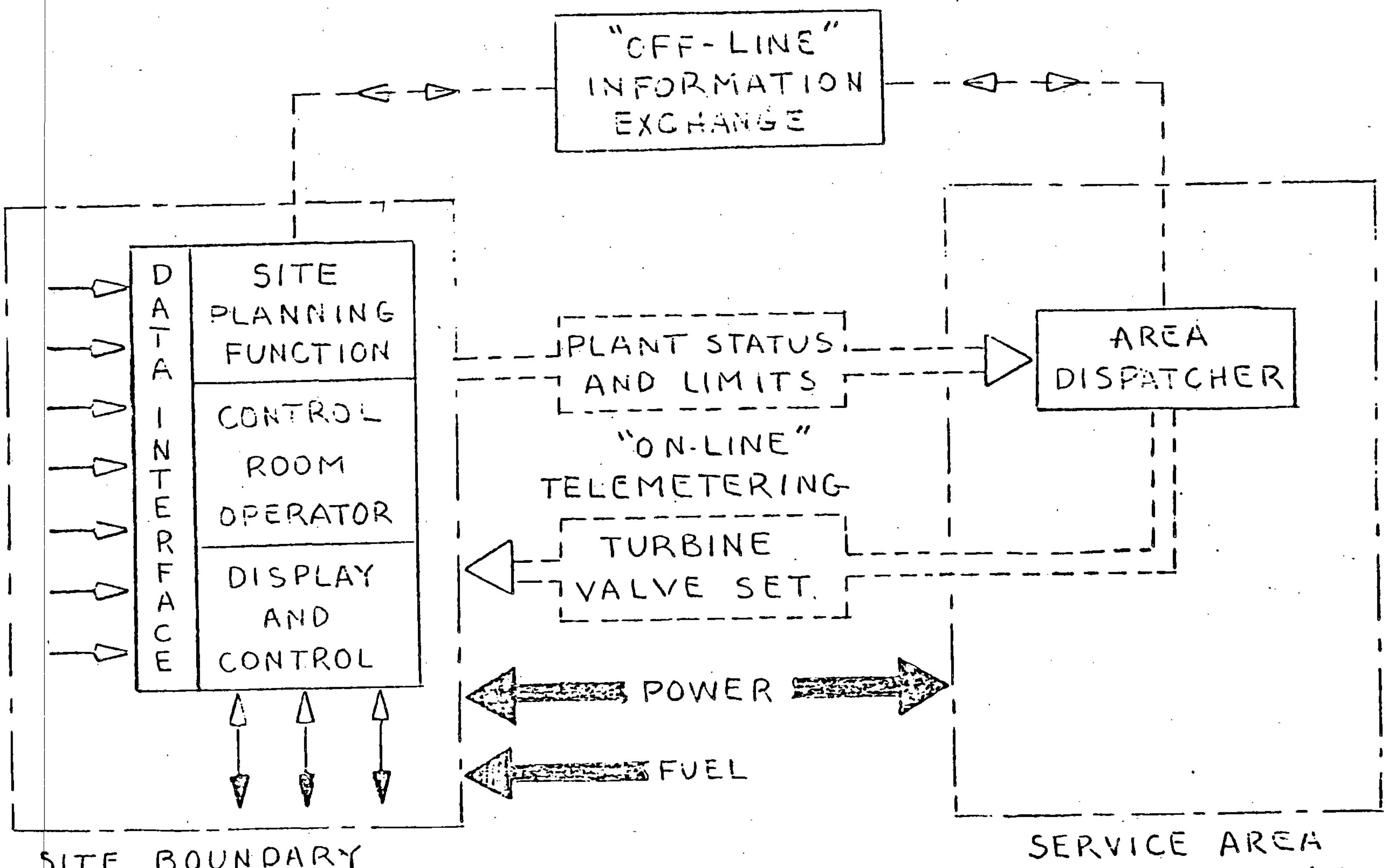
Solar Power Levels	
During Receiver Operation (MWe, gross)	50
Operation Exclusively from Storage	50
Insolation W/m^2, (Btu/ft^2-hr) Equinox Noon	1000(317.3)
Nominal Wind m/s,(mph)*	3.5(8)
Nominal Ambient Temperature C(F)	12.8(55)

*At a reference height of 10 m (32.8 ft)

4.2.4 Plant Instrumentation and Control Philosophy

The overall control of Permian Basin, Unit 5 is shown in broad terms in Figure 4.2-1. The operation shown is typical for the overall operation of most power plants, particularly those in the size range of 50-250 megawatts.

The planning function shown by the "off-line" information exchange box is important to control in that it establishes targets for individual stations based on the needs of the service area, in a way that minimizes cost to the user, within the capability of the system. The targets change in a predictalble way with the clock and calendar and with scheduled outage. However, the service area load requirement is variable and subject to upset as is the capacity of stations. Thus, an up-to-date flow of information to the dispatcher on the status and limits of the plant is required, as shown on the diagram. Since solar energy that is not immediately converted into stored heat (and then to electrical energy) is lost, an important telemetered item is the "instantaneous megawatt capability" of the solar boiler.



OVERALL CONTROL OF PERMIAN BASIN, UNIT 5

Figure 4.2-1

The area dispatcher will use this and other system data to telemeter a setting on the plant turbine admission valves. A change in these valves will cause a change in turbine flowrate and generated power, and these will be corrected by suitable changes in the steam generating systems.

An additional consideration in the design of the plant instrumentation and control system is to minimize any changes in the exsisting fossil plant controls or the current methods of plant operations.

Other design criteria include:

1) Perational simplicity and flexibility by providing automatic and manual control options for all systems.
2) Similar equipment in both solar and fossil master controls.
3) Adequate alarms and trips to prevent off-limit operations.
4) Use of proven control designs.
5) Integrated console control for combined plant operation.
6) Selection of off-the-shelf equipment.
7) Modularity among major subsystems.
8) Software driven operational control of startup and shutdown of receiver systems with manual overide capability.

4.3 DESIGN AND OPERATING CHARACTERISTICS

4.3.1 Operating Modes

The following plant operating modes have been identified: A combined mode wherein steam is supplied by the fossil and solar steam generators simultaneously (the receiver operates and storage is charging, discharging or maintained), A solar only mode with all steam requirements supplied by the solar steam generator (again the receiver operates and recharges the storage system at a rate lessthan, greater than, or equal to the rate at which energy is being used by the steam generator), a fossil only mode corresponding to current plant operation (receiver and storage susbystems secured), a storage charge mode wherein the reciever and storage systems operate to recharge storage and the fossil and solar steam generators as well as the EPGS are secured, and finally a storage discharge mode consisting of two submodes. In the first submode steam would be supplied by the solar steam generator only, as in the solar only mode. In the second submode steam would be contributed by both the solar and fossil steam generators, as in the combined mode. In the storage discharge mode the receiver is secured.

4.3.2 Flow Diagrams

In conjunction with the operating modes identified in section 4.3.1, flow diagrams have been prepared and are shown in Figures 4.3-1 through 5.

SOLAR REPOWERING FLOW DIAGRAM
PERMIAN BASIN - UNIT NO. 5 TESCO

COMBINED MODE

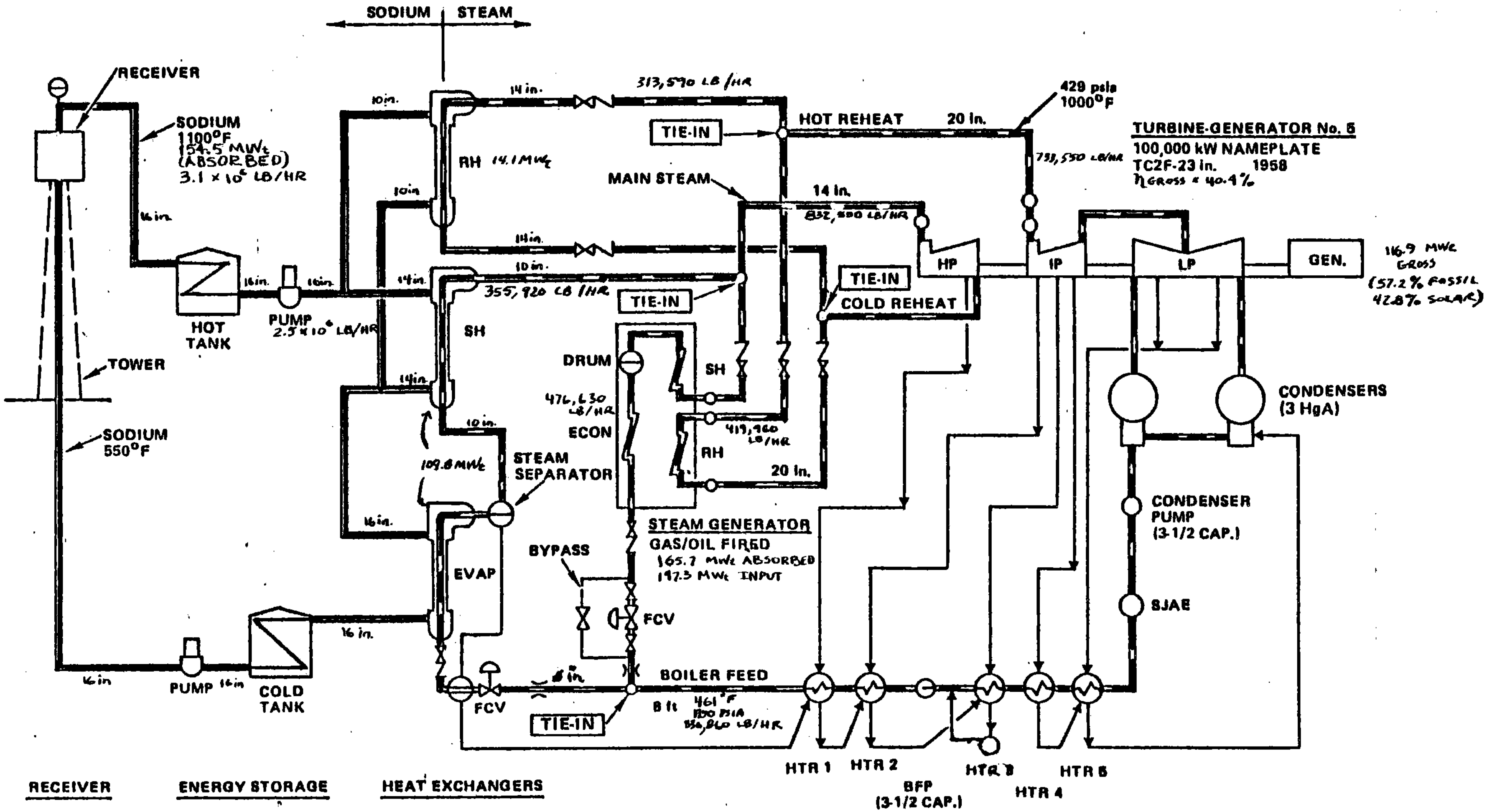
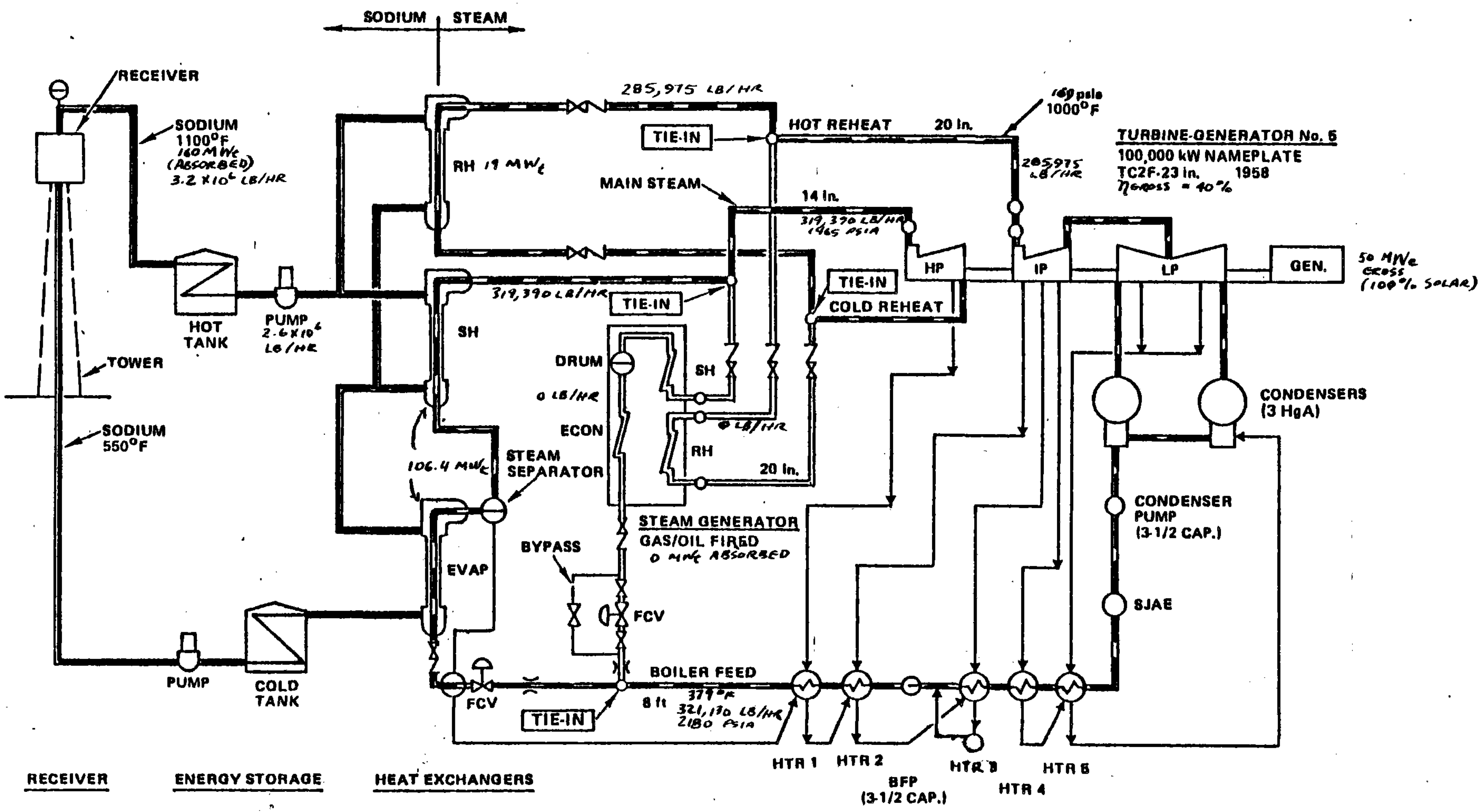


FIGURE 4.3-1

SOLAR REPOWERING FLOW DIAGRAM
PERMIAN BASIN - UNIT NO. 5 TESCO

SOLAR ONLY MODE



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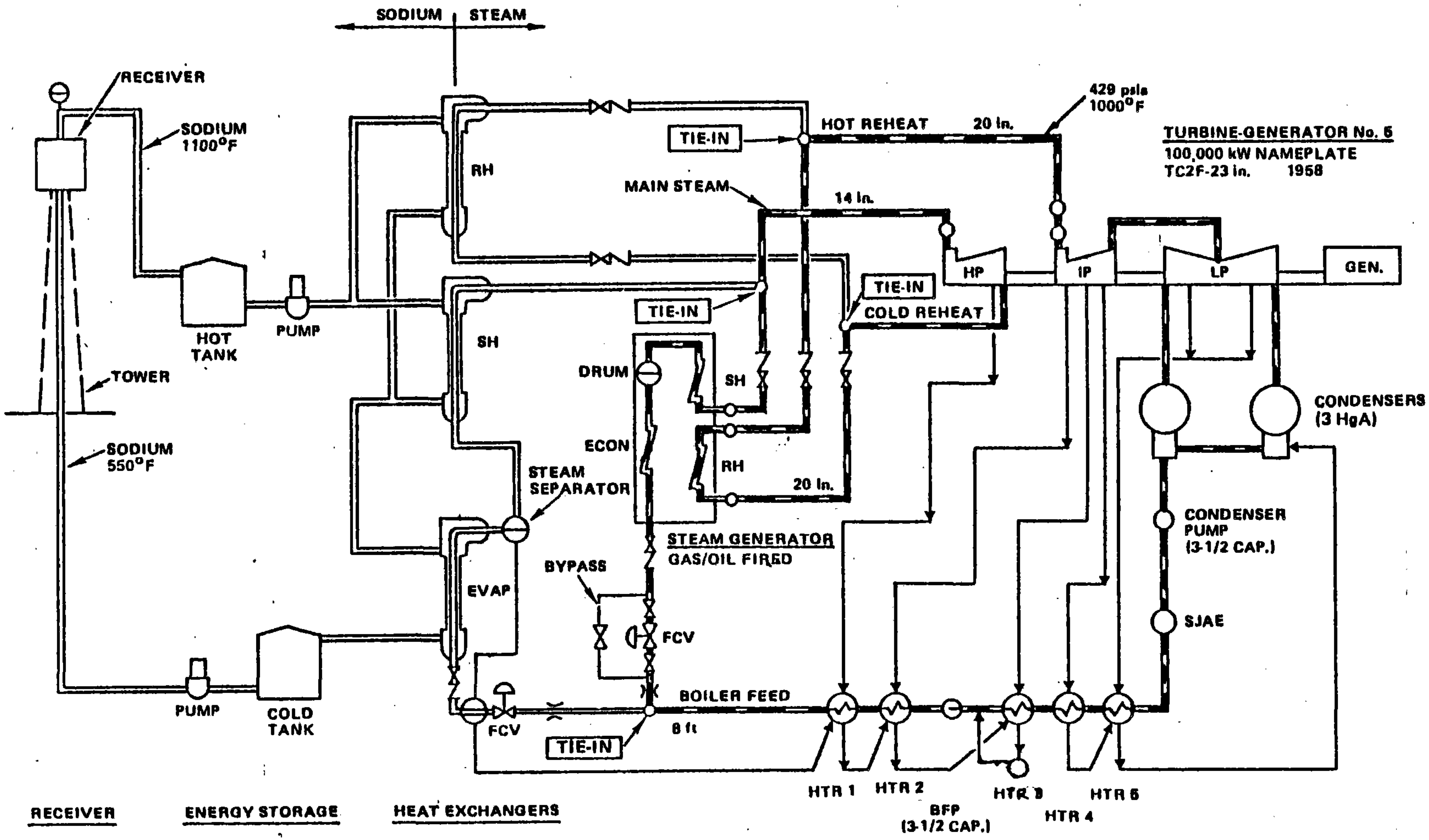
80-F28-1-39

FIGURE 4.3-2

SOLAR REPOWERING FLOW DIAGRAM
PERMIAN BASIN - UNIT NO. 5 TESCO

FOSSIL ONLY MODE



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Energy Systems Group

Figure 4-3-3

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SOLAR REPOWERING FLOW DIAGRAM
PERMIAN BASIN - UNIT NO. 5 TESCO

STORAGE CHARGE MODE

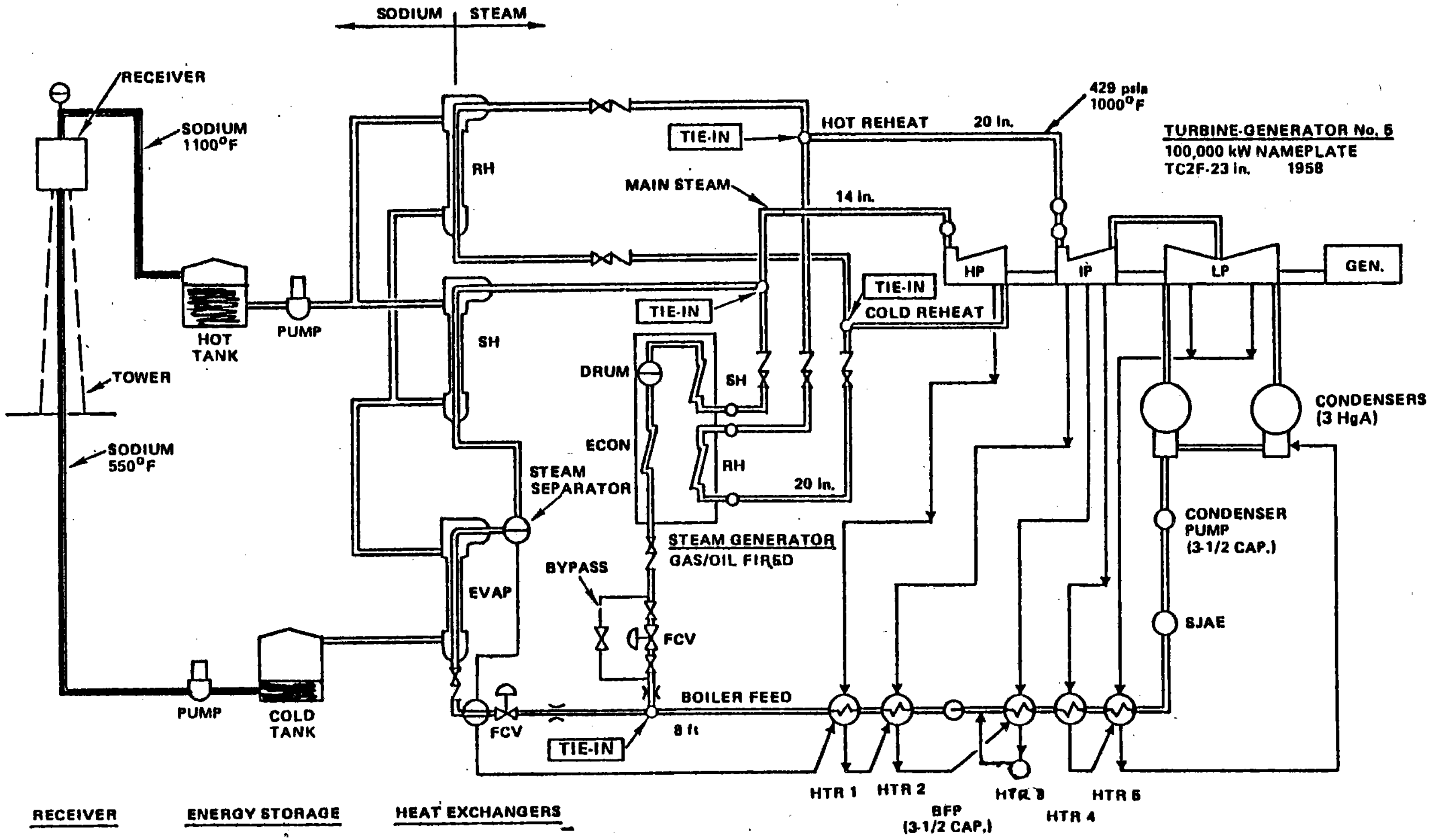

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Figure 4.3-4

SOLAR REPOWERING FLOW DIAGRAM
PERMIAN BASIN - UNIT NO. 5 TESCO

STORAGE DISCHARGE MODE

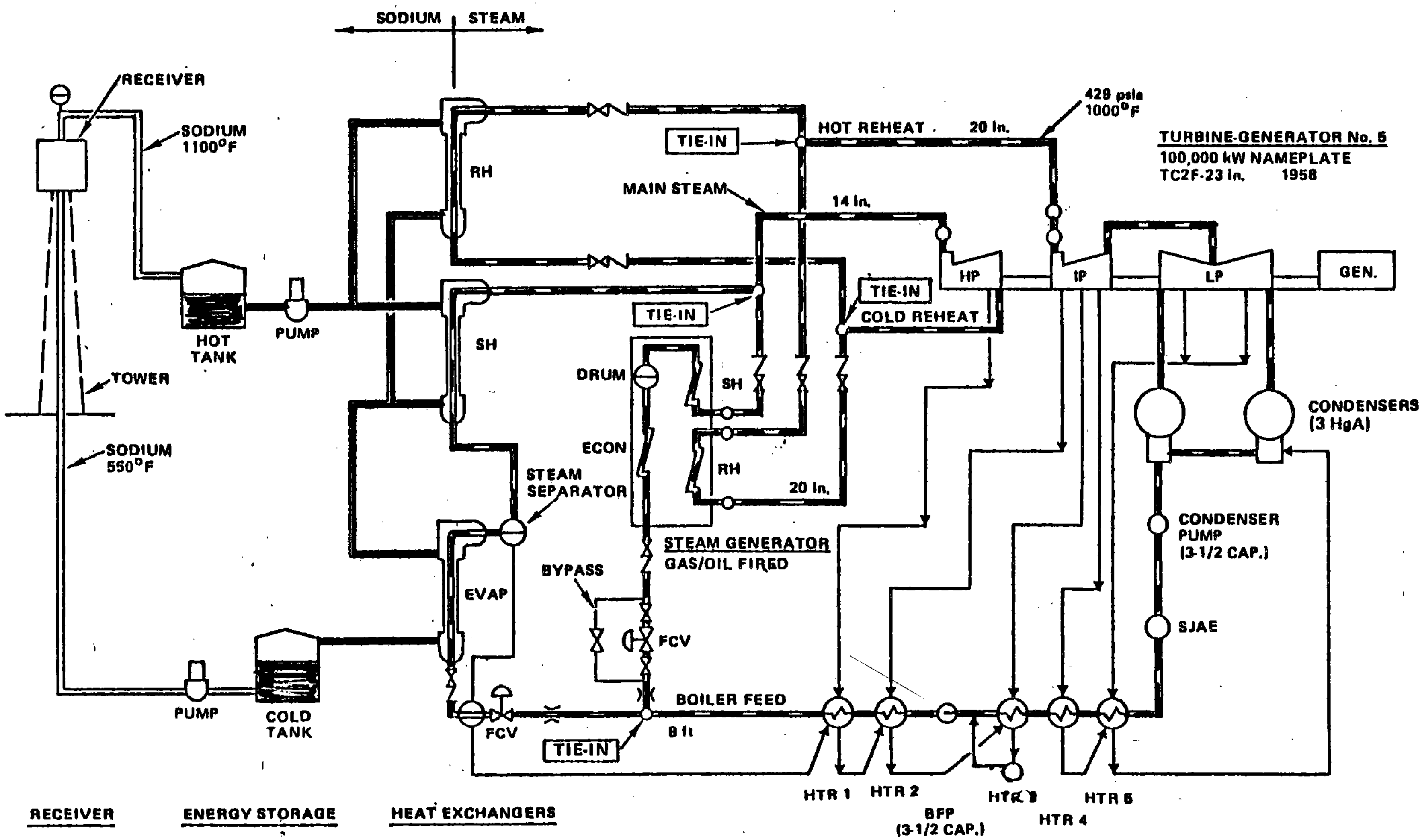

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Figure 4.3-5

80-F28-1-39

4.3.3 Heat Balances

Heat balances for the repowered plant were prepared by Stearns-Roger using an in-house heat balance computer program based on the Westinghouse turbine performance characteristics at Permian Basin, Unit . The turbine performance summary for the design hybrid and solar only operating modes is shown in Table 4.3-1. A summary of the other heat balance cases run is shown in Table 4.3-2.

The process flow diagram for hybrid operation at maximum load (Case 13) is shown in Figure 4.3-6. Case 13 reflects valves wide open operation at rated pressure and temperature, with a generation of 118,403 kWe gross (110,169 kWe, net), including 50,000 KwE gross solar contribution at equinox.

The process flow diagram for the solar only design case (Case 15) is shown in Figure 4.3-7. Case 15 reflects operation at 50,000 kWe gross (44,399 kWe net) with the collector subsystem in operation at equinox. The turbine operates at rated steam pressure.

TABLE 4.3-1

TURBINE PERFORMANCE SUMMARY
PERMIAN BASIN - UNIT NO. 5

Operating Mode	Season	Gross Generation Fossil (kWe)	Solar (kWe)	Total (kWe)	Throttle Pressure MPa (psia)	Throttle Temp. °C (°F)	Reheat Temp. °C (°F)	Condenser Pressure kPa (InHgA)	Feedwater Temp. °C (°F)	Gross Heat Rate kJ/kW-h (Btu/kW-h)
Hybrid (Case 13)	Equinox	68,403	50,000	118,403	10.1 (1455)	538 (1000)	538 (1000)	8.97 (2.65)	242 (468)	8830 (8370
Solar Only (Case 15)	Equinox	0	50,000	50,000	10.1 (1465)	538 (1000)	538 (1000)	8.97 (2.65)	193 (380)	9062 (8590)

Turbine Date

Manufacturer - Westinghouse

Rating - 100,000 kW (135,240 kVa at 0.85 PF)

Type - TC2F-23 in. LSB Reheat

Rated Steam Conditions 10 MPa (1450 psig) - 538°C (1000°F)/538°C (1000°F)

TABLE 4.3-2

SUMMARY OF HEAT BALANCE CASES

Case No.	Season	Gross Generation, kW Fossil	Solar	Total	Throttle Conditions Press PSIG	Temp °F	Reheat Temp. °F	Cond Press In. HGA	Gross Heat Rate BTU/KWH
1	Summer	53,930	60,000	113,930	1,450	988	974	3.20	8,557
2	Summer	0	60,000	60,000	1,450	1000	1000	2.50	8,625
*3	Equinox	66,930	50,000	116,930	1,450	995	1000	2.65	8,398
4	Summer	65,250	50,000	115,250	1,450	995	1000	3.20	8,520
5	Equinox	0	50,000	50,000	1,450	1000	1000	1.75	8,516
6	Summer	0	50,000	50,000	1,450	1000	1000	2.25	8,668
7	Equinox	0	50,000	50,000	1,450	1000	1000	1.75	8,540
**8	Equinox	0	50,000	50,000	1,450	1000	1000	1.75	8,540

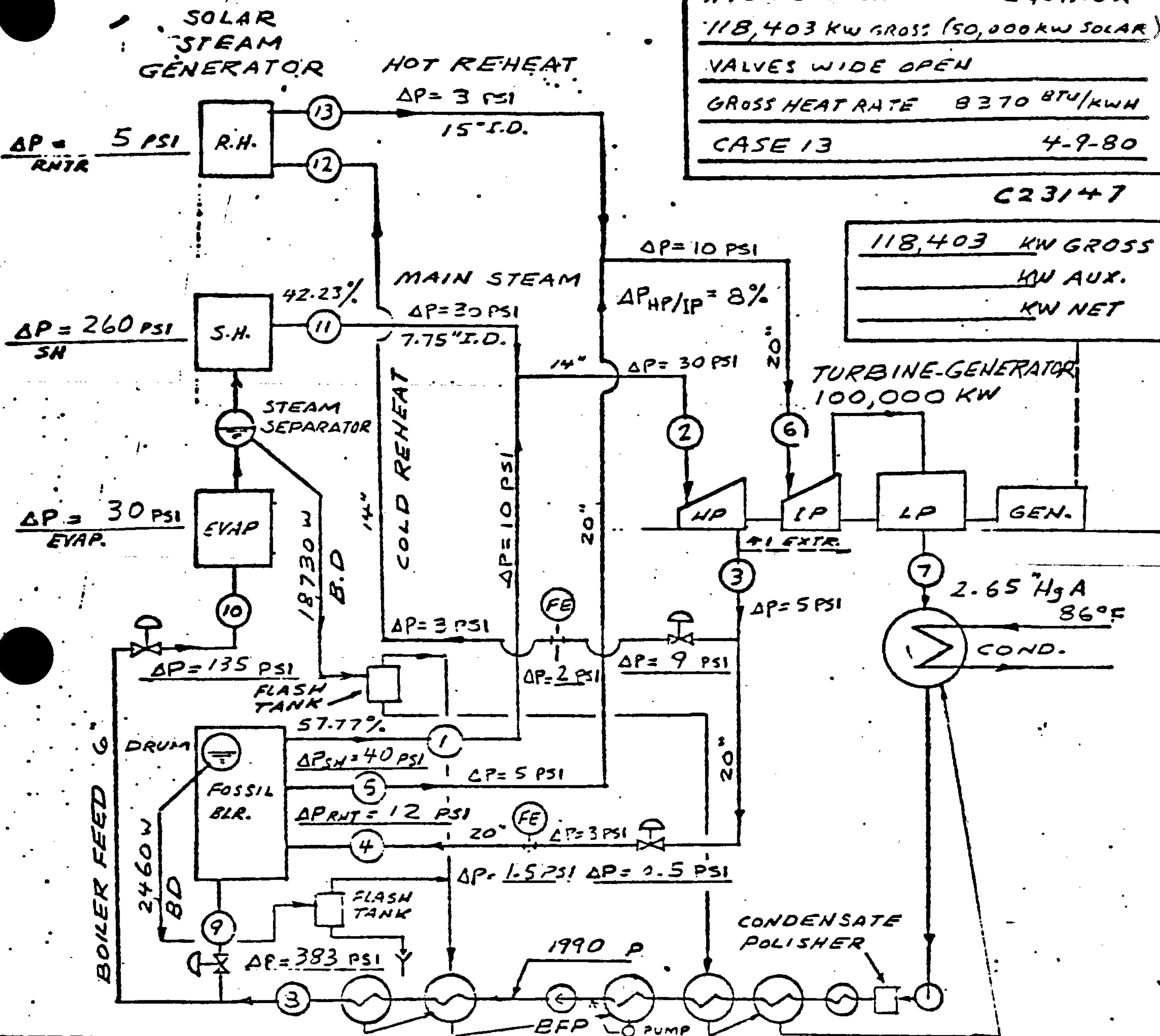
*Hybrid Design Case
**Solar Only Design Case

Figure 4.3-6

HYBRID DESIGN CASE

SOLAR REPOWERING
PERMIAN BASIN - UNIT NO. 5
HYBRID OPERATION EQUINOX
118,403 KW GROSS (50,000 KW SOLAR)
VALVES WIDE OPEN
GROSS HEAT RATE 8370 BTU/KWH
CASE 13 4-9-80

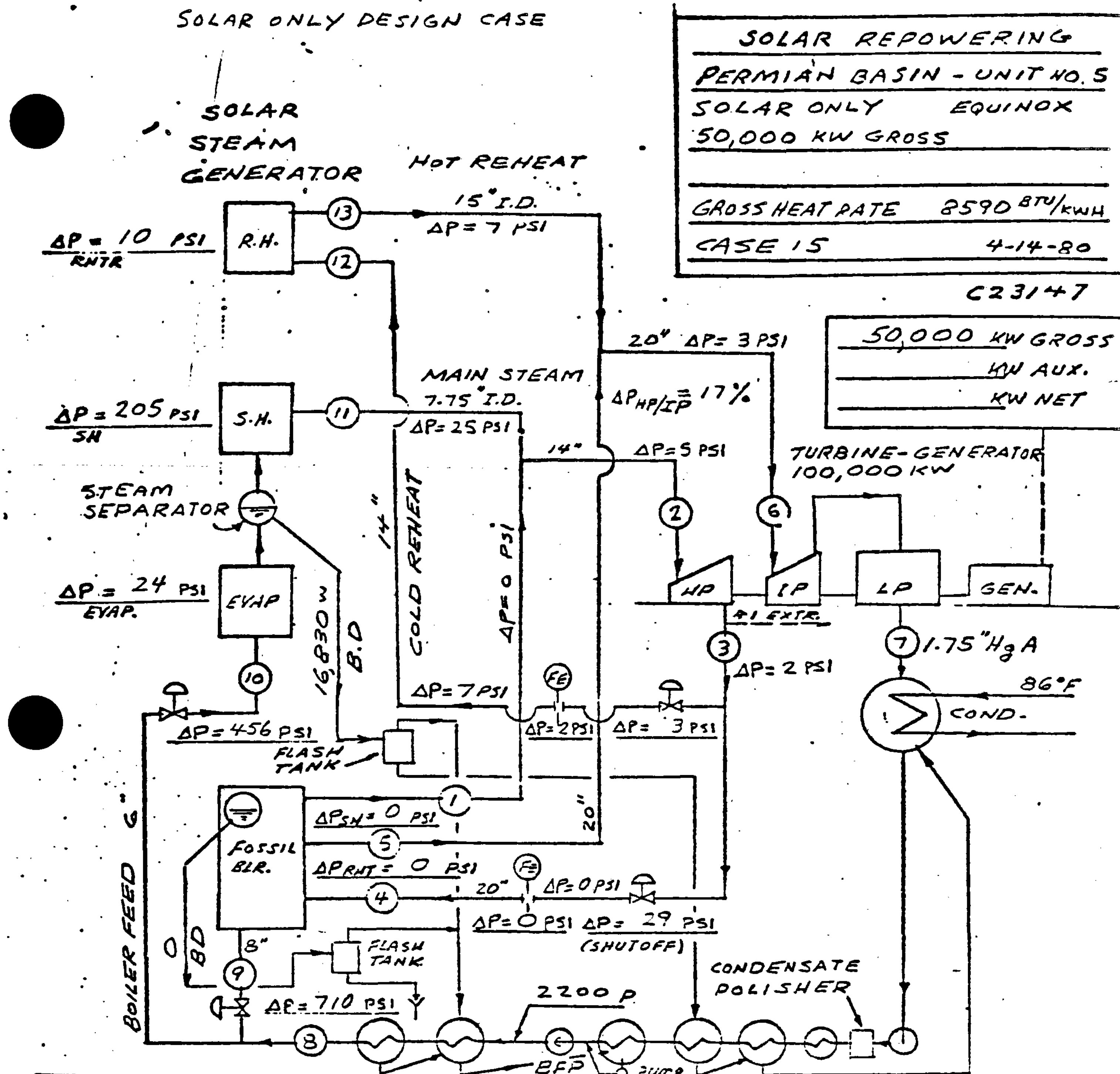
C23147



POINT		1	2	3	4	5	6	7
FLOW	LB/HR	479,880	630,670	735010	424620	424620	735,010	593,290
PRESS	PSIA	1505	1465	468	458	446	431	1.30
TEMP	°F	1005	1000	717	717	1005	1000	110.7
ENTH	BTU/LB	1482.8	1491.2	1369.2	1369.2	1524.6	1522.4	1055.7

POINT		8	9	10	11	12	13	
FLOW	LB/HR	851,860	482340	369,520	350,790	310,390	310,390	
PRESS	PSIA	1950	1567	1815	1525	449	444	
TEMP	°F	457	457	457	1005	717	1005	
ENTH	BTU/LB	439.0	439.0	439.0	1492.3	1369.2	1524.8	

Figure 4.37



POINT		1	2	3	4	5	6	7
FLOW	LB/HR	0	318,930	284,110	0	0	284,110	248,010
PRESS	PSIA		1465	202			168	0.86
TEMP	°F		1000	577			1000	96.7
ENTH	BTU/LB		1491.2	1310.2			1530.0	1088.4

POINT		8	9	10	11	12	13	
FLOW	LB/HR	355,760	0	335,760	318,930	284,110	284,110	
PRESS	PSIA	2180		1724	1495	188	178	
TEMP	°F	380		380	1005	577	1005	
ENTH	BTU/LB	355.7		355.7	1493.3	1310.2	1532.3	

4.3.4 Instrumentation

The system level instrumentation includes those instruments, which have been allocated by subsystem, required to control the overall system, and to obtain and record system performance data. The top-level instrumentation has been shown in Figure 4.1-2.

4.3.5 Controls

System level controls have also been allocated by subsystem. The primary system controls reside physically and functionally in the Master Control Subsystem. Consequently, the reader is refered to Section 5.3 for a detailed controls description.

4.3.6 Key Design and Operating Data

The key design and operating data for the conceptual design of the repowered configuration of Permian Basin, Unit 5 is shown in Table 4.3-3.

TABLE 4.3-3

SOLAR REPOWERING OF PERMIAN BASIN UNIT 5
SUMMARY OF PLANT PARAMETERS BY SUBSYSTEM

Collector Subsystem	
Number of Heliostats	4610
Total Mirror Area (Km^2 (10^6 ft^2))	0.26 (2.80)
Collector Land Area (acres)	252
Mirror Area/Heliostat (m^2 (ft^2))	56.4 (606.8)
Peak Incident Receiver Flux (MWt/m^2)	1.5
Receiver Subsystem	
Receiver Coolant	Sodium
Receiver Type	External Circular Cylinder
Material (Absorber Surface)	304 SS
Absorber Tube OD (cm (in.))	1.91 (0.75)
Tubes per Absorber Panel	96
Number of Panels	18
Receiver Diameter (m (ft))	10.6 (34.7)
Receiver Height (m (ft))	13.5 (44.3)
Receiver Midplane Elevation* (m (ft))	124 (406.7)
Tower Height (m (ft))	91 (298)
Receiver Inlet Temperature (^oC (^oF))	288 (550)
Receiver Outlet Temperature (^oC (^oF))	593 (1100)
Receiver Nominal Inlet Pressure (MPa (psia))	0.62 (90)
Receiver Nominal Outlet Pressure (MPa (psia))	0.10 (15)
Receiver Design Power (MWt)	160
Receiver Nominal Power (MWt)	129.6
Solar Multiplier	1.23
Receiver Peak Absorber Flux (MWt/m^2)	1.48
Receiver Peak Temperature (^oC (^oF))	643 (1190)
Receiver Design Sodium Flow Rate (kg/hr (lb/hr)	1.47×10^6 (3.24×10^6)

TABLE 4.3-3

SOLAR REPOWERING OF PERMIAN BASIN UNIT 5
SUMMARY OF PLANT PARAMETERS BY SUBSYSTEM
(Continued)

Evaporator	
Evaporator Design Power (MWt)	74.1
Number	1
Type	Tube and Shell Hockeystick
Design Sodium Flow (kg/hr (lb/hr))	1.142×10^6 (2.513×10^6)
Sodium Inlet Temperature (°C (°F))	471 (879)
Sodium Outlet Temperature (°C (°F))	288 (550)
Feedwater Flow (kg/hr (lb/hr))	162,618 (357,760)
Feedwater Inlet Temperature (°C (°F))	238 (461)
Steam Exit Temperature (°C (°F))	327 (620)
Superheater	
Design Power (MWt)	35.7
Number	1
Type	Tube and Shell Hockeystick
Design Sodium Flow (Kg/hr (lb/hr))	818,636 (1.80×10^6)
Sodium Inlet Temperature (°C (°F))	593 (1100)
Steam Flow (kg/hr (lb/hr))	161,782 (355,920)
Steam Exit Temperature (°C (°F))	541 (1005)
steam Exit Pressure (MPa (psia))	10.51 (1525)
Reheater	
Design Power (MWt)	18.5
Number	1
Type	Tube and Shell Hockeystick
Design Sodium Flow (Kg/hr (lb/hr))	428,003 (941,607)
Sodium Inlet Temperature (°C (°F))	593 (1100)
Sodium Exit Temperature (°C (°F))	472 (881)

TABLE 4.3-3

SOLAR REPOWERING OF PERMIAN BASIN UNIT 5
SUMMARY OF PLANT PARAMETERS BY SUBSYSTEM
(Continued)

Reheater	
Steam Flow (Kb/hr (lb/hr))	129,141 (284,110)
Steam Inlet Temperature (^{o}C (^{o}F))	303 (577)
Steam Exit Temperature (^{o}C (^{o}F))	541 (1005)
Steam Exit Pressure (MPa (psia))	1.23 (178)
Receiver Pump Flow (m^3/sec (gpm))	0.47 (7500)
Receiver Pump Head Rise (m (ft))	186 (610)
Receiver Pump Input Hydraulic Power (kw (hp))	1063 (1450)
Master Control Subsystem	
Load Following Capability	Solar or Fossil
Solar Steam Generator Automatic Control Range (MWe)	5-50
Minimum Automatic Fossil Load Level (MWe)	30
Control Modes	Full Automatic or Manual
Fossil Energy Subsystem	
Boiler Type	Riley Stoker, Gas-Fired (Oil Backup) Radiant Type Boiler With Superheater and Reheater
Steam Generation Capacity (Kg/hr (lb/hr))	375,000 (825,000)
Superheat Steam Rating (MPa (psig))	10.0 (1450)
Superheat Steam Outlet Temperature (^{o}C (^{o}F))	541 (1005)
Reheat Steam Outlet Temperature (^{o}C (^{o}F))	541 (1005)
Energy Storage Subsystem	
Storage Capacity (MWht)	128.3
Storage Capacity at Rated Power (hr)	1.0
Storage Media	Sodium
Storage Outlet Temperature (^{o}C (^{o}F))	593 (1100)
Storage Inlet Temperature (^{o}C (^{o}F))	288 (550)
Sodium Inventory (10^6 Kg (10^6 lb))	1.18 (2.6)

TABLE 4.3-3

SOLAR REPOWERING OF PERMIAN BASIN UNIT 5
SUMMARY OF PLANT PARAMETERS BY SUBSYSTEM
(Continued)

Energy Storage Subsystem	
Hot Tank Internal Volume (m^3 (ft^3))	2510 (88,600)
Hot Tank Material	304 SS
Cold Tank Internal Volume (m^3 (ft^3))	2510 (88,600)
Cold Tank Material	Carbon Steel
Electric Power Generation Subsystem	
Turbine Type	Westinghouse Tandem Compound, Dual Flow Exhaust Reheat
Name Plate Rating (kWe)	100,000
Repowered Operating Rating (kWe)	50,000
Turbine Inlet Temperature (^oC (^oF))	538 (1000)
Turbine Inlet Pressure (MPa (psig))	10.0 (1450)
Generator Rating (kva)	135,240
Generator Speed (rpm)	3600
Solar Standalone Heat Rate (Btu/kWhe)	8590
Combined Heat Rate (Btu/kWhe)	8370

4.4 SITE REQUIREMENTS

4.4.1 Site and Soil Characteristics

The site surface has a general slope of 1% from NW to SE, from the main plant area towards the collector field, and is covered with sage brush, mesquite, and small vegetation.

Soil borings at the Permian Basin Plant indicate that the soils in approximately the upper 4.6 m (15 ft) are generally tan caliche with gravel and sand mixed. From 4.6 m (15 ft) to approximately 11 m (36 ft), these soils are generally reddish brown sand, loosely cemented with sandstone and clay lenses. Red sandy shale is generally found below 11 m (36 ft).

Allowable soil bearing pressures vary uniformly with depth, ranging from 0.4 MPa (8300 psf) at 1.3 m (4.4 ft) to 0.77 MPa (16,000 psf) at 7.1 m (23.4 ft).

4.4.2 Site Preparation

The site plan showing the proposed repowering layout at the Permian Basin Plant of Texas Electric Service Company is shown in Figure 4.4-1 . Site preparation activities at the Permian Plant would include:

1) Preparation of plant site -- preliminary grading, clearing brush, rock, and debris removal.
2) Fine grading of plant site.
3) Roads, including base and surfacing.
4) Fencing (1.8 m (6 ft)) chain link security fence at existing and proposed property lines around collector field as shown in Site Plan.
5) Plant identification signs.
6) Truck and rail unloading facilities.
7) Yard drainage piping, fire protection, piping and raw water supply (extended).

4.4.3 Building Modifications/New Facilities Added

The required building modifications and new facilities required to facilitate solar repowering at TESCO's Permian Basin, Unit 5, include:

1) Control room modifications and addition of new computer room.
2) Condensate polisher (demineralizer) building.
3) Storage and maintenance building.

Control Room Modifications

The proposed control room modifications at Permian Basin are shown in 4.4-2 , Control Room Layout. Space was available to expand the existing control room by approximately 5.2 m (17 ft) by 16.3 m (53 ft 6 in.) to facilitate the new solar control board, logic equipment and new, air conditioned computer room.

4.4.4 Solar/Fossil Plant Interfaces

4.4.4.1 Repowered Plant Layout

The plant layout for Permian Basin solar repowering is shown in Figure 4.4-1

The site plan shows the receiver tower located approximately 914 m (3000 ft) east of the Permian Basin Station. The sodium piping run from the tower to the hot sodium tank is approximately 1205 m (3950 ft) long. The hot and cold sodium storage tanks are located within the plant area, each tank located inside a berm designed to contain the entire tank content. The sodium pumps are located adjacent to each tank. The solar steam generator is located directly behind of Unit 5. This solar equipment layout is designed to provide a good arrangement from an operational and maintenance standpoint, with minimum impact on existing plant facilities or future plant expansion.

4.4.4.2 Piping Interfaces

As indicated on the P&I Diagram, Figure 4.1-2, the solar/fossil piping interfaces occur at the tie-ins for main steam, hot reheat steam, cold reheat steam, and boiler feedwater. They are described in detail in section 5.6

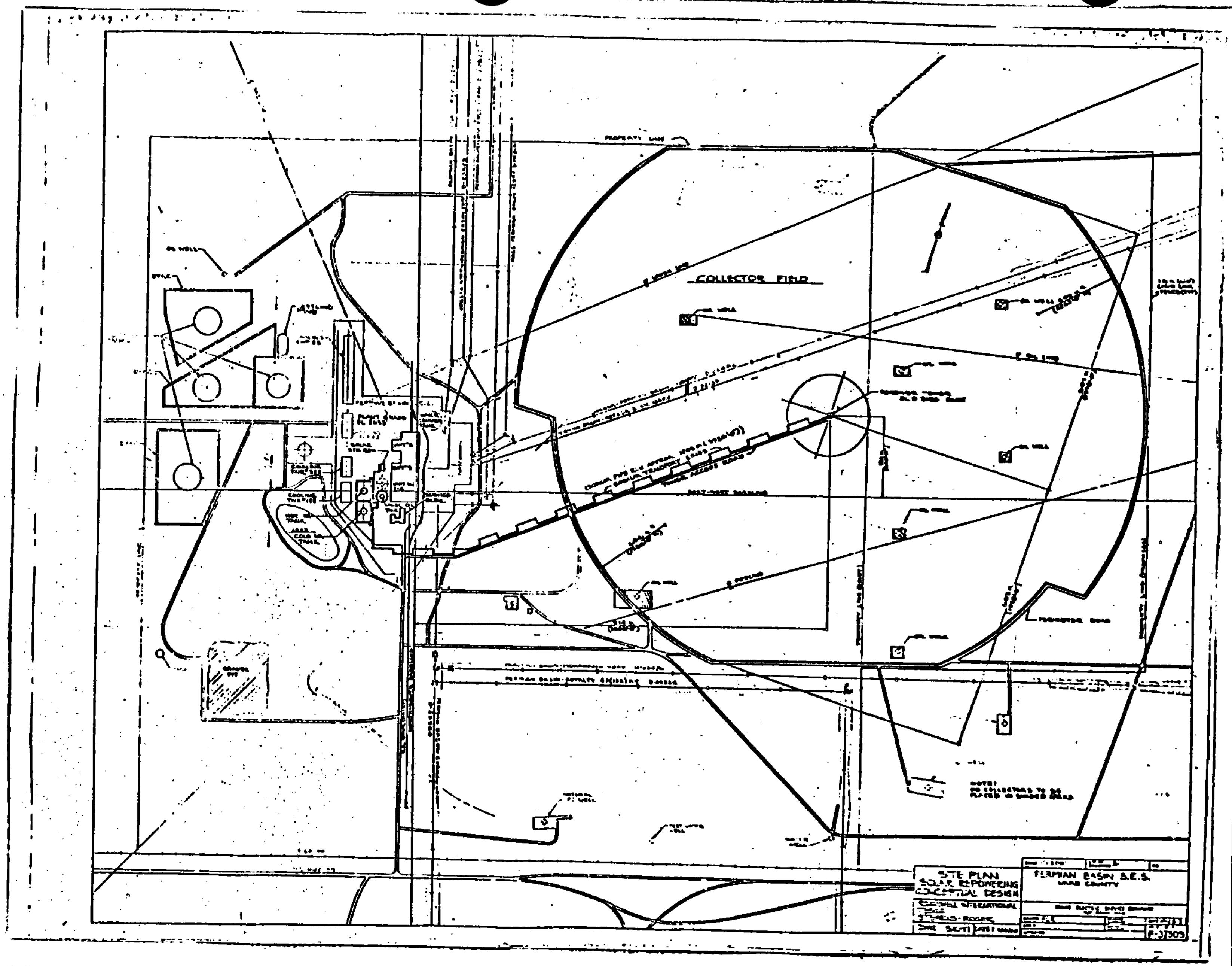


FIGURE 4.4-1 - SITE PLAN

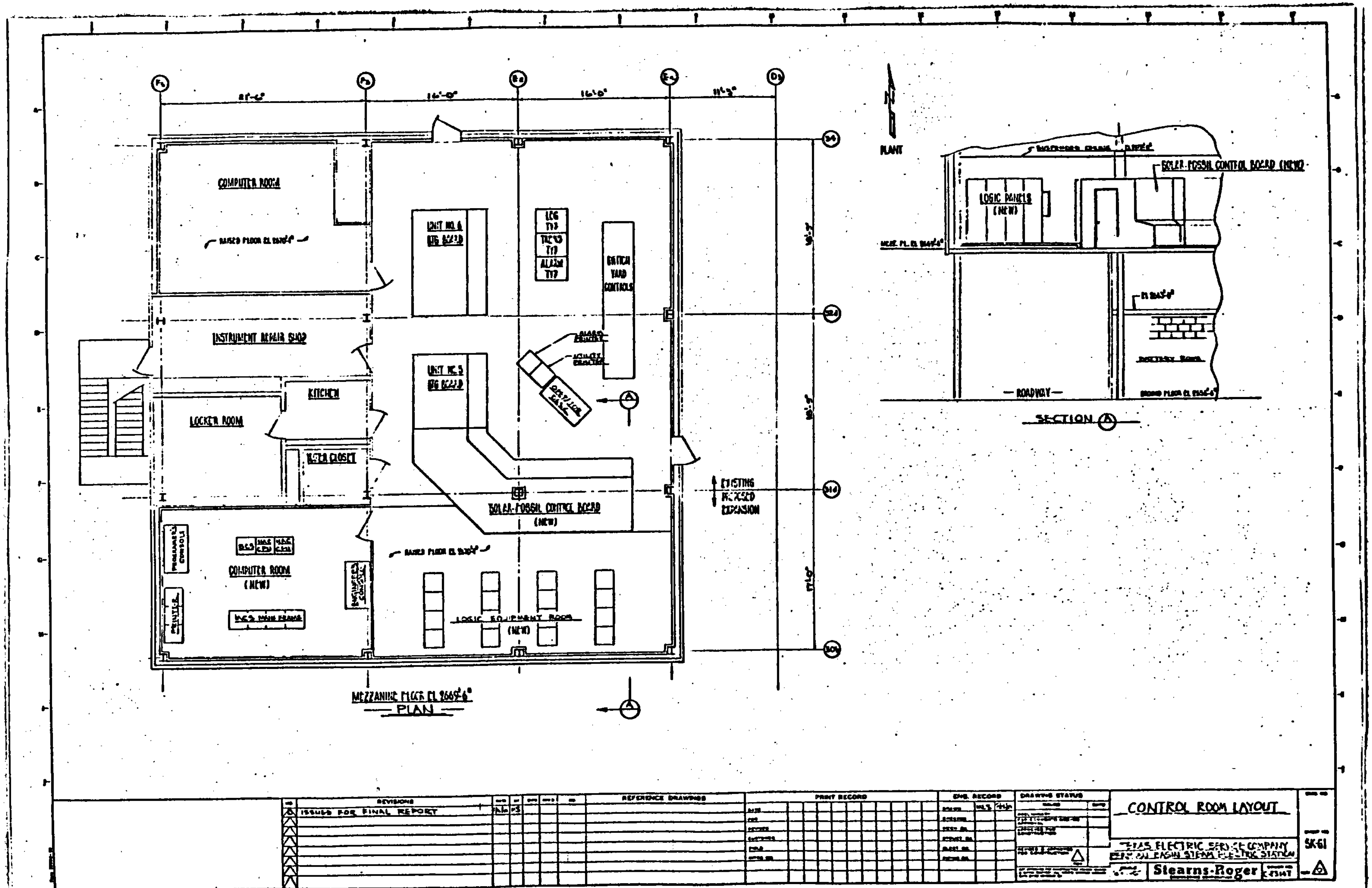

COMPUTER ROOM
INSTRUMENT REPAIR SHOP
KITCHEN
LOCKER ROOM
WATER CLOSET
COMPUTER ROOM (NEW)
PRINTER
LOGIC EQUIPMENT ROOM (NEW)
UNIT NO. 6 BTG BOARD
UNIT NO. 5 BTG BOARD
SWITCH YARD CONTROLS
SOLAR-FOSSIL CONTROL BOARD (NEW)
EXISTING PROPOSED EXPANSION
MEZZANINE FLOOR EL 2669'-6"
PLAN
PLANT
LOGIC PANELS (NEW)
SOLAR-FOSSIL CONTROL BOARD (NEW)
ROADWAY
SECTION A
CONTROL ROOM LAYOUT
TEXAS ELECTRIC SERVICE COMPANY
Stearns-Roger
SK-61
ISSUED FOR FINAL REPORT
REVISIONS
REFERENCE DRAWINGS
PRINT RECORD
DWG. RECORD
DRAWING STATUS

FIGURE 4.4-2

4.5 SYSTEM PERFORMANCE

This section contains estimates of design point and overall system performance. The performance criteria include: energy produced, system efficiency, and fossil fuel displaced. Waterfall energy flow charts, auxiliary system load estimates, and thermal energy losses are also addressed.

4.5.1 Design Point and Annual Average

4.5.1.1 Thermal Losses

Design point thermal energy losses for all sodium subsystems are shown in Table 4.5-1. These losses are based on actually calculated peak heat losses to the ambient 128°C (55°F) air or are estimated from assumed surface temperatures of 54.4°C (130°F) (the OSHA mandated safety limit). As noted in Section 5, the solar steam generator energy requirements will vary depending upon the operating mode and plant load. In the combined mode, the total design steam generator output is 123.6 MWt. In the solar-only mode, the design output is 126.3 MWt. At the design point, equinox noon, Section 5.1, indicates that the sodium absorbed power is 158.5 MWt. After accounting for steam generation energy requirements and sodium component thermal losses, 30.2 MWt would be deposited in storage during operation in the combined mode. This results in a solar multiple of 1.28 and provides a performance margin of about 2.5% over the nominal design requirements. The margin can be used to slightly overdrive the steam generators or can be spilled, if necessary, by defocusing heliostats. In the solar-only mode, the energy delivered to storage is 27.5, resulting in a solar multiple of 1.25, the nominal design goal.

4.5.1.2 Auxiliary Power Losses

The auxiliary power losses for each operating mode is shown in Table 4.5-2. Combining this information with the thermal losses previously estimated results in predictions for design point net output. For the combined mode, the net output is 110,587 kWe, of which 46,700 kWe is attributable to solar. For the solar-only mode, the net output is 44,399 kWe.

TABLE 4.5-1

SODIUM COMPONENT NOMINAL* HEAT LOSS SUMMARY

Component	Loss Mechanism		Loss (kWt)
Downcomer	Convection + Radiation		120
Return Line			1,001
Hot Tank			146
Pumps			10
Steam Generator			30
Cold Tank			142
Supply Line			398
Riser			48
Miscellaneous Plant Lines (Vents, Valves, Etc.)			75
		Total	1,970

*At Design Conditions listed in SRS

TABLE 4.5-2

AUXILIARY POWER (kWe)

Subsystem	Combined	Solar Only	Fossil Only	Solar Charge Fossil Only	Storage Discharge Combined	Storage Discharge Solar Only	Storage Charge No Output
	Operating Mode						
RECEIVER	1209.9	1209.9	1687.9	1500.9	1528.9	1528.9	1500.9
Including Receiver Pump, Trace Heating, Na Purification System, Cover Gas System, Controls and Miscellaneous Receiver Loads							
COLLECTOR	172.0	172.0	10.6	172.0	10.6	10.7	172.0
Including Heliostats, Field Control, Array Cont.							
ENERGY STORAGE	225	225	813	20	225	225	20
Including Steam Generator Pump, Trace Heating, Cover Gas System, Controls							
FOSSIL ENERGY AND EPGS	5453.7	3239.0	5871.5	5871.5	5453.7	3229.0	140.5
Includes: F.D. Fans, Boiler Feed Pumps, Condensate Pumps, Service and Instrument Air, Cooling Tower Pumps and Fans, Turbine Oil Pumps, Condensate Polisher, Air Heater, Feedwater Train Pumps and Miscellaneous Pumps, Controls							
MASTER CONTROL	65	65	65	65	65	65	65
Includes: Computer, BTG Board, Control HVAC							
BALANCE OF PLANT	690.3	690.3	690.3	690.3	690.3	690.3	690.3
Includes: HVAC, Sewage, Lighting, and Transformer Losses							
TOTAL	7,816	5,601	9,138	8,320	7,974	5,749	2,589

4.5.1.3 Annual Average

Since it is not now known what mix of modes will be employed in the operation of this plant, it is impossible to accurately predict the annual average output of the plant without assuming such a mix. The basis of the system-level trade studies was an 18.5% total plant capacity factor (100 MWe Nameplate Rating) with solar contributing as much of this as possible. Using this capacity factor as a basis, the total salable energy output of the plant would be 162,020 MWHe. The annual average solar thermal energy absorbed in sodium is 355.5 GWHe (See section 5.1.5). Since the sodium system heat losses continue on a 24-hr basis, this results in a yearly loss of 17.3 GWh_t. The total thermal energy available for conversion is 338.2 GWh_t/year. If this were all converted in a solar-only mode, the plant solar capacity would be 13.57%. The corresponding fossil capacity would be 4.93%. Conversion in a combined mode results in a solar capacity factor of 13.87% and a fossil capacity factor of 4.63%.

These values represent the theoretically maximum available capacity factor assuming no losses for startup, shutdown, or off-design loads, but do include solar-related weather, planned and forced outages. The system performance is summarized graphically in Section 4.5.3.

4.5.2 System Efficiency

Based on the foregoing discussion, the design point system efficiency in converting solar isolation incident on the heliostats to salable electricity in the solar-only mode is 16.58%. The overall system efficiency in the combined mode improves to 16.94% due to the apparent decrease in the solar heat rate. The system efficiency is shown graphically in Section 4.5.3.

