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SIERRA PACIFIC UTILITY REPOWERING

Final Technical Report for September 24, 1979—June 23, 1980

By
C. R. Easton
D. L. Endicott

June 1980

Work Performed Under Contract No. AC03-79SF10609

McDonnell Douglas Astronautics Company
Huntington Beach, California

and

Sierra Pacific Power Company
Reno, Nevada

U.S. Department of Energy

Solar Energy

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MCDONNELL DOUGLAS CORPORATION

SIERRA PACIFIC UTILITY REPOWERING

FINAL TECHNICAL REPORT

June 1980

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Covering the period of September 24, 1979 through June 23, 1980

Prepared for the U.S. Department of Energy
Under Contract Number DE-AC03-79SF10609

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ABSTRACT

The Sierra Pacific Power Company (SPPCo.) participated with the McDonnell Douglas team to define a conceptual design for repowering their Ft. Churchill plant, Unit 1. This unit has a modern, 110 MWe reheat turbine. The boiler is fired by oil and natural gas. The unit is based loaded at 0.78 capacity factor.

The Ft. Churchill site is located in high desert, 75 km (47 mi) southeast of Reno, Nevada. The estimated annual average insolation is 7.2 $kWh/m^2/day$.

The repowered plant conceptual design was a molten salt receiver fluid and 6 hours storage capacity. A north field collector with 130° azimuth extent was found to be optimum. The partial cavity receiver combines both external and cavity absorber regions to provide a compact, highly efficient design. A two tank storage unit with external insulation buffers system operation and provides for extended operation. A four element, tube and shell heat exchanger produces steam for turbine operation.

The estimated annual average energy collection efficiency is 0.618. The plant annual energy output is about 290 GWhe, displacing the equivalent of 490,000 bbl oil per year.

Repowering was found to be close enough to breakeven, economically, to be very attractive. Legal and institutional barriers are minimal. As a result, a very aggressive repowering program including Ft. Churchill is recommended as a means for reducing dependence on foreign oil.

PREFACE

This report was prepared for the Department of Energy under Contract No. DE-AC03-79SF 10609. It presents the results of a nine (9) month study to define a site specific conceptual design for solar repowering of Sierra Pacific Power Company's Fort Churchill No. 1, located near Yerington, Nevada.

This report is published in a single volume. In addition, the Executive Summary, Section 1, is published as a separate volume with wider distribution.

The guidance and support of the Department of Energy Program Manager, Fred Corona, and the technical assistance and suuport of Dr. J. J. Bartel of the Sandia National Laboratories were of great benefit in the conduct of this study, and we acknowledge their contributions.

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R. G. Richards and W. Branch of Sierra Pacific Power Company
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Section 1

EXECUTIVE SUMMARY

This section contains an overview of the Sierra Pacific Utility Repowering study conducted under contract to Department of Energy, San Francisco Operations Office (DOE).

1.1 BACKGROUND

1.1.1 Objectives

The objectives of this study were to:

- Develop a conceptual design for repowering Sierra Pacific Power Company's Ft. Churchill plant, unit No. 1 which
  - Will provide a practical and effective use of solar energy
  - Can be constructed and operating in 1985
  - Will provide the best economics for overall plant operation.
- Utilize technology being developed by DOE.
- Show the technical potential and cost effectiveness for electric power plant repowering

1.1.2 Technical Approach

The technical approach to this study is illustrated in the study flow network of Figure 1-1.

The System Requirement Specifications (SRS) were drafted using characteristics of the existing Ft. Churchill plant, the known or estimated site characteristics, DOE guidelines/specifications, and results of previous studies.

A system configuration was defined to meet the requirements through the conducting of trade studies and the application of results from previous studies. Results were used to update the SRS.

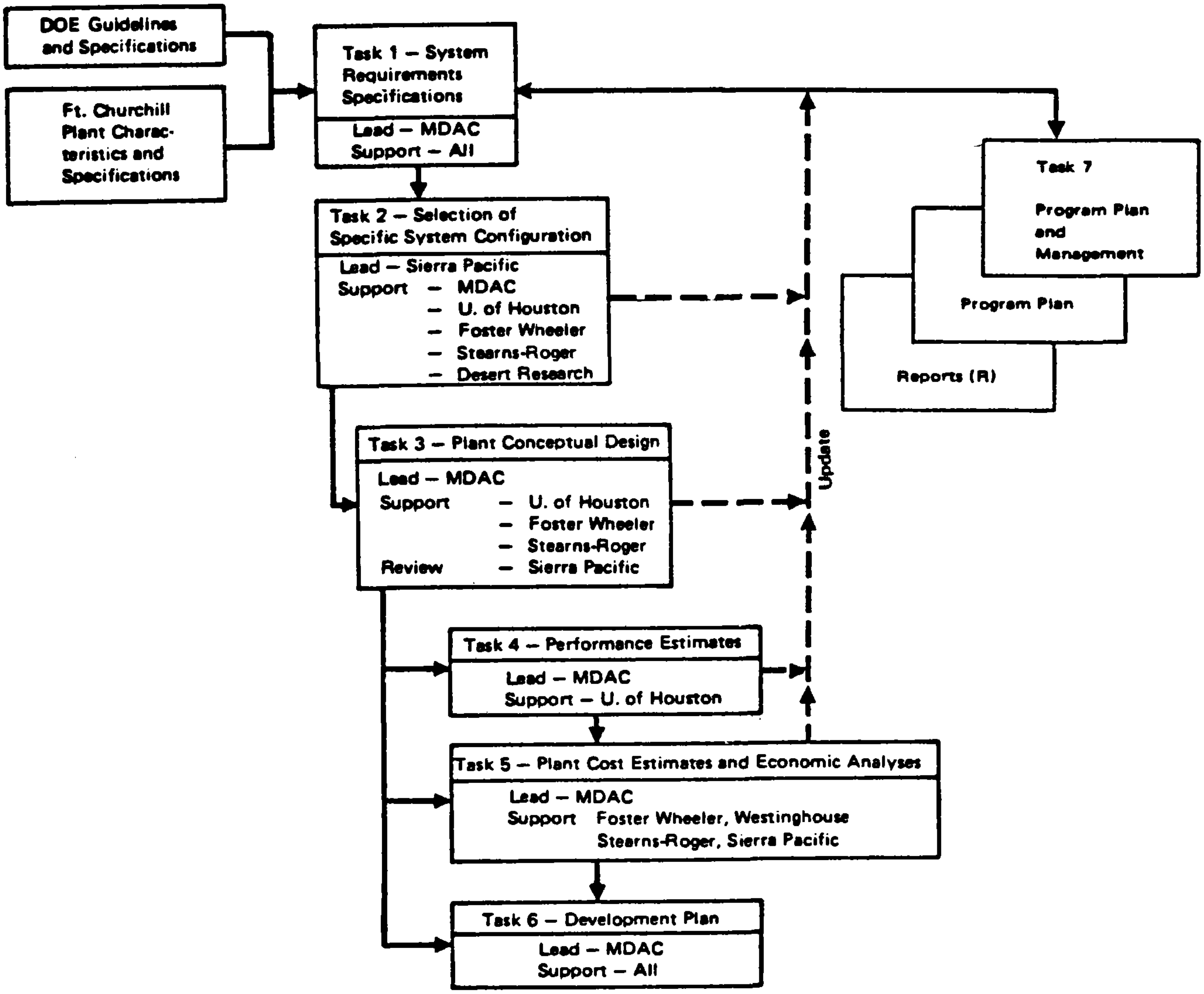


Figure 1-1 Study Flow Network

A conceptual design for the repowered plant was then prepared. Results were used to complete the SRS.

From the conceptual design and the SRS, performance and cost were estimated. The repowered plant economic value was estimated from a detailed, dynamic, grid dispatch analysis that developed the value of fuel displaced and a capacity credit for the repowered plant.

A development plan was prepared to show schedules and significant milestones in preliminary design, detailed design, fabrication, construction, checkout and operation of the repowered plant.

1.1.3 Study Team

The study team and their responsibilities are shown in Figure 1-2. The McDonnell Douglas Astronautics Company (MDAC) was the prime contractor. The Sierra Pacific Power Company (SPPCo.) appears as a subcontractor on the organization chart, providing the utility interface, review/approval, and

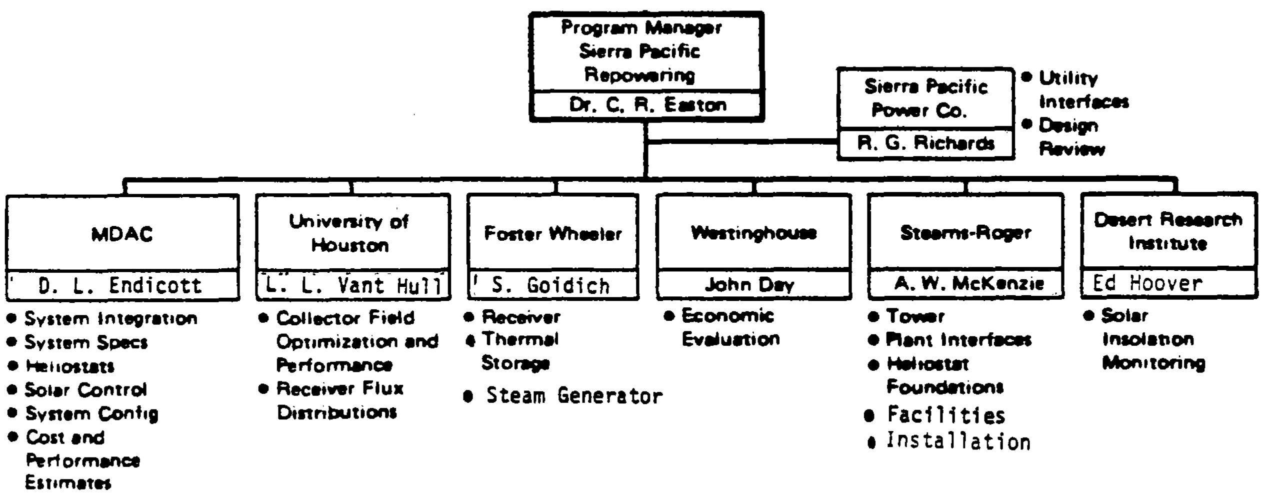


Figure 1-2. Study Organization

utility data. This role for SPPCo. is consistent with their normal practice for new plant expansion/modification. In this organization, MDAC has assumed a solar system design and integration role.

The key personnel and the roles undertaken by the other team members are indicated on Figure 1-2.

1.1.4 Repowered Plant Concept

An artist's sketch of the repowered plant is shown in Figure 1-3, superimposed on an aerial photograph of the site provided by Sandia Laboratories. The collector field, tower and receiver are on the left. The existing Ft. Churchill Units 1 and 2 are on the right, next to the cooling ponds. Switch yards are located to the north and west of the existing units and connect into the two transmission lines which tie the Ft. Churchill plant into the grid. Three oil storage tanks are located to the northwest. Behind the existing units are the thermal storage and steam generator units.

A top level plant schematic is shown in Figure 1-4. The repowering conceptual design uses a 130° north collector field. The partial cavity receiver (combination of external and cavity absorber surfaces) heats molten salt to a temperature of 566°C (1050°F). The heated salt flows to a hot storage tank, while molten salt at 288°C (550°F) is withdrawn from a cold storage tank for receiver feed. A four element steam generator provides superheated steam at 538°C (1000°F) to the turbine and reheats the partially expanded steam to 538°C (1000°F). The molten salt is pumped from the hot storage tank and flows in parallel through the superheater and reheater. The two salt flows are then combined and flow first through the evaporator, then through the preheater, and dump into the cold storage tank.

1.2 SITE/SYSTEM DESCRIPTION

SPPCO's grid network will have seven operating units in three plants in 1985, as shown in Table 1-1. Ft. Churchill Unit No. 1, was selected for this study.

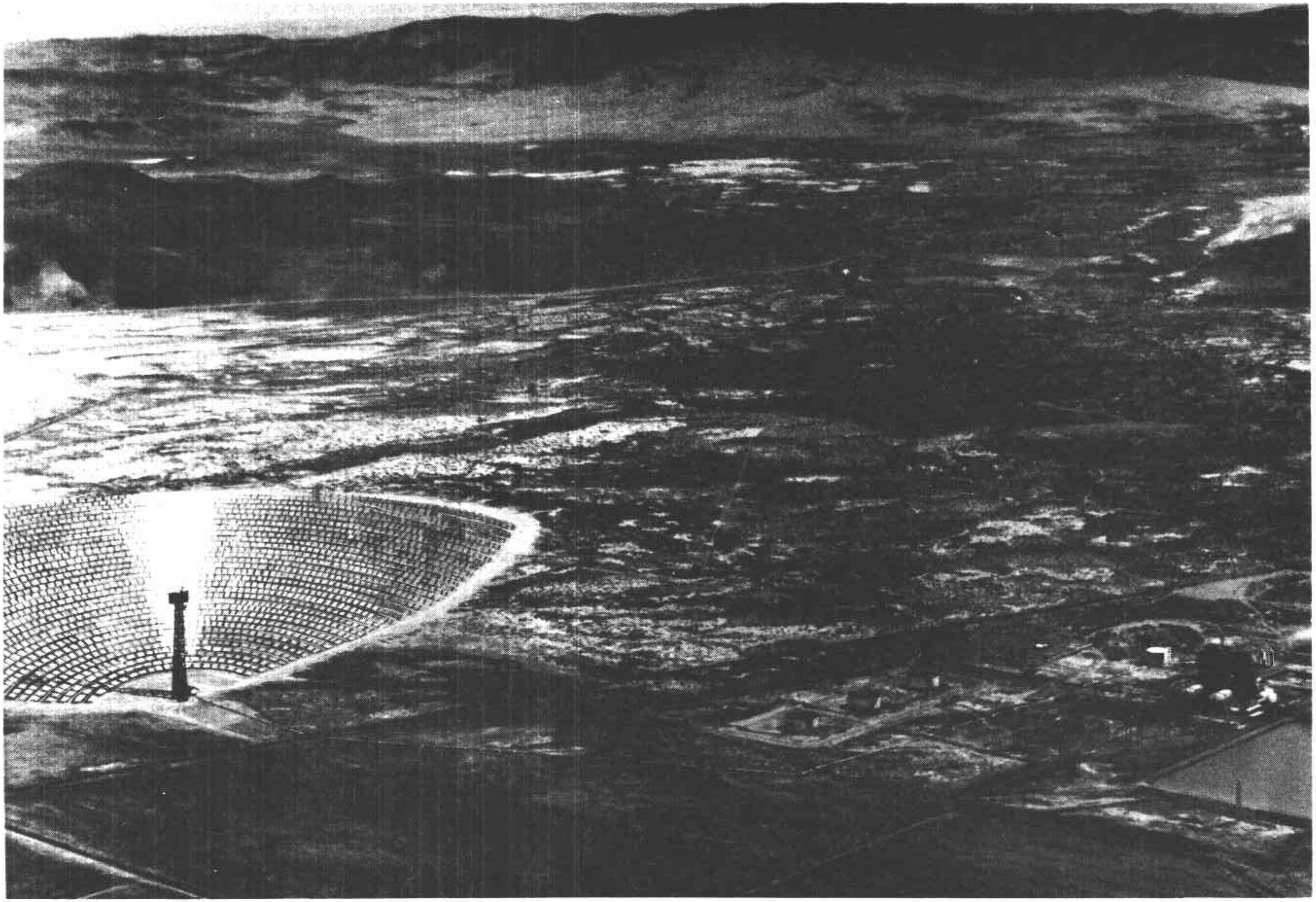


Figure 1-3 Artists Rendition of Repowered Ft. Churchill No. 1

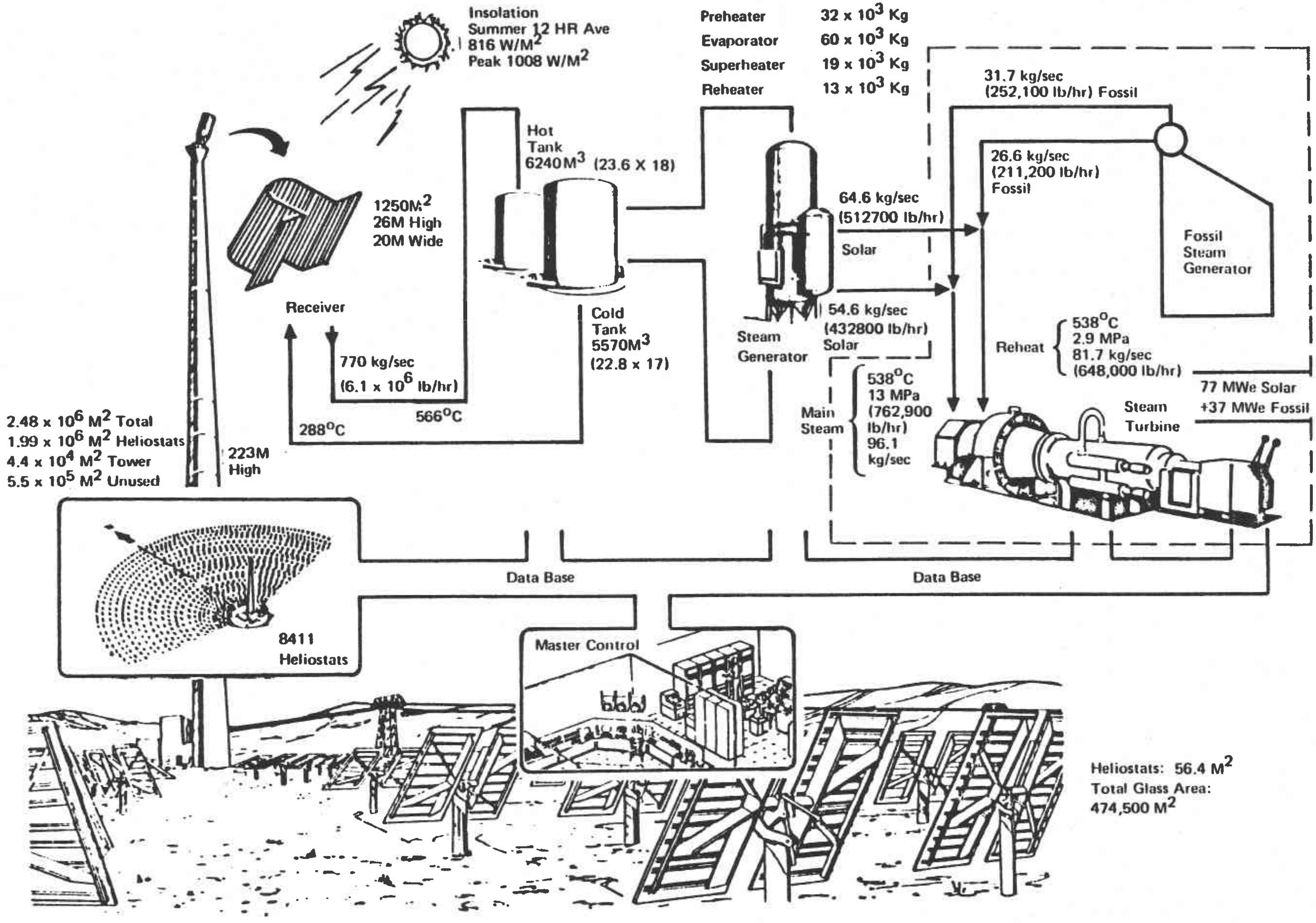


Figure 1-4. Sierra Pacific Power Co. Fort Churchill No. 1

Table 1-1

SIERRA PACIFIC POWER COMPANY NETWORK INCLUDES THREE REHEAT UNITS WITH SIGNIFICANT REPOWERING POTENTIAL

Unit No.	Rating (MWe)	Projected 1980 Service	(1985 Scheduled) Service
1. Tracy No. 1	56	Standby/Peak	Standby Peak
2. Tracy No. 2	80	Intermediate	Standby Peak
3. Tracy No. 3	110✓	Baseloaded	Intermediate
4. Ft. Churchill No. 1	110✓	Baseloaded	Intermediate
5. Ft. Churchill No. 2	110✓	Baseloaded	Intermediate
6. North Valmy No. 1	125*	-	Baseloaded
7. North Valmy No. 2	125*	-	Baseloaded

*Note: Both North Valmy Units are rated at 250 MWe each with 50 percent output to Sierra Pacific Power, 50 percent to others.

✓ Potential for repowering.

The higher efficiency reheat units, Tracy 3 and Ft. Churchill 1 and 2 were preferred over the non-reheat Tracy 1 and 2. North Valmy was not considered because it is coal fired. Ft. Churchill was preferred over Tracy because of higher insolation and more accessible land. Ft. Churchill units 1 and 2 and Tracy 3 are all excellent prospects for repowering. The site is located 75 Km (47 miles) southeast of Reno, Nevada. The primary and secondary fuels for this unit are oil and natural gas. Unit No. 1 entered service in 1968, and presently operates at a capacity factor of 0.78. In 1985 the two Ft. Churchill units are scheduled for load-following duty (24-hour service power) in the winter and part of the summer and load-following (24-hour service at variable output to match load requirements).
Typical of newer units in the range of 100 MWe, those at Ft. Churchill operate on a reheat cycle at 13 MPa (1890 psig), 538°C (1000°F) high pressure turbine inlet and 538°C (1000°F) reheat.

The insolation at this site is very favorable for solar repowering. The site is located in the high desert, near Yerington, Nevada, far enough from the mountains to have less cloud cover than either the Reno or Ely locations where insolation data have been collected. Weather data show that for an average year, the sun will shine for 84 percent of daylight hours at Reno. The clear day percentage is believed to be higher at Yerington than at Reno because of the greater distance from the Sierra Nevada range. Insolation at the site is being measured by the Desert Research Institute. Using a combination of measured clear day insolation and Reno cloud cover factors, an average annual insolation estimate of 7.2 kWh/m^2/day was generated for the Ft. Churchill site.

Adequate adjacent land is available for the collector field. The site is surrounded by flat, high desert, of which the land to the immediate northwest is owned partially by SPPCO and partially by the Bureau of Land Management (BLM), as indicated in Figure 1-5. Lands of the Sierra, a holding company of SPPCO, manages company property not occupied by equipment. The specific location of the collector field can be moved to the northwest and tailored to the land boundaries if the indicated land cannot be made available from the BLM.

1.3 PROJECT SUMMARY

The general conclusion of this study is that repowering of existing electric power generation plans is an economic and highly desirable means for reducing our nation's dependence on oil and natural gas. This conclusion has been verified by the present study in three ways:

1. The present value of 30 years of levelized fixed charge against the capital cost of the repowered plant is less than the present value of the fuel displaced if the plant continues to burn oil and gas at the projected capacity factor. This conclusion was reached based on conservative assumptions of:

   - First unit repowering plant costs
   - Levelized fixed charge rate of 15%/year
   - Fuel escalation rate of 10%/year
   - General inflation rate of 8%/year
   - Discount rate for present value of 11.6%/year

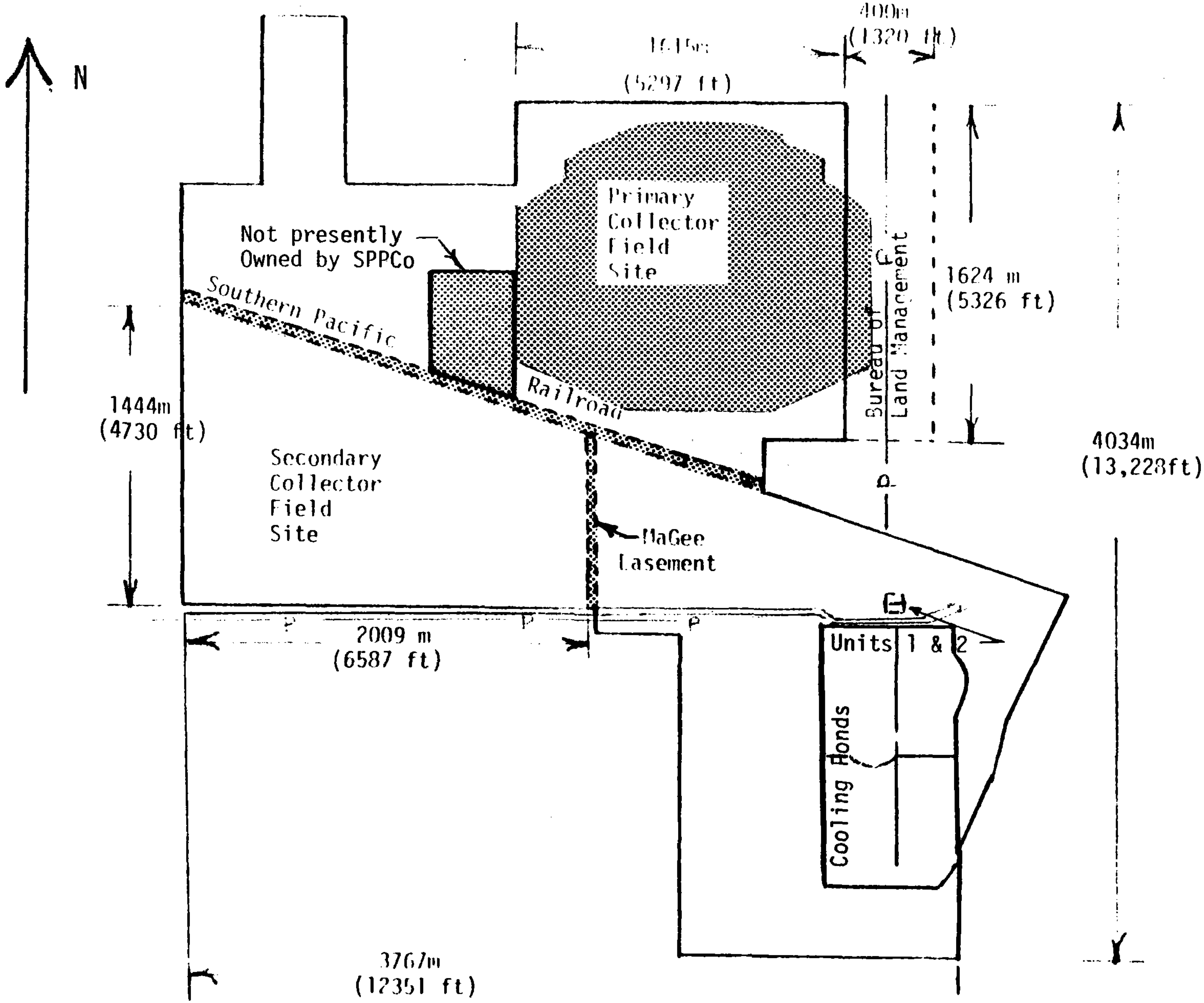


Figure 1-5   Fort Churchill Site Plot

2. The life cycle economics for a repowered plant compare favorably with economics for new coal capacity. At 10 percent per year fuel escalation and the SPPCo estimate of $1000/kWe capital cost for new coal capacity typical of the West, solar stand alone repowering is more economic than new coal capacity if the coal capacity is to replace existing oil/gas fired units at intermediate capacity factor.

3. Solar repowering was compared to published data on coal liquefaction as an alternate means for oil displacement. For an equivalent amount of oil displaced, solar repowering was found to be more economic than coal liquefaction. This result is due primarily to a low efficiency of conversion from energy in coal to energy in the product. It is recognized that coal liquifaction provides a fuel which can replace oil for most applications, whereas the opportunities for solar repowering are geographically and otherwise limited. The Synfuel program is valuable for applications where solid coal cannot be used effectively and solar insolation is low, or solar is otherwise not applicable.

The above conclusions lead to the recommendation that solar repowering of existing power plants should be pursued as aggressively as technology development and funding limitations permit.

1.3.1 Programmatic Conclusions

THE STATE OF NEVADA IS SUPPORTIVE OF SOLAR ENERGY DEVELOPMENT

Sierra Pacific Power Co. is actively working with the Nevada State Legislature and the Public Service Commission to develop risk sharing legislation for solar and geothermal development. The positive state government posture on solar and geothermal development is expected to benefit the energy development risk sharing legislature initiatives planned for the 1981 session.

SPPCO'S FT. CHURCHILL PLANT IS AN OUTSTANDING APPLICATION FOR REPOWERING.

This conclusion is based on the following findings:

- The site insolation level is high for both clear day and average annual insolation.
- An adequate amount of suitable land is already available at the site.

- The plant is relatively new (1968 IOC) and in excellent condition.
- The reheat cycle provides the high cycle efficiency desirable for solar repowering.
- The plant has proven to be extremely reliable, with a forced outage rate less than 1%, and a total outage less than 5%.
- The plant is of a standard design used for many plants in the west and southwest. There are three such units in Sierra Pacific's grid. Equipment and concepts developed for this unit can be used with minimum redesign for many other applications.
- The economic outlook for solar repowering is quite favorable because of the high fraction of capacity in SPPCo's grid using oil/gas.

OPERATION OF THE REPOWERED PLANT IN 1985 IS FEASIBLE

This conclusion is based on the following considerations:

- There are no component development requirements which cannot be successfully completed in the time allotted for the development program.
- Components which require development and/or qualifications are identified in the development plan and alternate approaches are provided where required by the development risk.
- The full repowering plant requirements for the production of 8411 second generation heliostats plus spare parts can be accomplished with the DOE plans.
- It is assumed that the DOE will provide for the production process development and capitalization of appropriate heliostat production facilities.
- The receiver development takes maximum advantage of the current DOE salt receiver development program. Molten salt receiver test results at the Central Receiver Test Facility (CRTF), at Sandia National Laboratories, Albuquerque will be utilized. In addition, a configuration test at CRTF is recommended, but final qualification must be conducted in the repowered plant.

THE SOLAR COLLECTOR FIELD MAY BE DIVIDED INTO TWO HALF SIZED MODULES

Collector and receiver subsystem capital costs are projected to be insensitive to dividing the collector field into two half sized modules, if heliostat costs are not affected. Non-recurring costs and thermal storage subsystem costs are expected to be the same. Modularization may be advantageous because it provides for reduced initial repowering demonstration costs to DOE and the user. The added flexibilities of modularity may also be desirable for subsequent applications.

1.3.2 Technical Conclusions

There are seven important technical conclusions which result from this study, as listed below:

Full Repowering Capability is Desirable - The initial operation of the plant as a hybrid will be desirable. However, during low demand times of the year and during the later portion of the life of the plant, it will be more economic to operate as a solar stand-alone plant at full rated power.

Repowered Design Lifetime is 30 Years - Solar repowering will cause design life critical components of the existing plant such as the fossil boiler to operate on a reduced duty cycle. Hence, the expected lifetime of the plant after repowering (1985) is 30 years.

A Molten Salt Receiver Fluid is Preferred - Molten salt and water/steam receiver fluids were compared. The molten salt system showed slightly lower costs per unit thermal energy collected, much simpler system control, capability for storage for extended/deferred operation, much higher fossil fuel displacement, no requirement to burn fossil fuel to operate the solar portion of the plant, and less imposing technical feasibility issues. User operating personnel are not familiar with molten salt systems. Operations and maintenance personnel require retraining for the safe operation and maintenance of the molten salt system. Development testing will also be required for the molten salt system. Molten salt was preferred over sodium primarily because of reduced costs for thermal storage.

A Northerly Collector Field is Preferred - A northerly collector field was found to be preferred because of several factors including a shorter piping run to the plant; the higher latitude, which accentuates the heliostat efficiency difference between north and south heliostat locations; and a new design approach to the receiver, which allows both a wide azimuthal extent of the north field and a high receiver efficiency. The key issues in selection the northerly field appear to be the partial cavity receiver and wide azimuth extent of the field.

Partial Cavity Receiver is Preferred - The partial cavity receiver concept was found to combine high efficiency with minimum absorber area and low system cost. The initial promise which led to our interest in the partial cavity approach has been realized. The partial cavity receiver concept is new, and many of the potentially desirable options have not been fully explored. These additional options are expected to lead to an even more beneficial final design.

Two Tank Thermal Storage is Preferred - A two tank thermal storage approach with external insulation is preferred. Technical risks appear to be excessive for developing a dual medium thermocline storate unit for the first repowering application. However, its cost advantage promises to be significant. Internal insulation poses excessive technical risk, and its cost advantage is small at best.

Repowering at Normal Operating Conditions is Feasible - The normal operating conditions of 13 MPa (1890 psia) at 538°C (1000°F) can be achieved in reasonable size heat exchangers with 566°C (1050°F) molten salt bulk temperature. A maximum receiver film temperature of 593°C (1100°F) appears feasible for achieving 566°C bulk temperature. These values are all within the state-of-the-art.

1.3.3 Economic Conclusions

The principal economic conclusion of this study is that repowering would be economically preferable to continued operation on oil/gas present capacity factors. Even at first unit costs and conservative economic assumptions, the present value of fuel saved is greater than the present value of the fixed charge against the capital investment to repower. However, the plant would not be projected to continue to operate at its present capacity factor. A portion of the fuel displacement for the repowered plant would come against oil/gas, but the majority of the fuel displacement would come against coal and lower cost purchased power.

The repowered plant operation was simulated in the changing mix of generation capacity expected for SPPCo. Approximately 55% of the fuel displacement for the repowered plant was against coal combustion and purchased power. The model used cost escalation rates for purchased power which are believed to be unrealistically low. As a result of low costs of power displaced, the plant did not show breakeven economics for the first plant cost model. However, even the first plant costs were within 10-30% of breakeven. This result was felt to be very encouraging.

1.4 CONCEPTUAL DESIGN SUMMARY

The conceptual design of the repowered plant is summarized in Table 1-2. The three possible operating modes for the repowered plant are illustrated in Figure 1-6. In the baseline mode, Unit No. 1 will be repowered for hybrid operation with the fossil side operated continuously at at least 37 MWe (gross) and the solar providing load-following up to 77 MWe (gross) during the high demand periods of the day. In addition, capacity will be provided for up to six hours of thermal storage. The plant would thus deliver up to 77 MWe from solar for up to 18 hours in mid-summer, and would displace about 80 percent of the fossil fuel annually. On low insolation days, the fossil boiler can be operated at a higher power level with lower power from the solar generator to avoid ramping of the fossil boiler. The repowered plant can also operate in solar stand-alone and fossil only modes. An option to generate full rated power in the solar stand-alone mode seems to be advantageous.

The system layout was shown in Figure 1-4, and the baseline is summarized in Table 1-3. The 130° north field is located to the northwest of the plant, and will occupy about 2.0 x 10^6 m^2 land area. The collector field will contain 8411 MDAC second generation heliostats at 56.4 m^2 each for a total mirror area of 474,500 m^2. The University of Houston has optimized the collector field layout as a radial staggered field.

The baseline receiver design is a partial cavity, as illustrated in Figure 1-7. The receiver uses a molten-salt working fluid. The front and side walls of the receiver are arranged in series/parallel sets of uncontrolled preheater panels. The east and west halves of the receiver each have two series passes

Table 1-2 (Page 1 of 3)

CONCEPTUAL DESIGN SUMMARY

		Comments
Prime Contractor	McDonnell Douglas Astronautics Company	Provides program management, system engineering, collector and solar master control
Associate Prime Contractor	Sierra Pacific Power Company	Associate prime contractor, design review, evaluation, approval, and utility data
Major Subcontractors	Foster Wheeler Development Company	Receiver, thermal storage unit, steam generator
	Stearns-Roger, Inc.	Plant interfaces, facilities, A&E services
	University of Houston	Collector field optimization, layout, and performance
	Westinghouse Advanced Systems Technology	Economic evaluation
	Desert Research Institute	Site insolation and weather measurements
Site Process	Utility Electric Power Generation	115 MWe General Electric, reheat turbine manufactured in 1967 . Rated turbine inlet conditions are 12.4 MPa (1800 psia), 538°C (1000°F) with 538°C (1000°F) reheat
Site Location	Fort Churchill Plant	75km (47 miles) southeast of Reno, Nevada, near Yerington
Design Point	Equinox Noon	Design point insolation is 1008 W/m^2
Receiver Design		
Fluid	Molten Salt	Eutectic sodium and potassium nitrate, normal melting point 221°C (430°F), maximum safe operating temperature 649°C (1200°F)

MCDONNELL DOUGLAS

Table 1-2 (Page 2 of 3)

CONCEPTUAL DESIGN SUMMARY

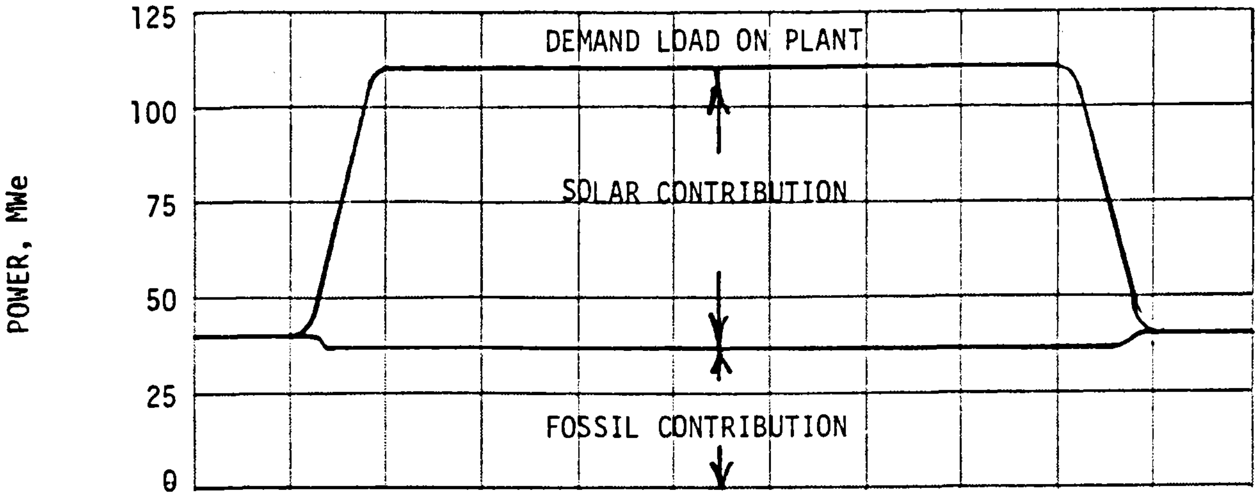
		Comments
Receiver Design (Cont'd)		
Configuration	Partial Cavity	156 m^2 external absorber, 1100 m^2 cavity absorber
Flow Routing	4 Pass	Two uncontrolled preheater passes in series followed by two controlled passes in series
Elements	20 Absorber Panels	12 preheater, 8 high temperature
Tube Size	25 mm (1 in.) O.D.	Incoloy 800 (may change to 304 S.S.)
Inlet Temperature	288°C (550°F)	
Outlet Temperature	566°C (1050°F)	
Heliostat		
Number	8411	MDAC Second Generation (Meets Sandia Specification Drawing A10772)
Area	56.42 m^2 (606 ft^2)	
Cost	\$224/m^2	Assumes 5000 u/yr production rate
Type	Non-Inverting	Site safety, dust buildup do not warrant the cost of inverting
Collector Field	North	130° azimuth angle in field with 25° receiver tilt
Storage		
Duration	Six Hours	1150 MWh_{th} storage capacity
Type	Two Tank	External insulation preferred. Storage in receiver fluid.

MCDONNELL DOUGLAS

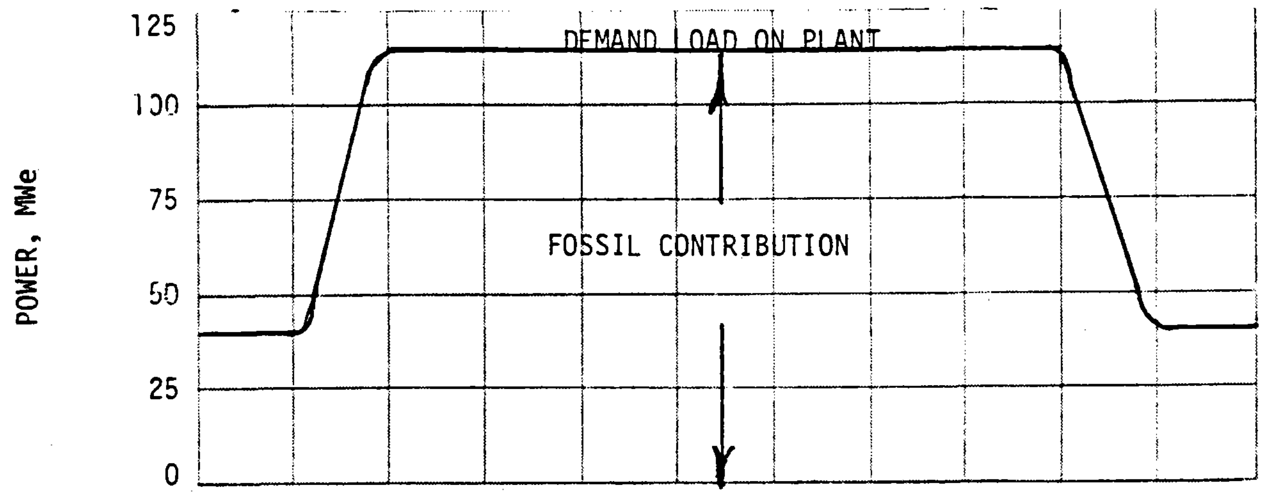
Table 1-2 (Page 3 of 3)

CONCEPTUAL DESIGN SUMMARY

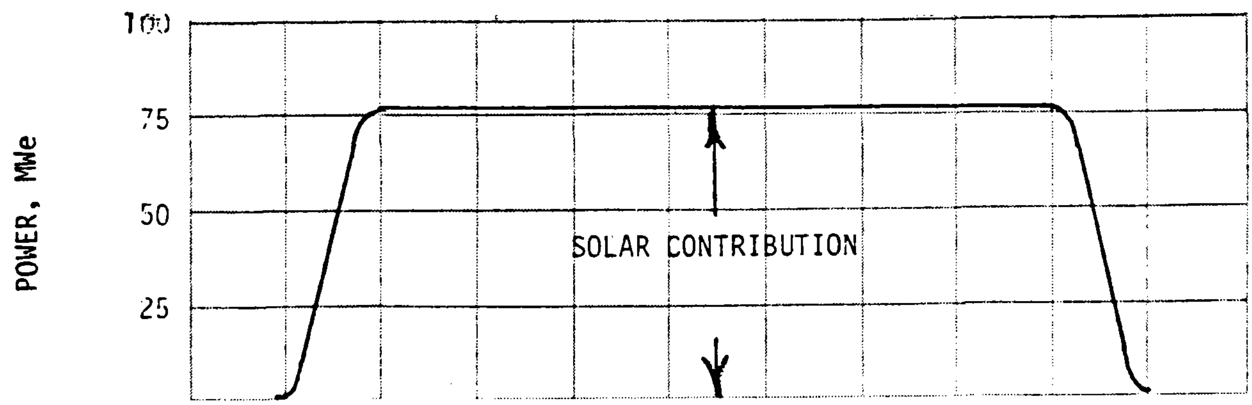
		Comments
Project Cost	$196 x 10^6 1980 Dollars	Uses estimated heliostat cost of $224/m^2.
Construction Time	Four Years	
Power Rating - Solar	77 MWe	May have provision for 110 MWe solar stand-alone.
Capacity Factor - Solar	0.34	Corresponds to solar fraction of 0.8 to 1.0.
Fossil Energy Saved	490,000 bbl/year	
Type of Fuel Displaced	#6 Oil/Natural Gas in Plant	1985 displacement 58% oil/gas,42% purchased. 1995 - 19% coal, 44% oil/gas, 37% purchased.
Annual Energy Produced	0.759×10^9 kWh_{th}	Thermal energy delivered to the turbine.
Ratio of Annual Energy Produced / Total Heliostat Mirror Area	1.5 MWh_{th}/m^2	Fuel displacement is 1.75 MWh_{th}/m^2 because of boiler efficiency
Ratio of Capital Cost / Annual Fuel Displaced	$258/$MWh_t$	
Site Insolation	2.63 MWh/m^2/year	Based on 5 months direct normal measurements for clear day, University of Houston insolation model extrapolation for remaining 5 months, and modified Reno weather factor. Measurements began November 19, 1979, and will end June 15, 1980.



(a) Baseline Hybrid Mode



(b) Fossil Only Mode



(c) Solar Only Mode Time of Day

Figure 1-6 Plant Operating Modes

Table 1-3

BASELINE SYSTEM SUMMARY

Plant	Baseline Selection	Rationale
Utility	Sierra Pacific Power Co. Ft. Churchill No. 1	Ideal repowering conditions, equipment in excellent condition, large oil displacement potential, progressive management outlook, high probability of repowering.
System	Rankine Cycle with Reheat	Represents majority of systems in the 50-150 MWe size range, large commercial potential with other utilities, low risk building on Barstow technology.
Mode	Hybrid with Solar Stand-Alone Option	Provides maximum design data, includes Solar only, Solar/Fossil Hybrid and Fossil Only scenarios, greatest flexibility for 1985 requirements, large potential oil displacement, ease of matching load requirements.
Turbine Cycle	Reheat	High performance in large power size, typical of late model system with equipment in good shape. Represents largest commercial market for fuel displacement. (6,800 GW_e)
Receiver Fluid	Molten Salt	High performance with reheat system. No fossil fuel fired reheaters required. Utilizes existing technology with lower risk/cost than sodium system in storage coupled mode.
Field	130° - North	Minimum total system cost for energy collected optimum utilization of land available, shortest piping run to plant, utilizes Barstow technology.
Receiver	Partial Cavity	Best cost/performance characteristics, best peak/average flux ratio with North Field, minimizes aiming sensitivity for Solar Field, minimum receiver weight for output. High receiver efficiency.
Tower	Concrete	Minimum risk
Thermal Storage	Two Tank	Minimum project risk, simple operation completely decouples systems for Solar-Only, Hybrid or Fossil-Only operation.
Heliostat	Second Generation Design	Minimum cost for equivalent performance, represents commercial production unit in 1985, utilizes latest Solar technology.

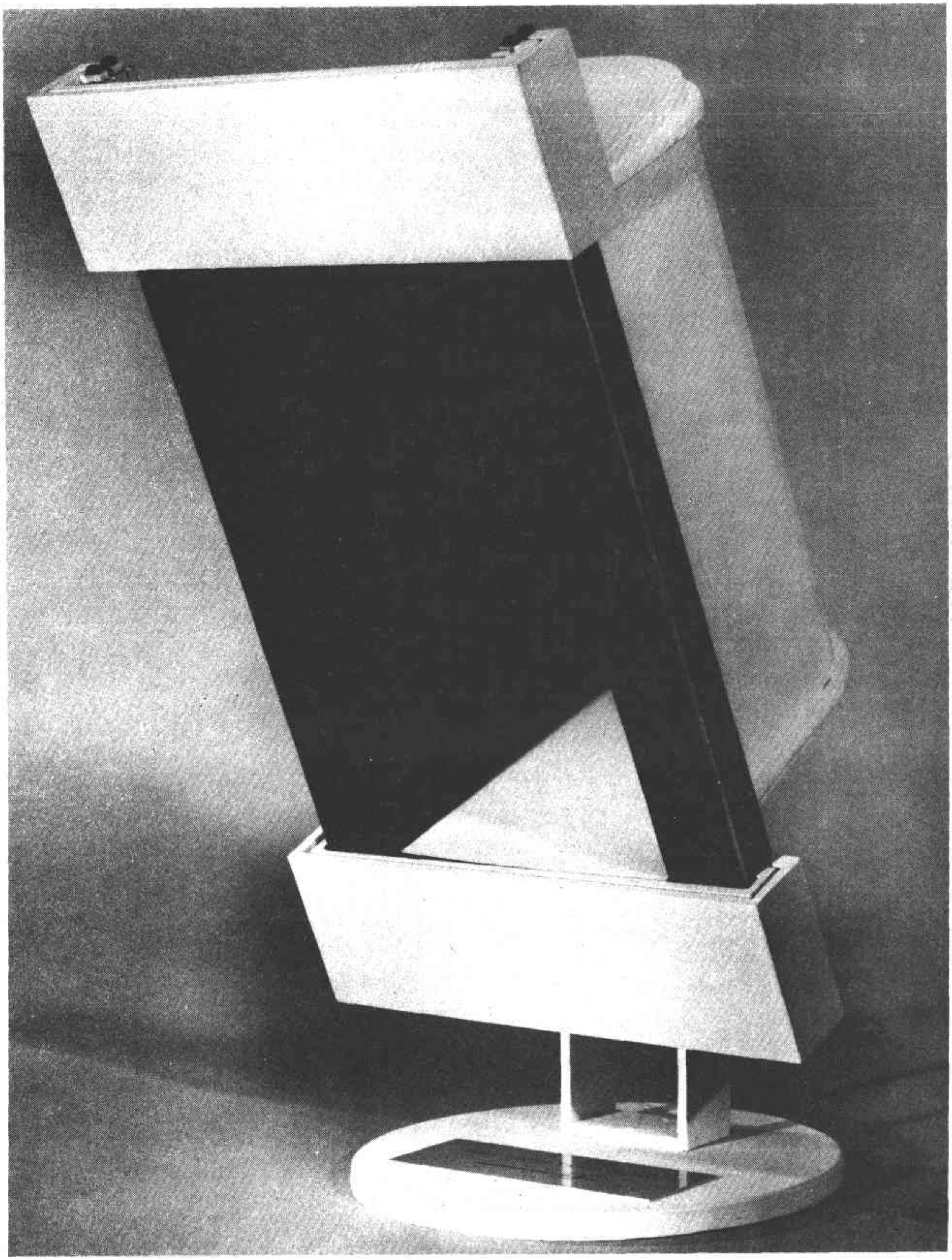


Figure 1-7 Photograph of Scale Model Receiver

of uncontrolled preheater panels. The cylindrical portion contains four parallel circuits of two panels each. Each circuit is series connected to provide an adequate heated path length and load.

The thermal storage baseline is a two tank, externally insulated unit. The hot tank is 23.6 m (77.4 ft) in diameter and 18m (59 ft) high. The cold tank is 22.8 m (74.8 ft) in diameter and 17 m (55.8 ft) high. A four element steam generation heat exchanger is also baselined. The cold salt line is carbon steel, 0.41 m (16 in) in diameter, and the hot salt line is 316 stainless steel 0.3 m (12 in) in diameter.

The center of the receiver aperture plane is 223 m above the ground, and the receiver is supported on a concrete tower. The tower is 24.2 m (79.5 ft) in diameter at the base and 20.3 m (66.7 ft) in diameter at the top. The wall thickness tapers from 0.38 m (15 in) at the base to 0.33 m (13 in) at the top. A slab foundation is preferred for withstanding seismic loads.

The present plant has a dual, manual/automatic, turbine lead (boiler following) control system located at the site. The repowered plant will retain the present automatic control (having manual override), and will add a separate automatically coordinated control system for the solar equipment. The plant operator will provide the primary control interface between the fossil and solar equipment. The repowered plant can be operated in hybrid, solar stand-alone and fossil, only modes.

The steam flow interfaces are located in the high and intermediate pressure turbine inlet lines, and flow control valves modulate the feedwater and cold reheat steam flow to the solar and fossil-fired sides to provide the correct mass flows for the grid required turbine power.

1.5 SYSTEM PERFORMANCE

System performance is discussed from the standpoints of insolation (how much solar energy is there to collect), collection efficiency (how much energy gets into the receiver fluid), plant cycle efficiency (how much of the thermal energy is delivered to the grid as electricity), and annual energy output.

1.5.1 Insolation

The insolation data establish that the Ft. Churchill site has approximately 7.2 kWh/m^2 average annual insolation. Hence, Ft. Churchill is an excellent site.

This insolation estimate was established from a combination of clear day insolation measurements at the site, clear day correlations for portions of the year for which no measurements are available, and weather factors (cloud cover reduction of clear day insolation) based on historic data from Reno. Site measurements of both direct normal insolation and total horizontal insolation, ambient temperature, wind speed, barometric pressure, and relative humidity were taken by Desert Research Institute.

Results from about five months site insolation measurements are available from the Desert Research Institute's station to support this study. These data were used to refine parameters in the University of Houston's computer program for calculating daily and annual insolations. Clear day total insolation levels and design point insulation levels are shown in Table 1-4.

No single year is reliably typical for measurements of cloud cover. Hence, no attempt has been made to correlate cloud cover at the Ft. Churchill site, as measured during this study, with other historical data sources. However, simultaneous measurements of total horizontal insolation at Ft. Churchill and Reno, together with Reno weather factors based on long term observations, were

Table 1-4

DIRECT NORMAL INSOLATION - SUMMARY

Season	Design Point Insolation (W/m^2)	Clear Day Insolation (kWh/m^2)	Weather Factor**	Annual Average Insolation ($kWh/m^2/day$)
Winter	840 (0900 hours)	7.1	0.67	4.7
Spring	1008 (1200 hours)	9.6	0.68	6.5
Summer	750* (0700 hours)	10.8*	0.85	9.2
Autumn	---	9.0*	0.92	8.3
ANNUAL	---	9.1	---	7.2

*Estimated - No confirming site data available

**Long term weather factors from Reno sunshine switch data, modified by estimates from simultaneous measurements of total horizontal insolation at Reno and Ft. Churchill.

used to estimate Ft. Churchill weather factors. Estimated weather factors are also shown in Table 1-4.

The product of clear day total insolation and weather factor gives the average insolation, as shown in Table 1-4 for the four seasons. The values shown in the table are generally higher than forecast because of higher than expected clear day insolation levels in the winter and higher weather factor. There is still an error band in site insolation estimates, and little or no significance should be attached to the second "significant" figure.

1.5.2 Collection Efficiency

Collection efficiency is defined as the ratio of the thermal energy absorbed into the receiver fluid to the thermal energy which would be incident on the collector field if all the mirrors were oriented normal to the sun. The constituent efficiencies making up the collection efficiency are shown in Figure 1-8. The design point efficiency (equinox noon) for the SPPCo field is 0.687. The annual average efficiency for clear days is 0.618. The actual annual efficiency may be a bit lower, because receiver radiation and convection losses are nearly constant, rather than proportional to the incident flux.

The design point and average annual efficiency waterfalls are shown in Figure 1-8. In addition to the usual constituent efficiencies, a field geometry factor has been added. The theoretical packing densities of heliostats as optimized by the University of Houston's RCELL program series cannot be achieved in practice. For example, RCELL does not account for the slip planes in a radial stagger layout. Experience with the detailed layout of the DOE 10 MW Pilot Plant collector field indicates that the average heliostat performance is over estimated by RCELL by about three percent. The field geometry factor includes this effect.

1.5.3 Plant Cycle Efficiency

The plant cycle efficiency includes conversion of heat energy to electricity and efficiency reductions due to plant parasitic loads. The net turbine-generator cycle efficiency is 0.426. Parasitic losses vary with the plant operation mode, as indicated in Table 1-5. The efficiency factor for parasitic loads ranges from 0.905 for direct solar operation to 0.958 for hybrid operation from storage.

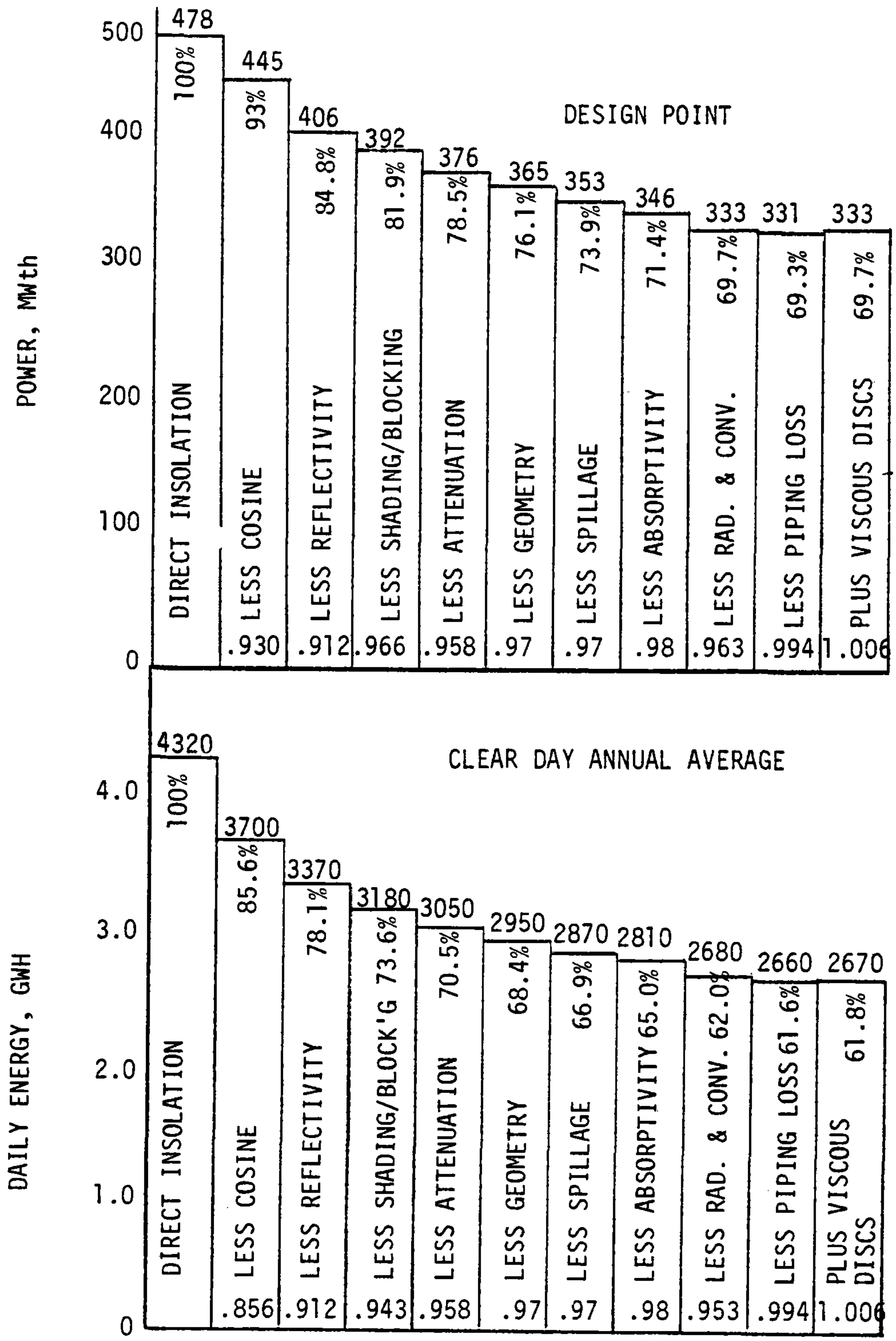


Figure 1-8 Design Point and Clear Day Average Collection Efficiency

Table 1-5

PLANT PARASITIC LOSSES

(KWe LOAD)

Mode	Forced Draft Fan	Solar Equipment	Other	Total	Parasitic Efficiency Factor
Fossil, Only	1200	1715	3065	5980	0.948
Hybrid, Direct Solar	300	4340	3550	8190	0.929
Hybrid, Solar	300	1835	3545	5680	0.950
Solar, Only Direct	0	4340	2980	7320	0.905
Solar, Only Storage	0	1835	2975	4810	0.937

1.5.4 Annual Energy Output

The average annual efficiency for energy collection was found to be 0.618, and the average solar conversion efficiency is estimated from Table 1-4 as 0.405, giving a net efficiency 0.246. With the average annual insolation of 7.2 KWh/m^2/day from Table 1-4, and the predicted availability of 0.958, the annual energy production from solar is 288 GWhe delivered to the grid.

The solar capacity factor is about 0.3, and the fuel savings is about the equivalent of 3.0×10^{15} J(490,000 bbl oil) per year.

The above are specific design point data and are believed to be near the optimum. The indications are that 100 percent repowering for a baseline stand-alone operating mode, with a solar multiple of about 1.4 and 6 hour storage for extended and deferred operation, would be desirable.

1.6 ECONOMIC FINDINGS

The economic findings of this study are summarized by five major conclusions as discussed below. Supporting data are provided in Table 1-6.

1.6.1 Repowering is Economically Preferable to Continued Oil/Gas Usage

This conclusion is drawn under the following assumptions, consistent with SSPCo's current economic parameters:

a. First unit plant costs of \$196 x 10^6, as summarized in Table 1-7.

b. Net levelized fixed charge rate of 15% (includes effects of a 10% investment tax credit)

c. Present worth discount rate of 11.6%

d. Fuel escalation rate of 10%/year

e. 1980 fuel cost for oil of \$5/GJ (\$30/bbl), based on \$27/bbl 1979 actuals for SPPCo

f. Useful life of the repowered plant of 30 years

The present worth of 30 years fixed charge against the capital cost of the plant plus O&M is about \$275 x 10^6. The present worth of 30 years fuel displacement, assuming 100 percent of the displacement is against oil and gas, is \$330 x 10^6.

However, the entire fuel displacement will not be against oil and gas. For the first 10 years of operation, the fuel displacement is about 60% against oil and gas and 40% against purchased power from Pacific Gas and Electric. For the remaining 20 years, the displacement is about 45% oil/gas, 20% coal, and 35% purchased power. Hence, the real benefit is reduced by about 35-40%. If, however, coal, oil/gas, and purchased power all escalated at 12%, the savings would grow to \$275 M.

1.6.2 Repowering is Competitive with New Coal Capacity

For an equal capacity factor from a new coal fired plant and current costs, SPPCo estimates a coal plant would cost about \$100 x 10^6 and the present worth of 30 years fuel cost would be about \$96 x 10^6. The present worth of 30 years

Table 1-6

ECONOMIC FINDINGS FOR SPPCo REPOWERING
(ALL COSTS IN 10^6 1980 DOLLARS)

Finding		Comments
Repowering Compared to Continued Oil/Gas Use		
Present worth of capital and O&M cost	$275	Varies with plant cost, includes O&M
Present worth of energy if displacement were all in oil/gas	$330-425	Fuel escalation at 10 and 12%
Probable present worth with real mix of fuel displacement	$210-275	10-12% escalation with displacement 20% coal, 35% purchased power, 45% oil/gas
Repowering Compared to New Coal Capacity		
Present worth of capital cost	$132	Assumes 42-44% capacity factor 10% fuel escalation
Present worth of O&M costs	$ 60	
Present worth of fuel cost	$ 96	
Total present worth of new coal capacity	$288	
Repowering Compared to Coal Repowering		
Present worth of capital cost	$ 66	
Present worth of O&M cost	$ 30	
Present worth of fuel cost	$106	
Total present worth of coal repowering	$202	
Repowering Compared to Coal Liquefaction		
Present worth of capital cost	$111	Costs to achieve the same total electric energy output if liquefied coal repowers Ft. Churchill
Present worth of O&M cost	$ 50	
Present worth of fuel cost	$217	
Total present worth cost of coal liquefaction	$378	

Table 1-7

PROJECT CAPITAL COST SUMMARY

Subsystem/Activity	Description	Cost Estimate (10^6 1980 Dollars)
Site Preparation	Grading, roads, soil tests, fences.	2.3
Site Facilities	Buildings and building modifications.	0.3
Collector Subsystem	Heliostats at $224/m^2 including installations, controls, wiring, and checkout.	136.6
Receiver Subsystem	Tower, receiver, receiver support structure, riser/downcomer piping and receiver feed pumps.	32.7
Solar Master Control Subsystem	Includes all subsystem controllers and software development.	5.0
Energy Storage Subsystem	Includes tanks, fluid, steam generators circulation equipment and piping.	15.0
Electric Power Generating Subsystem	Includes modifications and interfaces to the existing plant.	3.8
TOTAL		195.7

Note: Each subsystem and activity cost carries its own allocated portion of indirects and distributables, including contingency and fee.

fixed charge on the cost of the coal plant is about $\$132 \times 10^6$. Additional O&M costs are estimated at $\$60 \times 10^6$ present value for 30 years O&M. The total cost is, then, about $\$288 \times 10^6$.

Again, one would not normally build a coal plant for operation at 40 percent capacity factor. If one did build such a plant, it would receive a capacity credit which would add to its value. However, 10 percent fuel escalation is still quite conservative. Such a plant would take 6-8 years to build, and the interest during construction would add about 40% to the cost to SPPCo.

Without a detailed analysis, it appears that repowering is in a cost range competitive with new intermediate capacity factor coal plants which would replace existing oil/gas plants retired early by excessive oil/gas costs or uncertain availability.

1.6.3 Solar Repowering Requires Incentives to Compete with Coal Repowering

A plant such as Ft. Churchill could be retrofit with coal fired boilers. A 1979 study conducted by Stone and Webster for SPPCo showed that the Ft. Churchill plant could be retrofit to coal combustion for about $420/net kW in 1979 dollars. Some loss of capacity would also occur because of the power required to operate the scrubbers.

Allowing for inflation and derating, we estimate the coal repowering direct cost to be $\$50 \times 10^6$. The present worth of 30 years fixed charge aginst capital cost is $\$66 \times 10^6$. The cost of fuel would be slightly higher than before because of a lower projected net heat rate, or about $\$106 \times 10^6$. The O&M costs are estimated at $\$30 \times 10^6$. The total cost is, then, $\$202 \times 10^6$. An additional subsidy of about $\$75 \times 10^6$ would be required to achieve breakeven life cycle economics at the nominal solar repowering cost.

1.6.4 Solar Repowering is More Economic than Coal Liquefaction

A coal liquefaction plant design described by Fluor Company in a recent article in the Los Angeles Times had the following characterizations:

1. Cost $\$3.5 \times 10^9$

2. Produces 58,000 bbl/oil per day

3. Consumes 40,000 tons coal per day.

To achieve the same fuel displacement as one repowering plant, the cost and coal consumption are scaled linearly to $\$84 \times 10^6$ capital cost and $\$10.5 \times 10^6$ annual fuel cost, both in 1980 dollars. The present worth of 30 years fuel costs is $\$217 \times 10^6$, and the present worth of 30 years fixed charge against capital is $\$111 \times 10^6$. The present worth of 30 years O&M cost is about $\$50 \times 10^6$ for a total life cycle present value cost of $\$378 \times 10^6$. This cost exceeds the repowering cost by about $\$110 \times 10^6$ in 1980 dollars.

1.6.5 Solar Repowering is Economically Feasible

Calculations of the performance of a solar repowering of Ft. Churchill unit by Westinghouse for this study show close to breakeven economics for the nominal first plant. The cost estimates, the performance models, the economic models and the optimization of the system and its dispatch are not sufficiently accurate at this time to make precise statements of cost/value ratios. However, cost reductions which would surely result from repowering several similar plants would almost certainly lead to early, positive economic benefits.

Because of the very positive economic benefits of repowering shown above, MDAC and SPPCo recommend that an aggressive repowering program be undertaken. In particular, the earliest feasible go-ahead for the detailed design and construction of the repowering plant for Ft. Churchill is recommended.

1.7 DEVELOPMENT PLAN

A top level view of the development schedule is shown in Figure 1-9. A total development period of 51 months is indicated, beginning 1 June 1981. The two pacing items in the schedule are heliostat production and receiver development and production. Both issues were discussed in paragraph 1.3.1, and will not be repeated here. The schedule of Figure 1-9 is very tight. Any slippage in the start date will result in a slippage of the entire schedule. MDAC further believes that a 9 month preliminary design phase beginning in early FY '81 would benefit the program.

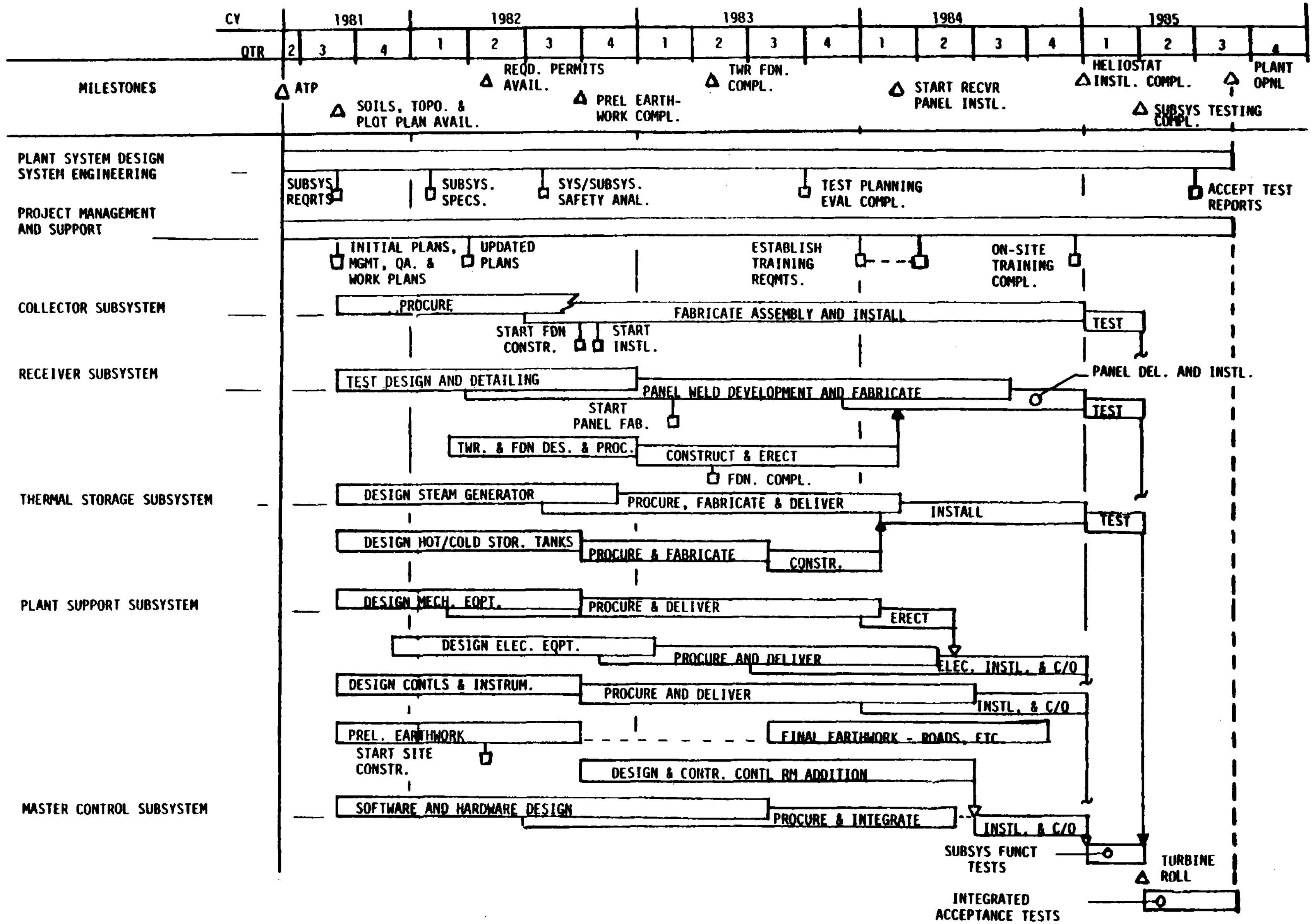


Figure 1-9 Development Plan Executive Summary

The program schedule provides for limited development and testing of critical components. Key issues include:

- Receiver panel fabrication method development
- Creep rupture life analysis on receiver tubes
- Receiver transient flow analysis
- Receiver configuration testing at CRTF
- Receiver feed pumps and seals testing
- Hot storage tank weld joint analysis at the floor/wall joint
- Insulation optimization for the thermal storage tanks
- Detailed analysis of thermal storage tank losses through the ground and temperatures and movement.

1.8 SITE OWNERS ASSESSMENT

1.8.1 Overview

In today's uncertain natural gas and petroleum market conditions, alternate energy repowering concepts for existing oil and gas fired plants are becoming attractive indeed. Coal repowering can create adverse environmental impacts at certain sites, and adds to future dependence on a single energy resource. Nevada's high solar insolation level is one of the bases for Sierra's interest and participation in the Solar Thermal Repowering Program.

We feel that the Conceptual Study produced for the Sierra Pacific Power Ft. Churchill Station project describes a practical and operationally acceptable repowering system. The projected oil or gas displacement of about one half million barrels of oil equivalent energy per year is perhaps the most dramatic indicator of the national significance of the Solar Thermal Repowering Program.

1.8.2 Value of Solar Repowering

Nevada is a state without significant natural fossil and surface water energy resources. The generally long highway, railway and transmission line distances to available energy resources add significant costs to our energy supply. The abundance of solar and geothermal energy in Sierra's northern Nevada service territory is the basis for our serious New Energy Systems development program.

The U.S. Department of Energy's Solar Thermal Repowering Program is a unique opportunity to accelerate the evaluation and development of our solar resource. The program is of particular value as its implementation secures and possibly extends the planned useful life of existing fossil generation facilities while dramatically reducing our oil and natural gas dependence. Experience gained through the program may well lead to participation in future hybrid and stand-alone solar plants exploiting the attractive projected benefits in solar hardware manufacturing economies of scale.

Sierra's future energy supply decisions will be based on both hard economics and often less tangible benefits including energy resource diversity. Industrial demonstration of new technologies provides essential hard operational data for energy system decisions.

1.8.3 System Repowering Potential

Sierra's two plant repowering potential represents slightly over 460 MWe. The portion of that total involved in future Fuel Use Act requirements and voluntary repowering is presumed large. The land availability at both sites is good, being a combination of Sierra Pacific ownership and Public Lands without competing beneficial use. The solar insolation at both sites is high, benefiting from buffering provided by the Sierra Nevada mountains and the general lack of heavy industrialization.

Of the total, 136 MWe are in two nonreheat units and 330 MWe are in three almost identical reheat units. This mixture provides a range of repowering system application. By 1985, 136 MWe will be scheduled for standby/peaking service and 330 MWe for intermediate service. This diversity should yield reasonable flexibility in developing repowering schedules and offer capacity combinations similar to Sierra's anticipated ownership portion of future joint new coal projects.

1.8.4 Operational and Environmental Considerations

The proposed integration of the controls and facilities into our existing operation is smooth and provides minimal impact to our existing plant operation. The control features and philosophy will minimize operator training requirements and allow hybrid operation of the total facility by existing personnel.

Substantial thermal storage facilities are an important operational plus, allowing relatively normal daily operation following the daily load cycle with reasonable short term isolation from solar insolation variations.

Although operating experience with molten salt is not widespread in industry, the location of the salt system components is such that safety hazards to plant personnel performing normal plant operation and maintenance activities should be low. The large temperature difference between the salt's melting point and the ambient, is viewed as a positive safety feature for containment and localization of spills.

Of Sierra's two generation plant sites, the Tracy site may suffer significant environmental impacts from direct coal repowering. Coal repowering might have to take the form of liquification or gasification to be environmentally safe. Both the Tracy and Ft. Churchill sites have a high potential for Solar Repowering. Although heliostat field construction and maintenance activities have a higher negative impact potential for fugitive dust than would arise for a coal conversion, solar repowering presents lower negative impact potentials in nearly all other categories.

1.8.5 Solar Repowering Development Plan

Sierra Pacific concurs with the Department of Energy's ambitious project schedule. The practical opportunity for repowering efforts is not a long term proposition. We also agree to the reasonableness of the extent of the proposed Federal cost sharing.

Sierra Pacific is a serious evaluator of the Solar Repowering option, and is prepared to commit to its share of the costs as the Department of Energy completes its program risk and extent definition.

The means of Federal cost sharing must provide complete ownership of the energy produced from the plant as it will be dispatched to our system grid. As Sierra must begin earning on its capital investments when the facilities become productive, or during construction if allowed, the means of Federal cost sharing in the construction must provide clear ownership definition.

Section 2
INTRODUCTION

2.0 INTRODUCTION

The Sierra Pacific Utility Repowering Study has been conducted for the DOE under contract number DE-AC03-795F 10609. McDonnell Douglas Astronautics Company has lead the study team under the direction of:

Dr. C. R. Easton
Mail Station 14-3
5301 Bolsa Avenue
Huntington Beach, CA 92647

The contract covered the period September 24, 1979 through June 23, 1980. The total cost was $379,100.

2.1 STUDY OBJECTIVE

The objective of this study was to develop a site specific conceptual design for repowering Sierra Pacific Power Company's Fort Churchill Plant, Unit No. 1. The repowering plant design should:

1. Provide a practical and effective use of solar energy. To be practical and effective, the application must meet at least the following criteria:
   - The technology should be acceptable to the utility operating personnel.
   - The repowered plant should provide a useful increment of capacity to the utility grid throughout its lifetime.
   - Stand alone capability should be available for all insolation conditions so that oil/gas combustion not required in order to generate electric power from solar energy.
   - The design should be transferable to other plants that are candidates for economic repowering with minimal modification.
   - The application should displace a significant portion of the oil/gas that would be consumed in the plant if it were not re-powered.
2. Be able to be constructed and operating in 1985. The four year design, development, and construction program implied by 1985 operation is

felt to be adequate. However, the program plan should provide the following to enhance the assurance of meeting schedule:

- Development required on hardware should be held to the minimum necessary to provide effective and economic use of solar energy.
- Hardware development programs which are included should be backed up with low risk contingency plans to prevent serious impact on program costs and schedule.

3. Provide the best economics for overall plant operation. The site specific characteristics of the application have their major impact in economic plant operation. Some of the desirable characteristics are:
   - Select a modern, high efficiency plant with a projected lifetime in repowered operation approaching 30 years.
   - Provide for generation of electric power from solar energy at the time of day when the power is most valuable to the utility.
   - Provide for the operation of the plant in its most cost effective mode.
   - Optimize for site specific insolation projections and sun positions using first plant cost models.
   - Provide for solar only operation at full rated power.
4. Utilize technology being developed by DOE in the most beneficial way. The receiver fluid technologies being developed include water/steam, molten salt, liquid sodium, and gas. The most appropriate of these technologies for the selected application is the molten salt. DOE has conducted laboratory, component, and subsystem level development on molten salt receiver fluid loop elements, and development is continuing on all levels. The resulting data were used in this study.
5. Show the technical potential and cost effectiveness of electric power plant repowering. In order to fulfill its role as a Commercial Demonstration Plant, the repowering plant should:
   - Use technology with a wide application to other utility plant repowering applications.
   - Demonstrate the operation of the most commercially viable repowering plant applications.
   - Show life cycle cost/value characteristics sufficiently close to breakeven that subsequent plants will be economically viable.

2.2 TECHNICAL APPROACH AND UNIT SELECTION

Sierra Pacific Power Company's (SPPCo.) Ft. Churchill Unit No. 1 was selected for this study. The selection criteria derived from the study objective are compared to the findings of this study in Table 2-1.

The technical approach was to use site specific system specifications and trade studies to define the preferred system configuration; to perform a conceptual design of the repowered plant; to estimate the plant performance, cost, and economic benefits; and to prepare a development plan for the design, construction and checkout of the repowered plant.

2.3 SITE LOCATION

The Fort Churchill Plant site is approximately 75 KM (47 air miles) southeast of Reno, Nevada, as shown on the map of Figure 2-1. Yerington (pop.~ 2000) is the closest town. Yerington is in a major agricultural center. The U. S. Department of Commerce, in conjunction with the University of Nevada, have collected published weather data for the past 33 years.

2.4 SITE GEOGRAPHY

The current site plot plan is shown in Figure 2-2. Current use of SPPCO and adjacent land is indicated. The total area owned by SPPCO. is about 10^7 m^2 (2400 acres), with the current plant occupying about 10^6 m^2 (250 acres), including the cooling ponds. The Bureau of Land Management (BLM) holds an additional $0.65 \times 10^6 m^2$ (160 acres), which should be available for collector field siting.

The baseline collector field requires a rectangular area of 1540m (5050 ft) deep by 1720m (5350) wide (650 acres), with about $2.0 \times 10^6 m^2$ (490 acres) actually occupied. Hence, the collector field can be readily fitted into the $3.3 \times 10^6 m^2$ (810 acres) parcel (including BLM land) north west of the plant. A second field for Unit 2 could fit into the parcel to the west of the plant. Hence, there is adequate land available at the site and currently owned by SPPCo. to repower both Fort Churchill units.

The Fort Churchill plant is situated in high desert at an elevation of about 1300m (4300 ft) above sea level. Vegetation is sparce, and consists primarily of low brush and grasses.

TABLE 2-1 UNIT SELECTION

CRITERION	STUDY FINDINGS
Useful Increment of Capacity	Projected Solar Capacity Factor is 0.34, Projected Plant Capacity Factor is 0.43 for Plant Lifetime.
Transferable to Other Plants	Standard Reheat Utility Turbine Representative of 6,800 MWe Current Installed Capability in the Southwest.
Displace Significant Portion of Oil/Gas Otherwise Burned.	Projected Solar Fraction for Plant is 0.75 to 0.80.
High Conversion Efficiency	Turbine Generator Cycle Efficiency is 0.426.
Long Useful Life	SPPCo Projects 30 Years Operation as a Repowered Plant.
High Average Insolation	Projected Annual Average Insolation is 7.2 kW/m^2
Available Land	Adequate Land is Available at the Site.
High Fraction of Capacity in Oil/Gas	65% of the Projected 1985 Capacity is Currently in Oil/Gas.
High Degree of User Interest	SPPCo is Studying Several Alternate Energy Projects and Plans to Implement Projects in Geothermal and Solar Thermal.

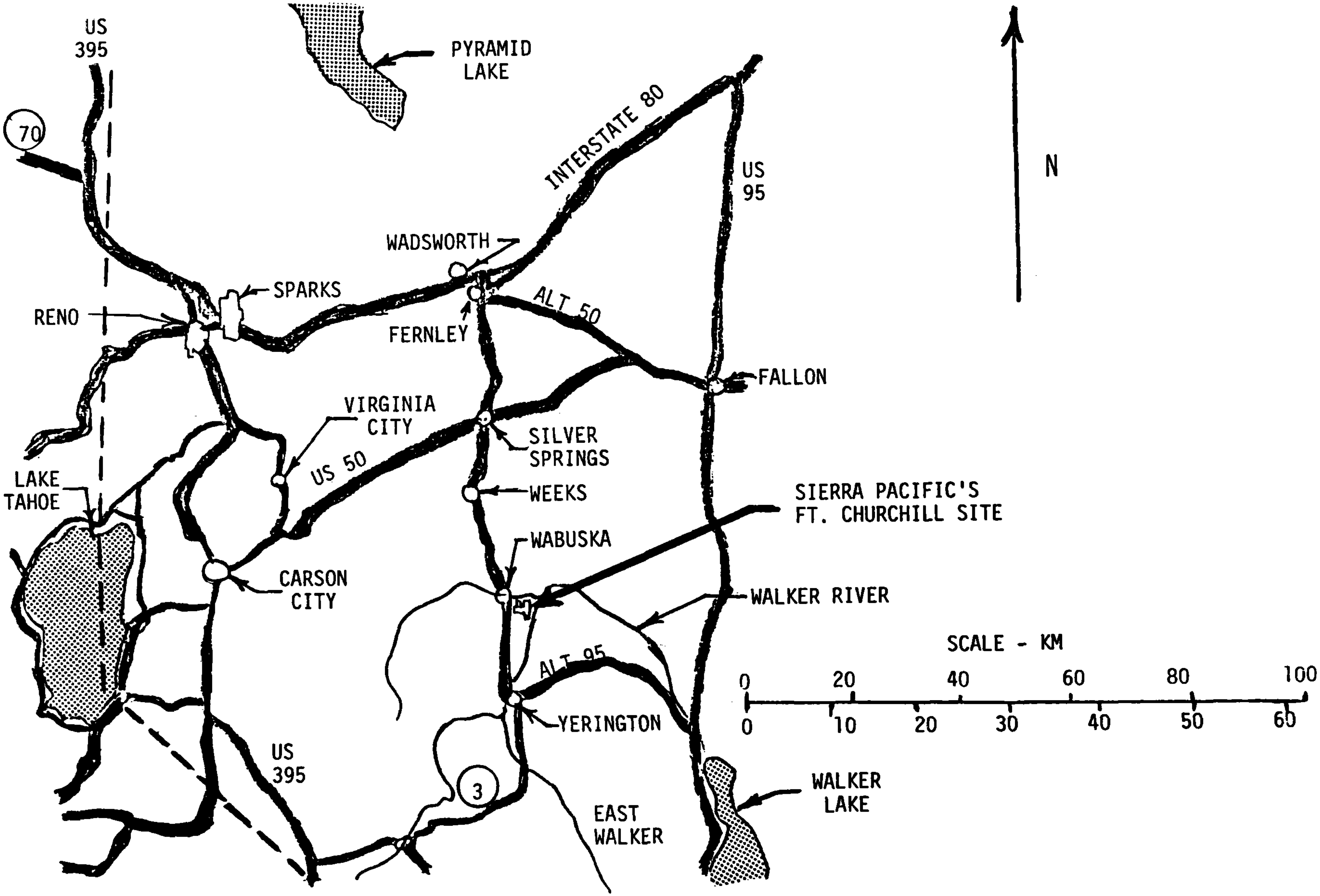


Figure 2-1 Site Location

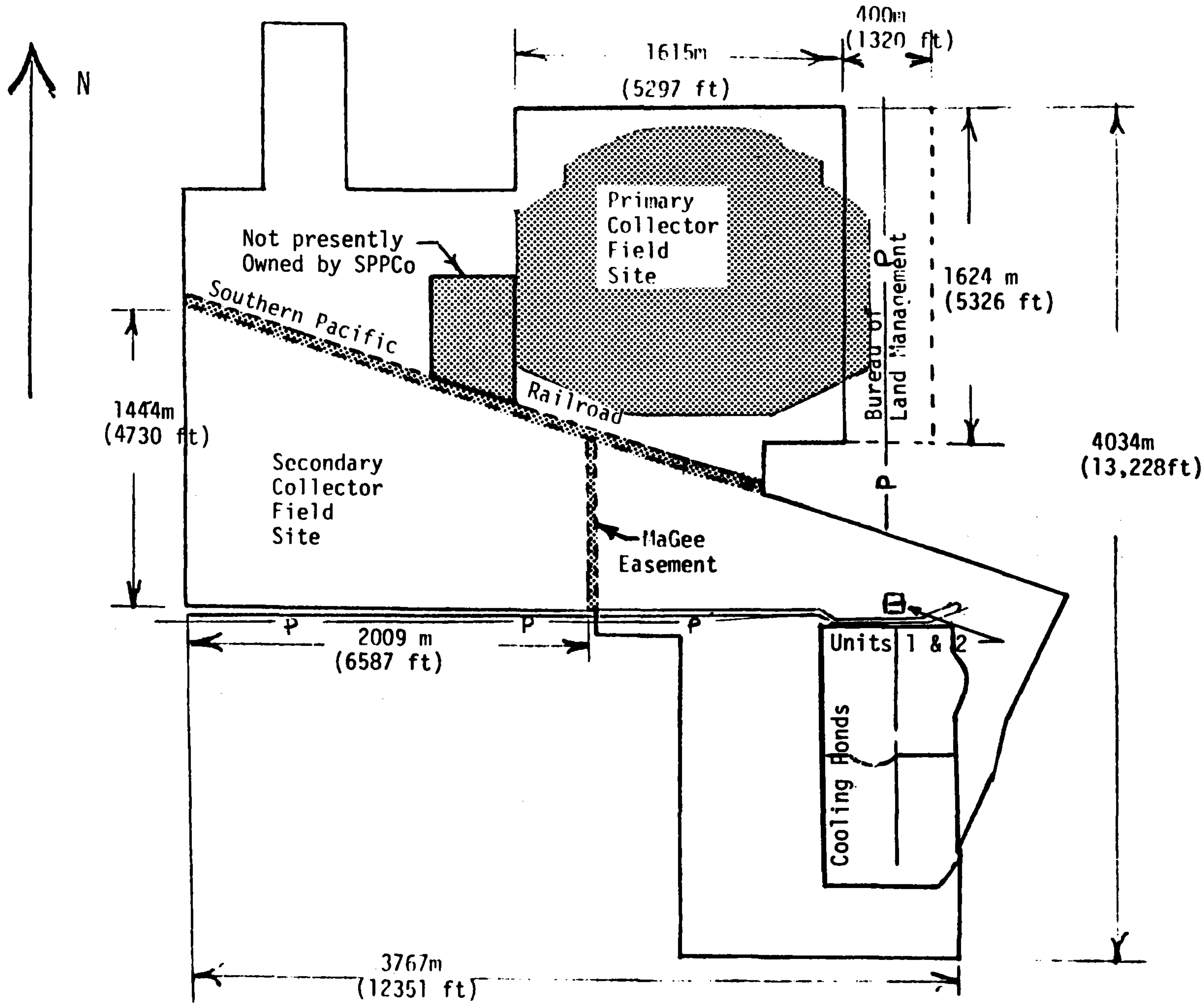


Figure 2-2 Fort Churchill Site Plot

The soil at the surface is a silty sand. It transitions to a clayey and sandy silt at a depth of 3-4.5 m (10-15 ft). The portions close to the Walker River (to the east) tend to be marshy in the winter and spring.

The land is quite flat. There are three drainage ditches in place to provide for surface run-off toward the east-northeast to the Walker River. One drainage ditch crosses the prospective collector field site, and probably provides adequate drainage for the site.

The site latitude is approximately 39°N and the longitude is about 119°W.

2.5 CLIMATE

A climatologic summary of 30-33 years observation is shown in Table 2-2. The mean annual precipitation is 0.133 m (5.23 in.), and the greatest daily precipitation over 33 years is 50.8 mm (2 in). The greatest daily snowfall is 0.152 m (6 in). The highest recorded temperature is 40.6°C (105°F) and the lowest is -32.2°C (-26°F). The average daily maximum temperature for the hottest month (July) is 33.2°C (91.7°F). The average minimum temperature for the coldest month (January) is -9.3°C (15.2°F).

The American National Standards Institute shows the 25 year recurrence fastest mile basic wind speed to be 31.3 m/s (70 mph). A 1.2 gust factor is recommended. Hence, a maximum wind speed with gusts of 37.6 m/s (84 mph) may be used.

Reno data were used to estimate the weather factor of 0.84 (fraction of annual, clear daylight hours). The Fort Churchill site is expected to have less cloud cover than Reno, because it is located further east, away from the Sierra lee wave cloud formations. An adjustment was made for the improved weather factor at Ft. Churchill based on simultaneous measurements of total hemispheric insolation at both Reno and Ft. Churchill.

Clear day insolation data were collected at the site for six months. These data, together with Ely Solmet data and the University of Houston insolation model extrapolations were used to estimate monthly clear day insolation levels.

Table 2-2 CLIMATOLOGICAL SUMMARY FOR YERINGTON, NEVADA

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
IN COOPERATION WITH THE UNIVERSITY OF NEVADA
CLIMATOGRAPHY OF THE UNITED STATES NO. 20 - 26

CLIMATOLOGICAL SUMMARY

LATITUDE 38° 59' N
LONGITUDE 119° 11' W
ELEV. (GROUND) 4375 feet

STATION Yerington, Nevada

MEANS AND EXTREMES FOR PERIOD (Means: 1936-1965) (Extremes: 1936-1968)

Month	Temperature (°F)							**	Precipitation Totals (Inches)								Mean number of days					Month
	Means			Extremes								Snow, Sleet						Temperatures				
																		Max.		Min.		
	Daily maximum	Daily minimum	Monthly	Record highest	Year	Record lowest	Year	Mean degree days	Mean	Greatest daily	Year	Mean	Maximum monthly	Year	Greatest daily	Year	Precip. .10 inch or more	90° and above	32° and below	32° and below	0° and below	Month
(a)	30	30	30	33		33			30	33		30	33		33		30	30	30	30	30	
Jan	46.4	15.2	30.8	70	1964+	-26	1937	1054	0.35	1.40	1943	3.0	20.4	1949	6.0	1954	2	0	3	28	3	Jan
Feb	52.6	20.5	36.6	74	1950	-14	1949	812	0.63	1.28	1962	2.0	8.7	1948	5.5	1948	2	0	*	26	1	Feb
Mar	59.3	23.9	41.6	81	1960	- 2	1950	719	0.41	0.98	1941	2.0	8.0	1954	6.0	1945	1	0	*	27	0	Mar
Apr	68.3	30.4	49.4	88	1950	5	1944	468	0.33	0.80	1951	*	4.0	1967	3.0	1967+	1	0	0	18	0	Apr
May	74.7	37.6	56.2	95	1954	15	1960	291	0.75	1.90	1939	0	6.5	1964	4.0	1964	2	1	0	7	0	May
Jun	82.4	43.8	63.1	102	1961	26	1954	129	0.55	0.79	1945	0	T	1963+	T	1963	2	7	0	1	0	Jun
Jul	91.7	49.5	69.1	105	1960	30	1955	22	0.30	0.85	1945	0	0	--	0	--	1	22	0	0	0	Jul
Aug	90.3	46.5	70.0	105	1967	26	1960	43	0.22	0.55	1936	0	0	--	0	--	1	18	0	0	0	Aug
Sep	83.2	39.4	61.3	100	1955+	20	1959	153	0.27	2.02	1955	0	0	--	0	--	1	7	0	5	0	Sep
Oct	71.6	31.3	51.5	90	1952	12	1956	434	0.40	1.40	1943	*	2.0	1943	4.0	1943	1	*	0	18	0	Oct
Nov	57.4	21.0	39.2	79	1958	0	1956	777	0.49	0.92	1944	1.0	11.5	1961	5.6	1943	1	0	*	27	0	Nov
Dec	49.1	17.0	33.1	74	1939	-20	1948	1008	0.53	2.00	1955	2.0	16.5	1936	5.0	1941	2	0	1	28	1	Dec
Year	68.9	31.3	50.2	105	1967+	-26	1937	5910	5.23	2.02	1955	10.0	20.4	1949	6.0	1954+	17	55	4	185	5	Year

(a) Average length of record, years.

T Trace, an amount too small to measure.

\+ Also on earlier dates, months, or years.

* Less than one half.

Combining the Reno weather factor with the clear day insolation, yielded an annual average insolation estimate of 7.2 kWh/m^2.

2.6 EXISTING PLANT DESCRIPTION

The existing Fort Churchill plant has two nearly identical units. The boilers are fueled with #6 fuel oil, natural gas, or various proportions of the two fuels. Both boilers were designed to accomodate retrofit to coal firing. The turbine rated pressure is 12.4 MPa (1800 psi). The normal operating pressure is 13 MPa (1890 psia). The turbine inlet temperature is 538°C (1000°F). There is a single reheat to 538°C (1000°F) at 7.9 MPa (422 psia).

Heat is rejected to cooling ponds located south of the plant. The gross plant efficiency is 0.349 (9790 Btu/kWh).

Unit No. 1 entered service in 1968. This unit has a design life of 30 years. However, SPPCO. estimates that the repowered unit could be economically operated for an additional 30 years after the repowered operational date of 1985.

The schematic of Figure 2-3 shows the baseline repowering concept with flow rates and state points for hybrid operation. The interfaces illustrated are:

Feedwater

A tee joint is put into the feedwater line between the final stage of feedwater preheat and the steam drum water level control valve. A valve is added to the solar feedwater line to control the steam drum water level in the solar boilers.

Main Steam Line

A tee is inserted in the main steam line near the fossil boiler outlet to merge solar and fossil steam sources. No mixing chamber appears to be required. Shutoff valves are supplied in both lines to prevent backflow of steam in fossil only and solar only operating modes.

Cold Reheat Line

A tee is added to the cold reheat line to provide flow to the solar reheater. Flow control valves in both lines regulate the apportioning of the flow to the fossil and solar reheaters. Flow is apportioned to maintain 540°C (1005°F) at the fossil reheater outlet.

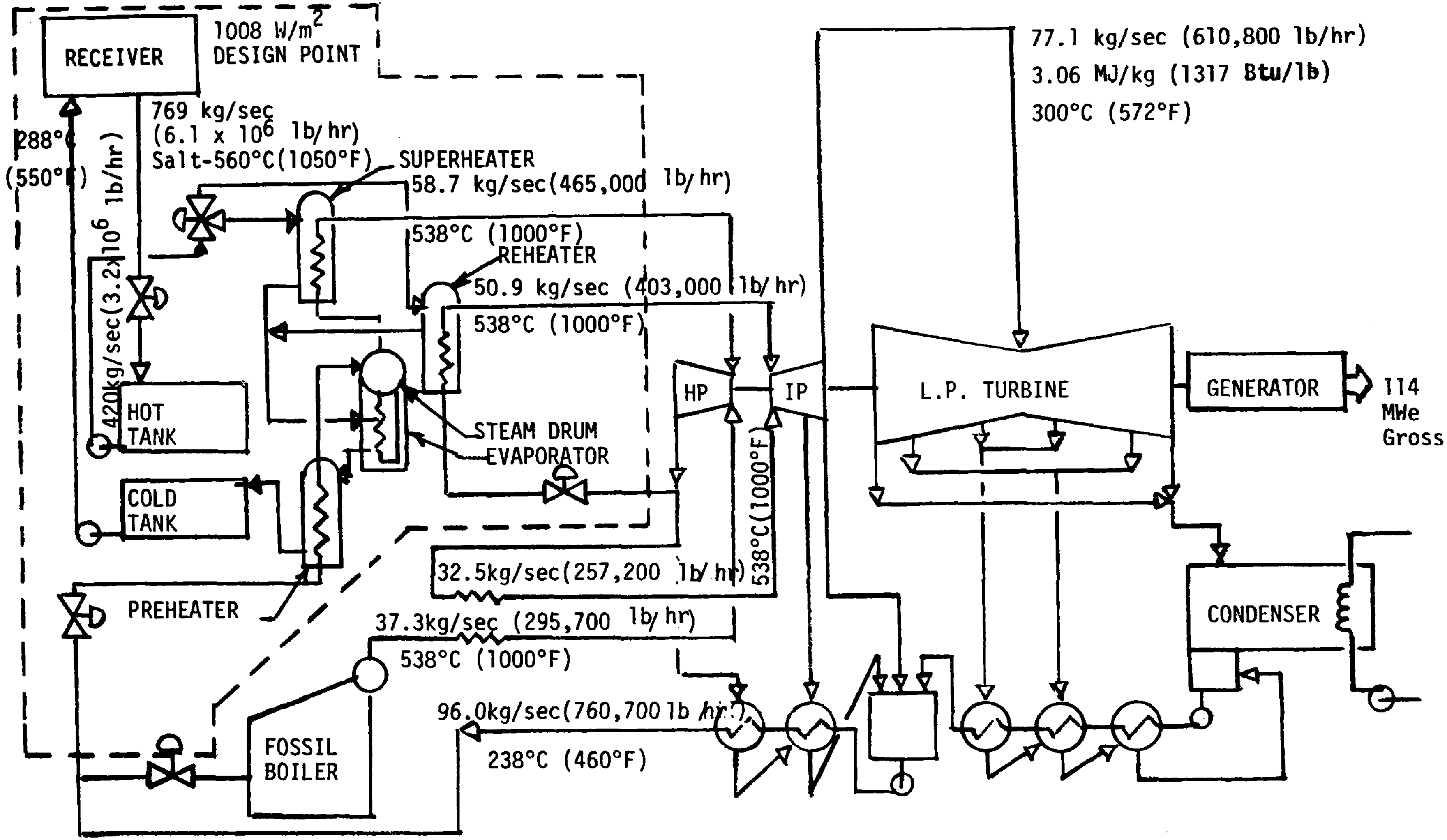


FIGURE 2-3 PLANT CYCLE SOLAR-FOSSIL HYBRID

Hot Reheat Line

A tee is added to the hot reheat line to mix the flow from the solar and fossil reheaters. Shutoff valves are provided in both lines.