4.5.3 Efficiency Diagrams

The performance of the system at the design point is expressed graphically in the form of water fall charts for the solar-only mode in Figure 4.5-1 and the combined mode in Figure 4.5-2. Annual average performance for a solar-only mode is shown in Figure 4.5-3. Combined Mode Annual average performance is shown in Figure 4.5-4

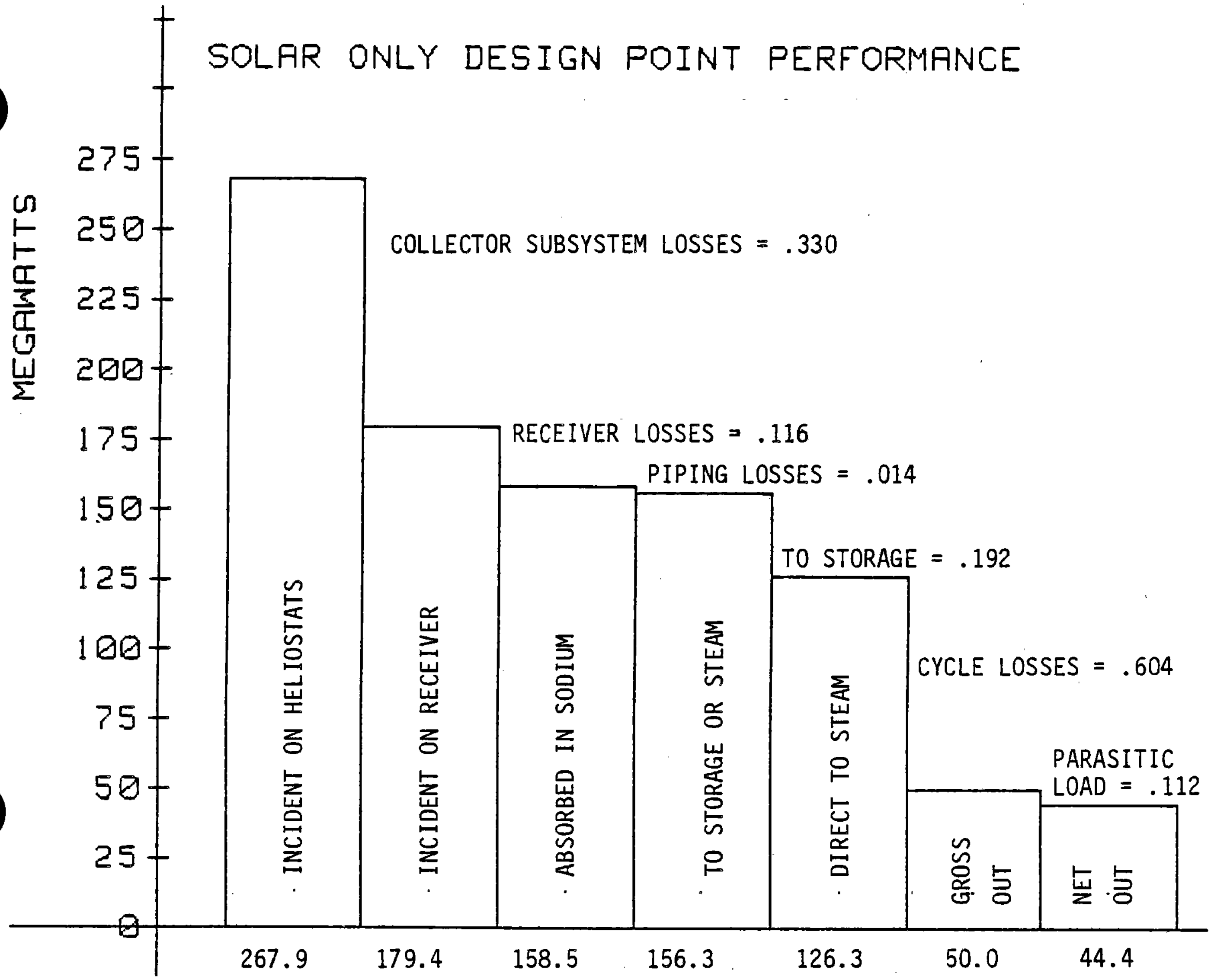


Figure 4.5-1 Solar Only, Design Point Waterfall Chart

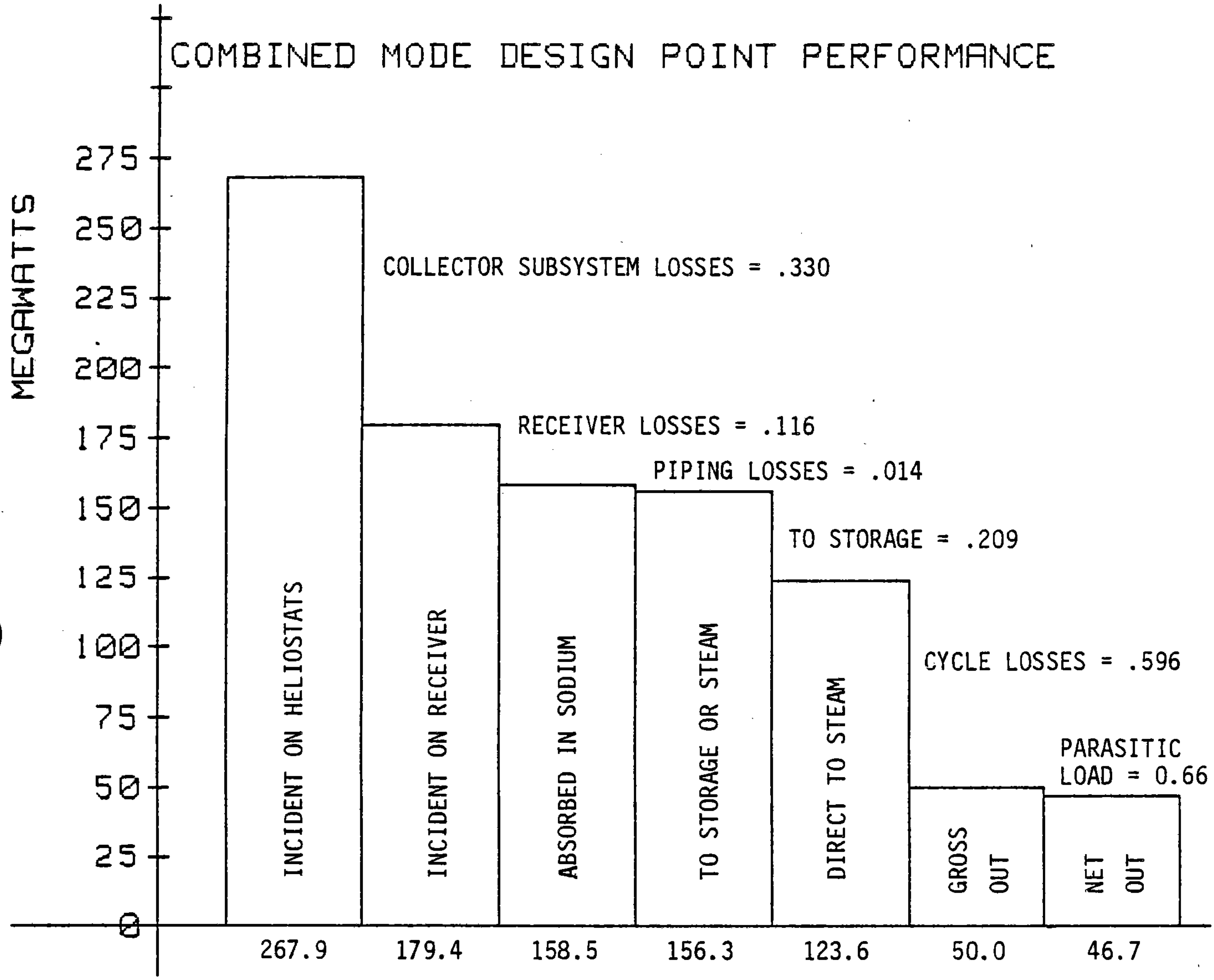


Figure 4.5-2 Combined Mode Design Point Waterfall Chart

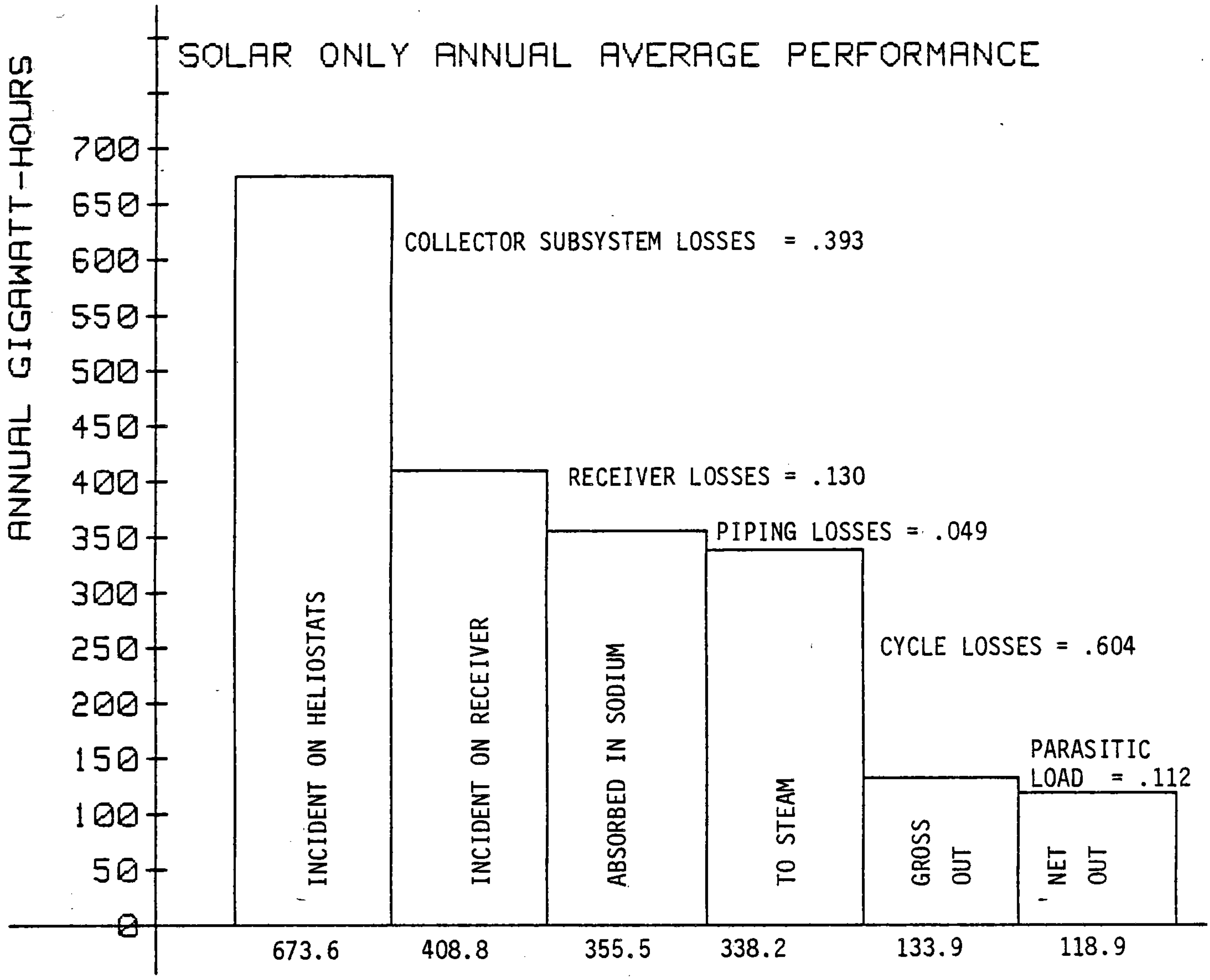


Figure 4.5- 3 Solar Only, Annual Average Waterfall Chart

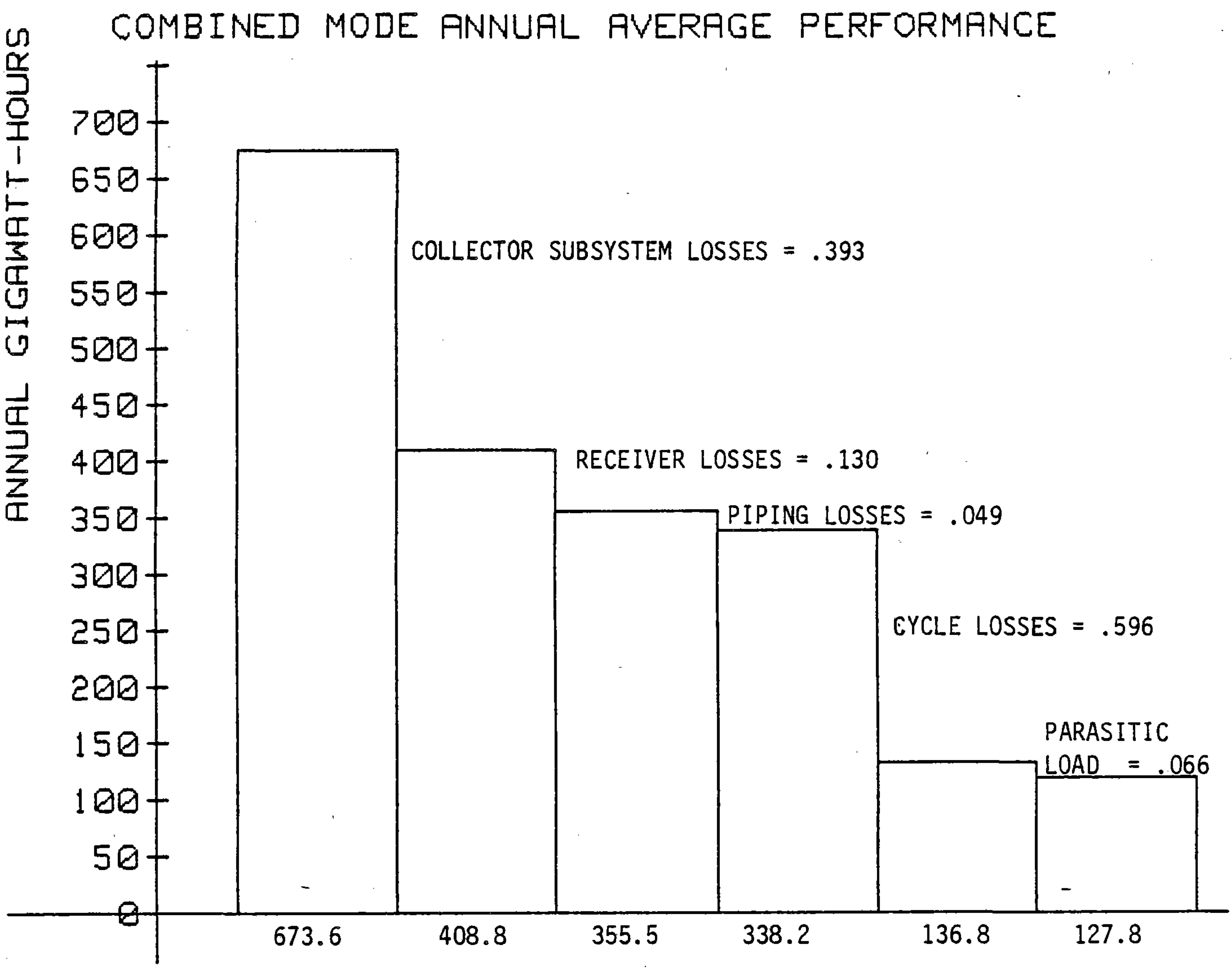


Figure 4.5-4 Combined Mode Annual Average Waterfall Chart

4.5.4 Fuel Savings

Based on the annual performance of the solar plant operating in the combined mode, the solar output of the plant would be 127,800 MWhe/year. This would result in a maximum fuel saving of 1,325 x 10^6 cubic feet of natural gas or 217,197 bbl of fuel oil per year. If, on the other hand, the plant is operated in the solar only mode the annual solar output decline to 118,900 MWhe/year resulting in natural gas savings of 1,233 x 10^6 cubic feet per year or fuel oil savings of 202,072 bbl per year.

4.6 PROJECT CAPITAL COST SUMMARY

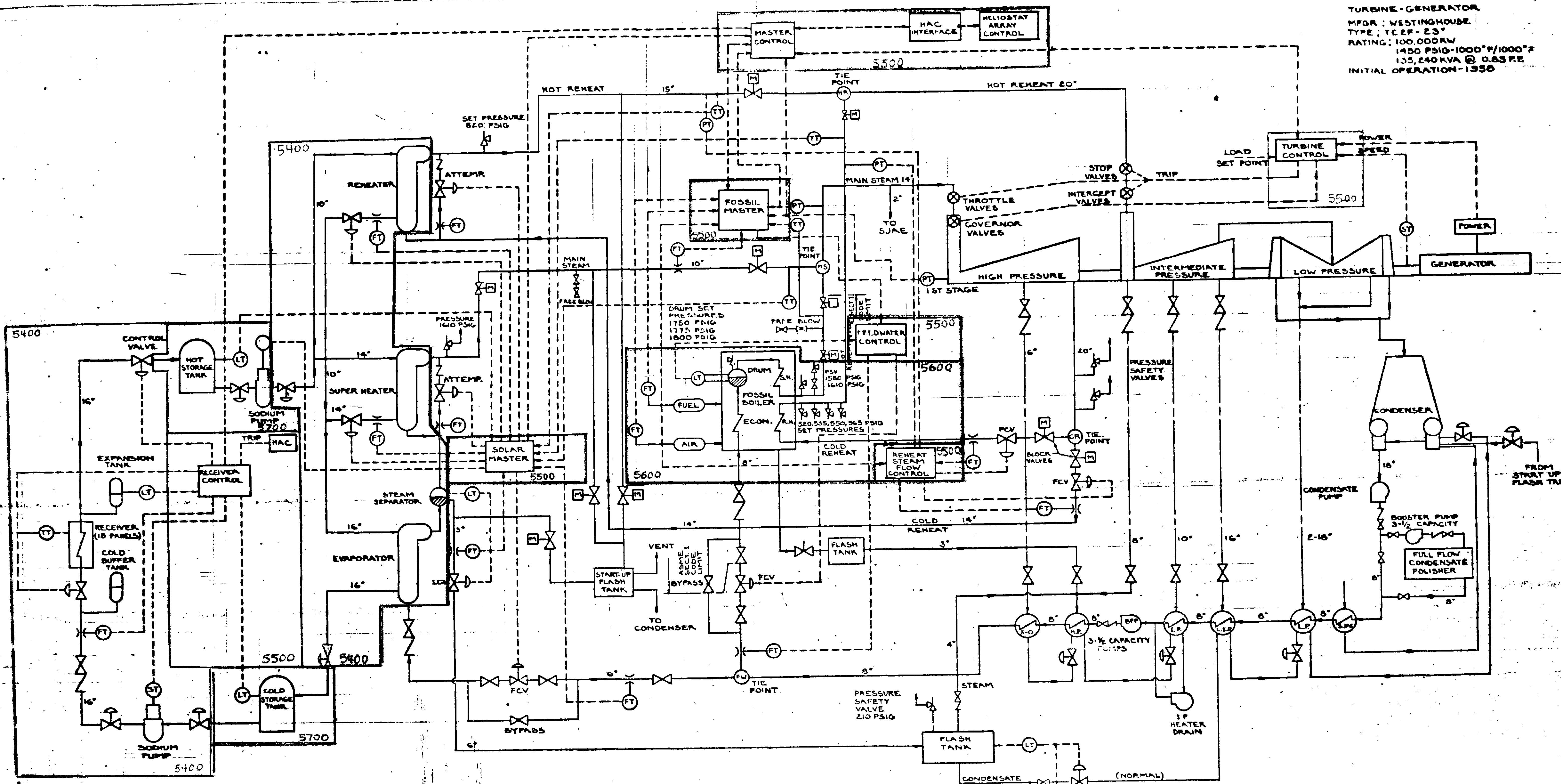
The project capital cost, broken down by cost account, is shown in Table 4.6-1. The total plant capital cost is 111.61 million 1980 dollars.

Top level subsystem cost summaries are distributed throughout section 5. Backup data to the subsystem cost estimates is located in Appendix B.

Figure 4.6-1 shows the functional cost code boundary zones superimposed on the process and instrumentation diagram. Figures 4.6-2 and 3 show geographical cost code boundaries.

Table 4.6-1 CAPITAL COST BREAKDOWN

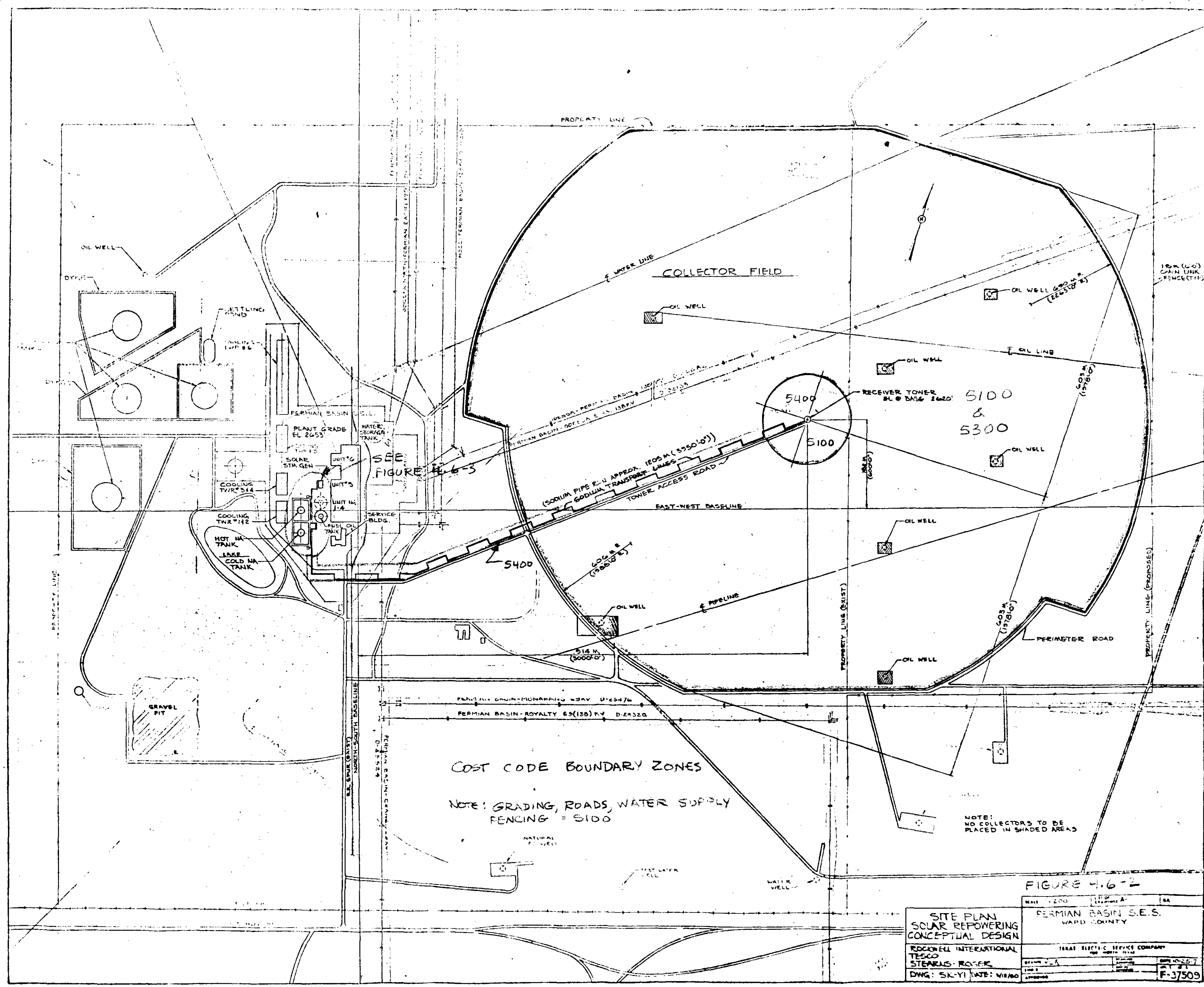
Subaccount Number	Description	Cost (1980 dollars x 10^6)
5100	Site Improvements	2.517
5200	Administrative Areas	DISTRIBUTED
5300	Collector Subsystem	69.576
5400	Receiver Subsystem	22.802
5500	Master Control Subsystem	1.206
5600	Non-Solar Energy Subsystem	-0-
5700	Energy Storage Subsystem	7.936
5800	Electric Power Generating Subsystem	7.574



NOTE: ALL UNINCORPERATED AREAS CODE 5800

FIGURE 4.6-1

PERMIAN BASIN
STEAM ELECTRIC STATION
P&I DIAGRAM
COST CODE BOUNDARY ZONES


COLLECTOR FIELD
PROPERTY LINE
WATER LINE
OIL WELL
OIL LINE
RECEIVER TOWER
5400
5100
5100 & 5300
SEE FIGURE 4.6-3
PLANT GRADE EL 2653'
SOLAR STM GEN
COOLING TWR #3&4
COOLING TWR #1&2
HOT NA TANK
COLD NA TANK
LAKE
WATER STORAGE TANK
SERVICE BLDG.
FUEL OIL TANK
SODIUM TRANSPORT LINES
TOWER ACCESS ROAD
EAST-WEST BASELINE
NORTH-SOUTH BASELINE
PIPELINE
PERIMETER ROAD
PROPERTY LINE (EXIST)
PROPERTY LINE (PROPOSED)
GRAVEL PIT
DYKE
SETTLING POND
PERMIAN BASIN-ROYALTY 69(138) KV
COST CODE BOUNDARY ZONES
NOTE: GRADING, ROADS, WATER SUPPLY FENCING = 5100
NOTE: NO COLLECTORS TO BE PLACED IN SHADED AREAS
FIGURE 4.6-2
SITE PLAN SOLAR REPOWERING CONCEPTUAL DESIGN
PERMIAN BASIN S.E.S.
WARD COUNTY
ROCKWELL INTERNATIONAL
TESCO
STEARNS-ROGER
DWG: SK-Y1
TEXAS ELECTRIC SERVICE COMPANY
F-37509

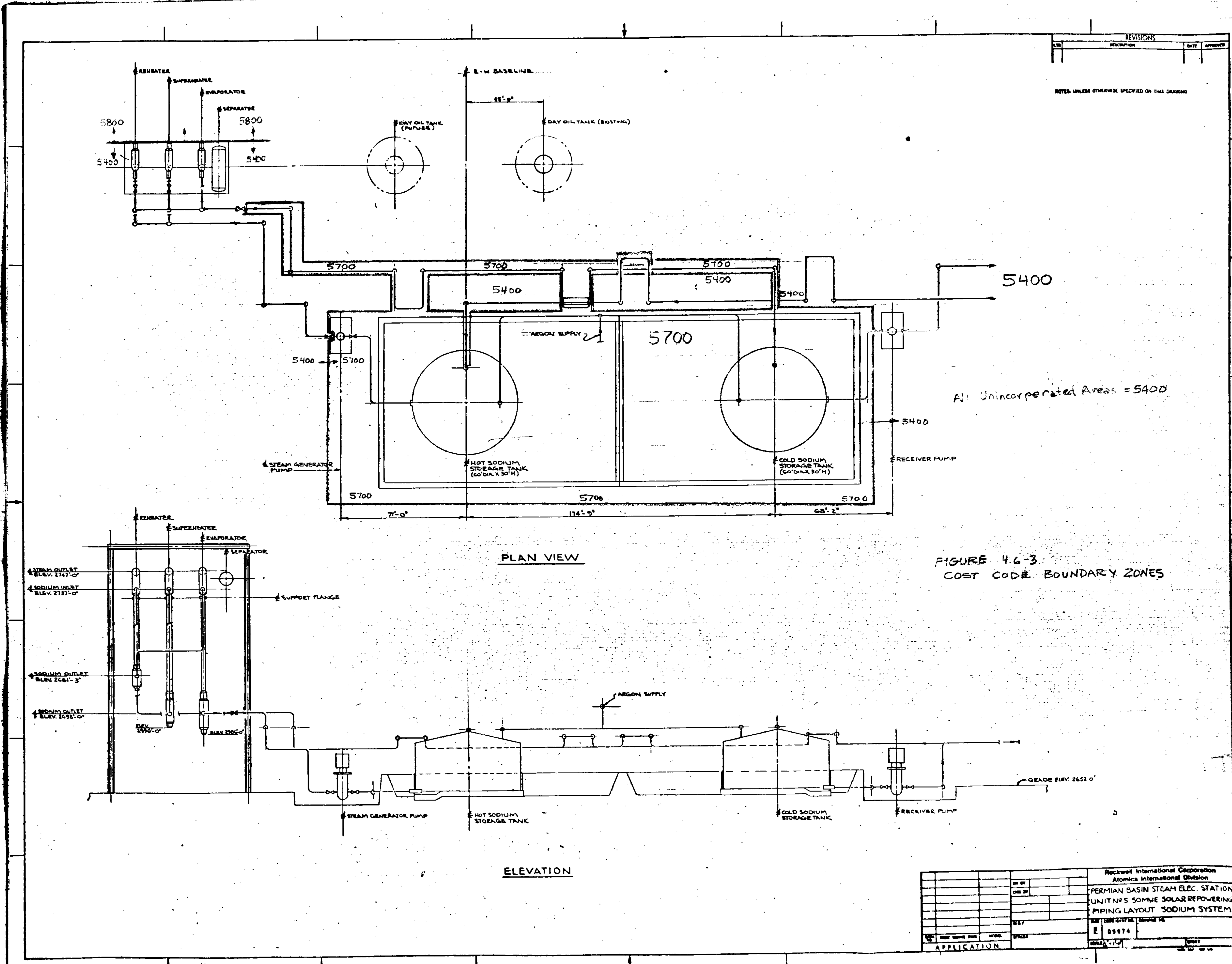


FIGURE 4.6-3
COST CODE BOUNDARY ZONES

4.7 OPERATING AND MAINTENANCE COST CONSIDERATIONS

The design, construction, operation and maintenance of a generating unit plays a large part in the availability and reliability of the unit and ultimately will be reflected in the operating and maintenance cost over the life of the unit.

Quality control in the design phase of every component, regardless of its location within the cycle, becomes increasingly important if it is to contribute to the unit reliability.

One area that impacts all facets of maintenance cost is the reliability, efficiency and quality assurance of vendor-furnished equipment. Along with the design and plant lay-out for ease of disassembly which ultimately results in decreased downtime of the equipment and increases the availability-reliability for any unit.

Likewise, proper construction methods and procedures must be followed so that premature failures or improper operation may be avoided. Without fail, some of the most expensive maintenance items are the result of either poor quality control or improper methods and procedures during construction. These may not be damaging to the equipment involved but result in extensive outage times to correct the fault.

The best design and construction of any unit contributes to the operation of the unit. A well designed system will accommodate those who must operate it. If valves and piping systems are improperly oriented, they become a burden to operating personnel. The same argument applies to each subsystem and will ultimately result in increased O & M cost.

The maintenance philosophy in the past has been one of Preventive and corrective maintenance. At the same time, to improve methods and procedures so that repetitive failures are minimized and the program is cost effective. To be cost effective, any maintenance management program must have a degree of administrative control that considers all of the areas that affect maintenance cost. Some of these include preventive maintenance, planned and forced outages, operating procedures, performance testing for efficiency and historical data to document all of these areas.

None of the above can be effective without the proper direction and resources to maintain the productivity ratio desired.

In the future, the possibility of increased participation of vendor-technical people involved in maintenance contracts associated with the major components within the cycle, in particular but not limited to, the central receiver and thermal transport system or subsystems associated with it, is recognized.

The operating and maintenance requirements for new units may vary on a unit to unit basis but historically during the initial check out phase and first year of operation, extensive schedules are required to monitor and test the performance of equipment and hardware that may be either deficient in design or unreliable for other reasons.

Maintenance of the receiver, therefore, becomes an unknown quantity since there are so many variables or combinations that can occur which could result in extreme temperature differentials and resultant problems. The external receiver is exposed to a heat flux of considerable magnitude which at any given instant may vary by at least a factor of four at different locations on the receiver. During the course of a day, a typical point on the receiver will have an incident flux that also varies by a factor of four. The heat flux on the receiver is such that a loss of coolant can cause severe overheating in a matter of seconds if not for the passive protection system. The heat flux pattern on a panel varies in space and time such that the thermal stresses in a <u>rigid</u> panel can lead to deformation and failure. Consequently, considerable flexibility has been designed into the panels. The proceeding problems have been, and will continue to be, vigorously addressed through-out the design phase.

~~Assuming~~ Thus these contributing factors to ~~failure~~ unscheduled maintenance are minimized when they do occur. ~~and~~ However, the frequency with which they occur will determine the maintenance requirements associated with the sodium ~~cycle~~ loops of the unit.

Another area which will impact O & M costs is that of training or familiarization of the equipment within the sodium cycle. Operators must be trained to successfully and safely operate the equipment and those charged with the responsibility to maintain the equipment must be given the benefit of additional training if the unit is to be reliable and dependable.

Normal maintenance of the fossil cycle will increase by reason of increased cyclic duty of the unit.

The current ~~Our~~ plans are to upgrade the existing feedwater and combustion controls of the fossil cycle which will increase the reliability of the unit; however, with the addition of the solar cycle the complement of instrument and control personnel must be increased to handle the additional control functions and maintenance of these facilities.

Maintenance of the heliostat field and its peripheral equipment will require additional personnel. The maintenance functions for this area will require people from within each work group in the plant along with contract services for labor associated with the various phases of maintenance. These are some specific areas, but by no means all areas, that will impact O & M cost on Permian Basin Unit No. 5.

Table 4.7-1 is a ~~The attached documents attempt to~~ forcast the additional manning levels required and indicates the O & M costs in 1980 dollars.

Table 4-7-1

50 MWe O & M Costs and Considerations

Operations

1. Operators/Shift

   1 Production Supervisor
   1 Operator Leadman
   2 Control Operators
   3 Plant Operators
   7 Per Shift x 3 shifts = 21 per 24 hour day

   2 Additional Plant Operators x 3 shifts = 6 per 24 hour day

   6 People x $20,916/yr x 1.05 Overtime = $131,770.00

2. Administrative

   1 Plant Superintendent
   1 Production Engineer
   1 Maintenance Engineer
   2 Maintenance Supervisors
   2 Secretaries
   1 Chief Clerk
   8 Per Day

   8 People x $24,817/yr. x 1.0 = $198,526 x .40 = $79,414.00

3. Stores

   1 Materials Coordinator

   1 Person x $17,268/yr x 1.05 Overtime = $18,131.00

4. Instrument and Control

   2 Plant Control Technicians
   2 Engineering Technicians
   1 Results Technician
   1 Plant Chemist
   6 Per Day

   6 People x $22,032/yr x 1.05 overtime = $138,801.00

Table 4.7-1

50 MWe O & M Costs and Considerations (cont'd)

5. Maintenance

Electrical Maintenance
1 Electrical Leadman
1 General Electrician
1 Maint. Electrician
1 Elect. Helper
4 Per Day

4 People x $21,550/yr x 1.05 Overtime = $90,510.00

Mechanical Maintenance
1 Mechanical Leadman
1 General Mechanic
1 Plant Mechanic
1 Maint. Mechanic
2 Mechanical Helpers
6 Per Day

6 People x $21,550/yr x 1.05 Overtime = $135,765.00

6. Contracts/Services

$75,242.00

7. Annual Inspection 40 Days

35 People x $21,550/yr x 15.38% =	$116,038.00
Expenses for 15 People at $70/Day	
15 People x $70/Day x 40 Days	$ 42,000.00
TOTAL	$158,038.00

Start Up & Check Out

4 Instrument Technicians		$ 22,032.00/year
1 Plant Chemist		
6 Operators		20,916.00/year
4 Electricians		21,550.00/year
4 Mechanics		21,550.00/year
19 People Per Day		21,512.00/year
(19)(21,512)(1.05)	=	$429,164.00/2
Admin.	=	99,268.00
Start Up Cost	=	214,582.00
TOTAL		$313,850.00

Table 4.7-1

O & M ITEMS		FIRST YEAR COMMERCIAL ($1,000/yr)
Maintenance Materials		586
Spare Parts	$511	
Materials & Supplies	75	
Maintenance Labor		827
Scheduled Maintenance	158	
Corrective Maintenance	594	
Contracts	75	
Training		150
Operators	75	
Maintenance	75	
Start Up & Check Out		314
TOTAL		1,877

4.8 SYSTEM SAFETY

The specific safety requirements for the Advanced Central Receiver Power System - Sodium Cooled Concept, include the conventional occupational safety requirements peculiar to a sodium-cooled solar power plant in addition to the Production Section Safe Practices and Procedures of Texas Electric Service Company. The conventional safety requirements will include the applicable OSHA regulations of the Federal Government for construction and operation phases of the unit plus the regulations for the state of Texas.

Other specific requirements will include the American National Standards Institute, the National Electrical Safety Code, the National Fire Protection Association, the National Electrical Manufacturers Association, the American Society of Mechanical Engineers Boiler and Pressure Vessel Code Sections I, II, V, Divisions I and IX; Standards of the American Institute of Steel Construction and the American Concrete Institute; applicable liquid metal safety criteria, building codes and air and water quality regulations for the state of Texas.

The System Safety Program Requirements Specification for Solar Thermal Power Systems and System Safety Receiver Solar Thermal Power System will be used as guidelines.

Our safety analysis embraces three specific areas as follows: the public, plant personnel and plant equipment.

Public Safety

There are three recognized potential safety hazards which may impact the areas beyond the site boundary.

1. Brush fires from coincident beams from the heliostats.
2. Damage to eye tissue from excessive irradiance.
3. Sodium combustion products aerosols from a leak in the exposed receiver tubes or from a ground level fire.

The first two items can be controlled by a brush-free fenced exclusion area of 1,000m from the edge of the heliostat field. The third conditon from sodium combustion products dispersed to the site boundary from leaks in the receiver or from pool fires at ground level creates an entirely different set of circumstances.

The largest leak expected to occur in the receiver is postulated to be caused by a rifle bullet piercing one of the tubes. The resulting 1cm (3/8") hole releases a jet of sodium which ignites and forms a plume of sodium and sodium combustion products. The plume develops into a cloud of aerosols and is carried downwind toward the site boundary. A computer code, based on the test data, has been developed and submitted by ESG as document 79-2 Vol. II, Book I which calculates the sodium and sodium combustion product distribution as a function of time and distance from the release point. A summary of these results is given in Tables 4.8-1 and 4.8-2.

Table 4.8-1 gives the maximum allowed release rates to produce acceptable long-term and emergency aerosol concentrations at the site boundary assuming conditions which maximize downwind concentrations. The long-term exposure limit is 2 mg/m^3. The limit for an emergency release is 80 mg/m^3.

The estimated release rate for the postulated accident at the top of the tower is 1 Kg/s (2 lb/s) or a factor of 20 below the limiting value.

The exposed surface area of a burning pool of sodium at ground level which will give the emergency limit at the site boundary is 160 m^2 (1,600 ft^2).

TABLE ~~10-1~~ 4.8-1

SODIUM RELEASE WHICH PRODUCES LIMITING AEROSOL CONCENTRATIONS AT PLANT BOUNDARY OF 1600 m (1 mile)

Type of Release	Amount of Release [kg/s (lb/s)]	Pasquill Weather Type	Reference Wind Speed [m/s (mi/h)]	Aerosol Particle Size [(μm) AED]	Aerosol Concentration Limit (mg/m^3)
Jet from 174 in (570 ft^2) Elevation	0.5 (1)	B*	1 (2)	20	2†
Pool on Ground	15 m^2 (150 ft^2)	F*	2 (4-1/2)	1	2
Jet from 174 m (570 ft) Elevation	20 (40)	B*	1 (2)	20	80§
Pool on Ground	160 m^2 (1600 ft^2)	F*	2 (4-1/2)	1	80

*Weather conditions which maximize the delivery of aerosols downwind
†Long-term limit (continuous exposure)
§Short-term limit (1/2 h to 1 h)

TABLE ~~10-2~~ 4.8-2

CALCULATED MAXIMUM SODIUM AEROSOL CONCENTRATIONS

Type of Release	Downwind Distance [m (miles)]	Concentration (mg/m^3)	Pasquill Weather Type	Reference Wind Speed [m/s (mi/h)]	Aerosol Particle Size [(μm) AED]
Jet from 174 m (570 ft) Elevation	700 (0.4)	3.5	A*	1 (2)	20
Pool on Ground	<100 (0.06)	<50.0	F*	2 (4.5)	1

NOTE: Maximum concentrations inside plant boundary for releases which produced limiting concentrations at assumed plant boundary of 1600 m (1 mile)

*Weather condition which maximizes the delivery of aerosols downwind

The free surface area for combustion in the catch pans will be limited to less than 1/20 of this value through the use of compartments and vented covers on the catch pans. With these precautions, it can be concluded that the combustion of sodium at the installation will not represent a hazard to the public.

Personnel Safety

Personnel safety will be adequately covered by the Occupational Safety and Health Administration governing this type installation along with the Production Section Safe Practices and Procedures Manual.

Particular emphasis will be placed on prevention of coincident multiple beam irradiance anywhere but at the receiver. In addition, personnel will be required to wear flame proof clothing, hard hats, PVC gloves and eye protection when outside the protection of the buildings or while working on open sodium systems.

Plant features which enhance personnel safety are:

1. Location of elevator ~~inside~~ on the tower.
2. Railed catwalks at elevations of the horizontal pipe runs with caged ladders for all vertical runs of risers and downcomers.
3. Exit doors at catwalk levels every 100 feet which leads to a protected exterior ladder. Personnel will not be permitted to the upper half of the tower during operation.
4. At least two exits will be required at the tower base.
5. Oxygen meters will be standard equipment in all pit areas subject to potential argon flooding.
6. Sodium-sensitive aerosol detectors will be located in enclosed spaces.

7. Emergency safety showers and eyewash fountains will be installed at strategic locations.
8. Approved fire suppressant extinguishers will be placed throughout the plant facility.
9. Provision will be made for proper draining of systems suspected of leaking.
10. Sodium catch pans will be provided under major components to confine any sodium during a leak to a controlled area until the component can be drained.
11. Nitrogen gas will be supplied for flooding the catch pans if N_a combustion is initiated.

Plant Equipment

Protecting the equipment and the integrity of the plant is an important first step in protection of the plant personnel and the public.

The identifed events which can damage the plant equipment are given in the attached table 4.8-3 together with plant features and actions planned to prevent or minimize the damage.

There are two independent operating sodium loops: the Energy Absorption Loop, consisting of the cold tank, the receiver pump, the receiver and the drag value; the Power Generation Loop which consist of the hot tank, steam generator pump and the steam generator.

The plant protective features respond to affected loop.

The plant safety features outlined and incorporated in the design and operation of the unit provides a wide margin of safety for the public, plant personnel and plant equipment.

4.8-3

TABLE

PLANT PROTECTION — SUMMARY FEATURES

Initiating Event	Plant Protective Features to Limit Consequences	Action Taken
Loss of Load	Alarm and P-2 pump speed reduction to condenser power capacity	Steam dumped to condenser.
Turbine and Steam Equipment Failure	Turbine trip circuits	Turbine trip PGL* shutdown.
Steam Generator to Sodium Leak	Rupture disk in steam generator shell; reaction products tank; isolation valves; antisyphon on T-1 inlet	Turbine trip and PGL tripped and secured.
Faulting in PGL	PGL trip circuits	Turbine and PGL trip.
Sodium-to-Air Leak in PGL Components	Sodium aerosol detectors; catch pans; N_2 supply for catch pans	PGL shutdown N_2 flood affected pan.
Leak in T-2 Tank	Sodium aerosol detectors; catch pans; pump connection to the T-1 tank	Plant shutdown.
Leak in T-1 tank	Sodium aerosol detector; catch pans; pump connection to T-2 tank	Plant shutdown.
Loss of Flow in the EAL	Check valve; syphon break in riser and downcomer lines; emergency slew circuits	Emergency slew mirror field. Shut down and secure the EAL loop.
Sodium Leak in Riser or Downcomer Lines	Sodium aerosol detectors; catch pans with N_2; drain lines	Defocus mirror field. Shut down EAL. Drain the affected lines.
Sodium Leak in the Receiver Headers	Sodium aerosol detectors; catch pans with N_2; receiver drain line; steel cover on top of tower	Defocus mirror field. Shut down EAL. Drain receiver.
Sodium Leak in Receiver	Television surveillance loop (or acoustic emission monitor); receiver drain line; top 30 m (100 ft) of tower insulated and steel capped; receiver support structure insulated	Slew mirror filed. Shut down EAL loop. Drain receiver.
Focusing Error at Tower	Temperature sensors on structures; receiver structure insulated	Slew mirror field.

*Power generation loop - hot tank, P-2 pump, and steam generator
+Energy absorption loop - cold tank, P-1 pump, and receiver assembly.

4.9 PROJECT ENVIRONMENTAL IMPACT ESTIMATE

This section gives a description of the environmental setting of the proposed Permian Basin site followed by an estimate of the environmental impact expected during the construction and operation of the solar repowered system. The information presented was gathered by the Texas Electric Service Company environmental staff from existing reports and data that has been collected over the years for the existing plant.

Site Description - The proposed site for the project is located on the eastern half of a one square mile section owned by TESCo that has been utilized since 1948 as a site for a six unit gas/oil power plant. The existing boilers, turbines, cooling towers and other structures occupy approximately $161873\ m^2$ (40 acres) at the center of the section. Another $141643\ m^2$ (35 acres) on the west side of the section is used for a fuel oil tank farm and associated dikes. Other significant features on the property include a $8094\ m^2$ (two acre) pond with surrounding park and a 26 house employee village that is currently being torn down. The site is bordered on the south by U. S. Highway 80 and Interstate 20. The south end of the section crossed by a Texas Pacific Railroad Line.

The surrounding area is essentially flat, open semi-desert range land with the city of Monahans (population 9,685) located 8.05 km (five miles) to the east and the small community of Wickett (population 625) 3.22 km (two miles) to the west. The closest airport is the small Monahans Municipal Airport 4.83 km (three miles) east of the site. The proposed heliostat site is primarily in a natural state except for several crossings of caliche roads, pipelines and a transmission line. In addition, there are several oil wells, a septic tank with latteral field and the remains of the dismantled employee village.

Geology - The proposed site lies in the southwest part of a broad structural basin called the Permian Basin. The soils under the site consist of about 350 feet of quarternary alluvium material deposited over underlying impermeable sediments of an older age. The deposits consist of permeable sand with lesser amounts of clay and gravel interbedded in the sand. A layer of caliche covering the entire area is exposed in some areas and covered with up to several feet of windblown sand in others.

Hydrology - The site slopes gently to the east (1.5 ft/100 ft). Because of the low rainfall and the highly permeable sandy soils, there are no defined streambeds or waterways. Most rainfall either percolates into the ground or evaporates. Fresh water-bearing sands under the site occur in two zones. The upper sand zone extends from the surface to depths from 19.8 - 36.6 m (65 to 120 feet). The lower zone which is approximately 38.1 m (125 feet) thick is separated from the upper zone by an impermeable layer of clay 30.5 - 38.1 m (100 to 125 feet) thick. Both sand layers contain water of good quality with several wells to the south tapping both zones.

Climatological Data - The climate of the area is semi-arid. The site lies at the northern edge of the Chihauhuan Desert which extends southward deep into Mexico. The average annual temperature is 17.7°C (63.9°F) with an average of 92 days per year over 32.2°C (90°F). The average annual rainfall is 0.342 m (13.51 inches) with the wettest month being May 0.055 m (2.16 inches) and the driest month being November 0.012 m (.49 inches). High winds occur in the spring months frequently creating blowing dust and sand.

Vegetation - The site is sparsely vegetated with low growing desert plants. The most common plants are mesquite, greasewood, prickly pear, and sparse grasses. The vegetation is typical of semi-arid areas throughout West Texas. There are no large trees native to the region. On the northern end of proposed heliostat field is a stand of (15-foot) 4.57m tall mesquite trees that have grown much larger than surrounding vegetation. The growth resulted from disposal of cooling tower blowdown from the plant in past years. There are many tall cottonwood, poplar and other trees located at the previous site of the company village of 26 houses. The village was closed in 1979 and houses removed, but the yards, trees and shrubs that had been planted by residents still remain. No grazing of cattle has been allowed on the site since 1948.

Wildlife - The area contains a wide variety of typical west Texas wildlife including snakes, lizards, mice, ground squirrels, rabbits, coyotes and skunks. Some of the birds in the area that have been observed are quail, doves, hawks, roadrunners, and sparrows. There are no known endangered species in the area. The two-acre pond located a few hundred yards west of the site attracts wildlife including some aquatic birds from surrounding areas.

Archaeological - No archaeological survey has been made at the site. However, employees who have lived and hunted on the site have never observed any archaeological signs or remains. It is unlikely that there are any historic or archaeological resources located on this site.

ENVIRONMENTAL IMPACT

This section identifies and evaluates the potential environmental impact of the proposed solar project. It is recognized that there would be a significant change in the (322 acres) 1.303 km^2 that will be covered by the heliostats and tower but impacts in the surrounding areas and communities would be minor. If proper precautions and planning are included in design of the plant, the benefits of the project should outweigh the minor environmental impacts indentifed in this review.

Disturbed Soils - Installation of the heliostat field will require the grading and leveling of over 1.214 km² (300 acres) of soil that consits of layers of caliche and fine sand. The disturbed caliche is stable but the sand is highly subject to wind errosion. Blowing sand would contribute to area sandstorms and to the danger of pitting surfaces of the heliostats. Some type of soil stabilization is needed for exposed sand covered areas. This could be accomplished with crushed caliche, gravel or some native grasses that do not require irrigation.

Runoff and Heliostat Washwater - The natural soils in the area are highly permeable resulting in very little runoff from the area. The creation of packed access roadways between heliostats and groundcover material will increase runoff rates. The design includes provisions to divert or collect runoff to prevent erosion or flooding. Heliostat wash water could have the potential to contaminate groundwater located approximately 30.5 m (100 feet) below the surface. Either pure water or detergents with non-toxic agents will be used in heliostat cleaning water.

Ecological Effects - The land clearing for the heliostat field will cause displacement of most of the wildlife that now occupies the area. The wildlife can be relocated to extensive areas of similar terrain and vegetation that is surrounding the site. At this time there are no known endangered plant or animal species known to be in the area.

Community Impact - The construction and operation of the solar plant is expected to have little impact on the community. The nearby city of Monahans has primary business interest in oil well drilling and supply companies. The existing power plant was welcomed by the community and it is expected the addition of solar capacity would similarly be welcomed. The city is accustomed to construction activity in the oil business and several local companies are capable of grading and roadbuilding work. The additional workers required for construction will be less than for past larger construction projects at the plant. Actual operation of the solar unit will require only a few more employees than the already existing staff of 75 employees.

The visual impact of the heliostats and tower is not expected to be a problem. The tower will be about a third taller than the existing boiler structures and stacks. Travelers on the interstate highway will only be able to see the side of the end row of heliostats. It is expected that the uniqueness of the project will be perceived as an attraction rather than a visual nusiance.

Misdirected Solar Radiation - The impact of misdirected solar radiation is still an unknown factor that actual experience will determine. As other experimental solar projects come into operation, this impact can be better resolved. Precautions will be taken to prevent partial focusing on the nearby boiler structures.

Hazardous Materials - The use of large quantities of sodium will present the potential hazard for spills. These hazards have been studied extensively by Rockwell International and spill protection has been designed into the system with the inclusion of containment dikes around all sodium storage tanks. Special training on handling and safety instructions will be given to employees. Rockwell International has also performed a special study to identify the environmental impact of a major spill and has determined the consequences were within currently acceptable levels. The desert location makes a spill into waters of the state impossible.

Benefits - The benefits of the solar repowering project should be identified when examining environmental impacts. The project would be a major step in providing information toward the national goal to utilize solar power and reduce purchases of foreign fuels. Any electricity generated by the solar unit would offset generation by fuel burning at other sites. The site would be an attraction for tourists and a source of community pride. The primary benefit will be the knowledge gained by TESCo and the utility industry about repowering existing steam electric generating units.

4.10 INSTITUTIONAL AND REGULATORY CONSIDERATIONS

An analysis of the regulatory requirements that would be applicable to the Permian Basin solar repowering project was conducted by the TESCo environmental and regulatory staffs. The purpose of the analysis was to identify all federal, state and local notifications, permits or approvals required for the specific project and site proposed. This was accomplished by reviewing applicable regulations and contacting several of the agencies. The following sections summarize the requirements of each agency.

Texas Air Control Board - Texas state law requires notification and permits prior to any new construction or major modification of existing sources if those actions will result in any increase in emissions. Since the solar repowering project would reduce fuel use of the existing gas-fired boiler, no notifications or permits would be required from the Texas Air Control Board. A question was raised about sodium aerosol emissions if a leak should occur high on the tower. This would be a hazardous material spill event rather than an air pollution espisode and would not be covered by state air regulations.

Texas Department of Water Resources - The existing gas/oil-fired plant retains all wastewater on company property in two waste disposal ponds. The company has two existing state permits to discharge typical power plant effluent streams such as boiler blowdown, cooling tower blowdown and floor drains to these two ponds. The solar repowering project will not create any significant change in the quality or quantity of wastewater so the existing permits will not require modification. Water rights in Texas are also under control of the Department of Water Resources. State law entitles landowners to use all groundwater under their property. The plant owns sufficient groundwater and has pumping capacity to supply all needs of the solar project with no water rights permits required.

Federal Aviation Agency - The Fort Worth FAA Regional Office was contacted to identify notification and marking requirements for the solar tower. An FAA Form 7460-1, Notice of Proposed Construction or Alteration, would have to be submitted at least 30 days prior to start of construction. The FAA's main interest is to analyze the tower's potential hazard to aircraft. The required form is one page which asks for a description of the structure, coordinates, elevation and location of nearby towns and airports. Agency approval usually takes only one week. The structure will also have to meet the lighting and marking requirements of FFA Obstruction Marking and Lighting Manual AC 10/7460-1F.

Texas Public Utility Commission - In order to have the expense of the solar repowering construction included in its rate base, the company would have to receive a Certificate of Convenience and Necessity from the Public Utility Commission prior to construction. Currently, the state of Texas has not developed a specific application form for solar plants but it can be assumed they will require information similar to what is required by the state's application form for coal plants. That application form has 37 questions about the location, engineering, costs, financing and construction schedule. Justification for site selection and fuel selection must be submitted. Generally, four to six months are required for the Commission to issue approval if no oppostion is expressed after public notices.

United States Environmental Protection Agency - The proposed solar repowering project would not create any new air emissions or discharges to waters of the United States so no EPA approvals or permits will be required. EPA Region VI office in Dallas has a new voluntary New Source Environmental Questionnaire which can be used to confirm that no permits are required but the company has elected not to submit one of these forms at this point in the study. Sodium would be defined as a hazardous material under new EPA regulations covering disposal of hazardous wastes. If waste sodium is generated by the facility, then the plant would have to register as a hazardous waste generator for sodium. Registration would not significantly affect the cost or design of the plant but would insure proper disposal of waste materials.

Solar Repowering Under the Fuel Use Act

All "Existing Electric Powerplants" are required to come into compliance with the Title III prohibitions of the Powerplant and Industrial Fuel Use Act of 1978 (FUA). Simply stated, an existing electric powerplant may not use natural gas as a "primary energy source" on or after January 1, 1990 unless an exemption from these prohibitions has been granted or the powerplant is included in an approved system compliance plan. To date, no system compliance plan has been approved.

Interim regulations for existing powerplants were issued effective August 20, 1979. No final regulations have been issued. Further, final regulations may be deferred indefinitely. In general, interim agency regulations are not subject to judicial review. As a result, deficiencies in the interim regulations cannot be easily cured. Thus, while several exemptions appear to be generally applicable, given other conditions, to solar repowering projects these exemptions are conditioned on certain requirements - some not yet clearly defined.

As an example, the most promising exemption for solar repowering projects is the "Permanent Exemption for Certain Fuel Mixtures Containing Natural Gas or Petroleum". One of the conditions for the granting of this exemption for solar repowering projects is the preparation and submission of a compliance plan according to §504.17 of the interim regulations. First, is the compliance plan concerned only with the unit being exempted or is it for part or all of the utility system involved? Second, since §504.17 does not mention compliance plans for "Permanent" exemptions, does this mean no compliance plan is necessary? Or is this an oversight to be changed in subsequent revisions to the interim regulations?

Recognition of the unique characteristics of solar repowered plants by the FUA regulators and a willingness to grant special status to such plants are prerequisite to a commitment for construction. Electric utilities committed to construction of solar repowering projects will be exposed to substantial risk due to the unproven technology involved. To compound this risk further with regulatory uncertainty could be sufficient to preclude any commitment for construction. In order to eliminate the regulatory uncertainty under the FUA, an unconditional exemption from FUA Title III prohibitions and continued status as an "existing" electric powerplant are essential.

United States Department of Energy

The final major unknown regulatory impact is the effect of the DOE's regulations for compliance with the National Environmental Policy Act (NEPA). These regulations require the DOE to prepare an Environmental Impact Statement prior to giving grants for construction projects that create an environmental impact. During the midterm planning meeting, the DOE representatives agreed to study this issue and determine what information is needed to make their assessment. This report contains a limited environmental analysis prepared by the company and based on data known about the existing plant site. If the DOE requires additional information, an environmental consultant firm who specializes in environmental studies may be required. If the project is financed totally with TESCo funds without a grant from the DOE, then no environmental impact study is required.

5.0 SUBSYSTEM CHARACTERISTICS

This section contains the description, functional requirements, design and operating characteristics, performance estimates, cost/performance trade-offs and top-level cost estimates for the major subsystems comprising the Permian Basin, Unit 5 solar repowering conceptual design. The subsystems included are: collector, receiver, master control, fossil energy, energy storage, and electric power generation. The site and site facility descriptions are included in section 4, as is the system level information.

5.1 COLLECTOR SUBSYSTEM

The collector subsystem is a field of two axis-tracking mirrors. The major components of this subsystem are the heliostats and their controls. This section discusses the major components as well as the field in total.

5.1.1 Description

5.1.1.1 Collector Field

The collector field is comprised of 4742 heliostats surrounding the receiver tower. The field is shown in Figure 5.1-1. The field is subdivided into 134 m^2 conceptual cells as shown in the figure. The number of heliostats in each cell is noted in the figure along with the overall field dimension. The south-east and north-west boundaries of the field were trimmed to avoid existing roads and powerlines on the south and the property line on the north. Nondimentional heliostat spacings are given in Figure 5.1-2. A typical heliostat layout using these spacings is shown for specific cell in Figure 5.1-3.

5.1.1.2 Heliostats

The MDAC Second Generation heliostat is used as a baseline in this study. The following is a description of the heliostat and its major components.

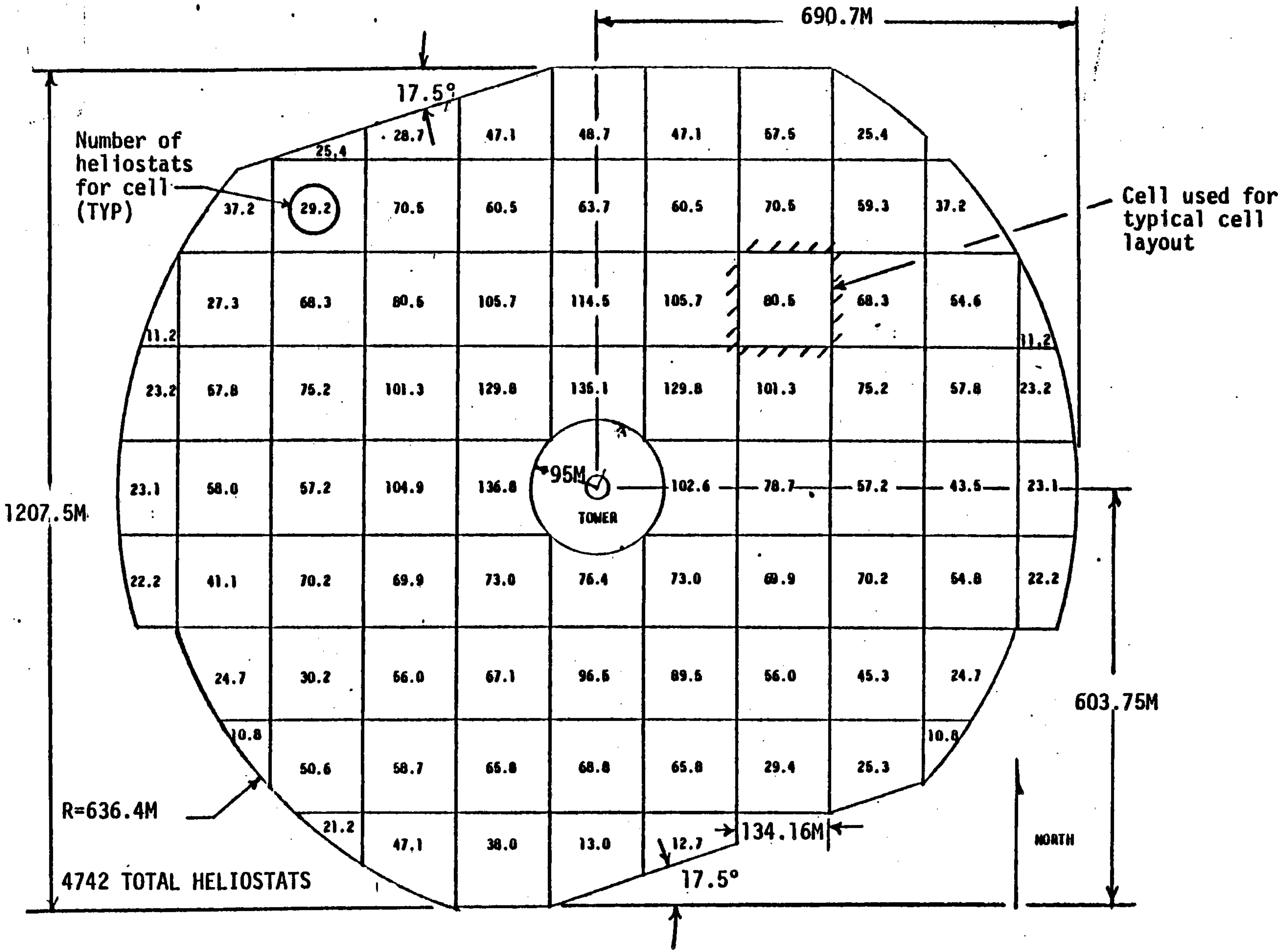
STRUCTURAL COMPONENTS.

Mirror Module

At the present state of design, the mirror module consists of the following: a 3/32 inch thick 48 by 132 inch clear float glass mirror bonded to a 3/16 inch thick 48 by 132 inch float glass backlight with a polyvinyl butrate. A primed and curved hat-section stiffener will be allowed to drape over a curved bonding tool. A channel shaped galvanized edge member and a butyl rubber seal will be pushed onto the laminated mirror and doubly sealed with a silicon adhesive. Figure 5.1-4 shows the current mirror module components.