Control

Solar controls will be located in the control room currently used for both Units 1 and 2. The plant operator will provide the primary interface between the solar and fossil steam sources. Critical data will be automatically supplied to the solar controller to facilitate coordinated control.

Parasitic Power

Plant parasitic power is provided for operation of the collector field, the receiver feed pumps, the controls, the salt circulation pumps, and miscellaneous equipment.

2.7 EXISTING PLANT PERFORMANCE

The existing Unit 1 is rated at 110 MWe net power delivered to the grid. The fuels are oil and natural gas.

The plant currently operates at 0.78 capacity factor, and is considered to be base load. The annual electrical energy production is about 750 GWh. The scheduled 1985 operation is as an intermediate capacity factor plant. The capacity factor was estimated at 0.42 by SPPCO. and 0.34 by Westinghouse AST. The primary difference between these two estimates appears to be a greater proportion of purchased power from adjacent utilities forecast by Westinghouse. The plant would be baseloaded in the winter and portions of the summer, and load following during the remainder of the year. The total annual electrical energy production would be about 405 GWh at 0.42 capacity factor and 328 GWh at 0.34 capacity factor.

At the current usage, the plant consumes the heat equivalent of $0.2 \times 10^6 m^3$ ($1.27\ 10^6$ bbl) of oil. The projected 1985 usage without repowering is $0.11 \times 10^6\ m^3$ (630,000 bbl) at 0.42 capacity factor and $86 \times 10^3 m^3$ (543,000 bbl) at 0.34 capacity factor.

The plant availability has been excellent. Forced outages are less than 1%, and total availability has been greater than 0.96.

The present worth and levelized fixed charge rate for 30 years operation of the non-repowered plant are shown in Table 2-3. The low economic parameter set uses 10% per year fuel escalation and 11.6% per year discount rate. Capacity factor is 0.72 through 1984, 0.34 from 1985 to 1994, and 0.2 past 1995. Operations and maintenance costs escalate at 9% per year.

The high economic parameter set was 12%/year fuel escalation, and 0.42 capacity factor from 1985 through 1994. Other parameters are the same.

2.8 PROJECT ORGANIZATION

The functional organization chart for the Sierra Pacific Power Co., solar repowering study is shown in Figure 2-4.

MDAC and Sierra Pacific Power Company, while shown in a classic prime/subcontractor relationship, have effectively operated as partners in the program. MDAC has acted as a prime in this phase to take advantage of our experience in integrating conceptual studies of this nature and our technical knowledge of the system. However, MDAC has fully recognized Sierra Pacific as an associate in this venture and we expect them to lead any follow-on effort.

MDAC utilized four subcontractors (Foster Wheeler, Stearns-Roger, University of Houston and Westinghouse) for conducting specific portions of this study as shown on Figure 2-4. These subcontractors have supported MDAC in the past, and a good working relationship exists with each subcontractor. MDAC also retained the service of the Desert Research Institute, who are the leaders in the development of solar monitoring equipment and who have had extensive work in energy-related fields in the state of Nevada. The key personnel assigned to this study, and their specific responsibilities by task, are shown in Figure 2-5.

2.9 FINAL REPORT ORGANIZATION

This final report is published as a single volume. In addition, the Executive Summary is published as a separate volume.

The introduction, including a description of the existing plant, is con tained in Section 2. Section 3 presents a summary of the trade studies and rationale use

TABLE 2-3 OPERATIONS AND MAINTENANCE (O&M) COSTS FOR NON-REPOWERED PLANT
(10^6 1980 DOLLARS)

	ECONOMIC PARAMETER SET	
	LOW	HIGH
Current Fixed O&M	0.7	0.7
Present Worth 30 Years O&M	13.7	13.7
Fuel Costs, Present Worth		
1980-85 Operation	156	162
1985-95 Operation	133	194
1995-2010 Operation	39	60
Total Present Worth O&M Plus Fuel	342	429
Levelized Fixed O&M Charge	1.5	1.5
Levelized Fixed Fuel Charge	35.4	44.8
Total Levelized Charge	36.9	46.3

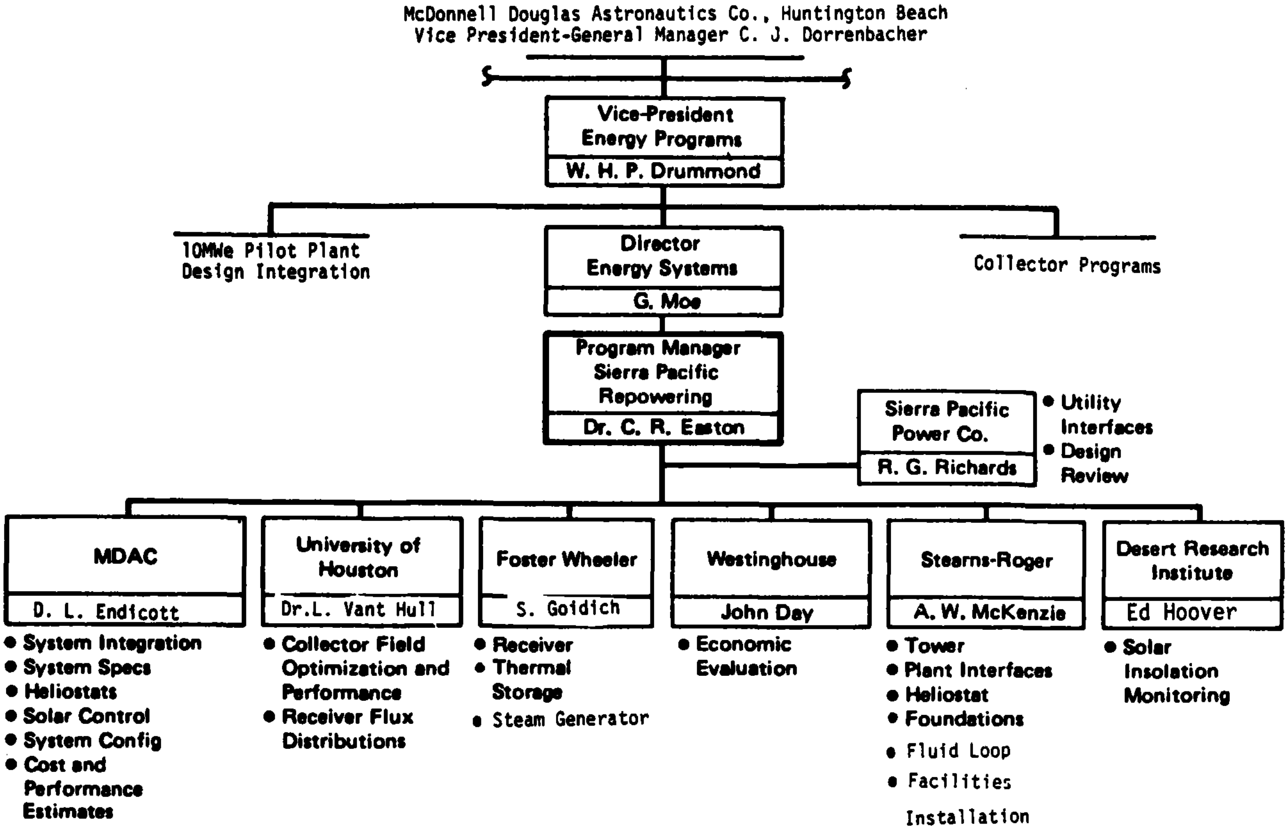


Figure 2-4 Sierra Pacific Utility Repowering Study Organization

to select the preferred system configuration. Detailed trade studies are presented in Appendix B. The system level design, requirements, performance estimates, capital and O&M cost estimates, and institutional and regulatory issues are described in Section 4. Subsystem characteristics as described in Section 5. Section 6 presents an analysis of the probable economic value of the repowered plant to SPPCO. Section 7 contains the development plan.

There are two appendices. Appendix A is the System Requirements Specifications. Appendix B contains the detailed trade study reports.

WBS 0.0 — Solar Repowering Ft. Churchill No. 1

	Task 1 (WBS 1.0) System Reqmts Specification (SRS)	Task 2 (WBS 2.0) Selection of System Config.	Task 3 (WBS 3.0) Conceptual Design	Task 4 (WBS 4.0) Performance Estimates	Task 5 (WBS 5.0) Cost Estimates and Economic Anal	Task 6 (WBS 6.0) Development Plan	Task 7 (WBS 7.0) Program Plan and Management
MDAC (C. R. Easton) (D. L. Endicott)	• Prepare System Reqmts Spec (SRS)	System Config Definition Solar System Sizing Heat Trans. Fluid Trades Receiver Config. Selection	• Design Integration Solar Control Design Solar Subsystem Specs	• System Perf Solar Perf	• Solar Equip Cost Estimates	• Prepare Development Plan	• Program Plan Program Mgmt Reporting
Sierra Pacific Power Co. (R. G. Richards)	Input to SRS For Existing Plant & Economics	• Provide Site Data Review & Select Preferred System Configuration	Design Review/ Evaluation	Review of Plant Perf Estimates	Existing Plant Mods Cost Est Economic Data	Inputs to Devel Plan Review of Plan	
Foster Wheeler (S. Goidich)	Input to SRS For Hot Salt Sys	Hot Salt System Trade Study	Receiver Design Thermal Storage Des Heat Exchanger Design	Hot Salt Sys Perf Estimates	Hot Salt Sys Cost Est	Inputs to Devel Plan	
Univ of Houston (L. L. Vant Hull)	Input to SRS For Collector Field	Collector Field Optimization	Collector Field Layout and Description	Collector Field Perf. Estimates			
Stearns-Roger (A. W. McKenzie)	Input to SRS For Plant Interface	Site Mod Interface Trade Study	Design of Solar/Nonsolar Interface Tower Design Site Preparation		Estimates For Tower Plant Interface & Field Construction	Inputs to Devel Plan	
Westinghouse (J. T. Day)					Economic Evaluation		
Desert Research Institute (Ed Hoover)		Solar Insolation Monitoring					

• Lead Role

Figure 2-5. **Contract Work Breakdown Structure (WBS)**

Section 3
SELECTION OF PREFERRED SYSTEM

This section contains a summary of the work performed on Task 2, "Selection of the Site-Specific System Configuration" and those portions of Task 3, "Plant Conceptual Design", relating to system concept selection rationale.

3.1 SYSTEM LEVEL TRADE STUDIES

Four system level trade studies were conducted under Task 2 to determine the general system approach. These studies and the three subsystem trade studies are summarized in Table 3-1. Details of these trade studies are contained in the individual trade study reports in Appendix B.

3.1.1 Receiver Fluid Selection

A trade study was conducted to select between water/steam and molten salt receiver fluids. The trade study is discussed here, with further commentary on the technology in Section 3.3. An auxiliary, fossil fired reheater was assumed to provide reheat for the solar generated steam in the water/steam system. Molten salt provides the heat for the reheater in the salt system.

For the water/steam system, buffer storage only was assumed. The molten salt system was considered for solar multiples of 1.0, 1.4 and 1.8, corresponding to buffer storage, and 2.7 and 6.5-hour storage, respectively.

Systems were sized with the above variables and cost estimates prepared. The cost estimates included sensitivity to heliostat unit costs ($\$/m^2$) and to fossil fuel reheater costs.

Estimates were made of the annual fuel displaced. A figure of merit was defined as the ratio of the present value of 20 years fuel displacement to the initial capital cost of the system. SPPCO estimates that the repowered plant can operate for 30 years. Hence, the 20 years fuel displacement assumed for the trade studies is conservative. Fuel costs were assumed at quoted U.S. average prices of $3.92/MJ

Table 3-1. Task 2 Trade Study Summary

Trade Study	Level	Candidates	Issues
Receiver Fluid	System	Water/Steam Molten Salt ✓	Cost, fuel displacement control, operations favor molten salt, development status favors water/steam
Collector Field Configuration	System	Surround North ✓	System Cost Favors North Field
Receiver Configuration	System	External Cavity Partial Cavity ✓	System cost, performance favor partial cavity
Thermal Storage Utilization	System	Buffer Storage Extended Operation ✓	Extended operation allows higher fuel displacement at the same unit cost
Receiver Tower	Subsystem	Concrete ✓ Steel	System costs are equal, maintenance cost, and wind deflection favor concrete
TSU Thermocline vs Two Tank	Subsystem	Dual medium thermocline Two Tank, External ins. ✓ Two Tank, Internal ins.	Cost favors dual medium, risk favors two tank, external insulation.
Heat Exchanger Design Selection	Subsystem	Counterflow ✓ Cross Flow Parallel Flow ✓	Preheater, reheater and superheater require counterflow; evaporator is parallel flow to enhance natural circulation and minimize piping.

✓ Selection

in 1980 dollars ($24/bbl), and annual escalation rates of 10 and 12 percent per year were assumed. A weighted discount rate of 9.23 percent (8 percent general inflation) was assumed to calculate present value.

Trade study results are summarized in Table 3-2. The cost data are adjusted to reflect results of subsequent trade studies and design activities. The nominal values of heliostat costs ($175/m^2) and fuel escalation rates (10 percent) used throughout the trade studies are shown. The high range system cost uses $230/m^2 heliostats and the high range of fuel savings uses 12% escalation.

Note that the figure of merit of Table 3-2 is not a true benefit/cost ratio. Items of common equipment such as Master Control and facilities are not included. Nor are nonrecurring (design and tooling), interest during construction, and contingency. O&M costs and the present value of the levelized, fixed charge against capital must also be considered to develop a real benefit/cost ratio.

The data of Table 3-2 show only minor differences in the figure of merit between water/steam and molten salt. Figures of merit for water/steam range from a low of 2.16 to a high of 4.48, while the range for molten salt is 2.45 to 4.69. The differences between the figures of merit for the two receiver fluids are seen to be much smaller than the uncertainties in the values.

Several additional considerations bear on the final selection. From Table 3-2, the molten salt system can displace more than twice the amount of fuel that the water/steam system can displace. The essentially decoupled operations of heat collection and steam generation make the molten salt system substantially easier to control. The capability for solar only operation and for somewhat deferred operation with the use of storage favor the molten salt system. Operation of the molten salt receiver with partial cloud cover is simplified.

3.1.2 Collector Field Layout

A trade study was conducted to compare a surround field with a north field. Further discussions on system sizing may be found in Section 3.2. This trade study has been run many times before, with a surround field normally being superior for larger plants (>50-100 MWe) and a north field being superior

Table 3-2. Receiver Fluid Selection Summary
(Costs in 10^6 1980 Dollars)

	Water Steam	Molten Salt		
	SM † = 0.53	SM † = 0.61	SM † = 0.86	SM † = 1.11
Collector ($175/m^2)	42.8	49.2	68.9	88.5
Receiver	8.9	8.9	11.1	13.0
Tower	2.5	2.9	4.0	5.2
Storage	0.4	0.8	4.2	10.2
Heat Exchanger	13.8	6.4	6.4	6.4
Piping	4.0	1.3	1.9	2.4
Cost Subtotal	72.4	69.5	96.5	125.7
Fuel Displaced 10^{15} J/yr (10^{12} Btu/yr)	1.42 (1.35)	1.66 (1.57)	2.32 (2.70)	2.98 (2.82)
FOM* Nominal	2.45	2.98	2.99	2.97
High/Low	4.5/2.1	4.5/2.5	4.6/2.5	4.7/2.6
Nominal ROI (%)	15	17	18	17

† SM = Solar Multiple = Ratio of design point receiver heat flow to design point turbine heat flow

$$*FOM = \frac{\text{Present value of 20 years fuel savings}}{\text{Initial system capital cost}}$$

for smaller plants (<10-30 MWe). However, four factors, two of which are site specific, differ from previous trade studies:

1. The collector field must be located some distance from the plant, and the piping run to the plant is shorter for a north field configuration.
2. The plant latitude is higher than for previous studies, also favoring a north field.
3. First unit heliostat costs are to be used, which tends to push the system optimization toward better heliostat performance (north field).
4. A partial cavity receiver is introduced which combines the better features of external and cavity receivers. Most importantly, the azimuthal extent of the field is not limited, as it was for previous north field/ cavity combinations.

The two systems were optimized by Sandia computer program DELSOL.* Results are summarized in Table 3-3. Characteristics of both the external and partial cavity receiver are shown to indicate the sensitivity of the final choice to the success of the partial cavity receiver design.

Table 3-3 clearly shows a substantial advantage to a north field if a partial cavity receiver can be successfully developed. The first unit cost benefits alone would more than pay for the development cost of the receiver. The predominant cost savings is seen to be that fewer heliostats are required for the north field. Most of the reduction in the number of heliostats required results from the high efficiency of the partial cavity receiver. This efficiency, together with the minimal restraint on the azimuthal extent of the collector fields is the key benefit of the north field.

A north field configuration is selected on the basis of a projected lower system cost. The selected collector field is outlined in Figure 3-1.

3.1.3 Receiver Configuration Selection

A trade study was conducted to select the general receiver configuration. This trade study was regarded as system level because of the major impact receiver

*Dellin, T. A. and M. J. Fish, "A User's Manual for DELSOL", Sandia Laboratories Energy Report SAND79-8215, dated June 1979.

MCDONNELL DOUGLAS

Table 3-3. Comparison of Optimum North and Surround Fields

	North Field		Surround Field
	External	Partial Cavity	External
Area of Heliostats (m^2)	517,000	466,000	533,000
Collector Cost ($M @ $175/$m^2$)	90.4	81.5	93.3
Tower Height (m)	220	220	200
Tower Cost ($M)	5.8	5.3	4.4
Receiver Area (m^2)	1340	1100	1240
Receiver Cost ($M)	15.8	13.0	13.9
Ground Piping Length (m)	1265	1265	1625
Piping Cost ($M)	2.4	2.4	3.1
Subtotal ($M)	114.6	102.1	114.7
@ $230/$m^2$ heliostat cost	142.8	127.8	144.0
@ $ 79/m^2 heliostat cost	64.8	57.4	63.5

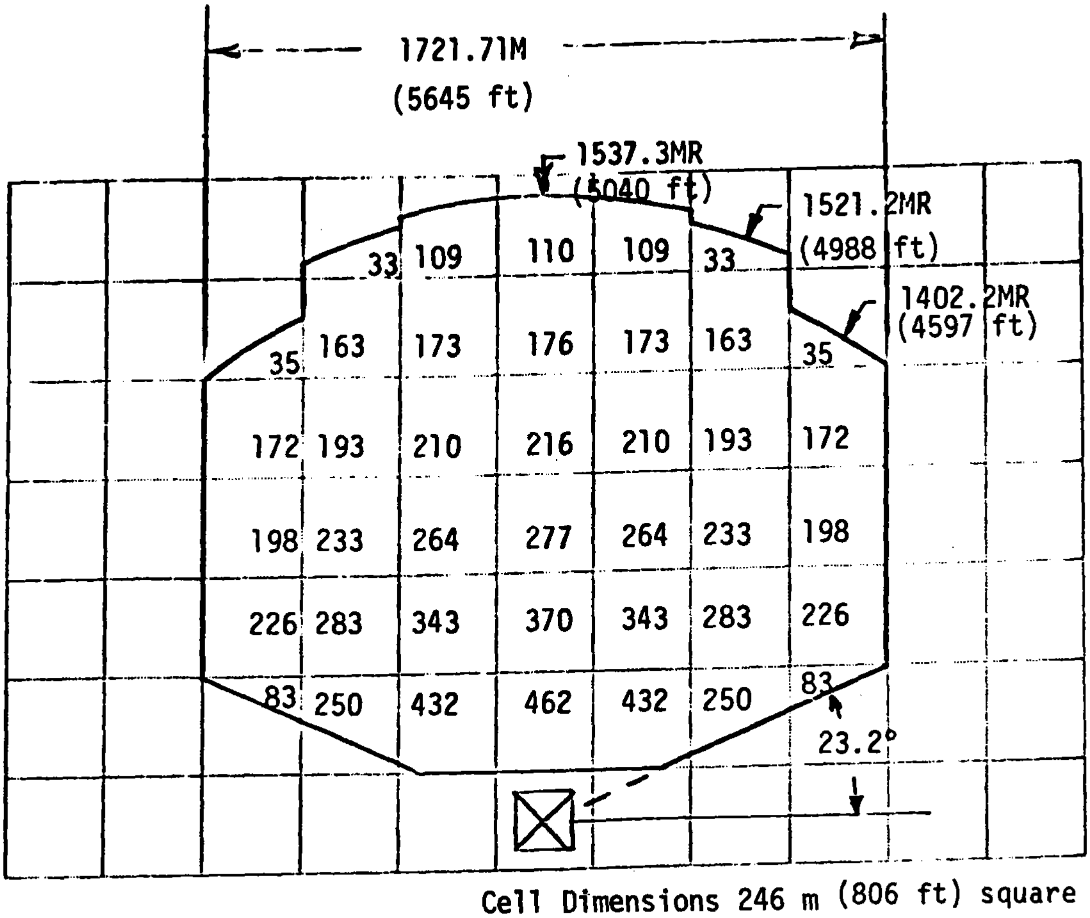


FIGURE 3-1 COLLECTOR FIELD LAYOUT

efficiency has on the system design. Candidates considered include partial cavity, full cavity, and external. These concepts are illustrated in Figure 3-2.

The external receiver is nearly cylindrical in shape. Since there is no south field, no absorber panels are required on the south. Dummy panels are installed on the south side of the receiver for reduced wind drag.

The partial cavity receiver has its external dimensions determined by the spot size from the more remote heliostats. The cavity zone extent is such that the peak incident heat flux is reduced to an acceptable level.

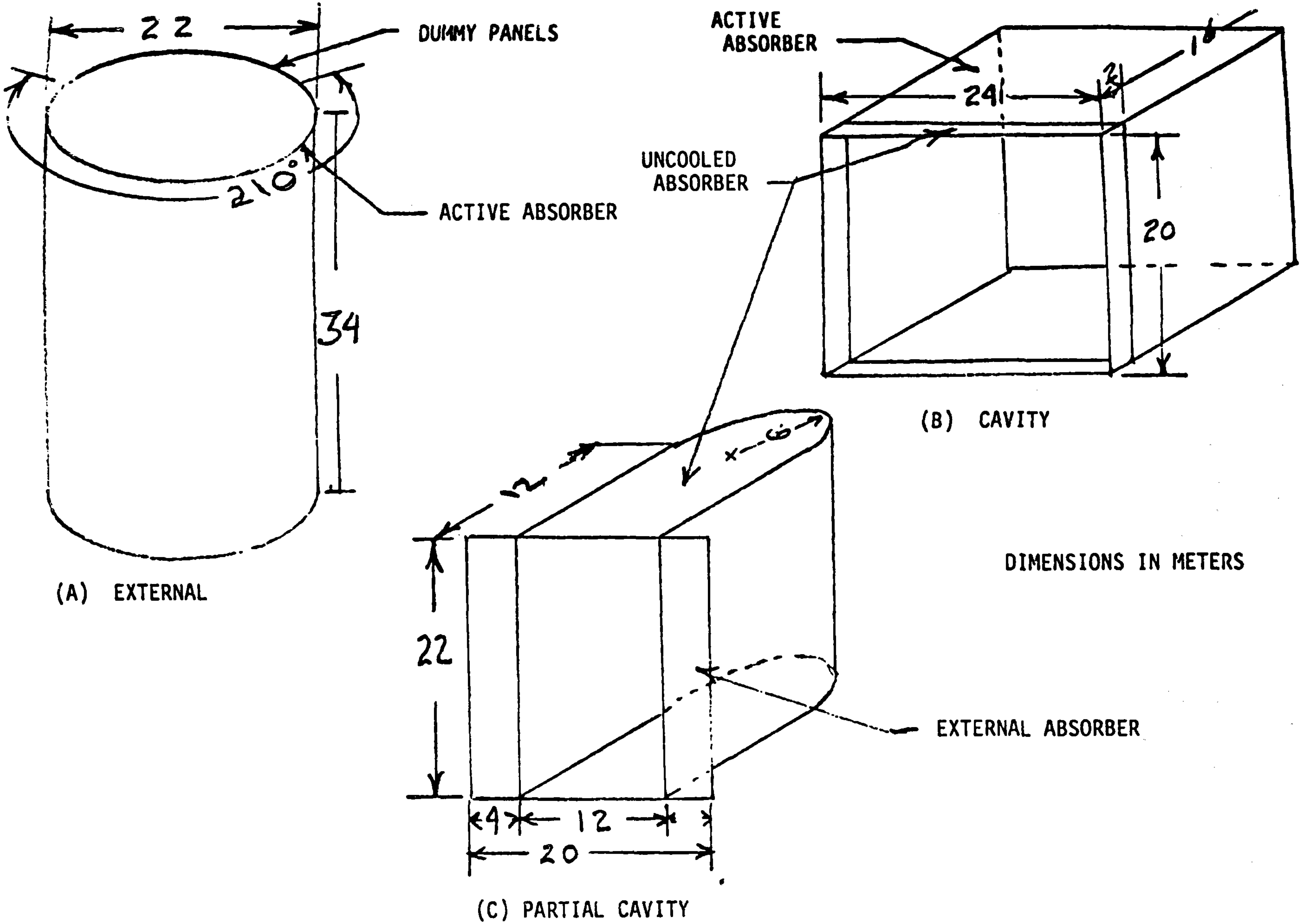


Figure 3-2 RECEIVER CONFIGURATIONS CONSIDERED

The full cavity receiver is given an aperture size adequate to reduce the flux falling on the structure outside the receiver to an acceptable level. The depth is that necessary to reduce the peak incident flux on the absorber to an acceptable level. The rectangular configuration was selected to allow all surfaces to be active absorbers.

Characteristics of the three receiver configurations are shown in Table 3-4. The data indicate that external and full cavity receivers are of approximately equal system cost at the higher heliostat costs. At Nth commercial system heliostat costs, the extra cost of the cavity receiver is not warranted by its improved performance.

The partial cavity receiver appears to be superior at all heliostat costs, and is selected on this basis.

3.1.4 Thermal Storage Utilization

The final system level trade study was conducted to determine whether thermal storage should be used for buffering only, or for extended operation.

The groundwork for this trade study was laid in Section 3.1.1. In that trade study, the figure of merit was essentially constant in going from buffer storage to 2.7 hours (solar multiple of 1.4) to 6.5 hours (solar multiple of 1.8). However, the fuel displacement went up 80 percent in going from buffer storage only to 6.5 hours storage.

A second, major operational advantage of storage for extended operation is that there is ample heat collection to operate the steam generators at their design point for most of a clear day throughout the year. Hence, the plant operators duties can be greatly simplified.

Because of the operational simplicity and flexibility and the greater fuel displacement capability, storage for extended operation was selected.

The amount of storage cannot be determined from the simple analyses shown in Section 3.1.1. The present value of fuel displaced considers that all fuel

Table 3-4. Comparison of Receiver Configurations

	External	Full Cavity	Partial Cavity
Effective Absorptivity	0.95	0.986	0.98
Interception Factor	0.99	0.995	0.97
Reradiation Loss (MW)	22	8	6
Convection Loss (MW)	26	9	9
Efficiency	0.821	0.933	0.909
Required Field Power (MW)	402	354	363
Receiver Absorber Area (m^2)	1340	1900	1100
Receiver Cost ($M)'	15.8	27.5	13.0
Tower Cost ($M)	5.8	5.2	5.3
Collector Cost ($M @ $175/$m^2$)	90.4	84.6	81.4
Subtotal ($M)	112.2	112.3	99.8
With collector cost @ $230/$m^2$	140.4	138.9	125.4
With collector cost@ @ $ 79/m^2	62.4	65.9	55.0

displacement is against oil. In fact, Sierra Pacific Power Company's plans call for an extended coal capacity, such that a significant part of the fuel displacement could come against coal in 1995, if too large a thermal storage unit is chosen. Detailed grid analysis studies were required to set the storage unit size. These analyses were performed and are reported in Section 6.

3.2 SYSTEM SIZE

There are three principal factors which combine to make up the system size. The degree of repowering, or solar fraction defines the capacity of the steam generators and related equipment. The collector field thermal power defines the annual energy collected and its daily and seasonal variations. The thermal storage unit size is established to provide the best matching between thermal energy collection and electrical energy dispatching profiles. These topics are discussed in order in the following paragraphs:

3.2.1 Solar Fraction

During the portion of the year when the plant is to be baseloaded, (winter and portions of summer) it is preferable to operate the fossil boiler at at least 37 MWe euqivalent firing rate. Dropping the firing rate on the fossil boiler below 37 MWe results in an inability to maintain rated temperature in the reheat section, and a resultant loss of efficiency.

Hybrid operation was selected as the baseline operating mode. Figure 3-3 illustrates alternate operating profiles for the hybrid operation. The upper illustration shows the solar energy dispatched at the maximum rate consistent with the 37 MWe minimum operating power level for fossil. The maximum usable size for the steam generators is seen to be 77 MWe equivalent. The size (77 MWe) was adopted as the study baseline. The lower illustration in Figure 3-3 shows that solar energy can be used to buffer the fossil boiler operation in the hybrid mode. This method of operation is preferred.

The economic dispatch analyses conducted by Westinghouse AST provided a strong indication that stand alone operation will be the predominant mode, especially for the later portions of the plant lifetime. Moreover, the capability to operate at full rated power in a stand alone mode appears to be economically desirable. Hence, steam generators for 100% repowering (110 MWe equivalent) may be the final choice. This conclusion is tentative, and must be confirmed during the preliminary design.

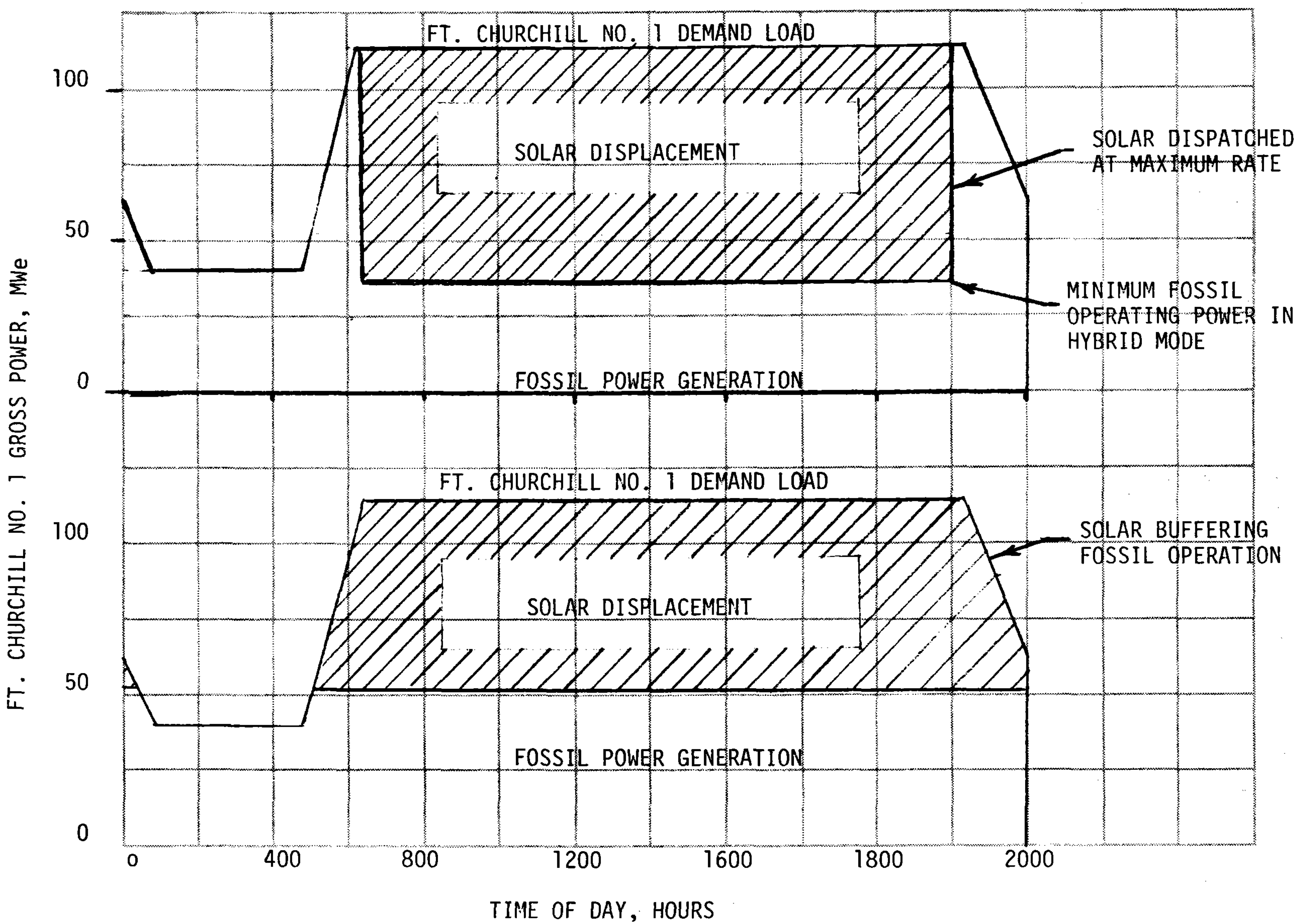


FIGURE 3-3 ALTERNATE CLEAR SUMMER DAY SOLAR PROFILES

3.2.2 Collector Field Rated Power

As previously discussed (paragraph 3.1.4), a detailed grid analysis study is required to determine the optimum collector field size and thermal storage unit size. The analysis must consider the grid demand and generation dispatch over the lifetime of the plant. The greater the solar power rating of the collector field, the greater the proportion of the fuel displacement which will come against coal as the coal generation grows, this trend to coal displacement will increase. This concept is illustrated qualitatively in Figure 3-4. The quantitative sizing optimization was beyond the scope of this study.

The baseline collector field size for the Phase I study was determined from the hybrid operating profile for mid-summer, as shown in Figure 3-3. The field was sized to collect enough solar energy over the summer day to meet the forecast 1985 demand in excess of the 37 MWe minimum fossil boiler operating level. From this requirement, the design point requirement of 330 MWth in the receiver fluid at equinox noon was derived.

3.2.3 Thermal Storage Sizing

The thermal storage unit size also requires an optimization against grid demand and generation capacity dispatch. This optimization must consider both adequate capacity to contain the thermal energy collected and the potential for deferring the dispatch of the thermal energy to steam generation to optimize the value of the electricity generated.

Tentative conclusions from the Westinghouse study are that 1080 MWh (6 hrs at 77 MWe) is adequate storage capacity for both purposes. Hence, this capacity was baselined.

3.3 TECHNOLOGY

The three receiver fluids considered were water/steam, molten salt, and liquid sodium. All gas receiver fluids, such as air or helium, were not considered because of the long line length between the collector field and the plant and the rather poor heat transfer properties of gases. The technology issues associated with receiver fluid selection pertain to compatibility with the turbine cycle, the need for storage, operational characteristics, development status and risk, technical feasibility, lifetime and manhour characteristics, and safety. Comments relative to these issues are summarized in Table 3-5.

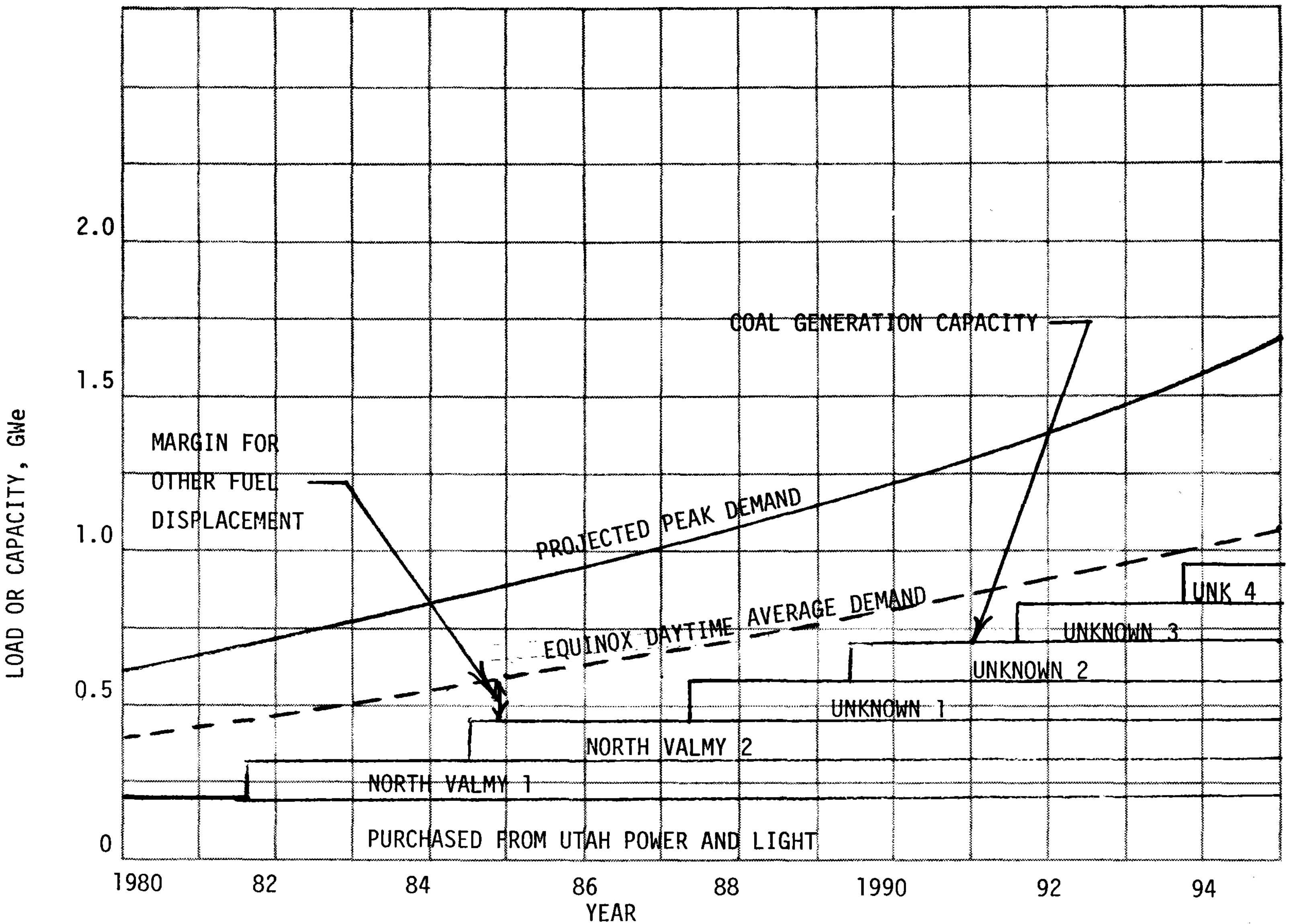


FIGURE 3-4 EFFECT OF COAL GENERATION CAPACITY GROWTH ON FUEL DISPLACEMENT

Table 3-5. Receiver Fluid Technology Status

Issue	Water/Steam	Molten Salt	Liquid Sodium
Reheat Turbine Cycle Compatibility	Requires Fossil Reheat	Good	Good
Buffer Storage	Significant Operational and Economic Penalty	Good	Good
Extended/Deferred Storage	Severe Economic Penalty	Good	Economic Penalty
Operational Characteristics	Complicated by Direct Feed of Receiver Fluid to Turbine	Good, Requires Trace Heating	Good, Requires Trace Heating
Development Status/Risk	Can Build on DOE 10 MWe Pilot Plant or use "Advanced Water/ Steam" designs	In use in Industry, Indicates Moderate Risk. Requires Development.	Requires Development LMFBR Development Limits Risk.
Lifetime/Maintenance	Requires Periodic Tube Cleaning & Water Polishing	May Require Salt Polishing. May Require Selective Tube Replacement. Receiver Feed Pumps May Require Periodic Overhaul.	Requires Sodium Polishing.
Safety	Current Procedures Should be Adequate	May Require Salt Composition Control and Handling Procedures.	Current Procedures Should Be Adequate
Technical Feasibility Issues	Fossil Reheater	None	None

3.3.1 Compatibility With Turbine Cycle

Both liquids are compatible with the reheat turbine cycle. Water/steam alone is not. A fossil reheater would be required. MDAC believes that solar steam reheat in the receiver will ultimately prove to be infeasible because of an inability to adequately control the receiver during diurnal and cloud induced transients.

3.3.2 Need for Storage

Storage is required for buffering system operation and solar/fossil transitions. Storage is also desired for extending hours of operation and providing deferred system operation to optimize the economic value of the electricity generated.

Buffer storage for water/steam can be provided by a steam accumulator. Five to ten minutes of operating time would be needed to enable the fossil boiler to range and maintain turbine load. The volume of an adequate steam accumulator would be 16,000 m^3 (560,000 ft^3). A spherical task of radius 15.6 m (51 ft) would have adequate volume, but would have walls too thick for practical operation.

Buffer storage can also be provided in a manner similar to that being used in the DOE 10MWe pilot plant at Barstow. Steam is routed to a charging heat exchanger when the probability of cloud induced transients is high. The thermal storage fluid flow uses thermal storage to levelize flow rate. Steam is generated at the proper pressure for the admission port. For a reheat cycle, the reheat pressure would be used, and the fossil reheater would raise the storage steam temperature to the required level.

The above process is operationally awkward, degrades efficiency, and restricts hybrid operation. Compared to a simple, two-tank storage system with the liquid receiver fluids, the water/steam storage issues are very much against its use.

Storage for extended operation may not be feasible with water/steam. If it is, it is certainly economically undesirable. The volume and cost of liquid sodium for extended/deferred operation appear to be excessive. This issue is one of the major reasons for selecting molten salt.

3.3.3 Operational Characteristics

Operational characteristics also favor the storable liquid receiver fluids. The water/steam receiver supplies steam directly to the turbine. Since there is no ability to control the solar "firing rate", the normal utility turbine operating mode (boiler following) cannot be used without hybrid operation, the fossil boiler may be severely taxed by the ramping requirements placed on it by the solar receiver. Fossil fuel must be used to operate in a solar-fossil hybrid mode. This results in very undesirable economics.

For solar stand-alone operation with water/steam, the turbine must be controlled to match the solar firing rate. Insolation transients result in turbine loading transients which could shorten turbine life and result in a loss of capacity credit for the repowered plant.

Operation with an intermediate fluid is simple. The solar energy is collected at the rate at which it is available. All energy goes to storage with no significant losses. Energy is withdrawn from storage at a controllable rate. Normal boiler following control can be used in both hybrid and stand alone operating modes.

3.3.4 Development Status and Risk

A direct scaleup of the single pass to superheat receiver concept used for the DOE 10 MWe Pilot Plant could be used for a water/steam receiver at very low apparent risk. Alternatively, one of the advanced water/steam receiver designs could be used. However, these designs have not been tested. There are development risks associated with all of these approaches, especially as regards reheat. These risks stem from rapid transients and uncontrollable heat load distribution. Extensive development testing will be required to adequately verify these approaches.

Both the molten salt and liquid sodium receiver approaches will also require development testing. Neither have the inherent problems of water/steam, but both will present problems of control, balancing, and lifetime/maintenance. The past and current DOE development programs should limit or completely negate the development risk.

3.3.5 Technical Feasibility

There are no clearly defined receiver technical feasibility issues for any of the three receiver fluids. The fossil reheater does present a feasibility issue for the water/steam system. In a normal boiler, there is a radiant heating section with rather high heat fluxes absorbed on a water cooled unit. The fossil reheater has no such highly cooled zones. Design for the low internal heat transfer coefficient of the reheater tubes has been a severe problem in the past in that it is very difficult to achieve predictable, acceptable heat fluxes in a readily fabricated configuration.

3.3.6 Lifetime and Maintenance

There do not seem to be any maintenance issues of great importance. A water/steam receiver will require periodic acid cleaning of the boiler tubes. A single pass to superheater water/steam receiver requires a full flow demineralizer. The other receivers will require some degree of receiver fluid chemistry maintenance. Absorber surfaces may require recoating.

The only clearly identified maintenance significant items have to do with the corrosion rates for the molten salt. The thin wall receiver tubes may be subject to corrosion requiring periodic replacement. Replacement, if required, is expected to be limited to the highest temperature panels. Seals and bearings for the receiver feed pumps may also be degraded by the salt corrosion and require periodic replacement. Neither of these problems is expected to cause extensive maintenance costs.

3.3.7 Safety

System safety does not appear to be an issue. There are safety procedures and standards for high pressure steam, towers, molten salt baths, and liquid sodium. These should all be adaptable to their respective technologies in central receiver applications. No critical or unusual safety problems are foreseen. The safety provisions expected to be required for the molten salt are defined in the CAL-OSHA* code. The molten salt compositon should be controlled to prevent an excess concentration of nitrite. The maximum salt bulk temperature must be limited to prevent exothermic decomposition. The CAL-OSHA provisions

*California Administration Code Title 8 Chapter 4 Division of Industrial Safety Subchapter 7, General Industry Safety Orders, Paragraph 5203 Molten Salt Baths, p. 439, release date July 15, 1978.

require temperature to be limited to no more than 649°F. Handling procedures need to be enforced for the solid salt to avoid the possibility of explosion. These procedures include not storing the solid material in the same area as the liquid is used, and preventing contamination by any organic material. Other provisions applicable to high temperature liquids under pressure must also be observed.

3.4 SYSTEM CONFIGURATION

The above system level trade studies and analyses were used to define the general system configuration. Additional trade studies and selections were conducted to define the system baseline configuration. This baseline is summarized below, together with the selection rationale or trade studies used to define the baseline design.

3.4.1 Design Condition Selection

The design point for the system was selected to be equinox noon. This choice was based on previous experience which indicates that peak receiver power probably will occur about this time of year.

The University of Houston has developed a clear day insolation model estimation technique. The method considers regional and seasonal models of upper and lower atmosphere turbidity and water vapor content. The University of Houston recommended equinox noon insolation level is 1008 W/m^2 at Yerington. Site measurements confirm that the design insolation should be over 1 kW/m^2, and the University of Houston recommendation was adopted.

The design condition for the thermal storage unit is selected as a nominally clear summer day. Off nominal design conditions at 0900 on summer solstice and 1000 on winter solstice will be considered for the receiver.

3.4.2 Collector Field Optimization

Using the RCELL program series, an optimization for a 223 m tower has been completed. Table 3-6 shows significant data from this optimization.

3.4.3 Heliostat Selection

The repowered plant conceptual design is able to use any second generation heliostat which meets DOE specifications. Where specific characteristics are required, the MDAC second generation heliostat is assumed.

Table 3-6. Collector Field Optimization Results

	Optimization	Comments
Absorbed Power (MWth)	330	Design power, equinox noon
Tower Height (m)	223	Slightly taller tower would be optimum. but results are with 1 percent of optimum cost
Total Reflector Area (m^2)	474,549	Corresponds to 8,411 heliostats at 56.42 m^2 each
North/South Extent of Field (km)	1.537	
East/West Extent of Field (km)	1.722	

3.4.4 Receiver Tower

A trade study was conducted to choose among concrete, free standing steel, and tubular steel towers. The three towers were found to be essentially equal in cost by Stearns-Roger estimators. The concrete tower is designed by seismic loads for Zone III, and the steel towers are designed by wind loads.

All three designs have small deflections at the tower top for operating winds. Concrete was selected as being the lowest risk approach.

3.4.5 Receiver Unit

The receiver unit was chosen to be a partial cavity. A sketch of the selected configuration is shown in Figure 3-5.

A four zone aim strategy was developed for the collector field, as shown in Figure 3-6, and flux maps were generated for the conceptual design using CONCEN. The peak absorbed flux on the external absorber portion of the receiver is about 350 kW/m^2. The side wall peak is 540 kW/m^2 at summer noon and 640 kW/m^2 at winter, 9 AM. The cylindrical section peak is about 630 kW/m^2. Some further aim strategy optimization would be able to further reduce the cylindrical section and side wall peak flux, but this is not felt to be necessary for a conceptual design.

3.4.6 Receiver Fluid Loop

The receiver fluid loop includes all of the piping between the thermal storage unit and the receiver, as well as pumps, valves, and other such equipment.

The hot salt pipe is 0.30 m (12 in.) diameter, 316 stainless steel pipe of minimum gage. The small diameter is used to allow viscous dissipation to reduce the head at the thermal storage unit to ambient. A drag valve at the base of the tower maintains a positive gage pressure at the top of the receiver.

The cold salt pipe is carbon steel, 0.41 m (16 in.) diameter, and minimum gage. Two staged, centrifugal receiver feedpumps provide the head for flow up the tower and through the receiver.