Reflector Support Structure

The reflector support structure consists of the inner and outer cross beams, two diagonal beams and the associated tabs and gussets all spot welded together to form the assembly as shown in Figure 5.1-5. For high quality production,



DISTRIBUTION OF HELIOSTATS IN TEXAS ELECTRIC SERVICE COMPANY FIELD

X = FIRST SPACING PARAMETER IN UNITS OF DMIR
(Radial Spacing)

MAX(A) = 1.2909E 01 MIN(A) = 2.1793E 00 AVR(A) = 4.1703E 00

AIJ = (10 ** 1) X PRINTED VALUES

1.291	1.206	1.129	1.063	1.010	0.970	0.945	0.937	0.945	0.970	1.010	1.063	1.129	1.206	1.291
1.202	1.110	1.027	0.955	0.895	0.850	0.823	0.813	0.823	0.850	0.895	0.955	1.027	1.110	1.202
1.119	1.021	0.930	0.851	0.784	0.734	0.702	0.691	0.702	0.734	0.784	0.851	0.930	1.021	1.119
1.046	0.939	0.841	0.753	0.678	0.621	0.584	0.572	0.584	0.621	0.678	0.753	0.841	0.939	1.046
0.983	0.869	0.762	0.665	0.580	0.514	0.471	0.456	0.471	0.514	0.580	0.665	0.762	0.869	0.983
0.932	0.811	0.696	0.589	0.494	0.417	0.366	0.348	0.366	0.417	0.494	0.589	0.696	0.811	0.932
0.897	0.770	0.647	0.531	0.425	0.337	0.278	0.257	0.278	*0.337	0.425	0.531	0.647	0.770	0.897
0.878	0.747	0.619	0.496	0.382	0.286	0.227	0.218	0.227	0.286	0.382	0.496	0.619	0.747	0.878
0.878	0.745	0.615	0.490	0.372	0.273	0.229	[redacted]	0.229	0.273	0.372	0.490	0.615	0.745	0.878
0.896	0.765	0.637	0.513	0.398	0.301	0.243	0.240	0.243	0.301	0.398	0.513	0.637	0.765	0.896
0.933	0.806	0.683	0.565	0.458	0.369	0.309	0.288	0.309	0.369	0.458	0.565	0.683	0.806	0.933
0.988	0.866	0.750	0.641	0.545	0.467	0.414	0.396	0.414	0.467	0.545	0.641	0.750	0.866	0.988
1.057	0.943	0.835	0.736	0.650	0.582	0.538	0.523	0.538	0.582	0.650	0.736	0.835	0.943	1.057
1.140	1.033	0.933	0.844	0.768	0.709	0.672	0.659	0.672	0.709	0.768	0.844	0.933	1.033	1.140

FIELD BOUNDARY

Y = SECOND SPACING PARAMETER IN UNITS OF DMIR
(Azimuthal Spacing)

MAX(A) = 2.2574E 00 MIN(A) = 1.5303E 00 AVR(A) = 2.1434E 00

AIJ = (10 ** 0) X PRINTED VALUES

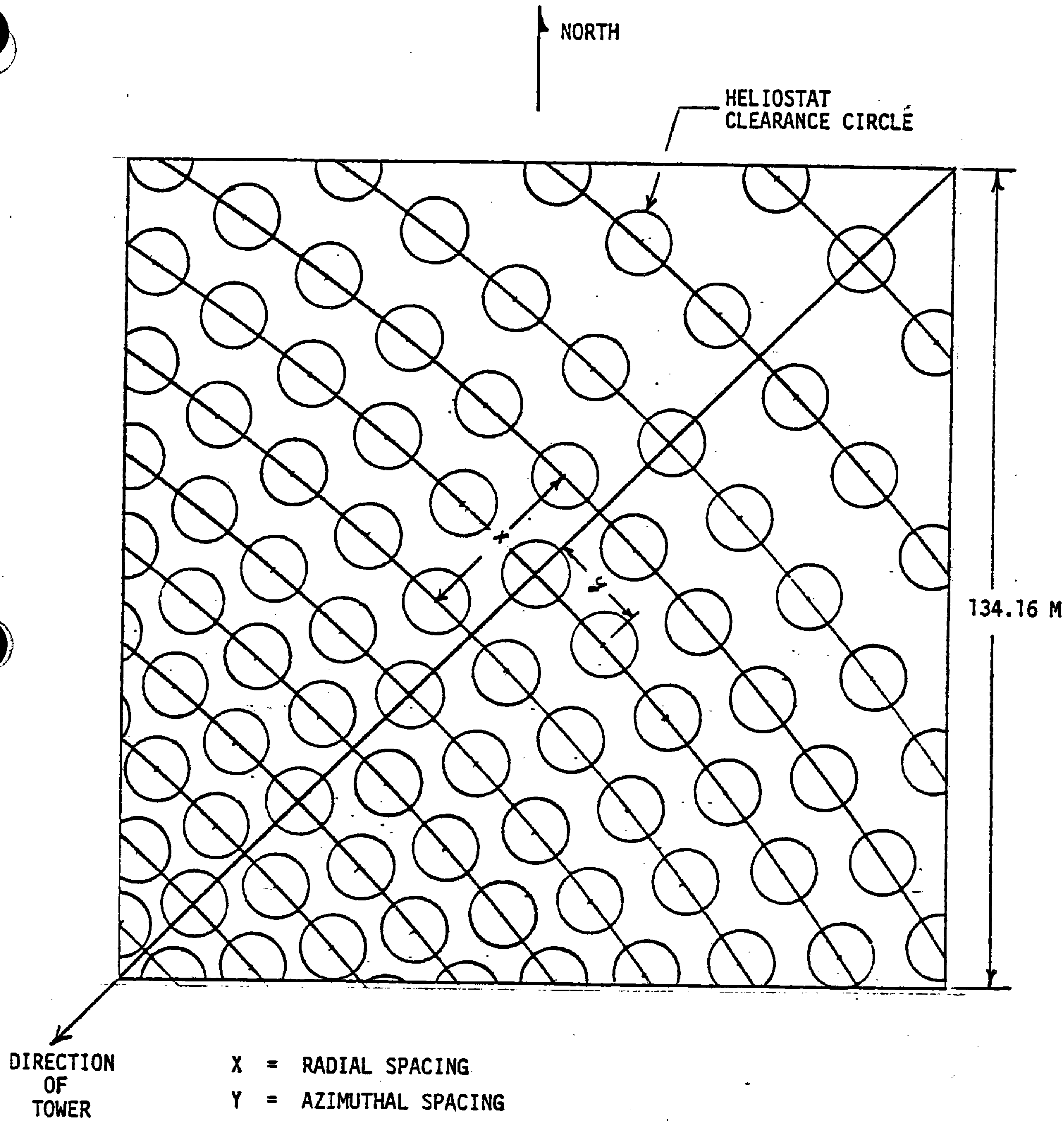
2.077	2.074	2.072	2.069	2.067	2.064	2.063	2.063	2.063	2.064	2.067	2.069	2.072	2.074	2.077
2.081	2.078	2.076	2.072	2.069	2.067	2.065	2.064	2.065	2.067	2.069	2.072	2.076	2.078	2.081
2.086	2.084	2.081	2.077	2.073	2.070	2.067	2.066	2.067	2.070	2.073	2.077	2.081	2.084	2.086
2.093	2.091	2.087	2.083	2.079	2.074	2.071	2.069	2.071	2.074	2.079	2.083	2.087	2.091	2.093
2.101	2.099	2.096	2.092	2.087	2.081	2.075	2.073	2.075	2.081	2.087	2.092	2.096	2.099	2.101
2.110	2.110	2.108	2.104	2.098	2.090	2.082	2.078	2.082	2.090	2.098	2.104	2.108	2.110	2.110
2.121	2.122	2.122	2.121	2.116	2.105	2.091	2.085	2.091	2.105	2.116	2.121	2.122	2.122	2.121
2.132	2.136	2.139	2.141	2.139	2.124	2.088	2.087	2.088	2.124	2.139	2.141	2.139	2.136	2.132
2.144	2.150	2.157	2.164	2.168	2.147	1.959	[redacted]	1.759	2.147	2.168	2.164	2.157	2.150	2.144
2.155	2.163	2.174	2.186	2.197	2.190	2.081	1.830	2.081	2.190	2.197	2.186	2.174	2.163	2.155
2.164	2.174	2.186	2.201	2.217	2.229	2.223	2.209	2.223	2.229	2.217	2.201	2.186	2.174	2.164
2.171	2.182	2.195	2.210	2.227	2.243	2.254	2.257	2.254	2.243	2.227	2.210	2.195	2.182	2.171
2.176	2.187	2.199	2.213	2.227	2.241	2.252	2.256	2.252	2.241	2.227	2.213	2.199	2.187	2.176
2.179	2.189	2.200	2.212	2.224	2.234	2.242	2.245	2.242	2.234	2.224	2.212	2.200	2.189	2.179

*Value Used in Typical Cell Layout (Figure 5.1-3)

$$\text{Spacing Factor} = \frac{\text{Spacing (Meters)}}{7.654 \text{ (Meters)}}$$

NON-DIMENSIONAL HELIOSTAT FIELD SPACING FACTORS

F5.1-2



X = RADIAL SPACING

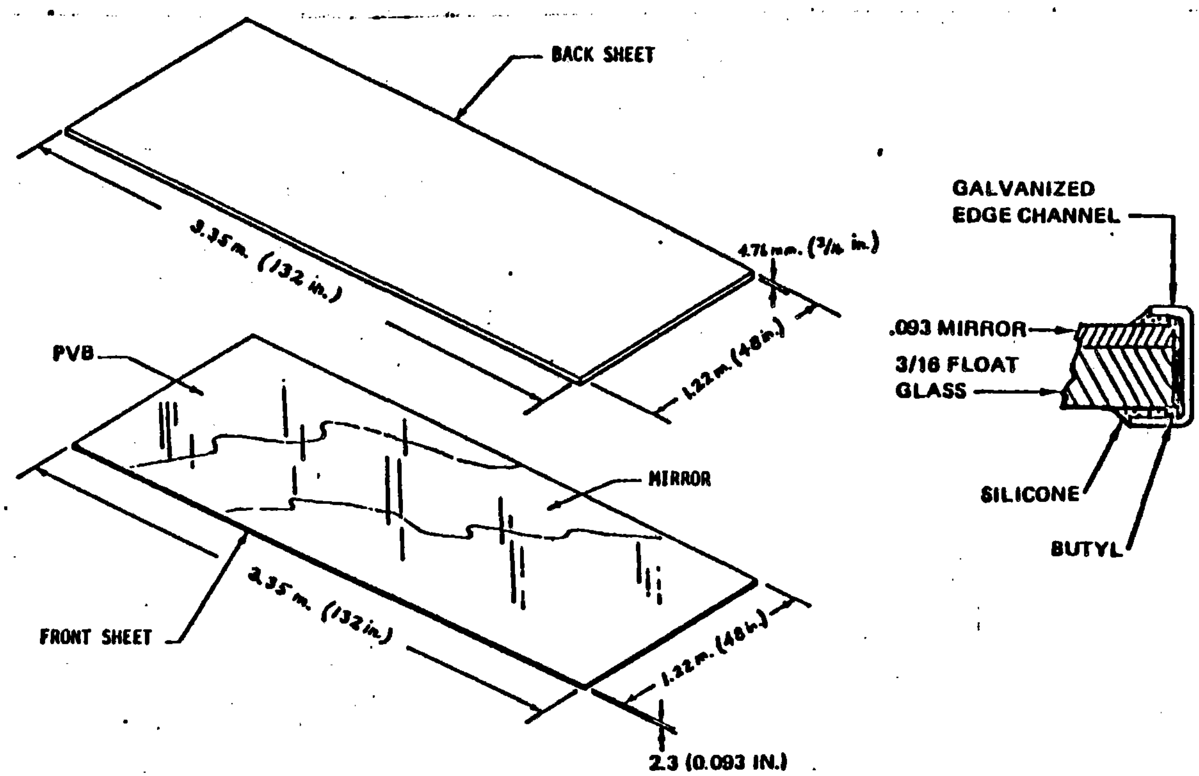
Y = AZIMUTHAL SPACING

LOCATED 2 CELLS NORTH AND EAST OF TOWER CELL

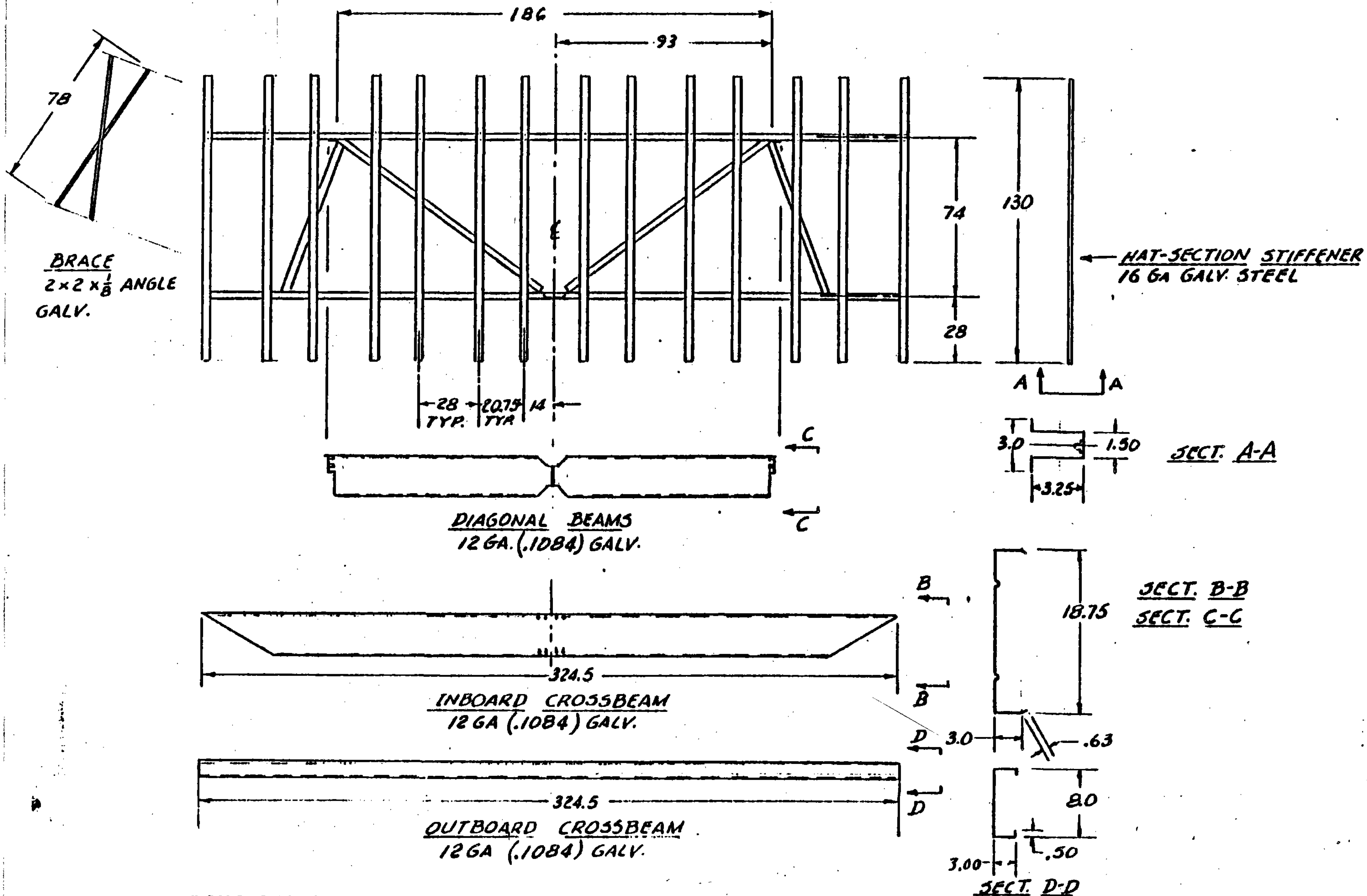
NUMBER OF HELIOSTATS IN CELL = 80.5

TYPICAL CELL HELIOSTAT LAYOUT

MIRROR MODULE DETAIL



8.1-4



DIMENSIONS IN INCHES

5.1-5

the hat section stiffeners are assembled with the support structure and bonded to the seven laminated mirrors (1/2 heliostat) at the same time.

Reflector Assembly

The reflector assembly is comprised of seven mirror modules and the reflector support structure as shown in Figure 5.1-6. The main improvements of this reflector assembly compared with previous designs is a weight and cost reduction and better transportability. The two diagonal beams are lighter than the torque tube they replace and allow for a much smaller outer cross beam. The joint between the main beam and the reflector assembly allows for complete factory assembly, ease of shipment of parts, and reduced field assembly time.

Main Beam

The main beam is a short section with welded lugs which are machined for attachment to the drive mechanism. Plates welded to the ends of the tube have threaded studs to facilitate quick, low-cost installation of the reflector assembly.

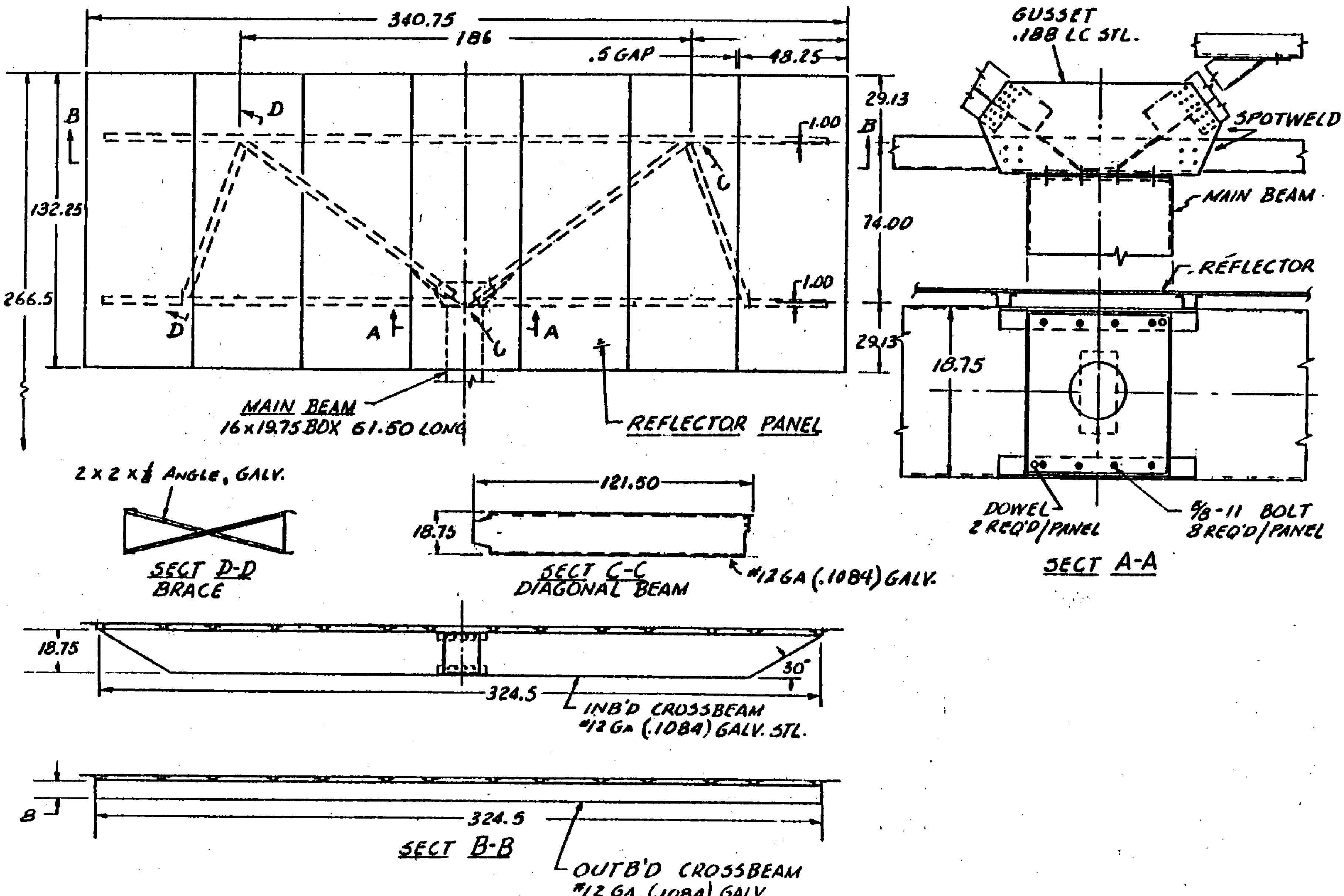
Drive Components

The drive unit concept consists of the azimuth drive and the elevation drive. The azimuth output reduction stage is the Harmonic Drive with Helicon input gearing. An AC motor with an integral Helicon pinion on its output shaft provides the input power. The lack of an inversion requirement allowed the use of a single elevation jack. The elevation ball screw jack has similar input Helicon gearing shown in Figure 5.1-7.

The azimuth drive design is shown in Firugre 5.1-8. A simplification and cost reduction have been achieved by inverting the azimuth harmonic drive mechanism. This change permits the azimuth drive housing to be converted from a highly loaded weldment to a more lightly loaded weldment, since heliostat gravitational and aerodynamic loads are distributed directly into the azimuth bearing by the new design. This change also enhanced environmental protection of azimuth drive components.

Heliostat Control System

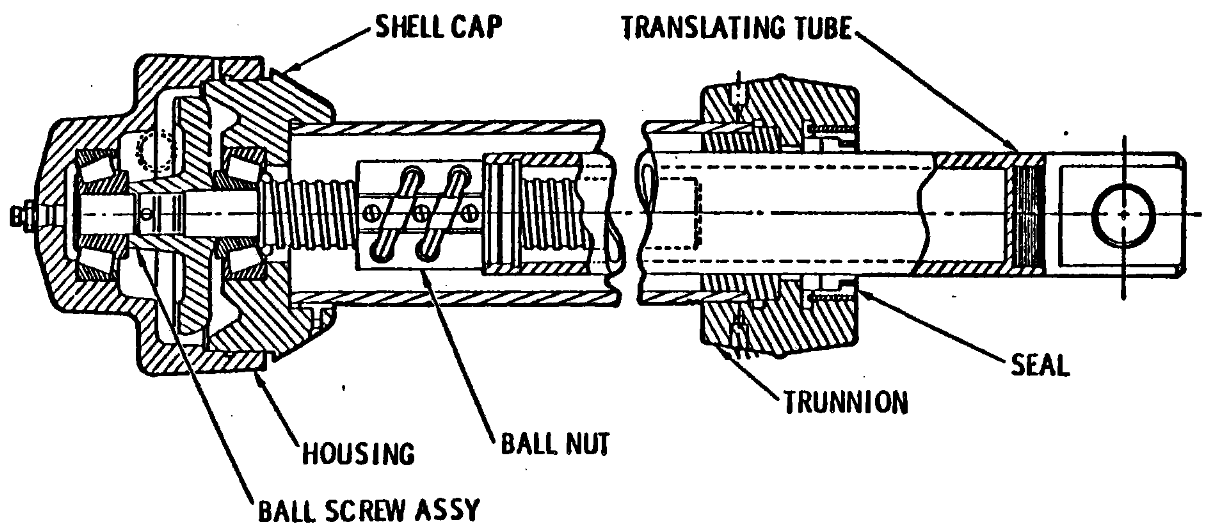
There are four basic electronic components of the second generation heliostat



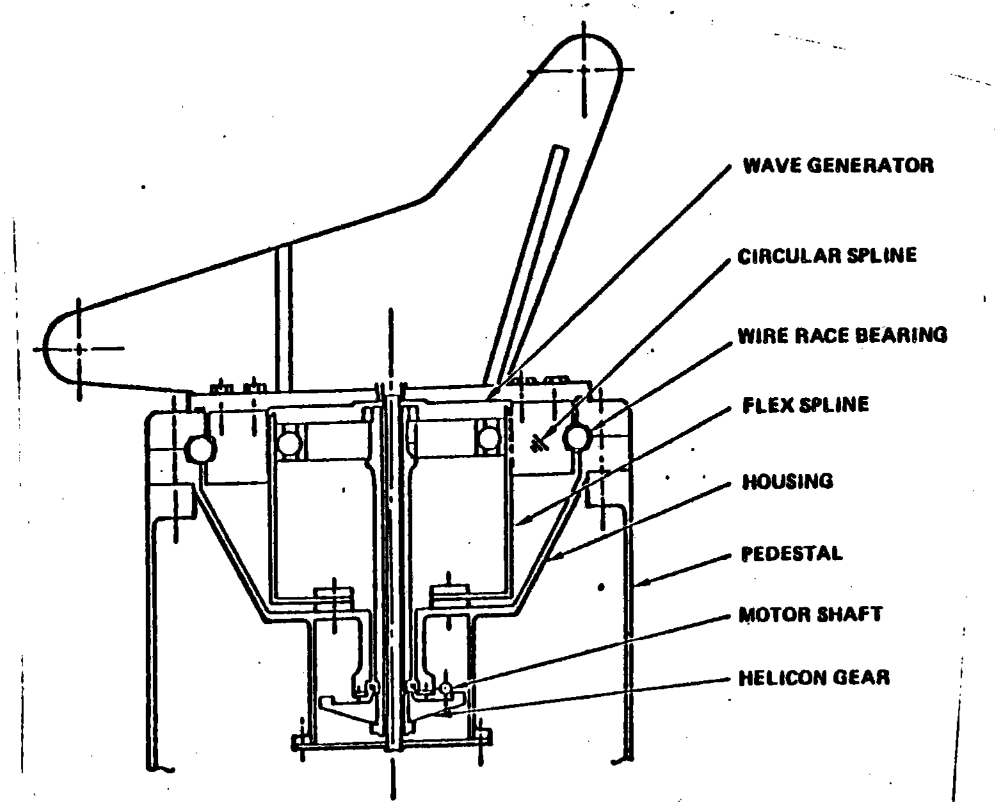
DIMENSIONS IN INCHES

5.1-6

ELEVATION DRIVE BALL SCREW ACTUATOR



AZIMUTH DRIVE UNIT



system that are used in controlling the heliostats in the collector field. These components are a Heliostat Array Controller (HAC), Heliostat Field Controller (HFC), Heliostat Controller (HC) and a Motor/Sensor system. The collector control system hardware architecture and the communication paths between the control system components are illustrated in Figure 5.1-9.

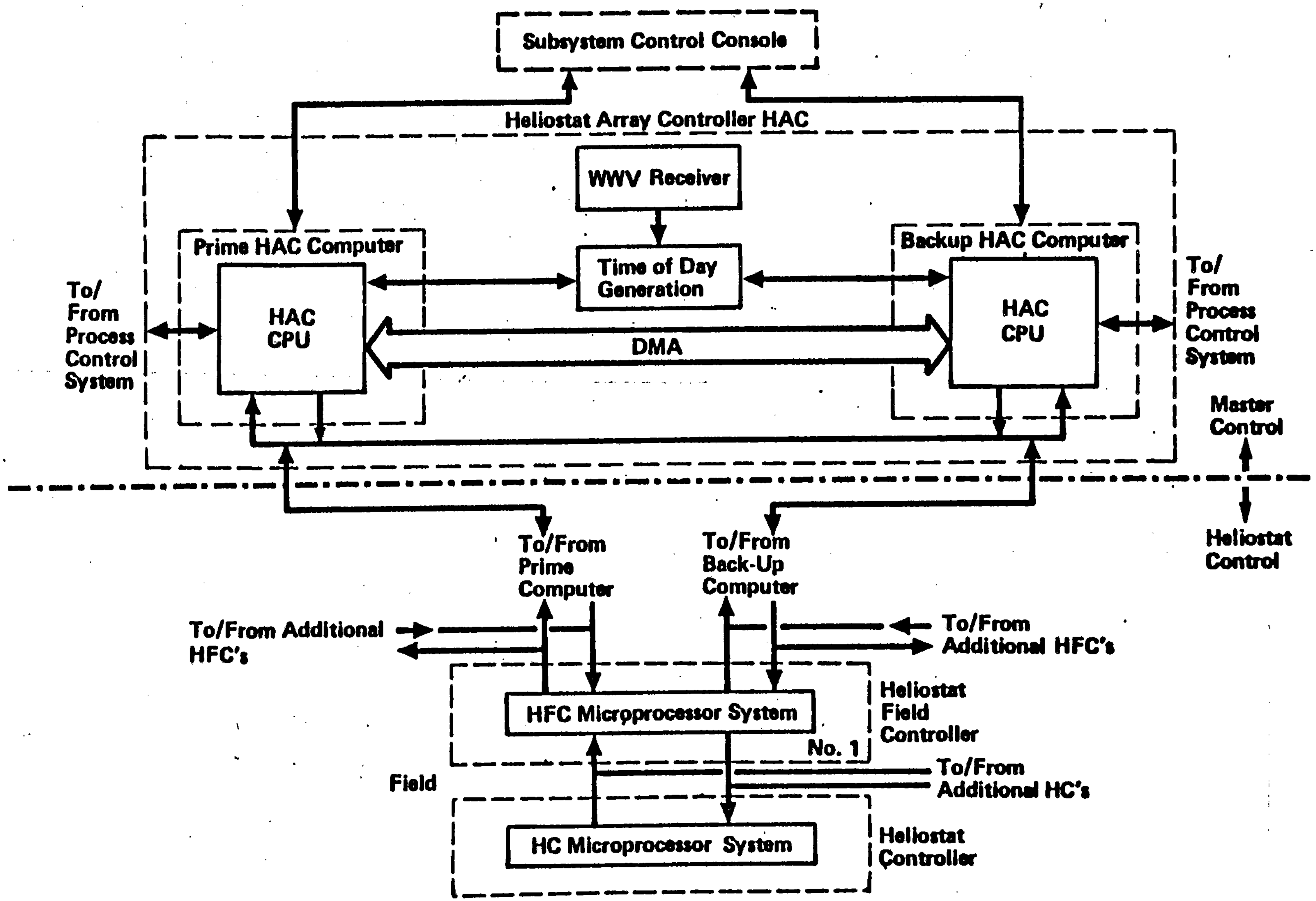
- Heliostat Array Controller (HAC) - The Heliostat Array Controller is comprised of a dual minicomputer system with peripherals and a CRT display console with keyboards that form the operator interface. The HAC computer system is developed around the Digital Equipment Corporation model PDP11/34 computer system.

  The dual computer system provides automatic fail-over capability in the event of a computer failure. The HAC is located in the control room along with the rest of the Master Control System.

- Heliostat Field Controller (HFC) - The Heliostat Field Controller is comprised of a microprocessor with memory and communications hardware that provides the capability for the HFC to communicate with the HAC and the Heliostat Controllers (HC). The HFC's are located throughout the collector field in nineteen (19) data distribution centers in weatherproof enclosures mounted on concrete foundations. Up to eight (8) HFC's are located in each of the data distribution centers, and buried twisted pair cables fan out from these locations to the heliostats serviced by the HFC. Each of the HFC's service up to thirty-two (32) heliostats.

  Each HFC is made up of a processor circuit board, a memory board, and a power supply. The HFC is built around the 8085 central processing unit (CPU). It operates at 3.072 MHz. Memory consists of 2K bytes of ultravoilet erasable PROM and 16K bytes RAM. Features include a direct memory access (DMA), an arithmetic processing unit (APU), an interrupt controller, a real time counter. Communication with HAC's and HC's is handled by three (3) universal synchronous/asynchronous receiver/transmitters (USART's) which are linked to the communication lines by transceivers. Field Programmable Logic Array (FPLA) is used for message decoding.

DESIGN ARCHITECTURE FOR COLLECTOR CONTROL



5.1-9

Heliostat Controller (HC) - The HC is developed around and INTEL 8049 one-chip microcomputer which contains 2K ROM and 120 bytes of RAM. It provides the capability of communicating with the HFC (through the USAR), inputting data from the detectors (incremental encoders and limit switches) and controlling the motors.

The incremental endoders are used to determine the position of the heliostat by counting the number of motor revolutions on each motor achieved from a known reference. The total number of turns for each motor will be accumulated and stored by the HC. The incremental encoder consists of two magnetic sensor assemblies and slotted ferrous metal vane attached to the motor shaft which protrudes from the end of the motor.

5.1.2 Functional Requirements

5.1.2.1 Collector Field

The basic function of the collector field is to provide concentrated solar energy to the surface of the receiver. Certain constraints are placed on the distribution of the energy incident on the receiver in terms of the maximum total incident power (181 MW at the design point), the peak flux (1.5 MW/m^2), and the flux distribution around the receiver (panel to panel peak flux ratio of less than 2.5).

The above requirements apply during the normal tracking mode of operation. The field is also required to operate in other modes dictated by safety, maintenance, and heliostat design. These modes include the ability to track in a standby mode where portions of the field are focused on areas in the near vicinity of the receiver, normal stow (face up), maintenance stow (for washing and repair), and wind stow (minimum drag). The ability to change from one mode to any other at any time is a basic requirement of the field. Stand-by is used during normal startup and shutdown operations when going to or from any of the stow positions. It is also used in the case of emergency defocus due to receiver coolant loss. The basis requirement for emergency defocus is to move all of the heliostats to their standby focus in less than ninety (90) seconds using less than 1400 KW of emergency power. Additional constraints on this operation can be defined by requiring that at least 50% of the heliostats be defocused in less than forty (40) seconds. This assures that the receiver will not experience an over-heated condition during this operation.

The only physical interface between the field and the rest of the system are the field power supply and the command data links. These interface requirements will be discussed in detail for the specific heliostat and heliostat control components later in the section.

5.1.2.2 Heliostat

Functional requirements for the heliostat relate primarily to pointing and tracking accuracy. Actual requirements for beam pointing and quality are contained in the SRS. These requirements translate to heliostat drive component backlash/hysteresis and stiffness parameters. In order to provide a better correlation with design requirements, they have been translated into actual deflection requirements at the maximum operational load for 12 m/sec (27 mph) winds. These and other key drive system requirements are summarized in Table 5.1-1.

In addition to the above pointing and tracking requirements, the heliostat control system must also respond to the overall field functional requirements. The requirements for each of the major control components are presented below.

The main requirements of the HAC are to:

1. Respond to commands from an operator at the control console.
2. Act as an executive controller of the heliostats in the automatic mode.
3. Monitor the performance of the heliostats specifically and the field in general.

The main requirements of the HFC are to:

1. Calculate heliostat position commands which will reflect the beam at a given aimpoint.
2. Transmit the commands to the HC's.
3. Compare all HC received messages with the transmitted message. Also, check for other communication errors.

KEY DRIVE SYSTEM REQUIREMENTS

TRAVEL ANGLE	ELEVATION - 90	AZIMUTH - + 270
TRAVEL TIME	90° IN 7.5 MINUTES	180° IN 15 MINUTES
BACKDRIVE	NONE	NONE
LIFE	30 YEARS	30 YEARS
SURVIVAL LOAD (90 MPH)	+ 20,300 LBS - 19,500 LBS (REFLECTOR FACE UP)	101,200 IN-LBS
MAX STATIC LOAD (50 MPH, ANY ORIENTATION)	+ 12,200 LBS	142,600 IN-LBS
MAX STARTING LOAD	+ 8,500 LBS	82,400 IN-LBS
MAX OPERATING LOAD	+ 8,800 LBS	82,400 IN-LBS
DEFLECTION AT 27 MPH	1.85 MRAD AT 60,000 IN-LBS AND $\alpha = 30°$	2.4 MRAD AT 41,600 IN-LBS
OVERTURNING MOMENT AT PEDESTAL TOP	---	±466,500 IN-LBS WITH - 6,900 LB AXIAL LOAD AND 1,600 LB RADIAL LOAD

4. Respond to commands received from the HAC, i.e., transmit requested data or to point a heliostat from one aimpoint to another aimpoint.
5. Monitor the performance of each HC.

The main requirements of the HC are to:

1. Execute heliostat position and/or rate commands which will reflect the solar beam at a given aimpoint.
2. Acknowledge the receipt of all messages (except sync messages) by echoing back the received message to the HFC.
3. Respond to HFC commands by the operating in the following control modes:
    a. Normal receiver tracking
    b. Standby position (emergency defocus)
    c. Special gimbal angle (maintenance stow)
    d. Heliostat stow
    e. Heliostat unstow
4. Store motor turn position data and transmit each data upon request.

The functions of control system components and the information flow between them is summarized in Figure 5.1-10. The communication paths/interface between them are illustrated in Figure 5.1-11.

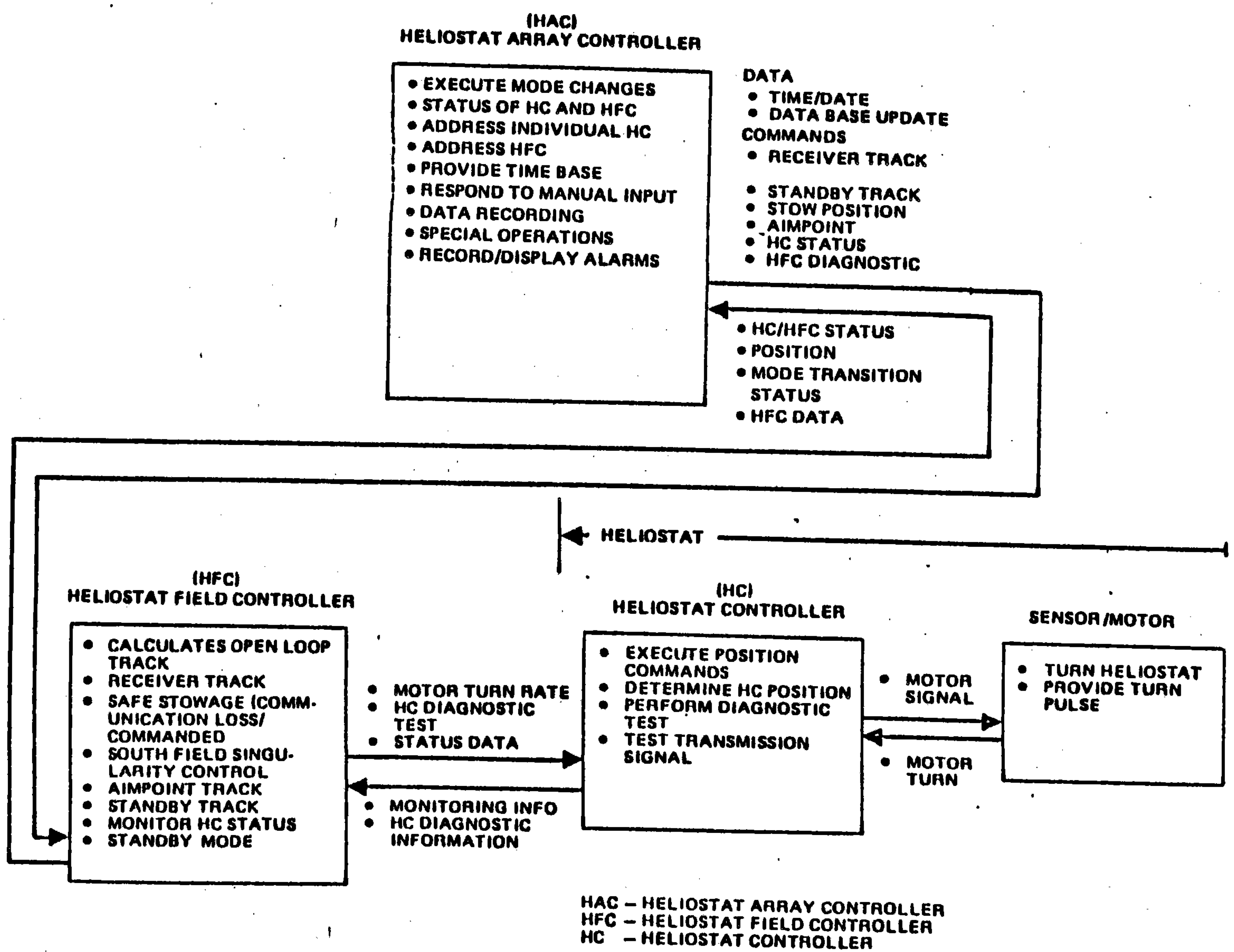


Figure 5.1-10. Collector Field Control Functions and Information Flow

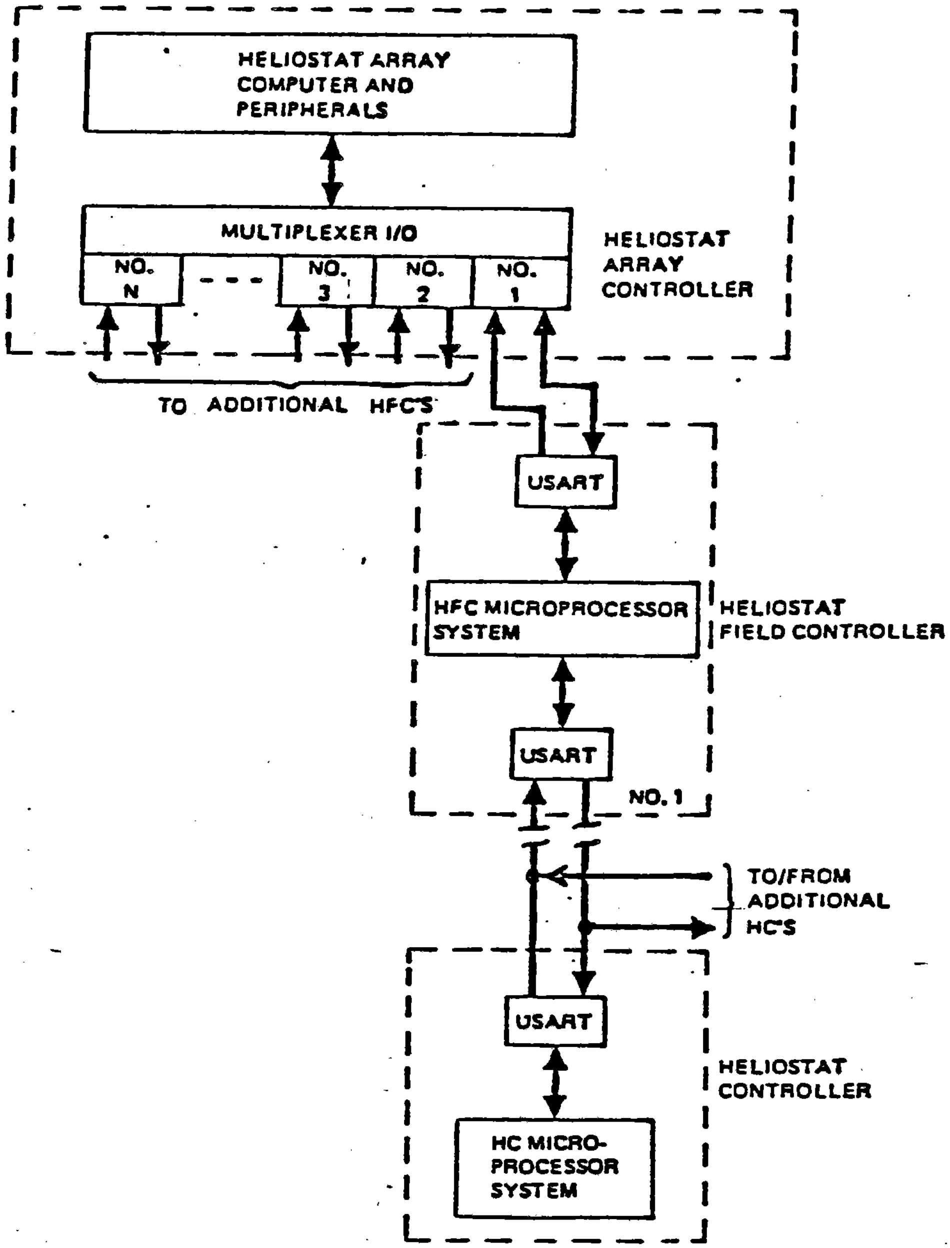


Figure 5.1-11. Collector Field Controller Interfaces

The field and equipment electrical interface requirements are summarized in Table 5.1-2.

The daily energy requirement for a typical day is shown in Figure 5.1-12. The peak power requirement occurs during emergency defocus and amounts to 870 KW at 1300 kVA. This is based on a maximum of 2600 heliostats slewing at once. If this field power is sized for this slew mode up to 1200 heliostats at a time can be operated in the stow mode.

5.1.3 Design Characteristics

5.1.3.1 Collector Field

The design characteristics are included in the field description in Section 5.1.1.1.

5.1.3.2 Heliostat

This study did not include any heliostat design effort. However, the most recent design characteristics available from the ongoing MDAC Second Generation heliostat project are shown in Table 5.1-3 for reference.

5.1.4 Operating Characteristics

5.1.4.1 Collector Field

In order for the field to operate in a controlled manner in any of the operating modes, a segmented field control approach has been devised such that control of the collector field will be by commands addressing groups of heliostats in one of the following groupings: (1) by a segmentation group (segment, wedge, ring) which is defined below; (2) by all the heliostats controlled by a single field controller (HFC); (3) by an individual heliostat; (4) by a contiguous group of heliostats on a radial arc; (5) by a number of heliostats within a segment. The segment scheme will be based on the simplified model shown here.

Table 5.1-2

COLLECTOR ELECTRICAL POWER INTERFACE REQUIREMENTS

FIELD

Heliostat

Tracking Mode (per heliostat)

Motors	2 watts	3 volt amps
Electronics	33 watts	69 volt amps
Total	35 watts	72 volt amps

Stow Mode (per heliostat)

Motors	624 watts	864 volt amps
Electronics	33 watts	69 volts amps
Total	657 watts	933 volt amps

Slew Mode (per heliostat)

Motors	302 watts	432 volt amps
Electronics	33 watts	69 volt amps
Total	335 watts	501 volt amps

Heliostat Field Controller

0.75 watts/heliostat	0.75 volt amp/heliostat

CONTROL ROOM

Heliostat Array Controller (Total Power)

800 watts + 1.2 watts/heliostat

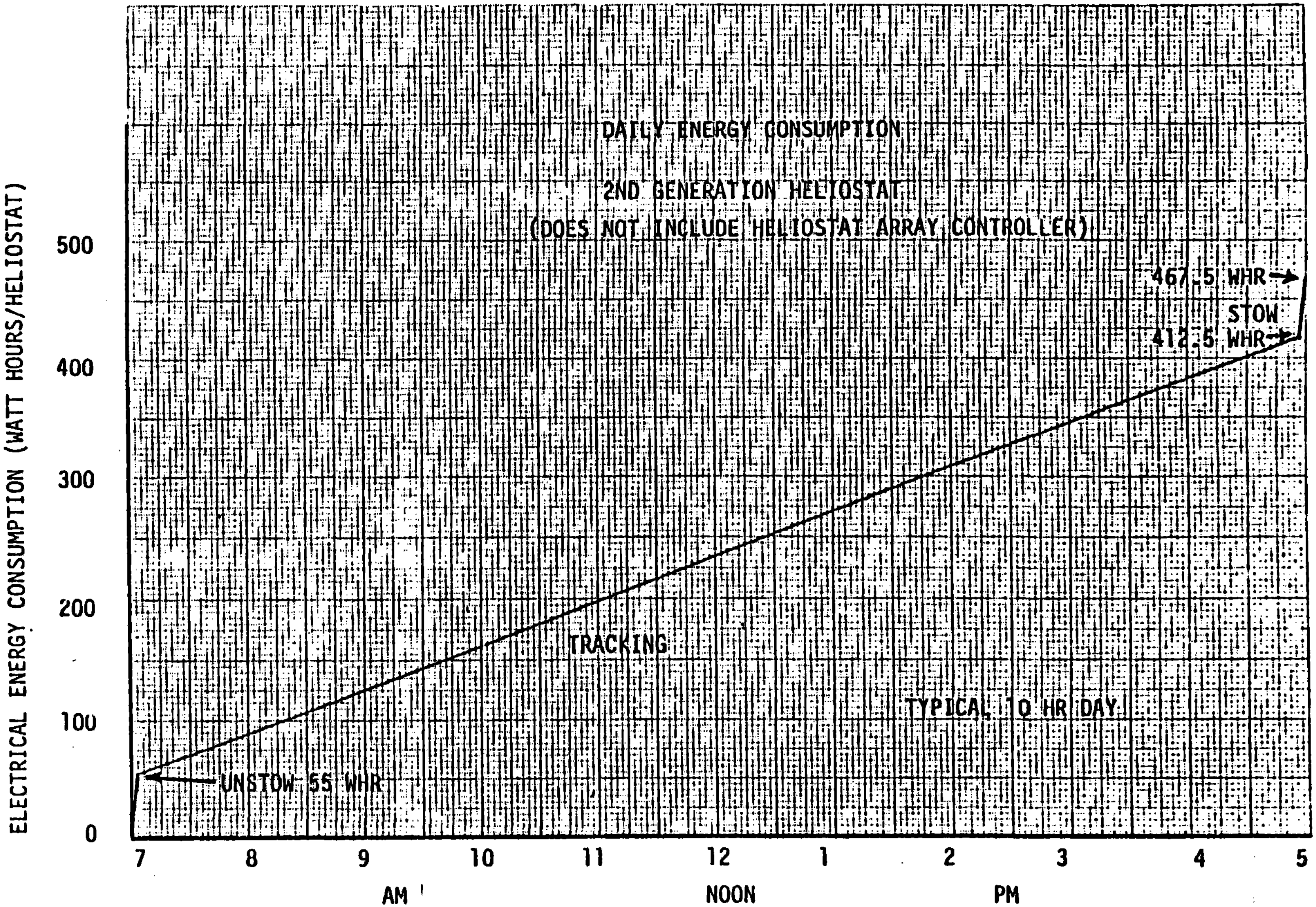

DAILY ENERGY CONSUMPTION
2ND GENERATION HELIOSTAT
(DOES NOT INCLUDE HELIOSTAT ARRAY CONTROLLER)
467.5 WHR
STOW
412.5 WHR
TRACKING
TYPICAL 10 HR DAY
UNSTOW 55 WHR
ELECTRICAL ENERGY CONSUMPTION (WATT HOURS/HELIOSTAT)
500
400
300
200
100
0
7
8
9
10
11
12
1
2
3
4
5
AM
NOON
PM

Table 5.1-3

CURRENT SECOND GENERATION BASELINE HELIOSTAT DESIGN CHARACTERISTICS

ASSEMBLY

- 56.42 m^2 (607 ft^2) reflective area - 14 - 1.23m x 3.36m (48 1/4" by 132 1/2") mirror modules
- Non-inverting - rotated design - A/R = 1.27
- Mirrors (hat sections) canted

MIRROR MODULE

- 1.22 m x 3.35 m (45" x 132") glass-cut - 2.36 mm (0.093") float mirrored - 4.76 mm (3/16") back lite
- PVB, pinched rolled-autoclaved to white backing paint
- Painted hat sections - bonded to primed back lite
- Galvanized edge member with butyl/silicone - baseline
  - Silicone grommet - silicone alternate
  - Butyl/silicone beads - smaller front lite - alternate

REFLECTOR SUPPORT STRUCTURE

- Thickness of beams (inboard and diagonal) increased to 12 gauge 2.66 mm (0.1046")
- Includes crossbracing

MAIN BEAM AND REFLECTOR ASSEMBLY

- Rectangular section main beam - 0.406 m x 0.483 m (16" x 19")
- Bolted joint 7-mirror modules per "wing"
- Painted main beam

PEDESTAL AND FOUNDATION

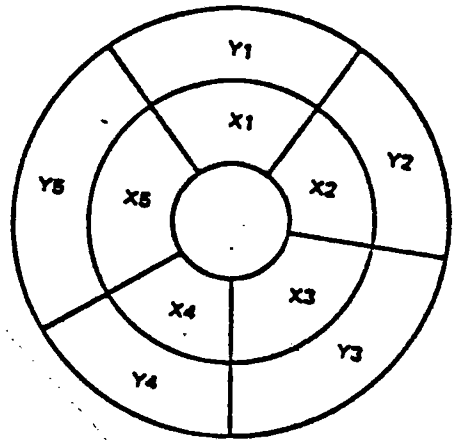
- Tapered pedestal - 0.508 m (20") OD tube - slip fit 1.22m (4') long flare
- Reinforced concrete pier - tapered cap
- Painted pedestal

Table 5.1-3

CURRENT SECOND GENERATION BASELINE HELIOSTAT DESIGN CHARACTERISTICS
(Continued)

DRIVE UNITS

- o Inverted harmonic drive - helicon gear input
- o Ball screw elevation jack with helicon input and improved rod bearing support
- o Improved pivot joints design
- o Simplified support structures - accommodates short jack and eliminates large plate
- o 250 w (1/4 hp) azimuth drive motor, 185 w (1/3 hp) elevation drive motor
- o Drives modified to accommodate reference switches
  - Azimuth - one on wave generator, one on output
  - Elevation - one jack helicon gear, one on gimbal (also serves limit switch for CRTF)



Each one of the numbered areas (X1, X2, Y1, etc.) in the diagram represent a contiguous group of heliostats called a segment. The field will be broken up into as many as 99 segments with each segment representing 10 to 50 heliostats. Segments will be grouped together to form two other control levels called rings and wedges. A ring in the diagram is a circle of segments (such as X1 through X5), and a wedge is all the segments between two radial lines (such as X1, Y1). There may be up to 9 rings and up to 30 wedges. This use of a segmentation scheme allows the HAC and/or the operator to control large areas of the field through a simple command interface.

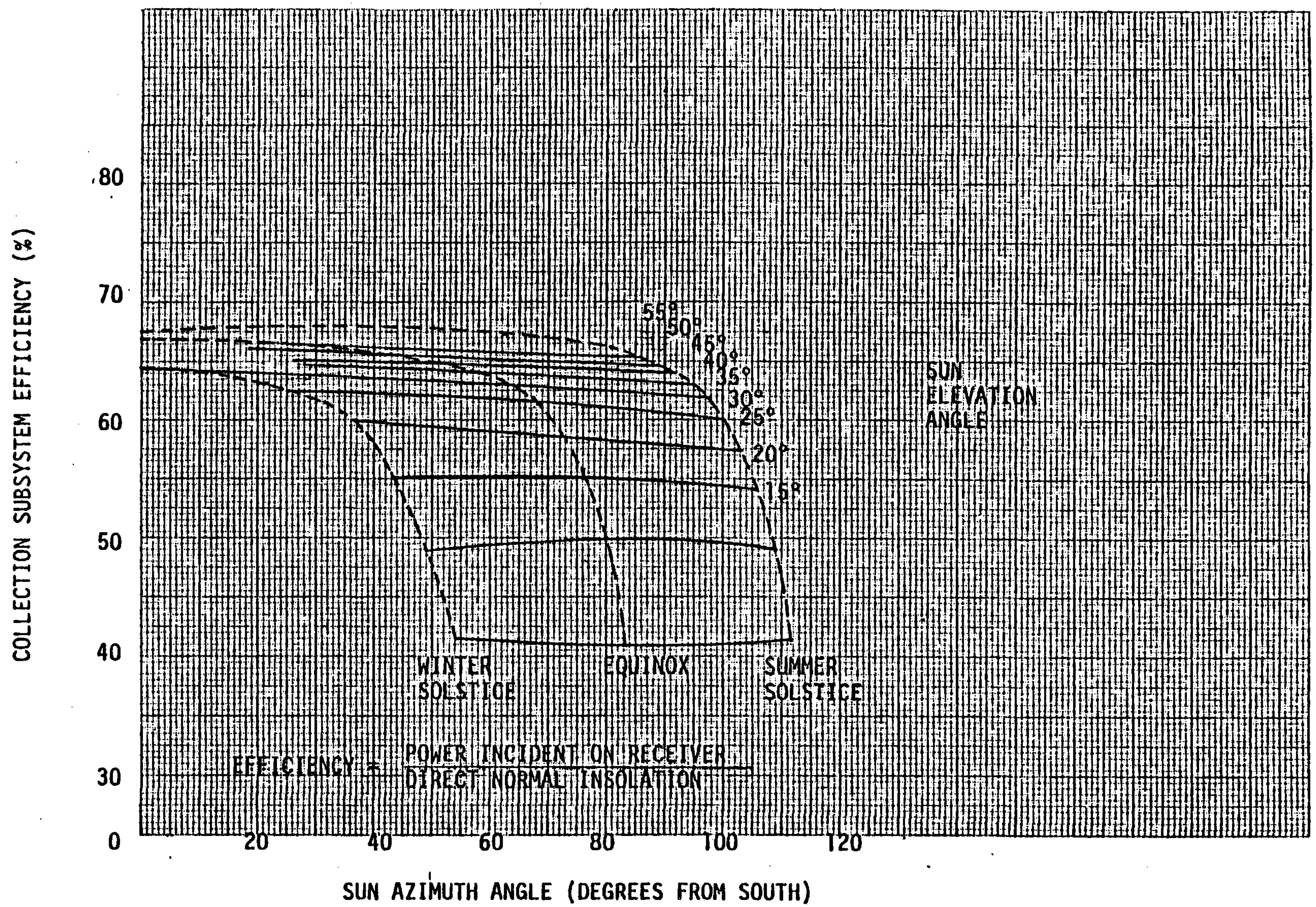
Control of the field will also be defined in terms of a number of heliostats from a segment (for incremental tracking control), all the heliostats on one HFC (such as would be used for testing or maintenance), an individual heliostat, or a group of contiguous heliostats on a radial arc (such as would be used for maintenance, washing, or beam characterization).

5.1.4.2 Heliostat

The operation characteristics of this heliostat are as defined in the SRS.

5.1.5 Performance Estimate

Performance estimates for the field were made using the University of Houston computer codes. The collector field efficiency as a function of sun position throughout the year is shown in Figure 5.1-13. These efficiencies are for



COLLECTION SUBSYSTEM EFFICIENCY (%)
80
70
60
50
40
30
0
20
40
60
80
100
120
SUN AZIMUTH ANGLE (DEGREES FROM SOUTH)
55°
50°
45°
40°
35°
30°
25°
20°
15°
SUN ELEVATION ANGLE
WINTER SOLSTICE
EQUINOX
SUMMER SOLSTICE
EFFICIENCY = POWER INCIDENT ON RECEIVER / DIRECT NORMAL INSOLATION

F 5.1-13.

the field only (as defined on the figure) and do not include the receiver losses. Figure 5.1-14 presents a "water fall" performance summary for the design point (spring equinox noon). All of the losses shown are standard loss factors and are self-explanatory, with the exception of the field geometry factor and heliostat availability. The field geometry factor is based on the observation, from past experience, that the field performance predicted by the idealized radial spacing layout model is slightly optimistic (high) when compared to the performance based on actual physical layout. This factor has been empirically determined to be approximately 0.97. The overall factor of 0.968 is the product of this 0.97 factor and a predicted heliostat availability factor of 0.998. The incident power shown is the product of total field reflective area (267,530 m^2 for the final field configuration) and the clear day direct normal insolation predicted by the University of Houston insolation model.

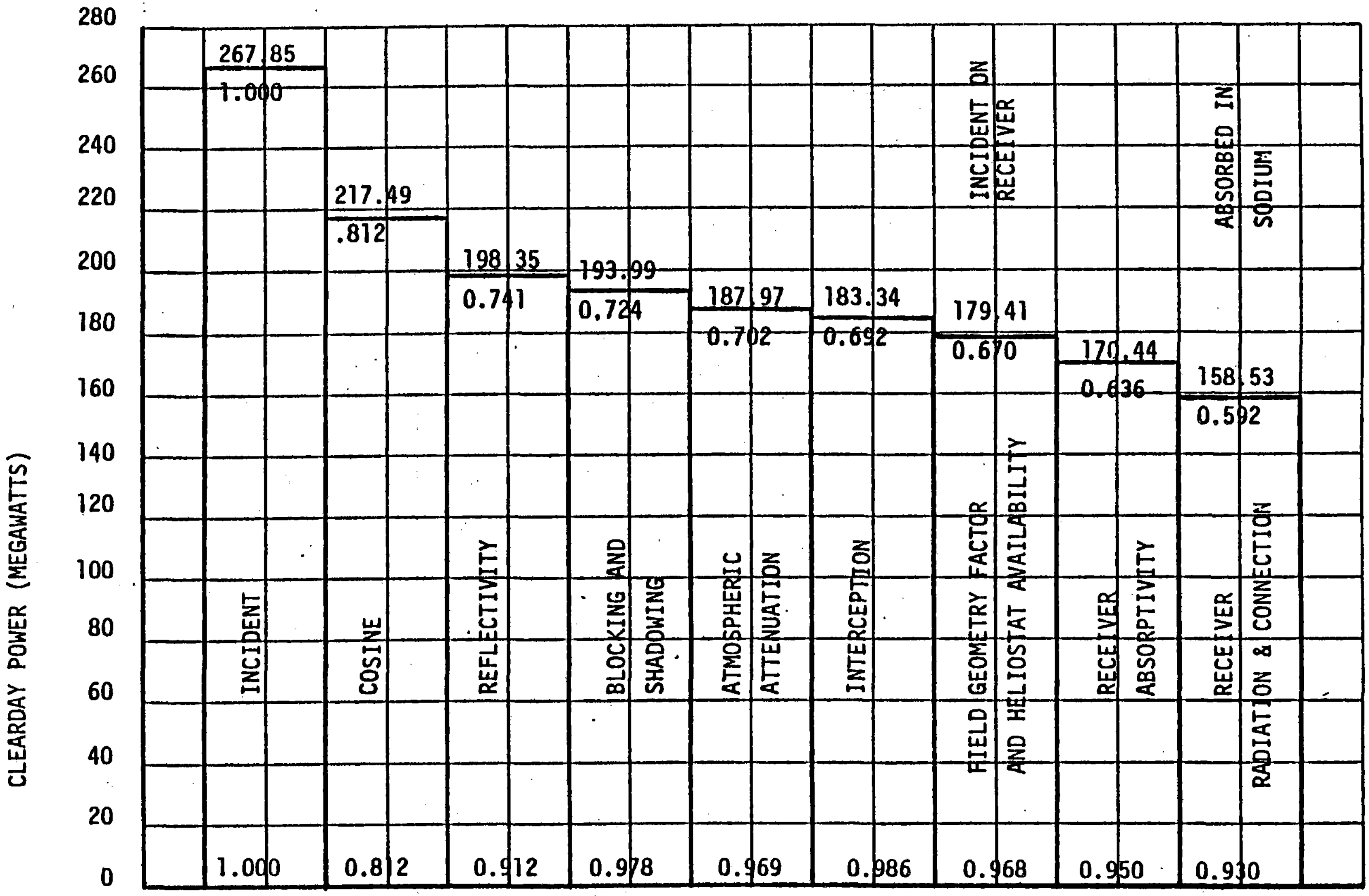
The performance of the system at noon on the other three seasons of the year are shown in Figures 5.1-15 through 5.1-17. The daily clear day performance (normalized to the noon spring equinox design point power) is shown for each of the seasons in Figure 5.1-18. The 10 degree sun acquisition angle is noted on the figure. The annual performance in terms of available and collected energy is shown in Figure 5.1-19. This performance includes the effects of weather as predicted by the insolation model. The total collected annual energy is predicted to be 355.5 GWHR absorbed into the sodium heat transfer medium.

5.1.6 Cost/Performance Tradeoffs

The cost performance trades done for the overall field were in the form of field optimizations which are reported ~~on elsewhere in~~ in section 3.1 of this report. There were no cost/performance trades made within this study for the heliostats. However, the results of such trades made in the MDAC Second Generation heliostat program havebeen incorporated in the baseline heliostat used in this study.

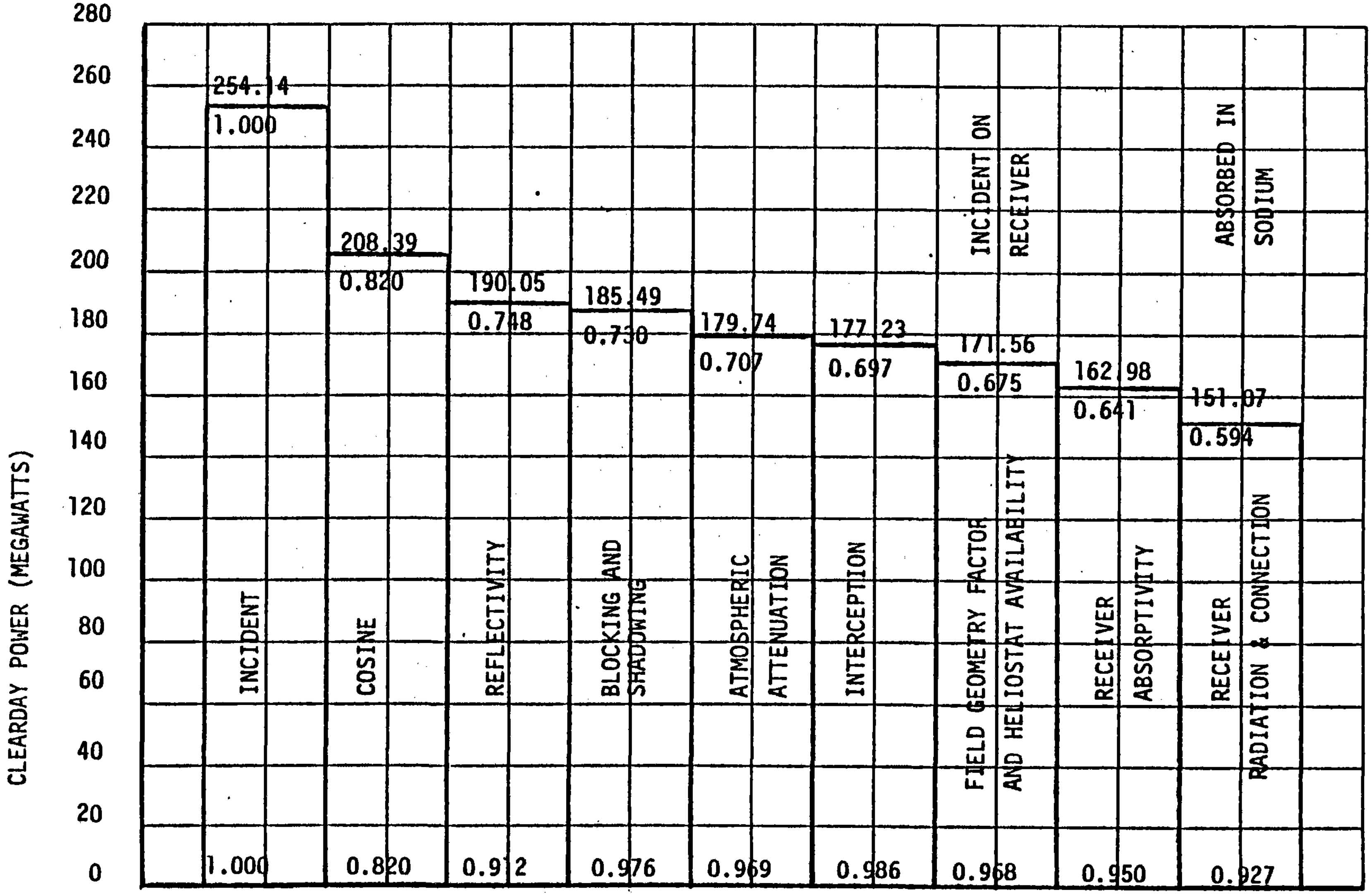
5.1.7 Top Level Cost Estimates

Top level cost estimates have been made for the heliostat system (account number 5300) and that portion of the master control system (account number 5500) that applies to the field control. Two sets of cost estimates were made for each



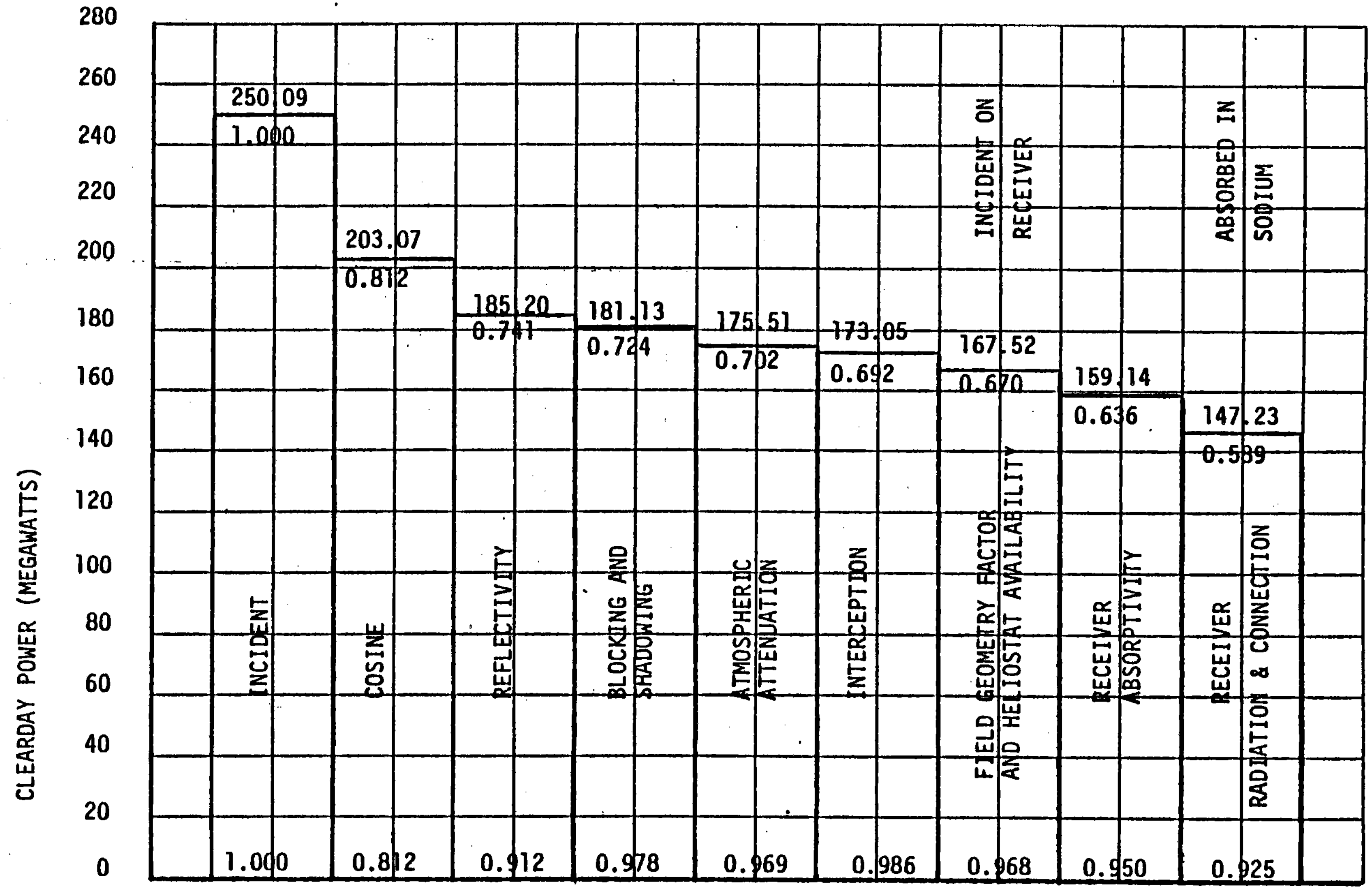
TEXAS ELECTRIC SERVICE CO. FIELD PERFORMANCE SPRING EQUINOX NOON

P 5.1-14



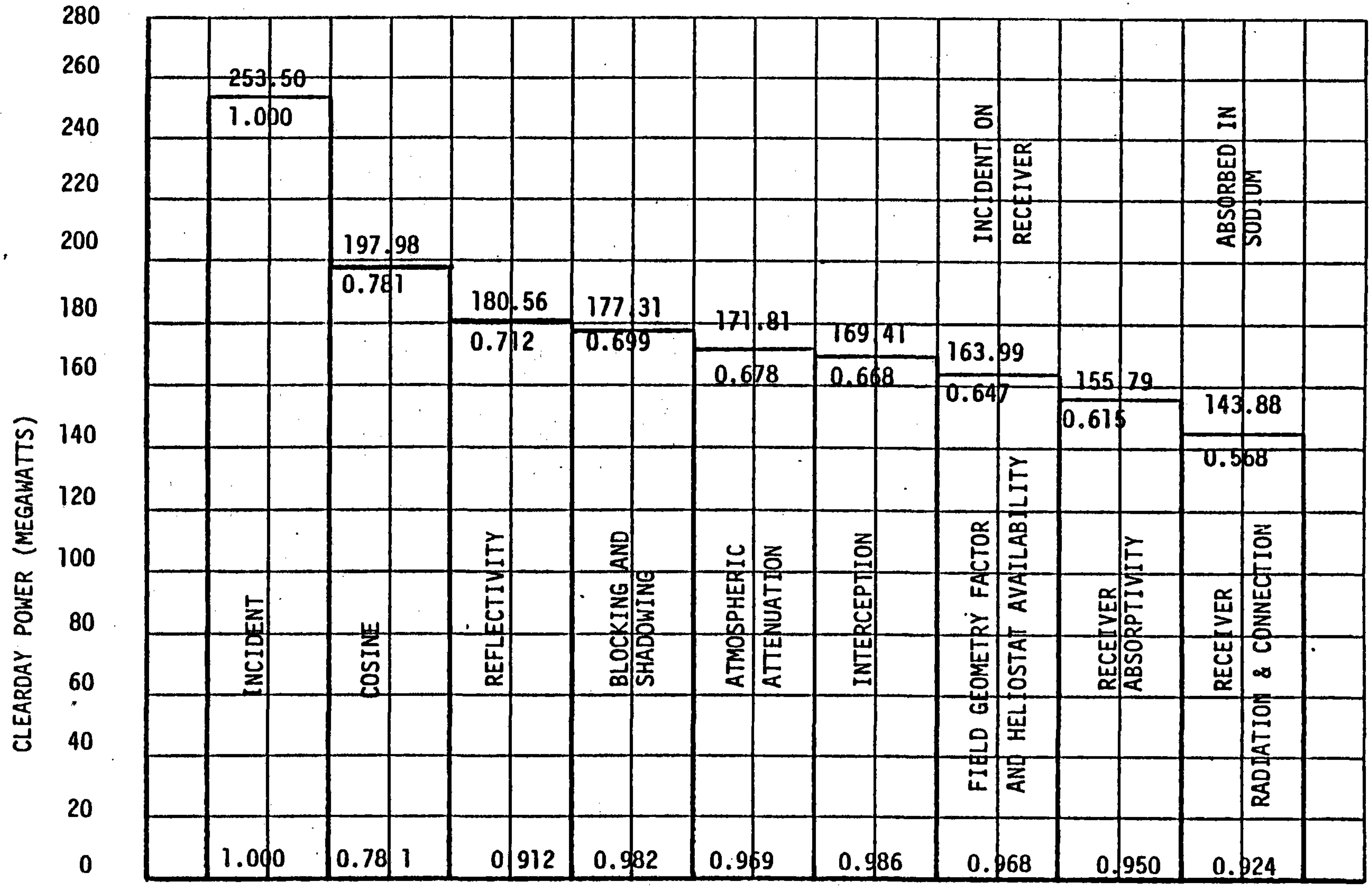
TEXAS ELECTRIC SERVICE CO. FIELD PERFORMANCE SUMMER SOLSTICE NOON

P5.1-15



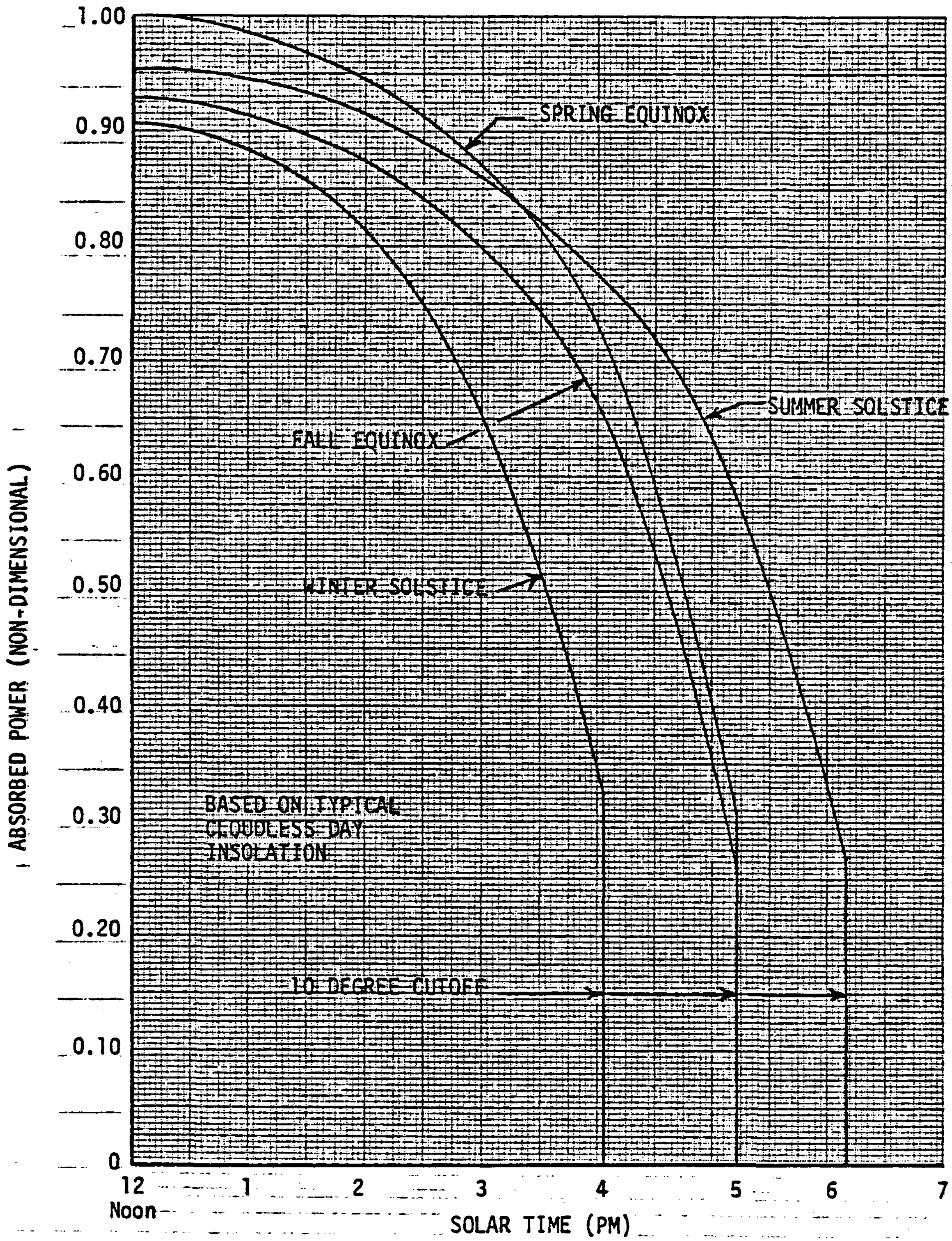
TEXAS ELECTRIC SERVICE CO. FIELD PERFORMANCE FALL EQUINOX NOON

F5.1-16



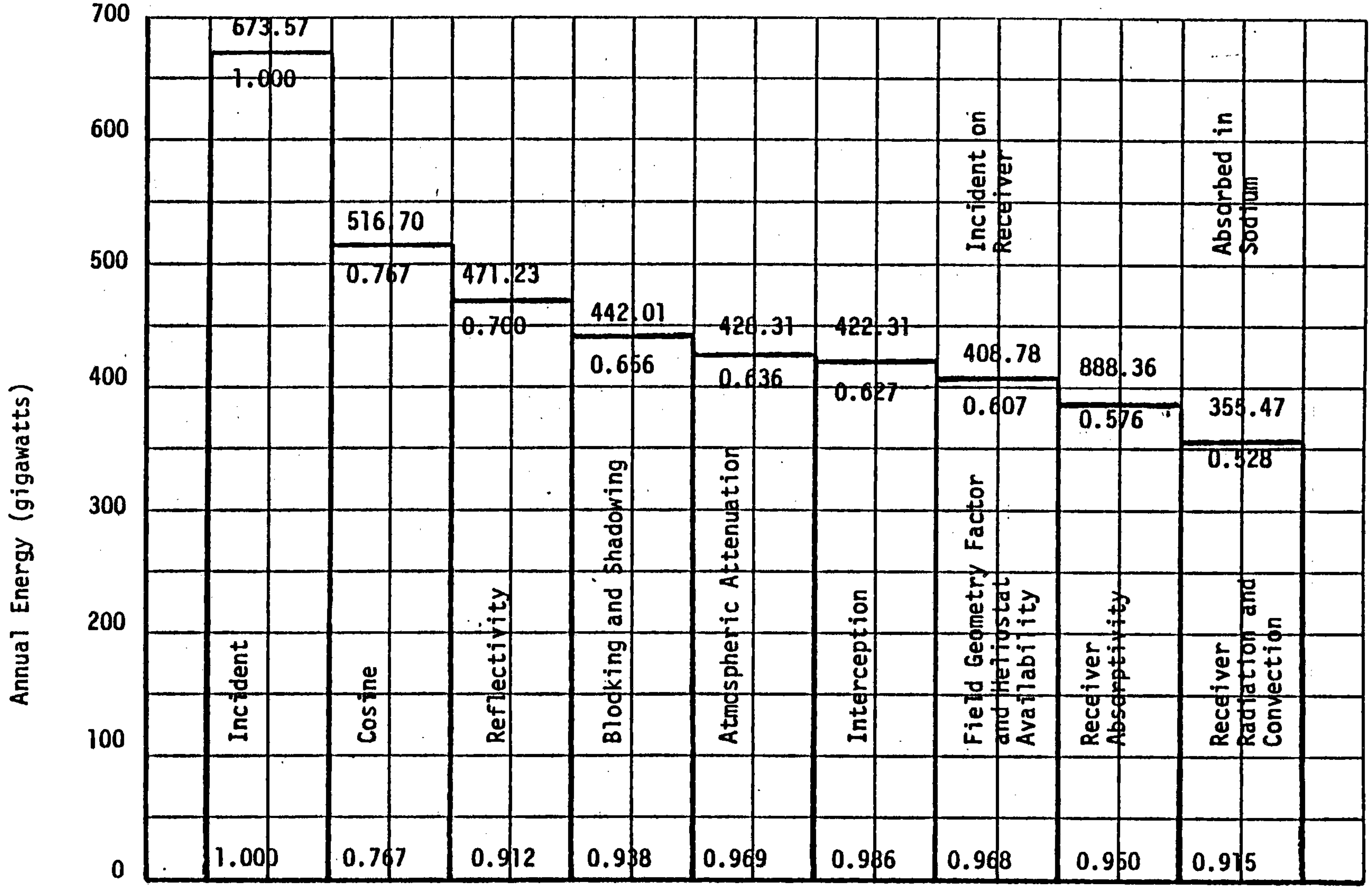
TEXAS ELECTRIC SERVICE CO. FIELD PERFORMANCE WINTER SOLSTICE NOON

F5.1-17



SOLAR SYSTEM PERFORMANCE TEXAS ELECTRIC SERVICE COMPANY

F5.1-18



Texas Electric Service Co. Annual Field Performance (Includes Cloud Cover)

F5.1-19

account based on two different heliostat procurement scenarios. The "first and only" costs were based on the assumption that this procurement is a first of a kind and includes a portion of the factory startup costs and tooling development required to start manufacture of the heliostats. The second or "baseline" case assumes the existence of a manufacturing facility and that this procurement is a follow-on order to an ongoing heliostat production. Top level cost breakdowns for both scenarios and the two account numbers are given in Tables 5.1-5 through 5.1-8.

T 5.1 - 5

CONSTRUCTION COST ESTIMATE

✓

CLIENT ______

LOCATION ______

PROJECT Texas Electric (LI)

DESCRIPTION First & Only
5300 Collector

CONT. NO. ______

MADE BY ______

APPROVED ______

A/C NO.	ITEM & DESCRIPTION	MAN HOURS	ESTIMATED COST LABOR	SUBCONTRACTS	MATERIALS	TOTALS
A	Excavation & Civil	10.3K	168			168
B	Concrete	26.9K	439		1238	1677
C	Structural Steel					
D	Buildings					
E	Machinery & Equipment	66.2K	1075		79,324	80,399
F	Piping					
G	Electrical	128.2K	2092		2869	4961
H	Instruments	.2K	2		11	13
J	Painting					
K	Insulation					
	DIRECT FIELD COSTS					87218
L	Temporary Construction Facilities					
M	Construction Services, Supplies & Expense					
N	Field Staff, Subsistence & Expense					
P	Craft Benefits, Payroll Burdens & Insurances					
Q	Equipment Rental					
	INDIRECT FIELD COSTS		3210		1003	4213
	TOTAL FIELD COSTS					91,431
R	Engineering					1516
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Major Equipment Procurement				-	294
T	Construction Management					
	TOTAL OFFICE COSTS					1810
	TOTAL FIELD & OFFICE COSTS					93241
U	Labor Productivity					2306
V	Contingency					
W	Fee					
	TOTAL CONSTRUCTION COST					95,547

DATE ______ REVISION NO. ______ REVISION DATE ______ PAGE NO. ______

T5-1-7

CONSTRUCTION COST ESTIMATE

CLIENT ____________

LOCATION ____________

PROJECT Texas Electric (AI)

DESCRIPTION Shared Baseline
5300 Collector

CONT. NO. ____________

MADE BY ____________

APPROVED ____________

A/C NO.	ITEM & DESCRIPTION	MAN HOURS	ESTIMATED COST: LABOR	SUBCONTRACTS	MATERIALS	TOTALS
A	Excavation & Civil	10,300	168			168
B	Concrete	26,900	439		1238	1,677
C	Structural Steel					
D	Buildings					
E	Machinery & Equipment	56,200	946		56,017	56,963
F	Piping					
G	Electrical	60,600	989		2,840	3,829
H	Instruments	200	2		11	13
J	Painting					
K	Insulation					
	DIRECT FIELD COSTS					62,650
L	Temporary Construction Facilities					
M	Construction Services, Supplies & Expense					
N	Field Staff, Subsistence & Expense					
P	Craft Benefits, Payroll Burdens & Insurances					
Q	Equipment Rental					
	INDIRECT FIELD COSTS					3,538
	TOTAL FIELD COSTS					66,188
R	Engineering					1,440
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Major Equipment Procurement					294
T	Construction Management					—
	TOTAL OFFICE COSTS					1,734
	TOTAL FIELD & OFFICE COSTS					67,922
U	Labor Productivity					1552
V	Contingency					
W	Fee					
	TOTAL CONSTRUCTION COST					69,474

DATE ____________ REVISION NO. ____________ REVISION DATE ____________ PAGE NO. ____________

5.2 RECEIVER SUBSYSTEM

The receiver subsystem contains the receiver, receiver tower, receiver pump, steam generator units, and the main sodium piping including the tower riser and downcomer, drag valve, and the field feed and return lines. The receiver subsystem also includes auxiliary sodium and cover gas handling equipment, sodium/water reaction safety equipment, and receiver passive protection and hydraulic surge tanks.

5.2.1 Description

The receiver subsystem can be considered to operate as two independent loops. A simplified receiver subsystem flow diagram is shown in Figure 5.2-1. The first loop transfers sodium from the cold storage tank, T-1, at 288°C (550°F) through field supply piping, tower riser, and the receiver, which heats it to 593°C (1100°F). The sodium then flows by gravity through downcomer, drag valve, and field return piping to the hot storage tank, T-2. Nominal maximum flow rates are about 0.5 m^3/s (7,400 gpm). The second loop transports sodium from the hot storage tank through the sodium-heated superheater and reheater, through the evaporator, and then to the cold storage tank, T-1. The maximum nominal flow is about 0.4 m^3/s (6,400 gpm).

Provided there is some reserve in Tank T-1, the first loop operates to transfer all of the energy received by the receiver to storage independent of the steam generator power requirements. As the insolation varies, the flow is modulated to maintain a constant receiver outlet temperature. The second system, after some storage accumulation in Tank T-2, operates independently of the insolation. The storage tank, being in series in the loop, functions as thermal inertia and thermal capacitance, thus protecting the pumps and the steam generating equipment from thermal shocks from the sodium. The independence of the second loop permits level loading the power output which minimizes thermal cycling of the steam generators. The stored energy accumulates or is drawn upon automatically since it is simply the difference between the inflow and outflow of Tank T-1.

P-1	T-1 T-2	P-2	X-1	X-2	X-3
TDH = 185 (607	D = 18.3 (60)	TDH = 52 (170)	T = 468 (874)	593 (1100	593 (1100)
F = 0.46 (7.3)	H = 8.5 (28)	F = 0.4 (6.4	P = 15.2 (2200)	15.2 (2200)	3.10 (450)
J = 1.06 (1.45	V = 2.5 (.66)	J = .17 (.22	J = 74.1	35.7	16.2

TDH – m (ft)
P – MN/m² (psi)
H – m (ft)
D – m (ft)
V – 10³m³ (10⁶ gal.)
S – gpm
S – sec

~~Σ – SIGNAL SUMMER~~
~~FFIC – RATIO FLOW CONTROL~~
~~SP – SETPOINT STATION~~
~~I – INDICATOR~~
~~C – CONTROL~~
T = TEMPERATURE °C (°F)
F = FLOW m³/s (10³ g)
~~S – SPEED (rpm)~~
J = POWER MW (10³ hp)
~~L – LEVEL~~

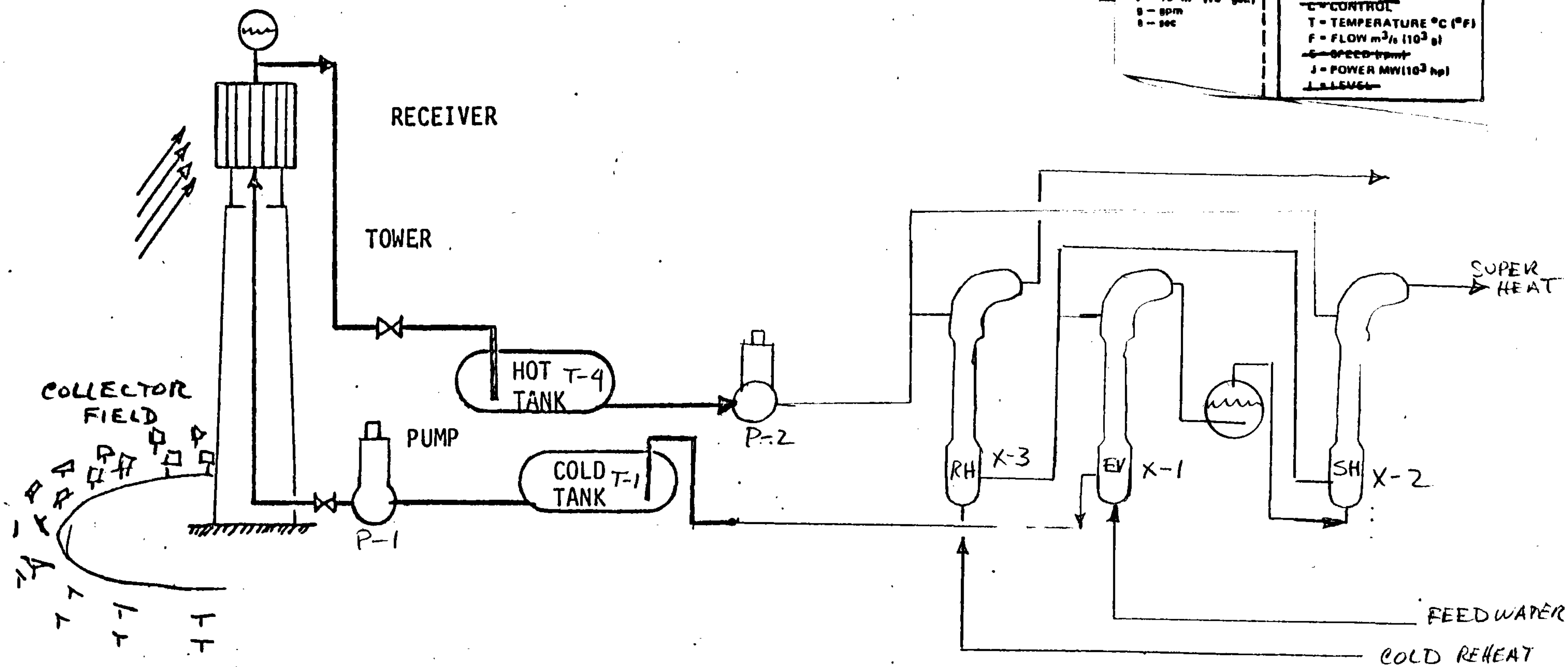


Figure 5.2-1. Receiver subsystem simplified flow diagram

Sodium circulation is provided by means of the P-1 and P-2 pumps. These are free surface "Fermi" type pump centrifugal pumps. The P-1 pump is a high-head (~185 m (607 ft) TDF) two-speed (full speed and 25% speed), single-stage centrifugal pump located adjacent to the cold tank outlet outside the storage subsystem berm.

The P-2 pump, a part of the storage subsystem, is a variable speed, single-stage pump of the same type as the P-1 pump. The speed control is a modified Kramer system which operates as a straight induction motor at full speed.

Sodium flow through the receiver is modulated by the control valves on each panel to maintain constant panel outlet temperature. A receiver outlet surge tank permits these fast-acting valves to operate independently of the drag valve. The drag valve reduces the sodium pressure to near atmospheric pressure plus the return line pressure drop to match the pressure requirements of the storage tank. The flow in the downcomer line is modulated to maintain the sodium level in the surge tank fixed. A detailed description of the sodium pumps, and drag valve is contained in Section 5.2.3.

The sodium flow in the steam generator loop is set by power requirements determined by the solar master element of the master control subsystem (see Section 5.3). It is planned to operate this system in a fossil or solar load following mode at various fixed power levels as required for the maximum utilization of the plant. The variable speed drive on the P-2 pump has a 10:1 turndown ratio which provides base flow settings. Trim control is provided by control valves in the supply and return lines of the steam generating modules.

The passive control system, riser check valve, and the surge tank operate to prevent the draining of the sodium from the receiver on loss of pump power. The check valve also presents backflow in this event which would draw hot sodium into the cold header and riser.

The receiver consists of an external cylindrical surface composed of 18 panels of 96 1.91 cm (0.64 in.) type 304 stainless steel tubes each. The active height of the receiver surface is 13.5 m (44.25 ft), the receiver diameter is 10.6 m

(34.75 ft). The difference between the 10.6 m actual diameter and the 10.4 m diameter by the results of the receiver/collector optimization is due to rounding upward when selecting the number of tubes per panel and the tolerance buildup between tubes required to accommodate circumferencial thermal expansion of the receiver. The optical elevation of the receiver centerline is 120 m (393.6 ft) above the heliostat centerline elevation. Each of the panel tubes is connected to panel inlet and outlet manifolds 15.23 cm (6 in.) carbon steel inlet on stainless outlet lines to each panel provide manifold sodium field and return. Each panel feed line contains an individually modulated panel control valve. A passive receiver protection system, consisting of a cover gas pressurized sodium accumulator tank "riding" on the panel feed line distribution manifold, is incorporated into the receiver design. The previously mentioned surge tank is not pressurized and "rides" on the panel outlet return line manifold. A 5-ton maintenance hoist is located above the surge tank to facilitate panel installation and replacement.

The receiver is located atop a 110.5 m (362.4 ft) structural steel tower in the center of the collector field. A tower interface structure, enclosing the panel supply manifolds, feed lines and control valves, is located between the bottom of the receiver and the top of the tower. This modified conic section steel structure transitions from the 7.3 m (24 ft) square tower top cross-section to the 11 m (36.1 ft) circular diameter of the receiver bottom and is approximately 6.75 m (22.1 ft) tall. A drawing showing the various receiver components and their locations is shown in Figure 5.2-2.

Sodium is supplied to the receiver by a 40.6 cm (16 in.) carbon steel riser supported from the tower steel sections. The riser includes dog-legs to accommodate thermal expansion and a check valve to prevent sodium backflow. Hot sodium is carried away from the receiver by a 40.6 cm (16 in.) 304 stainless steel downcomer line. The downcomer also contains thermal expansion loops. At the base of the tower, a 40.6 cm (16 in.) drag valve in the downcomer absorbs approximately 1/3 of the tower static head. The remaining tower static head is sufficient to push the heated sodium through the 40.6 cm (16 in.) stainless steel return line. The drag valve pressure drop is adjusted such that the surge tank level and hot tank pressures are always maintained.

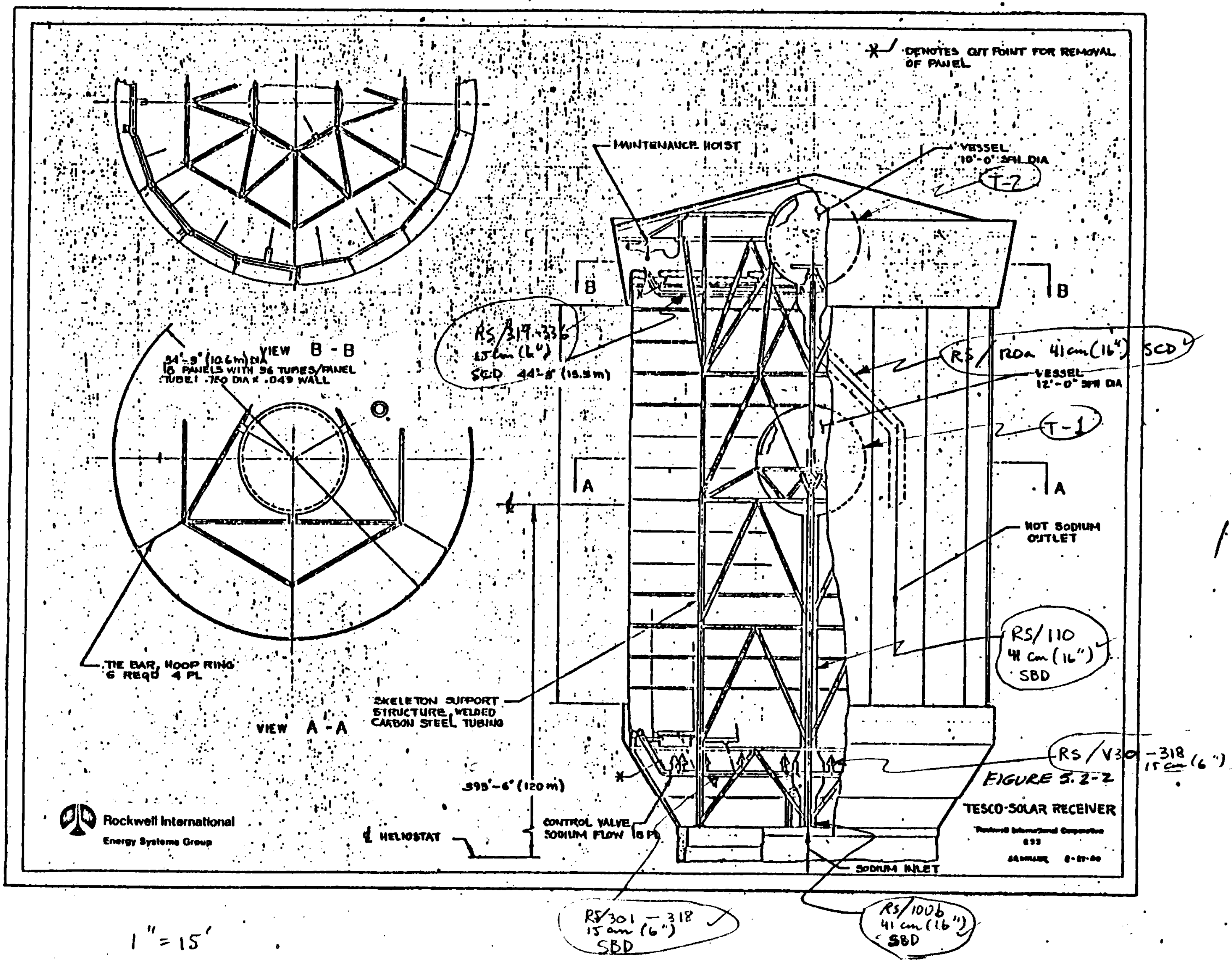


FIGURE 5.2-2

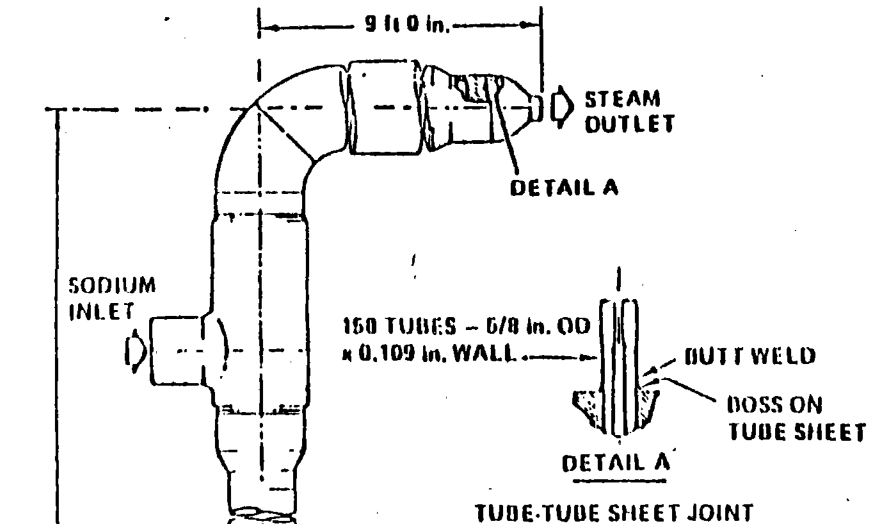
TESCO-SOLAR RECEIVER

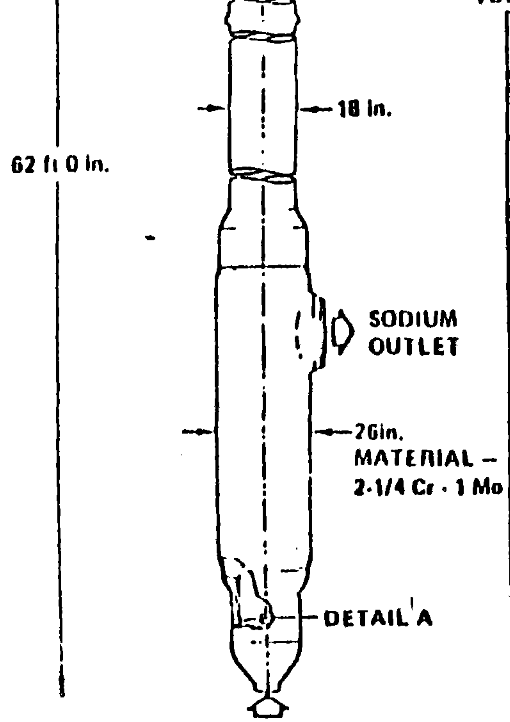
Rockwell International
Energy Systems Group

The tower riser is fed by a 40.6 cm (16 in.) carbon steel sodium line originating at the receiver pump discharge and terminating at the base of the tower at the riser check valve. The 40.6 cm (16 in.) 304 stainless steel field return line orginates at the base of the tower downstream of the drag valve and terminated at the hot tank inlet. Both feed and return lines accommodate thermal expansion through expansion loops and are elevated 6.1 meters (20 ft) to facilitate collection field access and to restrict personnel access to the hot pipes. The layout of the field piping collector field and tower is shown in Figure 4.6-2.

The sodium steam generators consist of an evaporator, superheater, reheater, and steam drum. A flow diagram is shown in Figure ____ of Section 4.5 for the condition of 126.3 MWt or 50 MWe for solar. The operating conditions are for maximum turbine load of 115 MWe requiring 100^{o}F main steam at 1525 psi at the superheater exit. The fossil boiler provides the remaining 65 MWe. Hot sodium from the Energy Storage Subsystem flow in parallel through the shell side of the hockeystick-type reheater and superheater before flowing through the evaporator shell and returning to the Energy Storage Subsystem. Water and steam flow through the tube side. A steam drum between the evaporator and superheater allows for water/steam separation. A blowdown of 0 to 5% is planned. The steam drum also allows for recirculation which will be used only in startup and shutdown to ensure stable flow conditions during low-flow operation.

The units to be used for the sodium steam generators are single-pass shell and tube-type heat exchangers. They are to be of hockeystock design similar to the 30 MWt modular steam generator (MSG) as shown in Figure 5.2-3. An extensive Rockwell International-funded program was conducted, covering the design, analysis, and fabrication of the MSG test unit. Test monitoring and evaluation, plus post-test examinations, was also performed on this program. The testing was funded by the Department of Energy, then Energy Research and Development Administration (ERDA), and was accomplished at the Energy Technology engineering Center (ETEC)/Sodium Component Test Installation (SCTI) Facility where various tests, including over 9,000 hr of sodium operation, were run. This company-funded effort, spanning more than 8 yr, has formed the basis for the design and fabrication of the Energy Systems Group (ESG) steam generator module for the Clinch River Breeder Reactor Program (CRBRP). A summary of the test results for the MSG is given in Figure 5.2-3.





• FIRST STEAM PRODUCED	7-9-72
• PERFORMANCE	
▪ DESIGN POWER	28.4 Mwt
▪ MAXIMUM POWER AT 100% FLOW	32.1 Mwt (FOR 2400 psig STEAM)
	33.8 Mwt (FOR 1450 psig STEAM)
▪ MAXIMUM STEAM CONDITIONS	2430 psig/930°F
• TEST RESULTS	
▪ TOTAL (MAIN LINE) STEAMING TIME	4015 hr
▪ TOTAL SODIUM OPERATING TIME	9305 hr
▪ VIBRATION	LEVELS LOW, SAFE
▪ STARTUP/SHUTDOWN	37 CYCLES, STABLE
▪ HEAT TRANSFER PERFORMANCE	PARAMETRIC DATA OBTAINED FROM 1450 TO 2450 psig
▪ ENDURANCE	
▲ COMBINED EVAPORATOR/SUPERHEATER MODE	500 hr
▲ EVAPORATOR MODE	500 hr
▪ LOW FLOW STABILITY	STABLE, ALL CONDITIONS OF INTEREST
▪ LEAK DETECTION	DETECTABILITY OF 10^{-6} lb/sec H_2O DEMONSTRATION
▪ TRANSIENTS	INTEGRITY MAINTAINED

Figure 3-~~42~~2. Highlights of LMEC/SCTI Test of MSG

One of the principal advantages of the sodium system with an energy storage subsystem is that the steam generators do not directly interface with the receiver. With the energy storage subsystem acting as a buffer, the steam generators will see a uniform sodium inlet temperature unaffected by receiver transients. This allows the production of consistent steam quality (reheat and main steam) which is so important to turbine efficiency and life analysis.

5.2.2 Functional Requirements

The receiver subsystem functional requirements are summarized in Table 5.2-1. These requirements are derived from the optimized performance characteristics of the EPGS, collector, and master control subsystem, which in turn satisfy the requirements of the system requirement specification of Appendix A. There are additional operational and sodium system requirements as follows:

1) Transport up to 128 MWt to the steam generator. Transport up to 160 MWt to storage or 32 MWt to storage and 128 MWt to the steam generator simultaneously, or 128 MWt from storage to the steam generator.
2) Provide the control of the receiver outlet sodium temperature and the evaporator temperature.
3) Provide for anti-siphoning of the receiver sodium.
4) Provide protection against reverse flow through the receiver.
5) Provide for purging and filling and draining the system sodium for maintenance.
6) Provide for draining the receiver on a daily basis.
7) Provide for maintaining the purity of the sodium below 2.0 ppm O_2 and 1 ppm H_2.

The receiver system interface requirements are illustrated geographically in Figures 4.6-1 and 4.6-2 and functionally in Figure 4.6-3. A summary of the major interfaces is listed in Table 5.2-2. A complete Receiver Subsystem Interface control document will be generated as part of the preliminary design phase.

TABLE 5.2-1

RECEIVER SUBSYSTEM FUNCTIONAL REQUIREMENTS

Solar Multiple	1.23	
Parameter	**Requirement**	
Nominal Thermal Power (MWt)		128
Maximum Thermal Power (MWt)		160
Receiver Mid-Point Elevation, m (ft)	124	(407)
Water/Steam Side		
Feedwater Temperature, In °C (°F)	193	(380)
Evaporator Temperature, Out °C (°F)	310	(590)
Steam Temperature, Out °C (°F)	541	(1005)
Reheat Temperature		
In °C (°F)	260	(500)
Out °C (°F)	541	(500)
Reduced Power Operation, %	10	— 100

	Receiver Requirements	
Configuration	External	
Receiver Fluid	Sodium	
Receiver Inlet Temperature °C (°F)	288	(550)
Receiver Outlet Temperature °C (°F)	593	(1100)
Lifetime (yr)	25	
Maximum Temperature °C (°F)	608	(1126)
Startup Sodium Temperature, °C (°F)	150	(302
Maximu Sodium Flow kg/h (lb/hr)	1.47×10^6	(3.24×10^6)
Receiver Flux Limit (MWt/M^2)	1.5	
Thermal Control	Nighttime Drain	

TABLE 5.2-2
RECEIVER SUBSYSTEM INTERFACES

Nomenclature	Location	Subsystem	Description
RS/SS1	Receiver pump suction isolation valve inlet	Storage	288°C sodium inflow
RS/SS2	Hot tank sodium inlet	Storage	593°C sodium outflow
RS/MCS 1	Drag valve control wiring	Master control	Drag valve position set point
RS/MCS 2A-R	Panel outlet temperature transmitter wiring	Master control	Sodium outlet temperature signals
RS/MCS 3A-R	Panel control valve position signal wiring	Master control	Control valve position signal
RS/MCS 4A-R	Panel control valve override signal wiring	Master control	Control valve demand override signal
RS/MCS 5	Surge tank level transmitter wiring	Master control	Surge tank level signal
RS/MCS 6	Riser flow transmitter wiring	Master control	Flow signal
RS/MCS 7	Receiver pump speed transmitter wiring	Master control	Speed signal
RS/SS3	Evaporator outlet isolation valve	Storage	288°C sodium outflow
RS/SS4	Steam generator pump discharge	Storage	593°C sodium inflow
RS/EPGS 1	Reheater steam outlet	EPGS	Hot reheat steam outflow
RS/EPGS 2	Reheater steam inlet	EPGS	Cold reheat steam inflow
RS/MCS 8	Reheater sodium flow transmitter wiring	Master control	Reheater sodium flow signal

TABLE 5.2-2

RECEIVER SUBSYSTEM INTERFACES
(Continued)

Nomenclature	Location	Subsystem	Description
RS/MCS 9	Reheater flow controller wiring	Master control	Reheater sodium flow control signal
RS/EPGS 3	Superheater steam outlet	EPGS	541^{o}F steam outflow
RS/EPGS 4	Superheater attemporator T	EPGS	Saturated steam outflow
RS/MCS 10	Superheat sodium flow transmitter wiring	Master control	Superheater sodium flow
RS/MCS 11	Superheat flow controller wiring	Master control	Superheater sodium flow control signal
RS/EPGS 5	Steam separator level transmitter wiring	EPGS	Steam separator level signal
RS/EPGS 6	Steam separator blowdown port	EPGS	Saturated water outflow
RS/EPGS 7	Evaporator feedwater nozzle	EPGS	Feedwater inflow

The sodium steam generators, consisting of an evaporator, superheater, and reheater, are required to transfer the thermal energy stored in the sodium to the water/steam system supplying steam to the turbine. The steam generators are to be sized for providing 50 MWe. The steam conditions and turbine efficiencies are different for the hybrid mode (50 MWe solar/65 MWe fossil) and the solar-only mode (50 MWe solar/ 0 MWe fossil). This results in two full-load operating conditions for the steam generators which are given in Figure ___ and in Section 4.5. Figures 5.2-4 and 5.2-5 show the steam generator heat balance for the hybrid and solar-only mode, respectively. Th

The functional requirements for the steam generators are:

- Sized to provide 50 MWe which is equivalent to 123.6 MWt during combined operation and 126.3 MWt during solar-only operation
- Stable operation over a range of powers of 5 to 50 MWe during combined operation and 23 to 50 MWe during solar only.
- Low flow stability during startup and shutdown
- Capability of repairing or plugging tube leaks
- Maintain integrity during thermal transients
- Design temperatures for the evaporator is (482°C) 900°F and (593°C) 1100°F for the superheater and reheater

5.2.3 Design Characteristics

The detailed design characteristics of the receiver subsystem are contained in the design data sheets, Appendix B of this document. A summary of these characteristics are located in Table 4.3-1.

The receiver-type selected for solar repowering Permain Basin Unit 5 is an external circular configuration. Previous studies carried out during the Advanced Central Receiver (ACR) program, comparing cavity and external receivers, showed the latter to be cost effective with respect to capital and busbar energy costs.

The design of the receiver surface, its support structure, feed and return plumbing, control methodology, passive potection system and overall configuration

TESCO Combined Operation
(Case 13)

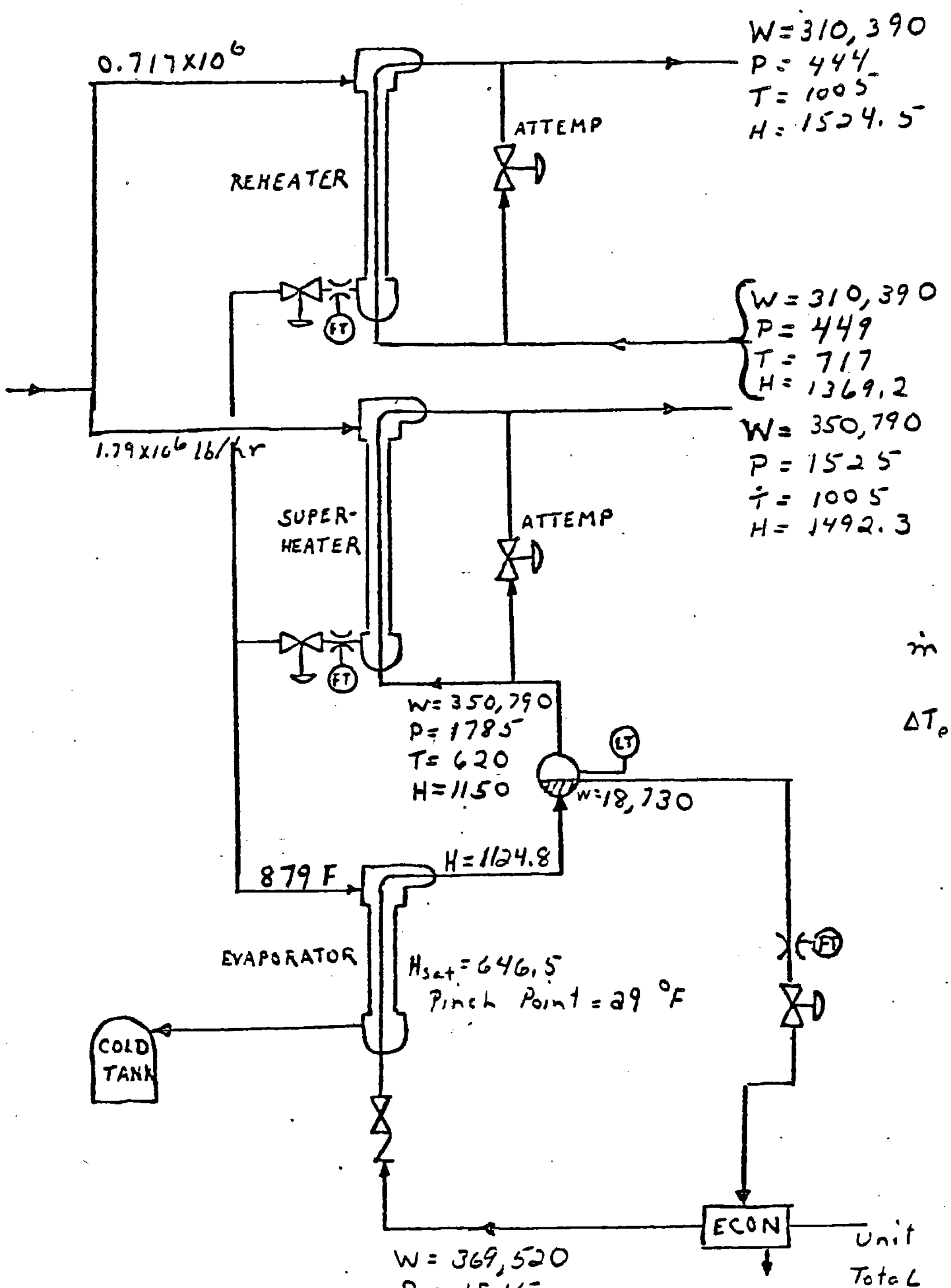


FIG 5.2-4

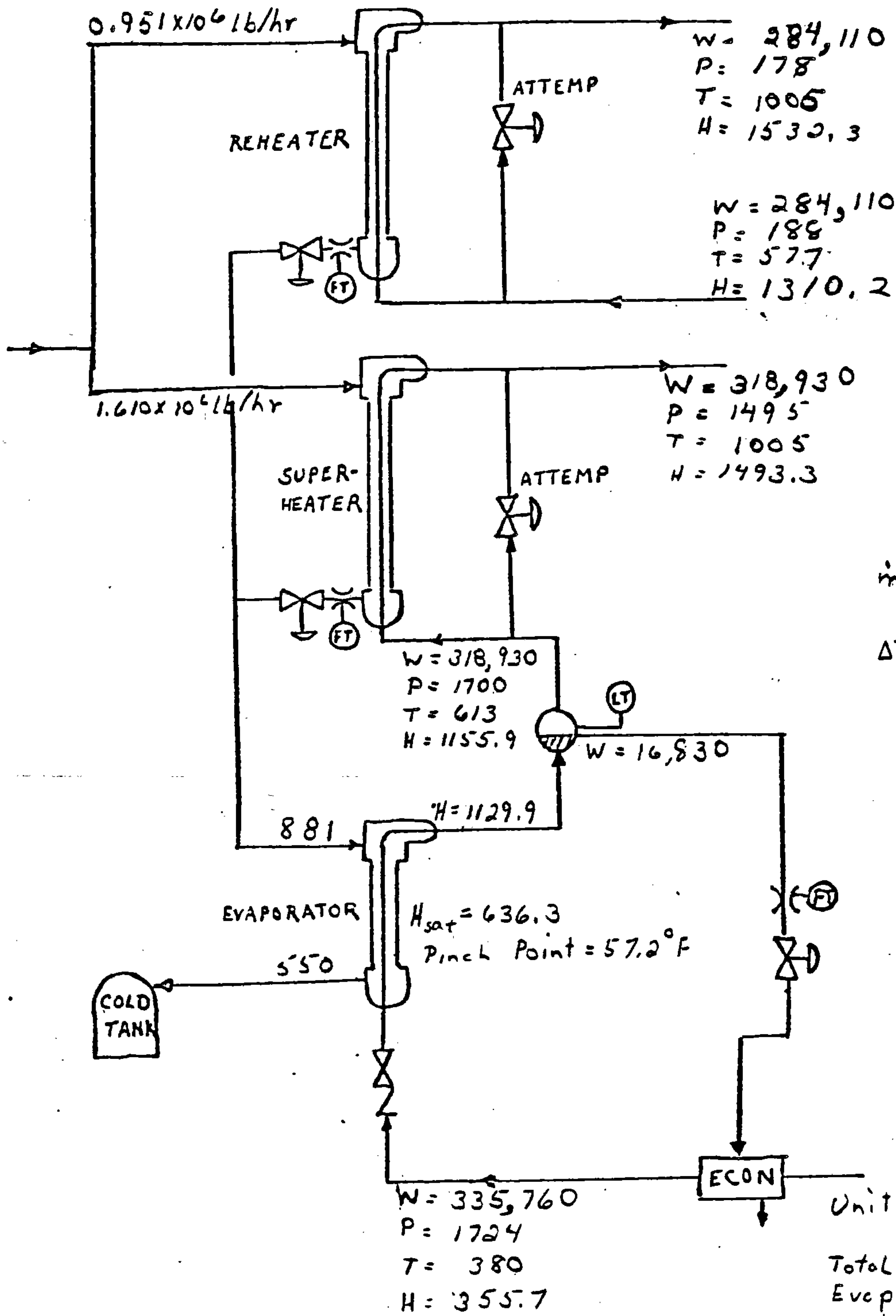
P = 14.1 MWt

$$\dot{m} = \frac{123.6 \times 3413}{0.306(550)} = 2.507 \times 10^6$$

$$\Delta T_{evap} = \frac{74.3 \times 3413}{0.308(2.507)} = 329$$

Unit	Power	%	Na Δ °F
Total	123.6		
Evap	74.3		
Suph	35.2		
Reheat	14.1		
Preheat	22.5		

TESCO SOLAR ONLY
(case 15)



P: 18.6 MWt.

$$\dot{m} = \frac{126.3 \times 3413}{0.306(550)} = 2.561 \times 10^6$$

$$\Delta T_{evap} = \frac{76.2 \times 3413}{0.308(2.561)} = 331$$

Unit	Power MWt	%	Na ΔT °F
Total	126.3		550
Evap	76.2		332
Suph	31.5		218
Reheat	18.6		218
Preheat	27.6		120

F. 5.2-5

is based on extensive receiver analyses conducted during the ACR and Hybrid Central Receiver Programs. These analyses are documented in the final reports of these programs. (6-2, 6-3) Maximum utilization of these analyses has been achieved by adopting receiver equipment designs whose generic configuration match previously analyzed designs to the greatest extent possible.

The maximum absorbed thermal power is 160 MWt. This is achieved while maintaining peak receiver heat flux below 1.5 MWt/m^2. The resulting receiver life is expected to exceed 10,000 cycles. The receiver is shown in Figure 5.2-2.

The receiver tower design, integrated with the receiver, is shown in Figure 5.2-6. The structural design is based on standard steel structural elements. The selection analysis for the tower is described in Section 5.2.5, including the structural analyses of the various tower configuration candidates. Detailed tower design data is included in Appendix B, Design Data Sheets.

The structural support design for the field and return piping is shown in Figure 5.2-7. The design of this structure is the same as for conventional high-temperature pipe and includes provisions for draining, sodium leak detection, and trace heating. Due to conventional nature of the design, no detailed structural analysis was necessary. Carbon steel piping has been specified for all 288°C (550°F) sodium piping. Stainless steel piping has been specified of all 593°C (1100°F) sodium piping.

~~Drawings of~~ The typical drag valves for use in the receiver downcomer ~~are~~ is shown in Figures 5.2-5 . The valve will either be in the form of an elbow as shown in Figure 5.2-5 or an in-line section,
In either case, the active pressure reduction element is the disk stack
The disk stack consists of many disks, integrated together, and fitting with a plug for modulating flow. Each disk has a finite flow capacity which is dependent on the area and number of flow passages between the inside and outside of this disk. The required disk impedance is developed by a series of turns in the flow passages with the number of turns chosed to limit the fluid velocity to an acceptable level regardless of the pressure drop. Since each disk has a specific flow capacity, an appropriate number of them are used to meet the

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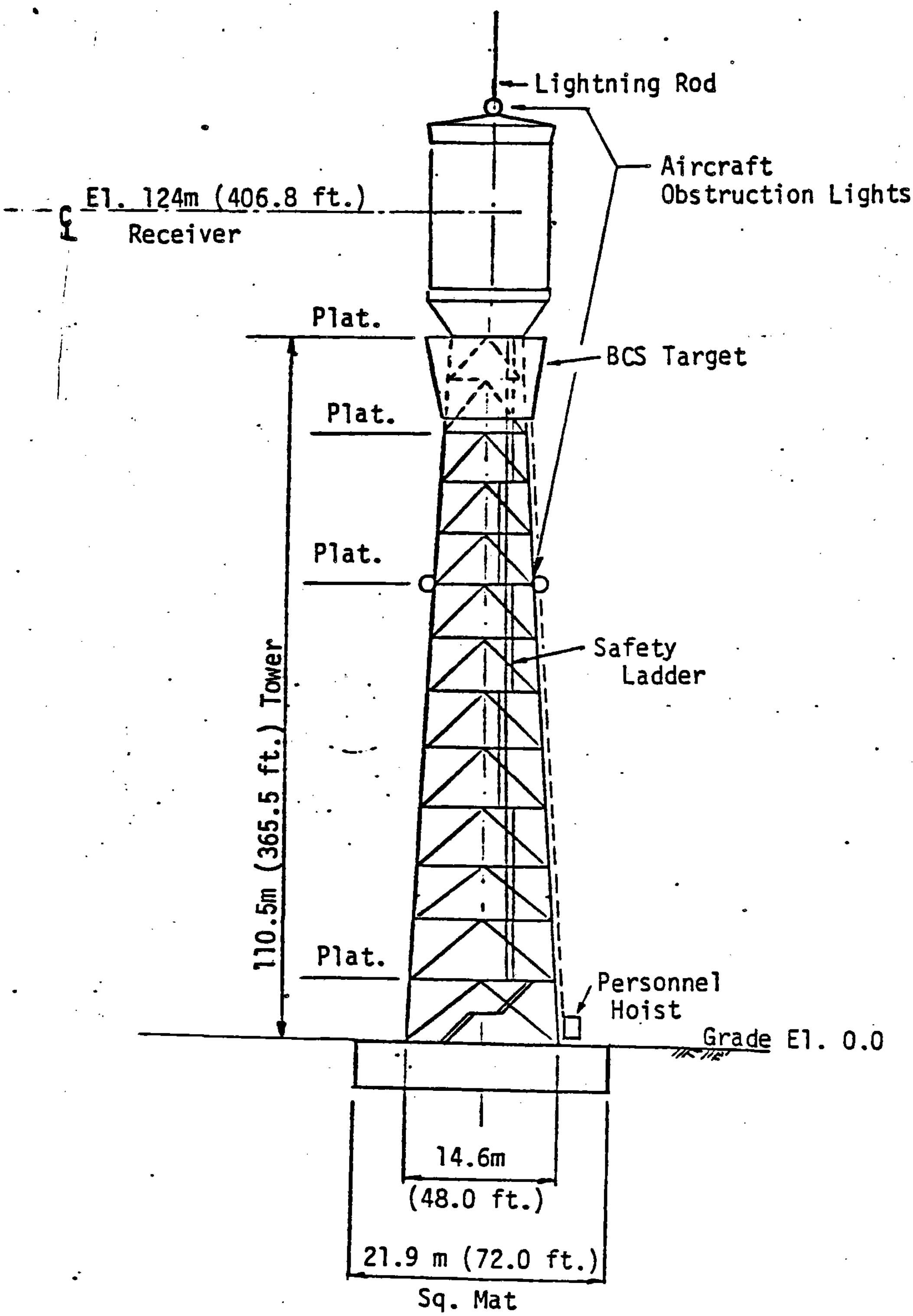

FIGURE 5.2-6

RECEIVER TOWER

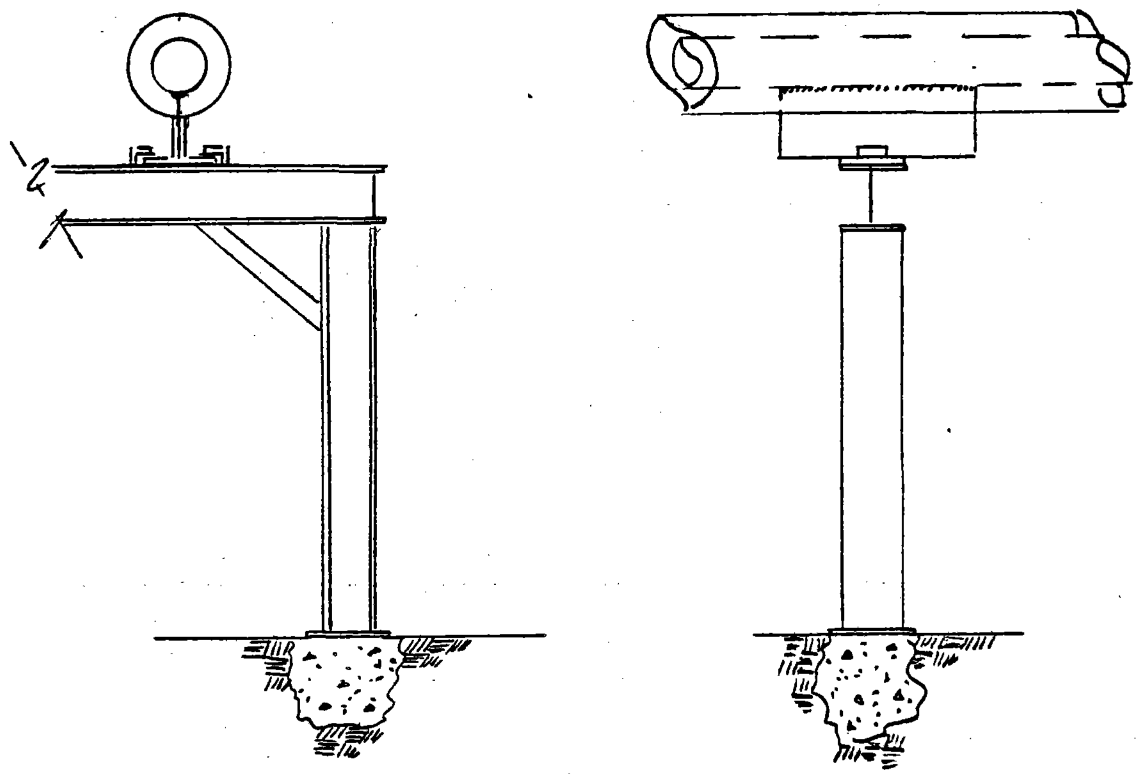

FIGURE 5.2-7 - FIELD PIPING CONCEPTUAL DESIGN

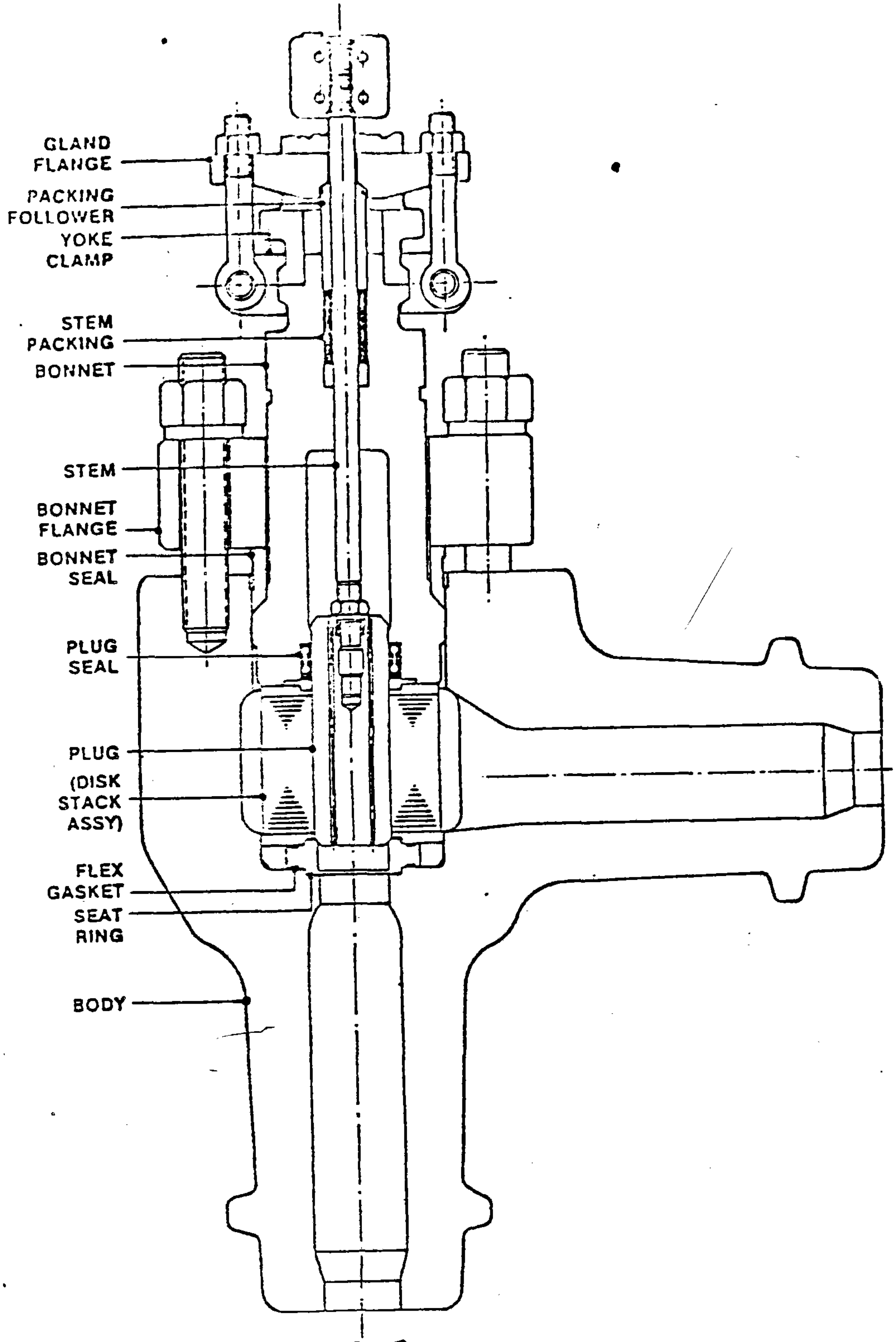

Figure ~~5-64.~~ 5.2-5 Drag Valve Construction total flow requirement. Two of these valves, a 6-in. and 30-in. model, have been tested in sodium service as part of our ongoing sodium component testing at the Energy Technology and Engineering Center (ETEC). The drag valve required for repowering Unit 5 must pass approximately 0.5 m^3/s (7,500 gpm) of sodium and dissipate between 30 and 100% of the tower static head of 131 m (430 ft). At a sodium density of 811 kg/m^3 (50.6 lb/ft^3), this corresponds to a maximum pressure drop of 1.04 MN/m^2 (151 psi).

The valve is sized with 294 m (16 in.) nominal end connections for smooth transition between the downcomer and field return piping.

A vast amount of experience has been accumulated over the past 25 years of ESG's involvement in the design and development of sodium system components. Pump development was initiated in 1955 at ESG for the Sodium Reactor Experiment (SRE), and continued development lead to design of the free-surface type Hallam pump, the Fast Flux Test Facility pump, the Clinch River Reactor Plant (CRBRP) pump, and the Inducer pump.

Recent main heat transfer system sodium pumps are free-surface, centrifugal impeller pumps, operating in the 850- to 1150-rpm range. Currently, several double-suction centrifugal impeller types are being designed or fabricated, most notably for the Clinch River Breeder Reactor Plant (CRBRP) and the BN-600 reactors.

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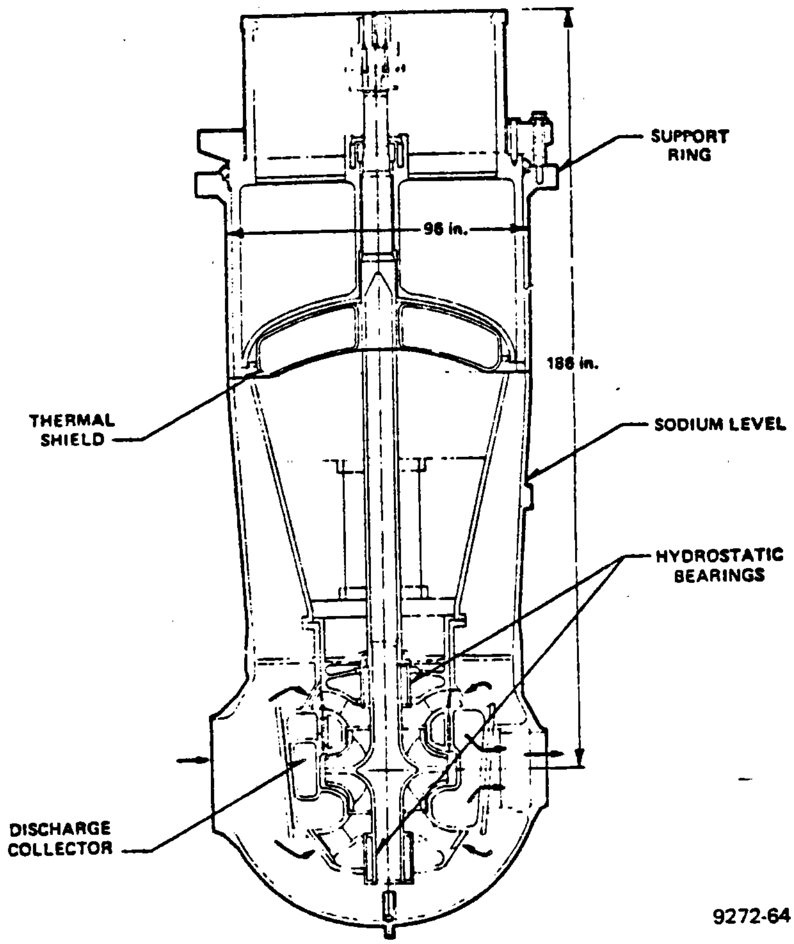
Some 33 pumps of the class and capacity (5,000 to 20,000 gpm) required for a repowered solar plant have successfully operated in sodium reactor loops throughout the world (USA, U.K., France, Germany, Italy, Holland, and the USSR). Pumps are being presently designed by Rockwell and others under contract to DOE for use in large scale breeder reactor plants with capacities in the range of 85,000 gpm. A prototype pump for France's Super Phoenix with a capacity of 79,000 gpm has been tested in water and the pumps full-scale rotating works are presently being tested in sodium.