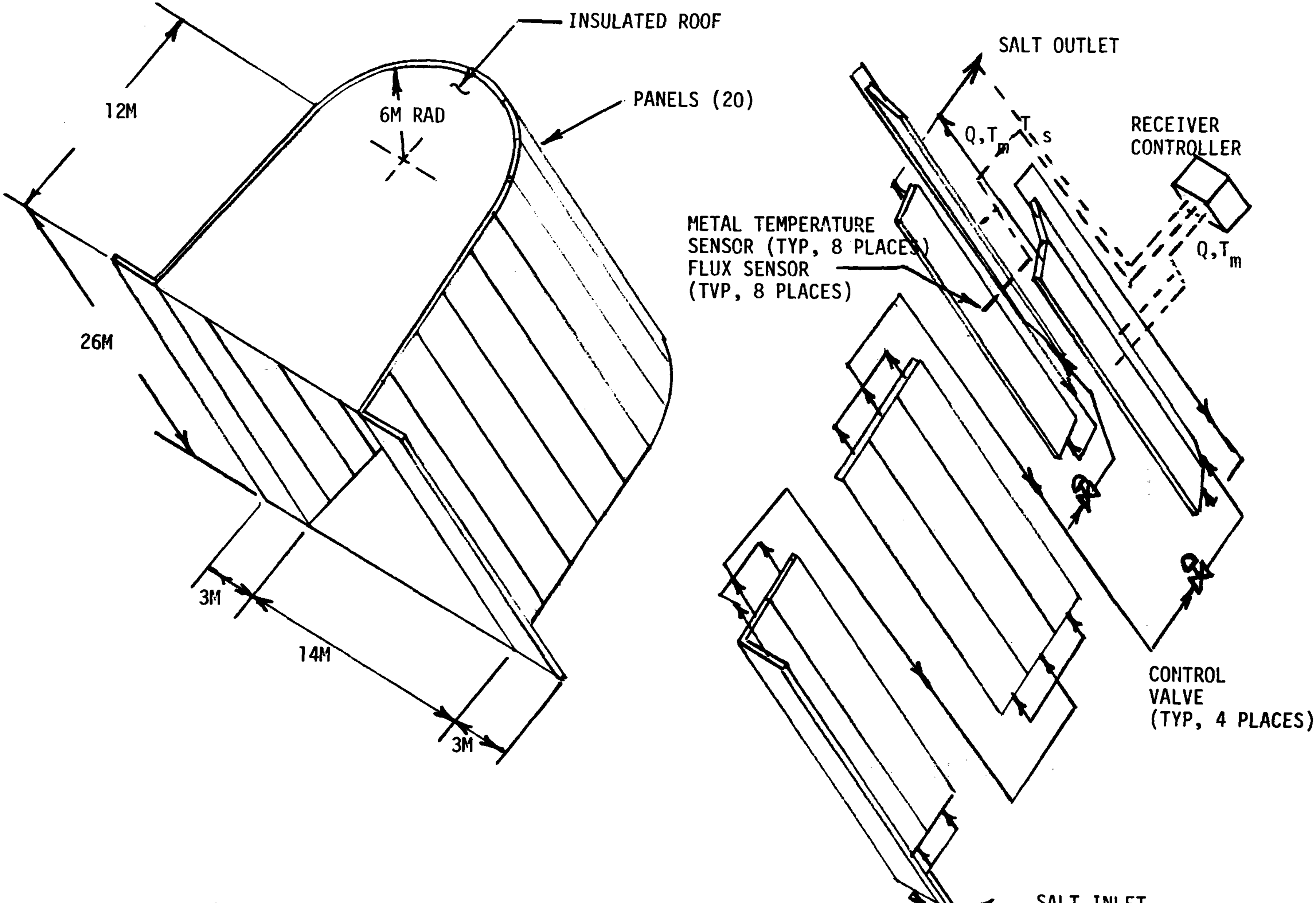


FIGURE 3-5 PARTIAL CAVITY RECEIVER

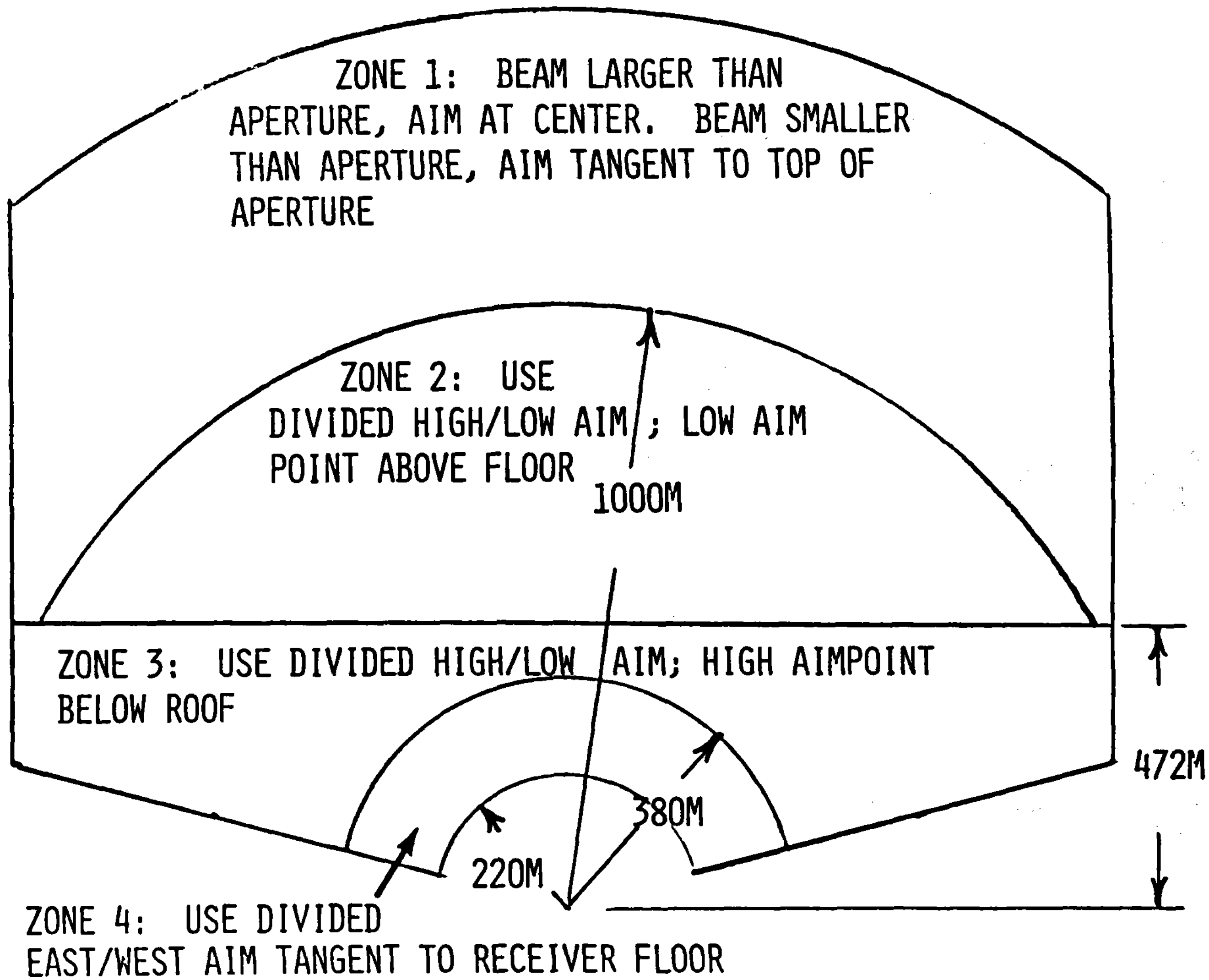


Figure 3-6 Receiver Aim Strategy

All salt lines are fully insulated and trace heated. Expansion loops are used as required.

3.4.7 Thermal Storage Unit

A trade study was conducted to determine the most cost effective approach to the thermal storage unit. Candidates were dual medium thermocline, two tank-external insulation, and two tank-internal insulation.

The dual medium thermocline was found to have by far the lowest cost. Comparative cost data are shown in Table 3-7. Costs are shown for both 24¢/kg and 79¢/kg salt costs, representing commercial and MIL-STD grade salts.

Development risks for the thermal storage unit were assessed and the following risk areas were identified as affecting the choice between dual medium thermocline and two tank:

- Commercial grade salt corrosion
- Suitable iron ore availability
- Thermal cycling stresses in the dual medium tankage
- Iron ore/salt compatibility
- Hot side pumping for two tank concepts

The attractive cost of the dual medium thermocline system suggests that such a system should be developed. However, a two tank, external insulation system was chosen on the basis of acceptable cost and low risk.

Both tanks and all interconnect piping are electrically heated. A level regulated sump pump in a separate tank is used for salt circulation.

3.4.8 Heat Exchangers

A trade study was conducted to select the type and method of operation of the steam generation heat exchangers.

All heat exchangers were chosen to be single pass, floating head, tube and shell type on the basis of lowest cost and technical risk.

Table 3-7. Thermal Storage Unit Cost Estimates
(10^6 1980 Dollars)

	Thermocline Tanks			Two Tank**	
Cost Element	One Tank	Two Tanks	Three Tanks	External Ins.	Internal Ins.
Tank 304 SS	1.24	1.38	1.49	2.38*	2.00*
Foundation	0.16	0.16	0.16	0.26	0.27
Insulation	0.38	0.45	0.50	0.84	0.84
Media High	2.50	2.50	2.50	5.90	5.90
Low	0.8	0.8	0.8	1.85	1.85
Piping	--	0.04	0.07	--	--
TOTAL High	4.28	4.53	4.72	9.38	9.02
Low	2.58	2.83	3.02	5.33	4.97

*Low carbon steel may be used on cold tank with external insulation and on hot tank with internal insulation.

Both the superheater and reheater will be operated counterflow. A salt bypass to the evaporator is recommended for reheater steam outlet temperature control. Steam attemporation will be used for reheater temperature control trim.

A salt inlet temperature of 563°C (1045°F) was found to be satisfactory for generating 540°C (1000°F) steam.

A parallel flow heat exchanger was selected for the evaporator. Simplified salt piping and better natural circulation were the primary considerations. The evaporator has an integral, vertical steam drum at the top.

A counterflow preheater was added to the heat exchanger set in order to reduce the salt outlet temperature to 287°C (550°F).

A typical heat exchanger unit design is shown in Figure 3-7.

3.4.9 Control

The solar equipment master control subsystem can be designed to be essentially independent of the existing plant control. The collection of heat is decoupled from the generation of steam by the thermal storage unit capacity.

The baseline operating mode is hybrid operation. The solar steam generator is operated at an operator selected set point. The fossil plant operates in its normal boiler following mode.

A simplified control interface schematic is shown in Figure 3-8. A minimum fossil boiler firing rate is assured by a cross-feed of fossil boiler firing rate to the controller. Primary control of the turbine inlet pressure is left to the fossil boiler.

In a solar-only operating mode, capability for both turbine following and boiler following control modes included in a coordinated control.

The master control will also supervisr solar startup, shutdown, and setpoint change transients.

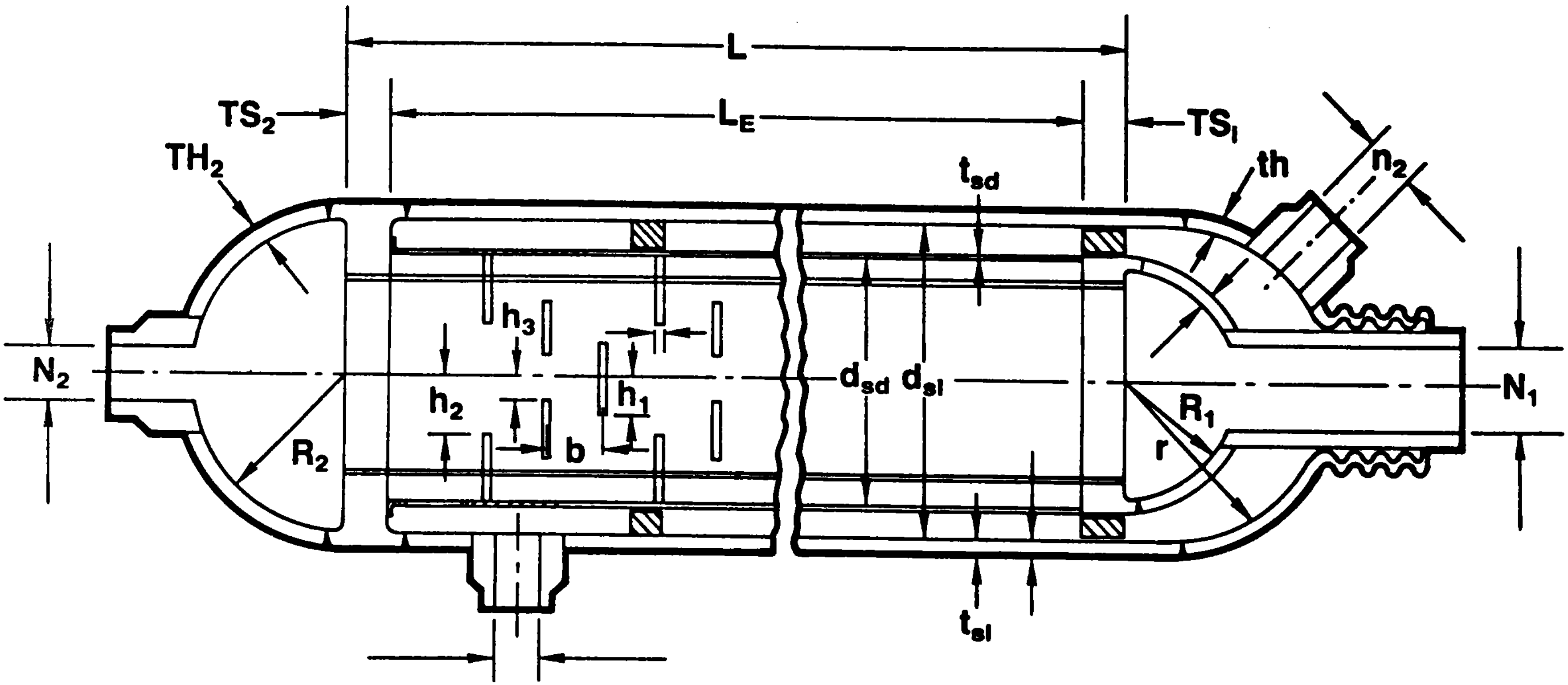


Figure 3-7 Typical Steam Generator Heat Exchanger

SIMPLIFIED BOILER FOLLOWING

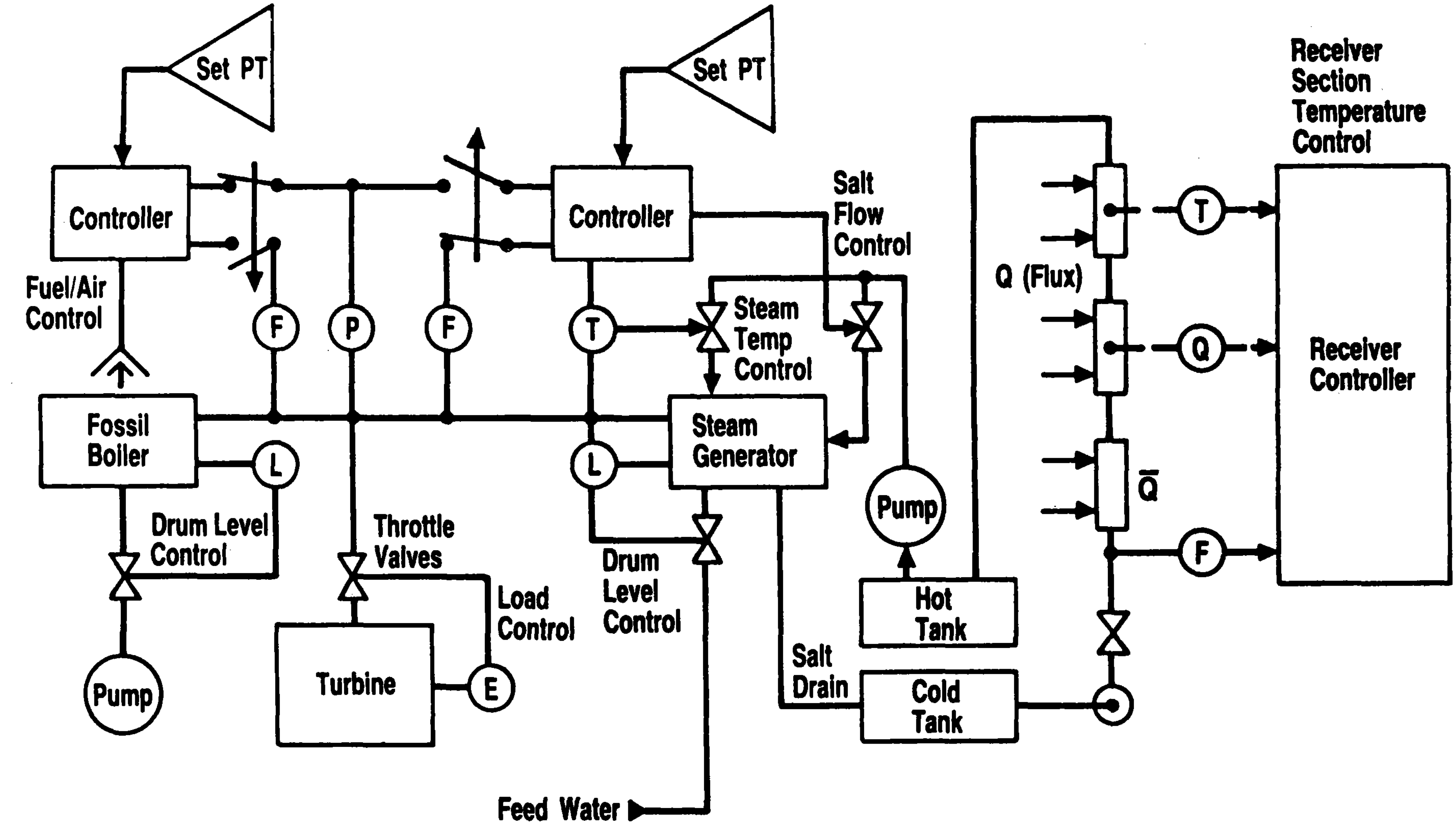


FIGURE 3-8 CONTROL MECHANIZATION FOR PLANT OPERATION

3.4.10 Interfaces

Interfaces are identified with the feedwater line, main steam line, and hot and cold reheater lines. Simple tee joints appear to be adequate for these interfaces. Separate mass flow control valves on the feedwater and cold reheater lines will be required. All solar steam equipment will be designed to ASME code requirements.

Electrical power will be required to operate the collector field, the salt pumps, and the instrumentation and control equipment. These parasitic loads will total about 6,000 kVA.

Section 4

CONCEPTUAL DESIGN

This section presents a system level description and characterization of the conceptual design for the repowering of SPPCo's Ft. Churchill Unit 1. Detailed subsystem level descriptions are contained in Section 5.

4.1 SYSTEM DESCRIPTION

An artist's sketch of the repowered plant is shown in Figure 4-1, superimposed on an aerial photograph of the site provided by Sandia Laboratories. The collector field, tower and receiver are on the left. The existing Ft. Churchill Units 1 and 2 are on the right, next to the cooling ponds. Switch yards are located to the north and west of the existing units and connect into the two transmission lines which tie the Ft. Churchill plant into the grid. Three oil storage tanks located to the northwest. Behind the existing units are the thermal storage and steam generator units.

The baseline operating mode for the repowered plant is hybrid operation. In this mode, Unit No. 1 will be repowered for hybrid operation with the fossil side operated continuously at at least 37 MWe (gross), and the solar will provide load-following up to 77 MWe (gross) during the high demand periods of the day. In addition, capacity will be provided for up to six hours of thermal storage. The plant would thus deliver up to 77 MWe from solar for up to 18 hours in mid-summer, and would displace about 80% of the fossil fuel annually. The repowered plant can also operate in solar stand-alone and fossil only modes. An option to generate full rated power in the solar stand alone mode seems to be advantageous.

The system layout is shown in Figure 4-2, and the baseline is summarized in Table 4-1. The 130° north field is located to the northwest of the plant, and will occupy about 2.1×10^6 m^2 (520 acres) land area. The collector field will contain 8411 MDAC second generation heliostats at 56.4 m^2 (606 ft^2) each for a total mirror area of 474,500 m^2. The University of Houston has optimized the collector field layout as a radial staggered field.

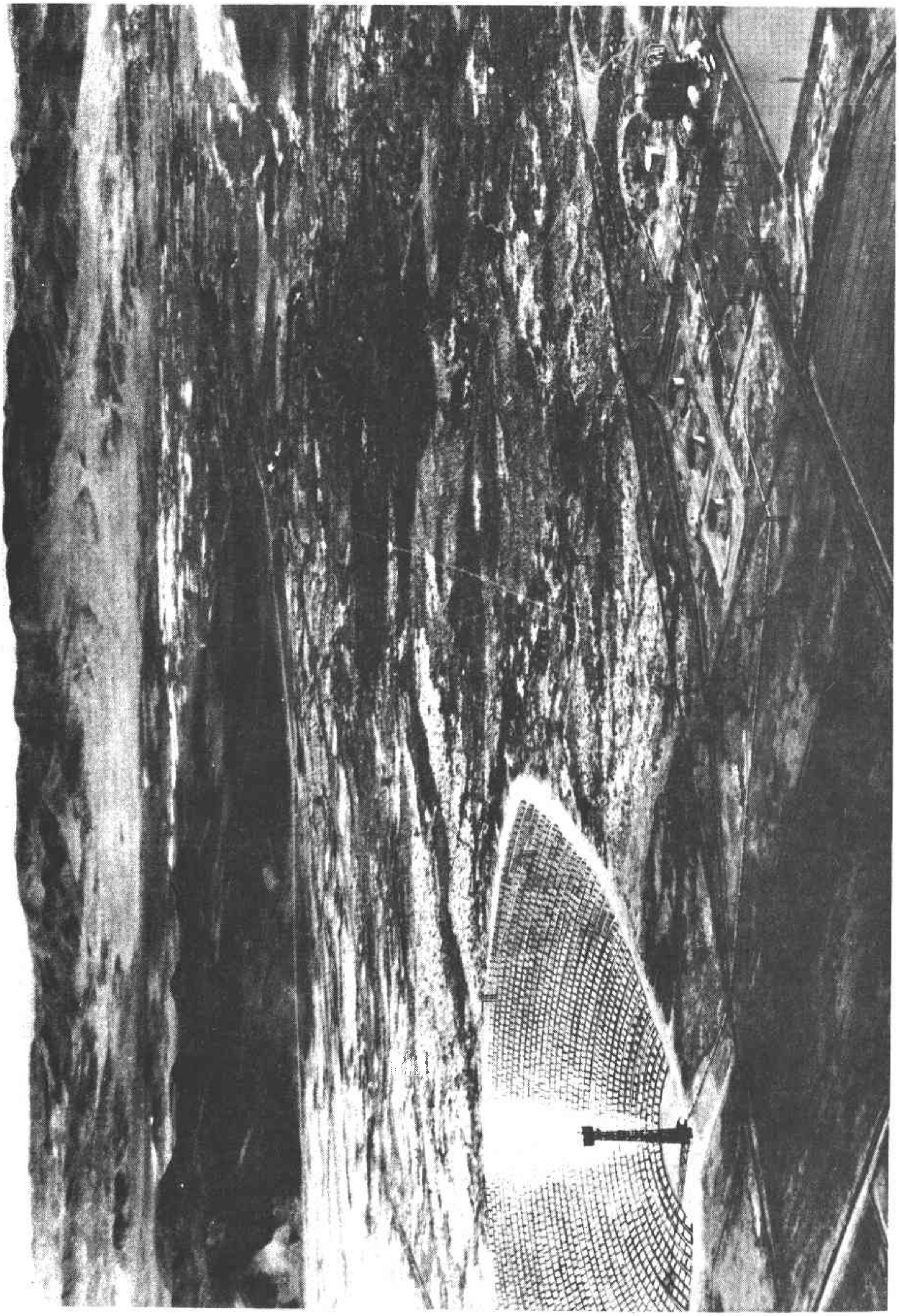


FIGURE 4-1 Artists Rendition Of Repowered Ft. Churchill No. 1

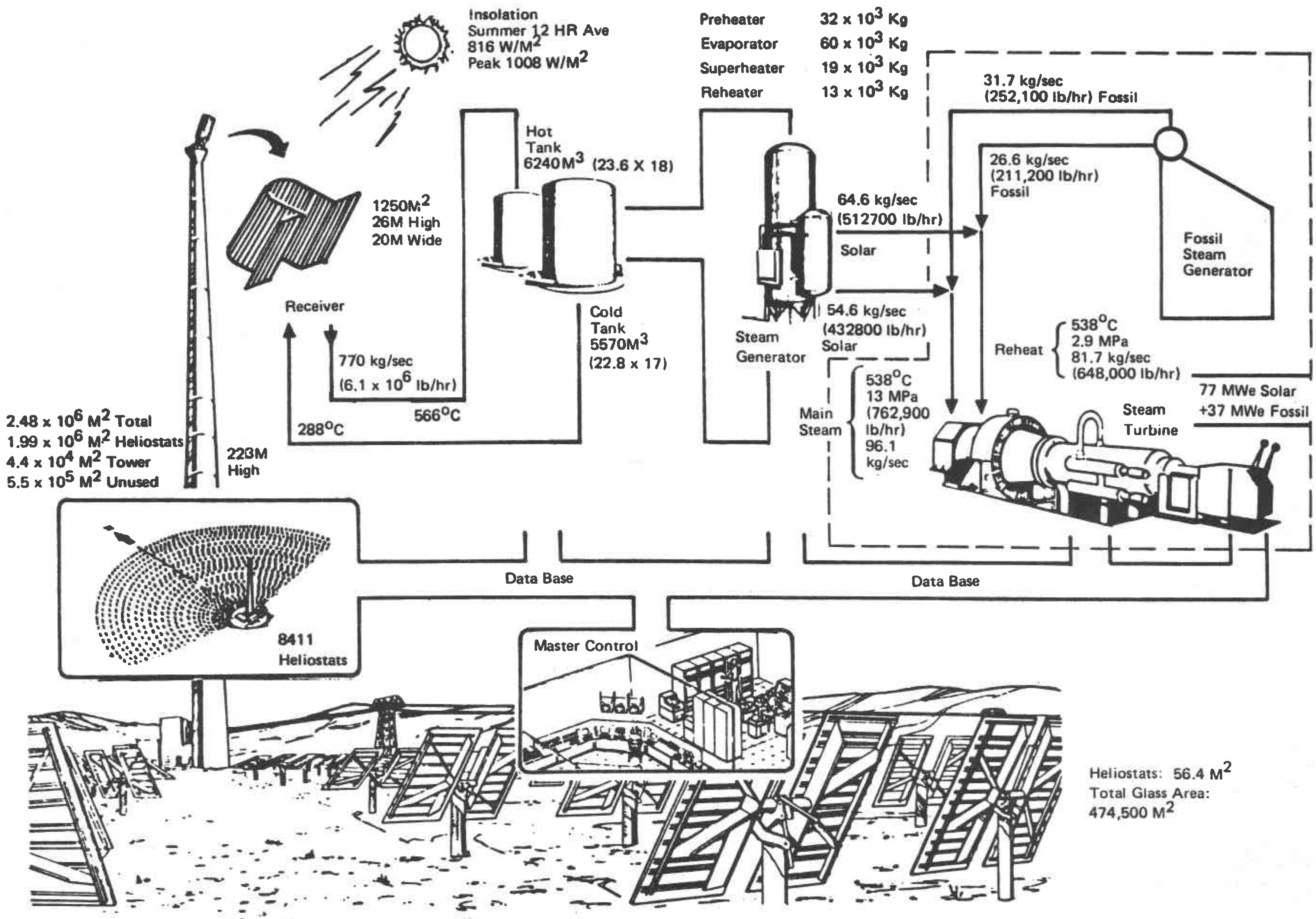


Figure 4-2. Sierra Pacific Power Co. Fort Churchill No. 1

Table 4-1

BASELINE SYSTEM SUMMARY

PLANT	BASELINE SELECTION	RATIONALE
Utility	Sierra Pacific Power Co. Ft. Churchill No. 1	Ideal repowering conditions, equipment in excellent condition, large oil displacement potential, progressive management outlook, high probability of repowering.
System	Rankine cycle with Preheat	Represents majority of systems in the 50-150 MWe size range, large commercial potential with other utilities, low risk building on Barstow technology.
Mode	Hybrid with Solar stand-alone option	Provides maximum design data, includes Solar only, Solar/Fossil Hybrid and Fossil Only scenarios, greatest flexibility for 1985 requirements, large potential oil displacement, ease of matching load requirements.
Turbine Cycle	Reheat	High performance in large power size, typical of late model system with equipment in good shape. Represents largest commercial market for fuel displacement. (68,00 + GWe)
Receiver Fluid	Molten Salt	High performance with reheat system. No fossil fuel field reheaters required. Utilizes existing technology with lower risk/cost than sodium system in storage coupled mode.
Field	130° - North	Minimum total system cost for energy collected optimum utilization of land available, shortest piping run to plant, utilizes Barstow technology.
Receiver	Partial Cavity	Best cost/performance characteristics, best peak/average flux ratio with North Field, minimizes aiming sensitivity for Solar Field, minimum receiver weight for output. High receiver efficiency.
Tower	Concrete	Minimum risk
Thermal Storage	Two Tank	Minimum project risk, simple operation completely decouples systems for Solar-Only, Hybrid or Fossil-Only operation.
Heliostat	Second Generation Design	Minimum cost for equivalent performance, represents commercial production unit in 1985, utilizes latest Solar technology.

The center of the receiver aperture is 223 m above the ground level, and the receiver is supported on a concrete tower. The tower is 24.2 m (79.5 ft) in diameter at the base and 20.3 m (66.7 ft) in diameter at the top. The wall thickness tapers from 0.38 m (15 in.) at the base to 0.33 m (13 in.) at the top. A slab foundation is preferred for withstanding seismic loads.

The partial cavity receiver design uses a molten salt working fluid. The front and side walls of the receiver are arranged in series/parallel sets of uncontrolled preheater panels. The cylindrical portion contains four parallel circuits of two panels each. Each circuit is series connected to provide an adequate heated path length and load. The outlet temperature is controlled to 566°C (1050°F) by feedback of outlet temperature, incident heat flux, and back wall metal temperature.

The receiver fluid is a eutectic mixture of sodium and potassium nitrates sometimes known as "drawsalt." The salt enters the receiver at 233°C (550°F). It is heated to an average or bulk temperature of 566°C (1050°F) in the receiver. The maximum temperature is well within the operating limit required by the California Occupational Safety and Health Administration Code of 649°C (1200°F).

The thermal storage unit baseline is an externally insulated, two tank unit. The hot tank is 23.6 m (77.4 ft) in diameter and 18 m (59 ft) high. The cold tank is 22.8 m (74.8 ft) in diameter and 17 m (55.8 ft) high. The cold salt line from the thermal storage cold tank to the receiver inlet is 0.41 m (16 in.) in diameter. The hot salt line from the receiver outlet to the thermal storage hot tank is 0.3 m (12 in.) in diameter.

The steam generator consists of four elements: a feedwater preheater, a combination evaporator and steam drum, a superheater, and a reheater. Molten salt from the hot storage tank is pumped to the steam generator. The salt flows in parallel to the reheater and superheater. A salt bypass line is used to control the reheater outlet temperature. The salt streams are then manifolded and flow through the evaporator and preheater in series.

The present plant has a dual, manual/automatic, turbine lead (boiler following) control system located at the site. The repowered plant will retain the present automatic control (having manual override), and will add a separate automatically coordinated control system for the solar equipment. The plant operator will provide the primary control interface between the fossil and solar equipment. Since the proposed system can be operated as a hybrid or as a solar stand-alone, the system integration is simplified. The steam flow interfaces are located in the high and intermediate pressure turbine inlet lines, and flow control valves modulate the feedwater and cold reheat steam flow to the solar and fossil-fired sides to provide the correct mass flows for the grid required turbine power.

4.2 FUNCTIONAL REQUIREMENTS

The requirements summarized in this section are defined more completely in Appendix A "System Requirements Specifications."

Functional requirements include design point, which shall be at local noon for a clear equinox day. The direct, normal insolation level at the design point shall be 1008 W/m^2.

The receiver design point shall be the same as the system design point. In addition, an off nominal design point of winter solstice at 0900 hours shall be used. The off nominal insolation level shall be 840 W/m^2 (Figure 4-7).

The receiver shall be able to produce rated outlet temperature in the molten salt (566°C, 1050°F) whenever the sun is more than 10° above the horizon and the direct, normal insolation is greater than 200 W/m^2.

4.2.2 Performance Requirements

At the system design point, the collector shall direct 345 MW_{th} incident power on the receiver. The receiver shall absorb and retain 330 MW_{th}.

The receiver outlet temperature shall be maintained at 566°C (1050°F) $\pm$ 5.5°C (10°F) throughout the range of insolation levels, receiver powers, and receiver incident flux levels implicit in the design point requirements of paragraph 4.2.1.

The thermal storage unit shall be capable of storing 1150 MWh_{th} for extended or deferred operation with a loss rate of less than 1% in 24 hours, after equilibrium has been established with the ground.

4.2.3 Instrumentation and Control Requirements

The solar equipment shall all be controlled from a single operator control station colocated with the existing plant control room. The solar master control will access such plant control data as are required to perform a coordinated control. However, no functional modifications will be made to the existing plant controller.

The solar Master Control will coordinate the collector field and receiver to collect as much solar energy as is available during sunlight hours. Steam will be generated at a set point on operator demand in the hybrid mode. Provision shall be included for boiler following, solar stand alone operation to a turbine set point selected by the operator in the existing plant control console.

The solar master control will also supervise the safe startup and shutdown of the solar equipment and the transitions into and out of hybrid operation. The solar master control will also exercise supervision of the non-operational modes. The transition and non-operational modes shall be supervised to prevent hazard to personnel, prevent damage to equipment, and to facilitate return to operational modes.

4.2.4 Lifetime and Availability Characteristics

The system design service life shall be 30 years. Scheduled maintenance shall be minimized and scheduled replacement shall be limited to:

Collector Subsystem - None

Receiver Subsystem - Receiver absorber panels in the cylindrical section, the receiver feed pumps, and the control valves may be scheduled for periodic replacement, if such replacement is shown to be cost-effective.

Thermal Storage Subsystem - Salt circulation pumps and control valves may be scheduled for periodic replacement, if such replacement is shown to be cost effective.

Master Control Subsystem - None

The solar equipment shall be designed for system availability greater than 0.96, exclusive of solar insolation outage.

As a maintainability design goal, all subsystems shall be designed so as to permit repair of critical failures by sunrise on the following day. Exceptions will be permitted for critical failures which are rare and do not contribute significantly to system unavailability. Exceptions are also permitted for failure modes for which longer repair times are more cost effective or damage to other components may result from rapid repair (e.g., excessive cooling and reheating rates of hot equipment).

4.3 DESIGN AND OPERATING CHARACTERISTICS

The design and operating characteristics required of the repowered plant are summarized in this section. Table 4-2 provides design and operating characteristics for system design and interface control.

4.3.1 Operating Modes

The system operating modes are:

(a) Fossil only - The plant produces electricity from steam generated in the fossil boiler, only. The output power level ranges from 40 to 115 MWe gross. Solar energy may be collected and stored in the thermal storage unit during fossil only operation.

(b) Hybrid - The plant produces electricity from steam generated in both the fossil boiler and the solar steam generator, simultaneously. The output power level ranges from 37 to 100 MWe gross from the fossil boiler and from 15 to 77 MWe gross from the solar boiler. The combined power level is 52 to 115 MWe gross. Hybrid operation will include operation from storage, with no solar energy collection.

(c) Solar only - The plant produces electricity from steam generated in the solar boiler, only. The output power level ranges from 15 to 77 MWe gross. Solar only operation will include operation from storage, with no solar energy collection.

TABLE 4-2

DESIGN/OPERATING CHARACTERISTICS (Page 1 of 3)

Collector Field Characteristics	
Number of Heliostats -	8411
Heliostat Mirror Area -	56.42 m^2 (606 ft^2)
Total Mirror Area -	474,549 m^2 (5,097,066 ft^2)
Collector Field Ground Area -	2.1 x 10^6 m^2 (520 acres)
Tower Height to Receiver Centerline -	223 m (731 ft)
Average Parasitic Power -	311 kW
Peak Parasitic Power -	1200 kVA
Receiver Characteristics	
Receiver Type -	Partial Cavity
External Absorber Area -	150 m^2 (1600 ft^2)
Cavity Absorber Area -	1100 m^2 (11800 ft^2)
Number of Absorber Parcels -	20
Number of Panels Controlled -	8
Control Parameters Measured -	Incident Flux, Receiver Fluid Temperature, Metal Temperature, Pressure
Absorber Tube Diameter -	25 mm (1 in.)
Absorber Tube Wall Thickness -	1.65 mm (0.065 in.)
Absorber Tube Material -	Incoloy 800 (May change to 304SS)
Receiver Fluid -	Molten Salt, 47 Weight Percent $NaNO_3$ 53 Weight Percent KNO_3
Inlet Temperature -	288°C (550°F)
Outlet Temperature -	566°C (1050°F)
Maximum Film Temperature Goal -	593°C (1100°F)
Current Maximum Film Temperature -	604°C (1120°F)

TABLE 4-2 DESIGN/OPERATING CHARACTERISTICS (Page 2 of 3)

Design Point Salt Flow Rate -	770 kg/sec (6.1 x 10^6 lb/hr)
Receiver Feed Pump Type -	Two Half Flow, Motor Driven Centrifugal Pumps
Peak Heat Flux Goal -	0.6 MW/m^2
Current Design Point Peak -	0.627 MW/m^2
Gross Receiver Unit Mass - (Includes Receiver Fluid)	340,000 kg (750,000 lb)
Support Structure Mass -	682,000 kg (1.5 x 10^6 lb)
Receiver Parasitic Power -	3730 kW_e
<u>Thermal Storage Unit Characteristics</u>	
Thermal Storage Unit Type -	Two Tank, External Insulation
Energy Storage Capacity -	1150 MWh_{th}
Storage Duration at Design Point -	6 hours
Total Receiver Fluid Mass -	4.7 x 10^6 kg (21 x 10^6 lb)
Salt Flow Rate to Steam Generator -	420 kg/sec (3.3 x 10^6 lb/hr)
Salt Circulation Pump Type -	Two Half Flow, Motor Driven, Cantilever Pumps
Salt Inlet Temperature -	566°C (1051°F)
Salt Outlet Temperature -	566°C (1050°F)
Tank Construction Material -	304 Stainless Steel
Hot Tank Insulation Type and Thickness	Perlite, 0.61m (24 in)
Cold Tank Insulation Type and Thickness	Perlite, 0.38m (15 in)
Hot Tank Foundation Type	Insulating Concrete Slab
Cold Tank Foundation Type	Insulating Concrete Slab
Thermal Storage Subsystem Parasitic Power-	350 kW_e
<u>Steam Generator Characteristics</u>	
Number of Heat Exchangers -	Four (Superheater, Reheater, Evaporator, Preheater)

TABLE 4-2 DESIGN/OPERATING CHARACTERISTICS (Page 3 of 3)

Heat Exchanger Type -	Counterflow, Straight Tube and Shelf for Superheater, Reheater and Preheater
Evaporator Heat Exchanger Type -	Parallel Flow, Tube and Shell with Integral Steam Drum
Salt Inlet Temperature -	560°C (1050°F)
Salt Outlet Temperature -	288°C (550°F)
Feedwater Inlet Temperature -	238°C (460°F)
Steam Outlet Temperature -	538°C (1005°F)
Evaporator/Superheater Steam Flow Rate -	64.7 kg/sec (512,730 lb/hr)
Reheater Steam Flow Rate -	54.6 kg/sec (432,550 lb/hr)
Preheater Inlet Pressure -	13.98 MPa (2028 psia)
Superheater Outlet Pressure -	13.58 MPa (1970 psia)
Reheater Inlet Pressure -	3.11 MPa (451 psia)
Reheater Outlet Pressure -	3.00 MPa (435 psia)
Reheater/Superheater Tube Material -	Incoloy 800 (May use 304 S.S.)
Evaporator/Preheater Tube Material -	304 S.S.
Shell Material -	304 S.S.
Superheater/Reheater Steam Flow Control -	Mass Flow Feedback in Hybrid Operation, Pressure Feedback in Stand Alone Operation
Superheater Outlet Temperature Control -	Salt Flow Regulation
Reheater Outlet Temperature Control -	Salt Bypass Regulation/Inlet Attemporation
<u>Existing Plant Characteristics</u>	
Fuel Type -	#6 Fuel Oil, Natural Gas
Turbine Type -	Single Reheat
Turbine-Generator Efficiency -	0.426 (8012 Btu/kWh)
Gross Plant Efficiency, Oil/Gas -	0.350 (9765 Btu/kWh)
Heat Rejection -	Cooling Pond

In addition to the steady state operating modes, there are transition modes (solar plant startup and shutdown and solar/fossil transition) and non-operational modes (hot standby, cold shutdown, and emergency stop).

4.3.2 Flow Diagrams

The piping and instrumentation diagram (P&ID) is shown in Figure 4-3. Beginning with the condenser in the lower right hand corner, the water/steam flow is as follows:

Makeup - Water is added to the condenser hot well to maintain condensate level.

Condensate - Two half flow condensate pumps raise the feedwater pressure to the deaerater pressure.

L. P. Heaters - Two heat exchangers preheat the feedwater with uncontrolled steam extraction from the low pressure turbine. LP5 discharges to the condenser, and LP4 discharges to LP5.

Deaeration - Feedwater flows into the deaerater through a level control valve. Air is removed from the feedwater by blowdown. Heat is supplied by uncontrolled extraction from the intermediate pressure turbine exhaust.

Boiler Feed - Two half flow boiler feed pumps raise the feedwater pressure to that required for boiler feed.

H. P. Heaters - Two high pressure feedwater preheaters raise the feedwater temperature to 238°C (460°F). HP2 uses steam from the intermediate pressure turbine and discharges to the deaerater. HP1 uses high pressure turbine exhaust and discharges to HP2.

Boiler Feed - The feedwater line is divided by inserting a tee. One branch goes to the fossil boiler and the other to the solar steam generator. Both branches use steam drum level sensing to regulate feedwater flow.

Solar Preheater - The feedwater to the preheater is mixed with water from the steam drum to raise the temperature to 260°C (500°F) to prevent the possibility of salt freezing in the preheater. The preheated feedwater returns to the steam drum.

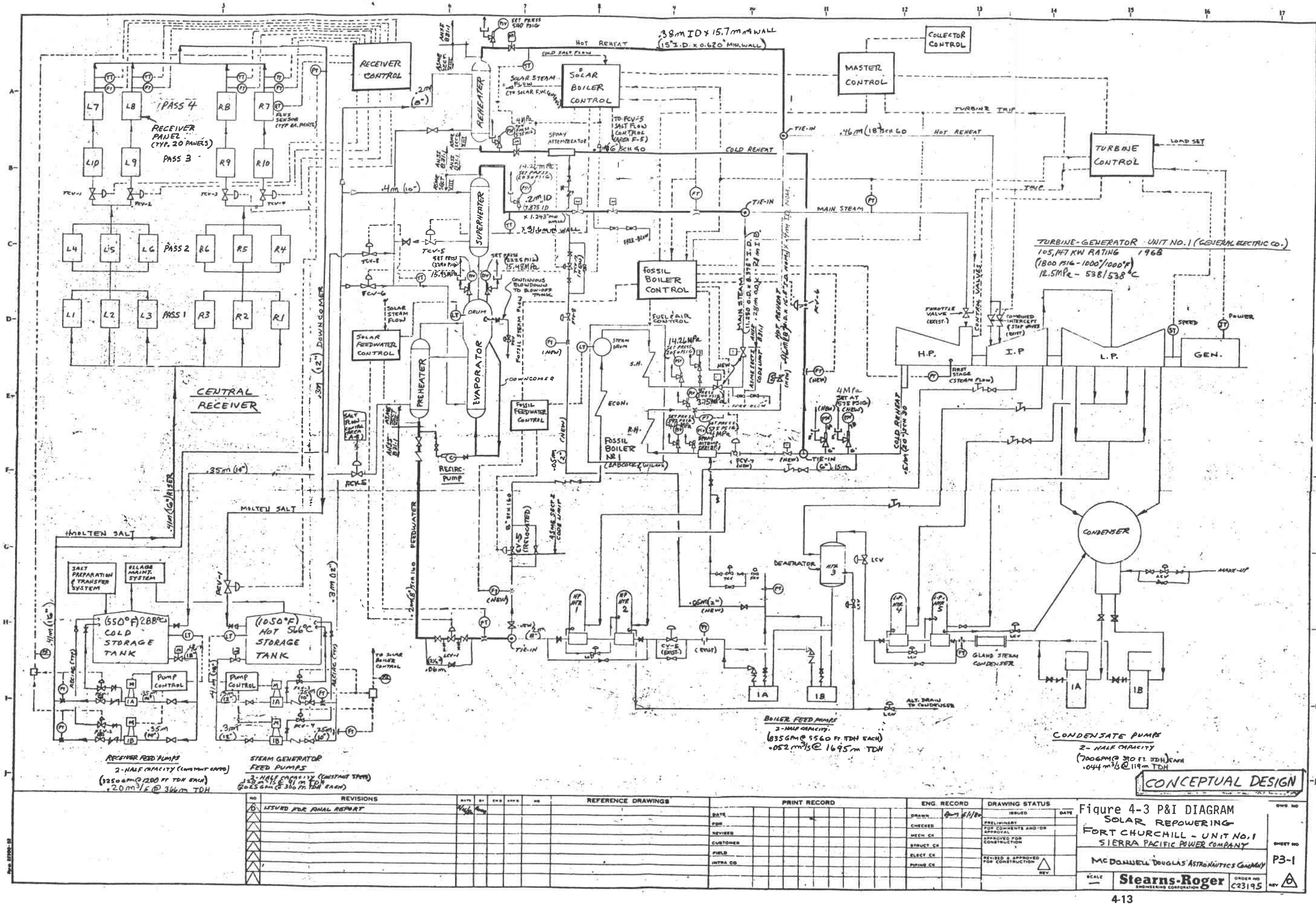


Figure 4-3 P&I DIAGRAM

Solar Boiler - The natural circulation solar heat exchanger generates low quality steam in parallel flow. The integral drum separator separates the steam from the feedwater and routes the dry steam to the superheater.

Solar Superheater - The counter flow heat exchanger raises the steam temperature to 541°C (1005°F). An outlet pressure safety valve limits the outlet pressure to 14.2 MPa (2065 psia). There is a shutoff valve in the main steam line for fossil only operation.

Fossil Boiler - The fossil boiler is not changed. There is a shutoff valve added to the main steam line for solar only operation. The solar and fossil main steam lines are joined in a tee and feed the high pressure turbine.

Cold Reheat - Steam from the exhaust of the high pressure turbine flows through a new back pressure safety valve which limits the line pressure to 4.1 MPa (590 psia). The cold reheat line is divided and both fossil and solar branches go through flow apportioning valves. These valves increase the fraction of flow through the solar reheater at low fossil boiler firing rates to maintain reheat temperature.

Solar Reheater - Outlet steam temperature is trimmed by a spray attemporator from HP1. The counter flow heat exchanger reheats the steam to 541°C (1005°F). The reheated steam is joined to the fossil reheated steam. Shutoff valves are provided for fossil only and solar only operating modes. The reheated steam enters the intermediate pressure turbine and is expanded through intermediate and low pressure turbines. The steam exhausts to the condenser.

Beginning with the cold storage tank in the lower left hand corner, the receiver salt flow loop is as follows:

Receiver Feed - The receiver fluid flows to the receiver feed pumps and is boosted to receiver feed pressure. A bypass dump line to the cold tank controls the salt flow rate.

Receiver Preheat - The salt flows to the receiver and is divided into two streams. The left and right hand halves of the receiver operate in the same manner. Three panels are flooded with unregulated salt flow. The outlets of the panels are manifolded and thru second pass preheat panels are flooded. The outlets are again manifolded. Hence, each side of the receiver has two unregulated preheated passes in the series. Each pass consists of three panels in parallel.

Receiver Final Heat - Again, each side of the receiver operates in the same manner. The flow on each side is divided into two regulated streams. Each stream passes through two panels on the cylindrical section of the receiver in series. Outlet temperature is used to trim the flow control valves. Incident flux is used in an inner control loop for fast response. Tube metal temperature is used in an intermediate loop for rapid transient control.

Back Pressure Control - The receiver fluid is brought to the ground in the downcomer. A drag valve is used to control the receiver back pressure and reduce the hot tank inlet pressure to ambient. The downcomer line then dumps to the hot storage tank.

Beginning with the hot tank in the lower left hand corner, the steam generator salt flow loop is as follows:

Circulation - Two half flow circulation pumps circulate salt to the steam generator. Dump lines into the hot tank regulate the flow.

Superheater/Reheater Flow - The hot salt line divides into three lines. One line goes to the reheater, one to the superheater, and one bypasses to the evaporator. Both heat exchangers use counter flow. The bypass line is regulated by TCV-6 to control reheater outlet temperature. A spray attemporator is used to trim reheater outlet temperature. TCV-5 controls superheater outlet temperature.

Evaporator/Preheater Flow - The three flows joint and pass in parallel flow through the evaporator. Parallel flow is used to minimize salt piping, enhance natural circulation, and minimize effects of varying steam flow rates on outlet conditions. The evaporator outlet salt flows to the preheater, then dumps to the cold tank. The bypass line from the cold receiver feed to the hot steam generator feed provides for gradual warmup of the steam generators by the molten salt.