A free-surface pump is a vertical mechanical pump placed in a close fitting vessel called the pump case. The liquid level ("free-surface") in the outer case is maintained above the impeller and below the top of the pump case. For this type of pump, a shaft seal is not required to seal in the liquid. Pumps which use an inert cover gas, such as sodium pumps, use a gas seal placed on the shaft to minimize cover gas leakage. Figure 5.2-6 shows typical free-surface pumps used for sodium applications.

The viable alternative sodium pumps for large-scale sodium systems appear to be ac electromagnetic induction pumps or centrifugal pumps. Electromagnetic induction pumps require no moving parts and no pressure boundary penetration for their operation. These excellent operational characteristics are offset by the difficulty of cooling the windings without freezing the sodium while maintaining the pump in a shutdown condition. In addition, the pumping efficiency of these pumps is less than 50% which leads to an unacceptable economic penalty.

Figure 5.2-6 ~~4-11~~. Reference Pump



The design of steam generators have been extensively analyzed, tested, and evaluated at ESG. For the current application, extensive use has been made of previous analysis in the selection of the steam generator configuration. The physical features of the units are shown in Figure 5.2-1. The high-pressure water/steam flows through the tube side, and sodium is on the shell side. The "hockey-stick" configuration allows individual tubes to expand differentially during thermal transients. The sodium flow bypasses the bend section because the tubes are supported in the horizontal plane only in this region. Elsewhere, tube spacers suppress any potential tube vibration due to flow. The units are mounted vertically to avoid problems which could arise due to temperature stratification on the sodium side and flow maldistribution on the steam side.

Table 5.2-2 is a brief description of the main design features of the steam generator units. A miore detailed list is given in the data lists of Appendix A. The evaporator and superheater are sized based on the combined mode operation (Figure 5.2-4 o~~f Section 5.2.3~~) and the reheater for the solar only operation (Figure 5.2-5 of ~~Section 5.2.3~~). These are the conditions requiring the largest heat transfer surface area. For the evaporator, the smaller pinch point ΔT during combined mode requires the higher surface area even through the thermal rating is slightly less. The much lower reheat pressures and higher thermal rating make the solar-only operation the design condition for the reheater.

Tube selection and materials were optimized during the ACR program (6-2) ~~and presented in Reference 1~~. For the current application, the evaporator (design temperature is 900°F) will be constructed of unstabilized 2-1/4 Cr - 1 Mo ferritic steel. This material was chosen because of its excellent resistance to chloride stress corrosion cracking in an aqueous environment and the excellent and extensive field experience with it. The superheater and reheater units (design temperature 1100°F) are Type 304 austenitic stainless steel. This material is used because its higher strength at the design temperature makes it cost effective compared to the 2-1/4 Cr - 1 Mo material.* Chloride stress corrosion can be a problem but it is only initiated in aqueous solution. Thus, if the bulk liquid

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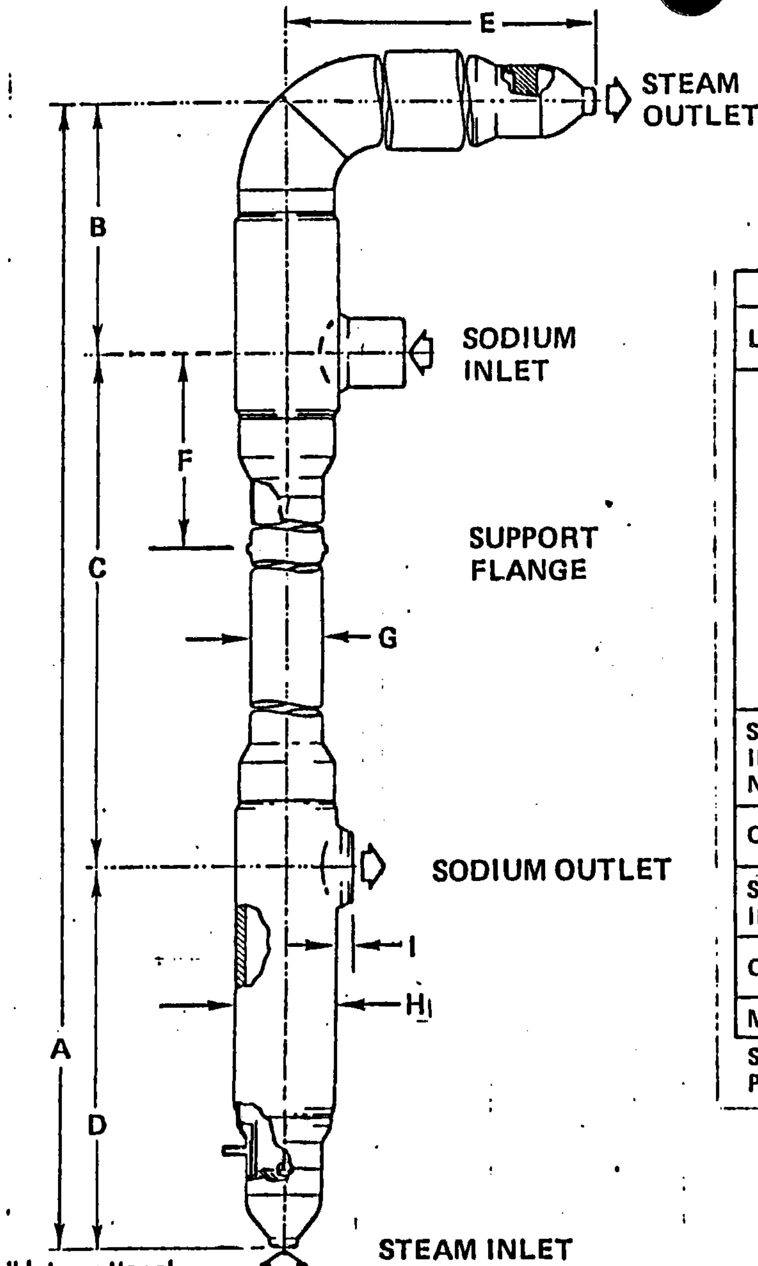
*Sodium decarborization of 2-1/4 Cr - 1 Mo significantly reduces the stress allowables above 1000°F.

TESCO REPOWERING STEAM GENERATING UNITS



DIMENSIONS (inches)

LOCATION	EVAPORATOR	SUPERHEAT	REHEAT
	NOMINAL RATING		
	74.1 MWt	35.7 MWt	18.2 MWt
A	95 (ft)	91 (ft)	63 (ft)
B	121	97	97
C	860	860	549
D	159	135	110
E	178	160	160
F	62	52	52
G	39	24	26
H	47	32	34
I	48	56	55
SODIUM INLET NOZZLE	16 SCH 40	14 SCH 40	10 SCH 40
OUTLET	16 SCH 40	14 SCH 40	10 SCH 40
STEAM INLET	6 SCH 160	10 SCH 160	14 SCH 60
OUTLET	10 SCH 160	10 SCH 160	14 SCH 60
MATERIAL	2-1/4 Cr - 1 Mo	304 SS	304 SS

SODIUM NOZZLES – ANY ORIENTATION.
PREFERRED SHOWN

Rockwell International
Energy Systems Group

80-M4-1-43

Figure 5.2-7

TABLE 5.2-2

SODIUM STEAM GENERATORS

	Evaporator	Superheater	Reheater
Type	Tube and shell, hockeystick	Tube and shell, hockeystick	Tube and shell, hockeystick
Height m (ft)	29.0 (95)	27.7 (91)	19.2 (63)
Shell diameter m (in.)	0.99 (39)	0.61 (24)	0.66 (26)
Heat transfer area m^2 (ft^2)	842 (9060)	220 (2365)	151 (1630)
Number of tubes	712	155	80
Tube size cm (in.)	1.59 (5/8)	1.91 (3/4)	2.81 (1-1/2)
Material	2-1/2 Cr - 1 Mo	Type 304 SS	Type 304 SS
Duty (MWt)*	83.2	43.7	18.1
Percent of total duty (%)	57	30	13

*Total duty = 145 MWt
Code - ASME Section VIII, Division I

is kept out of the stainless steel units, chloride stress corrosion does not become a problem. To accomplish this, a combined steam drum and steam separator are installed between the evaporator and the superheater to assure that no bulk liquid is carried over to the superheater.

& Performance Characteristics

5.2.4 Operating Characteristics

Tentative operating sequence outlines, based on test experience with sodium systems, are presented in Tables 5.2-3 through 5.2-7. Outlines are as follows: (1) Table 5.2-3, Prestartup, gives the basic steps required for preparing the system to receive sodium; (2) Table 5.2-4, Initial Startup, gives the steps required for bringing the sodium systems up to cold leg temperature for the first time; (3) Table 5.2-5 gives the steps needed to bring the sodium and steam system to part load. The system is leveled at 1/2 full power to permit its characteristics to be examined before proceeding to full power. Subsequent cold startups should be possible in 4 h or less, depending on the starting temperature (never <149°C (300°F); (4) Table 5.2-6, Shutdown, gives the steps needed to secure the plant for an expeditious startup the following day; and (5) Table 5.2-7, provides

TABLE 5.2-3

OPERATIONS PRESTARTUP

. Check Out Instrumentation
. Preheat Sodium Systems to 150°C (300°F)
. Purge with Argon
. Heat Tank Car
. Fill Drain Tank Cars--12 Days*

*An alternate procedure is to fill 25% in 25 days, start limited operations and complete filling as required.

TABLE 5.2-4

OPERATIONS INITIAL STARTUP - FIRST DAY

	Clock Time
. Sunrise	0730
. Preheat Receiver - Solar - 200°C (400°F)	0800
. Start P-1 Pump	
. Fill Raiser and Downcomer to Receiver Bypass Line	0830
. Open Control Valve Part Way	
. Circulate Sodium - Bypass Steam Generator - 174°C (350°F)	
. Fill Dry Steam Generator with Na and Circulate	0900
. Close Receiver Bypass and Fill Receiver and Cold Tanks	0930
. Raise Sodium Temperature to 270°C (525°F) with Solar Heating	1030
. Circulate Sodium and Check Out the System	
. Shut Down System - Drain Receiver to Stanby	1600
. Sundown	1645

TABLE 5.2-5

OPERATIONS STARTUP - SECOND DAY

	Clock Time
. Heat Feedwater on Bypass Flow	0500
. Pressurize Evaporator to ~6.89 MN/m^2 (1000 psi)	
. Admit Water to Evaporator 260°C (500°F)	0600
. Start Na Flow	0600
. Flash Steam to S.H. and R.H. - Condenser	0615
. Balance Water, Steam, and Na Temperature	0630
. Stepwise Raise and Spread at Log Mean ΔT	
. Roll Turbine (Min. - 40% Press. - 100°F S.H.)	0715
. Sunrise - Power to Grid	0730
. Stepwise Increase Steam Temperature and Flow	
. Level at 1/2 Power	0815

TABLE 5.2-6

OPERATIONS SHUTDOWN - SECOND DAY

	Clock Time
. Reduce Load to 20%	1630
. Collapse the Log Mean ΔT	
. Trip Turbine - Dump to Condenser	1730
. Bypass Evaporator - Na and H_2O - Evaporator Dry	
. Isolate - Full Na - NO H_2O	1800

TABLE 5.2-7

OPERATION STARTUP - THIRD DAY

	Clock Time
. Heat Feedwater on Bypass Flow	0500
. Pressurize Evaporator to ~6.89 MN/m^2 (1000 psi)	
. Admit Water to Evaporator 260°C (500°F)	0600
. Start Na Flow from Bypass Line	0600
. Flash Steam through S.H. and R.H. to Condenser	0615
. Balance Water, Steam, and Na Temperature	0630
. Stepwise Raise and Spread at Log Mean ΔT	
. Close Bypass Line	0710
. Sunrise Power to Grid	0730
. Fill Receiver and Circulate to Storage	0730
. Stepwise Increase Steam Temperature and Flow and Power	
. Level at Full Power	0800

the hot startup sequence for full power operation by 0815 midwinter. The steam generator cooldown characteristics are given in Figure 5.2-8. The startup and operating steps for the operation of the steam system is given in Section 5.3.4.

As part of the ACR program, a detailed receiver subsystem (less steam generators) simulation study was completed[(6-2)] which verified the receiver subsystem design proposed for the repowered system. The specific operations simulated included cloud transients, insolation step charges and receiver pump flow failures. The last simulations provided the impetus for including the passive receiver protection system included in all subsequent receiver designs. This system has also been extensively modeled and its effectiveness verified.[(6-3)]

5.2.4 Receiver Subsystem Operating and Performance Characteristics

5.2.4._ Steam Generators

Operating conditions for the steam generator require it to operate under the following capabilities:

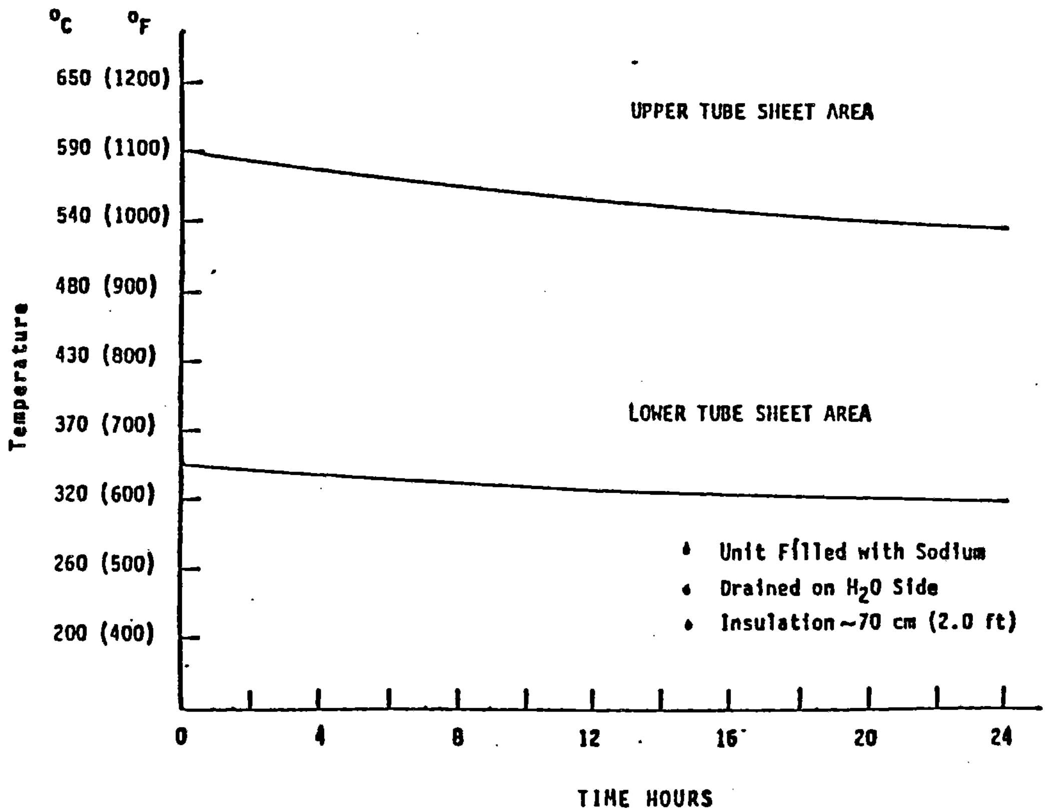


Figure 5.2-8 Superheater Cooldown

1) Supply 12.4 to 124 MWt during combined mode operation
2) Supply 58 to 126 MWt during solar-only operation
3) Startup/shutdown during combined mode operation
4) Startup/shutdown during solar-only operation
5) Cold startup

As the steam generators are sized for the full-load conditions, under partial load conditions, steam generator effectiveness is increased. Performance curves are shown in Figures 5.2-9 and 5.2-10 for the superheater and reheater as a function of percent steam flow rate. Without changing inlet conditions, the steam produced would approach the sodium inlet temperature of 1100°F as sodium and steam flow rates are decreased. The evaporator is not shown as no simple relationship exists because of the two-phase flow.

STEAM GENERATOR PERFORMANCE CURVES

SUPERHEATER

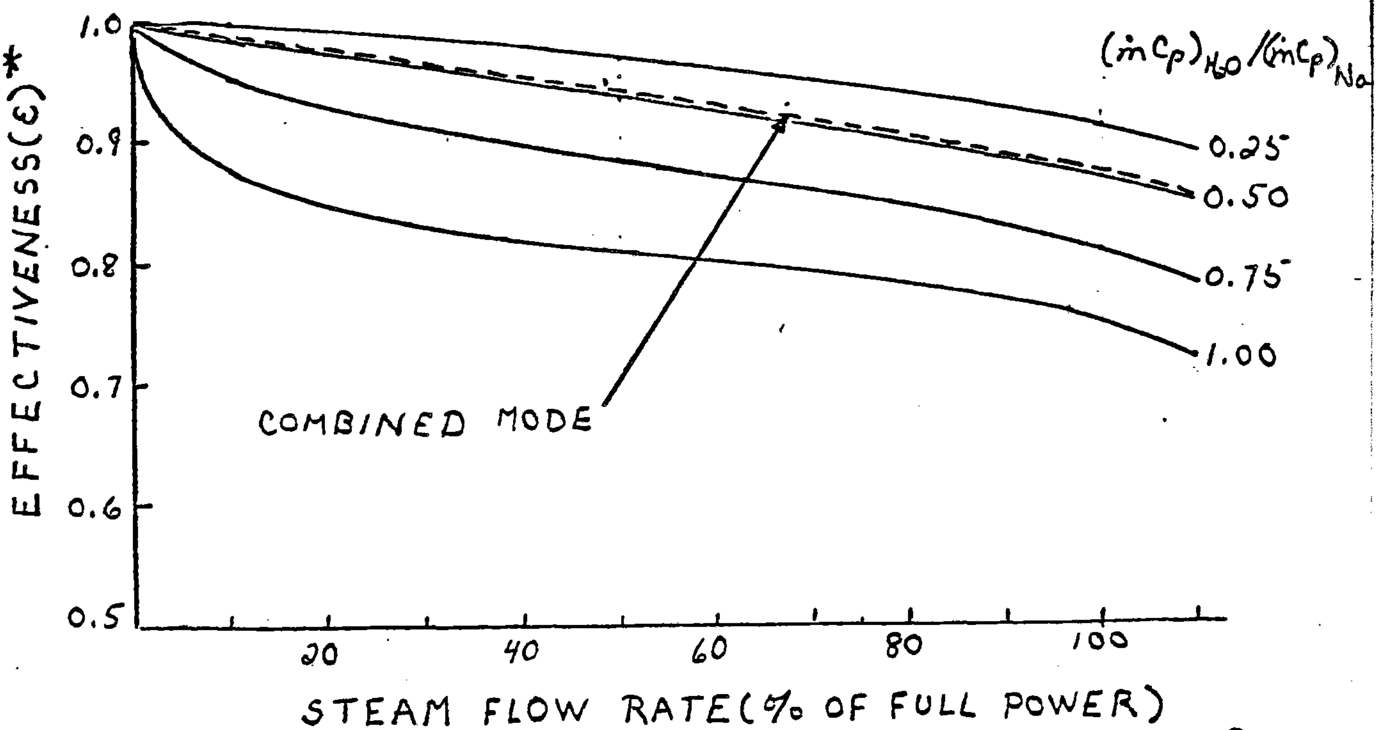
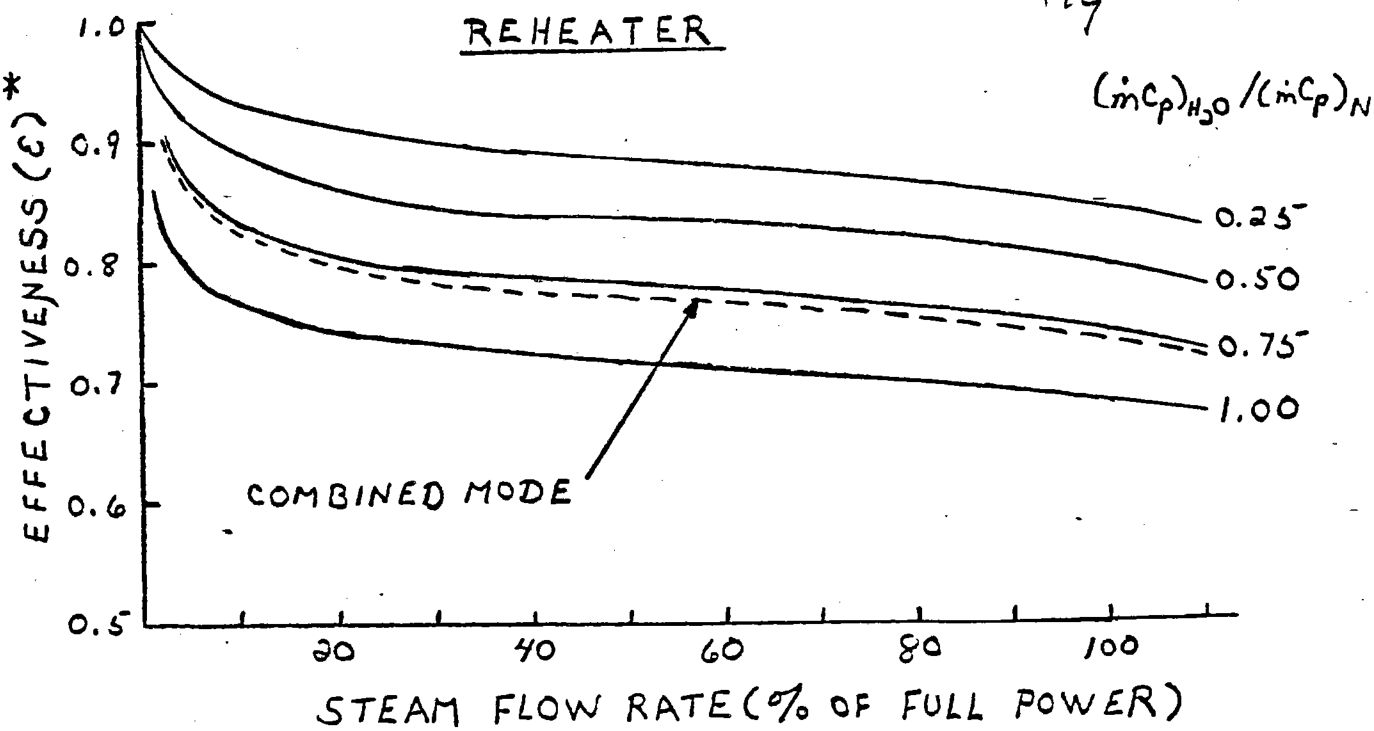


Fig 5.2-9

REHEATER



$* \quad \varepsilon = (T_{Co} - T_{Ci})/(T_{Hi} - T_{Ci})$ Fig 5.2-10

In conjunction with the control philosophy presented in Figure ____ of Section 4.5.__, steam generator operating characteristics were determine for low flow conditions. Figures 5.2-11 and 5.2-12 are operating parameters when solar is running at 50% and 10% of normal load or 25 kWe and 5 kWe, respectively. The sequence of events when reducing power would be as follows:

1) Reduce feedwater and sodium flow rates by percentage reduction in power desired
2) Higher exit steam temperatures from reheater and superheater will cause attemperator control valves to open until mixed steam temperatures match fossil steam temperatures.
3) Pressure will decrease in steam drum resulting in a lower saturation temperature.
4) Increased evaporator efficiencies will result in superheated steam and, thereby, lower water level in steam drum. This in turn will cause an additional reduction in sodium flow rate (0-6%) and reduction in sodium cold leg temperature.

When operating at low loads during solar only, the same operating philosophy would result in a similar response. However, the main steam and reheat temperature and pressures would have to respond to the turbine requirements at these low loads.

For startup procedures, refer to Section 5.2.3.

5.2.5 Cost Performance Tradeoffs

System level cost performance tradeoffs affecting the selection of the size and configuration of various receiver subsystem components are documented in Sections 3.1, 3.2, and 3.4. The affected components include the receiver, the riser and downcomer, the field feed and return sodium lines, the receiver pump, and the steam generator size. The only receiver subsystem component not sized or selected on the basis of system level studies was the tower. The tower height, and structural requirements for repowering Permain Basin Unit 5 are somewhat

Operating Characteristics for combined Mode with solar at 25 KWe

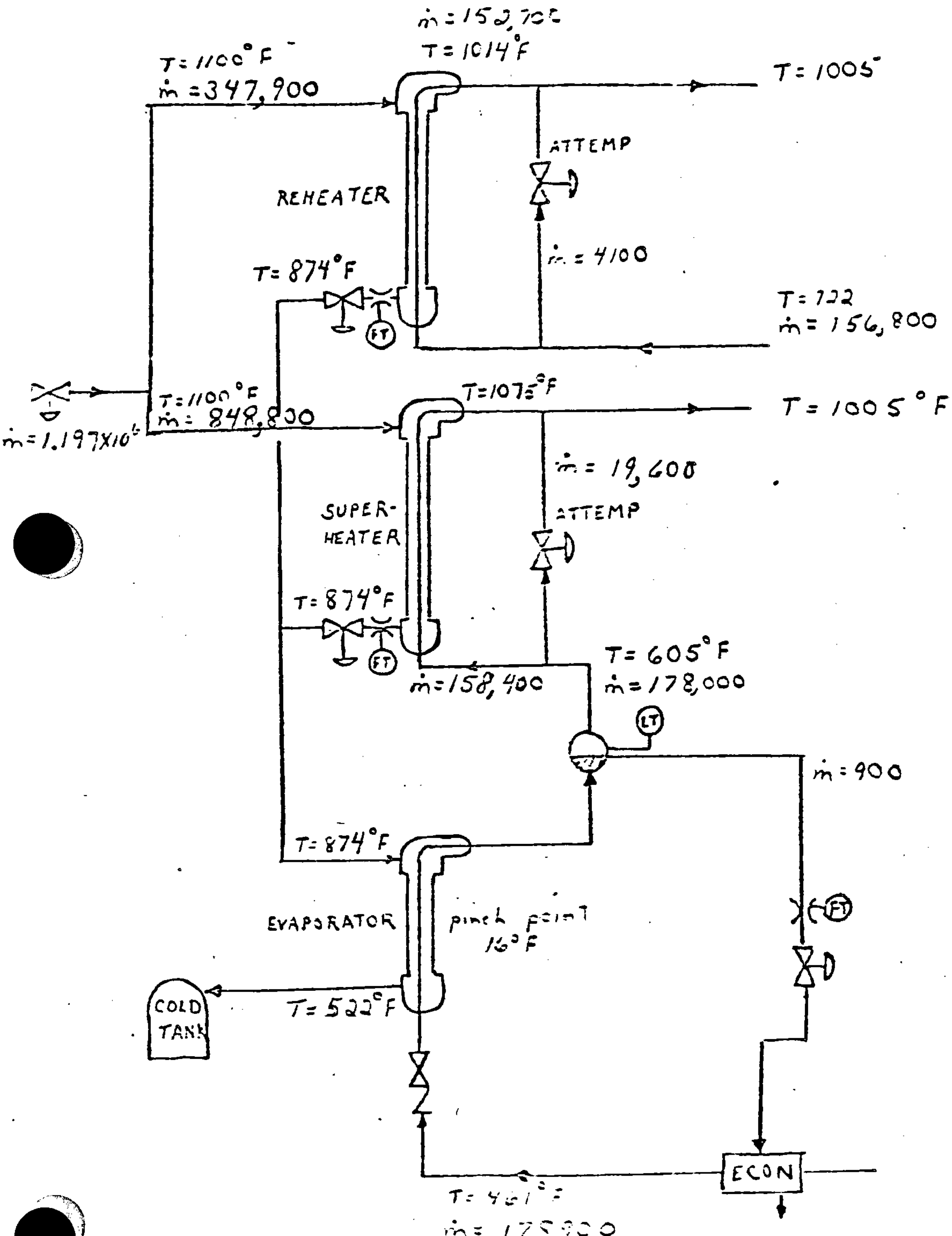
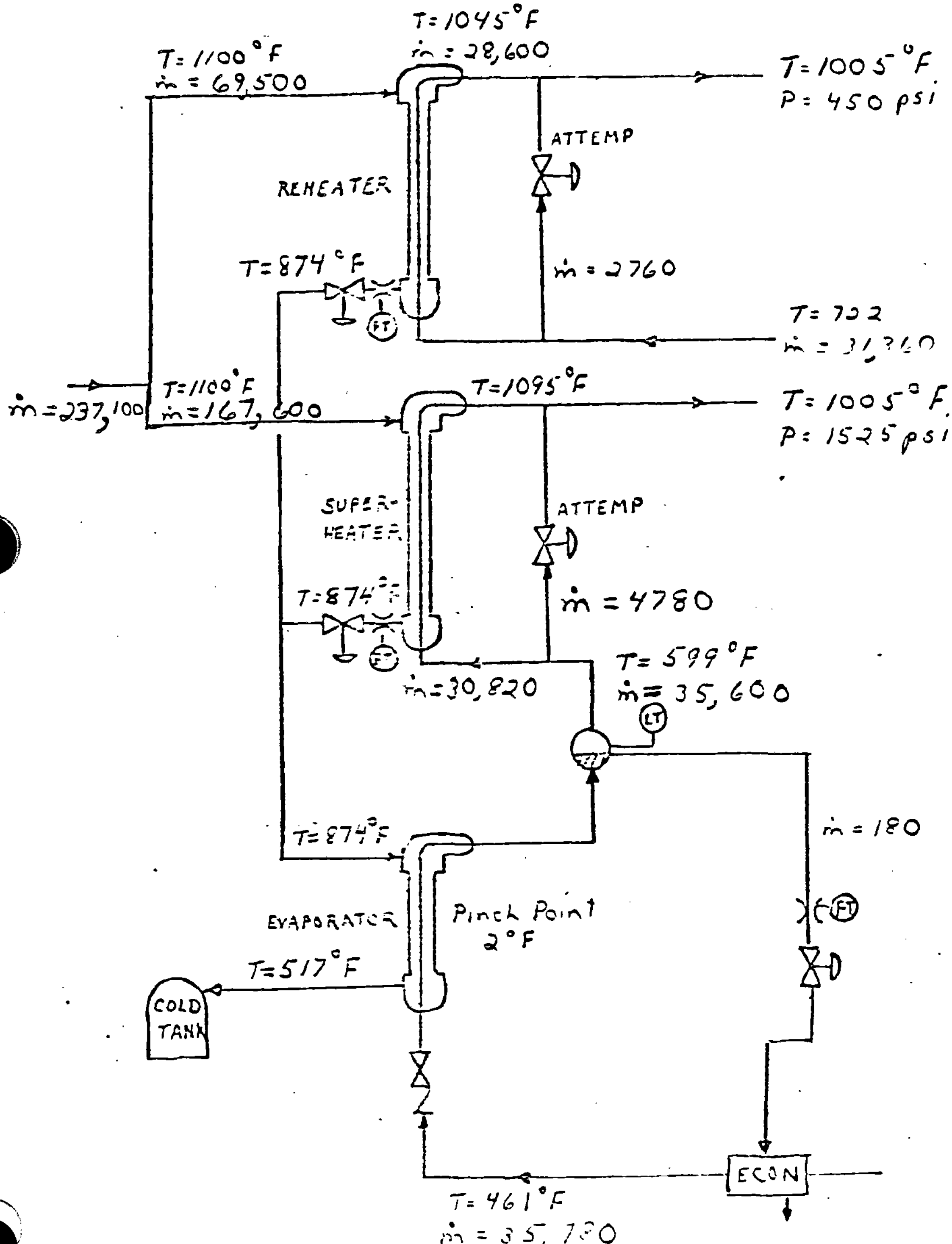


Fig 5.2-11

Fig 5 Operating Characteristics for Combined Mode with Solar at 5 KWe



relaxes when compared to the ACR and hybrid study tower requirements. Consequently, a separate configuration and material selection trade study was completed and is documented below.

5.2.5.1 Tower Selection Study

The objective of this trade study was to select the receiver tower configuration which results in the most cost-effective design meeting the design criteria while utilizing accepted construction practice. Three tower configurations were compared: Reinforced concrete, conventional steel and tubular steel.

This study includes the structural dynamic analysis and costing for the various receiver towers and foundations only; tower design, engineering, accessories and appurtenances are considered a stand-off and are not included.

Table 5.2-8 summarizes the trade study objective and approach.

Every tower was modeled as a multi-mass cantilever beam structure. The tower masses consisted of the tributary mass from the tower structure itself plus supported equipment. The rotary inertia of the tower masses was neglected in the dynamic analysis.

Each concrete tower was divided into fifteen segments of equal length, with the mass of each segment located at the segment centroid. These masses were connected by prismatic beam elements, which inlcuded the effect of shear deformation (see, e.g., J. S. Przemieniecki, Theory of Matrix Structural Analysis, McGraw-Hill, 1968). The element area and moment of inertia were computed for the gross uncracked concrete section, using the average radius and thickness along the length of the element. The effective shear area was obtained using information from G. R. Cowper, "The Shear Coefficient in Timeshenko's Beam Theory," Journal of Applied Mechanics, June 1966, pp. 335-340.

For steel towers, the masses were located at the level of each horizontal brace. The tower truss structure was represented by equivalent beam elements.

TABLE 5.2-8

RECEIVER TOWER SELECTION

OBJECTIVE:	To select the receiver tower configuration.
CANDIDATES:	Baseline - Reinforced concrete Alternates - Conventional steel - Tubular steel
SELECTION CRITERIA:	Tower cost, construction considerations, operational considerations.
APPROACH:	Determine tower configuration meeting specified site-specific envirmental and receiver design conditions. Prepare list of tower and foundation material quantities for construction cost estimate. Prepare construction cost estimate for the various receiver towers and foundations, including indirect field costs.
INPUT DATA:	. Site: Monahans, Texas . Environmental design data . Wind Operational: 13.3 m/s (30 mph) @ 10 m (30 ft) Survival: 40 m/s (90 mph) @ 10 m (30 ft) . Seismic 0.15_g peak ground accel. (UBC Zone 2) . Soil bearing (varies uniformly with depth): 40,500 kg/m^2 (9,300 psf) @ 1.3 m (4.4 ft) 78,100 kglm^2 (16,000 psf) @ 7.1 m (23.4 ft) . Tower height 119 m (390 ft) . Receiver weight 362,900 kg (800,000 lb) . Current construction cost factors for material and labor.

For all towers, the entire receiver mass was located at the centroid of the receiver (the centroid was assumed to be located at 2/3 of the receiver panel height), and a rigid element connected this mass to the top of the towers.

All horizontal and vertical (i.e., transverse and logitudinal) natural frequencies and corresponding mode shapes were computed for each tower model by the jacobi method. Details of the procedure may be found in S. H. Crandall, Engineering Analysis, McGraw-Hill, 1956.

Tower responses to both horizontal (one component) and vertical earthquake loading were computed using the response spectrum method. The ground response spectra were obtained from Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants," issued by the U.S. Nuclear Regulatory Commission, scaled to 0.15 g maximum ground acceleration.

Modal damping ratios for the towers were obtained from Regulatory Guide 1.61, "Damping Values for Siesmic Design of Nuclear Power Plants." Values listed for the safe shutdown earthquake (SSE) were used, i.e., 7 percent of critical for both concrete and steel.

The structural response to each earthquake component was computed from the appropriate modal responses using the square root of the sum of the squares (SRSS). To compute member forces for design purposes, these component responses were then combined to obtain the complete earthquake response. For steel towers, the combined response was computed by SRSS, while the concrete towers the absolute sum was employed.

Drag wind loads were computed per the provisions of the "American National Standard Building Code Requirements for Minimum Design Loads in Buildings and Other Structures (ANSI A58.1-1972)", with various tables and appendices used as applicable.

The design wind force, F_r, on any node "r" of the structure was calculated using the following formula:

$$F_r = C_f K_z q_{30} A_r,$$

where

C_f = net pressure coefficient. For the concrete towers C_f was obtained using the values given in Table ______ for moderately smooth round shapes.

For the conventional steel tower, C_f was obtained for each node using the values given in Table ______. For the tubular steel tower, these values of C_f were modified using Table ____. C_f for the receiver was assumed equal to 0.522.

K_z = velocity pressure coefficient. Values for K_z were obtained using Figure ______ of Appendix _______ for exposure Type C (flat, open country).

G_f = gust factor. Values of G_f were obtained using the provisions of Appendix ______. In calculating G_f, the structure damping coefficients were assumed to be .01 and .02 for the steel and concrete towers, respectively.

q_{30} = basic wind pressure at a height of 30 ft.
= $0.00256\ V_{30}^2$, where V_{30} = specified basic wind velocity 40 m/s (90 mph) at a height of 10 m (30 ft)

A_r = projected area on a vertical plane normal to the wind direction tributory to node "r". For the steel towers, the projected area, A_r, was calculated as the summation of the projected areas of the individual members on the windward side of the tower. For the conventional steel tower, the projected area of the columns was taken to be the product of the maximum column dimension (flange width or web depth) times the vertical height tributary to node "r", due to the unspecified orientation of the column cross-sectional axes.

The following load factor equations were used:

1) Concrete Towers
   a) Wind Loads
      W = maximum wind
      D = dead loads
      Load Combinations: 1.05D + 1.28W; 0.9D + 1.3W
   b) Seismic Loads
      E = earthquake
      Load Combinations: 1.05D + 1.40E; 0.9D + 1.43E
2) Steel Towers
   a) Wind Loads
      W = maximum wind
      Load Combination: 0.75D + 0.75W
   b) Seismic Loads
      Load Combination: 0.75D + 0.75E

In determining the design of reinforced concrete towers, minimum shell wall thickness and minimum circumferential reinforcement were determine in accordance with Sections 4.1.3 and 4.7.3, respectively, of the "Specification for the Design and Construction of Reinforced Concrete Chimneys (ACI 307-69)". Vertical reinforcement was calculated using the strength design provisions found in Chapters 9 and 10 of the "Building Code Requirements for Reinforced Concrete (ACI 318-71)."

In designing the steel towers, steel members were sized in accordance with allowable stresses given in Section 1.5.1.3 of the AISC "Manual of Steel Construction," 7th Edition.

The foundation mats were sized to meet the following two criteria:

1) Calculated net soil bearing pressures should be less than or equal to the specified allowable soil bearing pressure increased by 1/3. Net soil bearing pressures were defined to be pressures in excess of those which would exist in the natural state at the base of the

foundation mat, i.e., $P_{net} = P_{gross} - \gamma t_m$, where γ = soil density 1922 kg/m^3 (120 pcf), and t_m = thickness of foundation mat. The foundation mats were assumed infinitely rigid and the calculated soil pressures were assumed to have a linear variation.

2) In the case of uplift, positive pressure must be maintained over at least 80% of the mat contact area.

The load factors of unit were used in calculating soil bearing pressures. The weight of reinforcing steel was based on an assumed 44.5 kg/m^3 (75 lb/yd^3) of concrete.

Piping was assumed to add a dead load 450 kg (1000 lb) per vertical foot.

The preliminary receiver configuration used in the analysis is shown in Figure 5.2-2. The total receiver mass located above the top of the tower is 362,900 kg (800,000 lb), which was located at the assumed centroid of the receiver.

Sketches of the concrete, convention steel and tubular steel towers, and foundations are shown in Figure 5.2-10.

As indicated in Figure 5.2-10, the reinforced concrete tower has a height of 199 m (390 ft) above the top of the 20 m (65 ft) diameter mat which corresponds to grade elevation. The diameter of the top and base of the tower is 7.5 m (24.67 ft) and 8.8 m (28.75 ft), respectively. The tower taper is 0.30 and the wall thickness is uniform at 0.20 m (0.677 ft). The mat thickness is 1.9 m (6.2 ft).

The 119 m (390 ft) conventional steel tower is constructed of standard structural steel shapes in a 4-legged structure. The dimensions across the flats is 7.3 m (24 ft) at the top and 14.6 m (48 ft) at the base. The mat dimensions are 21.9 m^2 (72 ft^2) by 2.1 m (7 ft) thick. The tubular steel tower is similar to the conventional steel tower in size and is also a 4-legged structure. The mat size is 20.4 m^2 (67 ft^2) by 2.0 m (6.5 ft) thick. The tubular steel tower is constructed of pipe or rolled plate members with bolted connections. Column

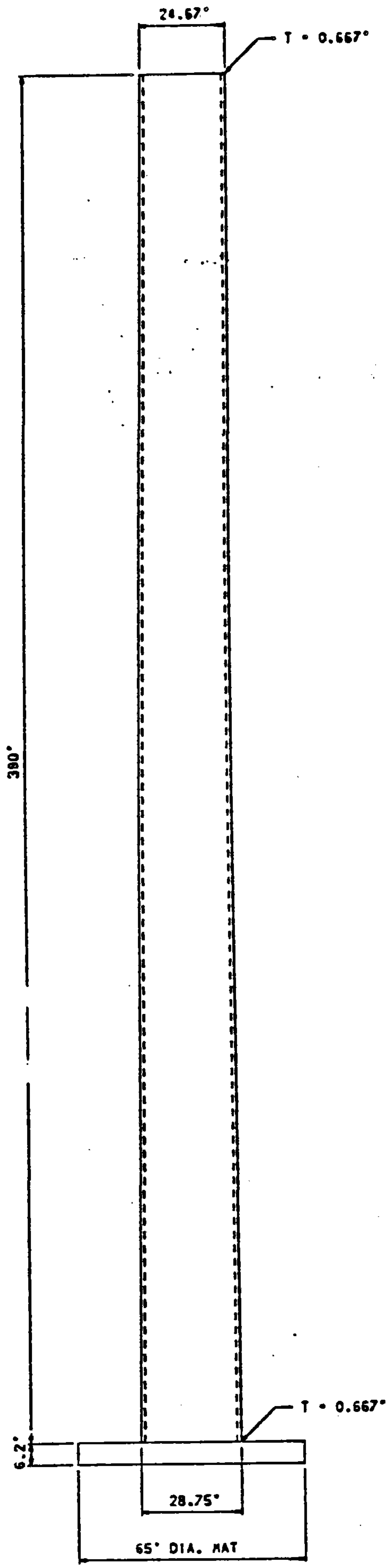


FIGURE - CONCRETE TOWER

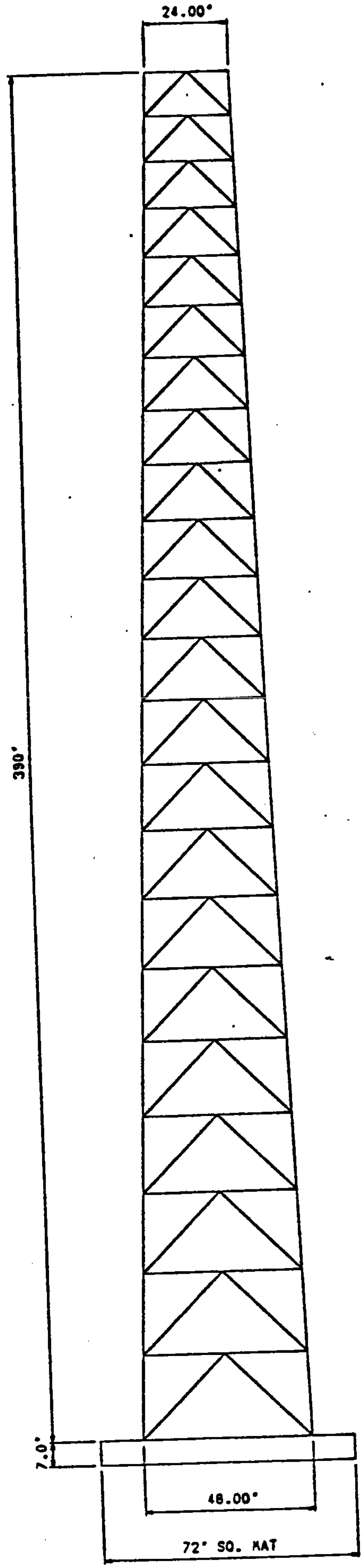


FIGURE _ - CONVENTIONAL STEEL TOWER

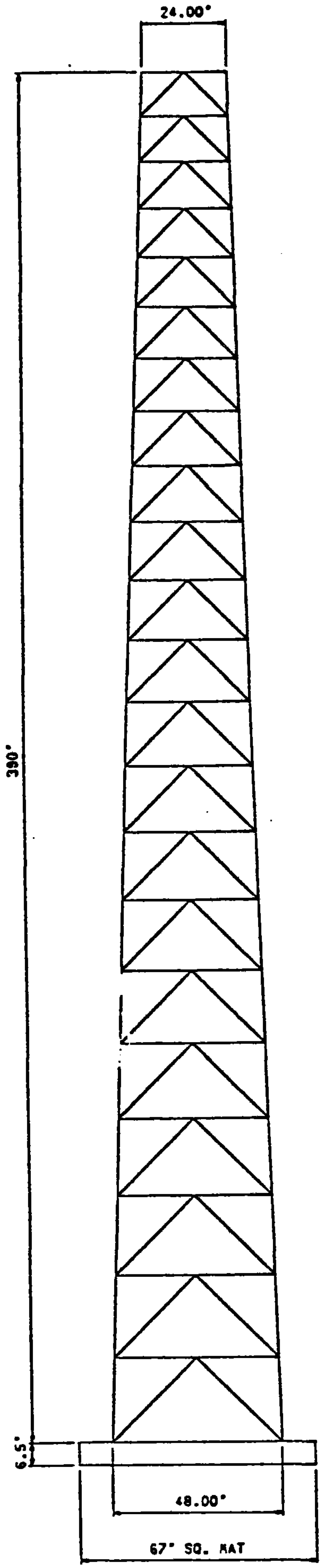


FIGURE 4 - TUBULAR STEEL TOWER

sizes are 0.51 m (20 in.) OD, with wall thickness varing from 0.006 m (0.250 in.) to 0.32 m (1.28 in.).

Table 5.2-9 shows a comparison of deflections, accelerations and shears for both wind and seismic design conditions for each tower configuration. As shown, the lateral displacement for the operational wind 13.4 m/s (30 mph) is very low for all the towers. Wind governs both the steel and concrete tower designs. Also, the results show an increase of approximately 50 percent above ground acceleration (0.15 g) for the maximum seismic acceleration at the top of the tower for the steel towers, with the corresponding value for the concrete tower being slightly less than ground acceleration. At the centroid of the receiver, however, the maximum seismic accelerations for the steel towers are considerably reduced, while increasing for the concrete tower owing to the stiffness of the concrete tower.

It should be noted that the foundations for all the towers were assumed to be of the mat type with the top of the mat at grade elevation. It is believed that some savings in foundation cost, particularly for the steel towers, could result from burying the mat below grade elevation.

Although the tower cost analyses were performed for a specific tower height and receiver mass, it is believed that a change in tower height of ±10% would not significantly affect the results or final selection of the tower configuration. Consequently, the structural steel configuration was retained for the final tower height of 110.5 meters, as shown in Figure 5.2-3.

The material quantities used in the cost estimates for the three tower configurations are shown in Table 5.2-10.

The comparison of tower costs are presented in Table 5.2-11. Indirect field cost has been assumed to be 75 percent of the direct labor plus special rental equipment in all cases. The concrete tower erection was estimated using a subcontractor for the tower column, with the earthwork and foundation being field cost items provided by the general contractor, thus indirect field cost appears

TABLE 5.2-9
SUMMARY OF RESULTS

Description	Concrete Tower	Conv. Steel Tower	Tubular Steel Tower
DEFLECTION, m (in.)			
a. 13.4 m/s (30 mph) Wind			
Top of Tower	0.043 (1.70)	0.052 (2.03)	0.044 (1.73)
Centroid of Receiver	0.052 (2.03)	0.063 (2.49)	0.054 (2.12)
b. 40.2 m/s (90 mph) Wind			
Top of Tower	0.483 (19.03)	0.589 (23.20)	0.477 (18.80)
Centroid of Receiver	0.576 (22.67)	0.723 (28.45)	0.614 (24.16)
c. 0.15 g Seismic			
Top of Tower	0.296 (11.66)	0.204 (8.05)	0.206 (8.12)
Centroid of Receiver	0.335 (14.00)	0.263 (10.36)	0.263 (10.36)
MAX. ACCELERATION, g's			
a. Top of Tower	0.138	0.226	0.211
b. Centroid of Receiver	0.165	0.081	0.080
MAX. WIND SHEAR, 10^3 kg (lb)			
a. Bottom of Tower	166.3 (366.7)	217.9 (480.3)	159.0 (350.5)
b. Top of Tower	31.0 (81.7)	40.2 (88.6)	40.3 (88.8)
SEISMIC SHEAR, 10^3 kg (lb)			
a. Bottom of Tower	138.7 (305.7)	52.8 (127.4)	52.3 (115.3)
b. Top of Tower	59.8 (131.8)	29.7 (65.5)	29.0 (64.0)

TABLE 5.2-10

MATERIAL QUANTITIES
119 m (390 FT) TOWERS

	Units	Concrete	Conv. Steel	Tubular Steel
1. TOWER				
a. Concrete (400 psi)	m^3	604	N/A	N/A
	(yd^3)	(789)		
b. Rebar (60,000 psi)	kg	48,081	N/A	N/A
	(ton)	(53)		
c. Columns (A400 Conv.;	kg	N/A	106,142	107,050
A36 or equiv. Tubular)	(ton)		(117)	(118)
d. Bracing & Connections	kg	N/A	156,050	104,350
(A36 Steel)	(ton)		(172)	(115)
2. FOUNDATION MAT				
a. Concrete (3000 psi)	m^3	587	1,027	826
	(yd^3)	(768)	(1,344)	(1,081)
b. Rebar (60,000 psi)	kg	26,300	45,400	36,300
	(ton)	(29)	(50)	(40)
3. SOIL EXCAVATION	m^3	919	1,579	1,291
	(yd^3)	(1,203)	(2,066)	(1,689)

TABLE 5.2-11

TOWER COST COMPARISON
119 m (390 FT) TOWERS
(1980 dollars)

	Concrete	Conv. Steel	Tubular Steel
Direct Field Cost	770,000	475,600	504,110
Indirect Field Cost	43,100	109,200	94,700
TOTAL FIELD COST	813,100	584,800	598,800
% Over Base	$39.04	Base	+2.39

Notes

1. Cost estimate is for tower and foundation only. Tower design, engineering, accessories, and appurtenances are not included.
2. Labor rates for Monahans, Texas

low. The steel towers were assumed to be erected entirely by the general contractor. These are "preliminary" cost estimates with an order og accuracy of +20%.

A convention steel tower was selected for the baseline conceptual design. This recommendation was made for the following reasons:

1) From a capital cost standpoint, the conventional steel tower on tubular steel tower can be erected for the same cost. The concrete tower cannot be justified based on cost.
2) The conventional steel tower is preferred over the tubular steel tower because standard structural shapes and connections can be used, thus utilizing proven construction practices based on years of experience on similar structures.
3) From an operational standpoint, tower sway for the steel towers compare favorably to the concrete tower. Also steel towers, owing to their flexibility, reduce the maximum seismic acceleration at the receiver centroid, thus should reduce receiver support structure cost.

CONSTRUCTION COST ESTIMATE

CLIENT ______ DESCRIPTION 5400 RECEIVER SUBSYSTEM

LOCATION ______ CONT. NO. ______

MADE BY ______

PROJECT ______ APPROVED ______

A/C NO.	ITEM & DESCRIPTION	ESTIMATED COST				
		MANHOURS	LABOR	SUBCONTRACTS	MATERIALS	TOTALS
	SUMMARY					
A	Excavation & Civil			2100		2100
B	Concrete	6425	128,500		113,800	242,300
C	Structural Steel RECEIVER, PIPE BRIDGE & STM. GEN.			1,411,195		1,411,195
D	~~Buildings~~ TOWER	2312	34,680	290,000	234,300	558,980
E	Machinery & Equipment	31,811	837,653		4,087,934	4,925,587
F	Piping	88,943	1,689,849		3,857,942	5,547,791
G	Electrical SEE 5800					-0-
H	Instruments	7079	140,872		80695	221,567
J	Painting			70,600		70,600
K	Insulation	70,952	1,560,944		1,141,586	2,702,530
	DIRECT FIELD COSTS		4,392,498	1,773,895	9,516,257	15,683,650
L	Temporary Construction Facilities					
M	Construction Services, Supplies & Expense					
N	Field Staff, Subsistence & Expense					
P	Craft Benefits, Payroll Burdens & Insurances	INCL. IN LABOR COST				
Q	Equipment Rental					
	INDIRECT FIELD COSTS	30% x DIRECT LABOR COST			✓	1,317,749
	TOTAL FIELD COSTS					17,001,399
R	Engineering Plant Design 8%/~~10%~~ of ~~TFC~~ BALANCE					522,242
	~~R&D~~ 24% x E & F					2,513,611
S	Major Equipment Procurement 3 ~~10%~~ of ~~Pump~~ TEC					510,042
T	Construction Management 3% of (TFC ~~+ R + S~~)					510,042
	TOTAL FIELD & ENGR. COSTS					21,057,336
U	Labor Productivity ~~See pg. 5/5~~ 15 % x D.L					658,874
V	Contingency Construction See pg. 5/5					-0-
	Design See pg. 5/5					-0-
W	Fee 5%/~~10%~~ of (A thru V)					1,085,810
	TOTAL CONSTRUCTION COST					22,802,020

DATE ______ REVISION NO. ______ REVISION DATE ______ PAGE NO. ______

5.3 MASTER CONTROL SUBSYSTEM

5.3.1 Description

The Master Control Subsystem (MCS) is provided to monitor and control overall operation of the repowered plant. The MCS integrates the control of the solar system and the existing fossil plant. MCS diagram is shown in Figure 5.3-1. It consists of a master control (MC) and six subsystem controls. The MC is used to generate major load-demand signals, operation mode commands, and coordinate parallel operating subsystem controls. Description of the MC and subsystem controls are described below.

5.3.1.1 Master Control

The master control (MC) is a heirarchy control system. It consists of three elements as follows:

1) The unit load master which is used to transfer the MW-load demand signal to the turbine generator control from the area dispatch. To separate the plant from the dispatch system the unit load master is placed on manual control, with the operator establishing the plant electrical output.
2) The fossil/solar load split programmer processes the plant load demand signal (first-stage steam pressure) and apportions the demand ratio between the solar system and the fossil plant. The programmer has the capability of being set to place either system on a fixed-load and the other on load-following mode, provided the capacities and load-following range of each system are observed (7.5 to 50 MW for solar and 30 to 110 MW for fossil plant).

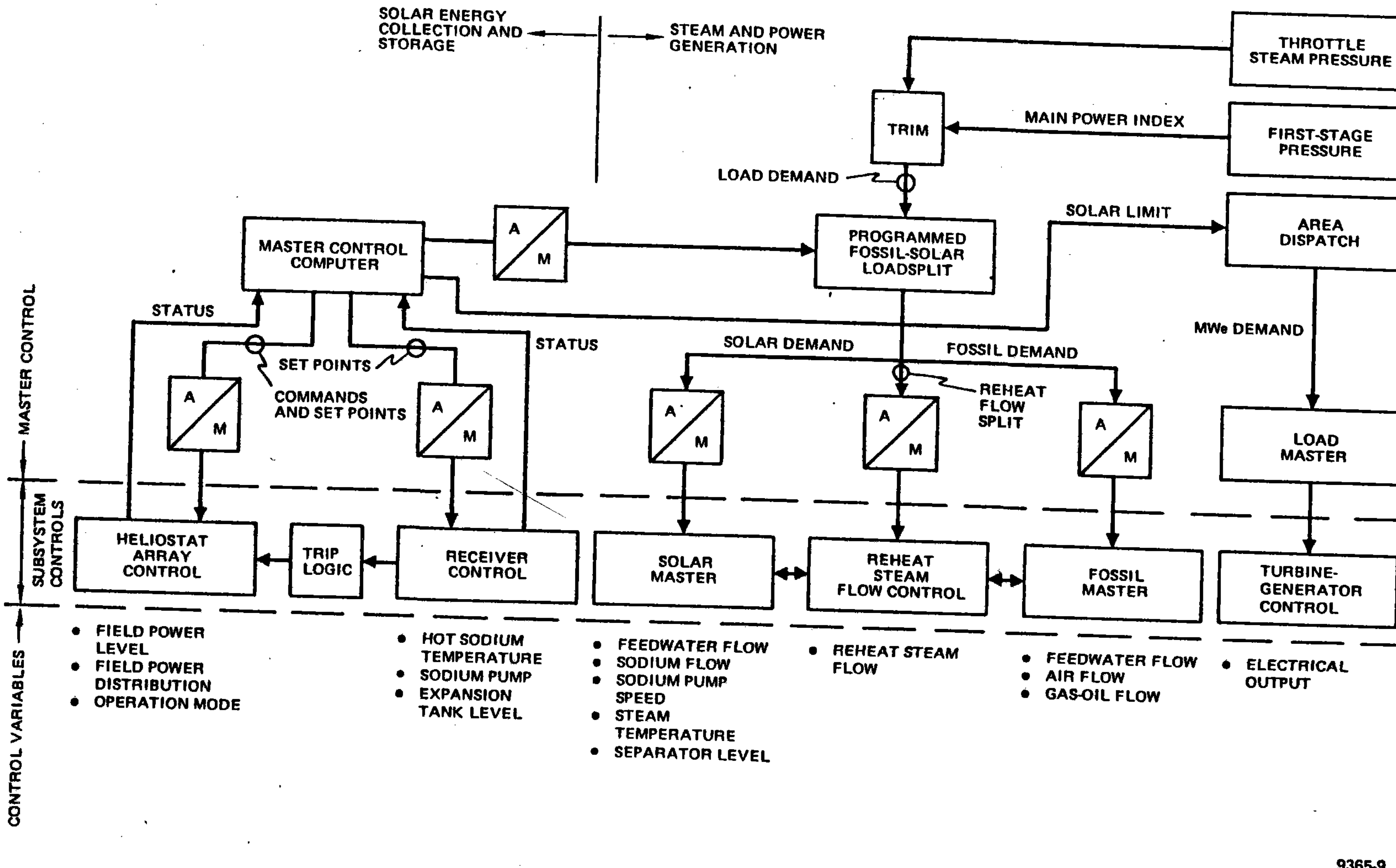


Fig 5.3-1 Integrated control System Diagram

3) The MC computer coordinates the operations of the heliostats and receiver through their controllers. It monitors the status of the components of these two subsystems, establishes their operation set points, and operating-mode commands. Software is provided to execute startup and shutdown routines of the heliostat and receiver subsystem controls. Solar energy availability and limits are determined by the MC computer based on Na inventories in the cold and hot tanks, discharge rate, weather, time, and insolation data, and receiver control valve positions. The results are made available to the area dispatcher for load dispatch information and can be used to manually or automatically adjust the fossil/solar load split programmer so that solar usage is maximized.

5.3.1.2 Heliostat Array Control

The Heliostat Array Control (HAC), through approximately 20 Heliostat Field Controllers (HFC), controls the operation of the 4,742 heliostats. Interfaces between the MCS computer and HAC are shown in Figure 5.3-2. There is a redundant HAC provided for the system to improve reliability. The HAC controls the heliostats in accordance with commands and set points established by the MC computer. In return, it feeds back heliostat status and operating data. The types of commands, operating set points, and status are also indicated in Figure 5.3-2. Detail description of the heliostat system is given in Section 5.1.

A loss of the cold tank pump will generate a trip signal which goes to the trip logic and directly to the HAC. It would command the heliostats to go into an emergency slew mode without going through the MC computer.

5.3.1.3 Receiver Control

The receiver control diagram is shown in Figure 5.3-3. It consists of three control programmers. The temperature programmer establishes the set point for control of sodium temperature at the outlet of each receiver panel. The panel Na inlet flow control valves will modulate as the outlet temperature deviates from the temperature set points. Na merged into the outlet header will have the

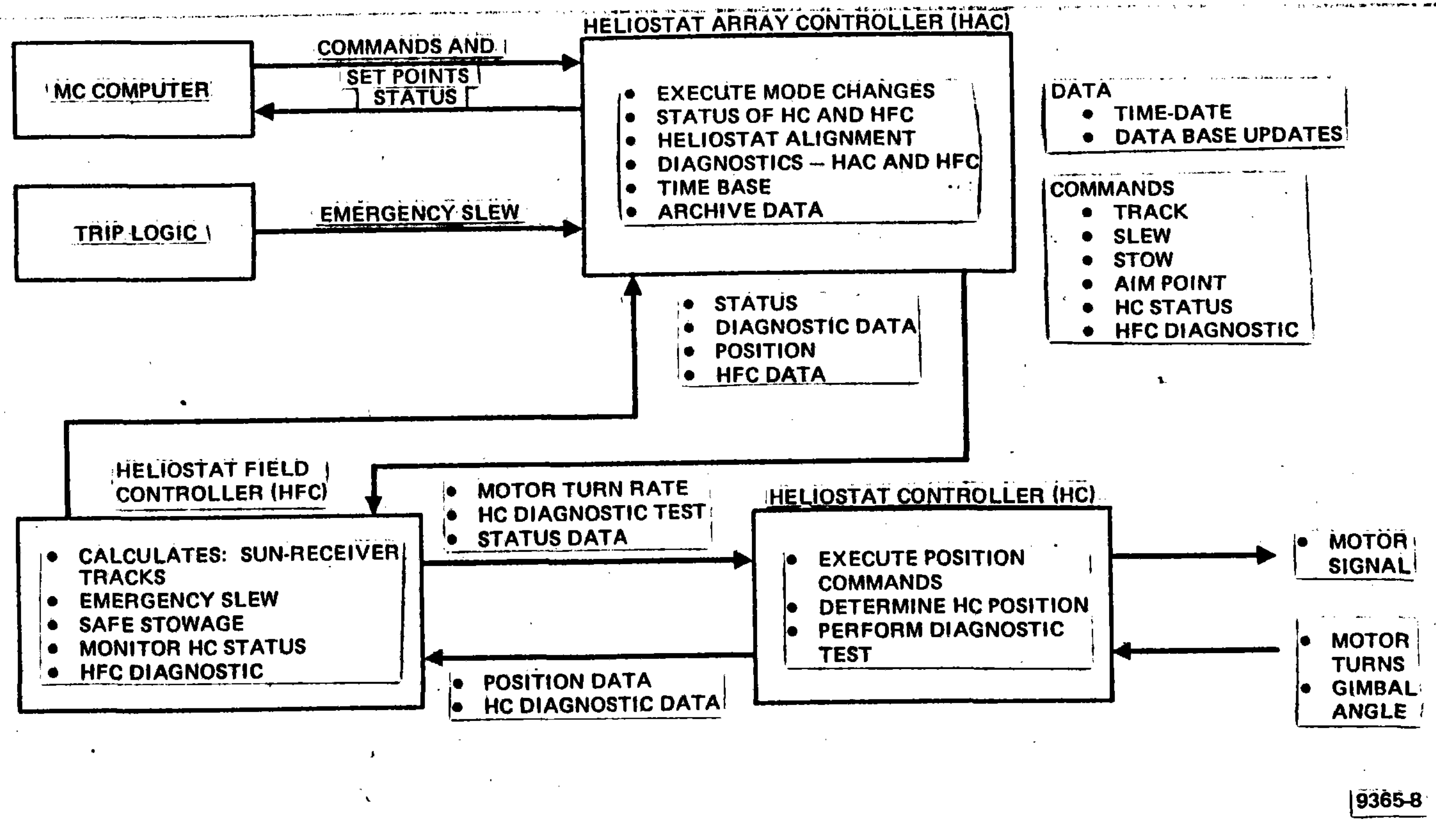


Figure 5.3-2 Heliostat array control Diagram

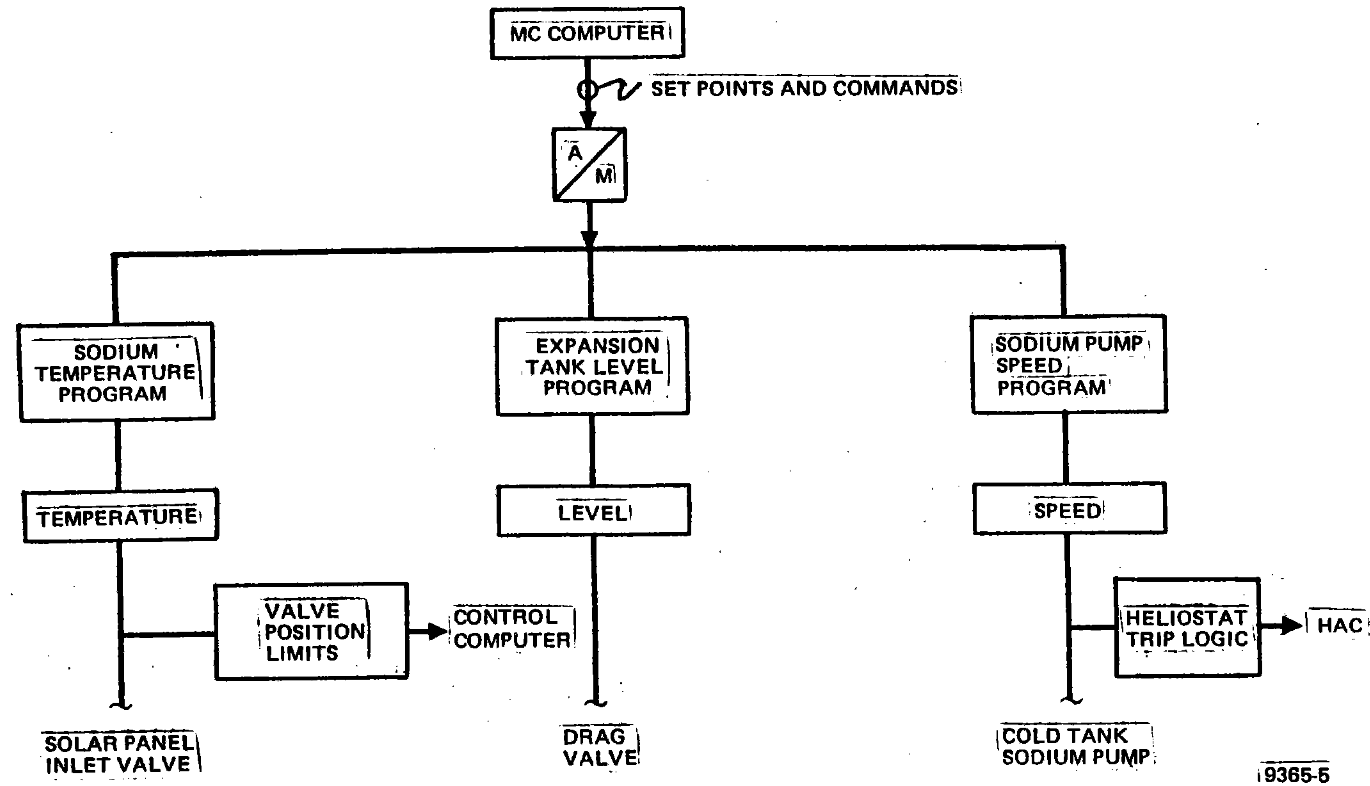


Figure 5.3-3 Solar Receiver Control Diagram

set point temperature (nominally 1100^{o}F) for storage in the hot tank. The pump speed programmer controls the gross speed of the receiver Na pump. The expansion tank level programmer controls the drag valve on the receiver Na outlet line. The drag valve serves to control Na level in the expansion tank as well as pressure of the flowing Na on the hot tank due to static head of the receiver.