4.3.3 Thermal Energy Balance

The thermal energy balance for the turbine generator cycle shows the flow rate and state point of the steam at various key points in the cycle. The key points are illustrated in Figure 4-4 and described below:

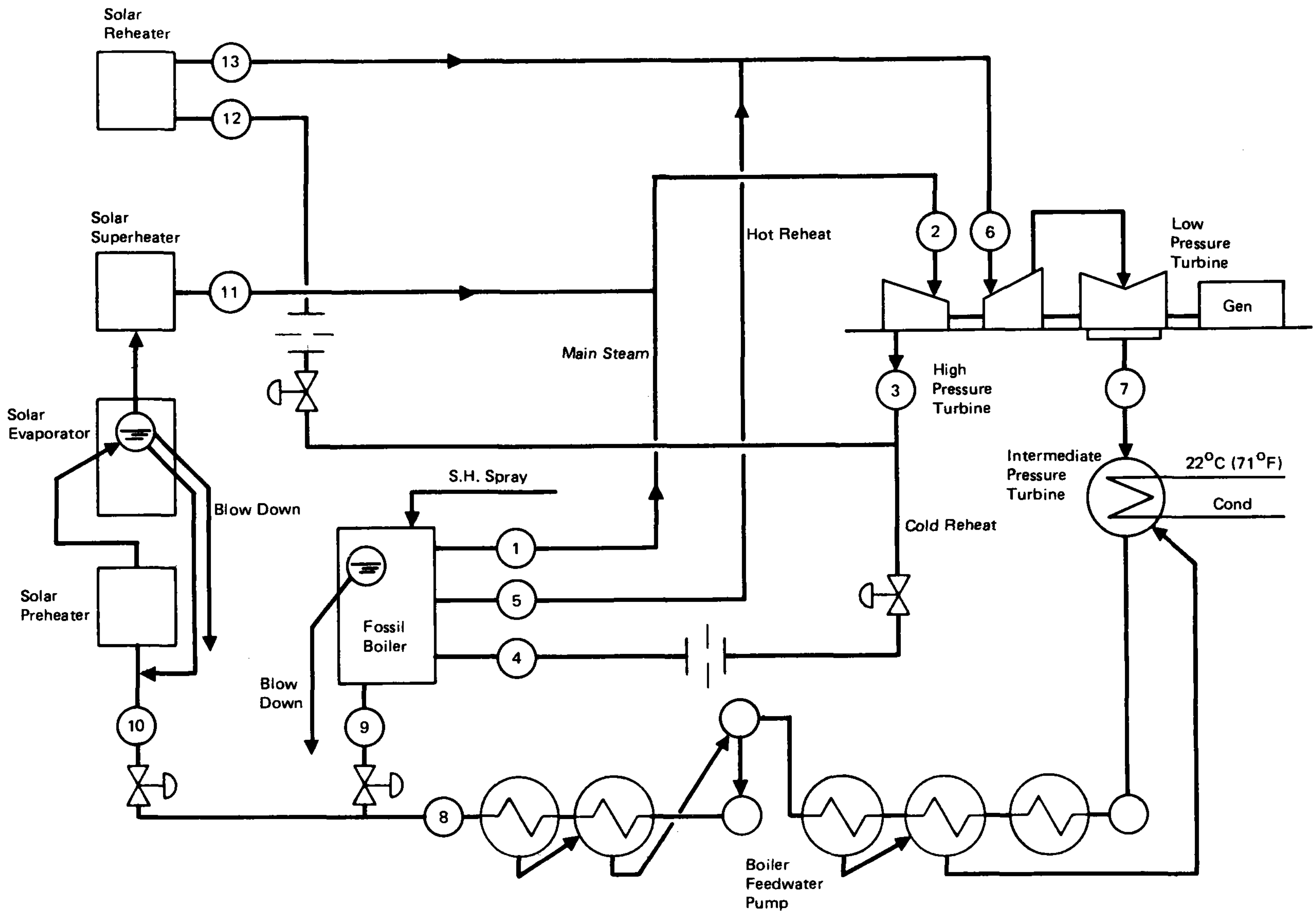


Figure 4-4. Heat Balance Data Points

1 - Main steam flow from the fossil boiler.

2 - Main steam flow to the high pressure turbine, including fossil and solar boiler flows, less heat, mass, and pressure losses.

3 - Exhaust flow from the high pressure turbine.

4 - Cold reheat flow to the fossil boiler.

5 - Hot reheat flow from the fossil boiler.

6 - Flow to the intermediate pressure turbine, including fossil and solar boiler flows, less heat, mass, and pressure losses and flow for feedwater heaters.

7 - Low pressure turbine exhaust to the condenser.

8 - Boiler feedwater preheated and at pressure.

9 - Boiler feedwater flow to the fossil boiler.

10 - Boiler feedwater flow to the solar preheater.

11 - Main steam flow from the solar superheater.

12 - Cold reheat flow to the solar reheater.

13 - Hot reheat flow from the solar reheater.

The flow rate, pressure, temperature, and enthalpy at each of the above points is given in Table 4-3. Separate tabulations for the three full power operating modes are shown.

4.4 SITE REQUIREMENTS

Site requirements pertain to preparation for new equipment, modification of existing facilities, interfaces with the existing plant and equipment, and the location of major items of equipment.

4.4.1 Site Preparation

Site preparation in the collector field is limited to the cut and fill and stripping required to provide drainage for the collector field. Since a drainage ditch is already in place, no additional drainage is expected to be required.

TABLE 4-3
HEAT BALANCE DATA

DATA POINT (Fig. 4.4)	1	2	3	4	5	6	7	8	9	10	11	12	13
FOSSIL ONLY (115 MWe)													
Flow, Kg/sec(lb/hr)	--	96.3 (762,859)	92.4 (731,784)	83.2 (659,278)	--	83.4 (660,278)	67.6 (535,140)	96.0 (760,674)	--	--	--	--	--
Pressure, MPa(Psia)		13.12 (1903)	3.19 (463)	3.19 (463)		2.91 (422)	0.0067 (0.98)	15.89 (2305)					
Temperature, °C(°F)		538 (1000)	342 (648)	342 (648)		538 (1000)	38.3 (101)	238 (460)					
Enthalpy, KJ/Kg ((BTU/LB)		3430 (1478)	3086 (1330)	3088 (1330)		3532 (1522)	2424 (1044)	980 (422)					
HYBRID (77 MWe SOLAR/37 MWe FOSSIL)													
Flow Kg/sec (LB/HR)	31.8 (252,130)	96.3 (762,860)	92.4 (731,784)	26.7 (211,160)	26.7 (211,160)	81.8 (648,050)	67.5 (534,515)	96.0 (760,670)	31.0 (245,380)	65.1 (515,290)	64.7 (512,730)	54.7 (432,850)	54.7 (432,850)
Pressure, MPA(Psia)	13.38 (1940)	13.12 (1903)	3.19 (463)	3.00 (435)	2.97 (431)	2.91 (422)	0.0064 (0.93)	15.89 (2305)	13.55 (1965)	13.98 (2028)	13.58 (1970)	3.11 (451)	3.00 (435)
Temperature, °C(°F)	541 (1005)	538 (1000)	341 (646)	341 (646)	541 (1005)	538 (1000)	37.4 (99.4)	238 (460)	238 (460)	238 (460)	541 (1005)	341 (646)	541 (1005)
Enthalpy, KJ/Kg (BTU/LB)	3433 (1479)	3429 (1477)	3085 (1329)	3085 (1329)	3540 (1525)	3534 (1523)	2424 (1044)	1027 (443)	1027 (443)	1027 (443)	3431 (1478)	3085 (1329)	3540 (1525)
SOLAR ONLY (77 MWe)													
Flow, Kg/Sec(LB/HR)		63.2 (500,350)	61.6 (488,182)			53.4 (422,510)	45.9 (363,820)	63.8 (505,530)		63.8 (505,530)	63.4 (502,350)	53.4 (422,510)	53.4 (422,510)
Pressure, MPa(Psia)		13.12 (1903)	2.23 (324)			1.92 (279)	0.0067 (0.98)	17.03 (2470)		13.83 (2006)	13.44 (1950)	2.16 (313)	2.01 (292)
Temperature, °C(°F)		538 (1000)	317 (602)			538 (1000)	38.3 (101)	219 (427)		219 (427)	541 (1005)	317 (602)	541 (1005)
Enthalpy, KJ/Kg (BTU/LB)		3429 (1477)	3050 (1314)			3544 (1527)	2450 (1056)	943 (406)		943 (406)	3433 (1479)	3050 (1314)	3549 (1529)

The installation of the foundations for the tower, storage tanks, and steam generators will require excavation, back filling and related operations. Depending on the season, it may be necessary to provide continuous pumping of residual ground water during the excavation and back filling operations. This pumping was required during the original installation of the Ft. Churchill plant and the same procedures are anticipated during the installation of the solar equipment. The determination of the soil characteristics will be required for each foundation location. These characteristics will be determined during the next phase of the program.

The Ft. Churchill site is located in an area where the ground water table level may be high during the winter months. Pumping may be required for construction operations occurring in the winter.

Depending on the depth of the final foundation designs, pumping may or may not be required during the remainder of the year. No significant difficulties were encountered during the original plant installation and none are expected during the construction phase of the solar repowering.

4.4.2 Site Facilities

The following site facilities are to be added:

(1) A 6.0 MVA auxiliary power source supplied from one of the 120-60 KV transformer tertiary or other suitable source.

(2) A 372 m^2 (4000 ft^2) warehouse with facilities and equipment for solar equipment maintenance, repair, and spares storage.

(3) A 446 m^2 (4800 ft^2) garage with facilities for parking and maintenance of the vehicles to be used for collector field maintenance.

The following site facilities are to be modified or expanded:

(1) Control room modification to accomodate the solar master control console and enlargement to provide space for the solar master control computer equipment.

(2) Relocation of the present office space and combined kitchen-rest room area.

4.4.3 Interfaces with Existing Plant

Physical interfaces are identified with the feedwater line, the main steam line, and the hot and cold reheat lines. Simple tee joints are adequate for each of these interfaces. Mixing chambers are not required, as line lengths are adequate to provide good mixing of solar and fossil boiler flows.

Additional interface equipment required in the steam piping includes:

(1) A shutoff valve on the fossil boiler feedwater line for solar only operation.

(2) A dual shutoff valve on the main steam line from the fossil boiler for solar only operation.

(3) A dual safety valve on the cold reheat line to prevent overpressurization in the event of imbalance between the fossil and solar reheat flows.

(4) A shutoff valve on the cold reheat line for solar only operation.

(5) Flow apportioning valves on both the fossil and solar cold reheat lines to adjust reheat flow between the fossil and solar reheaters.

(6) A shutoff valve on the hot reheat line for solar only operation.

In addition, shutoff valves are provided on the solar main steam, feedwater, and hot and cold reheat lines for fossil only operation.

The solar master control interfaces with the existing plant controller primarily through the operator. Coordination of the two controllers is facilitated by providing selected plant operating data to the solar master control. The following parameters have been identified as required for coordinated control:

(1) Main steam pressure
(2) Turbine trip
(3) Turbine load set point
(4) Turbine inlet pressure

Other parameters may be added as the master control subsystem definition is refined.

As previously indicated, a 6,000 kVA tap into one of the main transformers is required to provide power to the solar equipment.

4.4.4 Site Plot Plan

The site plot plan is shown in Figure 4-5. The collector field is located in the upper left hand portion of the plan. As previously shown in Figure 2-2, this area is in the northeastern portion of the SPPCo. property. BLM land is assumed to be used to minimize the distance from the receiver tower to the existing plant. However, a constrained optimization of the collector field could be used to keep within the bounds of the SPPCo. property.

The collector field is surrounded with a 1.8 m (6 ft) chain link security fence and a gravel road. The area is accessed by a new paved road.

The piping run from the tower to the thermal storage subsystem is about 1500 m (5000 ft).

Details of the area around the existing plan are shown in the inset. A berm is provided for the thermal storage tanks in the event of a major leak.

The details of the steam generator piping and elevation are shown in Section 5.

4.5 SYSTEM PERFORMANCE

System performance estimation is divided into energy collection in the receiver fluid, energy conversion in the existing power plant, and insolation. The above estimates are then summarized in the context of probable operating scenarios as expected energy displacement. The types and values of fuel displaced are considered separately in Section 6.

4.5.1 Energy Collection Efficiency

The energy collection efficiency is separated from the energy conversion efficiency for simplicity of understanding. To the degree allowed by the thermal energy storage capacity, the collection and conversion of energy are separate operations. The conversion process may also combine varying degrees of hybrid and solar only operation.

The detailed description of the energy collection efficiencies are discussed in Section 5.3. The efficiencies cover all losses from direct beam energy incident on the mirrors when normal to the sun to energy delivered to the thermal storage subsystem. The end-to-end collection efficiency is

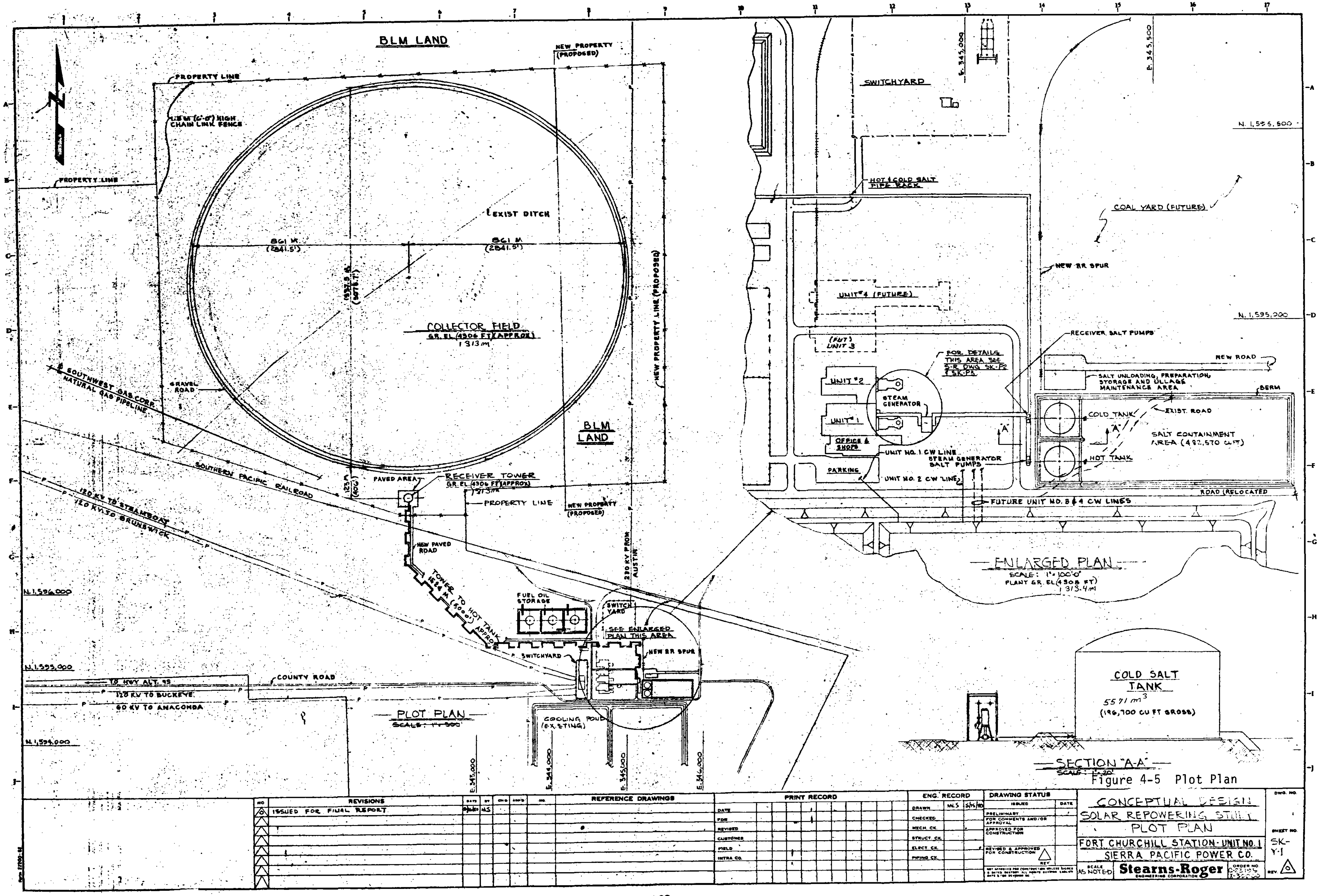


Figure 4-5 Plot Plan

estimated at 0.697 at the design point. Annual average efficiency is lower primarily because of lower average cosine factors and receiver efficiencies. The average annual efficiency is estimated at 0.618.

4.5.2 Energy Conversion Efficiency

The second set of efficiencies discussed covers all of the aspects of the conversion of the thermal energy into electricity. The heat balance data shown in Table 4-3 were output from a heat balance calculation by Stearns Roger. The calcualtion used the heat and mass balance data developed for the actual Ft. Churchill unit #1. These data, calculations, and parasitic losses were used to estimate the conversion efficiencies.

Parasitic losses are shown in Table 4-4. The variable loads include the fossil boiler forced draft fan, the boiler fuel pumps, and the condensate pumps. Constant loads include circulating water pumps, deep well pump, mechanical equipment, building service, lighting, and miscellaneous.

Plant efficiencies were estimated, based on the above data. The results are shown in Table 4-5. For hybrid operation, the total parasitic load is apportioned to fossil and solar according to the type of load. The net solar efficiencies shown include collector efficiency and relate direct normal insolation to electricity delivered to the grid.

The efficiency estimates of Table 4-5 will be used to estimate the energy displacement capability of the repowered plant.

4.5.3 Insolation Estimation

The insolation estimates are divided into clear day insolation, monthly weather factor, and total insolation.

4.5.3.1 Clear Day Insolation

The on-site measurements by the Direct Research Institute are the primary source for clear day insolation data.

The clear day profiles and total insolation values will be used to estimate the total annual energy. Combining the clearest day for each month with a weather factor estimated from sunshine switch data would over estimate the total insolation. An approximate 50 percentile clear day nominal would be more accurate when used in conjunction with sunshine switch data. However, there were too few days showing zero cloud cover during the period monitored

TABLE 4-4 PARASITIC LOADS

(Loads in kW_e)

Load	Fossil Only	Hybrid Daytime	Hybrid Storage	Solar Daytime	Solar Storage
Receiver					
Feed Pumps	----	3730	----	3730	----
Trace Heating	1535	----	1535	----	1535
Collector	----	311	----	311	----
Thermal Storage					
Circulation	----	300	300	300	300
Heating	180	----	----	----	----
Master Control	50	50	50	50	50
Variable Load	3441	3022	3022	2152	2152
Constant Load	775	775	775	775	775
Total	5981	8183	5682	7318	4812
Fraction of Gross Power	0.052	0.071	0.050	0.095	0.063

TABLE 4-5 PLANT EFFICIENCY ESTIMATES

Efficiency	Fossil Only	Hybrid Daytime	Hybrid Storage	Solar Daytime	Solar Storage
Boiler Efficiency	0.848	0.848	0.848	N/A	N/A
Collector Efficiency	N/A	0.618	0.618	0.618	0.618
Turbine Generator	0.426	0.425	0.425	0.42	0.42
Parasitic Factor, Fossil	0.948	0.955	0.955	N/A	N/A
Parasitic Factor, Solar	N/A	0.915	0.948	0.905	0.937
Net Fossil Efficiency	0.343	0.344	0.344	N/A	N/A
Net Solar Efficiency	N/A	0.240	0.249	0.235	0.243

to determine a 50 percentile. Hence, a judgement selection of clear days from the available data was used.

A second source of clear day insolation data is the University of Houston model. This model uses corrections to insolation for air mass, turbidity, and water vapor. Data for turbidity and water vapor are input from contour maps from the American Meteorological Society* and A.D. Watt.†

A November clear day is compared to the University of Houston correlation in Figure 4-6. A consistent trend toward measurements of direct, normal insulation above University of Houston data is seen. It is believed that this trend results from a somewhat high estimate of atmospheric water vapor and turbidity by the U of H data sources. As will be seen on subsequent charts, the correlation becomes better for the warmer months. The peak recorded insolation for the month was 1036 W/m^2, while the clear day peak was taken as 1020 W/m^2.

The total clear day insolation for November is taken as the integral under the clear day curve between the hours for sun elevation of 10°. For the November clear day, this integral is 7.3 kWh/m^2.

Figure 4-7 shows clear day insolation for December. The monthly peak insolation was 1018 W/m^2. The clear day estimate uses 1000 W/m^2. The total clear day insolation for December is 6.7 kWh/m^2.

No clear days were recorded in January. Figure 4-8 shows one of the two recorded days in February. There was a data cable failure which resulted in the loss of the direct normal insolation for the rest of the month. The data indicate that there was some opaque sky cover on February 28th. This day should be considered as "best available." However, as will be shown in 4.5.3.3, the data do correlate well, and February clear day probably is representative. The peak insolation level is 1025 W/m^2 and the daily total is 8.48 kWh/m^2.

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* Reitan, C.H., "Distribution of Precipitable Water Vapor Over the Continental United States". Bulletin of the American Meterological Society, Vol. 41, No. 2, February, 1960 pp. 79-87.

† On the Nature and Distribution of Solar Radiation; Watt Engineering Ltd. GPO, 1978, pp 110, 114-115. (Dept. of Energy, Report No. HCP/T2552-01.)

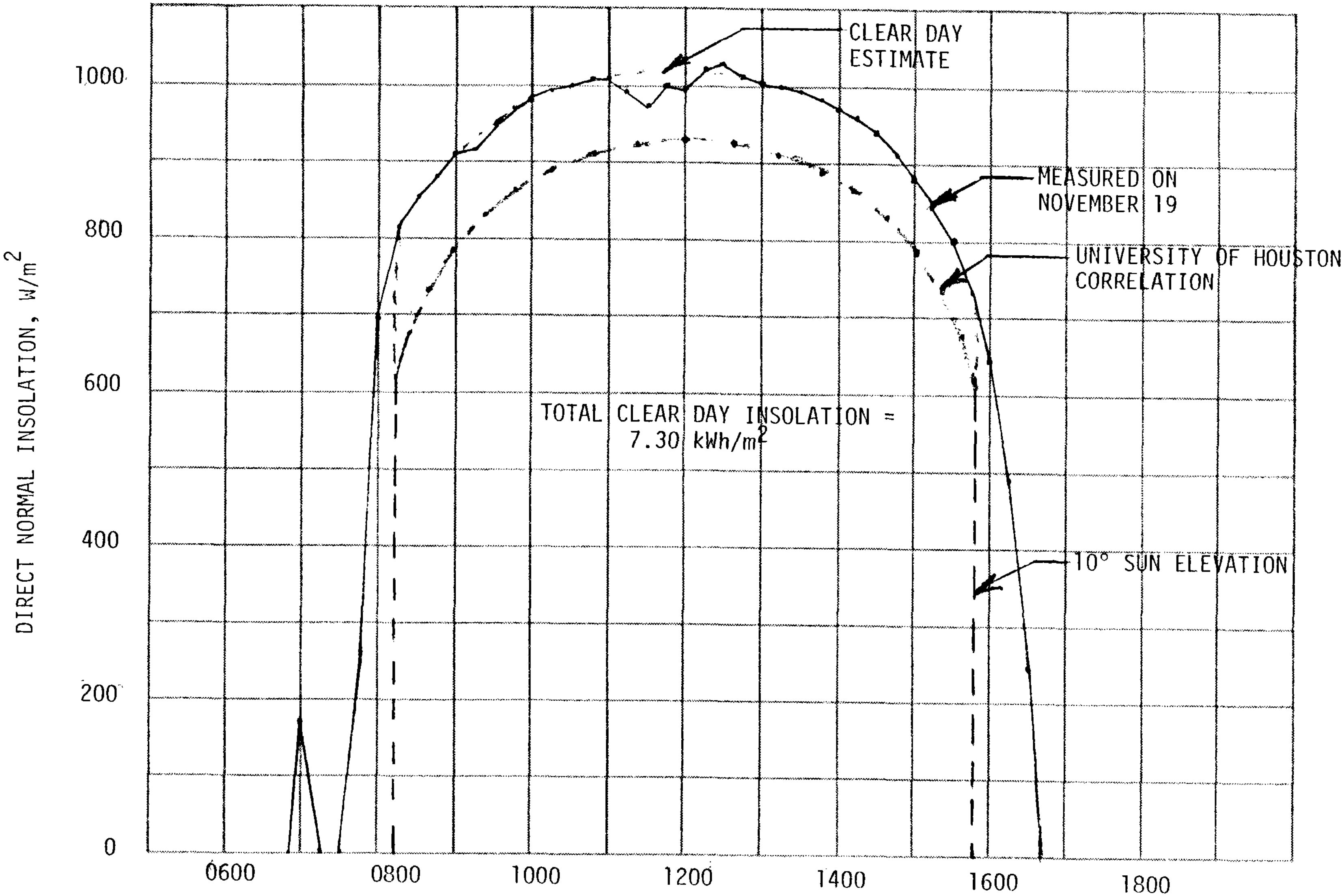

FIGURE 4-6 CLEAR DAY INSOLATION FOR NOVEMBER

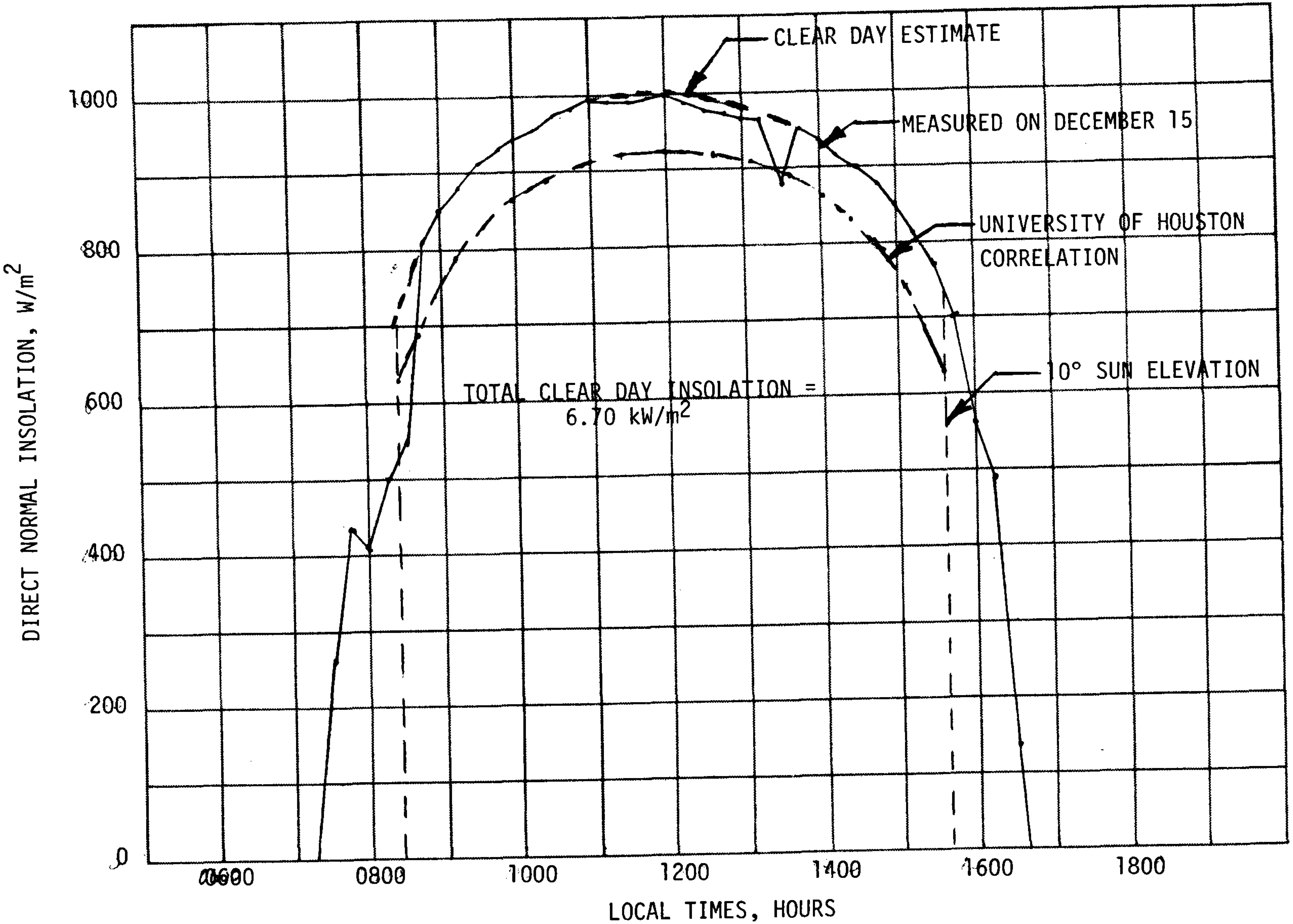

FIGURE 4-7 CLEAR DAY INSOLATION FOR DECEMBER

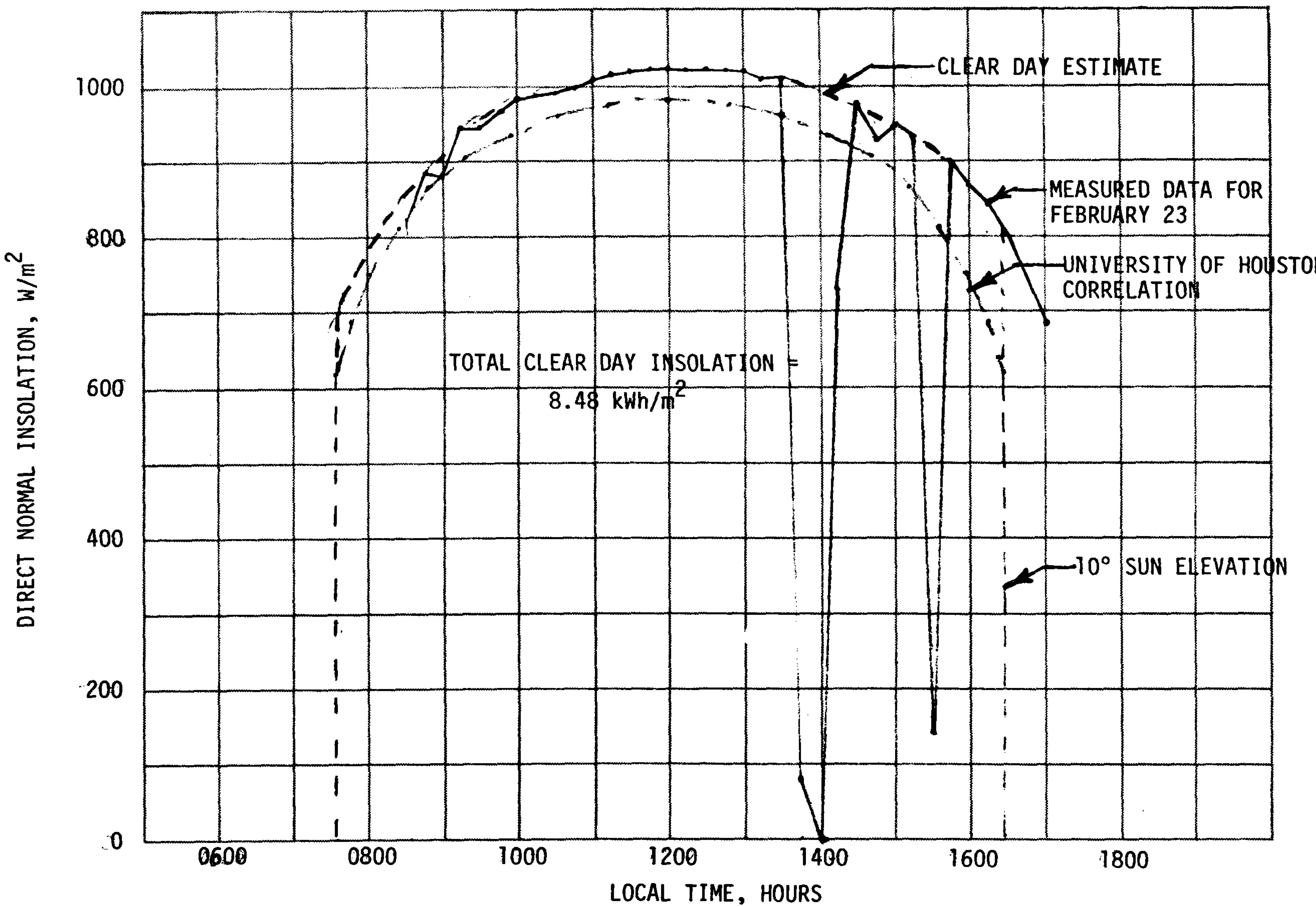

FIGURE 4-8 CLEAR DAY INSOLATION FOR FEBRUARY

The March clear day estimate is shown in Figure 4-9. Since there is an indication of early morning cloud or haze reduction of the insolation, the clear day model uses University of Houston data for this part of the day. As was previously indicated, the correlation between the University of Houston data and the site measurements appears to be much better in the warmer months than during mid-Winter. The March data correlate to about 1.5%.

The April clear day is plotted in Figure 4-10. Again, the correlation with University of Houston predictions is excellent.

4.5.3.2 Weather Factor

The clear day insolation model gives an indication of the possible insolation if all days were clear. The weather factor is a multiplier on the clear day insolation to account for cloud cover and haze.

The weather factor, because of its statistical nature, cannot be reliably determined from a single year's insolation data. The closest site for which long term data are available is Reno. The long term weather factor for Reno is plotted in Figure 4-11.

Simultaneous total horizontal insolation measurements have been collected at SPPCo's Mill Street Facility and at Ft. Churchill. If these data were compared on a 15-minute interval, relative percent possible readings and an estimate of variation in weather factor from Reno to Ft. Churchill could be developed. While this comparison could not be accomplished within the scope of this study, daily total data were used to estimate weather factor.

Monthly averages of daily total horizontal insolation were compared for November 1979 through March 1980. Ft. Churchill was found to be consistently 8% higher in monthly average insolation than Mill St. Some of this difference is due to higher clear sky insolation, and some to an alleged lower degree of cloud cover at Ft. Churchill. As a first estimate, the 8% can be apportioned half to cloud cover and half to clear day insolation. The result would be a 4% increase of weather factor over the five months, November through March.

The absolute magnitude of the cloud cover differences was taken to be constant over the year. This results in a lower percentage increase over the higher weather factor months. The resultant weather factor distribution is plotted on Figure 4-11.

MCDONNELL DOUGLAS

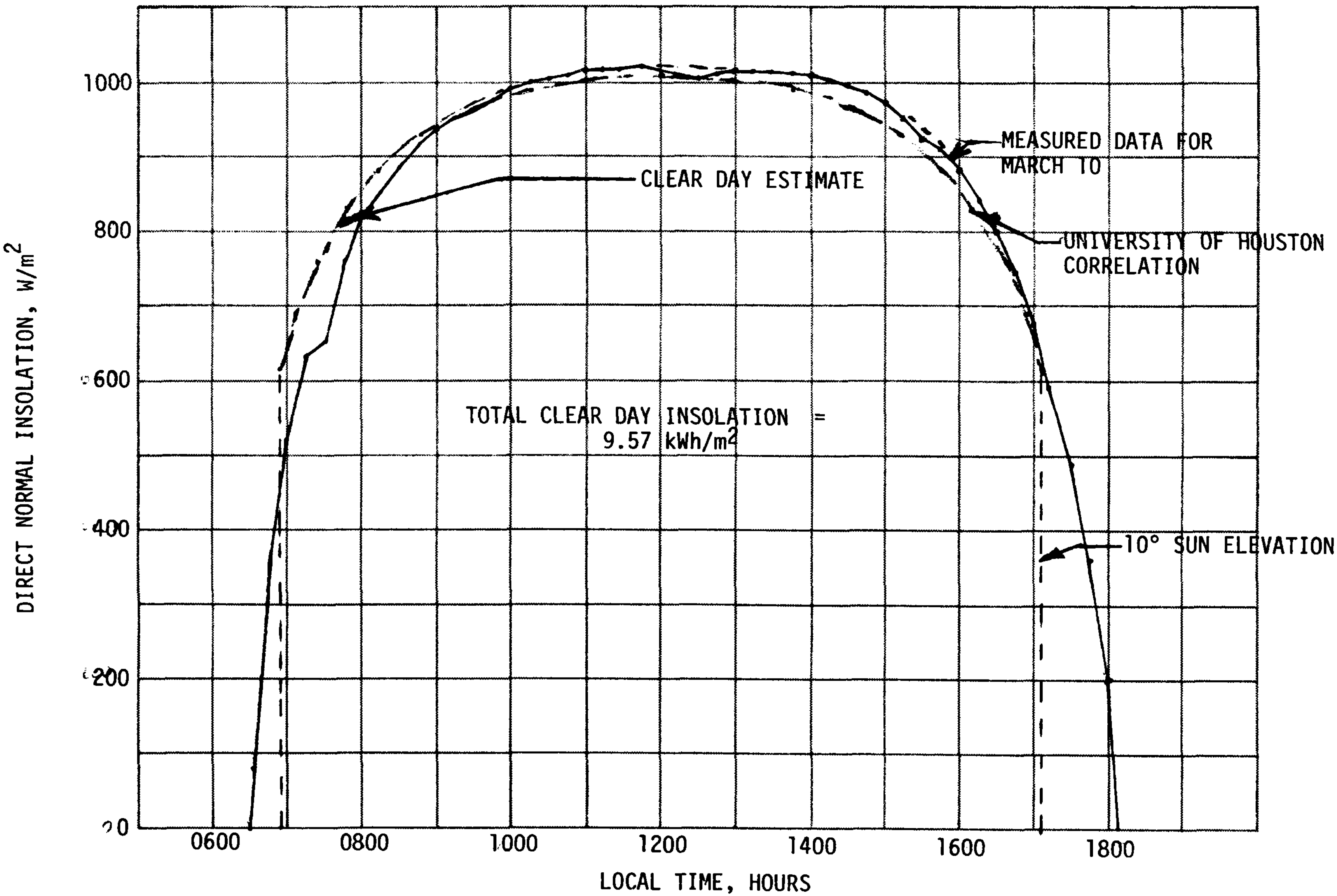

FIGURE 4-9 CLEAR DAY INSOLATION FOR MARCH

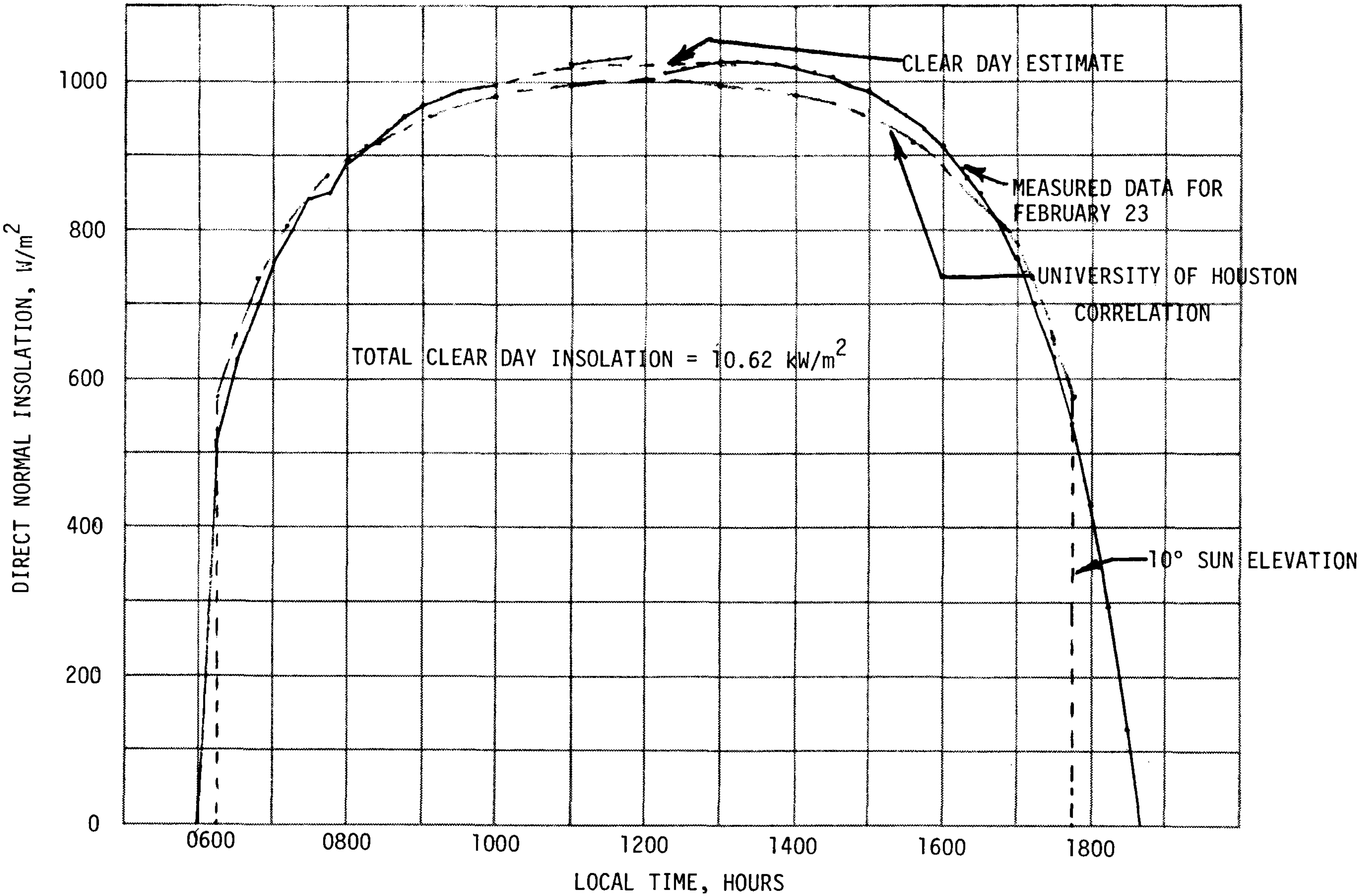

FIGURE 4-10 CLEAR DAY INSOLATION FOR APRIL

MCDONNELL DOUGLAS

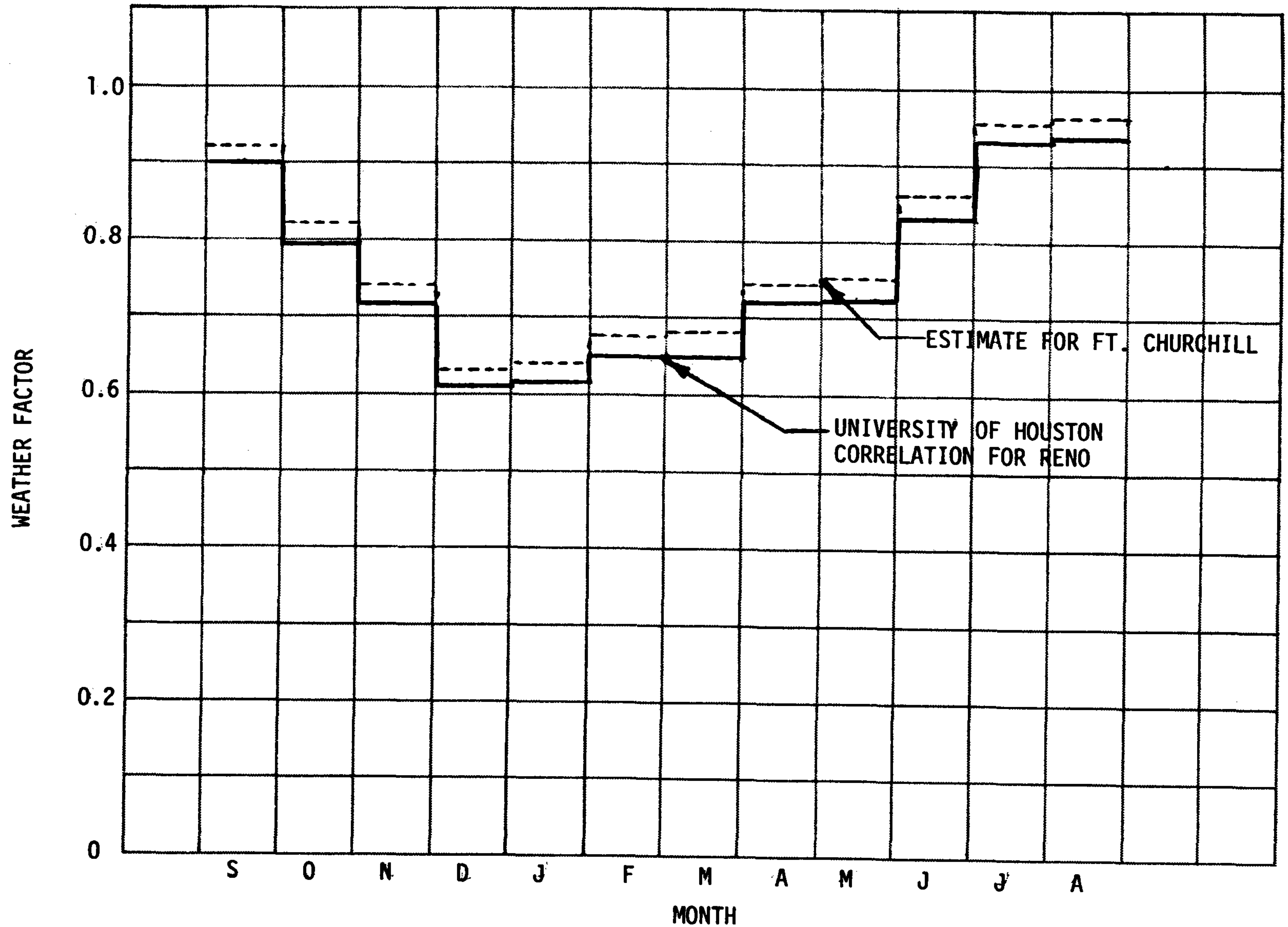

FIGURE 4-11 MONTHLY WEATHER FACTOR

4.5.3.3 Monthly and Annual Average Insolation

The clear day total direct normal insolation is plotted by month in Figure 4-12. As previously indicated, the greatest difference between site measurements and the University of Houston correlation occurs during the coldest months of the year. Therefore, the site measurements curve was faired into the University of Houston curve for months which no site data were available.

The daily average total direct normal insolation is the product of the clear day insolation and the weather factor. The estimate for daily average is also shown on Figure 4-12.

The annual average total direct normal insolation, as given by the average of the monthly values, is 7.21 $kWh/m^2/day$.

4.5.4 Fuel Displacement

The average insolation estimate of 7.21 $kWh/m^2/day$ derived in Section 4.5.3 may be multiplied sequentially to arrive at an equivalent fuel displacement. The steps are:

(1) Multiply by collection efficiency (0.618).

(2) Multiply by heliostat area ($56.42m^2$).

(3) Multiply by number of heliostats (8411).

(4) Multiply by days per year (365).

(5) Multiply by weighted parasitic factor (0.953*).

(6) Divide by boiler efficiency (0.848).

(7) Multiply by plant availability factor (0.958).

The result is an estimated 831 GWH_{th} equivalent in fuel displaced. If all of the displaced fuel were #6 fuel oil with a heating value of 10,689 kWh_{th}/m^3 (5.8×10^6 Btu/bbl) the fuel displacement would be about 78,200 m^3 (490,000 bbl) per year.

*The weighted parasitic factor is comprised of about 66%, direct solar and 34% solar storage from Table 4-5. The resultant is divided by the fossil parasitic factor from Table 4-4 without the trace heating load.