5.3.1.4 Solar Master

The solar master diagram is shown in Figure 5.3-4. It consists of five controllers. The feedwater rate programmer establishes set points for controlling feedwater flow rate to meet load demand assigned by the load split programmer. The flow rate control is achieved by flow control valves. A blowdown flow is provided to maintain a predetermined water level in the moisture separator. The steam output mass flow is equal to the feedwater minus the blowdown mass flows. If the blowdown flow deviates from the set point (say, 5% of feedwater), a trim signal from the blowdown flow transmitter to the sodium flow controller will increase or decrease Na flow rate so that the desired quality of saturated steam is generated.

The sodium flow rate programmer controls sodium flows to the superheater and reheater. The superheater Na flow is trimmed by the feedwater blowdown flow as described earlier. The reheater Na flow is also trimmed to maintain steam temperature at the outlet tie point. If total Na flow demand exceeds the limits of the control valve operating range, the valve position limit signals will trim the steam generator Na pump speed which has a variable speed drive.

The steam generator sodium pump speed programmer establishes the pump speed to produce the required heat rate for the steam generators.

The mixing tank temperature programmer controls the sodium flow and temperatures during startup.

The steam temperature programmer establishes both the main steam and reheat steam temperature set points. The control of steam temperatures is accomplished by attemperation. The control valves on the superheater and reheater bypass lines control bypass saturated steam and cold reheat steam flows to the attempera-

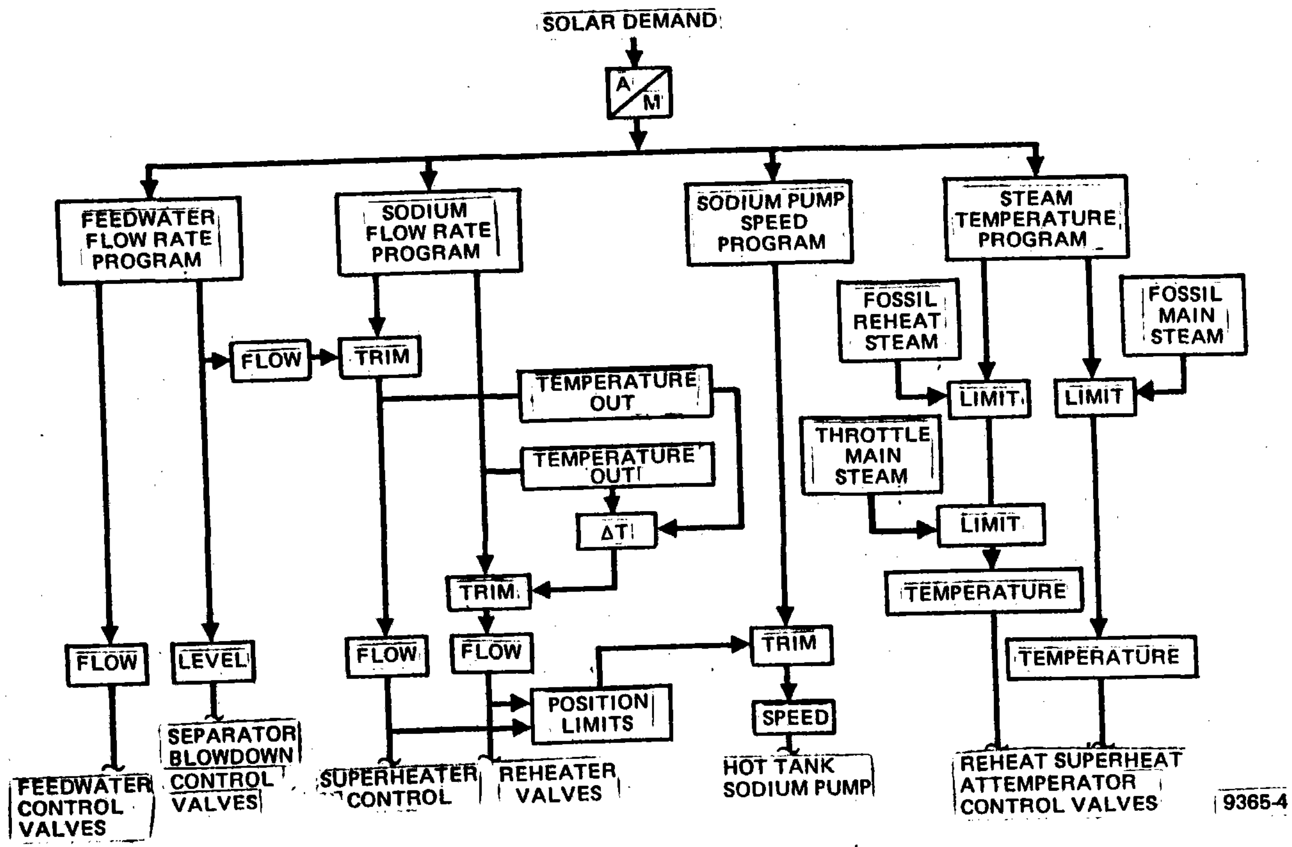


Figure 5-3-4 Solar Steam Control Diagram

tors. They mix with the superheat and hot reheat steam to achieve the required temperatures.

5.3.1.5 Reheat Steam Flow Control

The reheat steam flow controller regulates reheat steam flow to the solar and fossil reheaters. In steady-state combined full-load operations, the ratio of flow split will be similar to the programmed solar and fossil load split. The temperature response to load changes is different for the solar and fossil reheaters. The reheat steam temperature decreases slightly with increases in load for the solar unit, whereas the reheat steam temperature increases with increased load. Adjustment of the reheat flow split ratio between the two units is therefore required in response to load demand changes.

5.3.1.6 Fossil Master

The fossil master is an existing control system. Load demand signals from the load split programmer establish the feedwater flow rate and firing rate set points to meet the steam load demand. The existing feedwater controller has a three-element control. Typical three-element feedwater and gas- and other-fired boiler control diagrams are shown in Figures 5.3-5 and 5.3-6. The existing feedwater and firing control instrumentation diagrams are shown in Reference ___.

5.3.1.7 Turbine-Generator Control

The turbine generator controller controls electrical output of the plant by positioning the steam admission valve. A valve position feedback control loop is in cascade with the electrical output control. The MW control is open loop and is adjusted manually.

5.3.1.8 Miscellaneous Control

Controls which are not included in the MCS are water purification system controls and sodium system controls. These controls have local boards. However, the key parameters are displayed in the control room.

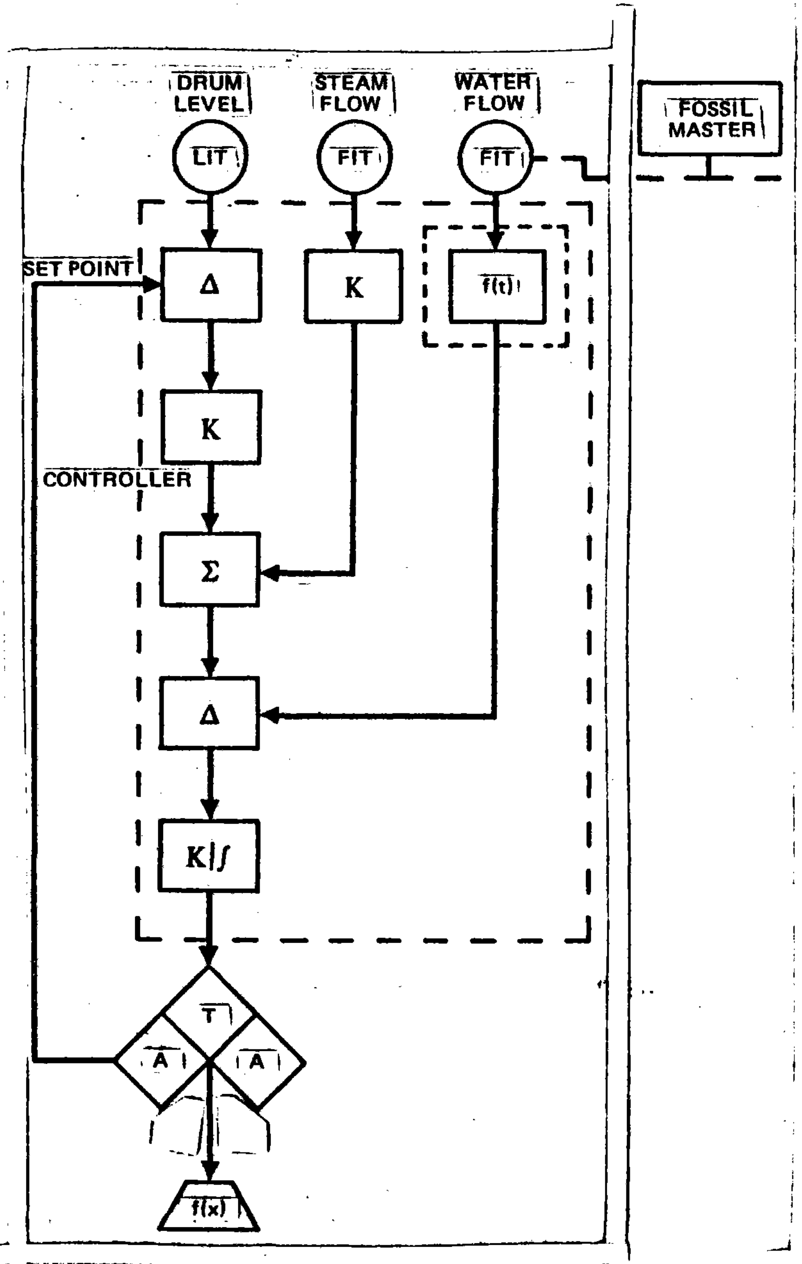


Fig 5.3-5 Three element feed water control

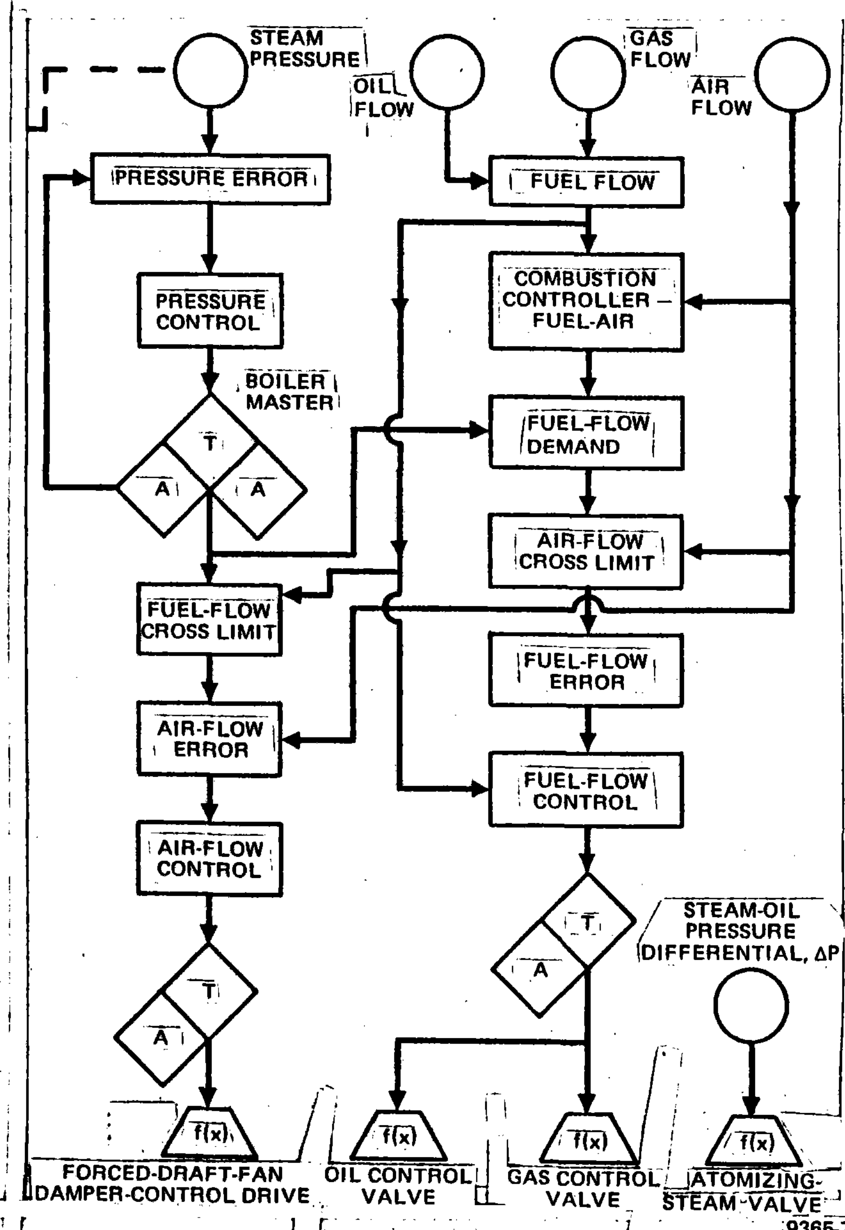


FIG 5.3-6 Diagram of combustion control for a gas- and oil-fired boiler

5.3.2 Functional Requirements

The master control system is required to monitor and control all operations of the repowering plant. The operation of each of the plant subsystems shall be automatic or manual. A data acquisition system is not required. However, the MCS shall independently provide the necessary data collection for plant performance evaluation. The operating modes to be controlled are shown in Table 5.3-1.

The master control subsystem interfaces are quite complex since they involve every other system. The top-level interfaces are shown in Table 5.3-2.

TABLE 5.3 1
SOLAR REPOWERING
OPERATING MODE OPTIONS

	Operation	Energy Source		Electric Power Level	Thermal Power Level		Storage, Rate		Comments
		Solar	Fossil	Total	Solar	Fossil	Charge/	Discharge	
1.	Normal Combined	X	X	P-F	P-F	P	0-F	-	Choice of Power Level, with or w/o Storage Charge
2.	Solar Only	X	-	P	P-F	0	0-F	-	Same as Above
3.	Fossil Only	-	X	P-F	0	P-F	-	-	Choice of Power Level
4.	Storage Charge	X	-	0	P-F	0	P-F	-	Choice of Charge Rate. If Combined w/Fossil Operation, Same as No. 1
5.	Storage Discharge	X	-	P	P-F	0	-	P-F	Choice of Power Level
6.	Storage Discharge Combined	X	X	P-F	P-F	P	-	P-F	Choice of Power Level

P - Partial; F - Full (w/reference to applicable system); P-F, 0-F - Parameter Range; 0 - Off

5.3.3 Design Characteristics

The primary design characteristics of the MCS are:

1) The controls of the solar energy storage and the steam generating subsystems are designed for independent operation. This provides the flexibility for performing all the operating modes described in Table 5.3-1.
2) Each of the control subsystems can be operated automatically or manually.
3) The solar master has a similar design to the fossil master. Only analog controls are used. No significant revision of the existing fossil plant controls is required.
4) Either one (solar or fossil) of the masters can be placed on load following mode. The minimum load following power range is 7.5 MW for solar and 30 MW for fossil.
5) The MCS control consoles are integrated into one unit and housed in the existing control room of Unit No. 5. All key controls and monitors are physically and visually accessable to the operator.

The master control subsystem functional design is shown in the piping and instrumentation diagram in Figure 4.1-1. The MCS controls are entirely located in Unit 5 control room. The control room layout is shown in Figure 4.4-2. It can be seen that the existing fossil control remains intact and the solar master controls are arranged identical to the fossil master.

5.3.4 Operating Characteristics

The MCS controls and monitors all plant operation, including startup and shutdown as well as operating mode changes. Characteristics of these control operations are discussed below:

5.3.4.1 Normal Combined Mode

In the normal combined mode, power demand is satisfied by output of both the solar and the fossil steam units. The load split programmer (Figure 5.3-1) apportions the ratio of demand for each unit. The normal combined mode is initiated at sunrise and terminated at sundown or upon depletion of hot sodium inventory. When a demand is set for the solar unit, the various programmers (Figure 5.3-2) of the solar master will automatically establish operating set points in accordance with load schedule to control feedwater flow, Na flow, Na pump speed, steam temperature, and separator water level to meet the load split programmer assigned demand. Reheat steam flow is programmed in accordance with load split ratios. These variables can also be manually and separately controlled to satisfy load demand requirements.

The Na steam system is designed such that the temperatures and temperature distributions of the system are not materially changed by an overnight shutdown. Therefore, the system will be ready for startup again in the morning. Startup of the solar unit is controlled manually so that the controlled variable can be adjusted independently to minimize mismatches of the steam conditions between two units. When operating conditions of both units are balanced, the dispatch power load demand can be imposed on the system and the load split adjusted to optimize usage of solar energy.

Transition from combined to the fossil-only mode is made by gradual reduction of the solar output ratio. The rate of change is consistent with the ability of the fossil boiler to make load changes.

5.3.4.2 Solar-Only Mode

In the solar stand-alone operation, the load split is set on 1005 solar and the solar master will automatically program set points for feedwater, Na flow, and Na temperature to meet power demand requirements. Since it is in the 100% solar operating mode, the cold reheat valve to the fossil reheater will be closed and the valve to the Na reheater in the full open position. If the solar steam unit is manually operated, each of the control variables will be adjusted by the operator in accordance with load schedules.

The solar-only mode can be initiated with the plant in the shutdown condition or else can be accomplished by transition from the combined mode by terminating the output of the fossil boiler output. The latter is carried out in accordance with the existing fossil plant procedures. The response of the solar unit is such that it will be capable of picking up the load at rate compatible with fossil turndown.

Startup of the solar-only mode with the turbine at ambient temperature requires steam temperature in the range between 500 to 700^{o}F for heating and rolling. Reduction of Na temperature required for producing steam in this temperature range is obtained by mixing. The flow diagram of the solar cold startup system is shown in Figure 5.5- 6 .

CONSTRUCTION COST ESTIMATE

CLIENT ____________________

DESCRIPTION Baseline

5500 Mi[illegible]

LOCATION ____________________

CONT. NO. ____________________

MADE BY ____________________

PROJECT AI Texas Electric

APPROVED ____________________

A/C NO.	ITEM & DESCRIPTION	MAN HOURS	ESTIMATED COST			
			LABOR	SUBCONTRACTS	MATERIALS	TOTALS
A	Excavation & Civil					
B	Concrete					
C	Structural Steel					
D	Buildings	1920				
E	Machinery & Equipment		34.3		55.8	90.1
F	Piping					
G	Electrical	—	—		—	—
H	Instruments					
J	Painting					
K	Insulation					
	DIRECT FIELD COSTS					90.1
L	Temporary Construction Facilities					
M	Construction Services, Supplies & Expense					
N	Field Staff, Subsistence & Expense					
P	Craft Benefits, Payroll Burdens & Insurances					
Q	Equipment Rental					
	INDIRECT FIELD COSTS					35.2
	TOTAL FIELD COSTS					125.3
R	Engineering					1080.6
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Major Equipment Procurement					
T	Construction Management					
	TOTAL OFFICE COSTS					1080.6
	TOTAL FIELD & OFFICE COSTS					1205.9
U	Labor Productivity					—
V	Contingency					
W	Fee					
	TOTAL CONSTRUCTION COST					1205.9

DATE __________ REVISION NO. __________ REVISION DATE __________ PAGE NO. __________

5.4 FOSSIL ENERGY SUBSYSTEM

The fossil energy subsystems consist solely of the existing fossil-fired steam generator and its accessories described herein. No modifications or additions are contemplated to this subsystem, save interfacing of the combustion and flow controls. The solar/nonsolar interfaces are described in the EPGS Section 5.6.

5.4.1 Description

Permian Basin Unit No. 5 fossil boiler supplies steam to a Westinghouse Electric Corporation turbogenerator, 100 MW, 3600 rpm, 10 M Pa (1450 psig), 537.8^{o}C(1000^{o}F)/537.8^{o}C(1000^{o}F). The boiler is an outdoor-type pressurized turbo-furnace with complete accessories furnished and erected by Riley-Stoker Corporation. The single-drum front and rear-fired steam generator is designed to burn natural gas as primary fuel and bunker-C fuel oil as secondary fuel.

At maximum opeeration, the unit will deliver 103.93 kg/S (825,000 lb/h) of steam continuously at 10.69 M Pa (1550 psig), 540.55^{o}C (1005^{o}F) steam temperature at the superheater outlet, and reheat 91.71 kg/S (728,000 lb/h) from 380^{o}C (717^{o}F) to 540.55^{o}C (1005^{o}F), when supplied with feedwater at 236.67^{o}C (458^{o}F) firing on gas or oil. At a capacity of 100.78 kg/S (800,000 lb/h) when firing natural gas with 8% excess air leaving the furnace, the efficiency of the unit is guaranteed to be not less than 84.1%. Associated components include a combination radiant and convection-type superheater, a convection-type reheater consisting of primary and high-temperature sections, a convection-type economizer, two air preheaters, two forced draft fans, etc.

Steam temperature is controlled automatically by means of damper bypassing and proportioning gas flow through low-temperature superheater, low-temperature reheater, and bypass sections. Bailey Meter Company steam temperature controls permit automatic or manual control of the dampers from the BTG board in a central control room.

An automatic combustion control including controllers, automatic valves, operating units, selector valves, gauges, and other equipment was furnished by Republic Flow Meters Company. This control regulates the flow of air and fuel gas supply to the furnace and furnace draft in accordance with metered requirements. Main steam pressure is translated to a master loading pressure to the fuel and air flow regulators.

Steam temperature is controlled automatically by means of damper bypassing. Bailey Meter Company steam temperature controls permit automatic or manual control from the BTG board.

Three-element automatic feedwater control was furnished by Republic Flow Meters Company. The feedwater valve is a .2032 by .1524 by .2032 m (8X6X8 in.), 10.34 M Pa (1500 psi) standard of chrome molybdenum steel, designed to pass 118.42 kg/S (940,000 lb/h) of water with a pressure drop of approximately 517.24 K Pa (75 psi); changes in steam flow, feedwater flow, or drum level vary the output of compressed-air transmitters connected to the master regulator, which integrates the elements to maintain a predetermined water level in the steam drum.

5.4.2 Functional Requirements

The control mode for Permian Basin Unit No. 5 is turbine lead, or boiler following mode. A change in governoring valve psoition from either automatic load dispatching, manual governor control, and governor response will cause a change in first-stage pressure. This pressure signal is transmitted to the master control system that will ultimately change the firing rate in the boiler by increasing or decreasing the gas and air flow until turbine throttle pressure is restored to normal. The first-stage pressure signal is also directly related to steam flow, so it is transmitted to the feedwater three-element flow control as the steam flow input signal, and will effect an increase, or decrease, in feedwater flow that is subsequently trimmed to normal level by the drum level transmitted control signal. The automatic steam temperature controls adjust to maintain the correct steam temperature.

The load range on the unit with all controls on automatic is from about 40 MW up to 100 MW, or a 2.5:1 turndown.

The fossil energy subsystem shall retain the same operating capability as existed prior to repowering. The added requirements for the fossil energy subsystem include operating in the combined mode with the solar subsystem as indicated in Table 5.3-1. The fossil energy subsystem shall be capable of operating at the minimum power level (~30%) for extended periods of time.

Nonsolar subsystem interface requirements are shown functionally in Figure 4.6-3. Top-level interface requirements are highlighted in Table 5.4-1.

5.4.3 Design Characteristics

All equipment at Permian Basin Unit No. 5 is of outdoor-type construction. The site is located 6.44 km (4 miles) west of Monahans, Texas, in Ward County, at an elevation of approximately 808.3 m (2652 ft) above sea level.

The boiler major fuel is natural gas with bunker-C fuel oil as emergency standby fuel. Twelve Riley-Stoker direction flame burners, combination gas, and mechanical atomizing fuel oil are furnished with the boiler. One row of six on the front of the boiler and one row of six on the rear of the boiler. Walkways are of galvanized steel grating. The 2.44-m(8 ft)-diameter stack is supported by the boiler structural steel. Two air heaters are horizontal-flow Ljungstrom Type 22, 1/2-H-54, having revolving heating elements mounted in baskets.

Additional design characteristics are described in Appendix B.

5.4.4 Operating Characteristics

Permian Basin Unit No. 5 is a base load unit. In the past, it has operated predominantly in a fuel load mode due to favorable fuel contracts.

Table 5.4.1

Top-Level Fossil Energy Subsystem Interfaces

The unit can operate over a load range of about 40 MW to 100 MW (2.5:1 turndown) with all controls on automatic. Some burners have to be cut out in the boiler at lower loads. Manual operation can extend the turndown to below the required 30% level.

The operating characteristics in the combined and solar-only operating modes is shown in Figures 4. - and . In the combined-mode, feedwater is supplied to the boiler at 236°C (457°F), 10.8 M Pa (1567 psi). The feedwater flow rate is 60.8 kg/S (134 lbm/S). 60.5 kg/S (133.3 lbm/S) of superheated steam will be produced at 541°C (1005°F), 10.4 M Pa (1505 psi). The difference in flows represents boiler drum blowdown. Cold reheat steam is supplied to the boiler at a rate of 53.5 kg/S (118 lbm/S), with a temperature of 381°C (717°F), and pressure of 3.2 M Pa (458 psi).

In the solar-only mode, the boiler will be valved off.

5.4.5 Performance Estimate

The heat balance for this unit indicates the following performance:

Gross generation, kW	- 118,490
Auxiliary power, kW	- 5,690 (4.8%)
Net output, kW	- 112,800
Boiler efficiency, %	- 85
Net station heat rate	- 10.825 x 10^6 J/kWh (10,260 Btu/kWh)
Turbine nameplate rating, kW	- 100,000

Other conditions:

Maximum expected throttle flow	- 104.56 kg/S (830,000 lb/h)
Back pressure	- 5.07 K Pa (1.5 in. of Hg absolute)
Blowdown	- .529 kg/S (4200 lb/h)
Cycle losses	- .441 kg/S (3500 lb/h)

5.4.6 Costs/Performance Tradeoffs - Not Applicable

5.4.7 Top-Level Cost Estimates - Not Applicable

5.5 ENERGY STORAGE SUBSYSTEM

The following section discusses the description, requirements, design, and operating characteristics, performance, and cost estimate for the energy storage subsystem. Also, included in Section 5.5.3 is a description of some of the auxiliary sodium service equipment and the startup system.

5.5.1 Description

The Energy Storage Subsystem (EES) consists of: two cylindrical, API-type, insulated sodium storage tanks; one hot and one cold, a centrifugal, variable-speed sodium pump, interconnecting sodium piping with the receiver subsystem, argon cover gas pressure equalization and makeup lines, and a bermed tank containment area. An overall diagram of the subsystem showing the components and the physical subsystem interfaces is shown in Figure 5.5-1.

5.5.2 Functional Requirements

The Energy Storage Subsystem Provides the means of storing energy which is available from the receiver, provides supplemental thermal energy when the thermal power from the receiver is less than that required for plant operation at nameplate solar electrical rating, provides all thermal energy for operation of the plant in the standalone mode at nameplate solar electrical rating (for the specified time period), and supplies energy which supplements the fossil boiler when the plant operates in a combined mode and the receiver operates at less than nameplate rating.

In general, the EES must be designed to maximize the economic recovery of useful energy from storage and to minimize, with cost-effective considerations, energy storage losses during the various operating modes. The EES shall also provide complete buffering between the receiver and steam generators. Operation and maintenance requirements must be provided for in the design, and the thermal storage subsystem must be compatible with the other subsystems during normal, transient, and emergency operations. The thermal storage subsystem functional requirements are given in Table 5.5-1. The energy storage subsystem top level interface requirements are shown in Table 5.5-2.

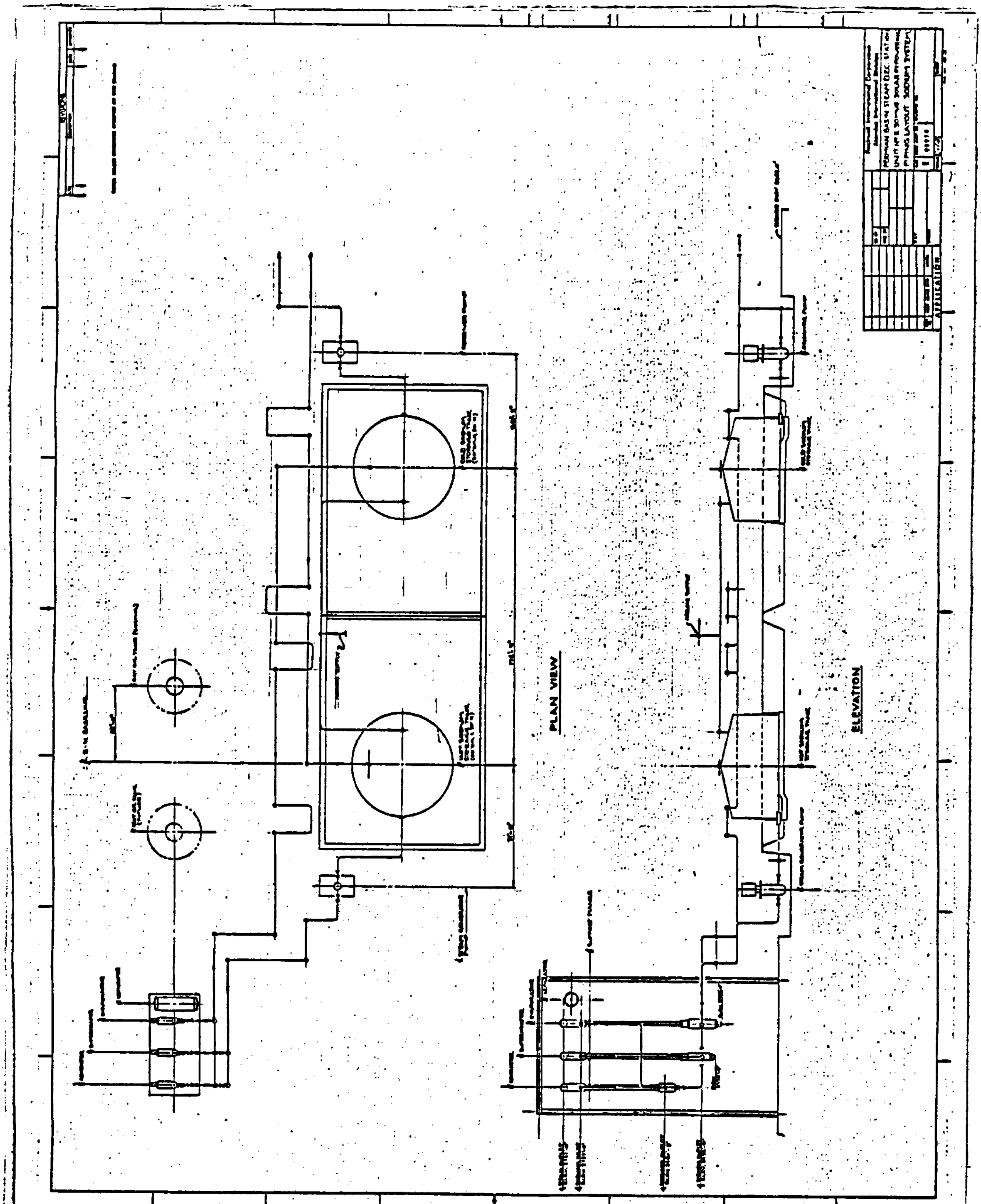

PLAN VIEW
ELEVATION
PERMIAN BASIN STEAM ELEC. STATION
UNIT NO. 8 SOLAR REPOWERING
PIPING LAYOUT SODIUM SYSTEM

FIG. 5.5-1

TABLE 5.5-1

ENERGY STORAGE SUBSYSTEM REQUIREMENTS

Storage Capacity at Full Solar Output (hours)	1
Storage Capacity (MWt-h)	128.3
Storage Fluid	Sodium
Hot Tank Temperature, ^{o}C (^{o}F)	593 (1100)
Cold Tank Temperature, ^{o}C (^{o}F)	288 (550)
Maximum Charging Rate (MWt)	160
Maximum Extraction Rate (MWt)	128.3
Cover Gas	Argon
Pressure	Atmospheric
Reduced Power Operation Range (%)	10-100

TABLE 5.5-2

STORAGE SUBSYSTEM INTERFACES

Nomenclature	Location	Subsystem	Description
RS/SS1	See Table 5.2-2		
RS/SS2	See Table 5.2-2		
RS/SS3	See Table 5.2-2		
RS/SS4	See Table 5.2-2		
RS/MCS1	Cold Tank Level Transmitter Wiring	Master Control	Cold Tank Level Signal
RS/MCS2	Hot Tank Level Transmitter Wiring	Master Control	Hot Tank Level Signal
RS/MCS3	Steam Generator Pump Speed Transmitter Wiring	Master Control	Steam Generator Pump Speed Signal
RS/MCS4	Steam Generator Pump Speed Controller Wiring	Master Control	Steam Generator Pump Speed Demand Signal

The EES is required by the System Requirement Specification to charge at a maximum rate of 100% of receiver thermal power or a nominal 160 MWt. The maximum discharge rate is 128.3 MWt for electric power generation at 50 MWe gross.

5.5.3 Design Characteristics

5.3.3.1 Energy Storage Subsystem

The all-sodium EES concept for solar repowering of Permian Basin Unit 5 is shown in Figure 5.5-1. The subsystem consists of one hot and one cold sodium storage tank, a sodium pump, interconnecting sodium piping, interconnecting cover gas vents, makeup lines and makeup system, a startup system, and a bermed sodium containment area. A pressure reducing device, physically and functionally located in the receiver subsystem (see Section 5.2), is required to maintain the hot tank pressure at atmospheric. Hot liquid sodium from the receiver subsystem is stored in the hot storage tank at energy rates up to 160 MWt, which corresponds to a flow of 1.47 x 10^6 kg/h (3.24 x 10^6 lb/h). Sodium is drawn from the hot storage tank at energy rates of up to 128.3 MWt 1.20 x 10^6 kg/h (2.71 x 10^6 lb/h) to generate steam for the Electric Power Generating Subsystem. Cold sodium from the steam generator units flows to the cold storage tank. During the day, hot sodium is accumulated by the hot tank in a sufficient quantity to store up to 1 h of operation at 100% rated solar power. With this storage arrangement, plant operation is always from storage. The steam conditions provided are the same regardless of whether the receiver loop is operating or not.

The storage tanks are 18.3 m (60 ft) in diameter with a height of 8.5 m (28 ft). The hot tank operating at 593^{o}C (1100^{o}F) is made of stainless steel; the cold tank at 288^{o}C (550^{o}F) is made of carbon steel. The tanks operate at static head pressures only in order to minimize cost, thus the requirement for a pressure-reducing device to dissipate the tower static head. A steam generator pump in this system moves the hot sodium through the steam generator units to the cold storage tank. The receiver pump identified in the receiver subsystem description charges the hot storage tank. The steam generator pump is similar to the Hallam pump with approximately the same flow requirements. The developed head for this pump is 52 m (170 ft) at 0.40 m^3/s (6,420 gpm).

The design characteristics of the all-sodium Thermal Storage Subsystem are presented in the Design Data Sheets of Appendix B. A layout drawing of the high-temperature storage tank constructed with stainless steel is shown in Figure 5.5-2. The low-temperature tank is similar, only using carbon steel. The insulation thickness of the hot tank is 30.5 cm (12 in.). The cold tank design includes 15.3 cm (6 in.) of external insulation.

5.5.3.2 Auxiliary Sodium Service Equipment

5.5.3.2.1 Fluid Maintenance

The cleanup and measurement techniques for sodium involve mainly the measurement and removal of oxygen. These techniques are based on the fact that oxygen has a positive temperature coefficient of solubility. The saturation solubility curve of oxygen in sodium as a function of temperature is given in Figure 5.5-3. As can be seen in the curve, as the temperature is reduced, the oxygen precipitates out (as Na_2O). For purposes of measurement, the precipitate plugs a calibrated orifice at a measured temperature. The temperature at which this plugging occurs is referred to as the plugging temperature. Referring to Figure 5.5-4, to make a "plugging" determination, the plugging orifice is lowered into position by deenergizing the electromagnet. As the sodium flows through the unit, its temperature is slowly lowered until oxides precipitate out and plug the orifice. This begins to decrease the flow which is detected by the flowmeter. At a predetermined flow decrement, the electromagnet is energized opening the orifice, thus flushing it out. As full flow is established, the cycle repeats. The temperature signal from the thermocouple and the signal from the flowmeter are recorded on a strip chart. The temperature at which the flow just begins to decrease is referred to as the plugging temperature.

The maintenance of the fluid utilizes the same principle of precipitating the contaminants as the temperature is lowered. This is accomplished by means of a device called a cold trap, depicted in Figure 5.5-5. In this system, the sodium enters the economizer section of the cold trap vessel and is reduced in temperature to just above the plugging temperature. It then enters the wire mesh section of the cold trap where it is cooled to below the precipitation temperature by the air cooling air flowing over the outside of the trap. As the sodium cools,

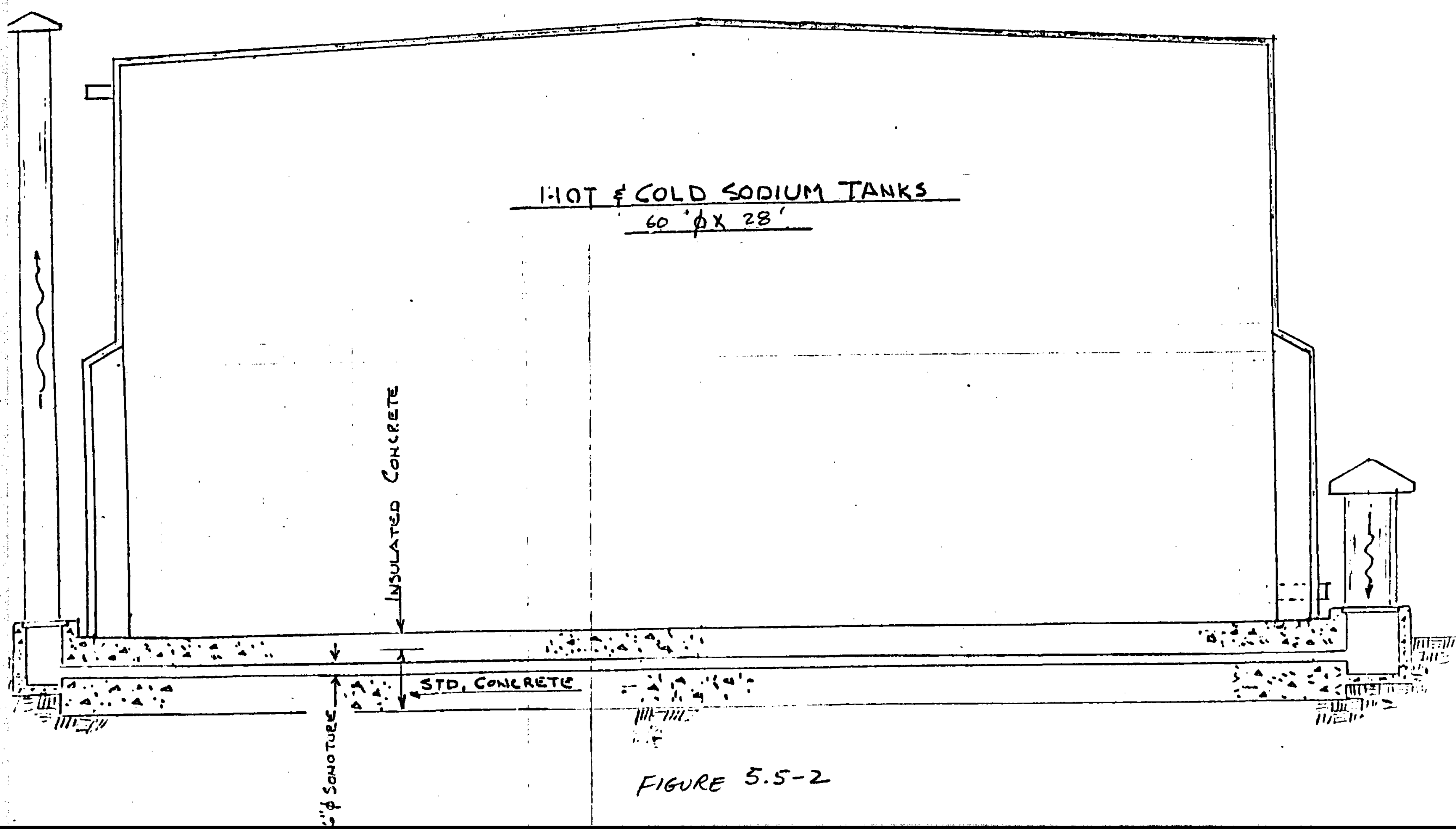

HOT & COLD SODIUM TANKS
60'ϕ X 28'
INSULATED CONCRETE
STD. CONCRETE
ϕ SONOTUBE

FIGURE 5.5-2

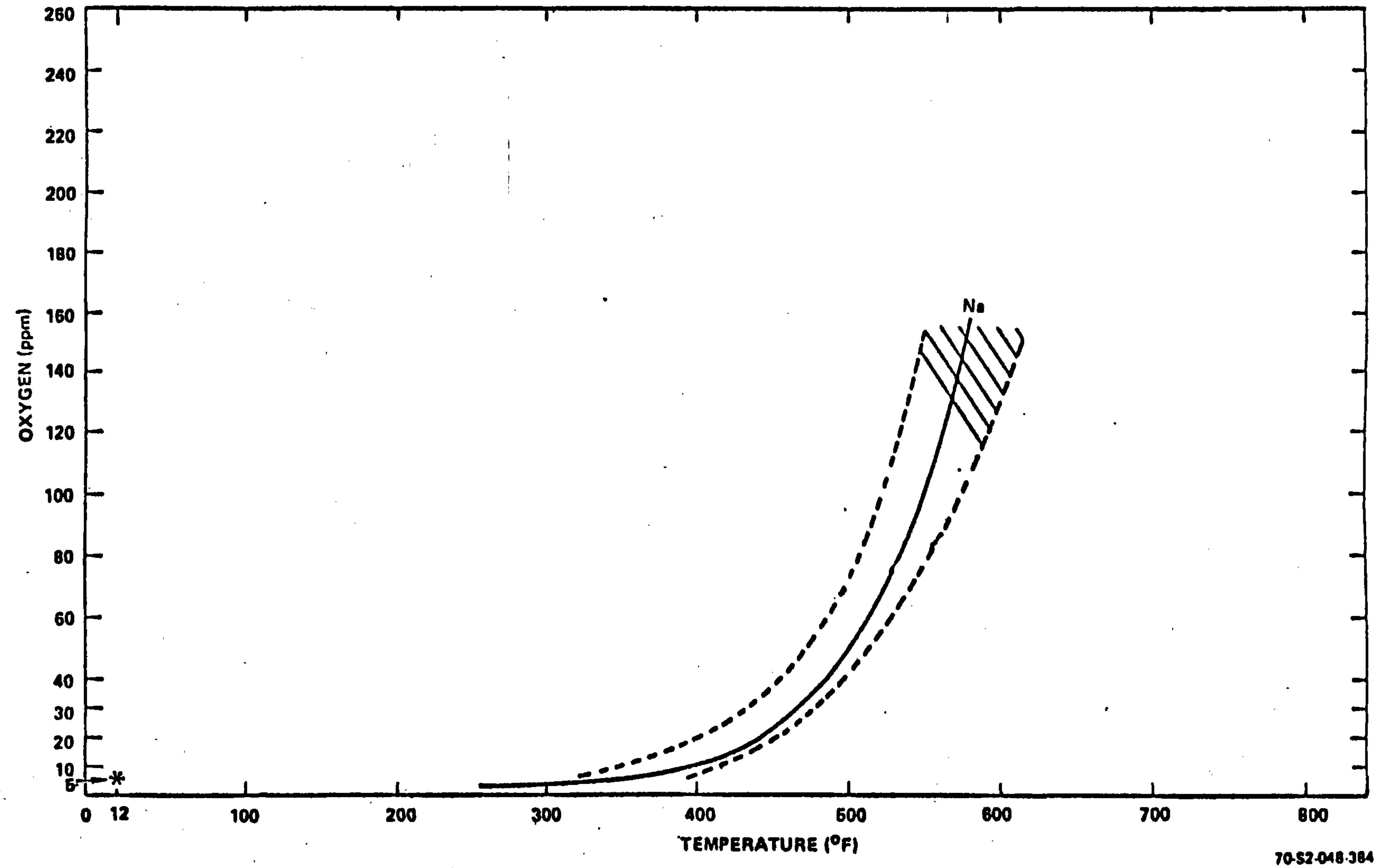


Figure 5.5-3 Saturation Concentration for Oxygen in Sodium

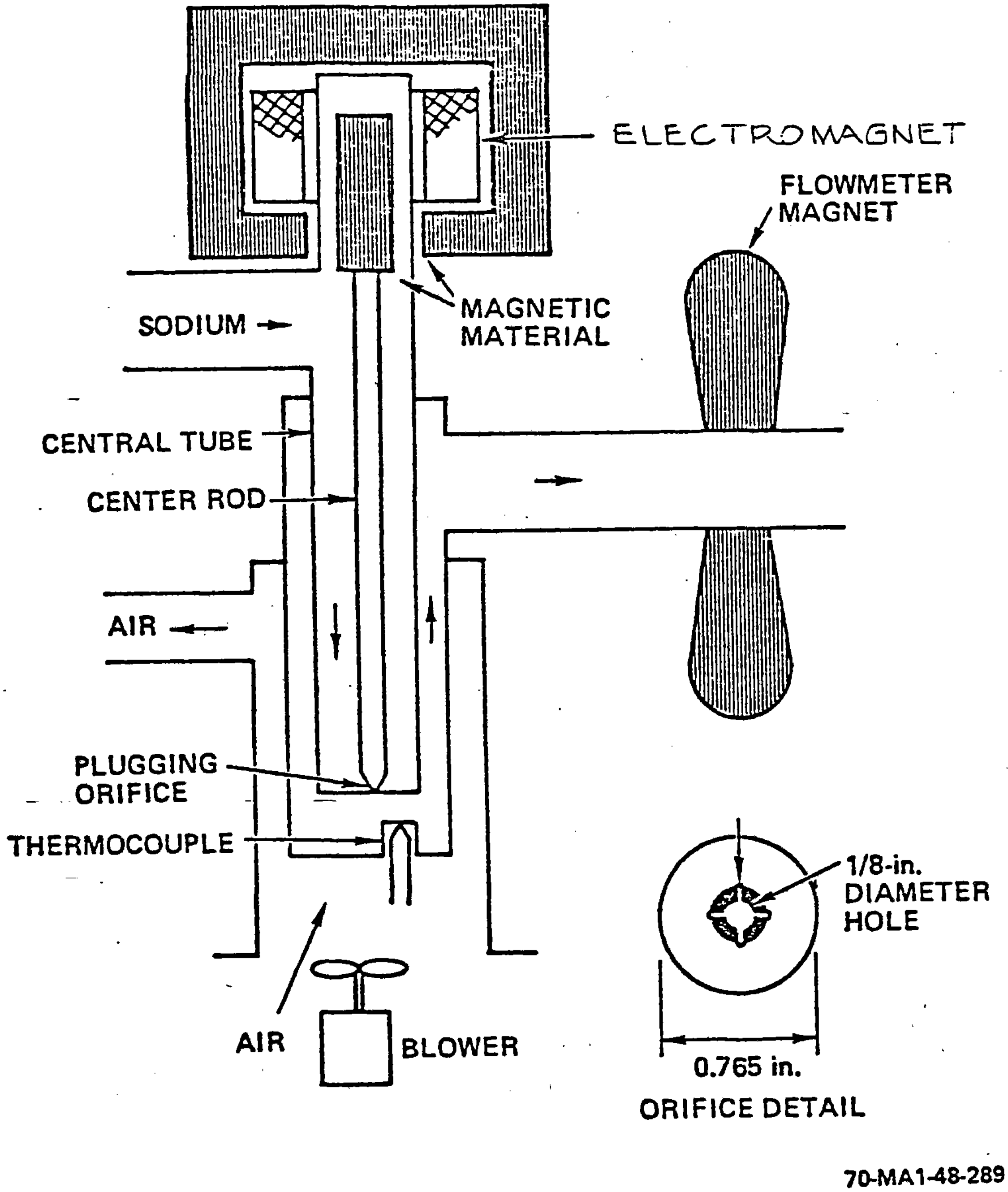


Figure 5.5-4 Plugging Meter Schematic

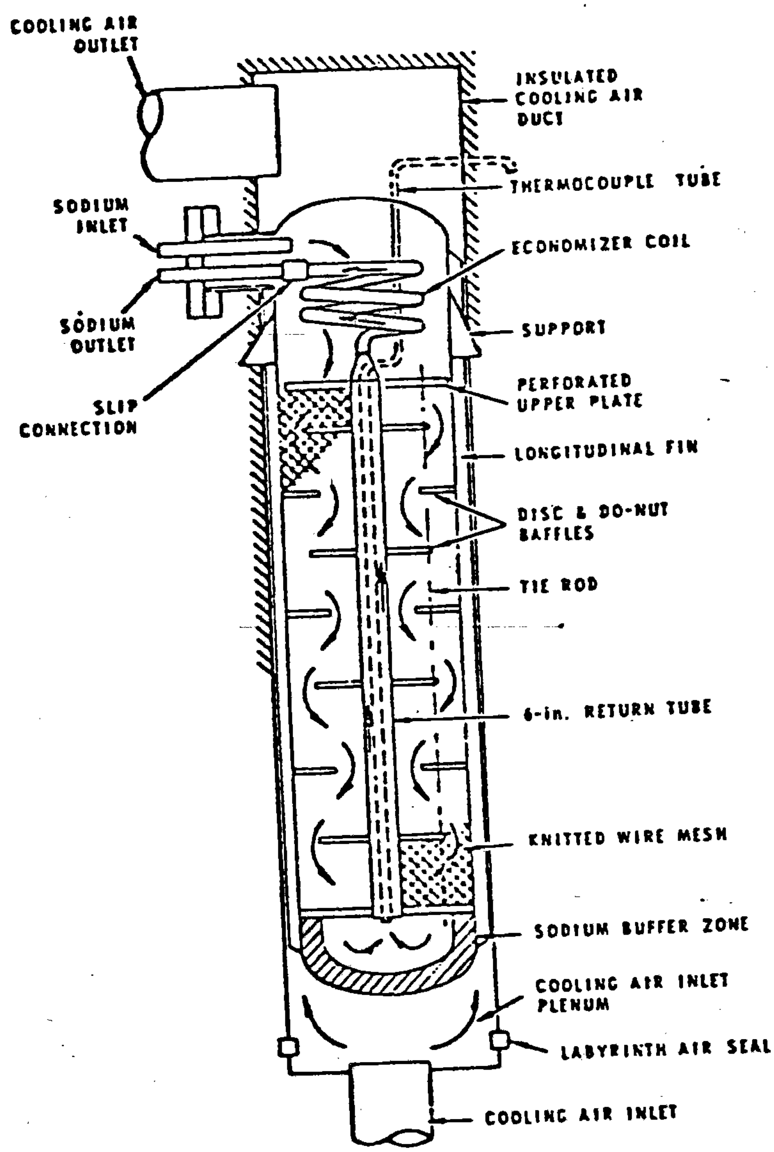


Figure 5.5-5 Schematic Hallam Cold Trap

Na_2O precipitates out and is collected in the knitted wire mesh. The sodium ultimately reaches a temperature of about 250°F which corresponds to an oxygen concentration of about 0.75 ppm. The clean sodium then flows up through the center tube and is heated in the economizer before being returned to the system. Experience has shown that in a system in equilibrium, the plugging temperature and the minimum cold trap temperature are identical.

During the initial filling operation, the sodium passes through a sintered filter at a temperature of about 300°F. The filter takes out the oxide and delivers sodium with an oxide concentration of about 2 ppm.

5.5.7 Leak Detection and Fire Protection

Leak detection techniques will vary, depending on the location of the expected leak.

The receiver and other unenclosed areas will be monitored by closed-loop television with a fixed image reference. At the initiation of a plume, which will change the image, an alarm signal in the control room will alert the operator and shutdown procedures will be implemented thus limiting the amount of sodium release. An alternate plan is to use acoustic emission techniques to detect leaks.

Sodium-sensitive aerosol detectors will be located in enclosed spaces.

Sodium catch pans will be provided under major components to confine the consequences of sodium leaks to a local controlled area until the component can be drained. The steam generator catch pans will be provided with a sump and pump to assure the catch pan remains dry. Nitrogen gas will be supplied for the purpose of flooding the catch pans if sodium combustion is initiated.

Approved fire suppressant extinguishers (Nax) will be placed throughout the facility.

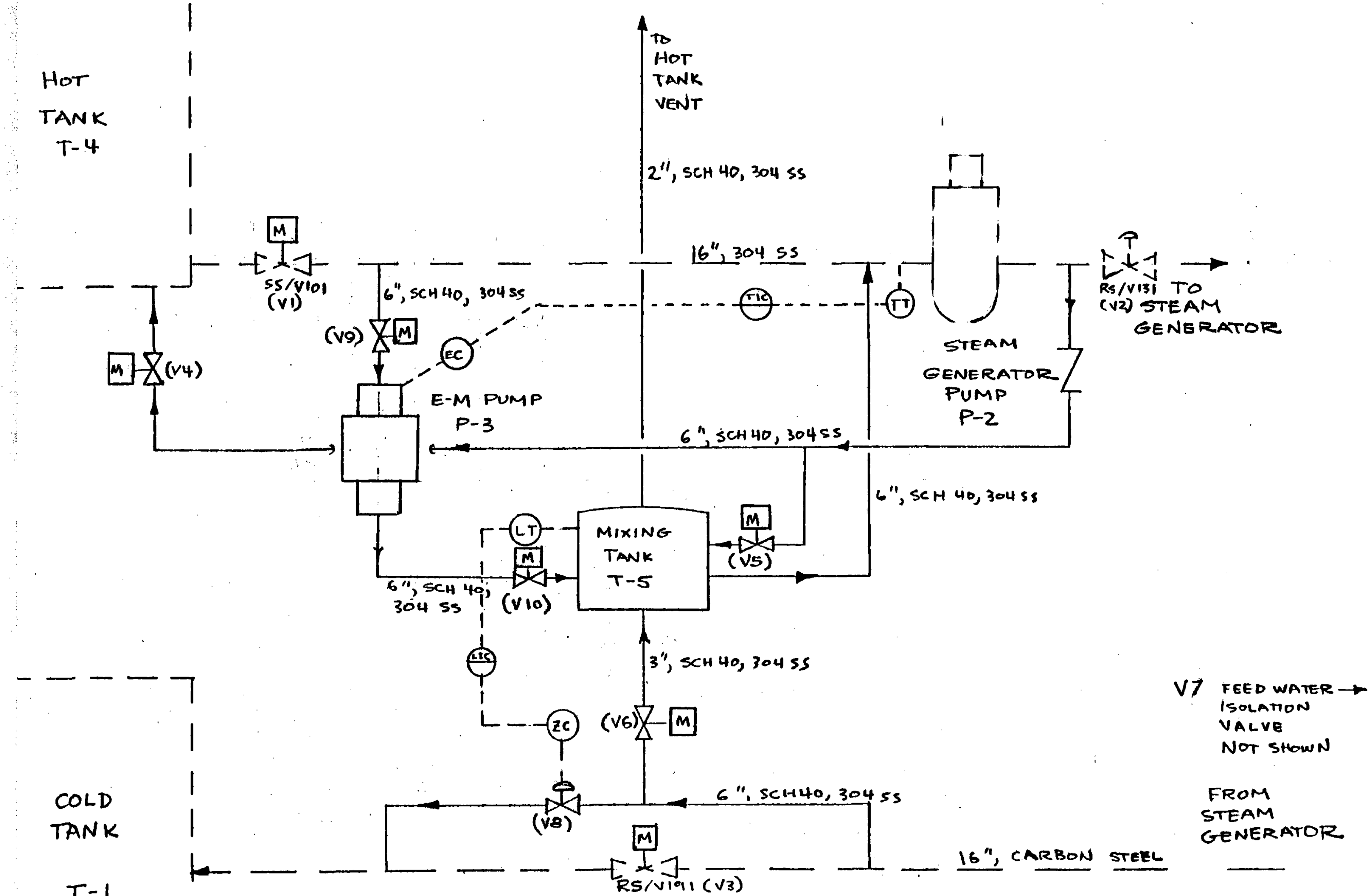


FIGURE 5.5-6 START-UP SYSTEM CONCEPTUAL PROCESS & INSTRUMENTATION DIAGRAM

5.5.3.3 Startup System

A startup system consisting of a 18.9 m^3 (5000 gal) mixing tank, a 0.006 m^3/s (100 gpm) electromagnetic sodium pump and associated piping and valves is provided in the energy storage subsystem in order to supply a tailored temperature, low flow sodium supply for cold startups. The system is shown in Figure 5.5-6 as the solid line equipment. A detailed description is included in the energy storage subsystem design data sheets in Appendix B.

5.5.4 Operating Characteristics

In the design, fully charged condition, the TES will contain a nominal 125 MWt-h of energy in the form of approximately 1,157,400 kg (2,552,000 lbm) of sodium at a nominal temperature of 593°C (1100°F) in the hot tank. The actual charged hot tank inventory conditions will vary as a function of the insolation history during charging, the time since charging ceased and the inventory requirements over 125 MWh-t for startup, shutdown, and steam generator pump NPSH maintenance. In the discharged condition, a small inventory 141,300 kg (311,000 lb), 0.6 m (2 ft) will be maintained in the hot tank to facilitate tank temperature maintenance and pump NPSH. Cold tank operating characteristics and inventories will be predicated on similar requirements.

5.5.4.1 Startup System

The startup system is operated as follows:

Establish Mixing Tank Na Level — Na level in the mixing tank is manually established for control of startup operation. It is accomplished by isolating V-1, V-2, and V-3 and operating the hot tank pump at the minimum rated speed. With V-5 open, Na in the mixing tank will continuously circulated. Since the main line valves (V-1, V-2, and V-3) are closed, there will be no forward flow through the steam generators. Initially, Na level in the mixing tank is in the vent line identical to the level in the hot tank. By opening V-4, some Na will be bled into the hot tank and lower the level in the mixing tank. When the desired level is obtained, V-4 will be closed and the Na level will remain constant.

Preparation of Startup Steam — With the Na pump operating at the minimum speed, Na circulation through the steam generators will be started by opening V-2 and closing V-5. Since there will be an appreciable amount of cold Na (~500^{o}F) in the steam generator circuit, the temperature of the mixing tank will be lowered as Na circulates when it reaches the predetermined limit, the mixing tank temperature controller will automatically open V-9 and start the EM pump to introduce Na into the mixing tank to maintain the set point temperature. Na pumped into the mixing tank is balanced by Na bleeding through V-8 which is actuated by the mixing tank level controlled to automatically maintain Na level. With Na circulating through the steam generator, steam for turbine cold startup can be produced by controlling feedwater flow and mixing tank temperature. When the mixing tank temperature approaches that of the hot tank, V-1 and V-3 will be opened, the mixing tank system can be locked out, and normal operation control established.

Shutdown of the solar-only operation can be initiated by automatically turning down its output to7.5 MWe and operating manually below7.5 MWe.

5.5.5 Performance Characteristics

While the hot tank and cold tank are extensively insulated with insulating concrete, both will experience heat losses on the order of 100-150 kWt each at an ambient temperature of 13^{o}C (55^{o}F).

Figure 5.5-7 shows the consequences of the thermal losses from storage as related to the resulting sodium temperature decay vs time for the hot tank for various levels of fluid content, i.e., full tank, half full, and with just the tank heel remaining. The curves indicate that an 8^{o}C (14^{o}F) fluid temperature drop may be expected over a 24-h period for a full hot tank. This is only about 2-1/2% of the initial temperature value. Figure 5.5-7 also expresses the thermal loss as a percentage of initial energy content for a full tank, half full, and tank heel remaining condition. For a full hot tank, this percentage loss is only about 9% after a 100-h standy period. This analysis indicates a high effectiveness for the storage system selected.

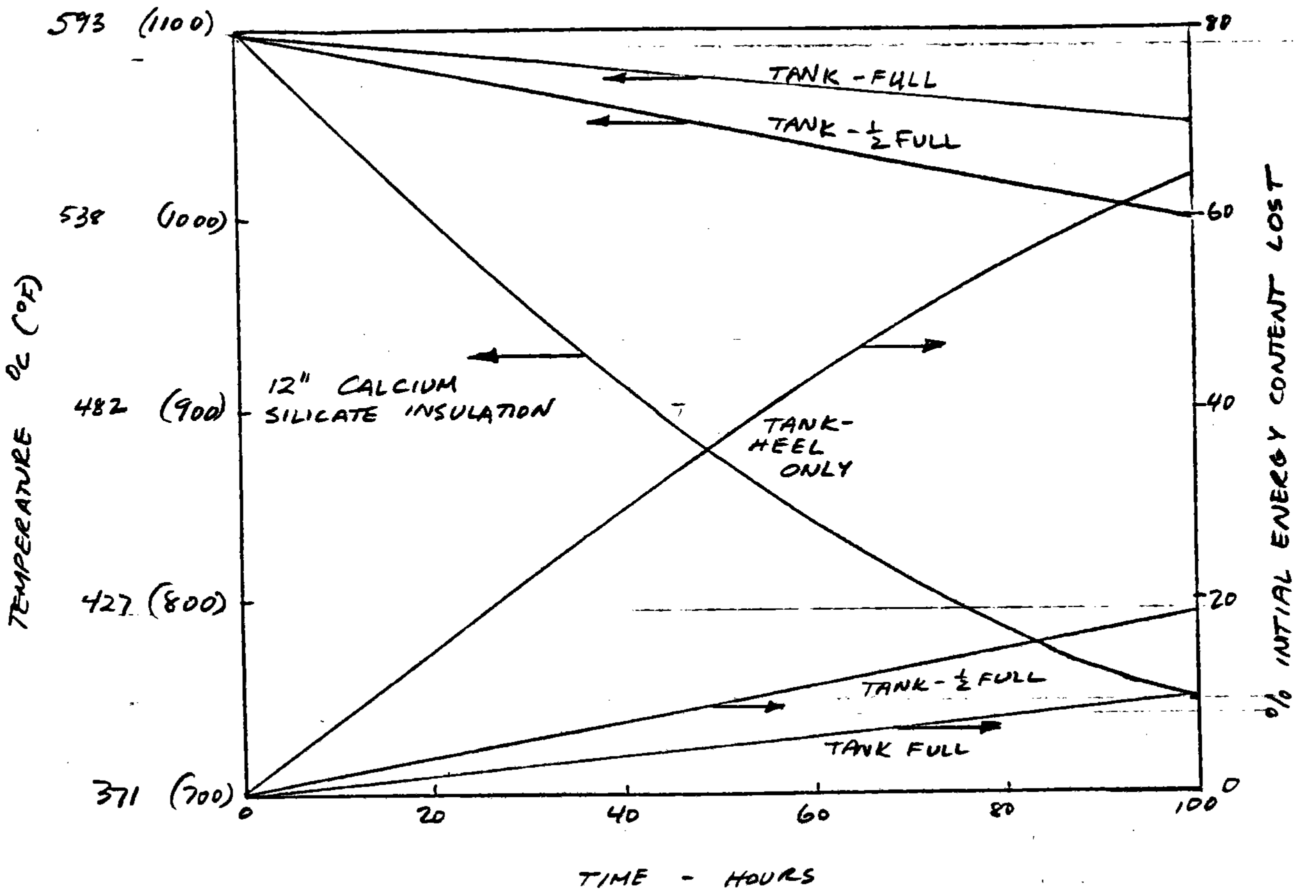


FIGURE 5.5-7 TEMPERATURE AND % HEAT LOSS VS TIME HOT TANK PERMIAN BASIN UNIT 5

5.5.6 Cost Performance Trade-offs

5.5.6.1 Storage Tank Trade Study

A trade-off study was conducted to determine the appropriate thermal storage tank design for the hot sodium fluid. The comparison was limited to two designs: (1) a traditional cylindrical tank design with domed roof and (2) a spherical tank design. Stainless steel was used for both of the designs with calcium silicate insulation, aluminum lagged, on the external of the vessel. The storage tank characteristics are given in Table 5.5-3.