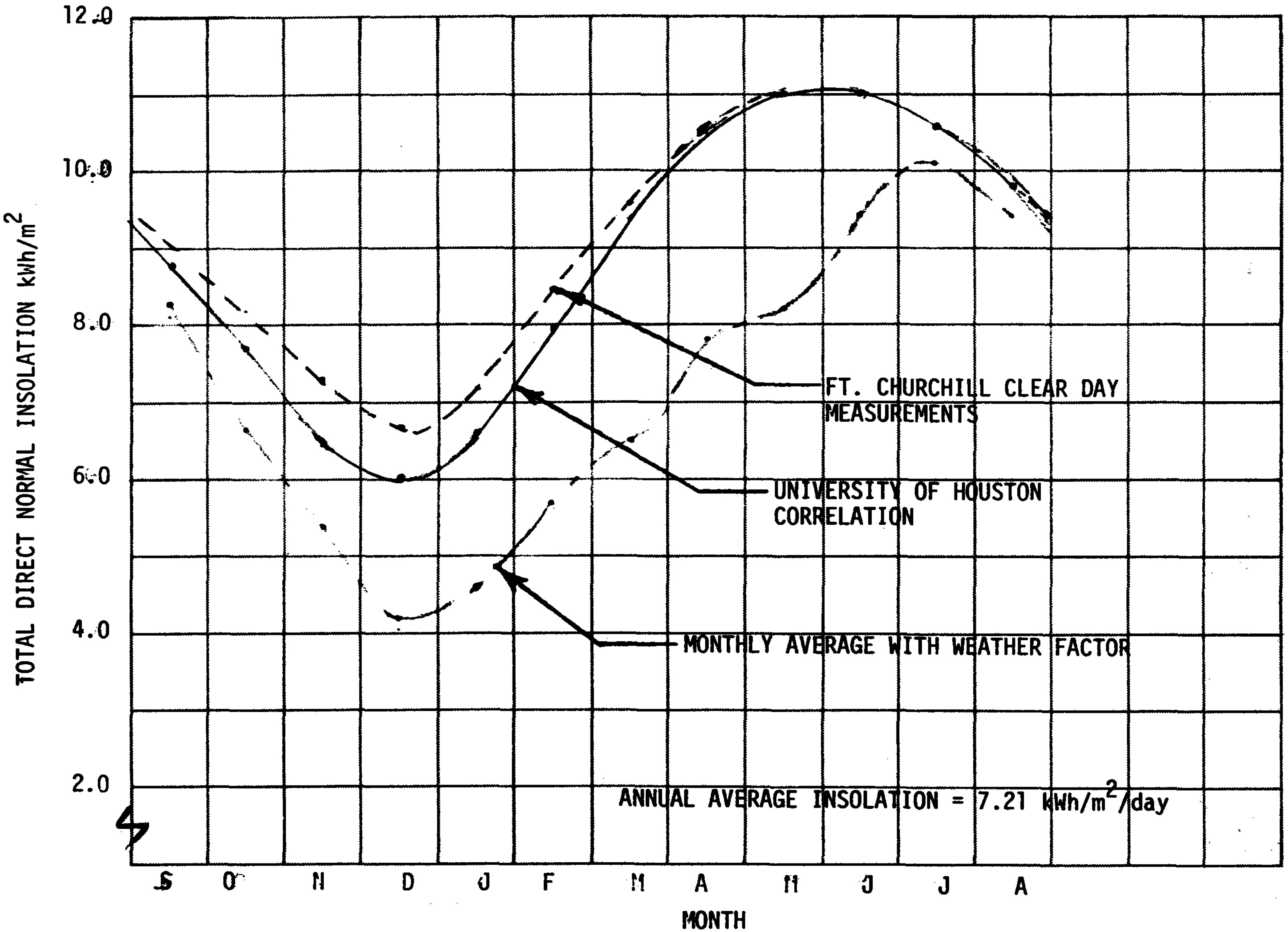

FIGURE 4-12 MONTHLY CLEAR DAY AND AVERAGE TOTAL INSOLATION

4.6 PROJECT CAPITAL COST SUMMARY

The new and modified equipment included in the capital cost estimates for the project may be seen in the piping and instrumentation diagram (Figure 4-3) and the plot plan (Figure 4-5).

On the plot plan, Figure 4-5, all equipment north of the Southern Pacific Railroad line is included, with the exception of the 230 kV line from Austin. The hot and cold salt piping to the existing plant is also included. In the enlarged plan view, the salt piping, hot and cold tanks, salt containment area, pumps and steam generator are new. The roads and railroad spur indicated as new are also included. New, but not shown, are modifications and additions to the control room, a new warehouse, a new garage and interface equipment.

On the P&ID, Figure 4-3, all new interface and control equipment shown are marked as new. In addition, all equipment above zone A and all equipment to the left of zone 7 are new, with the exception of the fossil boiler control.

A top level cost summary by CBS account is given in Table 4-6. Detailed cost estimates are provided in the SRS, Section 5. The heliostat costs shown are preliminary estimates, and do not represent results of a detailed manufacturing study of the second generation heliostat design. The major uncertainty of heliostat costs is expected to be resolved during the next few months as the heliostat design and production plans mature.

Since detailed heliostat production cost estimates for the repowering heliostat are not available, it seems important to set probable bounds on the cost. One cost estimate was derived from the Prototype Heliostat Phase 1 study completed in August, 1978. Figure 1-1 from the final report* is reproduced as Figure 4-13. The abscissa has been expanded to focus on the range of interest, and the ordinate changed to average cost per unit. Subassembly costs are also shown to provide a breakout of the costs of importance. Site work includes foundations, wiring, assembly and checkout. These costs were adjusted for changes which have occurred in the design during the second generation contract. These changes are:

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*C. R. Easton, "Solar Central Receiver Prototype Heliostat CDRL Item Bid., Final Technical Report," Report No. SAN-1605-7, dated August, 1978.

Table 4-6

FT. CHURCHILL NO. 1 REPOWERING CAPITAL COST SUMMARY

CBS	DESCRIPTION	COST ESTIMATE (10^6 1980 DOLLARS)
5100	Site Preparation	2.3
5200	Administrative Areas	
5300	Collector *	136.6
5400	Receiver	32.7
5600	Energy Storage	15.0
5700	Electrical Power Generation	3.8
	TOTAL	195.7

*Heliostats estimated at 224/m^2

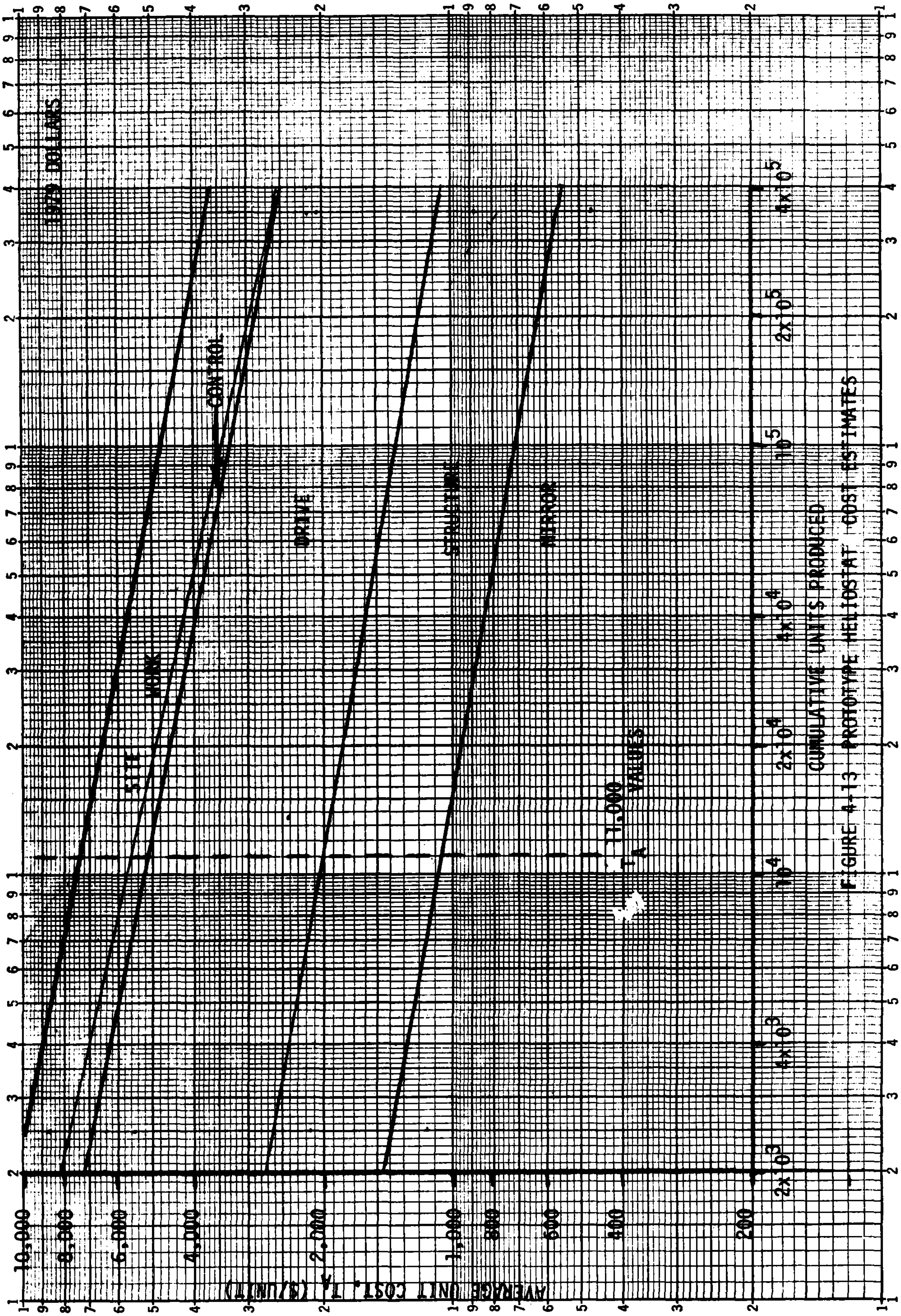

FIGURE 4-13 PROTOTYPE HELIOSTAT COST ESTIMATES

Mirror	-	Increased area
	-	PVB laminate
	-	Edge seal
Structure	-	Increased area
	-	Plan form change
	-	Increased stiffness
Drive	-	Improved Az design
	-	Non-inverting
Control	-	First generation approach
	-	1980 technology
Foundation/Pedestal	-	Increased area
	-	Revised loads
	-	Revised soil allowables
Wiring	-	Two cable
Assembly/Checkout	-	No change

The resultant cost was escalated to 1980 dollars. The estimate for the average cost of the first 11,000 units is $\$183/m^2$. This cost was used for collector field optimization. Since wiring costs are variable in the optimization, the actual cost was $\$174/m^2$ plus wiring costs.

Other estimates were derived from published data sources as follows:

Battell Pacific Northwest Laboratory, 2,500 heliostats/year*

- Minimum tooling and equipment - $\$260/m^2$
- Optimum tooling and equipment - $\$215/m^2$

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*Drumheller, K., et. al., "The Cost of Heliostats in Low Volume Production" Report SERI/TR-8043-2, Solar Energy Research Institute and Pacific Northwest Laboratories, January, 1980.

Battelle Pacific Northwest Laboratory, 25,000 heliostats/year †

- 100% recovery of factory and equipment cost against 8411 heliostats -$220/m^2
  (Next unit cost $120/m^2)
- 30% Return on Investment at 25,000 heliostats/year production -$135/m^2

These examples, included to establish high and low costs for the heliostats, differ primarily because of the impact of different production and production facility assumptions. The examples drawn from the Battelle data indicate that a plant with a major degree of automation and special equipment would easily pay for itself on the Ft. Churchill repowering project, above. The inference drawn from these data is that a plant with an investment in production process development, tooling, and equipment to some level between the two Battelle cases would lead to the lowest cost for heliostats for repowering. The cost reduction to the repowering program should be quite substantial. But equally important, heliostat prices for subsequent projects should approach an economically viable cost range because the non-recurring cost will have been written off. To develop such a factory and minimize costs, the schedule for heliostat production design and factory development must be accelerated and the capital investment for the factory must be begun early enough to enable the factory to be on line by mid-to-late 1983.

4.7 OPERATING AND MAINTENANCE COSTS AND CONSIDERATIONS

The operating and maintenance staff requirements for the new solar equipment are shown on Table 4-7.

The primary mode of collector maintenance is to remove and replace failed parts with spares. Repair of failed parts is performed either at the warehouse on site, or offsite at the manufacturer's facility or other specialized repair facilities.

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† Drumheller, K., et. al., "Heliostat Manufacturing Cost Analysis" Report SERI/TR-8043-1 Solar Energy Research Institute and Pacific Northwest Laboratories, October 1979.

TABLE 4-7 FIRST YEAR OPERATING AND MAINTENANCE STAFF

CATEGORY	ASSIGNMENT	STAFF LEVEL
SUPERVISORY	COLLECTOR MAINTENANCE AND REPAIR	1
ELECTRICAL TECHNICIAN	COLLECTOR MAINTENANCE	6
	COLLECTOR REPAIR	5
	OTHER SOLAR EQUIPMENT	2
MECHANICAL TECHNICIAN	COLLECTOR MAINTENANCE	3
	COLLECTOR REPAIR	0
	OTHER SOLAR EQUIPMENT	2
DRIVER	COLLECTOR WASHING	2
OPERATOR	SOLAR MASTER CONTROL (1 PER SHIFT)	2
TOTAL		21

The operating and maintenance cost summary is shown in Table 4-8. Note that training is included in the capital cost summary as an initial cost. Any retraining or training of new personnel is assumed to be accomplished during performance of the maintenance and repair tasks. The O&M costs of Table 4-8 consider only the annual, recurring costs.

4.8 SYSTEM SAFETY

The safety procedures and features for the plant are in general covered by existing standards, codes, and procedures. Some of the highlights are described in the following paragraphs.

4.8.1 Collector

The majority of the potential safety problems associated with the collector subsystem will be of a conventional type and will be covered by OSHA type requirements. The one non-conventional potential hazard concerns the energy in the reflected beams from the heliostats. Extensive analysis from previous programs (10 MWe Pilot Plant at Barstow CA)* show that the reflected beams from one heliostat will be safe at any pont in the beam, but a point which is in the beams from two or more heliostats may be unsafe. The dominant damage mechanism is a burn on the retina of the eye but cornea (eye) or skin burns must also be conisdered.

Operational requirements require that the beams from many heliostats converge at specified points in the airspace above the collector field (for example at the receiver); therefore, this will be unsafe regions in this airspace which must be considered Potentially unsafe regions may also exist at or near ground level. Airspace and ground level exclusion areas for personnel will be required.

4.8.2 Receiver

The receiver unit design is governed by Section VIII of the ASME Boiler and Pressure Vessel Code. The piping is designed to ANSI B31.1. Insulation is provided to prevent excessive temperature on the external surfaces of the receiver and fluid loop piping.

* "System Safety Plan" Report SAN/0499-6 (MDC G7855), dated June 1979.

TABLE 4-8 FIRST YEAR OPERATING AND MAINTENANCE COST SUMMARY

COST ESTIMATE	ANNUAL COST (10^3 1980 DOLLARS)
Non-Labor Collector Costs	
Spares and Repair Parts	271
Collector Labor Costs	
Corrective Maintenance	439
Scheduled Maintenance	106
Other Solar Equipment Costs *	509
TOTAL	1,485

* Estimated at 3% of capital cost per year.

The receiver unit is capable of being drained into the cold storage tank to prevent freezing in the event of extended shutdown and to allow personnel access to the interior of the receiver for maintenance or replacement.

The CAL-OSHA Code requires that the receiver fluid not be allowed to exceed 649°C (1200°F). The bulk temperature design point is 566°C (1050°F), and the maximum film temperature design goal is to 593°C (1100°F). A bypass quench loop may be added to correct receiver fluid overtemperature resulting from a failure in another part of the system. An FMEA analysis in the preliminary design will be used to determine whether a quench loop is required and adequate.

A shower should be installed near the base of the tower in the event of personnel exposure to molten salt leakage. Non-flammable, protective clothing will be provided for personnel in the tower/receiver area.

The tower will require ventilation to prevent the buildup of heat leakage through the insulation and possible buildup of fumes from salt leakage. Natural convection is expected to be able to provide adequate ventilation.

Contact between the molten salt and magnesium alloys, carbon seals, oil, grease, flammable insulation, other organic materials, and water is prevented throughout the system by the correct choice of materials and components.

Special provisions for a melting of the salt in the event of freezeup must be devised.

The receiver tower will require aircraft warning lights and listing on air navigation maps.

4.8.3 Thermal Storage

The general provisions for salt safety described above will also be observed in the thermal storage area. Protective clothing and showers will be provided. Control of the fossil heater will prevent excessive salt temperatures. Proper materials and components will be chosen to prevent materials compatibility problems.

A berm and salt containment area is provided around the thermal storage tanks to contain major salt leakage. The containment area will be kept free of vegetation and other organic materials.

No solid salt will be stored in the vicinity of the liquid storage tanks. Tank vents will be designed to prevent liquid water incursion.

The steam generator heat exchangers are designed to Section VIII of the ASME Boiler and Pressure Vessel Code. Pressure relief to prevent rupture of the shell in the event of a liquid water leak into the molten salt is provided. The vent will be designed to avoid showering personnel in the area with hot salt, should a leakage occur.

Salt polishing equipment will be provided to maintain salt chemistry within an acceptable range.

Steam piping and interfaces with the existing plant will be designed to the ANSI B31.1 power piping code.

4.8.4 Solar Master Control

The solar master control is provided with appropriate interlock logic to prevent operation in an unsafe manner. Mode changes and trip conditions are coordinated to provide safe transitions and shutdown.

The stowage of the heliostats and their transition between stowage and standby is under the control of the HAC and will be programmed to prevent an unsafe beam intensity in the surrounding air space, on the ground, or on any buildings, equipment or facilities.

4.9 PROJECT ENVIRONMENTAL IMPACT ESTIMATE

The regulatory requirements pertaining to the project environmental impact were Compiled in a report* by Science Applications, Incorporated (SAI) for SERI. These regulatory requirements were reviewed and no problems with obtaining approvals were identified.

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*P. Ehr and M. Brainard, "Regulatory Requirements and their Effects on Solar Thermal Facility Siting," Submitted June 29, 1979 under SERI Contract 31-109-38-3764

Particular comments regarding the environmental impact include:

Impact on Land - The impact on the land should be less than that of farming, and already approved use of the land. The salt, itself, is used as a commercial fertilizer and poses no additional environmental impact from salt spills or leakage.

Impact on Air - The air quality impact should be beneficial, because less fossil fuel will be burned.

Impact on Water - Water use for heat rejection is already approved. No additional water for this purpose will be required. The water use for heliostat cleaning will be small compared to boiler makeup water; hence no significant impact is expected. The wash solution of dilute acetic acid in demineralized water should be acceptable if dropped on the ground. The annual detergent cleaning will use a biodegradable, environmentally acceptable solution.

Alternative Methods of Operation - Continued use of oil/gas or conversion to coal would have a greater environmental impact than conversion to solar.

Asthetic Impact - The remote, agricultural area should be able to accept the asthetic impact of the collector and tower.

Health and Safety Impacts - Health and safety issues were discussed in Section 4.8. No significant problems were identified.

4.10 INSTITUTIONAL AND REGULATORY CONSIDERATIONS

In addition to the above, up to 28 regulatory approvals may be required. These regulations have been reviewed. Key permits expected to be required are:

Construction Order - A construction order is required by the Nevada State Public Services Commission (PSC) under Utility Environmental Protection Act, Rule 25. This permit normally requires about 6 months to obtain.

Offset-Operating Permit - The Offset-Operating Permit is required by the Division of Environmental Protection to insure that air and water quality will not be unacceptably degraded by operation of the new plant. The Offset-Operating permit is required under the Clean Air Act Amendments of 1977, specifically:

Title I; Section 127, Prevention of Significant Deterioration
Title I, Section 128, Visibility Protection
Title I, Section 129, Non-attainment Areas, and the Code of Federal Regulations, Title 40, Part 6, Appendix S-Emission Effect.

This permit normally requires 12 months baseline data collection and offsets will be specified in the permit.

Environmental Assessment and Cultural Resource Report - This report is required under the code of federal regulations Title 40, Part 6 - Environmental Assessment Historic Preservation Act of 1966-Public Law 89-665. The report normally requires 8-12 months to receive approval. No known resources are in the area, and no difficulties in obtaining approval are anticipated.

Cultural Resource Clearance - This clearance is also required under the historic Preservation Act of 1966-Public Law 89-665. A duplicate of the Cultural Resource Report is filed with the Nevada State Historic Preservation Officer. Approximately three months is required to obtain this clearance. No difficulties are anticipated.

Aviation Hazard Permit - This permit is required by Federal Aviation Regulations, Part 77, Subchapter B. Approximately three months is required for this permit, and no difficulties are anticipated.

Section 5
SUBSYSTEM CHARACTERISTICS

The major subsystems for this solar repowered plant will be discussed in this section. This discussion will be limited to solar related, new additions, modifications, and interfaces to the Ft. Churchill plant. The related data on the existing, conventional portion of the plant are presented in Section 5 of the System Requirements Specifications (SRS), (Appendix A). The major site activities and subsystems of the solar related portion of this plant are:

- Site Preparation
- Site Facilities
- Collector
- Receiver/Tower
- Master Control
- Fossil Energy
- Energy Storage
- Electric Power Generation Subsystem
- Specialized Equipment

5.1 SITE PREPARATION

5.1.1 Site

The site is located 75 km southeast of Reno, Nevada, as was shown in Figure 2-1. The terrain, as shown in Figure 1-3, is typical of a high desert with an elevation of 1300 m (4300 feet). The land surrounding the plant is a combination of open desert (brush covered) and irrigated farm land. There are no significant topographic changes on the site. The terrain is relatively smooth and level and has a slight slope toward the east where the Walker River flows. The river is located further to the east than the eastern extreme of the solar repowering plant. The lands on the east side of the plant are used for cattle grazing. On the west is irrigated farm land and open desert land is located north of the plant. The open desert in this location is sandy, may be marshy during the wet season, and requires gravel footings to provide a load bearing surface. One land drainage ditch, indicated on Figure 4-5, runs across the land from the southwest to the northeast, through the prime location for the solar field. A Southern Pacific railroad right of way is located to the immediate north of the Ft. Churchill site. Two spur lines connect the main line and the plant. Four large evaporative cooling ponds are located to the south of the plant.

5.1.2 Soil Characteristics

The soil characteristics in the area which will contain the receiver tower and the collector field appear to be sililar to the soil at the present site location. The records of the soil characteristics made for the installation of the main plant are no longer available. However, some of the original core sample data is available and this data was evaluated in this study.

Core sample data for the Fort Churchill Plant indicate that the soils in the upper 3m (10 ft) to 4.6m (15 ft) are generally loose silty sand. Below 3m (10 ft) to 4.6m (15 ft), these soils are generally silty sand and clayey and sandy silt of medium to high density, with density typically increasing with depth.

Based on the available soils data, a maximum allowable net soil bearing pressure of 0.24 mPa (5000 psf) will be assumed for foundation design.

Additional soil test bore holes should be made at the proposed tower location (to a depth of 18m (60 ft), and at the proposed salt storage tank and steam generator locations during the next phase of this program.

5.1.3 Site Preparation

Site preparation activities at Fort Churchill will include the following elements:

a. Preparation of plant site - preliminary grading, clearing brush, rock and debris removal from major equipment areas (not including collector field).

b. Roads, including base and surface, rerouting of country road, paved road from plant area to receiver tower and salt unloading facility and gravel road around collector field as shown on the Plot Plan, Figure 4 5.

c. Fencing 1.8 m (6 ft) chain link security fence at existing and proposed property lines around collector field as shown on Plot Plan, Figure 4-5.

d. Plant identification signs.

5.2 SITE FACILITIES

The Ft. Churchill plant is a modern, well-equipped utility plant and a minimum of new plant facilities will be required to support the solar repowering of Unit No. 1. The modifications/additions considered on this study include the following:

1. Control room modification and addition of a new computer room.
2. Addition of a solar storage and maintenance building.
3. Addition of a garage and storage area for mobile solar equipment.

Each of these are discussed in the following paragraphs.

5.2.1 Control Room/Computer Room

The equipment needed to incorporate the solar control functions into the repowered plant will not fit into the existing plant control room. The new equipment consists of the solar master control console (discussed in Section 5.5) and the computer equipment needed to support the control functions. Several potential locations for the equipment were considered on this study. The location selected is shown in Figure 5-1. This arrangement was the layout preferred by the present plant operating personnel, and it meets with their approval. With the new arrangement, the solar operating console is located in the area at the east edge of the present control room for Units 1 and 2. This area presently contains an office space, a kitchen, and a rest room area. This area will be joined into a single area and used for the solar master control console. A new addition will be made on the south side of the solar console area which will contain the relocated office space. Another addition will be made on the north side to relocate the kitchen/rest room area. Since the solar master control console area is too small to contain the solar computer equipment, a new addition will be made along the north side of the present control room and the six logic panels will be located in this area. This new room will be 4.9 m (16 ft) x 4.9 m (16 ft) and will be located at the same level as the present control room (elevation 1320.7 m, 4333 ft).

5.2.2 Storage and Maintenance Building

A repair and storage building will be provided to support the solar system equipment. This building will be 24.2 m (80 ft) x 15.1 m (50 ft). A typical layout for this building is shown in Figure 5-2. This building will be constructed of prefabricated metal panels and installed on a concrete floor. The building will be insulated and heated. The repair and storage building (warehouse) will be located to the north of and adjacent to the existing storage building. This location is shown on the Plot Plan, Figure 4-5.

5.2.3 Garage and Service Building

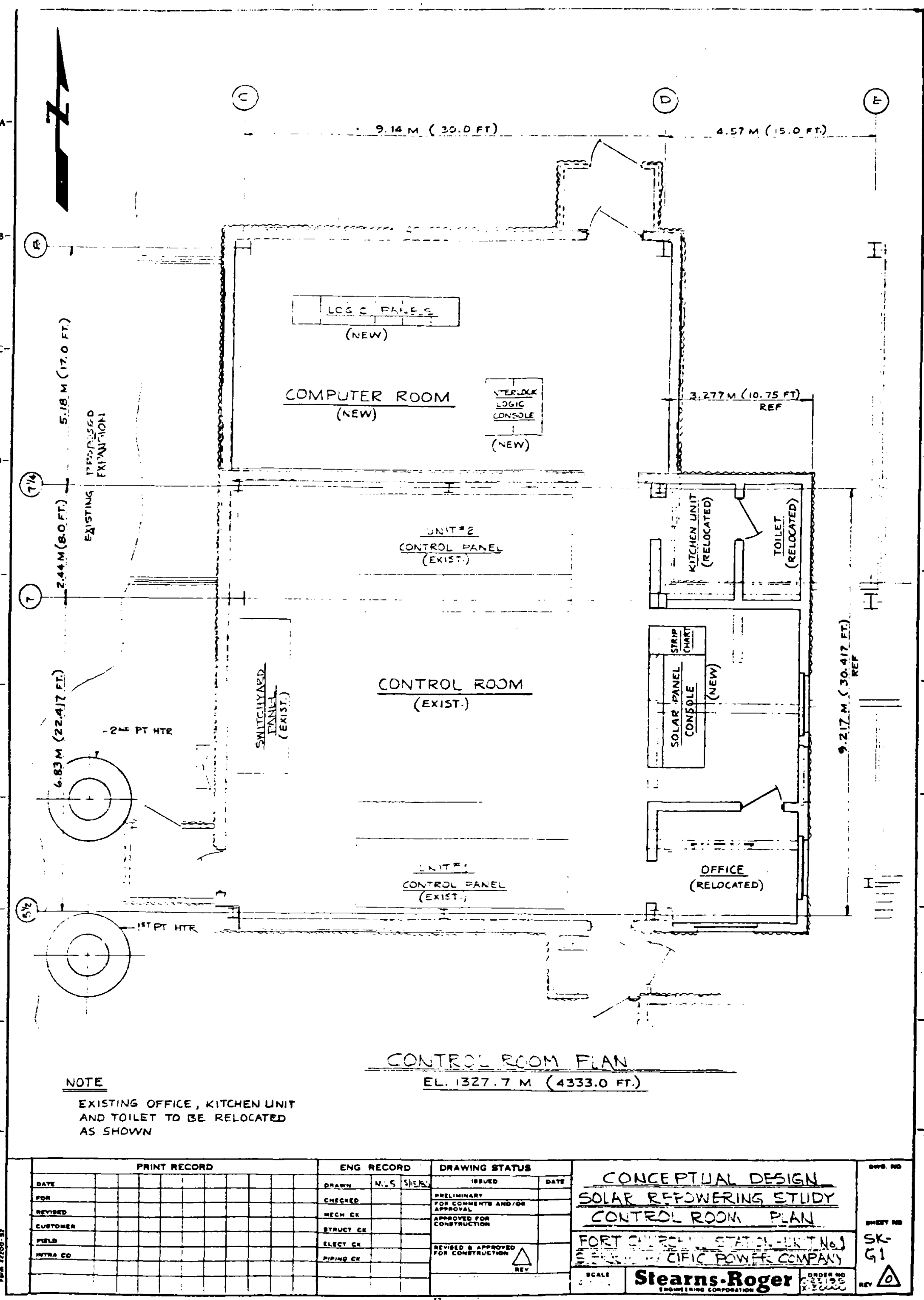
A garage and service building will be provided to support the mobile equipment used for the maintenance of the solar plant. This building will handle the service and parking of the two (2) washing trucks and additional mobile equipment that will be defined during the next phase of the program. This building will be 18.18 m (60 ft) x 24.24 (80 ft) and will contain 440 m^2 (4800 ft^2) of floor space. This building will be constructed of the same type of materials as the storage and maintenance building. The garage will be located to the west of the storage and maintenance building and adjacent to that building.

5.3 COLLECTOR SUBSYSTEM

The collector subsystem consists of the collector field containing 8411 individual heliostats and their controls, power supplies, and field wiring. The collector field is located to the west and north of the plant as shown in the Plot Plan (Figure 4-5).

5.3.1 Collector Field Layout

The collector field is located north of the tower. The collector field was optimized in a radial staggered layout. The optimization was conducted for 40 individual cells. The optimum number of heliostats for each cell is shown on Figure 5-3. The location of the 277 heliostats in a typical cell is shown on Figure 5-3.


9.14 M (30.0 FT)
4.57 M (15.0 FT)
LOGIC PANELS
(NEW)
COMPUTER ROOM
(NEW)
INTERLOCK LOGIC CONSOLE
(NEW)
3.277 M (10.75 FT)
REF
5.18 M (17.0 FT)
2.44 M (8.0 FT)
6.83 M (22.417 FT)
EXISTING
EXPANSION
UNIT #2
CONTROL PANEL
(EXIST.)
KITCHEN UNIT (RELOCATED)
TOILET (RELOCATED)
STRIP CHART
SOLAR PANEL CONSOLE
(NEW)
9.217 M (30.417 FT)
REF
CONTROL ROOM
(EXIST.)
SWITCHYARD PANEL
(EXIST.)
2ND PT HTR
UNIT #1
CONTROL PANEL
(EXIST.)
OFFICE
(RELOCATED)
1ST PT HTR
CONTROL ROOM PLAN
EL. 1327.7 M (4333.0 FT.)
NOTE
EXISTING OFFICE, KITCHEN UNIT
AND TOILET TO BE RELOCATED
AS SHOWN
PRINT RECORD
DATE
FOR
REVISED
CUSTOMER
FIELD
INTRA CO
ENG RECORD
DRAWN
CHECKED
MECH CK
STRUCT CK
ELECT CK
PIPING CK
DRAWING STATUS
ISSUED
DATE
PRELIMINARY
FOR COMMENTS AND/OR APPROVAL
APPROVED FOR CONSTRUCTION
REVISED & APPROVED FOR CONSTRUCTION
REV
CONCEPTUAL DESIGN
SOLAR REPOWERING STUDY
CONTROL ROOM PLAN
SCALE
Stearns-Roger
ENGINEERING CORPORATION
DWG. NO
SHEET NO
SK-G1
REV

5-5 Figure 5-1

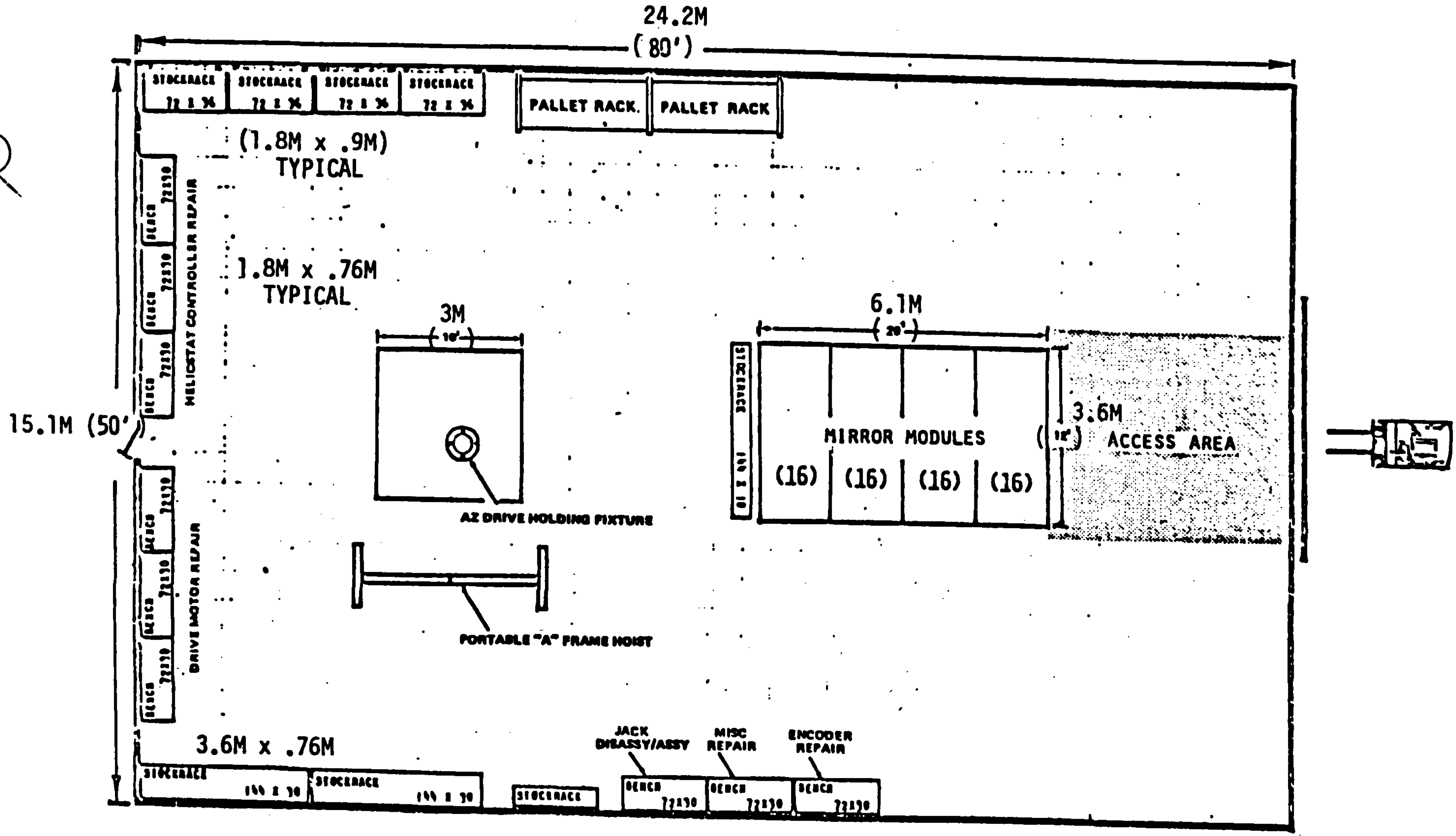


Figure 5-2 REPAIR AND STORAGE FACILITY

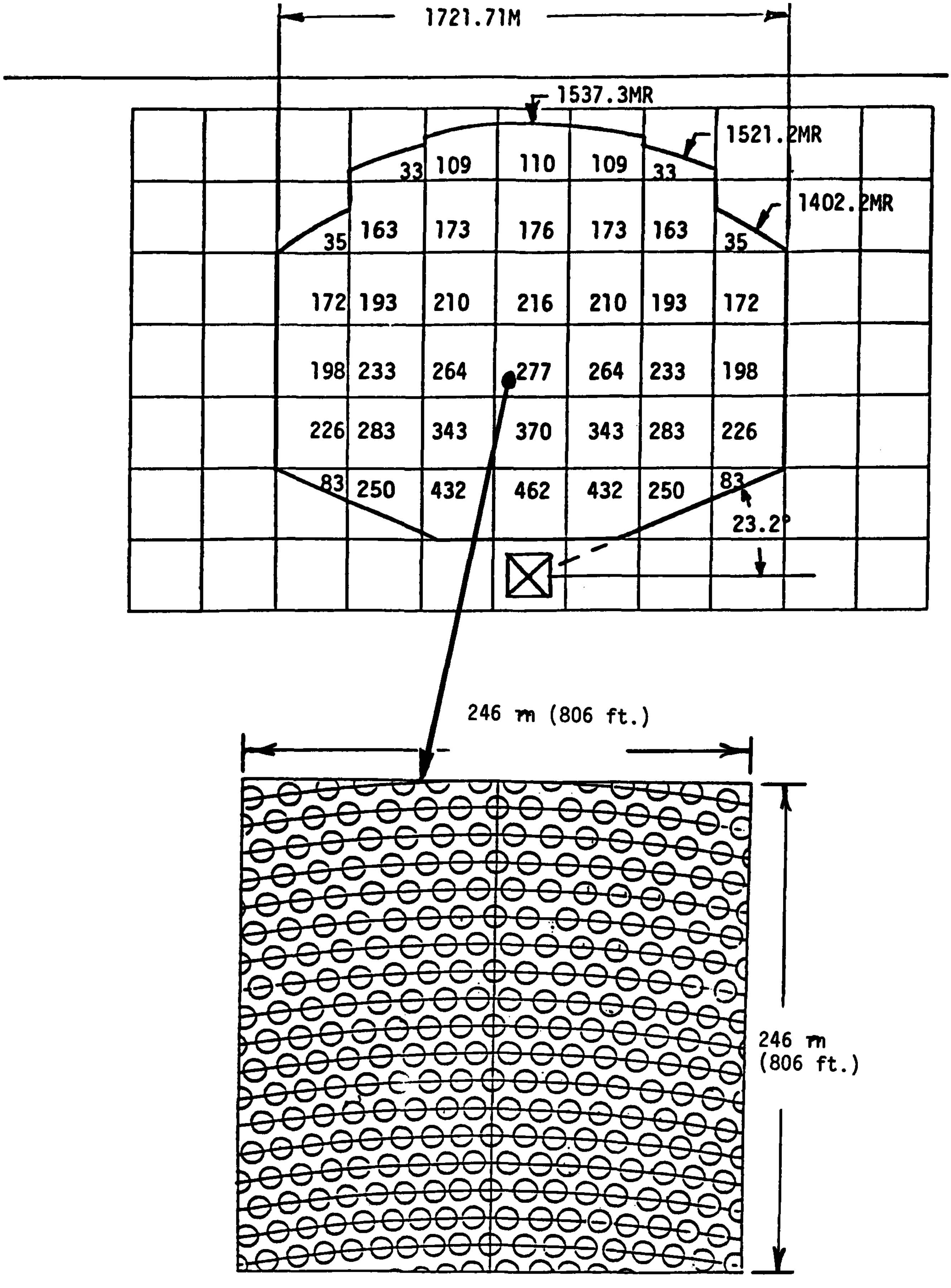


Figure 5-3 Collector Field Layout

5.3.2 Aim Strategy

The collector field is divided into four separate zones which have different aim strategies. These four zones are shown in Figure 5-4 and are as follows:

Zone 1 - In the outer part of this zone, where the beam is larger than the aperture, the aim point will be on the center of the aperture. Where the beam is smaller than the aperture, the aim will be tangent to the top of the aperture and on the vertical centerline. This zone contains 2640 heliostats.

Zone 2 - This zone will use a divided high/low aim strategy with both points on the vertical centerline. The low aim point will be high enough to minimize impingement of radiation on the floor. This zone will contain 2438 heliostats.

Zone 3 - This zone uses a divided high/low aim strategy with the high aim point low enough to minimize impingement on the receiver ceiling. This zone contains 897 heliostats.

Zone 4 - The inner zone uses a divided east/west aim strategy with both sets low enough to minimize impingement on the receiver ceiling. This zone contains 897 heliostats.

5.3.3 Heliostat

The heliostat selected for this application is based on the MDAC/DOE Second Generatio Design. Each heliostat contains 56.4 m^2 of reflector mirror area. Normal stow is with the reflector surface vertical. Survival stow for high winds is with the reflector face up. Inverting stow is not provided.

The heliostat design used for the study is basically in agreement with the collector subsystem requirements generated by Sandia National Laboratories.*

The minor differences between the Sandia requirements and the requirements for this site specific application are presented in Section 3.3.2 of SRS.

The electrical requirements for these heliostats are estimated to be as follows:

* Collector Subsystem Requirements, A10772, Issue C, dated 10-10-79, Sandia National Laboratory.

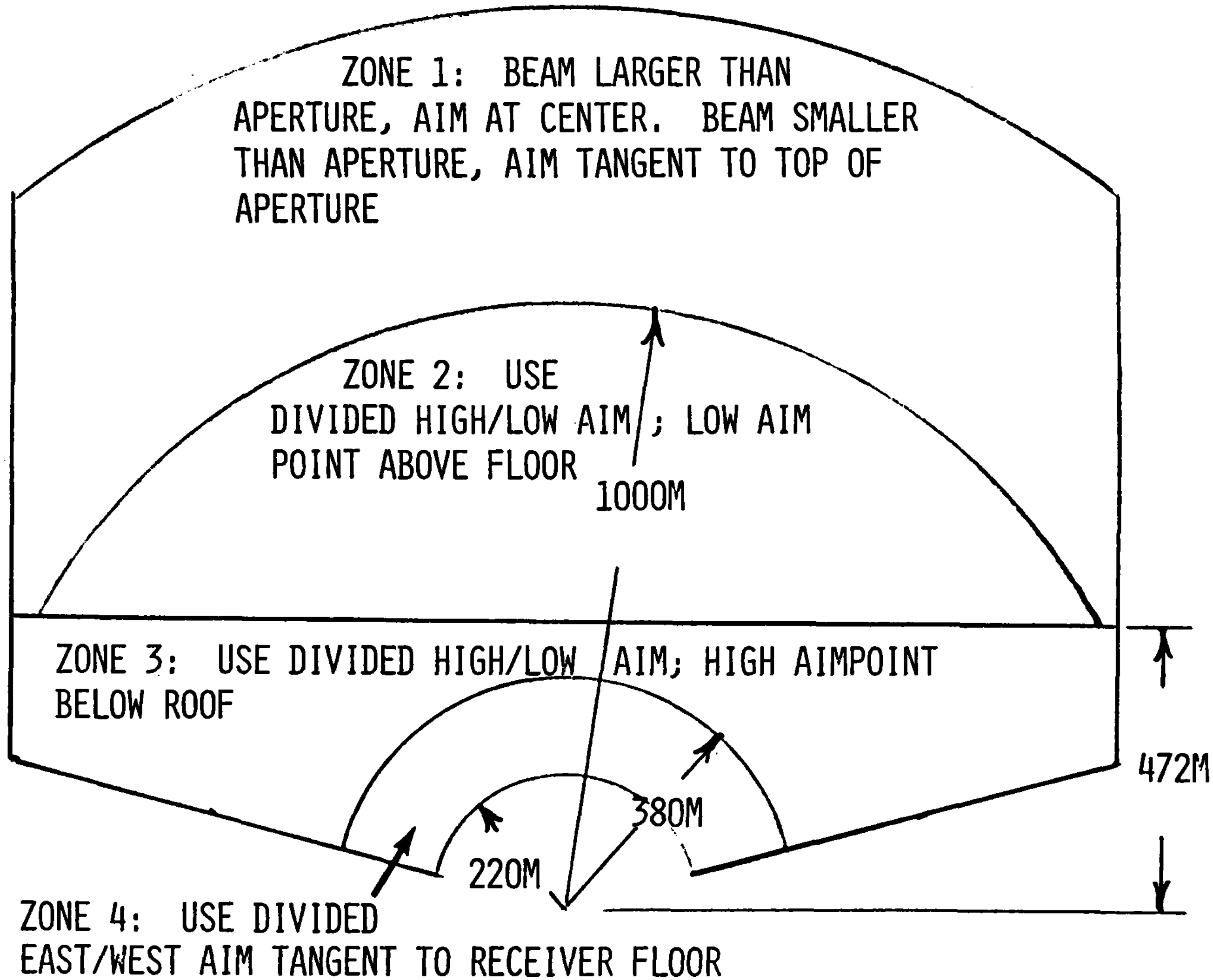


Figure 5-4 RECEIVER AIM STRATEGY

HELIOSTAT ELECTRICAL REQUIREMENTS

	Power For Each Heliostat		Power For Total Field	
	Watts	Volt-Amp	KW	KVA
a) Tracking Mode				
Motors	2 watts	3VA		
Electronics	33 watts	69VA		
Total	35 watts	72 VA	294 KW	605 KVA
b) Slew Mode (Emergency Defocus) - Sequential Program				
Motors	302 W	432VA		
Electronics	33 W	69VA		
Total	335	501	800 KW	1196 KVA
c) Stow Mode, normal				
Motors	624 W	864VA		
Electronics	33	69		
Total	657	933VA	131 KW	186 KVA
d) Stow Mode, (Emergency, High Wind)				
Motors	347 W	480		
Electronics	33	69		
Total	380	549	798 KW	1153 KVA

The basic configuration of the heliostat used in this study is shown on Figure 5-5. The detailed description of these heliostats is presented in Section 5 of the SRS. The actual cost of these heliostats is a function of production plant design, production rate and the period of time that the units are in production, and these parameters are now known at this time. Hence, a range of costs was used in this study. Collector field optimization used a cost of $183/m^2 (174/m^2 plus variable wiring costs). Economic evaluations are based on a range of heliostat costs from $175/m^2 to $285/m^2. A nominal value of $224/m^2 was used as a baseline cost model and the various trade studies were conducted using $175/m^2 and $230/m^2 values.

5.3.4 Collector Field Performance

The predicted performance for the collector field was compiled by the University of Houston, using their standard RCELL program.

REFLECTOR SHAPE	RECTANGULAR (8.66 M x 6.87 M)
MIRROR AREA	56.42 M^2
NUMBER OF MIRROR MODULES	14
MIRROR MODULE SIZE	1.22 M x 3.35 M
REFLECTIVITY	0.87 - 0.92 (DEPENDANT ON IRON CONTENT AND OXIDATION STATE)
REFLECTOR CONFIGURATION	CANTED AND FOCUSED
BEAM ERROR (AS USED IN PERFORMANCE CALCULATIONS)	2.83 MR
SLEW RATE	15 DEGREES/SEC.
DRIVE	AZIMUTH: HARMONIC DRIVE ELEVATION: LINEAR ACTUATORS
CONTROL SIGNAL DISTRIBUTION	HARD WIRE

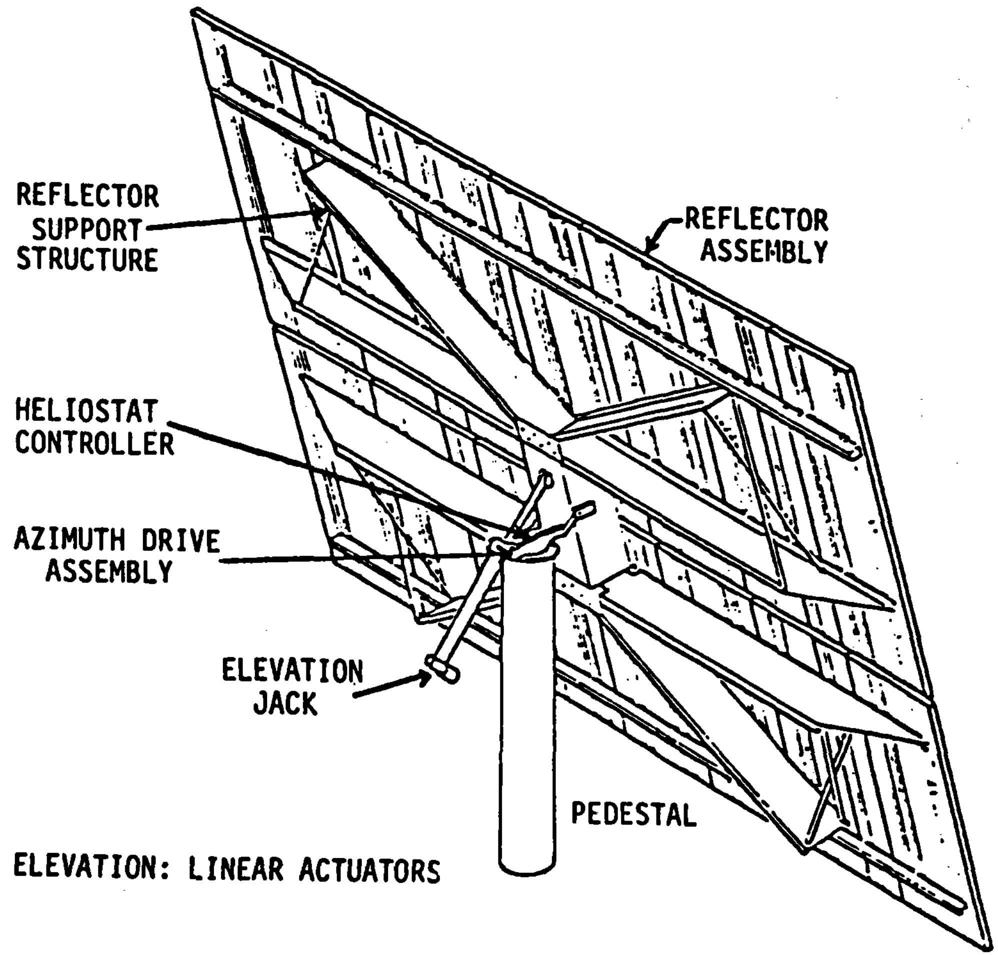


Figure 5-5 MDAC SECOND GENERATION HELIOSTAT

The results of the field performance prediction are shown on Figure 5-6 to 5-9 for a clear day at spring equinox, summer and winter solstice. Annual average performance is shown in Figure 5-9.

The collector field performance data of Figures 5-6 to 5-9 were generated using the following data sources:

- Cosine Losses - University of Houston RCELL series.
- Reflectivity - Estimate from prototype heliostat study including a 3% reduction for average dust buildup.
- Shadowing and Blocking - University of Houston RCELL series.
- Atmospheric Attenuation - LOW TRAN II calculation with 50 km visibility.
- Spillage - CONCEN calculation.
- Field Geometry Factor - Experiential estimate of average heliostat performance degradation due to departures of real spacing and field layout from idealized optima.
- Availability - Essentially unity from prototype heliostat availability analysis.
- Receiver Absorptivity - Multiple reflection analysis by MDAC program TRASYS using incident flux from CONCEN.
- Receiver Re-Radiation - Multiple reflection analysis by MDAC program TRASYS using calculated surface temperatures.
- Receiver Convection - Estimated from Martin Marietta correlation of scaled cavity receiver tests.
- Piping Losses - Calculation with selected insulation.
- Viscous Dissipation - Estimated recovery of receiver head as heat by viscous dissipation in the drag valve and hot salt pipe.

5.4 RECEIVER SUBSYSTEM

The receiver subsystem includes assembly, the receiver tower, and the fluid loop. These are described in the following section.

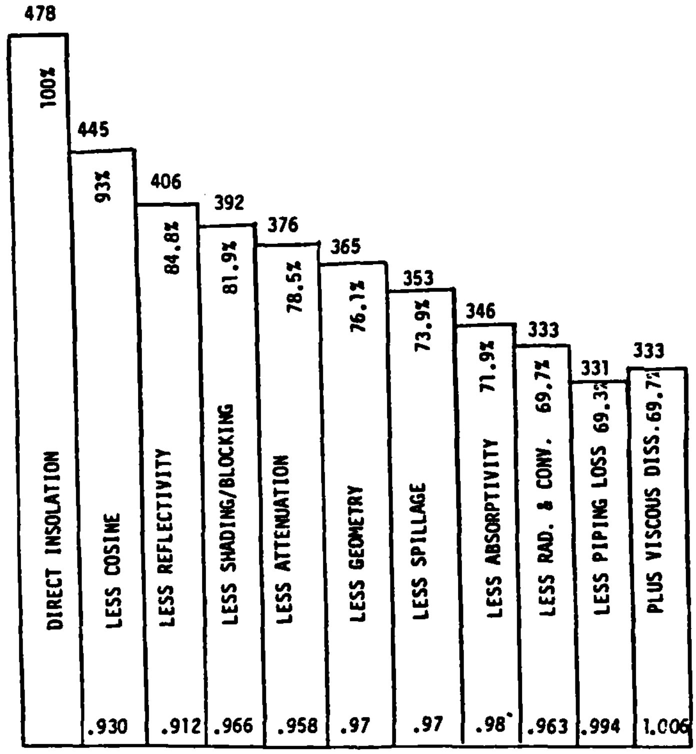


Figure 5-6 Design Point--Spring Equinox

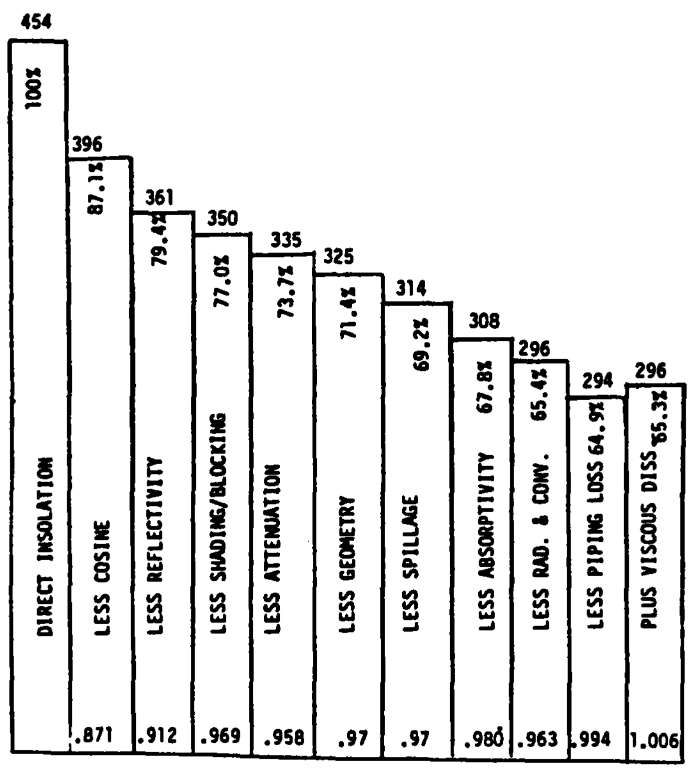


Figure 5-7 Summer Solstice Noon Performance

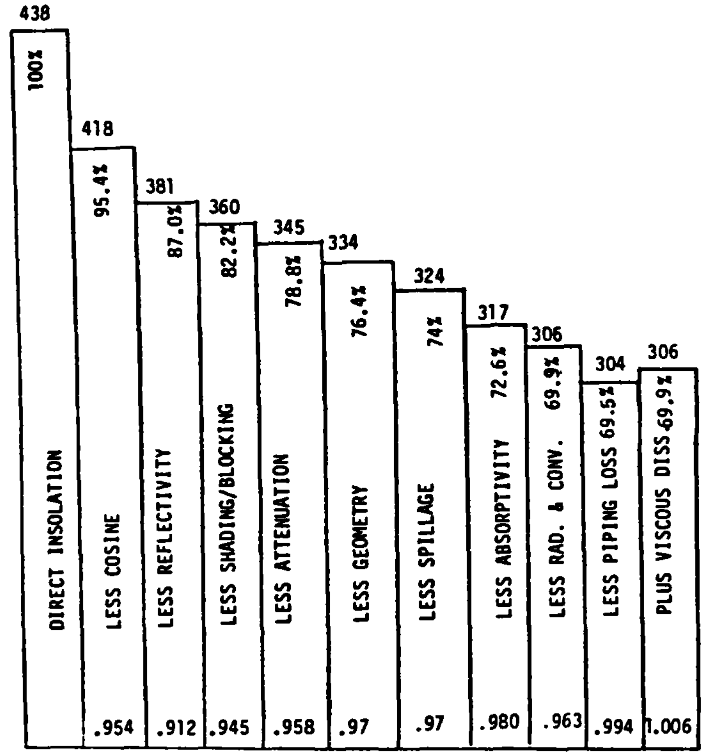


Figure 5-8 Winter Solstice Noon Performance

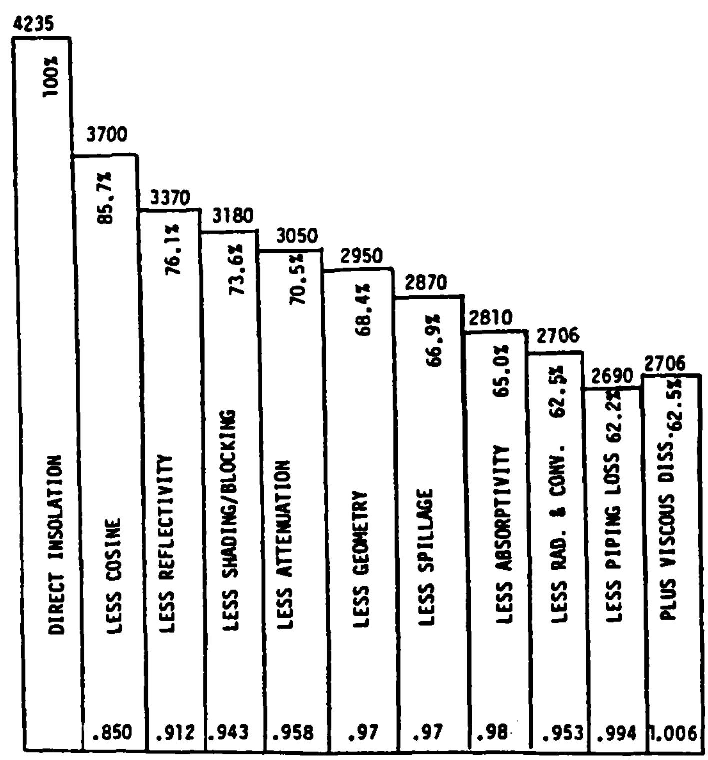


Figure 5-9 Clear Day Annual Average

5.4.1 RECEIVER

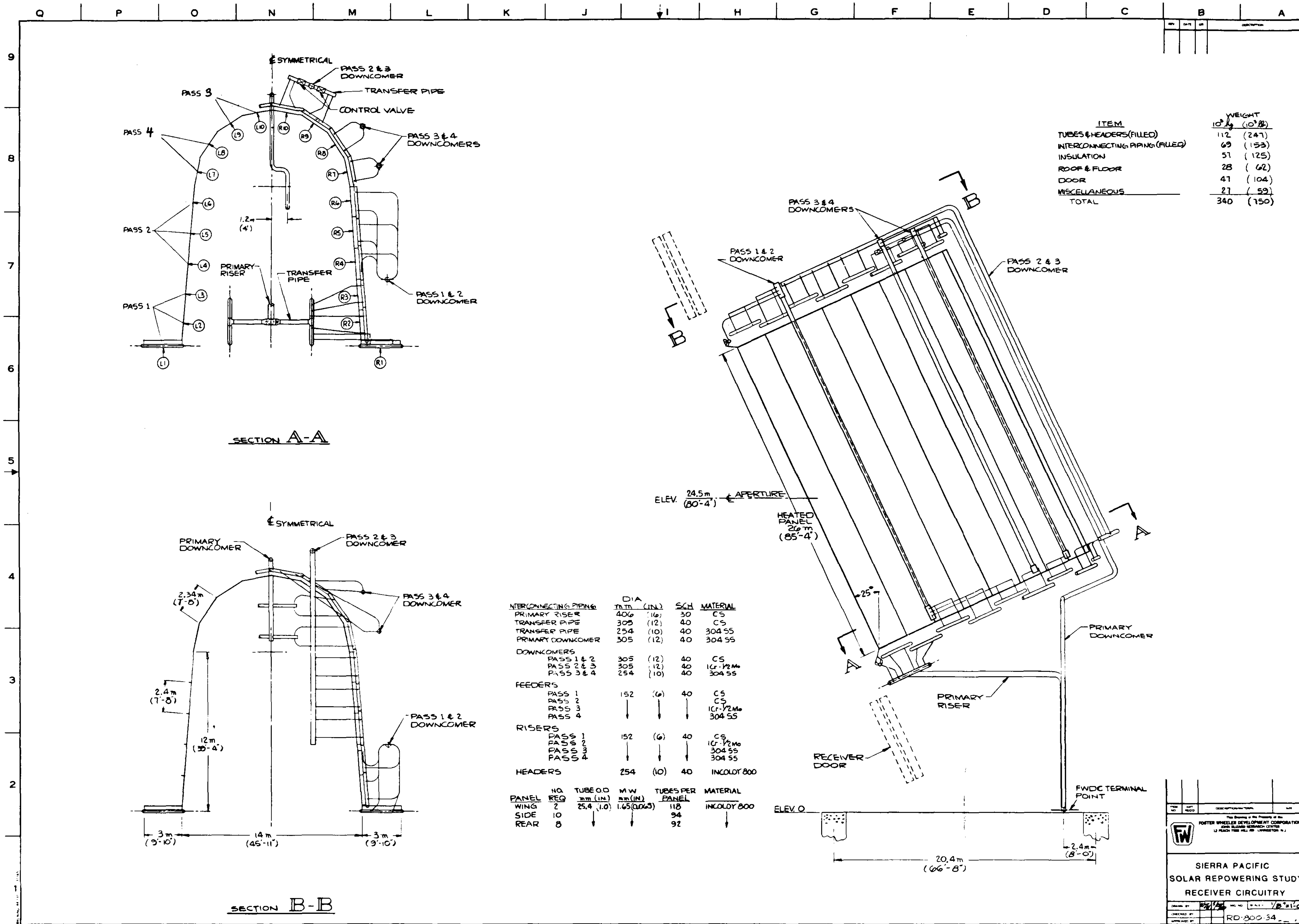
5.4.1.1 Description

The receiver is an omega-shaped, partial cavity design consisting of two (2) external wing panels, ten (10) internal side panels, and eight (8) internal rear panels as shown in Figure 5-10. The aperture plane is tilted 25° from vertical to face the north collector field. Molten salt entering the receiver is heated from 288° C (550°F) to 566°C (1050°F). The design point (equinox noon) thermal rating of the receiver is 330 MW_{th}.

The absorber portion of a receiver panel consists of 25.4 mm (1.0 in.) O.D. Incoloy 800 tubes with 1.65 mm (0.065 in.) minimum wall thickness. The tubes are parallel, in plane, and continuously welded to the adjacent tubes on 25.4 mm (1.0 in.) centers. The heated length of each panel is 26 m (85.3 ft.). Panel widths vary from 2.34 m (7.67 ft) to 3 m (9.84 ft) as noted in Figure 5-10. The heated face of each panel is coated with a high temperature absorptive paint (Pyromark).

Panels are grouped in a four (4) pass arrangement. Low temperature preheater passes 1 and 2 are positioned toward the front of the receiver, while high temperature passes 3 and 4 are positioned toward the rear of the receiver to minimize ambient heat losses. Outlet pass 4, with the highest salt temperature, was positioned in the rear portion of the receiver with the lowest peak heat flux levels (panels L7, L8, R7, R8).

The arrangement of the receiver circuitry is schematically illustrated in Figure 5-11. The arrangement was designed for salt to flow up through each panel. The left and right halves of the receiver operate as independent parallel flow circuits with the flow through each dependent upon the total heat absorbed in the respective half of the receiver. Pass 1 and pass 2 of each circuit have three (3) uncontrolled, parallel flow panels. Each pass 1 and pass 2 tube in a given circuit receives approximately the same salt flow. Flow leaving the pass 1 and pass 2 panels mix in a downcomer which delivers salt at a uniform temperature to the down stream panels. Pass 3 of each circuit has two (2) panels in parallel. Each is connected in series to specific pass 4 panels. The salt flow rate through each series of panels is controlled to maintain the leaving salt temperature at 566°C (1050°F). The receiver controller is discussed in section 5.5.2. High absorption panels in

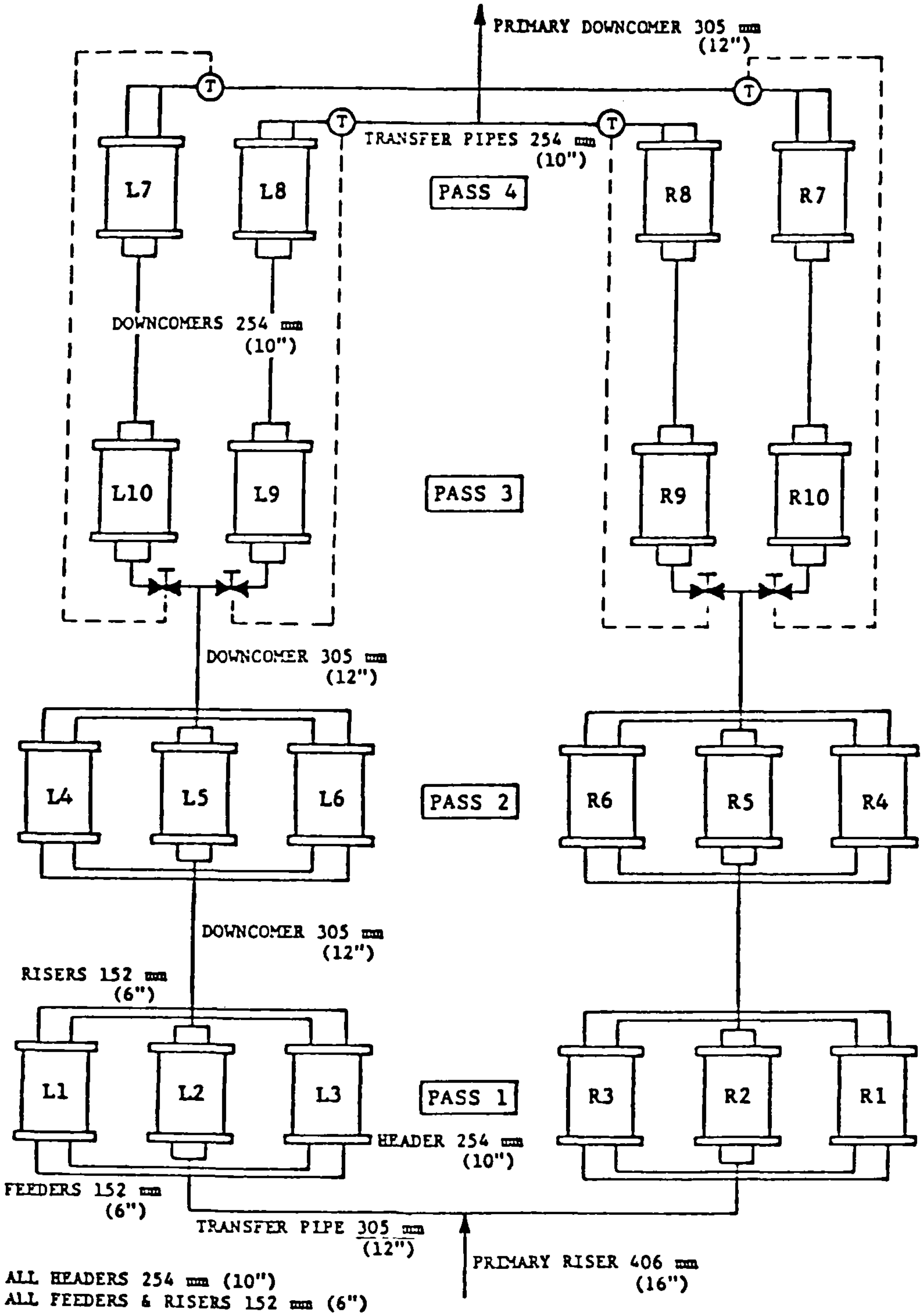


ITEM	WEIGHT 10^3 kg	(10^3 lb)
TUBES & HEADERS (FILLED)	112	(247)
INTERCONNECTING PIPING (FILLED)	69	(153)
INSULATION	57	(125)
ROOF & FLOOR	28	(62)
DOOR	47	(104)
MISCELLANEOUS	27	(59)
TOTAL	340	(750)

INTERCONNECTING PIPING	DIA mm	(IN)	SCH	MATERIAL
PRIMARY RISER	406	(16)	30	CS
TRANSFER PIPE	305	(12)	40	CS
TRANSFER PIPE	254	(10)	40	304 SS
PRIMARY DOWNCOMER	305	(12)	40	304 SS
DOWNCOMERS				
PASS 1 & 2	305	(12)	40	CS
PASS 2 & 3	305	(12)	40	1Cr-1/2Mo
PASS 3 & 4	254	(10)	40	304 SS
FEEDERS				
PASS 1	152	(6)	40	CS
PASS 2	↓	↓	↓	CS
PASS 3	↓	↓	↓	1Cr-1/2Mo
PASS 4	↓	↓	↓	304 SS
RISERS				
PASS 1	152	(6)	40	CS
PASS 2	↓	↓	↓	1Cr-1/2Mo
PASS 3	↓	↓	↓	304 SS
PASS 4	↓	↓	↓	304 SS
HEADERS	254	(10)	40	INCOLOY 800

PANEL	NO. REQ	TUBE O.D mm (IN)	MW mm (IN)	TUBES PER PANEL	MATERIAL
WING	2	25.4 (1.0)	1.65 (0.065)	118	INCOLOY 800
SIDE	10	↓	↓	94	↓
REAR	8	↓	↓	92	↓

Figure 5-10 RECEIVER DESIGN



5-11 Receiver Circuitry Arrangement

pass 3 were connected in series to low absorption panels in pass 4 in order to minimize the variation in flow rate through each of the outlet pass panels.

All headers, feeders, and risers are 0.254 m (10 in.), 0.152 m (6 in.) and 0.152 m (6 in.) schedule 40 pipe, respectively. Sizes were selected to minimize header flow imbalance, pressure drop, and length required for flexibility. The layout of all interconnecting salt piping is illustrated in Figure 5-10. The piping layout was arranged so that the system is completely drainable.

The receiver floor and roof are uncooled reflective surfaces, insulated on the outside. For the purpose of the conceptual design study, a waffled 304 stainless steel floor and roof (supplied by Glitsch Cryogenics) were selected since a surface is required that can expand within the bounds of the receiver panels.

All panels, headers, and interconnecting salt piping are electrically trace heated to preheat and maintain the receiver circuitry at a temperature of 288°C (550°F). A four (4) panel door assembly is provided to minimize ambient heat losses when the unit is not in operation. The receiver panels are insulated with a mineral wool blanket while all interconnecting salt piping is insulated with calcium silicate. This arrangement was selected in order to provide personnel protection as well as minimize ambient heat losses. All insulation is covered with aluminum lagging.

5.4.1.2 Performance

Significant receiver performance characteristics include the following:

- The receiver design point is equinox noon with 330 MW_{th} absorbed, heating 767 kg/sec (6.09 x 10^6 lb/h) of molten salt from 288°C (550°F) to 566°C (1050°F).

- Heat absorbed in each receiver panel was determined from the product of the receiver panel flat projected heated area and the panel's average absorbed heat flux obtained from Figure 5-12 for equinox (noon and 4:00 p.m.) and from Figure 5-13 for winter solstice 9:00 a.m.). The absorbed heat flux values around the receiver perimeter plotted in Figures 5-12 and 5-13, were determined from two-dimensional heat flux

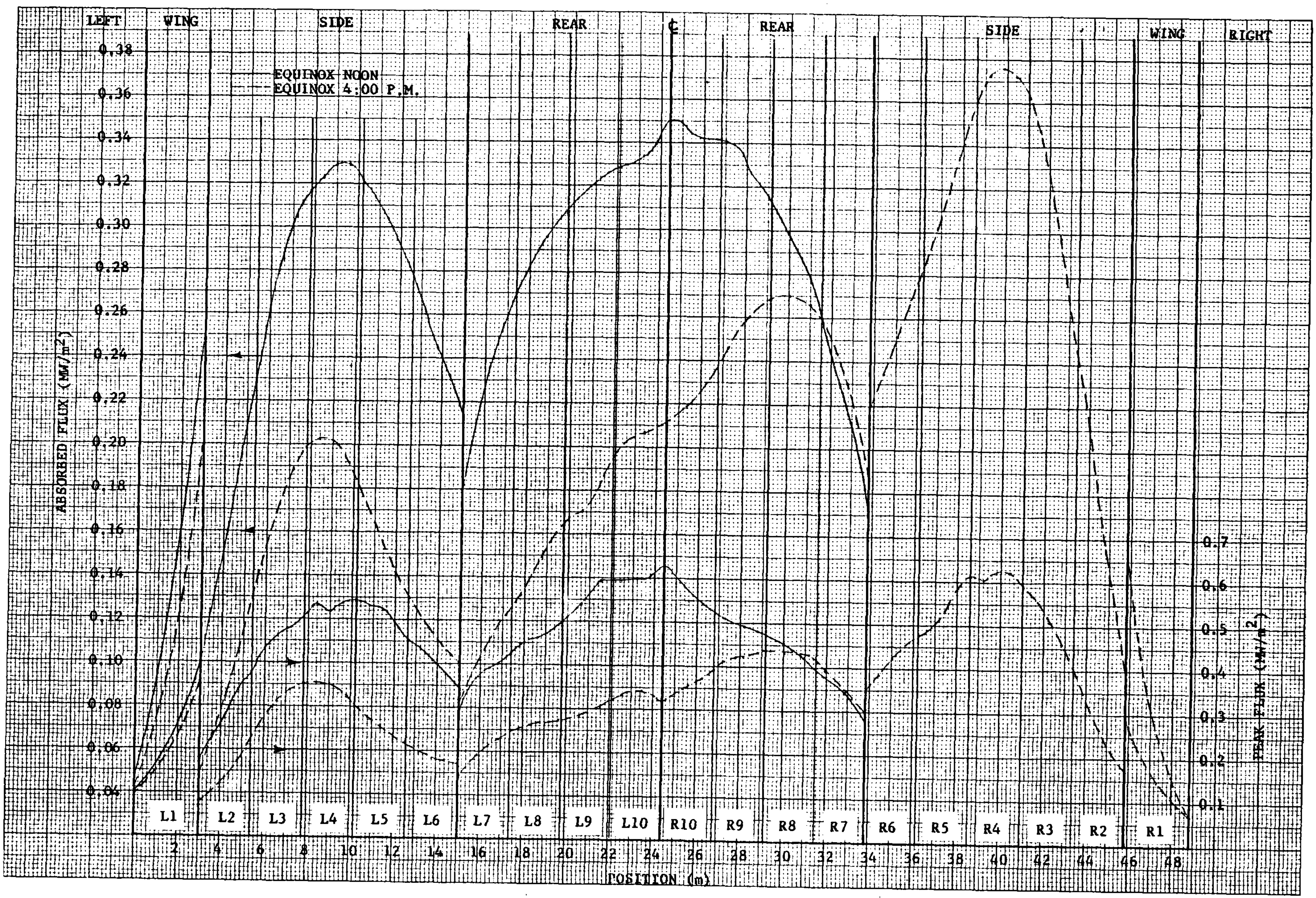


Figure 5-12 Receiver Absorbed Flux - Equinox

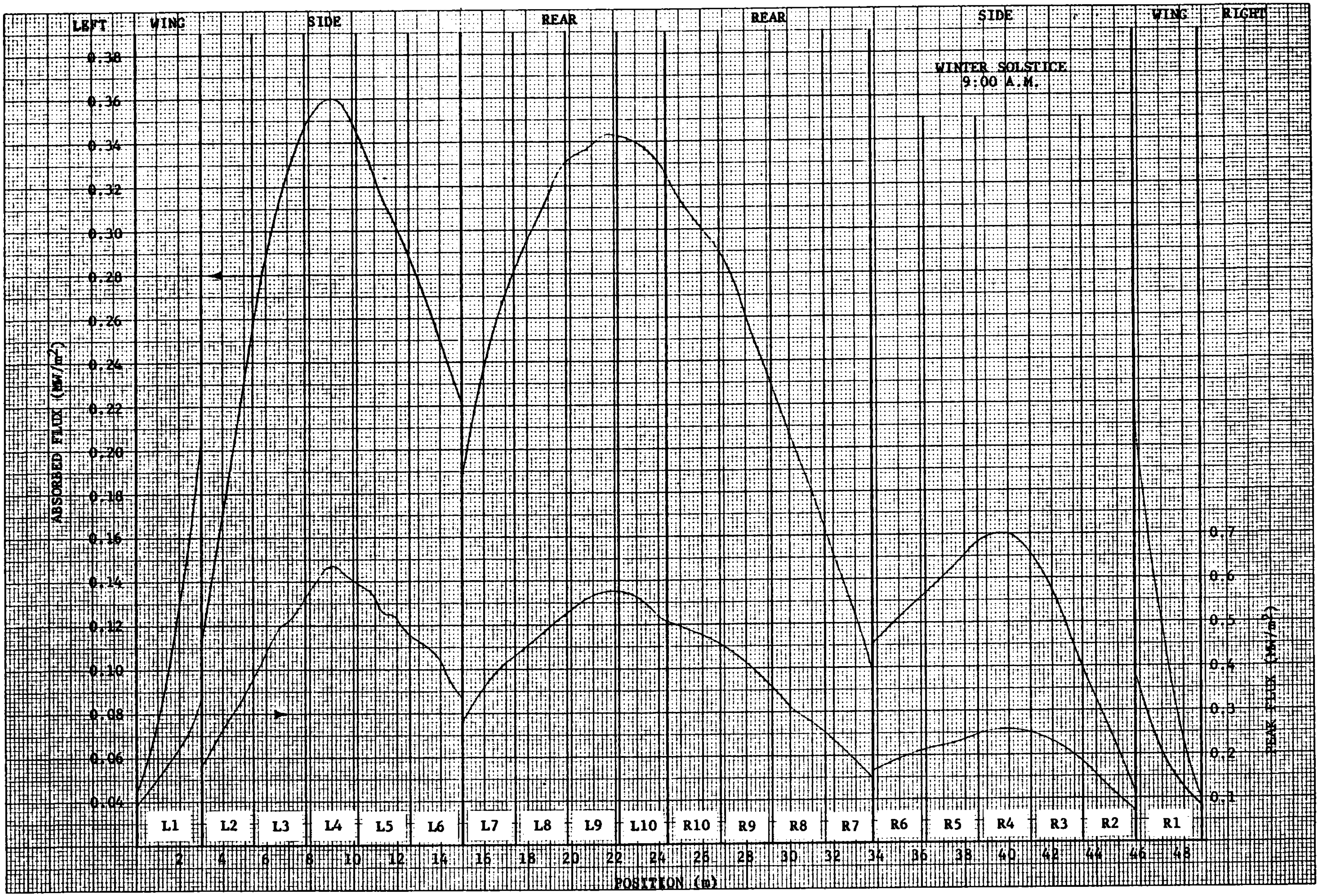


Figure 5-13 Receiver Absorbed Flux - Winter Solstice

maps supplied by MDAC computer program CONCEN. The heat flux distribution for equinox noon is symmetrical about the receiver centerline. Variation in heat flux across each receiver panel can be noted from Figures 5-12 and 5-13.

- Flow sensitivity to heat flux variations across the panel width was checked for wing panel L1 with equinox noon conditions. Total pressure drop (frictional and gravity head) was computed for the coldest tube (36% of the average tube heat load) and the hottest tube (186% of the average tube heat load) and the average tube as a function of flow multiplier. The flow multiplier is defined as the fraction of the average flow rate. Results are plotted in Figure 5-14. As noted in the figure, the cold tube has approximately 1.5% more flow than the average tube. Consequently, salt flow through the panel is very insensitive to heat flux variations across the panel width and each tube within a panel will have essentially the same salt flow rate.

- Salt inlet temperatures and lateral outlet temperature distributions for each panel are plotted in Figure 5-15 and 5-16 for equinox noon and winter solstice at 9:00 a.m., respectively. Equal flow per tube within a panel was assumed based on the aforementioned flow sensitivity analysis. Wing panel R1 during winter solstice at 9:00 a.m. has a leaving salt temperature variation of 74.4°C (166°F) which results in an average mean metal temperature variation of 83.3°C (182°F) across the panel width. Foster Wheeler's past experience with various panel designs indicates that a metal temperature variation of approximately 57.8°C (100°F) is tolerable. However, a detailed analysis is required to determine the specific temperature variation limits for this application. It may be necessary to divide each wing panel into two (2) separate panels or provide means for varying the flow rate through wing panel tubes by means of tube

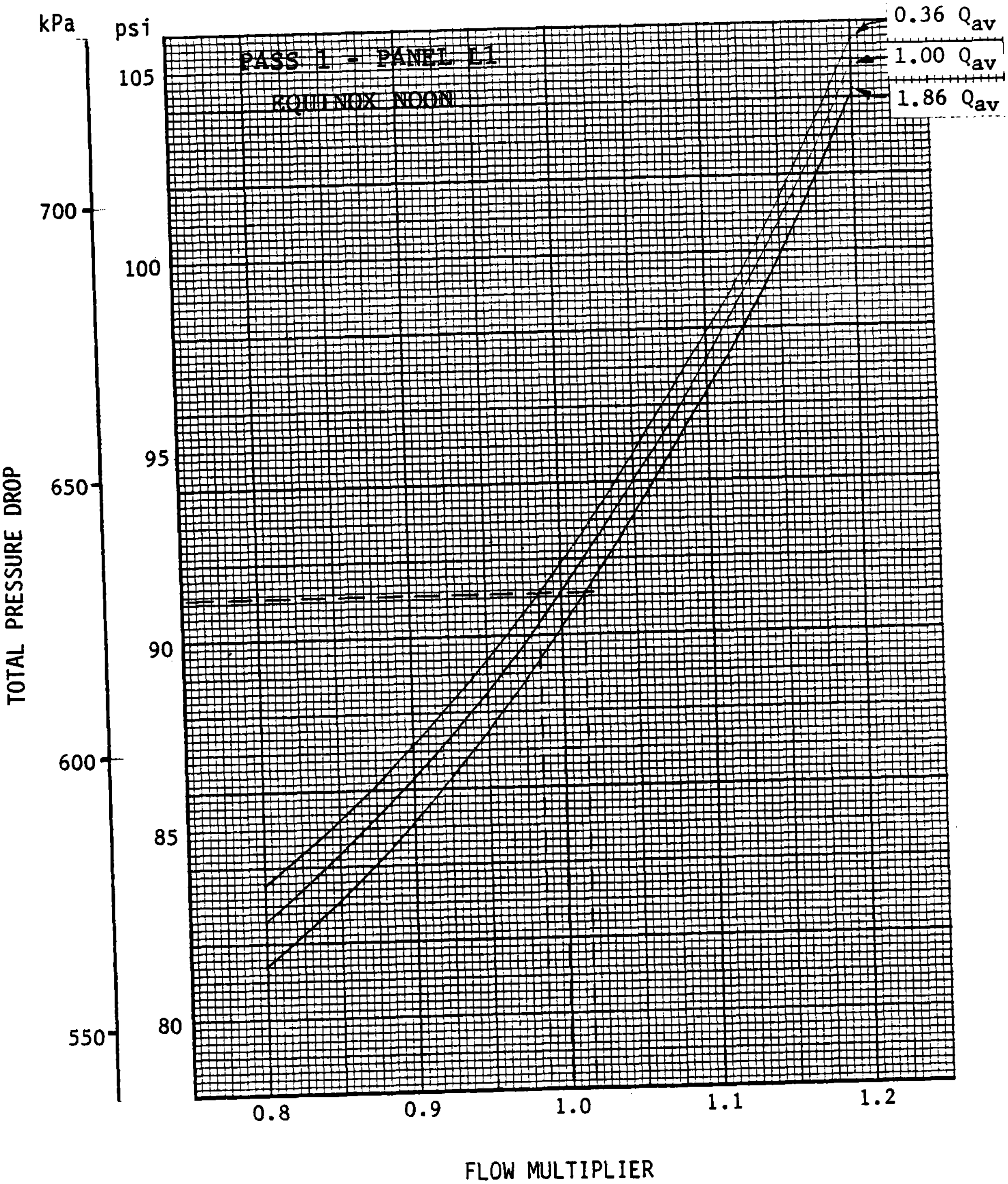


Figure 5-14 Receiver Flow Sensitivity

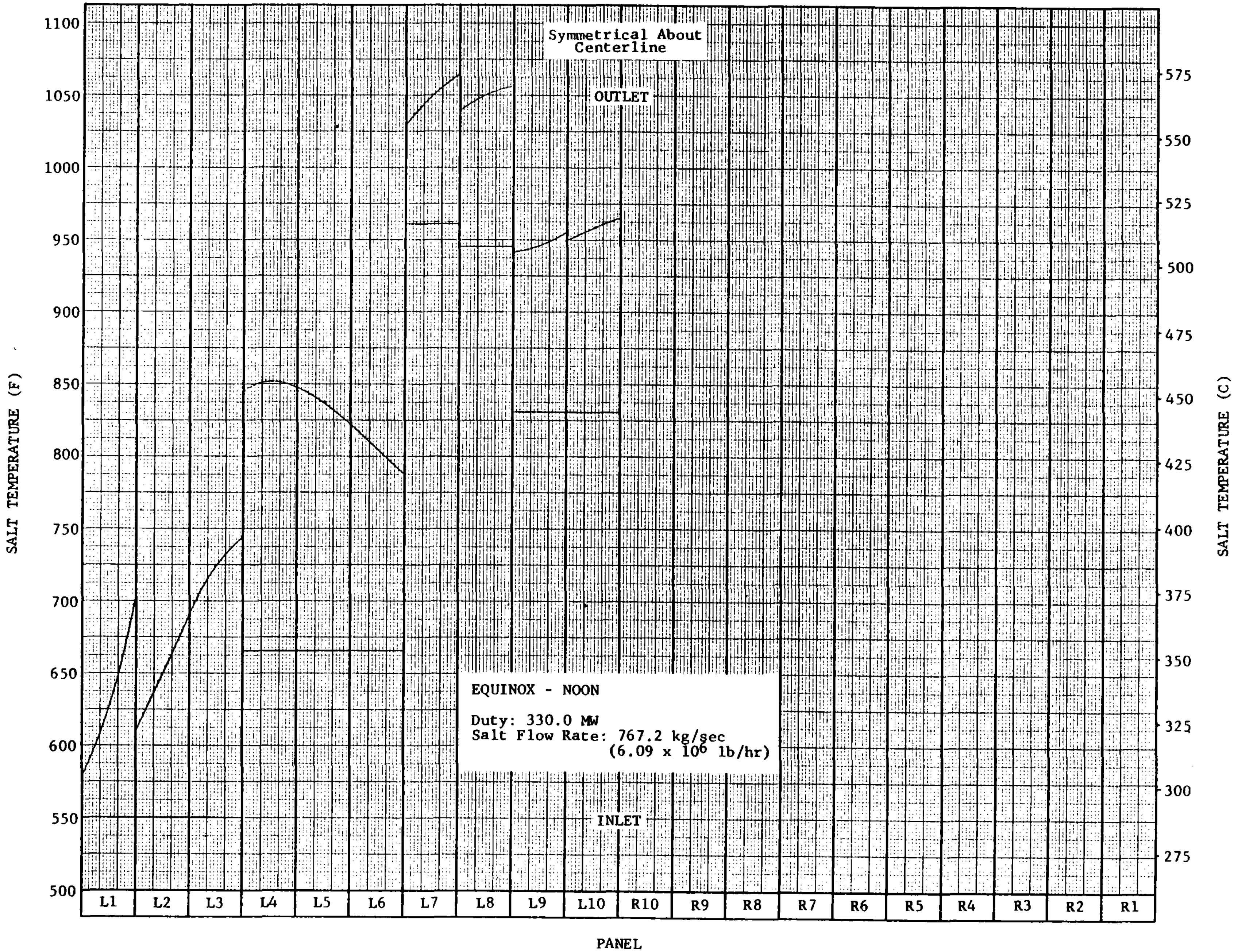


Figure 5-15 Receiver Salt Temperatures - Equinox

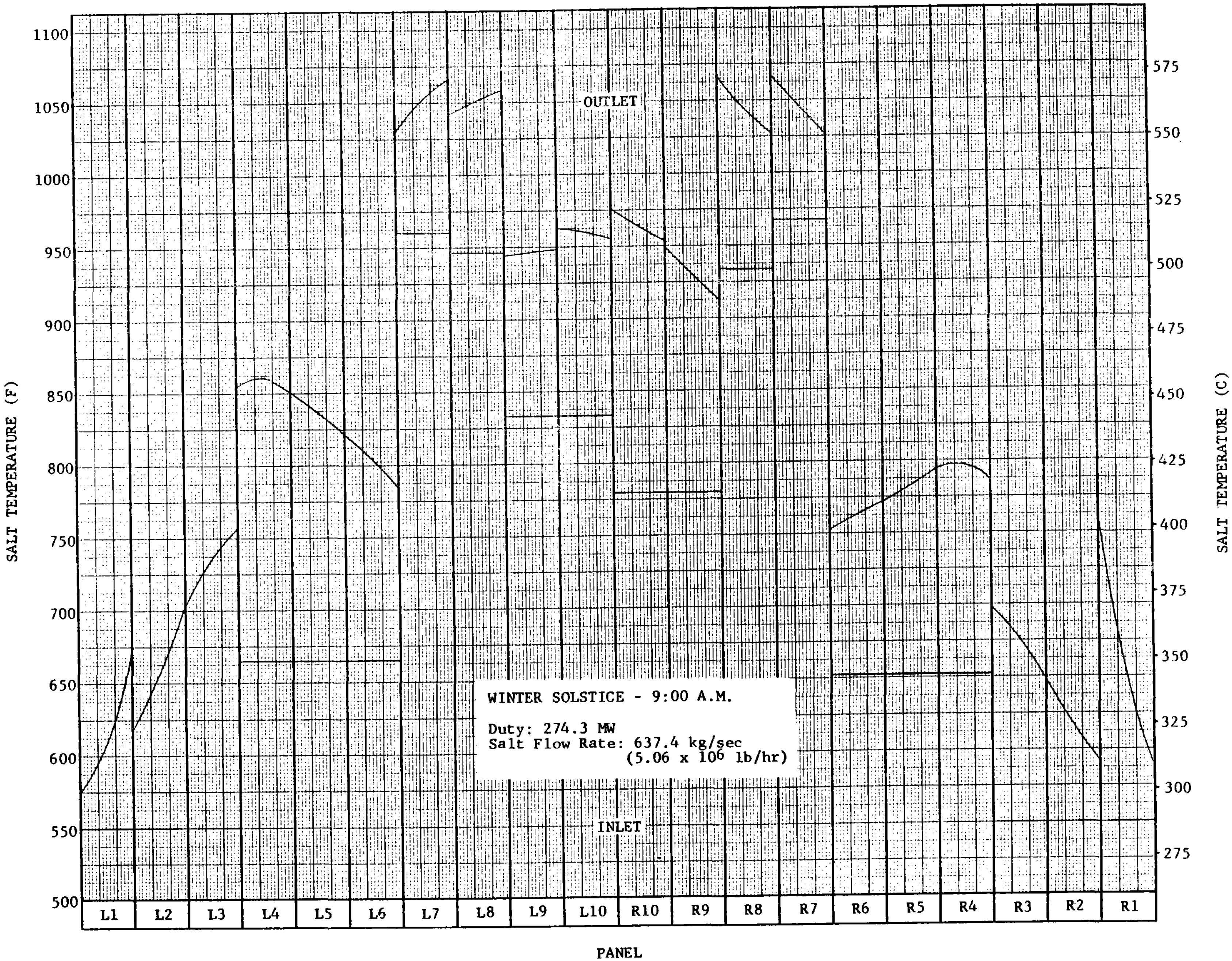


Figure 5-16 Receiver Salt Temperature - Winter Solstice

orifices, varying tube size, or baffling the inlet header and orificing the feeders to each inlet header section.

- Design point frictional pressure drops through the receiver circuitry are as follows:

	Pressue Drop kPa (psi)
Inlet Piping	26.2 (3.8)
Pass 1	98.6 (14.3)
Interconnecting Piping	26.2 (3.8)
Pass 2	109.0 (15.8)
Interconnecting Piping	29.7 (4.3)
Control Valve (as per Stearns-Roger)	--
Pass 3	221.4 (32.1)
Interconnecting Piping	21.4 (3.1)
Pass 4	249.0 (36.1)
Outlet Piping	40.0 (5.8)
Total	821.5 (119.1)

Inlet passes 1 and 2 have low temperature salt (see Figure 5-15) and as a result low tube metal temperatures. Consequently, high heat flux levels and low salt side film coefficients can be tolerated. Outlet passes 3 and 4 have high temperature salt and as a result high tube metal temperatures. Consequently, high salt side film coefficients are required to minimize the front-to-back tube temperature gradient and the resultant tube stress levels. In order to minimize the overall pressure drop through the receiver, passes 1 and 2 were designed for low mass flow rates and passes 3 and 4 were designed for high mass flow rates.

- A computer program was written to analyze individual receiver tubes. The heated portion (26 m [85.3 ft]) of the receiver tube was broken down into twenty (20) equal nodes, each of which was 1.3 m (4.3 ft) long. The Dittus-Boelter correlation was used to determine the salt film coefficient. Properties for Partherm 430 and Incoloy 800 were used. Total pressure drop calculations included losses for the unheated inlet and outlet tube lengths. Significant results for the hottest tube in each pass for equinox noon conditions are plotted in Figures 5-17 and 5-20.