5.5.6.2 Spherical Configuration

The support of the 14.5 m (47.5 ft) diameter SS sphere is with either 24 0.25 m (10 in.) Schedule 40 pipe columns or 12 A-frames. The columns or A-frames. The columns or A-frames would be fastened to a skirt at the sphere equator and fastened to the concrete ring foundation at the bottom. Connecting joints will be pinned to accommodate the thermal expansion of the sphere. A sketch of the proposed spherical tank design is shown in Figure 5.5-8.

5.5.6.3 Cylindrical Configuration

The hot cylindrical tank is placed on a cylindrical concrete foundation comprised of two layers; the uppermost being insulating concrete and the lower layer being lightweight concrete. The cylindrical tank is allowed to grow radically (i.e., due to thermal expansion). The cylindrical tank design is shown in Figure 5.5-9.

The cylindrical storage tank foundation design is as shown in Figure 5.5-10.

One inch of sand is placed under the tank to provide a material to accommodate the irregularities inherent in a concrete (insulating concrete) surface. A Johns-Manville refactory product, Marinete I, is specified under the rigit tank shell bottom joint to provide (1) a noncombustible filler material between the tank and the irregularities in the concrete and (2) to confine the 1 in. of sand.

TABLE 5.5-3

Storage Tank Characteristics

	Spherical Tank		Cylindrical Tank	
	Hot Tank	Cold Tank	Hot Tank	Cold Tank
Operating Temp., °C (°F)	593 (1100)	288 (550)	593 (1100)	288 (550)
Number of Tanks	One	(Not Considered)	One	One
Gross, m^3 (ft^3)	1.58E3 (5.61E4)		1.66E3 (5.89E4)	1.66E3 (5.89E4)
Net, m^3 (ft^3)	1.45E3 (5.15E4)		1.65E3 (5.54E4)	1.44E3 (5.12E4)
Foundation				
Type	Ring		Mat	Mat
Diameter, m (ft)	14 (78.8)/15.5 (50.8)		(63)	(61)
Thickness, m (ft)	1.5 (5)		2.7 (9) Total	2.1 (7) Total
Insulation				
Type	Calcium Silicate		Calcium Silicate	Calcium Silicate
Thickness, m (in.)	0.30 (12)		0.30 (12)	0.24 (9.5)
Weights				
Tank, kg (lb)	132,000 (290,000)		71,800 (158,000)	60,900 (134,000)
Foundation, kg (lb)	663,000 (146E6)		891,000 (1.96E6)	765,000 (1.68E6)
Insulation, kg (lb)	43,600 (96,000)		40,500 (89,000)	34,600 (76,200)
Sodium, kg (lb)	1.24E6 (2.73E6)		1.33E6 (2.93E6)	1.34E6 (2.95E6)

715-A.75/sjh

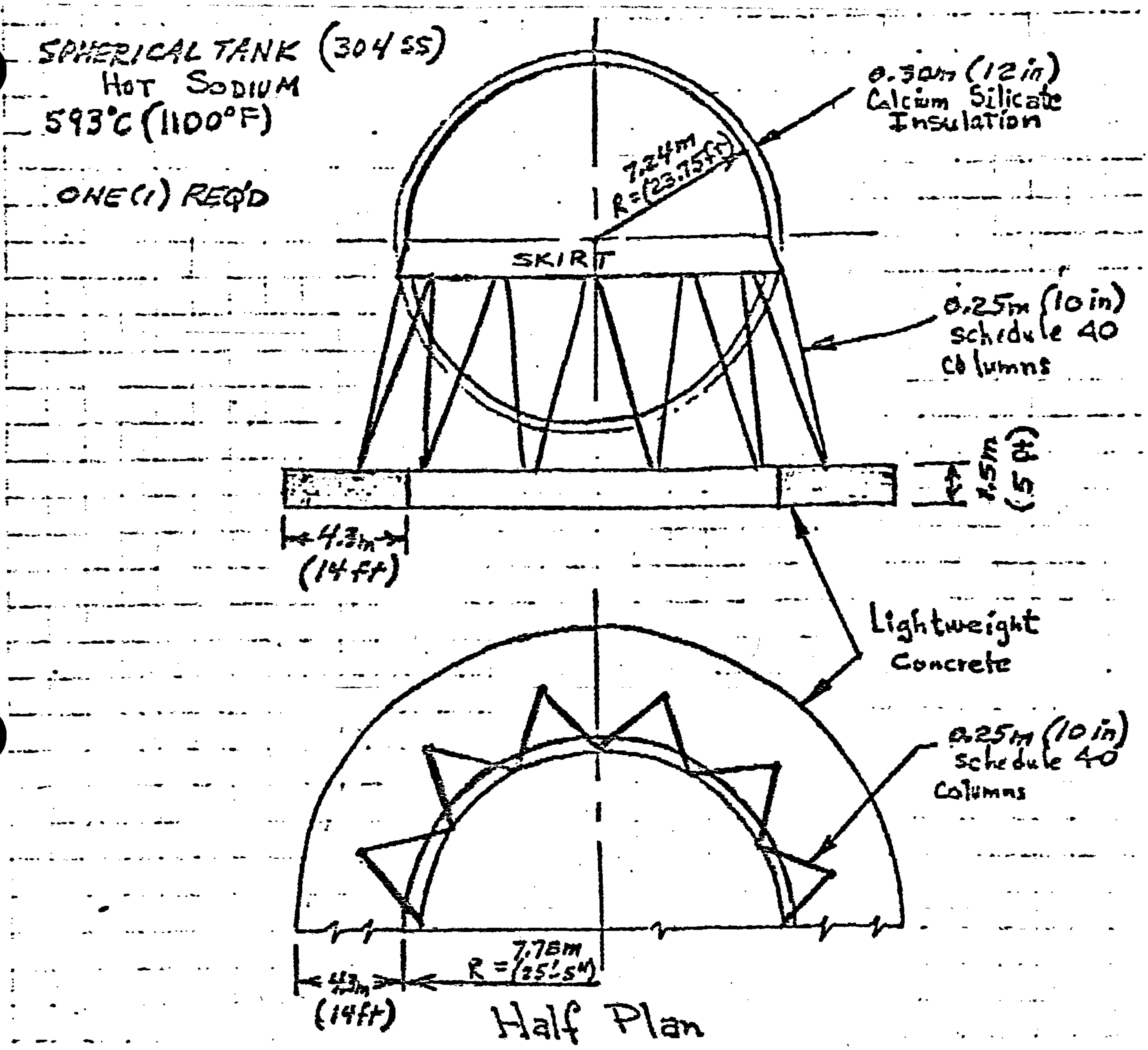
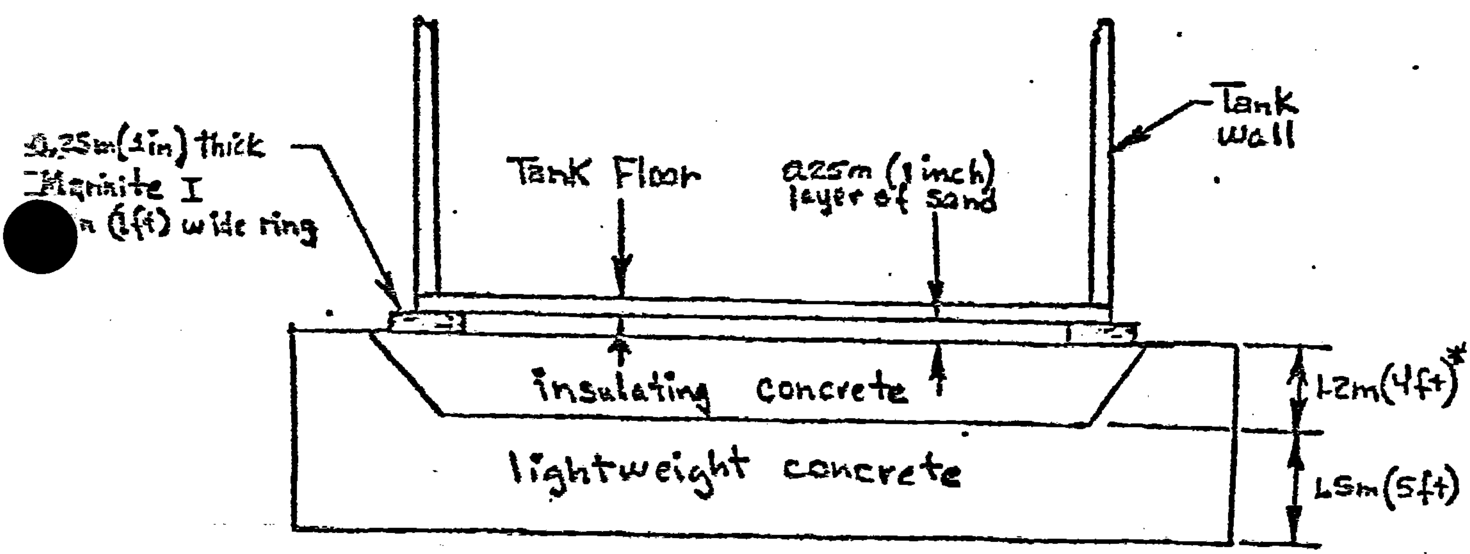

SPHERICAL TANK (304 SS)
HOT SODIUM
593°C (1100°F)
ONE (1) REQ'D
0.30m (12 in) Calcium Silicate Insulation
7.24m R=(23.75ft)
SKIRT
0.25m (10 in) schedule 40 columns
1.5m (5 ft)
4.3m (14 ft)
Lightweight Concrete
0.25m (10 in) schedule 40 Columns
7.78m R = (25'-5")
(14ft)
Half Plan

FIGURE 5.5-8

FIGURE ~~3.14~~ 5.5-9 STORAGE TANK FOUNDATION



NOTE: NO ANCHOR BOLTS

(*) 0.6m (2ft) thick insulating concrete for low temperature sodium tank foundation i.e. 288°C (550°F)

CYLINDRICAL TANK (304SS)
HOT SODIUM
593°C (1100°F)

ONE (1) REQ'D.

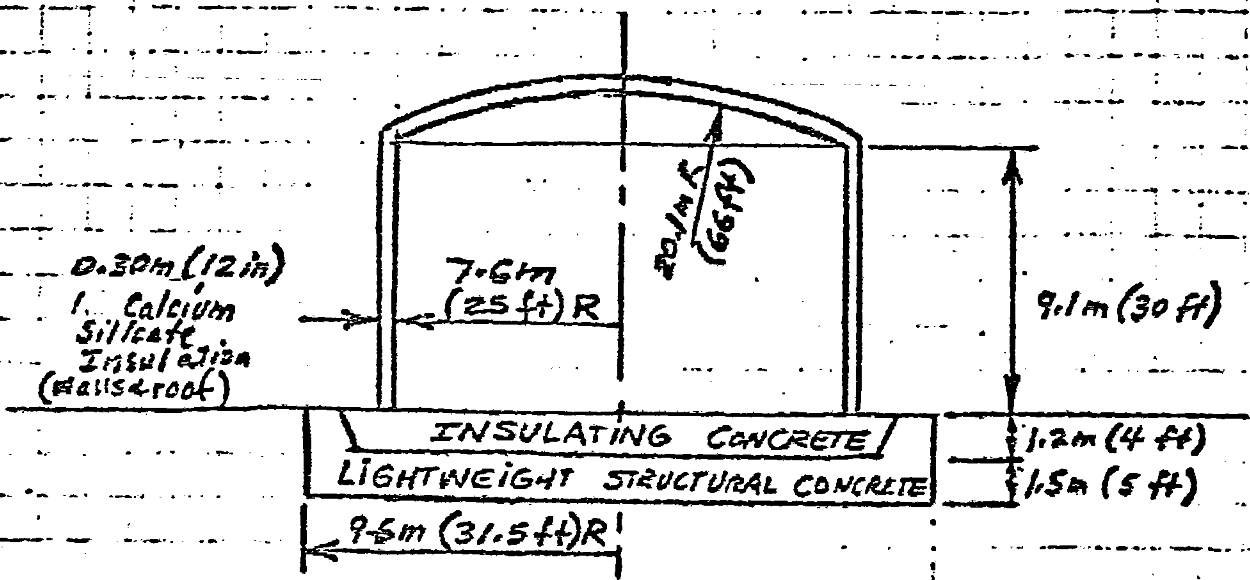


Figure 5.5 – 10

CYLINDRICAL TANK (C.S.)
COLD SODIUM
288°C (550°F)

Same as hot tank except:

1) INSULATION THICKNESS = 0.24m (9.5 in) (WALLS & ROOF)
2) RADIUS OF CONCRETE BASE = 9.3 m (30.5 ft)
3) INSULATING CONCRETE BASE = 0.61m (2 ft) thick
4) Carbon steel tank

The Marinite I is a 649°C (1200°F) fireproof structural insulation. The use of concrete at high temperatures was investigated, and it was determined* that the compressive strength of lightweight concrete when stressed prior to heating showed little loss in compressive strength for temperatures to 649°C (1200°F). The same concretes showed a compressive strength loss of about 25% when heated to 649°C (1200°F) in an unstressed condition for testing. The insulating concrete was, therefore, conservatively assumed to lose 50% of its initial strengths due to high temperature exposure. Since these concretes will be heated while loaded in compression, and according to work done by Adams,* should retain more than one-half of its initial strength.

Budget cost estimates were prepared for both designs, sphere and cylindrical tanks. The total erected cost including insulation and foundation were estimated to be $\$1.9 \times 10^6$ and $\$1.3 \times 10^6$ for the sphere and cylindrical tank designs, respectively.

On the basis of cost, the cylindrical tank was selected to be used for the conceptual design of the hot sodium fluid storage.

The breakdown of the estimated costs are given in Table 5.5-4.

A breakdown of the material and labor costs for the selected design is included in Section 4.6.

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*M. S. Abrams, "Compressive Strength of Contrete at Temperatures to 1600°F; Effects of High Temperature Exposure on Concrete"

TABLE 5.5-4

Budget Cost Estimates

Hot Sodium Storage

	Sphere	Cylindrical
Dimensions	47-1/2 ft dia	50 ft dia x 30 ft high
Costs - Material and Labor:		
(1) Vessel	$ 855,000	$ 454,000
(2) Insulation and Lagging	385,000	350,000
(3) Foundation and Support	159,000	140,000
TOTAL	$1,399,000	$ 944,000
10% Contingency	140,000	94,000
25% Contractors OH&P	385,000	260,000
TOTAL ERECTED COST	$1,924,000	$1,298,000

715-A.75/sjh

CONSTRUCTION COST ESTIMATE

CLIENT ________ DESCRIPTION 5700

LOCATION ________ ENERGY STORAGE SUBSYSTEM CONT. NO. ________

MADE BY ________

PROJECT ________ APPROVED ________

A/C NO.	ITEM & DESCRIPTION	ESTIMATED COST				
		MANHOURS	LABOR	SUBCONTRACTS	MATERIALS	TOTALS
	SUMMARY					
A	Excavation & Civil INCL. IN "B"					-0-
B	Concrete	262	3930	1800	91728	97,458
C	Structural Steel					-0-
D	Buildings					-0-
E	Machinery & Equipment HOT & COLD TANK & PUMP	1602	30,438	584750	2,409,300	3,024,488
F	Piping	11,604	220,476		701,450	921,926
G	Electrical SEE 5800					-0-
H	Instruments	492	9791		30,566	40,357
J	Painting			18,000		18,000
K	Insulation	13,267	291,874		223,586	515,460
	DIRECT FIELD COSTS		556,509			4,617,689
L	Temporary Construction Facilities					
M	Construction Services, Supplies & Expense					
N	Field Staff, Subsistence & Expense					
P	Craft Benefits, Payroll Burdens & Insurances	INCL. IN LABOR COST				
Q	Equipment Rental					
	INDIRECT FIELD COSTS	30% X DIRECT LABOR				1,385,307
	TOTAL FIELD COSTS					6,002,996
R	Engineering Plant Design 8 ~~10%~~ of ~~TFC~~ BALANCE					164,526
	~~R&D~~ 24% x E&F					947,139
S	Major Equipment Procurement 3% ~~10%~~ of ~~Pump~~ TFC					180,090
T	Construction Management 3% of (TFC ~~+ R + S~~)					180,090
	TOTAL FIELD & ENGR. COSTS					7,474,841
U	Labor Productivity See pg. 5/5 15% x D.L					83,476
V	Contingency Construction See pg. 5/5 -0-					
	Design See pg. 5/5					
W	Fee 5 ~~10%~~ of ~~(A thru V)~~					377,916
	TOTAL CONSTRUCTION COST					7,936,233

DATE ________ REVISION NO. ________ REVISION DATE ________ PAGE NO. ________

5.6 ELECTRIC POWER GENERATING SUBSYSTEM

The Electric Power Generating Subsystem (EPGS) consists of the turbine generator, condenser, feedwater train, cooling tower, and auxiliary equipment, which are all existing equipment, and the solar/non-solar interface piping and controls, the new water treatment equipment and the added auxiliary power supplies, which are all new additions to the plant as well as the EPGS. In order to distinguish between existing and new equipment, some subsections of this section have been further divided to differentiate between the two.

5.6.1 Description

5.6.1.1 Existing Equipment

This is a 115,000-kW gas/oil-fueled steam electric generator installed on the TESCo system near Monahans, Texas, and first put in commercial operation June 1, 1958.

This was initially a base-load unit designed to operate on natural gas with oil-burning capability on a standby basis. There is a 138/60-kV switchyard at the plant with 138-kV and 69-kV transmission tie lines to the TESCo system.

The generator feeds into the system through a 140-MVA, FOA 132/13.2-kV outdoor main transformer tied to the 138-kV bus through an OCB. The generator unit operates in conjunction with four 11.5-MW units installed in 1949 and one 540-MW unit installed in 1973.

Three Pacific 0.1524-m (6 in.) SX-type BFI, nine-stage boiler feed pumping units were furnished by Pacific Pump Company. Each pump is designed to deliver its maximum-rated capacity of 59.21 Kg/S (470,000 lb/hr) at 160°C (320°F) feedwater against a discharge head of 1280.1 m (4200 ft) at an efficiency of 76%. Each pump will supply half-plant capacity of feedwater with one of the three pumps serving on standby.

There are three low-pressure feedwater heaters and two high-pressure feedwater heaters. Heater drains cascade from the cross-over (X-O) heater to the high-pressure (H.P.) heater and from the H.P. heater to the intermediate-pressure heater (I.P.). Drains from the I.P. heater are pumped to the MBFP suction. The low-intermediate-pressure heater (L.I.P.) cascade to the low-pressure heater (L.P.), and the L.P. heater drains to the condenser hotwell.

The surface condenser is a deaerating type to remove the noncondensable gases. It is designed to maintain a back-pressure of 11.75 KPa (3.48 in. of Hg absolute) when supplied with 4.1 x 10^4 m^3/sec (65,000 gpm) at 35^oC (95^oF) circulating water. Two vertical circulating water pumps are designed to deliver 2.11 x 10^4 m^3/sec (33,500 gpm) at 35^oC (95^oF) against a total head of 23.47 m (77 ft) with an 84% efficiency.

A turn element two-stage steam jet air ejector with complete combined inter and after condenser was furnished to maintain a vacuum in the condenser.

Boiler blowdown is recovered after concentrations are within acceptable limits. The blowdown is diverted to the steam extraction line going to the H.P. heater after the initial startup and concentrations are below maximum requirements.

Two instrument air compressors complete with a 1.22-m (4-ft) diameter by 3.66-m (12-ft) long air receiver after cooler with moisture separator and drain traps supply control air for all pneumatic control systems.

The unit can either be loaded manually at the request of the system dispatcher or by automatic load dispatching. Signals from the computer in the system load dispatcher's office in Fort Worth, Texas, is transmitted by microwave. The signal is transmitted and converted to electrical impulses that drive the turbine governor control motor. The turbine load console at the plant has setters for rate of pickup, MW/min, maximum load limit sets, and an audible impulse signal to indicate when load change signals are being received. All other systems respond accordingly since this unit currently operates on the boiler load following mode, over a range of about 40 to 100 MW, with combustion, feedwater, steam temperature, and feedwater heater drains all responding automatically.

For boiler makeup, a 3.15×10^{-3} m^3/sec (3,000 gal/hr) demineralizer was purchased from Graver Water Conditioning Company. The demineralizer effluent does not exceed 3-ppm TDS.

The plant discharges are controlled by permits from the Environmental Protection Agency and the Texas Department of Water Resources and according to limits as set forth in these permits. All wastewater that is not within the limits as desginated in the permits are piped to a remote pond that is located on Monument Draw about 13.37 kM (8.3 miles) west of the plant. The cooling tower blowdown and other wastewater is pumped through an 0.4572-m (18 in.) transite pipeline to the pond.

A central control room provides space for the boiler-turbine-generator (BTG) board. On this console-type BTG board are mounted all essential instrumentation and controls for operating all vital equipment. Manual/automatic controls for the combustion, feedwater flow and steam temperature controls, miniaturized switches for all major motors for condensate and boiler feed pumps, FD fans, and the boiler and turbine auxiliaries are provided. Mounted on the BTG board are annunciator panels to alarm any condition that approaches an unsafe limit. Gauges, recorders, and indicators are appropriately arranged in a mimic diagram representing major pieces of equipment for which they supply information.

5.6.1.2 New Equipment

The solar/non-solar interface piping and control is shown isometrically in Figure 5.6-1. The interface points for the interface fluid, water-steam, are as follows:

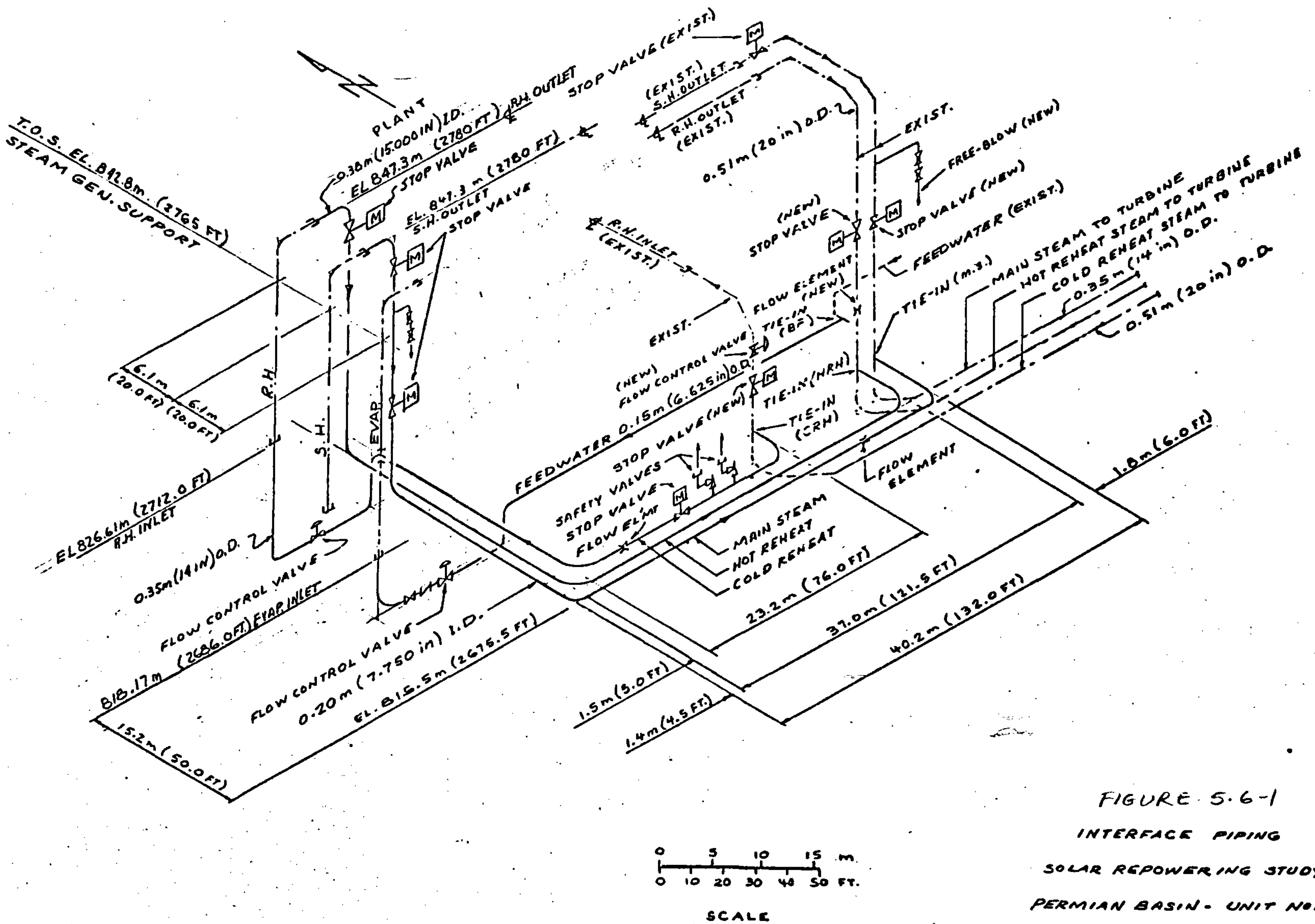

FIGURE 5.6-1
INTERFACE PIPING
SOLAR REPOWERING STUDY,
PERMIAN BASIN - UNIT No. 5
TEXAS ELECTRIC SERVICE COMPANY

1) Feedwater: Between the final feedwater heater and the boiler feedwater control valve.
2) Superheated Steam: On the boiler mainst eam downcomer just prior to the mainst eam line turn toward the turbine.
3) Cold Reheat: On the boiler cold-reheat riser near the bottom of the boiler.
4) Hot reheat on the boiler, hot-reheat downcomer at the same elevation as the mainst eam tie-in.

Added feedwater treatment equipment is provided to insure that the water quality requirements of the sodium steam generators are met. This equipment is in the form of a condensate polisher system consisting of three one-half-capacity condensate demineralizer tanks, one mixed-bed regeneration tank, one resin storage tank, one hot-water tank, two each sluice, acid and caustic pumps and associated piping, valves, and controls on local boards. In addition to the condensate polisher system, three additional condensate booster pumps, motors, and controls will be required to provide the additional head for the polisher. The layout of the condensate polishing system is shown in Figure 5.6-2.

The additional electrical equipment, provided for auxiliary loads due to solar repowering only, are shown in Figure 5.6-3, along with the existing equipment.

Power for the solar system will be supplied from the tertiary of auto-transformer No. 1 (located in the switchyard). Switchgear (Solar 2400-V Bus A) located near the auto-transformer will feed the existing 2400-V unit auxiliaries (startup source), the heliostat fields, and Solar 2400-V Bus B as shown. An existing emergency generator will supply power to the heliostat field to assure safe shutdown.

The Solar 2400-V Bus B will feed the receiver feed pump, trace heating, and a 2400-480-V load center. The load center will supply a steam generator pump, some trace heating, and a motor control center. The motor control center will supply small loads associated with the solar system in the plant area.

Figure 5.6.-2

Condensate Polisher Layout

The 2400-V trace heating feeder will feed 2400-208Y/120-V transformers which will supply the trace heating system.

The heliostat field will be supplied by four 2400-V feeders. Pad-mount transformers will step the 2400 V down to 408Y/120 V for the heliostats. The heliostat field transformers will be distributed throughout the heliostat field.

A battery, charger, inverter, rectifier power supply, blocking diode, and solid-state transfer switch will supply uninterruptible power for the master control system.

5.6.2 Functional Requirements

The electrical power generation subsystem shall retain the same operating capability as existed prior to repowering. Extensive operation at the 40% power level (~50 MWe) may be required. Daily start and stop cycles may be required. The feedwater heaters and drains to the condensate system shall accept up to 5% blowdown from the separator located between the solar system evaporator and superheater units.

The primary solar/EPGS interface requirements will include the following:

1) Main steam connection
2) Hot-reheat steam connection
3) Cold-reheat steam connection
4) Boiler feedwater connection
5) Control system interfaces
6) Auxiliary electrical power supply

The piping design conditions (e.g., pressure and temperature) for the main steam, hot and cold reheat steam, and boiler feedwater piping will match that of the existing system. The piping systems will be designed in accordance with ANSI B31.1 or ASME Power Boiler Code Section I, as required.

5.6.3 Design Characteristics

5.6.3.1 Existing Equipment

5.6.3.1.1 Turbine-Generator

The turbine-generator is a Westinghouse unit with complete accessories.

The turbine is a tandem compound, two-cylinder flow exhaust reheat, impulse type in the lower stages. The unit has side exhausts for use with twin-shell condensers.

The nominal rating of the turbine is 100,000 kW designed for throttle condition of 10-mPa (1450-psig), 537.8^{o}C (1000^{o}F), and 537.8^{o}C (1000^{o}F) reheat.

The generator is rated 100,000 kW; 0.85 pf; 135,240 KVA with 310.3-kPa (45-psig) hydrogen pressure; 13,800 V; three-phase; 60-cycle; 3600 rpm, with the following capacity in ratings:

A. 123,000 kW, 0.85 pf at 206.9-kPa (30-psig) hydrogen pressure
B. 135,240 kW, 0.85 pf at 310.3-kPa (45-psig) hydrogen pressure
C. 147,000 kW, 0.85 pf at 413.8-kPa (60-psig) hydrogen pressure

5.6.3.1.2 Surface Condensing Plant

The unit is furnished with one 5574-m^2 (60,000-ft^2), 172,919-W (590,000-Btu/hr), two-pass twin shell, deaerating-type surface condenser. This is a Westinghouse condenser designed to use 4.23 m^3/sec (67,000 gpm) of cooling water with an inlet temperature of 35^{o}C (95^{o}F) through 0.025-m (1-in.) OD, 18-BWG arsenical copper, welded steel plate water boxes, 29.8-m^3 (1,052 ft^3) hotwell and accessories, including the following:

Two Westinghouse 1.22-m (48-in.) discharge one-stage vertical pullout-type circulating water pumps, each designed for 2.11-m^3/sec (33,500-gpm) flow at 23.47-m (77-ft) TDH. Each pump is driven by a 597-kW (800-hp), 500-rpm, 2300-V vertical pump.

Three Westinghouse 0.152-m (6-in.) discharge five-stage vertical submerged suction condensate pumps each designed for a capacity of 0.06-m^3/sec (940-gpm) at 170.7-m (560-ft) TDH. Each pump is driven by a 149.3-kW (200-hp), 1760-rpm, 2300-V vertical motor.

One Westinghouse Size E-125 twin-element, two-stage steam jet air ejector. The inter- and after-condensers have Admiralty tubes and the ejector is designed to evacuate 0.236 kg/sec (1,875 lb/hr) of air and water vapor with design back pressure of 3.38 kPa (1.0-in. Hg), requiring 0.094 kg/sec (750 lb/hr) of HP steam and a minimum condensate flow of 18.9 kg/sec (150,000 lb/hr).

One Westinghouse size 0.283-m^3/sec (600-cfm), 0.381-m (15-in.) vacuum, one-stage noncondensing hogging ejector.

5.6.3.1.3 Unit Auxiliary Transformer

A 7500-KVA, self-cooled (OA), 13,200-2400-V delta-delta connected inerteen-filled, outdoor-type, Westinghouse transformer. The forced-air rating is 9375 KVA.

5.6.3.1.4 2400-V Switchgear

A 15-unit, 2400-V Westinghouse, outdoor weatherproof design, metal-clad drawout-type switchgear with air circuit breakers was furnished.

5.6.3.1.5 480-V Power Centers

One Westinghouse, 480-V, outdoor, metal-clad switchgear with associated 1000-KVA, 2400/480-V delta-delta connected transformer was furnished. The switchgear consists of three sections containing a total of 12 compartments.

One Westinghouse, 480-V, outdoor, metal-clad switchgear with associated 750-KVA, 2400/480-V delta-delta connected transformer with four manaully operative circuit breakers to serve the cooling tower.

Three Westinghouse, 480-V, outdoor-type motor control centers with combination air circuit breakers-magnetic contactors to serve the boiler area, turbine area, and water treatment area.

5.6.3.1.6 Paging and Communication System

Provided by Gai-tronics Corporation to allow control room operators to communicate with boiler area and turbine-generator areas of the plant.

5.6.3.1.7 Electrical Fault Protection

The generator, main transformer, and unit auxiliary transformer are tied to the system through a 138-kV OCB. A lockout relay opens this breaker and shuts the unit down for faults in the windings or leads of any of these components.

Standby and startup power for this unit is provided through the 2400-V delta tertiary winding of a 36,000-KVA, 132/67.2-kV auto-transformer. Bus differential and breaker failure backup schemes protect the transformer for external faults on the system.

The plant layout follows the "single-level" design. The turbine operating level is 4.88 m (16 ft) above-ground elevation and serves as a base level for all major equipment such as fans, feed pumps, feedwater heaters, condensate pumps, switchgear, compressors, etc.

Circulating water is cooled by recirculating through a Fluor Corporation redwood cooling tower with 4.29×10^4-m^3/sec (68,000-gpm) capacity.

Makeup and cooling water is provided by industrial-type water wells ranging from 121.9 to 182.9-m (400 to 600-ft) deep, pumping at capacities of 189.3 to 504.7 m^3/sec (300 to 800 gpm). Water from the wells is pumped into a 1.272×10^4-m^3 (80,000-bbl) storage tank at the plant.

All equipment is erected outdoors, except some equipment located beneath the concrete turbine pedestal. Piping is insulated and covered with aluminum lagging and protected with heating cable for freeze protection where exposed to ambient temperatures.

A 2.27×10^4- kg (25-ton) Colby crane staddles the turbo-generator which is located equidistant between the crane rails.

Freeze protection heating cable was applied to all piping where water or condensation was subject to freezing.

Detailed design characteristics for the existing EPGS equipment is included in the Design Data Sheets, Appendix B.

5.6.3.2 New Equipment

5.6.3.2.1 Solar Steam and Feedwater Piping

As indicated on the P&I Diagram 4.1-2, the solar/fossil piping interfaces occur at the tie-ins for main steam, hot-reheat steam, cold-reheat steam, and boiler feedwater.

The design and characteristics for the solar steam and feedwater piping is shown in Table 5.6-1. The design pressures and temperatures used for the solar piping match those in the existing plant.

Other piping modifications are required for the installation of a new condensate polisher and steam generator separator drains flash tank as shown on the P&I Diagram.

The solar steam and feedwater piping additions come under the jurisdiction of ANSI B31.3, Power Piping Code.

The existing Permian Basin Unit 5 piping was designed in accordance with both ASME and Boiler & Pressure Vessel Code Section I Power Boilers and ANSI B31.1 Power Piping for a single-boiler, single-turbine unit. With the addition of the solar plant, the boiler piping must meet the ASME Section I Code requirements for multiple boiler installation. This modification requires a change in Boiler Code limits and in addition, required double-stop valves, with a free-blow line located between the valves in each main steam supply line. The existing main steam line has a single valve, therefore, a second stop valve and free-blow line must be installed. Also, with the addition of the solar reheat system, isolation valves and flow control valves are required in both the fossil and solar reheat piping. The installation of valves in the cold-reheat piping between the turbine and existing reheater safety valves requires the addition of new safety valves in the cold-reheat piping design to relieve the entire high-pressure turbine exhaust flow in accordance with ANSI B31.1.

The proposed routing for the new steam and feedwater piping and points of interconnection with the existing piping is shown in Figure 5.6-1, Piping Interface.

5.6.3.2.2 Condensate Polishing Equipment

The detail design data for the condensate polishing system is included in the Design Data Sheets, Appendix B.

TABLE 5.6-1

SOLAR REPOWERING PERMAIN BASIN
UNIT NO. 5
SOLAR STEAM AND FEEDWATER PIPING

		Main Steam	Hot Reheat	Cold Reheat	Boiler Feed
Design Pressure	psig	1640	600	600	2600
Design Temp.	°F	1015	1015	775	465
Material	-	A335-P22 2-1/4 Cr - 1 Mo Seamless	A335-P22 2-1/4 Cr - 1 Mo Seamless	A105-GR.B Carbon Steel Seamless	A106-GR.B Carbon Steel Seamless
Code		ANSI B31.1	ANSI B31.1	ANSI B31.1	ANSI B31.1
Minimum ID	In.	7.750	15.000	14" Sch. 40	6" Sch. 160
Minimum Wall	In.	0.961	0.648		
Nom. OD	In.	9.909	16.487		
Wt./ft	lb	100	120	65	45
Insulation	-	Calcium Silicate	Calcium Silicate	Calcium Silicate	Calcium Silicate
In. Thickness	In.	6	6	5	3

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5.6.3.2.3 Electrical Equipment

The added electrical equipment list is shown in Table 5.6-2.

TABLE 5.6-2.

ADDED ELECTRICAL EQUIPMENT LIST

4	Switchgear Units, 4.16 kV, 1200 A, 250 MVA, indoor
8	Switchgear Units, 4.16 kV, 1200 A, 250 MVA, outdoor
1	Load Center consisting of:
	1 Transformer, power, 3-phase, 750 kVA, 65^{o}C rise, 2400-480 V
	1 Circuit Breaker, power, 1600 A, 600 V
	3 Circuit Breakers, power 800 A, 600 V
1	Motor Control Center
40	Transformers, 3-phase, pad mount, 2400-208Y/120 V, 112.5 kVA, for heliostat field
4	Transformers, 3-phase, pad mount, 2400-208Y/120 V, 500 kVA, for heat tracing
	Lot Lighting and Power Panels
1	Battery, lead acid, 60-cell, 125 V, 400 amp-hr
1	Battery Charger, 480 V ac, 125 V dc, 50 A
1	Uninterruptible Power System, 45 kVA, 120/208 V, 3-phase, 125 V dc consisting of inverter, blocking diode, rectifier power supply and solid-state transfer switch

5.6.4 Operating Characteristics

While the Unit No. 5 fossil fuel plant was initially a base load unit, it is now operated as an intermediate load unit and runs only when No. 6 is off or when the system demand is up during the summer months. The unit was not designed for cyclic duty and efforts will be made to keep the number of cold starts to a minimum.

It is anticipated that the solar unit will operate alone most of the time except during the hot summer months or possibly during the winter when No. 6 is off and its cloudy for a day or two in a row. System operation may require the fossil boiler to be on most of the time to assure adequate spinning reserve or to limit number of cold starts.

The EPGS auxiliary motor load is shown in Table 5.6-3.

TABLE 5.6-3
EPGS AUXILIARY MOTOR LOAD

Quantity	Description	HP	kW	Voltage	RPM	Encl.
3	Boiler Feed Pumps	1500	1119	2300	3600	WP
2	Circulating Water Pumps	800	597	2300	514	WP
2	Forced Draft Fans	700	522	2300	900	WP
3	Condensate Pumps	200	149	2300	1800	MSP
12	Cooling Tower Fans	60	45	440	1800	FC
2	Cooling Water Pumps	100	75	440	1800	TEFC
2	Fuel Oil Burner Pumps	100	75	440	1800	TEFC
1	Station Air Compressor	100	75	440	1800	TEFC
2	Instrument Air Compressor	25	19	440	1800	TEFC
2	Service Water Pumps	100	75	440	1800	TEFC
2	Condensate Transfer Pumps	7-1/2	5.6	440	1800	TEFC
1	1P Heater Drain Pump	75	56	440	3600	TEFC

The operating characteristics are inextricably tied to the system operating mode and resulting system implied operating requirements. Consequently, the detailed system operating characteristics have been presented as part of Section 4.3.

5.6.5 Performance Estimate

Rated Turbine Steam Conditions

The rated steam conditions for Permian Basin, Unit 5, turbine are 10.1 MPa (1465 psia) initial pressure, 538^{o}C (1000^{o}F) initial temperature, and 538^{o}C (1000^{o}F) reheat temperature.

Throttle Pressure

Rated turbine throttle pressure is maintained at all loads during normal operation. The unit is not operated at 5% overpressure.

Some fossil plants utilize variable pressure operation, reducing the throttle pressure as load decreases while maintaining near-rated throttle temperature. The main advantage is that station heat rate is improved at low loads owing to the fact that steam temperature in a fossil boiler normally drops off rapidly at low loads with constant throttle pressure, whereas temperature can be maintained near rated at reduced loads with reduced pressure. This is often accompanied by reduced boiler feed pump power.

For solar-only operation, however, there is no advantage gained by reduced pressure operation since rated throttle temperature can be maintained at all loads with the solar steam generator. This is shown in Table 4.3-1 which compares rated pressure vs reduced pressure operation at 50,000 kWe.

During the turbine shutdown operation, however, there is a benefit gained by reducing the throttle pressure while maintaining steam temperature at a high value while decreasing load. This procedure results in higher first-state metal temperature than would have been obtained using fixed pressure operation, thus facilitates faster restarts and minimizes cyclic fatigue. If it is planned to start and stop the solar repowered turbine daily, then variable pressure operation is recommended to facilitate faster restarts.

Throttle Temperature

From the standpoint of maximizing cycle efficiency, it is desirable to operate at rated temperature at all loads. This is easily achieved during solar-only operation. However, as previously mentioned, it is a characteristic of a fossil boiler that steam temperature drops off when reducing load.

For example, when operating the turbine at full load in the solar hybrid mode, the fossil steam flow is about 60 kg/s (480,000 lb/h) or about 58% of its maximum continuous capacity. At this load, the superheat (main steam) temperature would be approximately 532°C (990°F), and the reheat temperature 525°C (978°F). The reheat inlet steam temperature at this fossil steam flow would normally be about 313°C (595°F). However, since the turbine is operating at full load, the cold reheat temperature is approximately 380°C (717°F) rather than 313°C (595°F). This higher reheater inlet steam temperature will, it was assumed, result in rated reheat outlet temperature of 540°C (1005°F). Also, the boiler gas pass steam temperature control dampers can, it was assumed, automatically control superheat temperature to rated value (540°C (1005°F) by bypassing more flue gas across the superheater and less across the reheat sections. Thus for the design hybrid operating mode, rated fossil superheat and reheat steam temperatures were assumed.

Turbine Backpressure (Condenser Pressure)

The predicted condenser performance for Permian Basin, Unit 1, is shown in Figure 5.6-4. Station operating data was provided giving turbine backpressures at the various seasons, e.g., summer solstice, equinox, and winter solstice, which were used in the heat balance calculations.

Since turbine performance is affected by backpressure, Figure 5.6-5 was prepared to show turbine heat rate correction for various backpressures vs throttle flow.

CONDENSER DESIGN DATA

MFGR	WESTINGHOUSE TWIN SHELL
SURFACE	60,000 FT.^{2}, 1" O.D. x 18 BWG ARS. COPPER, 28'
PASSES	2
HEAT LOAD	590 x 10^6 BTU/HR
CIRC. WTR. FLOW	65,000 GPM

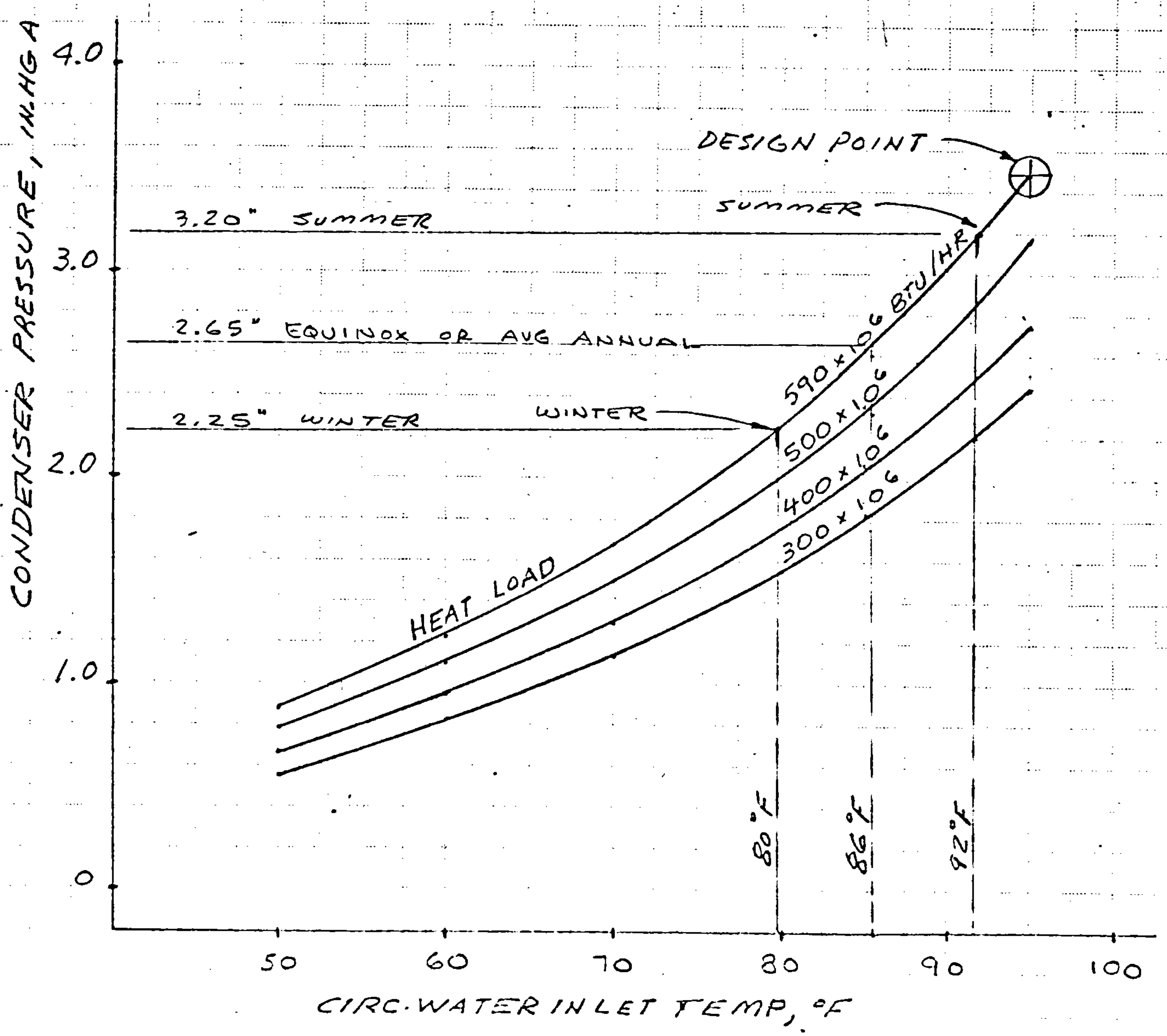
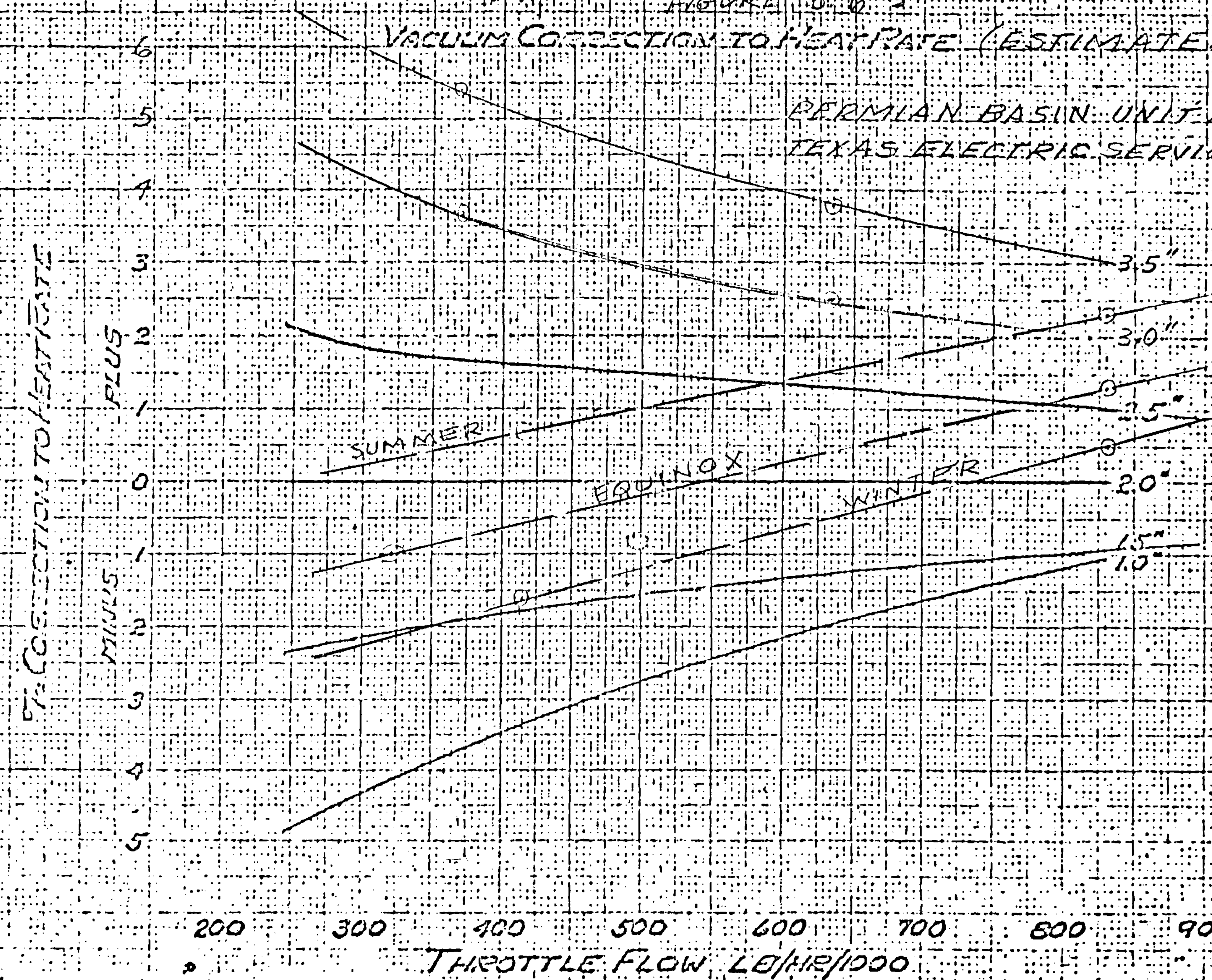


FIGURE 5.6-4

FIGURE 5.6-5
VACUUM CORRECTION TO HEAT RATE (ESTIMATED)



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5.6.6 Cost/Performance Trade-offs

No formalized cost/performance trade studies were completed regarding the EPGS during this study. An informal survey of the plant was completed and best engineering judgment exercised in the selection of the solar/now-solar interfaces, which, due to the current plant layout and considerations of plant maintenance and expansions, were strongly influenced by TESCO operations personnel.

5.6.7 Top Level Cost Estimate

CONSTRUCTION COST ESTIMATE

CLIENT ______________________ DESCRIPTION EPGS - 5800

LOCATION ______________________ CONT. NO. ______________

MADE BY ______________

PROJECT ______________________ APPROVED ______________

A/C NO.	ITEM & DESCRIPTION	ESTIMATED COST				
		MANHOURS	LABOR	SUBCONTRACTS	MATERIALS	TOTALS
	SUMMARY					
A	Excavation & Civil					
B	Concrete					
C	Structural Steel					
D	Buildings					
E	Machinery & Equipment	388	7360		118,400	125,760
F	Piping	20,648	392,310		1,023,930	1,416,240
G	Electrical	31,865	634,174		2,589,558	3,223,732
H	Instruments	16,719	332,708		278,603	611,311
J	Painting					
K	Insulation			77,805		77,805
	DIRECT FIELD COSTS	69,620	1,366,552	77,805	4,010,491	5,454,848
L	Temporary Construction Facilities					
M	Construction Services, Supplies & Expense		/			
N	Field Staff, Subsistence & Expense					
P	Craft Benefits, Payroll Burdens & Insurances					
Q	Equipment Rental					
	INDIRECT FIELD COSTS	30% OF	DIRECT LABOR		✓	409,965
	TOTAL FIELD COSTS					5,864,813
R	Engineering Plant Design 13.5% ~~10%~~ of TFC —					791,750
	R&D					
S	Major Equipment Procurement 3 ~~10%~~ of ~~Pump~~ TFC					175,944
T	Construction Management 3% of (TFC + ~~R+S~~)					175,944
	TOTAL FIELD & ENGR. COSTS					7,008,451
U	Labor Productivity See pg. 5/5 15% x D.L					204,983
V	Contingency Construction See pg. 5/5					-0-
	Design See pg. 5/5					-0-
W	Fee 5 ~~10~~% of (A thru V)					360,671
	TOTAL CONSTRUCTION COST					7,574,105

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6.0 ECONOMIC ANALYSIS

This section contains the economic analysis of the Permian Basin Unit No. 5 solar repowering application.

6.1 METHOD

The economic analysis of the repowered plant has been made with the techniques, assumptions, and evaluation parameters normally used by TESCO in the assessment of new plant options as discussed in 6.1.1. A second set of analysis has included the more generalized methods of 6-1 as well as a set of economic assumptions specific by the technical monitor for this study. The methods of 6-1 have been used previously in the studies of advanced central receiver concepts of 6-2 and 6-3. Basic characteristics of this latter method are given in 6.1.2.

6.1.1 TESCO Evaluation Method

The method of economic analysis utilized by Texas Electric Service Company, hereafter noted as the TESCO method, involves calculating the various expenditures each year during the construction period and then during the operating life of the plant. A computer program is employed to calculate all expenditures and cash flows directly each year, and no approximating equations are utilized.

The equations which are used to derive the various expenditures are included in the Appendix.

The evaluation parameters which demonstrate the economics of the solar repowered plant include modified busbar energy cost (BBEC), present worth analyses, and fuel equivalent plant worth. Since the existing plant cost is not included in the energy cost, the BBEC is not a true indication of the cost of energy produced by the repowered plant. The BBEC shown is only an indication of the difference in energy cost between the repowered plant and nonrepowered plant.

There are some differences in the methods of economic analysis utilized by Texas Electric and the Department of Energy (JPL methodology). The cost of capital rate used by TESCO is before taxes and the JPL cost of capital is an after-taxes rate. The TESCO method calculates all costs on a year-by-year basis and returns the costs to the reference year; an equivalent levelized fixed-charge rate is then determined. The JPL method uses an approximating equation to determine the levelized fixed-charge rate. The JPL method employs an after-tax cost of capital in calculating the capital recovery factor to determine present worth values for fuel savings and plant capital costs. The TESCO method utilizes before-tax cost of capital for those calculations.

Since Texas Electric is an investor-owned utility, the before-tax cost of capital must be utilized in determining economic choice of a project. The after-tax cost of capital may be a satisfactory method to use under certain very restricted assumptions; however, TESCO's assumptions better fit the before-tax calculation.

6.1.2 Generalized Method

Reference 6-1 describes the methodology used to determine the present values of the capital expenditures, O&M, and fuel costs over the life of the plant. These values when summed and divided by the energy output become the busbar energy cost of the plant. Since the method is widely used on the report and readily available, more details will not be given here.

ESG has programmed the methodology of 6-1 with added features to account for solar stand-alone operation, fossil-only operation, and combined operation for various capacity factors. Discussion of the model is given in 6.3.

6.2 ASSUMPTIONS WITH RATIONALE

The economic assumptions used by TESCO are presented in 6.2.1. The alternative set is discussed in 6.2.2.

6.2.1 TESCO Economic Assumptions

Table 6-1 includes the various economic parameters for the TESCO economic method.

TABLE 6-1

Service Life	7 years
Reference Year	1980
Year of Start of Commercial Operation	1985
Construction Period (Begin in 1981)	4 years
Cost of Capital	11.9%
Income Tax Rate	46%
Revenue Related Tax Rate	3.5129%
Investment Tax Credit Rate	10%
Annual Property Taxes and Insurance	2.25%
Depreciation Life (Tax Purposes)	6 years
AFUDC Rate	8%
Levelized Fixed-Charge Rate (in 1985)	30.19%
General Escalation Rate	10%
Capital Escalation Rate	10%
O&M Escalation Rate	10%
Fuel Escalation Rates:*	
1980-1984	11.5%
1985-1989	12.0%
1990-1994	14.3%
1985 O&M Cost	1% of Installed Capital Cost
1980 Natural Gas Cost*	$\$2.50/10^6$ Btu

*The 1980 fuel cost was obtained from the Sandia economics parameters. The escalation rates for fuel cost were obtained form The Annual Report to Congress - 1978: Volume 3 - Forecasts, prepared by the Energy Information Administration of the United States Department of Energy. The escalation rates were obtained by adding the fuel inflation factors obtained from Table 4.3, "U.S. Energy Prices: Projection Series C, 1962-1995," to the assumed general inflation factor of 10%.

Table 6-2 shows the forecasted fuel costs during the life of the repowered plant:

TABLE 6-2

Year	Fuel Cost ($\$/10^6$ Btu)*	Year	Fuel Cost ($\$/10^6$ Btu)
1980	2.50	1986	4.85
1981	2.79	1987	5.43
1982	3.11	1988	6.08
1983	3.47	1989	6.81
1984	3.87	1990	7.78
1985	4.33	1991	8.89

*The 1980 fuel cost was obtained from the Sandia economics parameters. The escalation rates for fuel cost were obtained from The Annual Report to Congress - 1978: Volume 3 - Forecasts, prepared by the Energy Information Administration of the United States Department of Energy. The escalation rates were obtained by adding the fuel inflation factors obtained from Table 4.3, "U.S. Energy Prices: Projection Series C, 1962-1995," to the assumed general inflation factor of 10%.

The methods employed to determine the number of operating hours annually are based upon experience with natural gas-fired power plants within the Texas Electric system. On a typical maintenance cycle, the required annual maintenance averages 20 days. Experience has shown the forced outage rate to be approximately 4% of the number of available operating hours.

The economic parameters are all based upon the best estimates of future trends in various costs. The plant is currently scheduled for retirement on December 31, 1991; thus, the plant service life after repowering is 7 years. The accelerated depreciation life (tax purposes) is 80% of the service life, rounded off to 6 years. The cost of capital is based upon the company's capitalization structure and the separate costs of bonds, common stock, and preferred stock. The cost of capital is currently 11.9%. The levelized annual property taxes and insurance cost has been estimated at 2.25%. The allowance for funds used during construction (AFUDC) is currently set at 8% by the Public Utility Commission of Texas. The general, capital, and O&M

escalation rates are estimated to average 10% annually. The current inflation rates is higher, but TESCO believes the long-term inflation rate will be about 10%. The annual levelized fixed-charge rate (LFCR) is calculated from the previous parameters. The LFCR is 30.19% annually. The LFCR sensitivity to variable inflation factors was checked; the LFCR remains unchanged by variable inflation rates, but the levelized fixed-charge does change.

The fuel escalation rates and the current, 1980, value for natural gas were obtained through Department of Energy and Sandia references. According to the Sandia economic analysis, the 1980 value for natural gas is $2.50 per million Btu. This value was used as the starting point of the TESCO economic study. To determine the fuel escalation rates, a medium supply and medium demand scenario was chosen. The EIA's 1978 Annual Report to Congress was chosen as a reference to forecast the cost of natural gas during the lifetime of the repowered plant. This report forecasts the marginal price of natural gas in the Southwestern United States to rise at the rate of 1.5% above general inflation between 1977 and 1985, 2.0% above general inflation between 1985 and 1990, and 4.3% above general inflation between 1990 and 1995. The resulting fuel escalation rates are:

1980-1984 - 11.5%
1985-1989 - 12.0%
1990-1994 - 14.3%

The various predicted energy outputs for different seasons of the year were calculated by Energy Systems Group. The forced outage and maintenance outage rates were supplied by Texas Electric.

6.2.2 Rationale for Alternative Economic Parameters

The parameters supplied by the technical monitor are indicated in Table 6-3. The remaining parameters were selected by ESG so that the methodology of (6-1) could be used. The cost of capital is selected to be 2% greater than the inflation rate. This value is considered to be realistic for a regulated industry. Over the long run, ESG considers that the escalation rate on capital investments and on O&M activities will be equal to the general inflation rate as is shown in Table 6-1.

The 25-year life was selected as representative of generalized repowering applications in comparison with alternative fossil energy plants. This value also demonstrates the strong impact of service life on the economic parameters.

TABLE 6-3
ALTERNATE ECONOMIC ASSUMPTIONS

Cost of Capital After Tax, %	10
Escalation Rates, %	
General	8*
Capital Investment	8
Operations and Maintenance	8
Fuel	
Gas	11*
Oil	12*
Coal	10*
Nuclear	9*
Plant Life and Amortization Period, Years	25
Start of Operations	1985*
Capital Investment Cash Flows, %/year	25
Annual Insurance, Percent of Capital	0.0025
Annual Property Taxes, Percent of Capital	0.02
Operations and Maintenance	
Fixed, Percent of Capital	1.0
Variable, Percent of Fuel Cost	**
Fuel Cost, $\$/10^6$ Btu	
Gas	2.50*
Oil	4.00*
Coal	1.25*

*Sandia specified, Technical Information Memo No. 6
**10% for gas and oil, 20% for coal, add 10% for flue gas desulfurization

The remaining assumptions are the same for the two sets of parameters. A 4-year construction period (cash flow of 25%/year) results in an allowance for funds used during construction of 17.7% of the estimated capital cost. This value tends to be larger than that resulting from the TESCO methodology in that TESCO is constrained to a lower cost of capital during the construction period and thus representation was not included in the JPL methodology.

6.3 PLANT AND SYSTEM SIMULATION MODEL

The insolation model and plant performance model are described in Appendix B of Volume III. The average yearly operating time for the solar system is 2744 hr including weather outage for the Permian Basin site, forced outage of 4%, and scheduled maintenance of 20 days. These latter values are representative of TESCO's experience.

Net power level is given in 4.6 for the various operating conditions. Plant cost data is given in 4.6 with the power, operating time, and cost data available, the economic methods discussed in 6.1 can be applied. The following sections discuss the economic models used.

6.3.1 TESCO Economic Model

The following tax equations are utilized:

(1) $T = \left(\frac{t}{t-1}\right) \times (Pt + ADR - SLDB - DT - ITCA - Pb + C - NI)$

(2) $T = R-BI-SLDB-RRT-DT-ITC-ITCA-Pb+C-NI$

where,

T = Income tax

t = Income tax rate

R = Revenue required

BI = Bond cost

Pt = Property taxes (tax purposes)

Pb = Property taxes (book purposes)

RRT = Revenue related taxes

ITC = Investment tax credit

ITCA = Investment tax credit amortized

ADR = Accelerated depreciation (tax purposes)

SLDB = Straight-line depreciation (book purposes)

DT = Deferred taxes

C = AFUDC, Allowance for funds used during construction

NI = Net income; common cost + preferred cost

CONSTRUCTION PERIOD

During the construction period, the following values are applicable to the general tax equations:

$Pb = o$ $ADR = o$
$SLDB = o$ $ITCA = o$

Also, the following values are used for the comparison example:

b = Bond rate = Bond interest X Bond capitalization
e = Equity rate = Equity earnings X Equity Capitalization
p = Preferred rate = Preferred earnings X Preferred Capitalization
Cc = Composite rate = b + e + p
ITC = Investment tax credit rate X capital investment
Property tax and insurance rate = .0225
t = .46
Revenue related tax rate = 0.035129
c = AFUDC rate

Annual Investment = AI = Amount invested during year
Average Investment = AVI = Average investment during year
It is assumed that the expenditures are divided equally during the 4-year construction period.

$$C(i) = (AI(i) - ITC(i)) \times c \times .5 + \sum_{j=1}^{i} (AI(j-1)-ITC(j-1)) \times c + \sum_{j=1}^{i} C(j-1) \times c$$

$$Pt(i) = \sum_{j=1}^{i} (AI(j-1) + C(j-1)) \times .0225$$

$$AVI(i) = (AI(i) - ITC(i)) \times .5 + \sum_{j=1}^{i} C(j) + \sum_{j=1}^{i} Pt(j) + \sum_{j=1}^{i} (AI(j-1)-ITC(j-1))$$

$$BI(i) = AVI(i) \times b$$

$$Equity(i) = AVI(i) \times e + ITC(i) \times Cc \times .5 + \sum_{j=1}^{i} ITC(j-1) \times C_c$$

$$Preferred(i) = AVI(i) \times p$$

$$NI(i) = Equity(i) + Preferred(i)$$

$$DT(i) = (t)\, Pt(i)$$

$$T(i) = (NI(i) - (Pt(i) - DT(i)) - C(i)) \times \frac{t}{1-t} - ITC(i)$$

$$Capitalized\ Taxes(i) = Pt(i-1)$$

$$RRT(i) = (NI(i) + BI(i) + DT(i) + ITC(i) + T(i) - C(i)) \times .035129$$

$$R(i) = (NI(i) + BI(i) + DT(i) + ITC(i) + T(i) - C(i)) \times 1.035129$$

$$Chargeable\ Investment(i) = \sum_{j=1}^{i} (AI(j) - ITC(j) + C(j) + (1-t) \times PT(j))$$

OPERATING PERIOD

During the operating period, the following values are applicable to the general tax equations:

St Line Depr life (book purposes) = St Line Depr life (tax purposes) = 7 years
Accelerated depreciation life (tax purposes) = 6 years
Property taxes and insurance premiums are levelized = .0225

NINV = Net investment

From the construction period, the following beginning points can be established:

$$NINV\ (1) = \sum_{i=1}^{4} AI(i) + \sum_{i=1}^{4} C(i) + \sum_{i=1}^{4} \text{Capitalized taxes } (i)$$

$$SL\bar{D}B = NINV\ (1) \div 7$$

$$SLDT = \sum_{i=1}^{4} AI(i) \div 7$$

$$NINV\ (i) = NINV\ (i-1) - SLDB$$

$$ADR\ (i) = \frac{(7-i)2}{6\ (7)} \times \sum_{j=1}^{4} AI(j)$$

$$DT(i) = (ADR(i) - SLDT) \times t - \sum_{j=1}^{4} \frac{\text{Capitalized taxes } (j) \times .46}{7}$$

$$ITCA = -\frac{ITCT}{7}, \text{ where } ITCT = \sum_{j=1}^{4} ITC(j)$$

Chargeable Investment (1) = Chargeable investment at end of construction period

Chargeable Investment (i) = Chargeable investment (i-1) - SLDB-DT(i-1) + ITCA

BI(i) = Chargeable investment (i) X b

$$\text{Equity } (i) = \text{Chargeable investment } (i) \times e + C_c \times (ITC + \sum_{j=1}^{i} ITCA(j-1)$$

Preferred (i) = Chargeable investment (i) X p

$$T(i) = \frac{t}{1-t} \times (SLDB + DT(i) + ITCA + \text{Equity } (i) + \text{Preferred } (i) - ADR(i))$$

6.3.2 ESG Economic Model

This model is a computerize version of the JPL method of (6-1) with additional features to calculate energy produced and energy saved by the use of solar repowering. The energy saved is experienced in dollars or equivalent quantities of various fossil fuels.

A sample computer printout is shown in Table 6-4 which shows many of the input parameters as well as the output parameters as well as the output parameters including levelized busbar energy cost (BBEC) and levelized annual cost (AC) for the capital investment, O&M, fuel, and the total. Additional parameters include cost-to-benefit ratio, payback period, and plant value based on the fuel savings. These latter parameters are defined as follows:

$$\frac{\text{Cost}}{\text{Benefit}} = \frac{c}{b} = \frac{\text{AC of Added Capital and O\&M}}{\text{AC of Fuel and O\&M Saved}}$$

$$\text{Payback Period} = \frac{\text{Capital Investment}}{\text{Yearly Fuel Cost Savings}}$$

$$\text{Plant Value} = \frac{b}{c} \times \left(\begin{array}{l}\text{Present Value of Capital Including Inflation} \\ \text{and cost allowance for funds used during} \\ \text{construction (AFDC)}\end{array}\right)$$

The plant value and BBEC are the main evaluation parameters used in this study.

6.4 RESULTS AND CONCLUSIONS

The results and conclusions using the TESCO parameters and models are given in 6.4.1 and using the alternative assumptions with the JPL methodology are given in 6.4.2.

TABLE 6-4

TYPICAL PRINTOUT OF ECONOMIC PARAMETERS

```
RUN DATE IS 6/03/80   ECON04,REV5/12/80 RUN NO.                  174.000
FUEL IS GAS/REPOWER FUELCOST= 2.500  $/MBTU

SYSTEM LIFE =  25.000 YEARS, PRICE YEAR 1980.000  BASE YEAR 1980.000
INITIAL OPERATION =  1985.000  CONSTRUCTION PERIOD= 4.000 YR
CAPITAL COST =  104.500 MILLION  CAPACITY CREDIT= 0.000
INITIAL ANNUAL O&M COST =  1.045 M$   FUEL O&M 10.000 %
CRF(k,N)= .110  DESCALATION= .681  GENERAL INTEREST= 10.000 %
PV FACTOR-O&M= 29.192 -FUEL= 47.487
FIXED CHARGE RATE =  17.963 % TAXRATE= .495  ALPHA= .100
ANNUAL CAPITAL ESCALATION RATE =  8.000 %
ANNUAL O&M ESCALATION RATE =  8.000 %
FUEL ESCALATION= 11.000 % GENERAL INFLATION= 8.000 %
AFDC FACTOR= 1.150 ESCAL FACTOR= 1.314
CAPITAL COST,Yco= 137.311 M$  AFDC= 20.552 M$  TOT COST= 157.863 M$
DISCOUNT RATE,k=  10.000 %

TOTAL OPERATING HOURS= 2744.000 H  SOLAR HOURS= 2744.000 H
CF SOLAR= .121  CF FOS= 0.000  CF TOTAL= .121  SF= 1.000
NET STATION RATING= 115.000 MWe   SOLAR = 44.500 MWe  TOTAL= 44.500
NET STATION HEAT RATE= 10000.000  TD SOL/FOS= 12500.000 FOS= 10939.556 BTU/KWHe
SAVINGS $= 3.340 $M/YR,  YEARLY FUEL $= 0.000 $M/YR
FUEL SAVING EQUIVALENT,M/YR, OIL= .212 BBL  GAS= 1295.642 CUFT  COAL= .051 TON

AC= .185 CIT+ 2.189 OMT+ 3.560 FLT+ .356 FLT
ACcap= 19.299    ACom= 2.352    ACfuel= 0.000    ACFLOM= 0.000
ACfuel saved= 11.890
COST= 21.651   BENEFIT= 13.079   C/B RATIO= 1.655  PAYBK= 31.292 YR
PLANT VALUE= 59.214 M$  PV OF CITOT= 98.020 M$
BBECcap= 158.052  BBECom= 19.258  BBECfl= 0.000  BBECTOT= 177.310 MILLS/KwH
```

6.4 Results and Conclusions

A copy of the computer output for the case identified in Section 6.2 is included as figure 6-5, and the following discussion is related to this printout.

The construction period is 4 years beginning in January, 1981. For ease in calculations, it was assumed that the work can be accomplished in 4 equal-cost segments: years 1-4. The cost of the plant construction is inflated 10% annually; thus, the cost of the first year of plant additions is (1.10) exp 1.5 - since no work is to be done in 1980. The remaining three years of work are inflated as follows:

Year 2 - (1.10) exp 2.5

Year 3 - (1.10) exp 3.5

Year 4 - (1.10) exp 4.5

The costs for the four construction years are as follows:

1981	$30,074,000
1982	$33,152,000
1983	$36,509,000
1984	$40,146,000

The service life of the plant is 7 years, beginning on January 1, 1985. The total installed cost of the plant at that time is $164,901,000, including AFUDC, taxes, etc. The present value of the capitalized cost of the plant during its service life is obtained from the computer printout, and that value is $129,922,000, as of January 1, 1980. The present value of the cost of building the plant is $93,990,000 ($164,901,000 ÷ 1.10 exp 5), as of January 1, 1980.

TEXAS ELECTRIC SERVICE COMPANY

ESTIMATED SOLAR REPOWERING COST * $1,000.

CONSTRUCTION PERIOD = 5 YEARS AFUDC RATE =.0800

YEAR	PERCENT COMPLETED	ANNUAL INVEST.	AFUDC CHARGED	INV TAX CREDIT	AVERAGE INVEST.	BOND COST	COMMON COST	PREF COST	INCOME TAX	CAP TAX AND INS	REVENUE TAX	CASH REQUIRED	CHARGED INVEST.	REVENUE REQUIRED
C 1	0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
C 2	0.215	30074.	1083.	3007.	14616.	666.	1085.	167.	-2863.	0.	34.	-911.	28149.	1014.
C 3	0.237	33152.	3445.	3315.	47214.	2153.	3482.	538.	-3148.	701.	113.	3840.	61810.	3331.
C 4	0.261	36509.	6229.	3651.	86330.	3937.	6322.	984.	-3442.	1540.	208.	9550.	101728.	6140.
C 5	0.287	40146.	9487.	4015.	132848.	6058.	9662.	1514.	-3742.	2536.	323.	16352.	148715.	9510.
TOTALS		139880.	20244.	13988.	56202.	12814.	20552.	3203.	-13194.	4778.	679.	28831.	148715.	19996.
PV TOTALS		93844.	12703.	10501.	176149.	8032.	12891.	2008.	-8861.	2928.	425.	17424.	216238.	13641.
LFCR T=CO		.1575	.0213	.0176	.0352	.0135	.0216	.0034	-.0149	.0049	.0007	.0292	.0432	.0229

TABLE 6-5

ESTIMATED SOLAR REPOWERING COST * $1,000.

BOOK LIFE	7.0	DEBT COST RATE	0.095
TAX LIFE	7.0	DEBT CAP. RATE	0.480
ADR LIFE	6.0	COMMON COST RATE	0.155
DISPERSION 7.0 S Q		COMMON CAP. RATE	0.400
SALVAGE RATE	0.0	PREF. COST RATE	0.095
PROP. TAX AND INS. RATE	0.022	PREF. CAP. RATE	0.120
INCOME TAX RATE	0.460	CAP. INT. RATE	0.123
INV. TAX CREDIT RATE	0.100	AFUDC RATE	0.080
REV. RELATED TAX RATE	0.035	CAPITAL COST RATE	0.119

YR	AVG AGE	NET INVEST	DEPR RES.	ST LN DEPR (BOOK)	RETIRE MENTS	ST LN DEPR (TAX)	ACC DEPR (TAX)	DEF TAX	INVEST TAX CREDIT	CHGD INVEST	BOND DEBT COST	COMMON STOCK COST	PREF STOCK COST	INCOME TAX	PROP TAX+ INS	REV REL TAX	TOTAL ANNUAL COST
1	1.00	164901.	23557.	23557.	0.	19983.	39966.	8878.	-1998.	148715.	6781.	10885.	1695.	2600.	3710.	1971.	58080.
2	2.00	141344.	47115.	23557.	0.	19983.	33305.	5814.	-1998.	118278.	5393.	8759.	1348.	3557.	3710.	1761.	51903.
3	3.00	117786.	70672.	23557.	0.	19983.	26644.	2750.	-1998.	90905.	4145.	6824.	1036.	4707.	3710.	1571.	46303.
4	4.00	94229.	94229.	23557.	0.	19983.	19983.	-314.	-1998.	66596.	3037.	5079.	759.	6049.	3710.	1401.	41280.
5	5.00	70672.	117786.	23557.	0.	19983.	13322.	-3378.	-1998.	45351.	2068.	3524.	517.	7582.	3710.	1250.	36832.
6	6.00	47114.	141344.	23557.	0.	19983.	6661.	-6442.	-1998.	27170.	1239.	2159.	310.	9306.	3710.	1119.	32960.
7	7.00	23557.	164901.	23557.	0.	19983.	0.	-9506.	-1998.	12053.	550.	984.	137.	11223.	3710.	1007.	29664.
TOTALS				164901.	0.	139880.	139880.	-2198.	-13988.		23213.	38214.	5803.	45023.	25972.	10080.	297021.
PV T=0		479408.		107852.		91487.	105060.	4806.	-9149.	379886.	17323.	28389.	4331.	26551.	16987.	6924.	204012.
PV*CC T=0		57049.								45206.							
LFCR T=0		0.0756		0.1429	0.2184	0.1212	0.1392	0.0064	-.0121	0.0599	0.0229	0.0376	0.0057	0.0352	0.0225	0.0092	0.2702
PV TOT T=0				107852.				7169.	9275.	90353.	31415.	51006.	7854.	11005.	16987.	7669.	227945.
LFCR TOT T=0				0.1429				0.0095	0.0123	0.1197	0.0416	0.0676	0.0104	0.0146	0.0225	0.0102	0.3019
PV T=CO				61472.				4086.	5287.	51499.	17906.	29072.	4476.	6273.	9682.	4371.	129922.
LFCR T=CO				0.0599	0.1607			0.0040	0.0052	0.0502	0.0174	0.0283	0.0044	0.0061	0.0094	0.0043	0.1266

TABLE 6-5 (cntd)

References

6-1 "The cost of Energy From Utility-Owned Solar Electric Systems", J. W Doane, et al, JPL 5040-27 (ERDA/JPL-1012-76/3), June 1976

6-2 Conceptual Design of Advanced Central Receiver Power Systems Sodium-Cooled Receiver Concept Final Report SAN/1483 (ESG-79-2) June 1979

6-3 Solar Central Receiver Hybrid Power Systems Sodium-Cooled Receiver concept - Final Report DOE/ET/20567, (ESG-79-30) Jan 1980

Table 6.4.1 includes the fuel savings, O&M costs, and capital costs for each year of the service life of the plant. The present worths of those costs and savings are also included.

Table 6.4.1

Year	Capital Cost	O&M Cost	Fuel Savings[2]
1985	$58,080,000	$1,649,000	$5,291,260
1986	51,903,000	1,813,900	5,926,700
1987	46,303,000	1,995,290	6,635,460
1988	41,280,000	2,194,820	7,429,760
1989	36,832,000	2,414,300	8,321,820
1990	32,960,000	2,655,730	9,507,160
1991	29,664,000	2,921,305	10,863,580
PW[1]	129,922,000	5,910,000	20,180,000

[1] January 1, 1980

[2] Fuel saving is 1.222×10^{12} BTU/year

The value of the repowered plant to Texas Electric Service Company is not the same as the fuel savings as shown in Table 6.4.1. The actual value of fuel savings is $14,270,000 ($20,180,000 - $5,910,000) as of January 1, 1980. From the computer printout, the initial investment of $104,500,000 results in a present worth of $129,922,000 in operating costs during the service life of the plant. Therefore, to determine the value of the fuel savings to TESCO, multiply the $14,270,000 by the ratio: $104,500,000/$129,922,000. The resulting plant equivalent cost of fuel savings is $11,478,000, as of January 1,

1980. This represents 10.98% of the January 1, 1980, estimate of the cost to repower Permian Basin Unit #5 with 50 megawatts solar electrical output and one hour of solar thermal storage.

The busbar energy cost (BBEC) can be calculated from information contained in the preceding paragraphs. The expected annual generation is 122,108,000 kwh (2744 operating hours x 44,500 kw net output). The BBEC is $0.152/kwh ($122,922,000/(7 x 122,108,000)) as of January 1, 1980.

7.0 DEVELOPMENT PLAN

The objective of this development plan is to have the TESCO repowering application checked out and in operation by early 1985. This goal is consistent with the DOE multi-year plans as given in 7-1 and 7-2. This repowering application is viewed as an essential "next step" beyond Barstow Solar One in the overall goal for the solar-thermal energy program. Successful operation of this repowered plant as well as Solar One will give central receiver solar thermal plants credibility as an energy option for utilities. There are many opportunities for repowering applications (7-3 and 7-4) in the late 1980's and early 1990's.

The Permian Basin repowering application is considered to be representative of a class of reheat steam power plants. Various surveys of potential repowering sites such as contained in References 7-3 and 7-4 show a total of 153 units (21,850 MWe) of potential repowering applications based on land availability. Additional assumptions concerning minimum repowering level, minimum percent repowering, age of plant, and distance from the tower to the steam turbine reduce the potential as indicated in Reference 2 to 93 units with 10,800 MWe capacity. Each potential site must be examined in some detail to determine suitability. While the Permian Basin site represents a reheat application, this repowering concept using sodium can also accommodate nonreheat capability, in which case the market potential for repowering is increased by 152 units (3950 MWe) based on land availability. With the additional constraints, the potential was reduced to 47 units with 1980 MWe. Hence, the total of reheat and nonreheat potential is 140 units with 12,780 MWe capacity.

Although the ~~proposed~~ Subject project ~~includes the design of~~ is for a site-specific application, the design constitutes a basic product that can then be used in other solar repowering applications. A preliminary market assessment indicates substantial application potential for this product with excellent potential for fossil fuel replacement.

The potential for cost-effective future plant application, without subsidy, is given in 6.4. Preliminary economic studies indicate that the cost-to-benefit ratio for a repowered plant will be attractive for a 1990 or later start date due to the reduced heliostat cost attendant with increase production quantity.

This section outlines the activities and steps necessary to accomplish the repowering of TESCO Permian Basin Unit No. 5. The overall logic for this program is shown in Figure 7-1. The overall schedule given in Section 7.6 is shown in Figure 7-2. Major milestone events are identified in Table 7-1 of Section 7.6. Figure 7-3 of Section 7.8 shows how the repowering plants form a basis for meshing the overall solar thermal effort to become a significant energy source. This schedule is obtained in part from Reference 7-1 and 7-2 for the earlier years and as projected by ESG in order to meet the Government goal of 0.4 guads of solar thermal energy by the year 2000. Detailed schedules for selected components are also shown in Section 7.6.

This development plan assumesthat Barstow Solar One Plant is completed and operational by 1982. The plan also assumes that the sodium receiver testing, both the government-funded effort and the ESG-funded effort, are completed as scheduled (by 1982) and additional receiver testing is not required.

The schedule of Figure 7-2, Section 7.6, shows preliminary design phase to be started on June 1, 1981, and checkout phase completed by March 1985. The projected start date allows 8 months for the evaluation of the Program Opportunity Notice Proposals. The desired operational date for First Quarter 1985 is considered a program requirement. The resulting design and construction duration of 3 years and 9 months is considered optimistic; and additional 6 months would be realistic. The initiation of long-lead procurement items must be made by the end of the preliminary design phase. Based on the disucssion of 4.9 and 4.10, approval of the permits and licenses required seem relatively certain and the application for these items can be pursued during the design effort.

The various program phases are discussed in the following paragraphs.

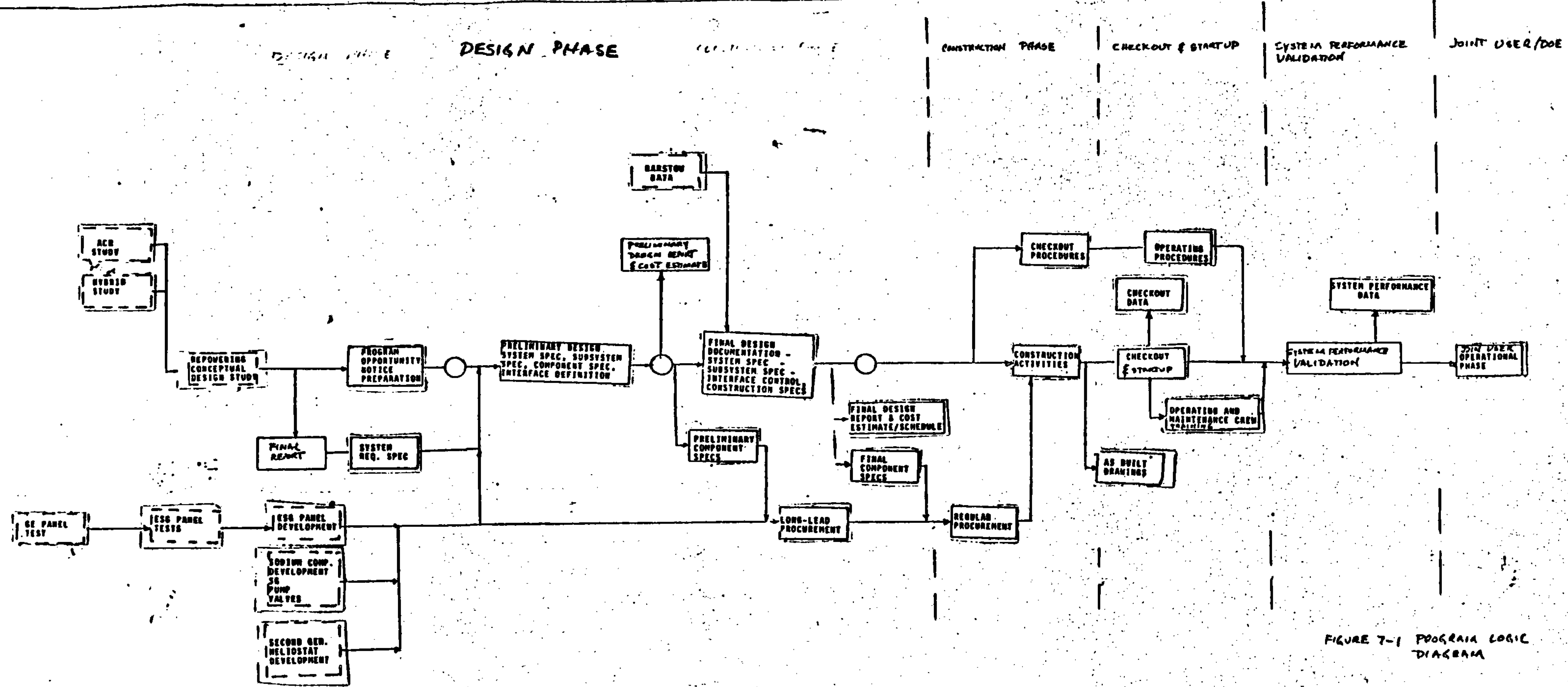

FIGURE 7-1 PROGRAM LOGIC DIAGRAM

7.1 DESIGN PHASE

The design phase is composed of a preliminary design and a final design phase. The two phases are separated by a formal design review which will result in approval of the long-lead procurement plan and initiate the final design phase.

7.1.1 Preliminary Design (Title I)

The preliminary design phase of 9 months duration will establish a system and subsystem configuration with Piping and Instrumentation (P and I), component layout, and piping arrangement drawings. The receiver component design and structural analysis effort will be initiated early in this phase. Steam generator design and structural analysis effort will also be initiated. A make-or-buy decision will be made. The piping layout will be evaluated and critical structural areas identified for additional analysis. An interface definition document will be prepared identifying all of the physical, functional, and electrical requirements between the subsystems. Long-lead components, materials, and service will be identified. A prospective list of long-lead items is given in Table 7-1. Preliminary specifications for design or procurement components depending on the make-or-buy decisions will be written. Detailed cost and schedules will be prepared for the completion of the design, procurement, and construction activities.

The only item that requires development for this program is the receiver. Since receiver development is being conducted under separate funding by both the DOE and ESG, the relationship to the subject program is shown in Figure 7-1 but remain as separate programs. It is possible that the results from these programs indicate the need for further development. In this case, it is recommended that the additional development efforts be incorporated into the subject program.

TABLE 7-1

PROSPECTIVE LONG-LEAD PROCUREMENT ITEMS

1. Collector Subsystem

   Heliostats

2. Receiver Subsystem

   Receiver
   Receiver Pump
   Pressure-Reducing Valve
   Steam Generator Units

3. Master Control

   None

4. Fossil Energy

   None

5. Energy Storage

   Stainless Steel Hot Storage Tank
   Steam Generator Pump

6. EPGS

   Superheat and Reheat Steam Heating

Master control activities will be emphasized during this phase to insure the proper integration of the subsystem controls into an operational control system. The control philosophy and requirements are identified in 4.3. Control instrumentation is added to the extent necessary to provide safe and efficient plant operation according to usual utility practice. Data instrumentation is added only as necessary to accomplish the above-mentioned safe and efficient operation.

The operating modes developed during the conceptual design will be more completely developed.

At the end of this phase, a formal design review will be conducted. This design review may be preceded by component and subsystem reviews. Approval of this phase will freeze the plant design at the system and subsystem level, approve the long-lead procurement plan, and initiate the final design phase.

7.1.2 Final Design (Title II)

The final design phase is expected to last 9 months. This phase develops the specification, drawing, and procurement documents such that fabrication and construction aids can be obtained. Documents in a preliminary form will be finalized and approved. Structural analysis will continue to resolve possible critical stress area.

Cost and schedule estimates based on the completed documentation shall be prepared. Engineering will supply assistance in the analyzing and evaluation of vendor bids for material, equipment, services, and construction. This phase ends with the approval for construction. However, an engineering activity (Title III, Construction Services) continues during the construction phase to support the ongoing construction activity.

7.2 CONSTRUCTION PHASE

The construction phase is scheduled for 18 months as shown in Figure 7-2 of Section 7.6 This phase is the start of major onsite activity, but is preceded by soils testing, brush clearance, rough grading, and site studies to establish such items as possible wildlife and archeological restrictions. Long-lead procurement of selected components precedes this phase as discussed in 7.1. Under present day economy, there will be very few items that are "shelf items," or in the manufacturer's stock or inventory. All major equipment for the Solar Repowering Project will be special order.

The control systems will need to be engineered and designed within the procurement time allocated for other major equipment so that the system can be assembled, factory tested under simulated conditions and delivery mode, then installed prior to completion of major components and auxiliaries. In this way, the control system will be available for use whenever checkout and testing of the entire plant components commences. This may be several months prior to completion of the construction of the major systems of the solar project.

Modifications and additions to the existing unit will need to be engineered and designed and equipment ordered in due time to check out those modifications prior to the scheduled checkout and testing of the solar equipment. This will also include extension of the existing control building and providing an additional BTG board for mounting the controls for the solar project.

A construction schedule, using a critical path method, shall be prepared to include all phases of construction from "start" to "final testing" and "startup." This method will identify those items that are critical for scheduled delivery dates. A critical path method of scheduling will be necessary and updated weekly to identify and prevent a particular phase of work falling behind schedule. The construction contractor should be made responsible for maintaining the schedule. The A/E and Owner (and others) will be responsible for assigning project or resident engineers to provide surveillance of the construction project and to see that field construction changes are expedited and approved by the proper authorized people. It is the opinion of Texas Electric that the construction schedule included in 7.6 is attainable. The site preparation, foundations, and modifications to the existing plant are areas in which TESCO personnel have experience, and those construction periods are reasonable. Early in the phase, foundations for sodium components, tanks, and the tower are placed and structural steel erected. Placement of heliostat foundations is begun in mid-1983. First delivery and installation of heliostat occurs in September 1983 as shown in Figure 7-4. The receiver panels are delivered to the site for installation early in 1984 along with a majority of the sodium components.

The A/E resident engineer may have the following responsibilities:

1. Provide general surveillance of the work of the General Contractor and subcontractor to obtain compliance with the specifications and drawings.
2. Determine the status of job progress and approve contractor's invoices for progressive payments (this may be an option to be decided upon later).
3. Review and advise owner's resident engineer on contractor's claims for extra work.
4. Evaluate and act on request from owner's engineer.
5. Work with equipment manufacturers and the A/E's office staff to correct deficiencies in manufactured equipment.
6. Coordinate changes to the engineering drawings and specifications with the A/E to resolve problems arising in the field.
7. Provide technical interpretation of the engineering specifications and drawings.
8. Coordinate releases of engineering information and approvals and act as liaison with the A/E engineering.
9. Work with contractor on a day-to-day basis in resolving problems related to meeting the design requirements.

10. Evaluate contractor's request for substitute material, referring such requests to the A/E engineering when required.
11. Coordinate expediting requirements with the A/E expeditors.
12. Prepare weekly construction progress reports and otherwise keep the owner and A/E informed of the progress of the work.

Specifications and instructions to manufacturers shall be to stress quality control. Where applicable, the following shall be observed: (1) test operate any equipment under simulated conditions and (2) properly package and seal prior to shipment to keep out contaminants, especially piping and rotating equipment.

During the construction phase, the contractor and subcontractor shall comply with all governmental rules and regulations and adhere to safe working practices for employee protection. A "no-strike" clause by labor (if a union contract) in the construction contract is desirable.

An approved bidders' list for major equipment and the solar plant auxiliaries shall be agreed upon between the A/E and the owner prior to issuing specifications for bidding. This may not include the solar panels, receiver and some other items that are specialty type solar equipment.

The construction contract shall designate how construction electrical power, water supply, compressed air supply, consumable and nonconsumable items are to be furnished.

The construction phase shall be scheduled at a time when the existing Unit 5 can be shut down and made available for interfacing with the solar system. Detail plans shall be made to have as much of the solar project constructed and complete so that the outage time on Unit 5 will be at a minimum. Only those tie points of the solar systems with the Unit 5 systems, the controls, electrical connections, etc., should be made during the outage for the changeover. The solar steam systems are to be chemically cleaned and/or all steam piping blown out to remove any debris or foreign objects prior to connecting to the Unit 5 steam piping systems.

The A/E, and/or ESG, shall prepare written descriptions for preparation and filling the sodium system in preparation for startup, as well as all other startup and checkout procedures.

7.3. SYSTEM CHECKOUT AND STARTUP PHASE

The checkout phase will have an overall duration of 7 months. This phase will overlap the construction phase in that as a system or subsystem is installed, checkout will be initiated as an isolated item. In this way, the operation of system or component can be verified or partially verified prior to completion of the plant. Checkout proceeds from the simplest elements of a system to the more complex until the entire subsystem is checked out.

A detailed system checkout and startup procedure shall be prepared by the A/E for all the equipment prior to trial operation. This should be coordinated with critical-path requirements of the construction schedule.

The system checkout and startup phase should be assigned to a startup engineer who plans the sequence of tests and coordinates all tests with the construction personnel and plant operators. When construction personnel complete the installation of a piece of equipment and the item is ready for checkout and test operations, a release form shall be completed and assigned to plant operations by the construction personnel. After the clearance check is completed and operation of the equipment is satisfactory, the plant operators shall reatin the release form. The equipment then becomes the responsibility of Operations. If additional work is required on the equipment, the release form is returned to the contractor for additional work. The startup engineer will coordinate these activities and plan the steps to check out and test operate the equipment. A procedure shall be worked out between the contractor's personnel, the plant operators and the startup engineer for accepting and releasing equipment, tagging for clearances, etc., to insure safety of personnel and equipment.

The services rendered by the checkout and startup engineer shall include the following responsibilities:

1) Preplanning and scheduling or orderly startup including review of systems, preparation of checkout procedures and startup schedules.
2) Preoperational inspection of installed equipment to determine if equipment is installed properly, safely, and otherwise ready for operation.
3) Preliminary trial operation of equipment, components, and systems to determine compliance with design and operating criteria.
4) Develop and implement a safety tagging procedure to insure a safe and coordinated turnover of equipment to operations personnel.
5) Develop site working procedures for conducting such activities as hydrostatic tests, system flushing, and chemical cleaning.
6) Prepare and submit reports of field tests and inspection results for records purposes and compare equipment performance analysis with regard to manufacturer's guarantees.
7) Coordination, scheduling, and participating with general contractor's personnel, vendor representatives, and owner's personnel to provide for orderly startup and correction of equipment deficiencies diagnosed during trial operations.
8) Overall coordination of plant operating activities during initial operation trial runs and functional operations leading to firm commercial operations.

Prior to system checkout and startup, the essential requirements must be provided, such as:

1) Instrument air supply
2) Vital automatic controls, data logger, annunciator, etc.
3) Service water or cooling water systems
4) D-C backup power, if required
5) 120 V vital A-C power, if provided
6) Power supply to 120 V, 480 V, and 4,160 V switchgear (also to any other voltage used for the heliostat field).
7) All sodium and steam equipment and piping shall be cleaned prior to shipment and cleanliness shall be maintained during shipment and installation.
8) The startup engineer shall work with construction personnel and plant operators on cleaning all piping systems. An outside contractor, such as Haliburton or Dow Chemical Company, should be considered for chemically cleaning those piping systems designated for chemical cleaning processes.

Any piping to be blown out with steam shall have temporary piping and valves especially installed for obtaining steam from the existing Unit 5 boiler. The temporary valves and piping shall be the responsibility of the contractor.

Any temporary strainers in the suction piping of the sodium pumps, or any other auxiliary pumps, shall be removed and cleaned as required during trial operations and will be the responsibility of the contractor, until all systems have been accepted as clean.

Any equipment that fails or does not operate properly during the checkout and startup phase shall be the responsibility of the contractor to coordinate whatever action is necessary with the equipment vendor to make repairs or replace the defective item before it is accepted by the owner.

After the checkout and test operation of all the euipment and the interconnections are made with the existing Unit 5, a startup procedure shall be implemented. After all the heliostats are checked out and the sodium cycle established and operational, the first phase of generating steam supply from the solar system shall be undertaken. The fossil boiler is to be fired and the unit placed in service with approximately 30-MW load. The pressure and temperature of the solar steam supply will be adjusted to match the steam pressure and temperature of the fossil boiler. The solar steam supply will then be mixed with the normal steam supply to the turbine.

Of course, all equipment, automatic controls, manual controls, and data logging equipment will be available for service and operational. No doubt, numerous operating conditions will be encountered before acceptable conditions are met. Unforeseen conditions will be corrected as they occur and as agreed between the owner and the contractors. Time and funds (omissions and contingencies) should be allowed for these conditions. The results of these test operations will be incorporated into the operator's manual. An operator and maintenance training program will be conducted for solar operations and for sodium system operations. Checkout is complete when all systems have been verified and dispatch-type operation can be initiated.

7.4 SYSTEM PERFORMANCE VALIDATION PHASE

The system performance validation phase willbe planned for 2 months. All systems shall be tested within a reasonable time after startup. When conditions permit, maximum flow rates shall be established to verify design conditions. Data will be taken to make system performance calculations and allow the evaluation of equipment performance. Some desired modes of operations are:

1. Fossil boiler and solar system operating in parallel supplying steam to the Unit 5 turbine. This will be in the boiler following mode and solar system following mode.

2) Fossil boiler base loaded and the solar system taking the load swings and controlling main steam pressure and temperature.

3) Solar system base loaded and the fossil boiler taking the load swings and controlling main steam pressure and temperature.

4) Solar system operating alone with the fossil boiler on standby reserve.

5) All of the above with Unit 5 operating on automatic load dispatching, receiving load change impulses from the computer in TESCO's system dispatcher's office in Fort Worth. This normally would be at a maximum rate of 2-3 MW/minute, either increasing or decreasing load to meet system demands.

Tests shall be made to determine the plant output of the solar system, energy consumption, and operating mode, whether continuous or peaking service.

Tests shall be performed on the heliostat field to determine whether or not it meets performance design point, number of heliostats to produce design load, and number of heliostats for standby reserve. The receiver sodium cycle performance is to be tested; determine is sodium storage capacity is adequate.

Tests shall be conducted in the fossil and solar following mode as well as the turbine following mode to determine which is the most economical and responsive to load changes when on automatic load dispatching, during system transient conditions, such as low system frequency and effects of governor response on the fossil and solar systems. The test shall determine system response during these transient conditions. Some of these tests may have to be simulated.

The automatic/manual control systems will be thoroughly exercised and adjusted to meet normal load changes as well as transient conditions. This may require some additional components or modifications to the control system after initial startup and testing.

All safety features or safety devices shall be tested for performance.

Familiarization of the characteristics of the receiver fluid (sodium) shall be demonstrated to plant operators, including the thermal characteristics, allowable leakage, disposal of waste, clearing and draining equipment for maintenance, preparations for recharging, etc. Startup and shutdown procedures are to be demonstrated by actual operations.

After all the tests have been performed, it is most likely the solar system will operate at mazimum allowable output. All systems shll be tested for the condition of continuous operation for the maximum number of hours each day the sun shines. Tests will be conducted to determine length of operating time from storage at various load levels.

Tests will be conducted to determine the effect on the solar system as a cloud cover occurs and the interaction with the network.

Operating and maintenance crew activities will be monitored to determine the added requirements due to the solar addition. Outages will be evaluated to determine those attributable to the solar addition. Solar insulation will be measured to aid in determining overall system performance. All components will be checked for function, integrity, and performance. Major components or subsystems to be monitored include:

Component	Verification
Piping	Deflection, Hanger Position, or Loads
Receiver Pump	Head, Flow, Calculated Efficiency, Vibration, Sodium Level Control
Steam Generator Pump	Same and Speed Control
Pressure Reducing Valve	Flow Stability, Noise, Pressure Drop, Operator, Position Accuracy

Component	Verification
Steam Generator	Steam Temperature, Sodium Flow, Steam Flow, Steam Quality, Steam Flow Stability for Both Superheat and Reheat
Master Control	Control Options, Stability, Accuracy
Storage Tanks	Temperatures, Thermal Growth, Surface Temperature
Steam Tie Points	Temperature Differences, Vibration
Feedwater Purfication	Water Purity
Heliostats	Area Accuracy, Reflectivity, Unit Outage
Receiver Panels	Outlet Temperature, Valve Operation, Flow Rate, Deflection, Losses

All other events that may be verified:

1) What happens upon loss of auxiliary power to the heliostat field?
2) What happens upon loss of power to the sodium pumps and other auxiliaries?
3) What happens upon complete loss of power to the plant, a complete blackout?
4) What happens upon loss of power to the automatic control components? Will a vital A-C supply be provided?
5) What happens when the turbine trips? What action shall be taken with the solar system and how soon?

The reliability and operation of the emergency diesel system should be demonstrated.

7.5 JOINT USER/DOE OPERATIONS PHASE

Assuming that the system validation phase is successfully completed, TESCO would reserve the sole right of plant operation and control. This right of control is considered necessary to insure the integrity of service, make efficient use of available manpower, and complete necessary scheduling of maintenance on this and other generating units. The need for production of electrical energy would also be given a high priority.

However, as conditions permit, efforts will be made to schedule plant operation in such a way that each mode of operation may be demonstrated. In general, the concepts which need to be demonstrated are the storage system, operating in a solar stand-alone mode, and the resulting cycling of the fossil boiler, steam turbine, and sodium steam generators. Each of these conditions and how they are interdependent are discussed in more detail in other sections of this report.

Conditions which will permit testing and demonstration of these concepts will be seasonal and subject to change. These conditions may require that some phases of testing be limited in time and scope.

There are two additional subjects which require comment for the operational phase. These are the availability of data and access to the plant site during operation and testing. Access to the plant site can be divided into two categories: visitors and non-TESCO personnel that are involved in the testing, monitoring, and plant operation.

General access for non-TESCO personnel that are involved with the project will be made available. This must be done with reason and prudence due to possible safety hazards and to minimize interference with normal work routines. TESCO would reserve the right of final review and decision in this area. Visitors to the site would be another subject. It is anticipated that access onto the plant site will be limited. The establishment of a visitor's center is one possibility. TESCO is unable to make any commitment related to the construction of a visitor's center or the manning of such a center if it is to be manned.

The quantity of an subject matter of operational data which will be available cannot be detailed in this report because of the unknown requirements. However, some general statements can be made. All data which is presently available to the public will, of course, be available. TESCO will be unable to reveal any specific fuel cost since the identity of any specific fuel saved would be on an average basis. The plant operational data would be determined on the basis of solar energy available, KWh energy output, etc. This would allow the calculation and evaluation of thermal efficiencies, busbar cost of energy generated from the solar source, and other quantities of a technical nature. This data would then allow other interested utilities to apply their operating cost data to the plant as if it were located on their system.

7.6 SCHEDULE AND MILESTONE CHART

The overall repowering schedule for Permian Basin Unit 5 is given in Figure 7-2. The milestones shown on this figure are listed in Table 7-2. More detailed schedules are shown for selected components as follows:

Figure No.	Schedule
7-4	Heliostats
7-5	Receiver
7-6	Pump
7-7	Steam Generator
7-8	Tower

These schedules are based on vendor comments and on ESG experience with the fabrication or procurement of similar components.

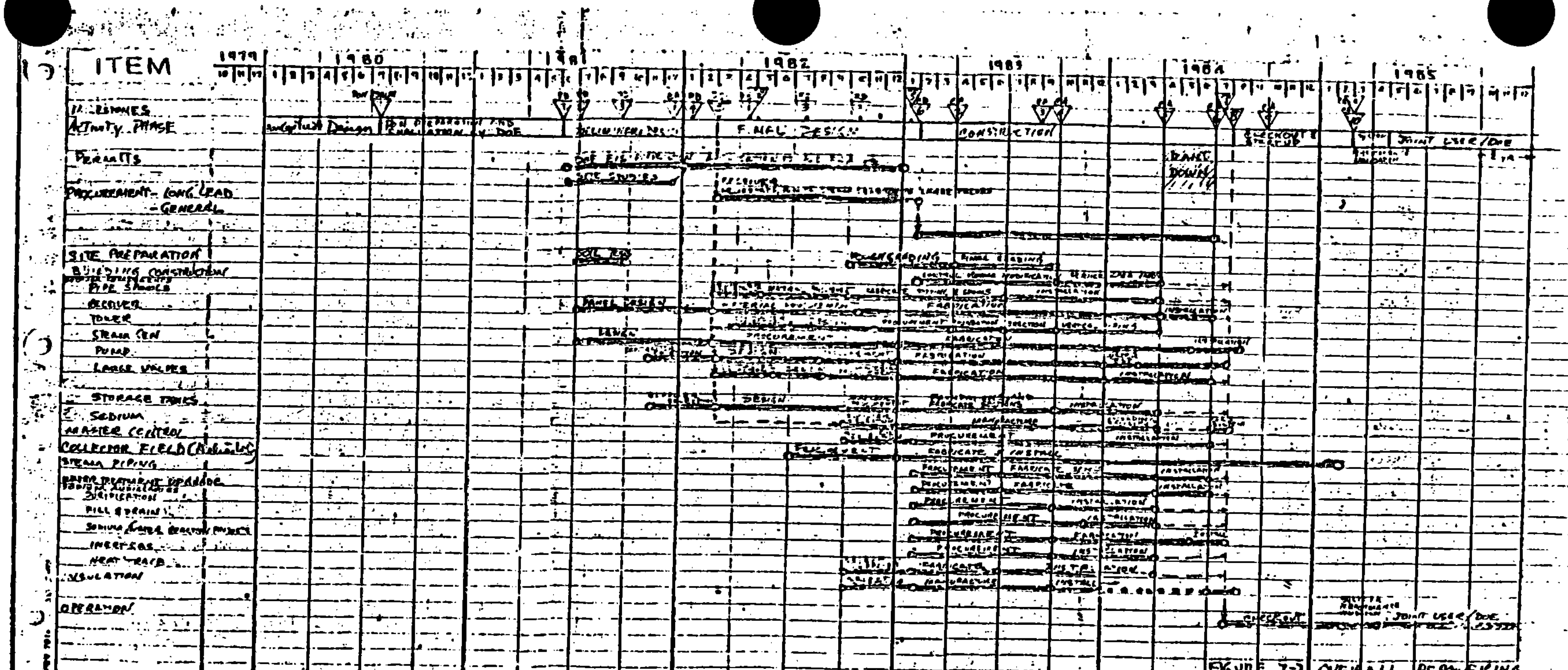

FIGURE 7-2 OVERALL PERFORMING SCHEDULE

TABLE 7-2

MAJOR MILESTONE LIST

Item		Date
Preliminary Design (PD)		
1.	Approval to Proceed	06/01/81
2.	Issue Revised System Requirements Spec.	07/01/81
3.	First Quarterly Review	09/15/81
4.	Design Review and Second Quarterly	01/15/82
5.	Long-Lead Procurement Authorization	03/01/82
Final Design (FD)		
1.	Third Quarterly Review	04/15/82
2.	Issue Subsystem Design Specs.	05/01/82
3.	Fourth Quarterly Review	07/15/82
4.	Fifth Quarterly Review	10/15/82
5.	Sixth Quarterly Review - Issue Final Component Procurement or Fabrication Specs. and Drawings	01/15/83
6.	Construction Authorization	
Construction Activities (CA)		
1.	Site Survey and Soil Samples Complete	01/01/82
2.	Rough Grading Complete	04/01/83
3.	Initiate Heliostat Installation	09/01/83
4.	Tower Complete	10/01/83
5.	Storage Tank Complete	04/01/84
6.	Receiver Installation Complete	07/01/84
7.	Sodium Fill Initiated	07/15/84
8.	System Checkout Initiated	08/01/84
9.	First Turbine Roll with Solar Stream	10/01/84
10.	Checkout Complete	03/01/85
11.	Plant Dispatch Operation	03/01/85

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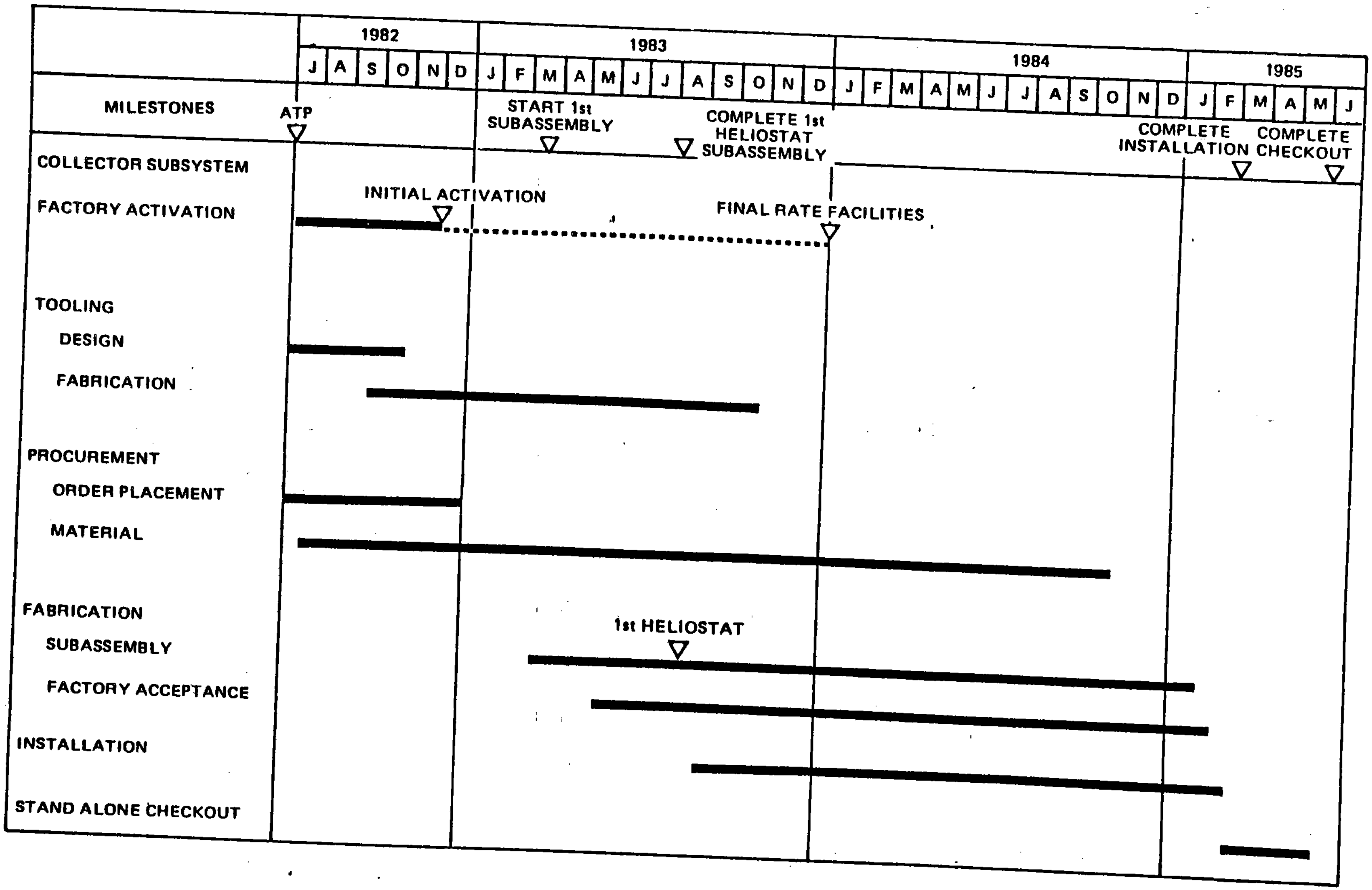

Fig 7-3 HELIOSTAT SCHEDULE

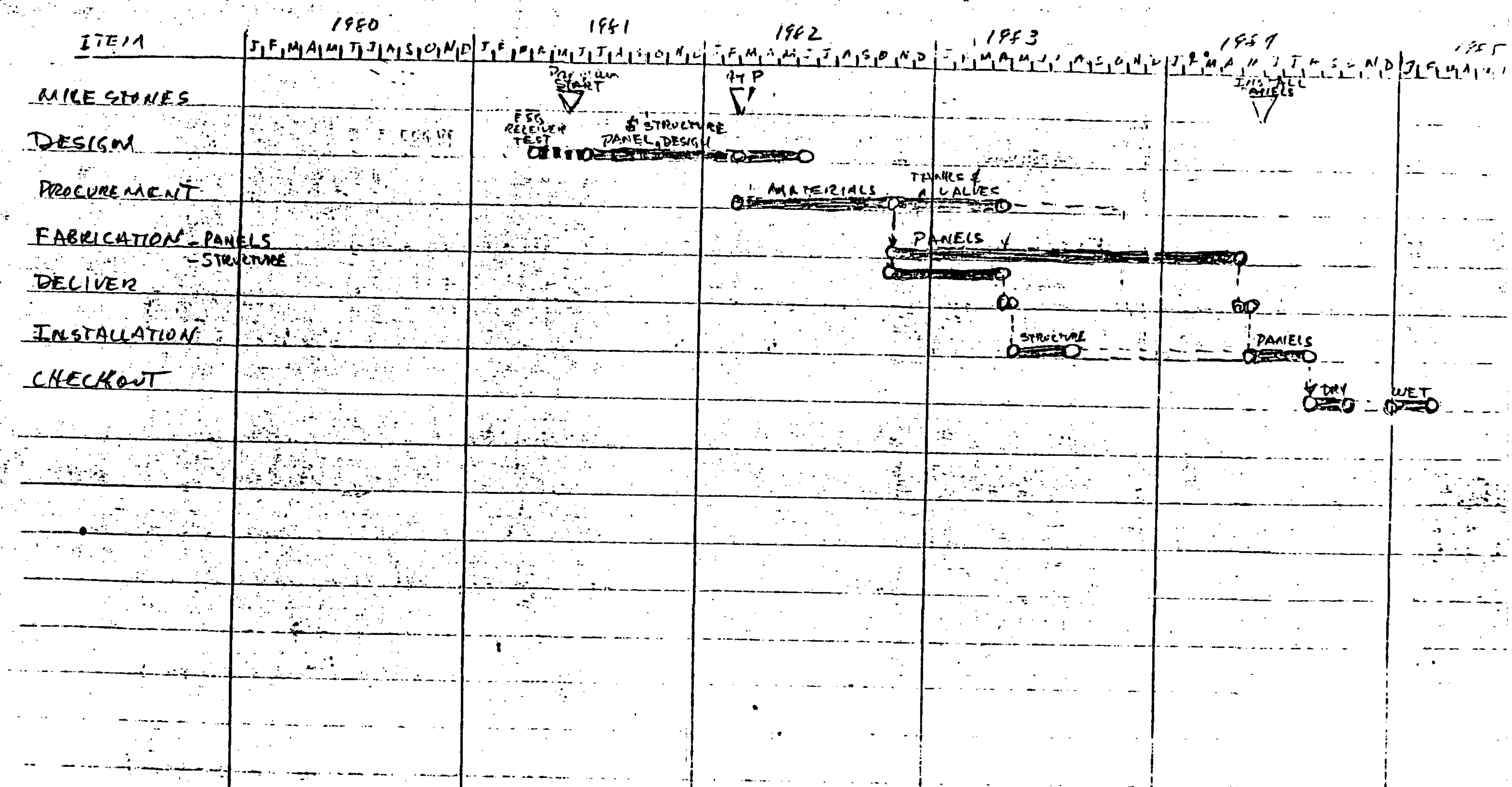

FIGURE 7-8 RECEIVER SCHEDULE

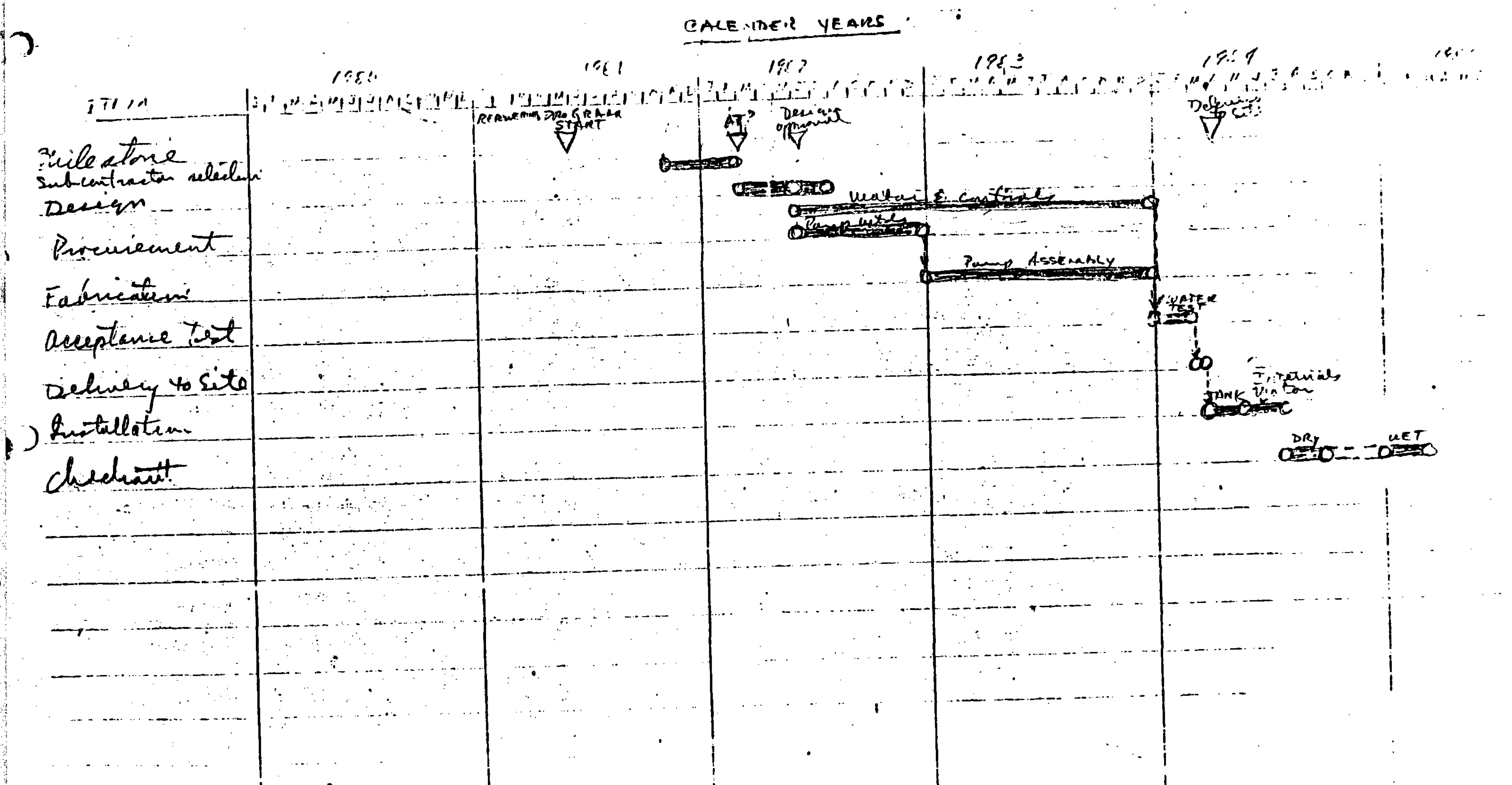

FIGURE 7-5 PUMP SCHEDULE

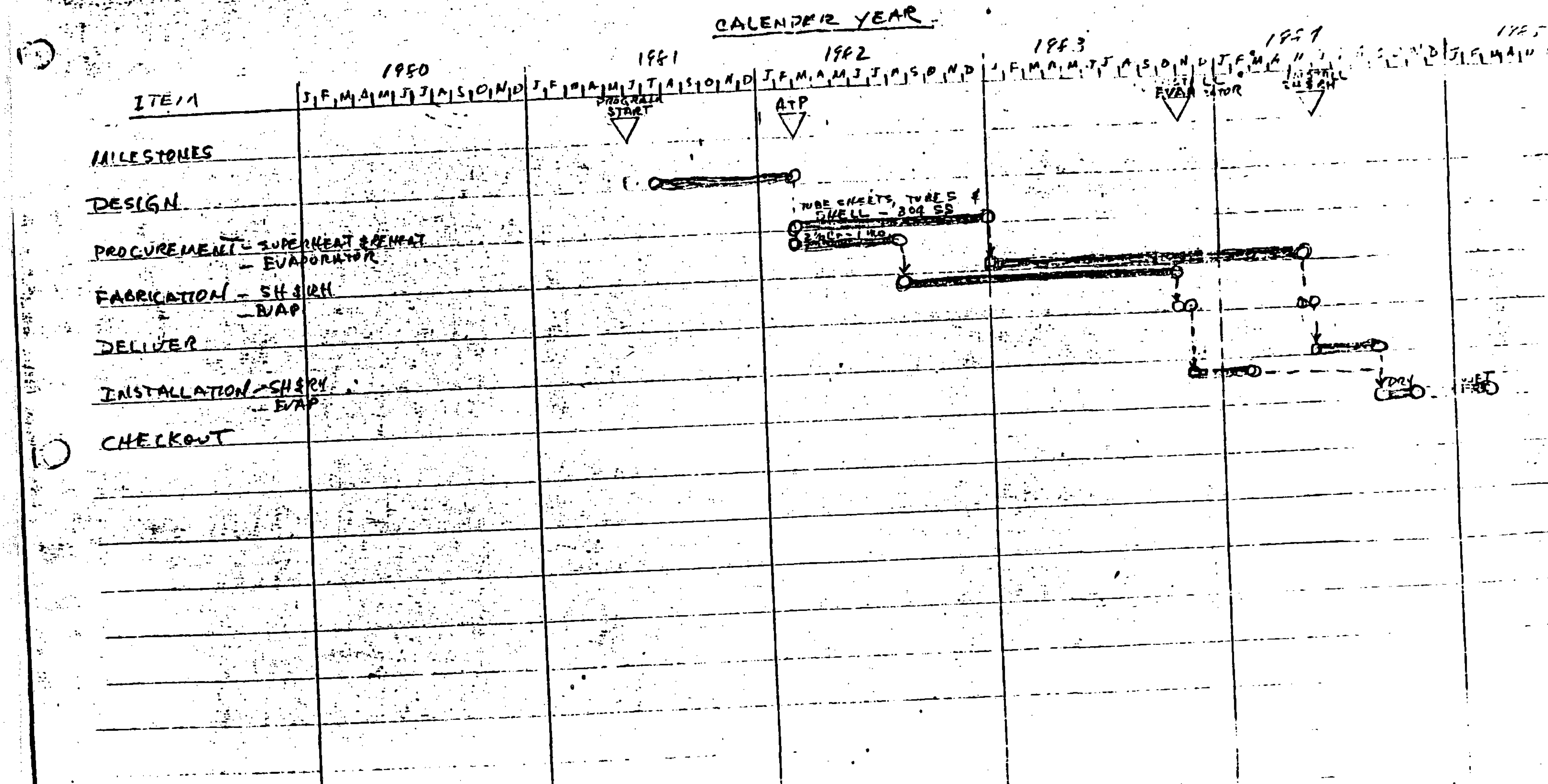

FIGURE 7-10 . STEAM GENE ER SCHEDULE

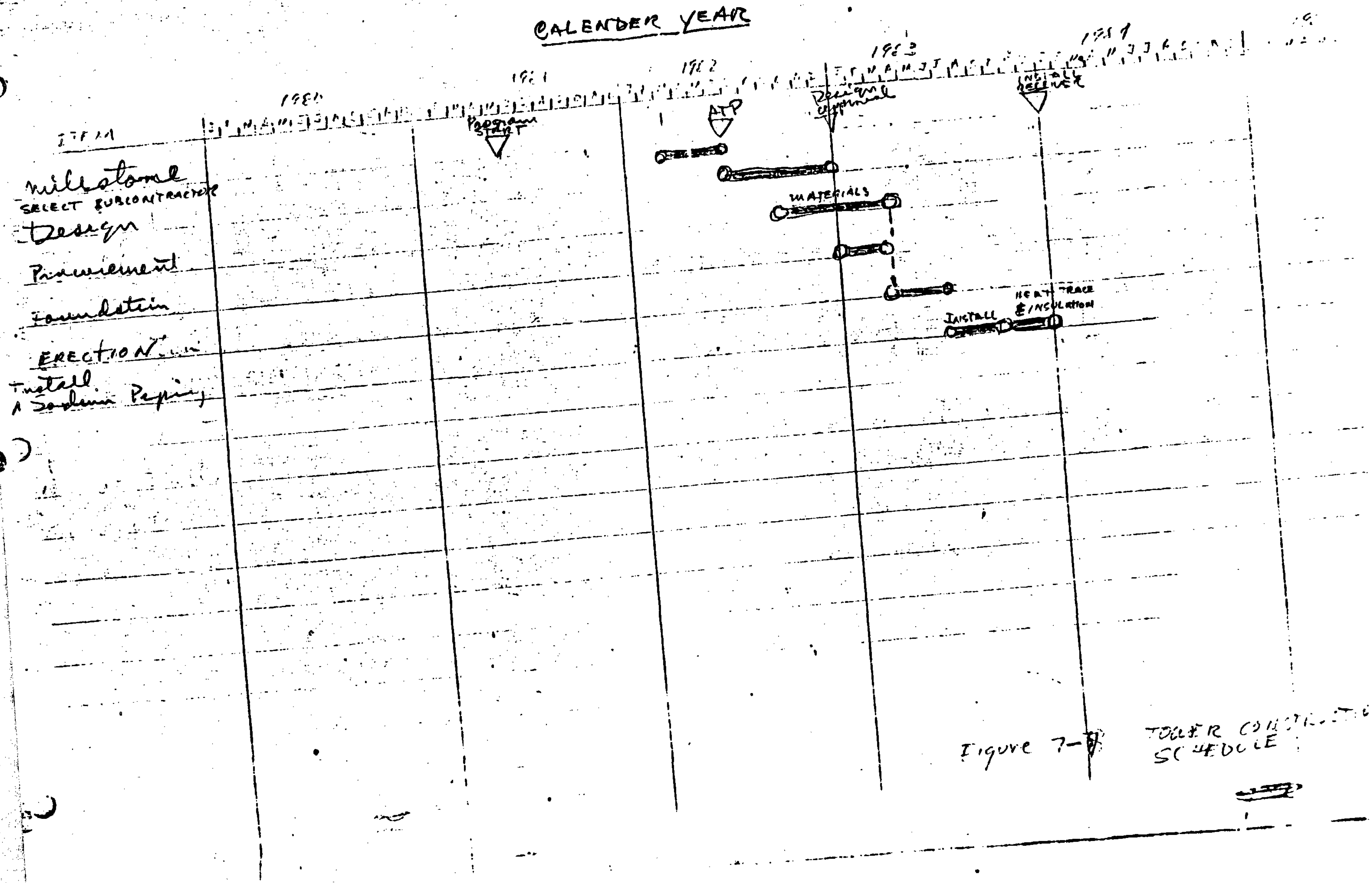

Figure 7-8 TOWER CONSTRUCTION SCHEDULE

7.7 Roles of Site Owner, Government, and Industry

At the present time, solar repowering with the central receiver technology must be viewed as a high risk technology. This is true, if for no other reason than it has never been demonstrated on any scale. Experience says that the "first" installation of a system of this magnitude will have many problems, some of which may prevent the system from performing at rated expectations. Some specific items of risk are the lack of actual capital cost experience, lack of operating and maintenance experience, and not knowing the actual useful life of the equipment.

In opposition to this concept of solar repowering being a high risk technology is the need for the utility to experience a minimum of risk. This is a necessity in order to assure fair rates to the customer and maintain the confidence of investors. One method of minimizing risk is to compare the economics of solar repowering with alternate systems. This is done in other sections of the report, but obvious alternatives for large scale generating of energy are coal and nuclear. Since these are proven systems, and they are more economical than repowering, the alternatives would be preferred.

However, since this is a demonstration project, it must also be considered as an R & D project. In this case, the competing alternatives might be wind, municipal solid waste, or other new sources of energy. One way of limiting the risk when considering R & D investment in these systems is to limit the capital investment in any one system. Each alternative must be evaluated for the benefit which will be received for the amount of economic investment required. Therefore other new energy sources may not require the capital investment of a repowering system and may provide more useful information.

Another method of limiting the risk to the utility is to assume a conservative life for the plant. With the developing technology of solar repowering, it would not be unrealistic to assume the possibility of an obsolete plant in seven years. This plant life for the solar portion would then coincide with the normal fossil plant retirement date and remove the unknowns which may result from attempting to extend the life of the fossil plant. Obviously, the solar and fossil plants may have longer useful lives than seven years after 1984, but the need to minimize the risk assumed by the utility would make this a good assumption.

There is the possibility of assumption of risk by other parties in several areas. Thus risks may be assumed by suppliers, the A/E, or other parties. These risks may be to guarantee estimates of capital requirements, system performance equipment life, or operating and maintenance costs. It is not the purpose of this study to detail the various combinations of such possibilities, but one method of limiting the risk to the utility is with an energy purchase plan. With such a plan, the utility would purchase energy at a fair value as it is produced. Such a scheme would also protect the utility in the event of program delays. The utility would not be required to furnish any capital until the system was in operation.

REFERENCES

7-1 Solar Thermal Program - Multiyear Plan Draft, August 28, 1979

7-2 Solar Repowering/Industrial Retrofit Program Plan

7-3 N. Lord, P. Curto, and S. True, "Solar Thermal Repowering, Utility/Industry Market Potential in the Southwest," MTR-7919, MITRE Corporation (December 1978)

7-4 "Technical and Economic Assessment of Solar Hybrid Repowering," SAN/1608-4.1, Public Service Company of New Mexico (September 1978)