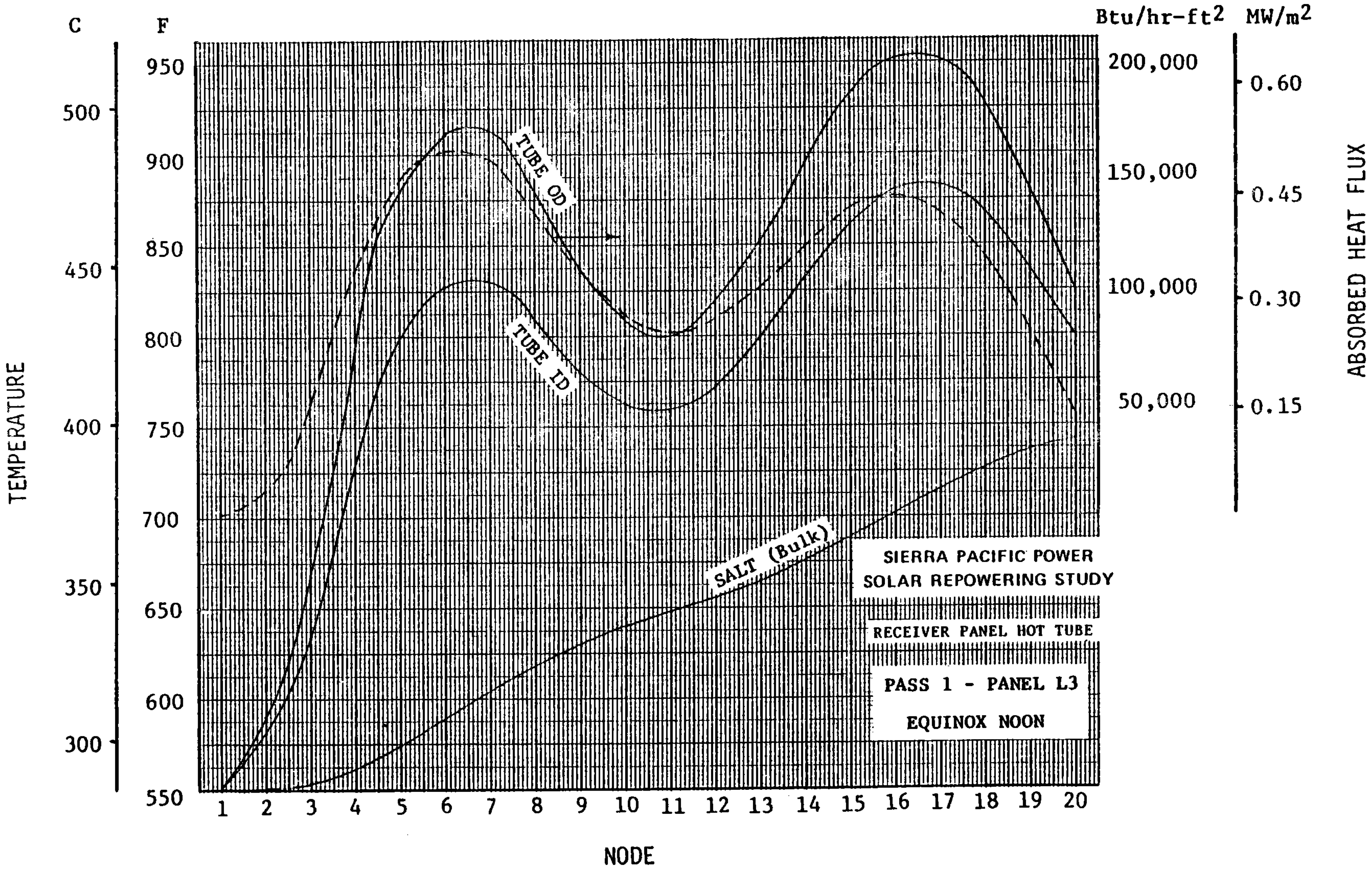


Figure 5-17 Receiver Tube Characteristics - Pass 1 - Panel L3

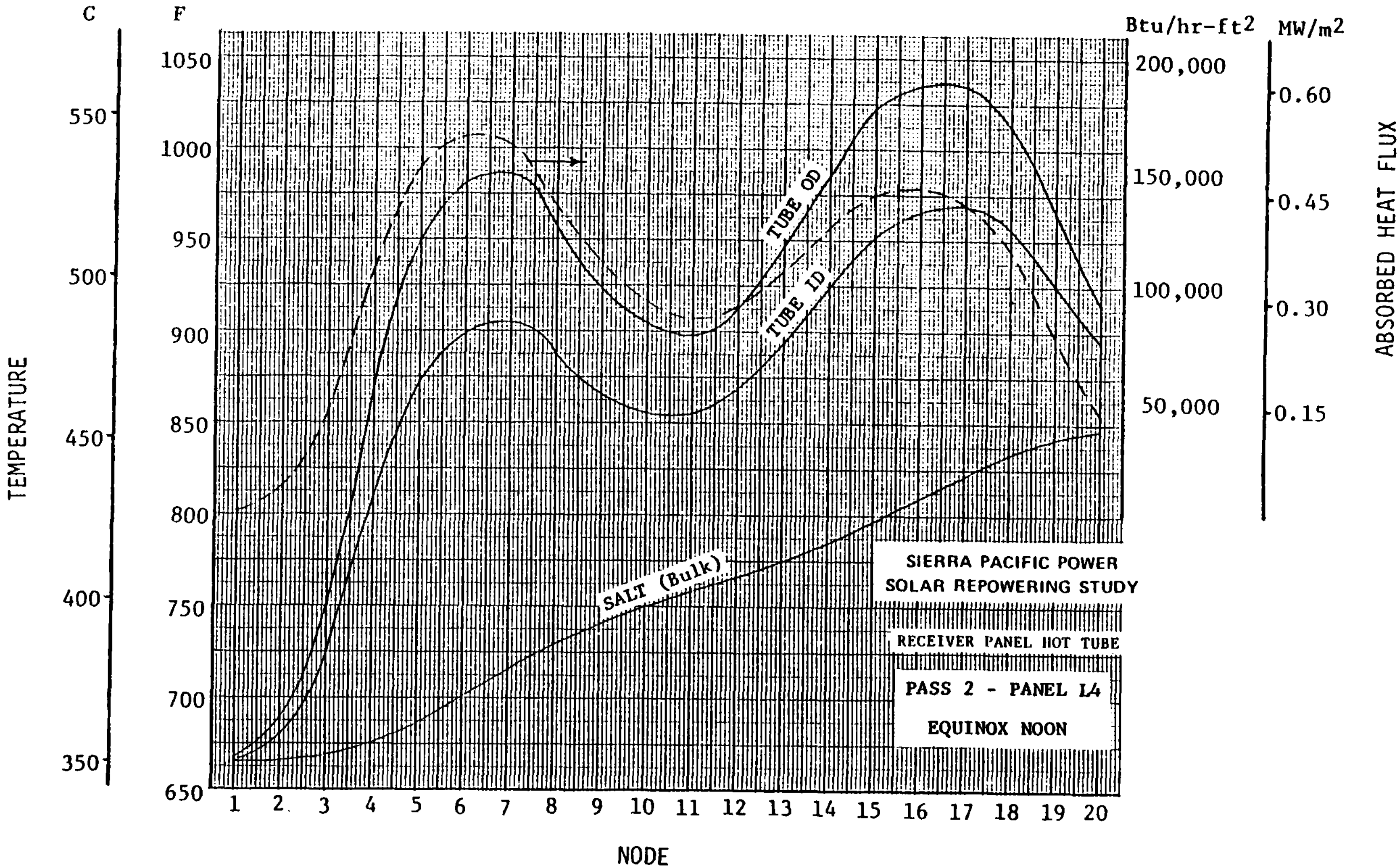


Figure 5-18 Receiver Tube Characteristics - Pass 2 - Panel L4

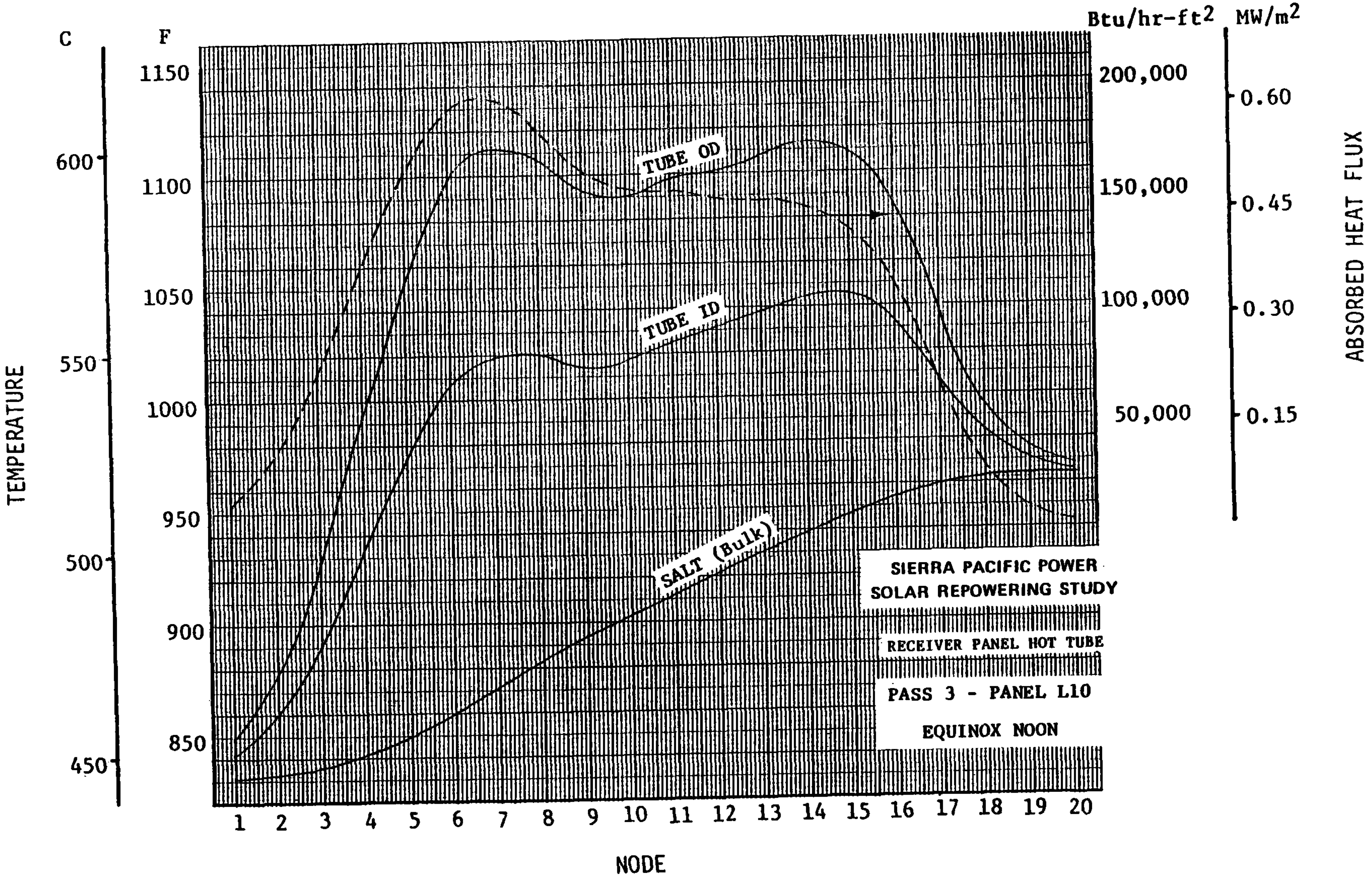


Figure 5-19 Receiver Tube Characteristics - Pass 3 - Panel L10

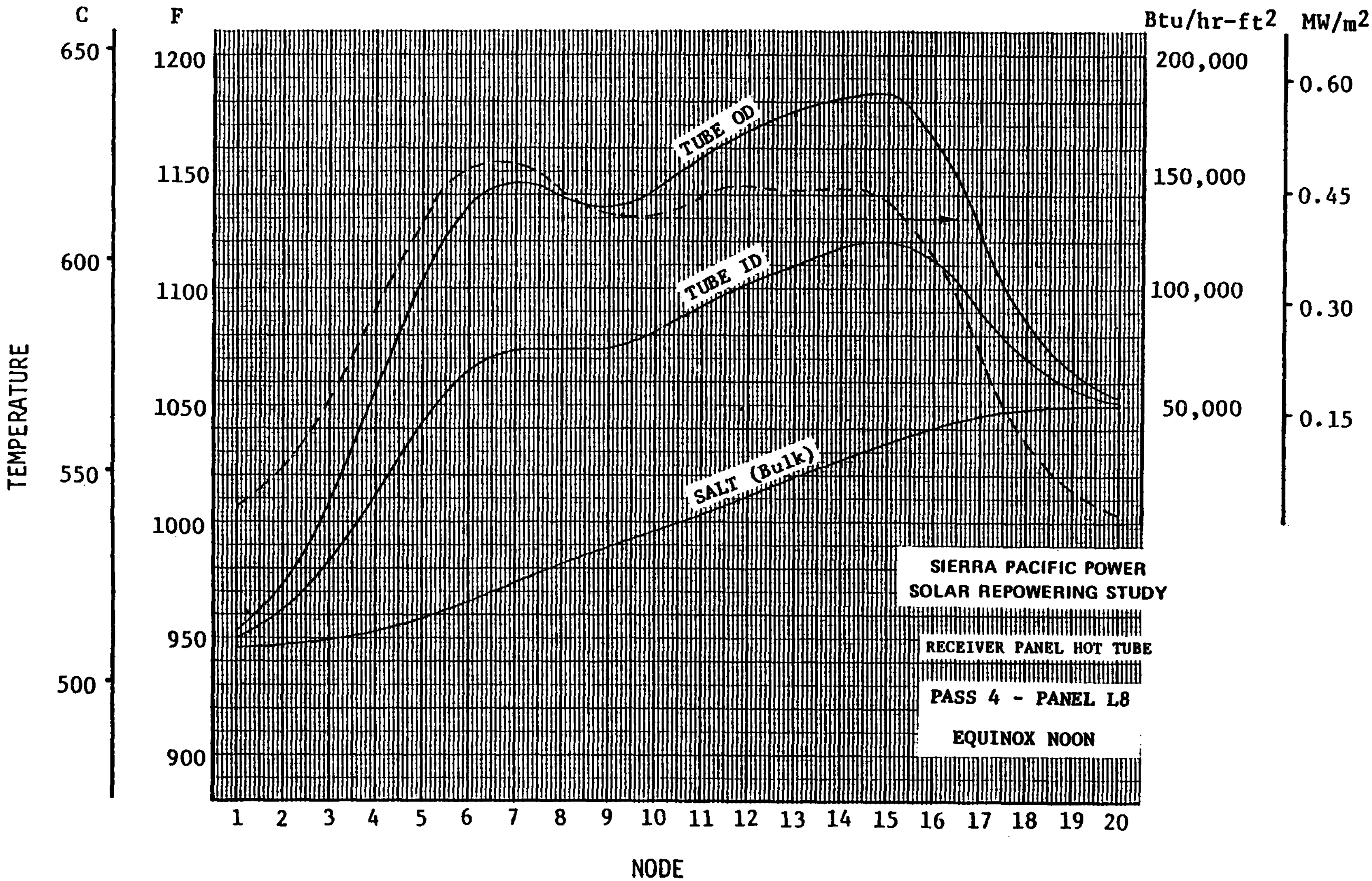


Figure 5-20 Receiver Tube Characteristics - Pass 4 - Panel L8

- Figure 5-20 indicates that panel L8 has a section with a local salt film temperature of approximately 604°C (1120°F) which exceeds the salt maximum temperature goal of 593°C (1100°F) specified by Park Chemical. The quantity of salt exposed to this temperature level is only a small fraction of the total salt flow rate and is exposed to this temperature level for only a short period of time due to the salt velocity through the tubing and the resultant turbulent mixing. As the design is refined, the salt temperature within this area can be reduced by optimizing the salt side flow characteristics through the receiver circuitry and the incident heat flux distribution.

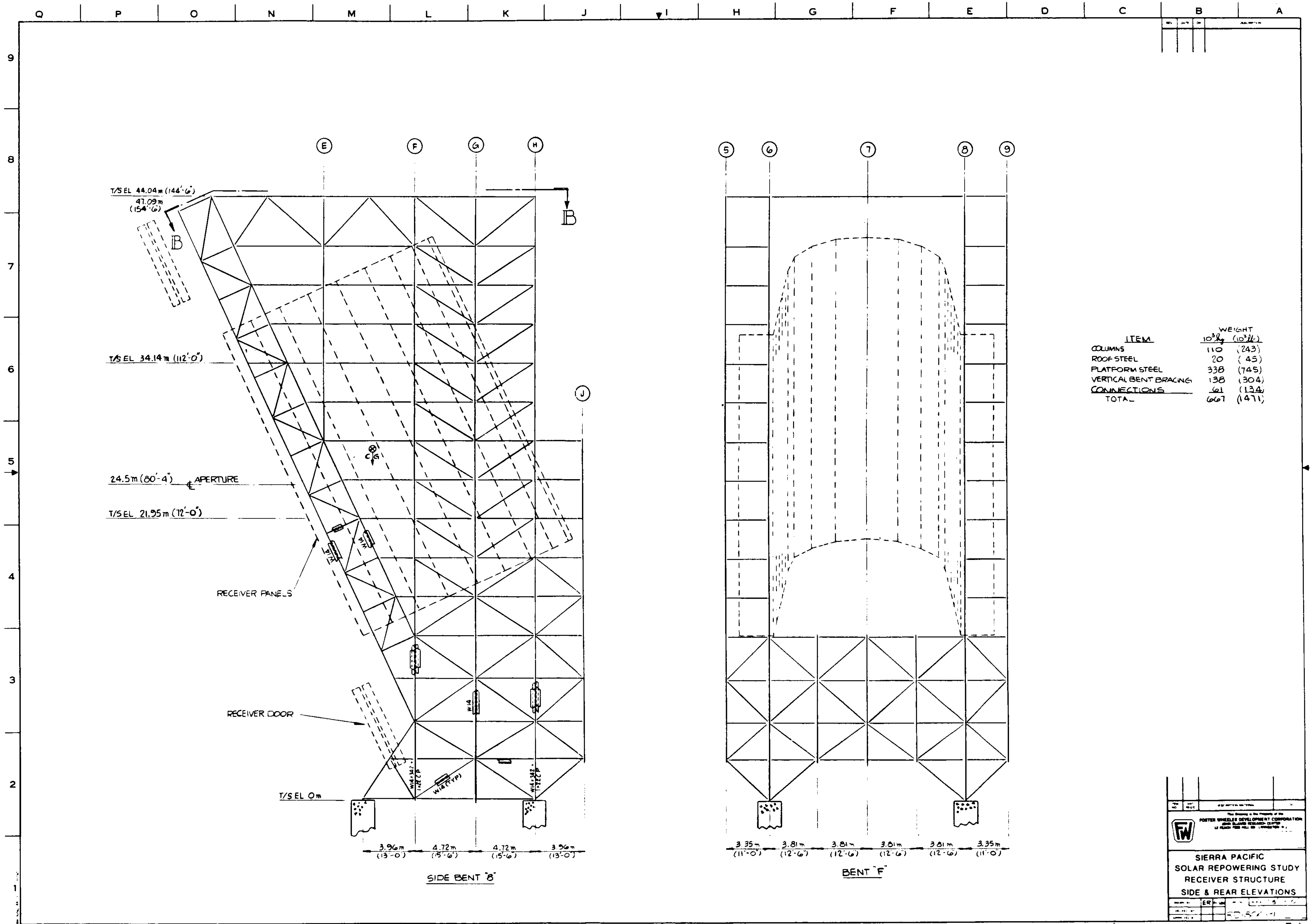
5.4.1.3.1 Support Structure Design

Figures 5-21 and 5-22 illustrate the structure required to support the 340,100 kg (750,000 lb) receiver. The structure was sized for a 0.57 g seismic load and a 2.4 kPa (50 lb/ft^2) wind load.

The front bent (vertical section) is open to allow for an uninterrupted path for solar radiation. A latticed column on both sides of this opening is used to transfer the shear resulting from the side-to-side seismic and wind loadings to the roof and to the base of the structure. The shear load, which is transferred to the roof truss, is transmitted to rear bent (H) and then down to the base. This causes torsion in the structure which is resisted by a couple whose forces are transmitted to the base of the structure via side bents 6 and 8. Seismic and wind loads in the front-to-rear direction are continuously transmitted to the base through shear via side bents 6 and 8.

The receiver gravity loads are taken to the roof via hangers and then transmitted to the base of the structure via bents 6, 8, and H. Lateral loads originating at the receiver and external wind loads are taken by horizontal ties to the structural steel. Horizontal trusses on both sides of the receiver at each level transmit the loads to the appropriate bents.

Platform loads are assigned to every other level at approximately 6 m (20 ft) intervals. Stairs can be accommodated within the structure but an external elevator bay is necessary in order to avoid disrupting the horizontal trusses at each level.



ITEM	WEIGHT 10^3 kg	(10^3 lb)
COLUMNS	110	(243)
ROOF STEEL	20	(45)
PLATFORM STEEL	338	(745)
VERTICAL BENT BRACING	138	(304)
CONNECTIONS	61	(134)
TOTAL	667	(1471)

Figure 5-21 RECEIVER SUPPORT STRUCTURE

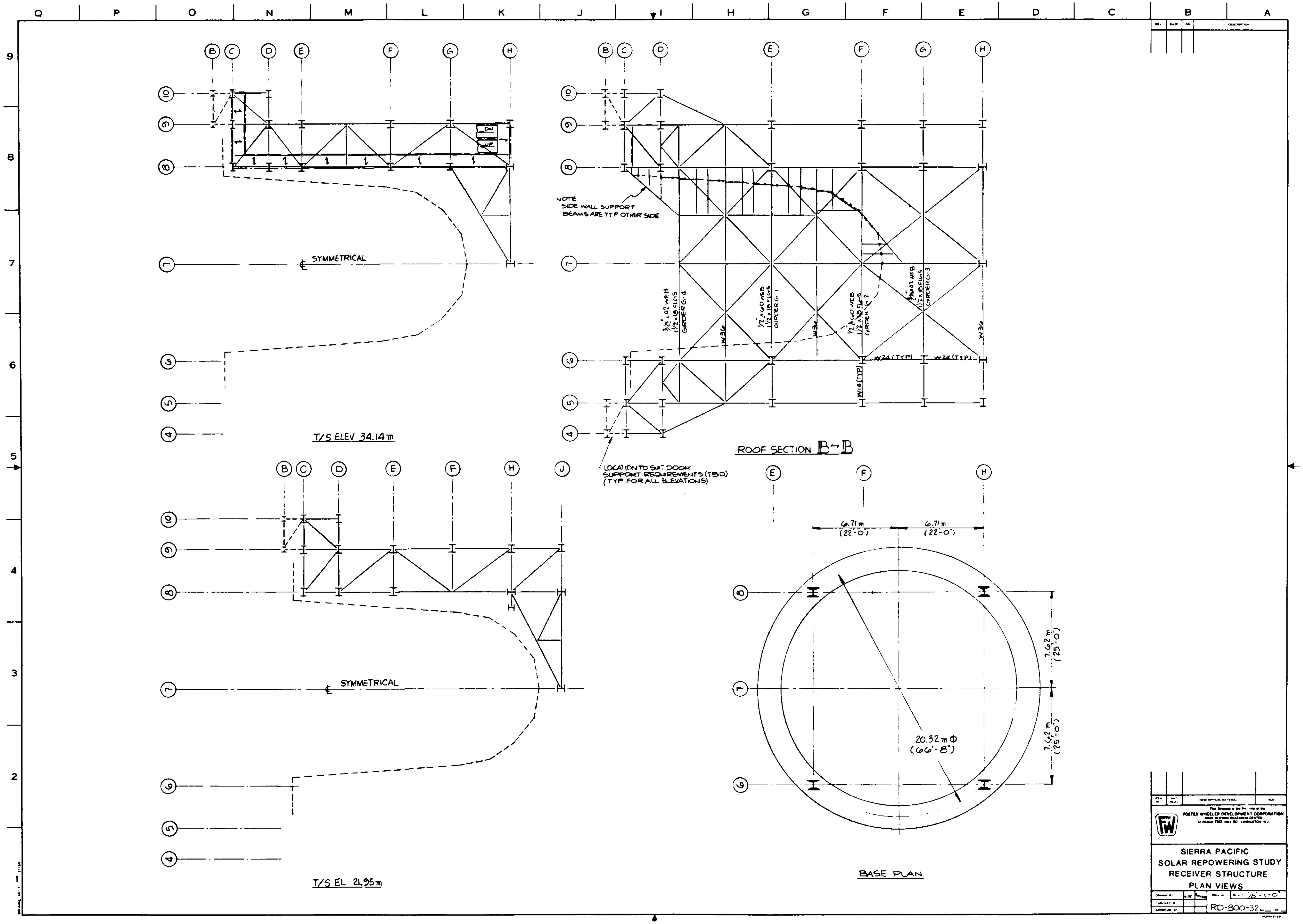


Figure 5-22 RECEIVER STRUCTURE

The structure was arranged to provide space for panel doors in the open position, to avoid, as much as possible, a gravity uplift condition on the bent H column bases. With a tower diameter of 20.3 m (66.7 ft) the seismic uplift on the rear bent columns is approximately 31 MPa (4500 ksi). This load will require special design consideration in transmitting the load to the concrete tower.

The weight estimate of the structure was based on an empirical volume analysis used successfully by Foster Wheeler for many years. It incorporates all pertinent design parameters including the seismic loadings. Estimated weights are tabulated in Figure 5-21. Approximately 680,300 kg (1,500,000) lb) of structural steel is required to make the structure sufficiently stiff to sustain a 0.57 g seismic load. For a 0.2 g seismic load that would result with a steel tower design, approximately 88,400 kg (195,000 lb) less support steel is required.

5.4.1.4 Absorber Panel Assembly

5.4.1.4.1 Absorber Panel

Each receiver panel is a shop fabricated unit consisting of the following:

- Panel Tubes - Incoloy 800, 25.4 mm (1.0 in.) O.D. with 1.65 mm (0.065 in.) minimum wall thickness continuously welded (See Section 3.4.2 for panel fabrication) on 25.4 mm (1.0 in.) centers. The wing, side, and rear panels have 118, 94, and 92 tubes, respectively. Each panel is 26 m (85.3 ft) long.

- Inlet and Outlet Headers - Incoloy 800, 0.25 m (10 in.), schedule 40 each with two (2) 0.15 m (6 in.) nozzle connections for feeders/risers.

- Unheated inlet and Outlet Tubes ("Jumper Tubes") - Incoloy 800, 25.4 mm (1.0 in.) O.D. with 1.65 mm (0.065 in.) minimum wall thickness used to connected panel tubes to header.

- Support Lugs

- Buckstays

A typical panel is illustrated in Figure 5-23. Each panel is shop assembled with the aforementioned items. Panels will be shipped in a specially designed shipping fixture, parts of which can be used as a handling fixture to install the panels in the support structure. The number of panels per shipping fixture will bepend on the erection schedule requirements. Removeable erection clips will be attached to selected buckstays to anchor the panels in the shipping fixture and to attach the panels to the handling fixture. Support links, hangers, etc., will be attached to the panels during erection. Panel and header electrical trace heaters (Section 5.4.4), insulation and lagging are to be field installed.

5.4.1.4.2 Absorber Panel Support

The proposed absorber panel support arrangement is illustrated in Figure 5-23. A typical side panel is shown to illustrate the concept. The wing and rear panel support arrangement is similar.

Support lugs are welded between every fifth panel tube and vertically spaced 1.2 m (4.2 ft) apart. The central lug at each elevation is fixed to a buckstay which traverses the panel width. Lateral expansion of the panel is permitted by movement of the remaining lugs relative to the buckstay. The buckstay is attached to the support structure by means of support links which permit longitudinal expansion of the panel. The central support links position the center of each panel.

The support lug spacing is dependent upon the panel wind loadings and the deflection resulting from the solar radiation heating one side of the panel. The spacings indicated in Figure 5-23 are based on Foster Wheeler experience in panel design. The exact spacing and details of the lug weld between tubes merit further analysis and testing because of the stress concentration at the weld and the tendency for nucleation and propagation of cracks. Lug attachment to the panel will bepend on the panel fabrication method which requires further analysis and development as noted in Section 5.4.3.3.

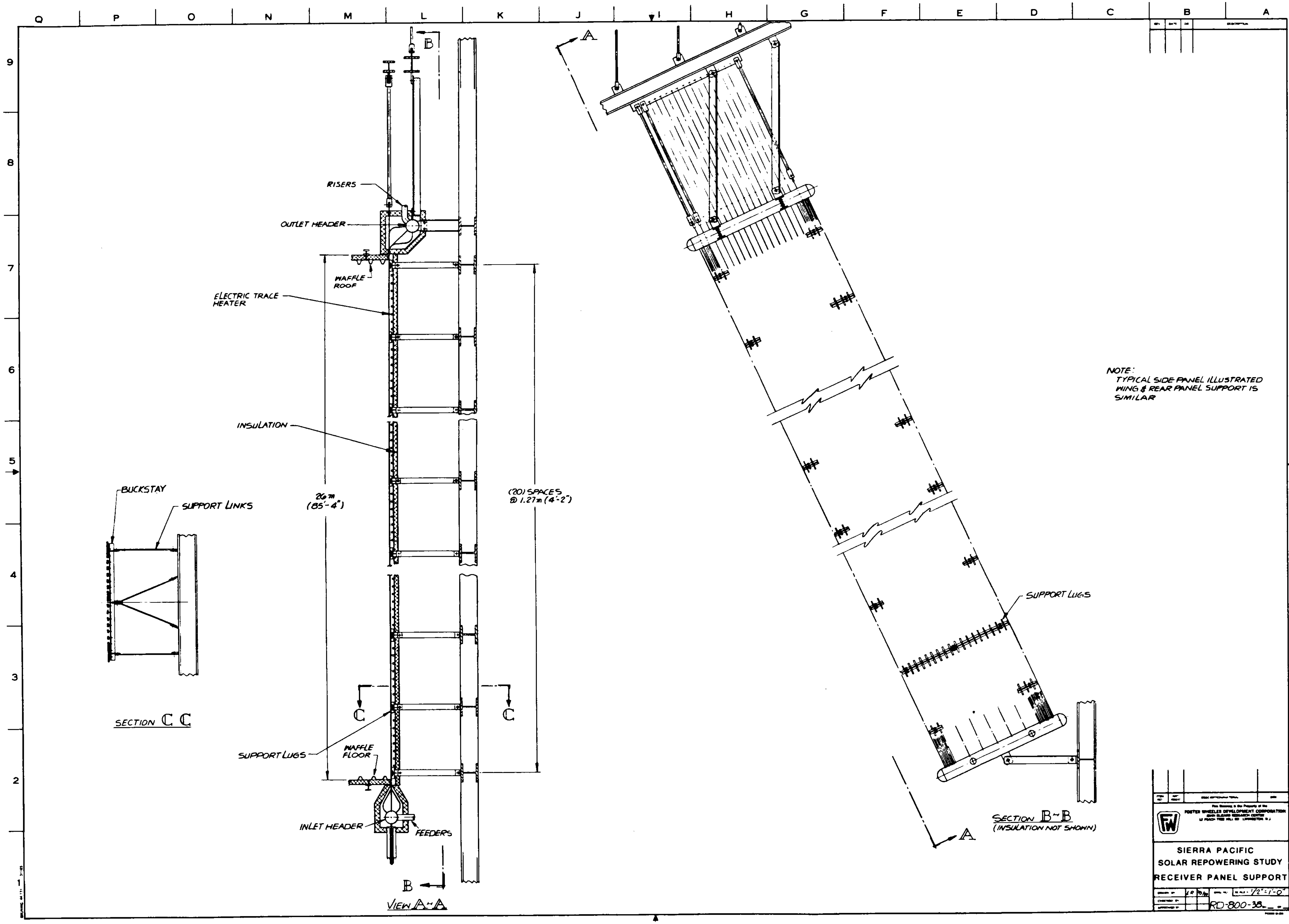


Figure 5-23 RECEIVER PANEL SUPPORT

The panel is hung from the support structure by means of buckstays attached to every fifth panel tube and these are then attached to hangers. The "jumper tubes" which connect the panel to the header are designed with sufficient flexibility to permit expansion between the fixed panel top and the upper header which is fixed to the support structure. The lower header is permitted to move with the longitudinal expansion of the panel. A support link is provided to position the lower header which is supported by the panel tubes.

5.4.1.4.3 Analysis

The structural analysis of the receiver panel tubes is described below. The methods, computer programs, and criteria used in the evaluation and the important results are discussed. The requirements of ASME Boiler and Pressure Vessel Code, Section VIII, Division 1* are fully met in the receiver panel design. The design philosophy of Section VIII, Division 1 is to set the wall thickness necessary to keep the hoop stress due to fluid pressure below the tabulated allowable stress. Section VIII, Division 1 does not require a detailed evaluation of the higher, more localized stresses known to exist, but instead, allows for these by safety factors and a set of design rules. In addition, Section VIII, Division 1, has no criteria to evaluate thermal stresses and fatigue. Experience has shown that this approach has worked reasonably well in fossil-fired power boilers. However, the load conditions in the solar receiver are different from those in conventional boilers, because the solar receiver is subjected to diurnal startup and shutdown cycles. The fatigue associated with thermal cycling is an important failure mode in a solar receiver, but Section VIII, Division 1 does not have explicit criteria to evaluate this failure mode. In this study, Section VIII, Division 1 was supp-

* ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 (Rules for Construction of Pressure Vessels), ASME, New York, 1977 Edition.

lemented with appropriate criteria from Section VIII, Division 2[a] and Code Case N-47[b]. This approach is consistent with the proposed interim structural design standard for solar energy application[c, d].

The temperature distribution and stresses in the tube were determined by using FWDC computer program NONAX[e]. This program has the capability to do thermal and stress analyses of tubes subjected to nonaxisymmetric radiant heating. The tube material can be elastic and elastic-plastic undergoing creep.

The model of the tube used in the analysis is shown in Figure 5-24. Because of symmetry, only one-half of the tube is analyzed. Generalized plane strain conditions are assumed in the tube. As a result of the intermediate and end supports and the axial variation of heat flux, the problem is three-dimensional. However, a study conducted by Sandia Laboratories (Livermore) has demonstrated that the two-dimensional generalized plane strain model reflects the state of stress and strain accurately[f]. A cosine heat flux distribution is assumed in the heated side of the tube.

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a. ASME Boiler and Pressure Vessel Code, Section VIII, Division 2 (Rules for Construction of Pressure Vessels - Alternative Rules), ASME New York, 1977 Edition.

b. ASME Boiler and Pressure Vessel Code, Section III, Code Case N-47, ASME, New York, 1977 Edition.

c. I. Berman, et al.: "An Interim Structural Design Standard for Solar Energy Applications," Report No. SAND79-8183, Sandia Laboratories, Livermore, April 1979.

d. T. V. Narayanan, et al.: "Structural Design of a Superheater for a Central Solar Receiver," Transactions of ASME, Journal of Pressure Vessel Technology Vol. 101, February 1979.

e. M. S. M. Rao, T. V. Narayanan, G. D. Gupta, "Inelastic Analysis of Non-asisymmetrically Heated Thick Cylindrical Shells," Transactions of ASME, Journal of Pressure Vessel Technology, Vol. 101, pp. 235-241, August 1979.

f. J. Jones: "Absence of Bending Effects on Solar-Receiver-Tube Fatigue," Journal of Energy, AIAA, Vol. 3, No. 3, May-June 1979.

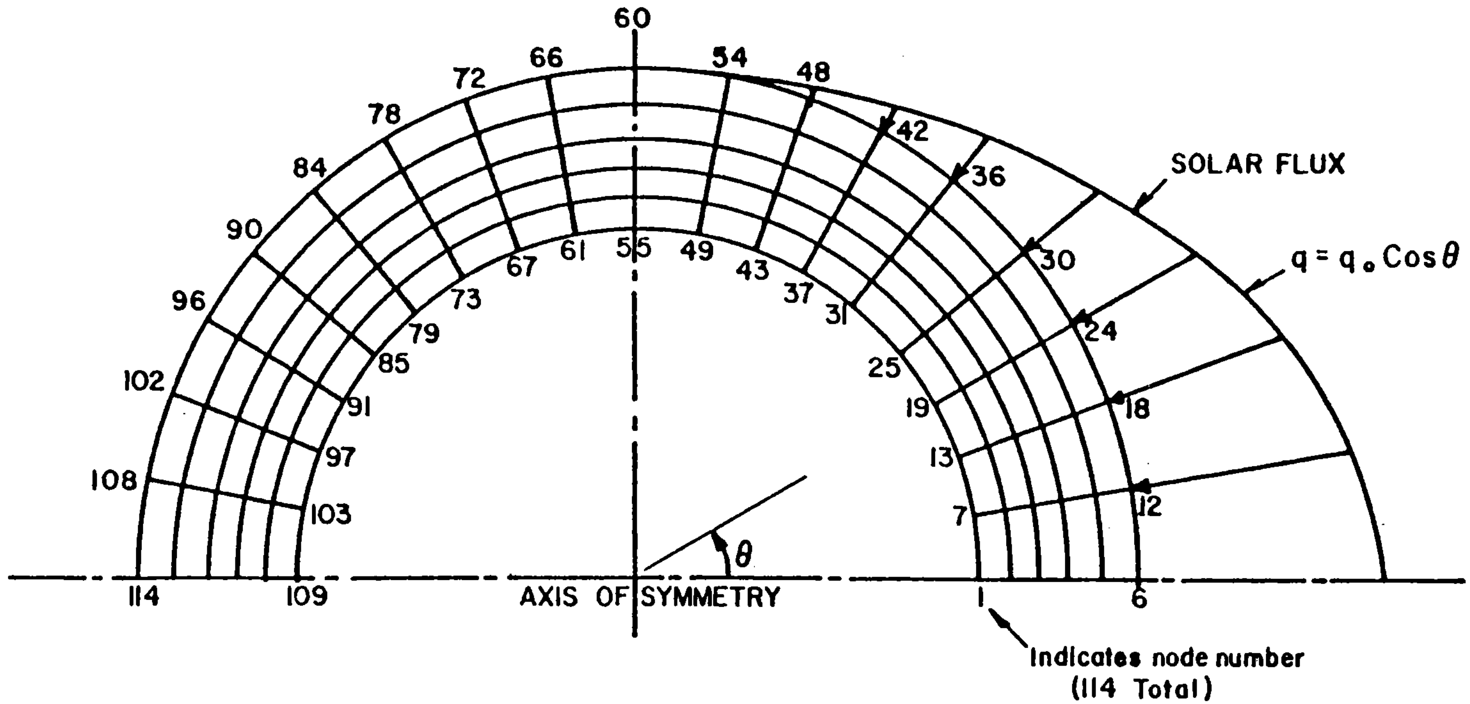


Figure 5-24 **TUBE MODEL**

The following criteria are used in evaluating the stresses:

1. Limit the primary stresses due to pressure to the allowable stress given in ASME Code Section VIII, Division 1.
2. Limit the primary plus secondary stresses (thermal stresses) to twice the yield stress.
3. Evaluate the creep-fatigue life using the fatigue curves and creep rupture curves given in Code Case N-47.

This approach is consistent with that of References c, d. The first of the above criteria is automatically satisfied by using the appropriate Section VIII, Division 1 formula in the thickness calculation. The second criterion is intended to ensure that shakedown occurs and continued plastic cycling does not occur.*

Four (4) critical locations in the receiver were analyzed for the design point (equinox noon) conditions. The points analyzed are points within each each receiver pass with the highest front-to-back tube temperature difference. Figures 5-17 and 5-20 indicate the temperature and heat flux distribution in each of the four tubes from which the critical locations were selected. Results of the analysis are summarized in Table 5-1.

Table 5-1 indicates that the linearized axial stress for each of the points analyzed is less than two times the yield stress, satisfying the aforementioned second criteria. The creep rupture life of the panel L10 (pass 3) and panel L8 (pass 4) tubes are not satisfactory. However, these calculations are based on elastic analysis. Creep-fatigue evaluation based on elastic analysis is very conservative. If an inelastic analysis is done, accounting for creep and plasticity, it can be shown that creep relaxation would reduce the stresses and increase the creep rupture life. For example, consider Table 5-2 which is taken from a Foster Wheeler report to MDAC on the creep-fatigue evaluation of the Barstow receiver. For the case under consideration in Table the effective stress reduced from 164,345 kPa (23,830 psi) to 111,931 kPa (16,230 psi) after creep relaxation for 8 hours (using inelastic properties at saturation) and the creep rupture life increased from 5000 hours to 100,000

* In elevated temperature design, because of creep, this criteria does not quite ensure shakedown. However, it is still a good guideline in a preliminary design.

TABLE 5-1

Receiver Tube Analysis

Pass	1	2	3	4
Panel	L3	L4	L10	L8
q_{FP}, MW/m^2 ($Btu/hr\text{-}ft^2$)	0.493 (156,400)	0.521 (165,300)	0.613 (194,400)	0.483 (153,200)
t_{OD}, C (F)	489 (913)	527 (981)	600 (1112)	618 (1145)
$t_{OD}-t_{Salt}$, C (F)	153 (308)	138 (280)	116 (240)	77 (171)
σ_z, kPa (psi)	-329,930 (-47,840)	-309,240 (-44,840)	-281,740 (-40,860)	205,310 (-29,770)
$\Delta\sigma$, kPa (psi)	-126,340 (-18,320)	-126,140 (-18,290)	-130,280 (-18,890)	-849,000 (-12,310)
σ_z^L, kPa (psi)	203,590 (29,520)	183,103 (26,550)	151,520 (21,970)	-106,620 (15,460)
σ_e, kPa (psi)	308,070 (44,670)	285,930 (41,460)	255,450 (37,040)	185,030 (26,830)
$2S_y$, kPa (psi)	224,830 (32,600)	220,690 (32,000)	211,030 (30,600)	206,900 (30,000)
Creep-Rupture Life based on 1.25 S_y, hr	>100,000	>100,000	44,000	14,000

<u>Nomenclature</u>:

q_{FP} = Maximum heat flux (flat projected)

t_{OD} = Peak outside surface temperature

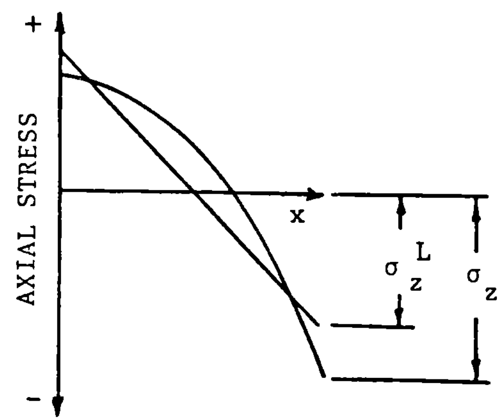
t_{salt} = Bulk salt temperature

σ_z = Axial stress

$|\sigma_z^L|$ = Linearized axial stress

σ_e = Effective stress

S_y = Yield stress



σ_z = axial stress from tube temp. distribution computer program for elastic analysis.

hours. Such increases may be expected for the tubes considered in this study. However, an inelastic analysis is needed to verify adequate creep reputure life. Such an analysis, which is beyond the scope of the conceptual design study, is recommended for the preliminary design phase. Table 5-2 also indicates that creep rupture is more limiting than fatigue.

Table 5-2
Barstow Panel Analysis

t_{max} = 607.2°C (1125°F)

Type of Analysis		$\Delta\epsilon_{eff}$ % Effective Strain Range	N_D Cycles Code Allowable	σ_{eff} MPa (ksi) Includes Peak	T_D - hours Code Allowable
Elastic		0.0886	$>10^6$	164.3 (23.83)	~5,000
Inelastic Morotonic Yield	Cycle 1 Cycle 2	0.0886 0.0886	$>10^6$ $>10^6$	86.8 (12.59) 86.8 (12.59)	>300,000 >300,000
Inelastic 10th Cycle Properties	Cycle 1 Cycle 2	0.0886 0.0886	$>10^6$ $>10^6$	119.5 (17.33) 119.5 (17.33)	~80,000 ~80,000
Inelastic Properties Saturation	Cycle 1	0.0886	$>10^6$	164.3 (23.83)	~5,000
Inelastic 10th Cycle with 8-hour Creep Relaxation	Cycle 1 Cycle 2 Cycle 3	0.0886 0.0886 0.0886	$>10^6$ $>10^6$ $>10^6$	119.5-102.7 (17.33-14.89) 102.7-100.2 (14.89-14.53) 100.2-98.7 (14.53-14.31)	~100,000* >300,000* >300,000*
Inelastic Properties at Saturation with 8-hour creep Relaxation	Cycle 1 Cycle 2 Cycle 3	0.0886 0.0886 0.0886	$>10^6$ $>10^6$ $>10^6$	164.3-119.0 (23.83-17.26) 119.0-114.5 (17.26-16.60) 114.5-111.9 (16.60-16.23)	~20,000* ~100,000* >100,000*

*Based on average stress in 8 hours.

5.4.1.4.4 Panel Fabrication

Because of the high solar heat flux incident on one side of the receiver panels, thin wall tubes are required to minimize peak tube metal temperature and the thermally induced stresses described in Section 5.4.3.4. Conventional boiler furnace panels fabricated by Foster Wheeler in the past have been designed with wall thicknesses greater than 3 mm (0.125 in.). Consequently, a fabrication technique must be developed to manufacture receiver panels with thin wall tubes.

Samples of 1.27 mm (0.050 in.) and 1.65 mm (0.065 in.) tubes fusion welded tube-to-tube in Foster Wheeler shops show promise that a welding procedure can be developed to fabricate continuously welded receiver panels with thin wall tubes. Foster Wheeler has also recently acquired high frequency resistance welding equipment to weld fins on thin wall tubes. The possibility exists for adapting the resistance welding equipment for tube-to-tube welding of thin wall tubes. It is felt that with further development, fusion welding, high frequency resistance welding, or a combination of both can be used to fabricate the receiver panels described in this study.

Alternatives to continuously welded panels include continuously brazed panels, stitch welded panels, or panels with loose tubes having support lugs welded to each tube. As with the continuously welded panel, each of the alternatives would require further analysis and development. At present there are no furnaces large enough to braze panels 26 m (85.3 ft) long. The cost for building such a furnace would be approximately $2,000,000. Stitch welded panels and panels with loose tubes having lugs welded or brazed to each tube would require detailed analysis to predict how the panels will distort due to differential thermal stresses and the effect of solar radiation passing through gaps between panel tubes.

5.4.2 Tower

5.4.2.1 Description

The receiver tower will be constructed of reinforced concrete using the slip form fabrication technique. The baseline tower design is shown in Figure 5-25. This tower is larger in diameter than the design originally selected. The original design was evaluated in trade study TS-4, and the result of that study are presented in Appendix B.

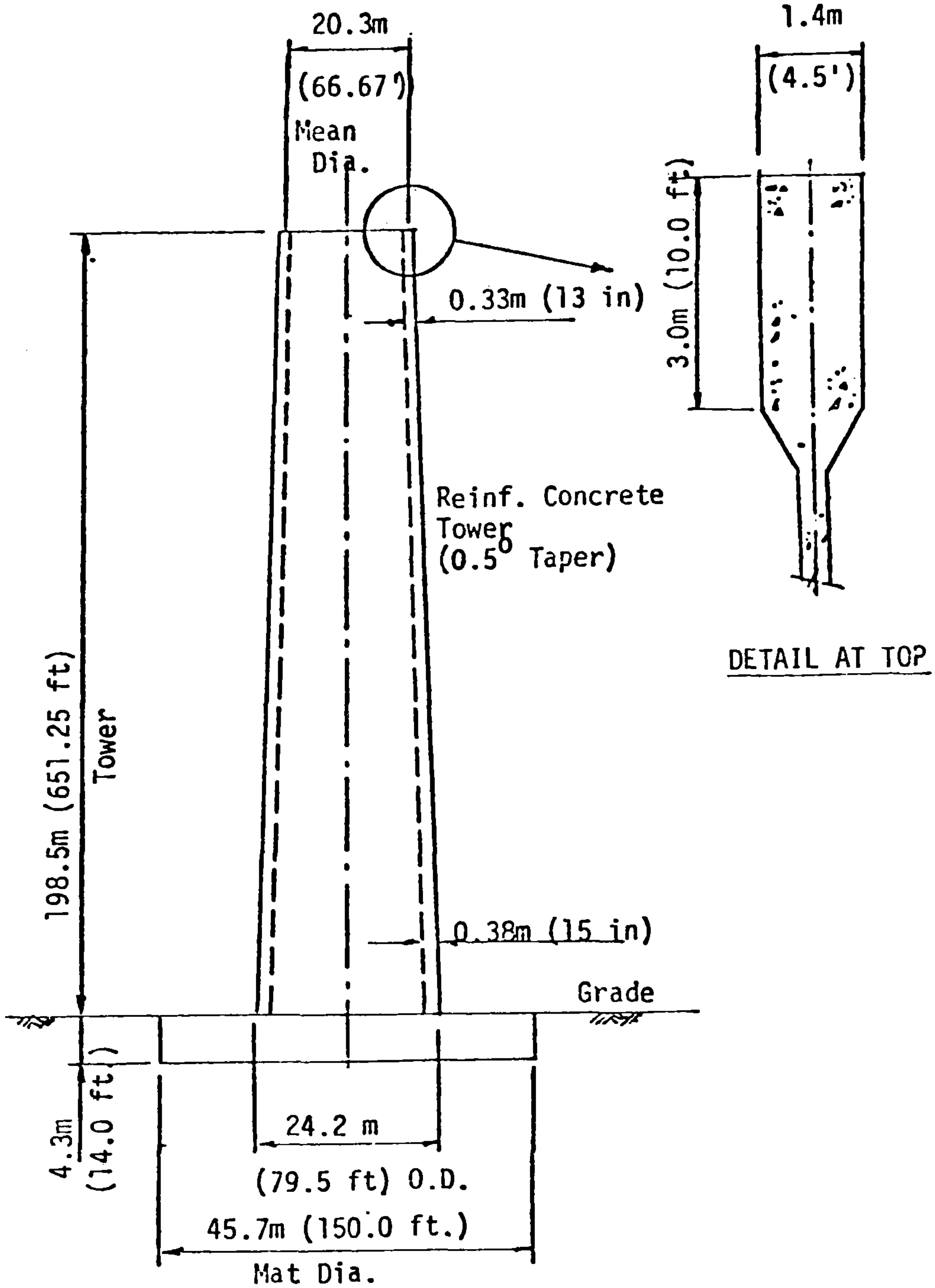


FIGURE 5-25 RECEIVER TOWER

The small diameter tower met all of the strength and load requirements dictated by the predicted wind and earthquake conditions applicable to the Ft. Churchill site. However, after the preliminary design of the receiver and receiver support assembly was completed, it was determined that a larger tower top platform area would offer greater stability to the receiver/support assembly and the diameter of the top of the baseline tower was increased to 20.3m (67 ft) from the original 12.2m (40 ft).

To accommodate this larger top platform with the least effects on the remainder of the tower, the tower taper was changed to .5° from the original 1° taper. This arrangement gives a tower bottom diameter of 24m (80 ft) instead of the original 19.2m (63 ft).

The load carrying capability and the vibrational response of the larger diameter tower were not recalculated. However, the load carrying capability should be increased. Both tower designs are extremely stiff and sway is quite low and receiver seismic loading should be unchanged. The larger diameter tower is still within the size range of state-of-the-art designs.

The change in diameter is not expected to make a significant effect on the tower response characteristics and the larger diameter version was used for the cost modeling on this study.

The baseline tower will consist of the reinforced concrete tower wall, a structural steel top deck and a substantial concrete foundation. The top deck will be covered with standard 6.3 mm (1/4") checkered steel plate. Secondary working decks will be provided within the receiver support structure and these will be "grated" type steel design.

The tower will contain an internal elevator running up the center of the tower. This elevator will go from the ground level through intermediate work station stops, and will terminate at the top deck level.

The tower/support structure will contain lightning protection equipment, aircraft warning lights, receiver support machinery, and worker protection restraints.

The main salt riser and downcomer will be supported to the inside of the tower shell and will include expansion loops at the appropriate intervals. The tower will have ventilation opening at the top and bottom of the tower. This will permit natural convection to circulate air and this will meet the present safety requirements.

5.4.2.2 Tower Performances

The exact performance of the large diameter tower will be analyzed during the next phase of this program. The performance of this tower should be equal to or better than the performance predicted for the small diameter tower discussed in trade study TS-4 and presented in Appendix B.

5.4.2.3 Tower Structural Design

The tower structural design will be completed during the next phase of the program. It is expected that the design of the large diameter tower will be similar to the design discussed in trade study TS-4 and presented in Appendix B.

5.4.2.4 Tower Construction/Erection

The receiver tower foundation and slip formed walls will be erected using normal tower construction procedures. The erection of the receiver support assembly, the receiver and the receiver doors will be accomplished through the use of a temporary steel work tower. This temporary tower will be erected next to the receiver tower, and will be used to support the power crane and to provide an adequate work area for the installation of the receiver tower top deck and then for the installation of the remaining equipment. The cost of the rental of the temporary steel tower is included in the cost estimates for the receiver tower installation. The power crane used in conjuction with the installation of the receiver and its support equipment, will be transferred to the completed receiver tower assembly and will be available for future repair/modification at the top of the receiver tower.

5.4.3 <u>Receiver Fluid Loop</u>

The receiver fluid loop consists of hot and cold molten salt piping, receiver feed pumps, steam generator feed pumps and associated controls, and salt preparation and maintenance systems.

5.4.3.1 Molten Salt Piping

A summary of the hot and cold piping characteristics is shown in Table 5-3.

Table 5-3

Receiver Fluid Piping Characteristics

	HOT SALT Downcomer and Horizontal Piping	COLD SALT Riser and Horizontal Piping
Design Pressure	4.0 MPa (575 psig)	9.6 MPa (1400 Psig)
Design Temperature	593°C (1100°F)	302°C (575°F)
Pipe Material	ASTM A312-(316 SS)	ASTM A106-Gr.B
Code	ANSI B31.1	ANSI B31.1
Pipe Size	0.3m (12 in) Nominal Sch. X s	0.41m (16 in) Nominal Sch 80
	12.7 mm (0.5 in) Nom. Wall	21 mm (0.843 in.) Nom. Wall
Wt. Per Meter (Ft)	97 kg (65 lb)	204 kg (137 lb)
Approx. Length	2057 m (6750 ft.)	1875 m (6150 ft)
Insulation Type	Calcium Silicate	Calcium Silicate
Ins. Thickness	0.15 m (6 in)	0.20 m (8 in.)

Size of the cold molten salt pipe was determined by employing a cost study based on present worth of fixed cost versus variable. The fixed cost used was the installed cost of the pipe and the variable cost used was the operating cost necessary to pump the liquid through each size of pipe. Pipe sizes of .36 to .61 m (14 to 24") were used in the study. A curve was plotted, Figure 5-26, for the fixed cost and variable cost with the intersection of the two curves determining the most economical size to use. The two curves intersected at a point slightly above 0.41m (16") size. Hence a 0.41 m (16") pipe diameter was selected.

The size of the hot molten salt pipe was selected based on a size that would have a friction loss less than the vertical drop from the top of the receiver to the hot storage tank to prevent adding additional head to the pumping equipment. The friction loss in a .3 m (12") pipe is approximately equal to 75% of the vertical head. The balance of the vertical head will be dissipated

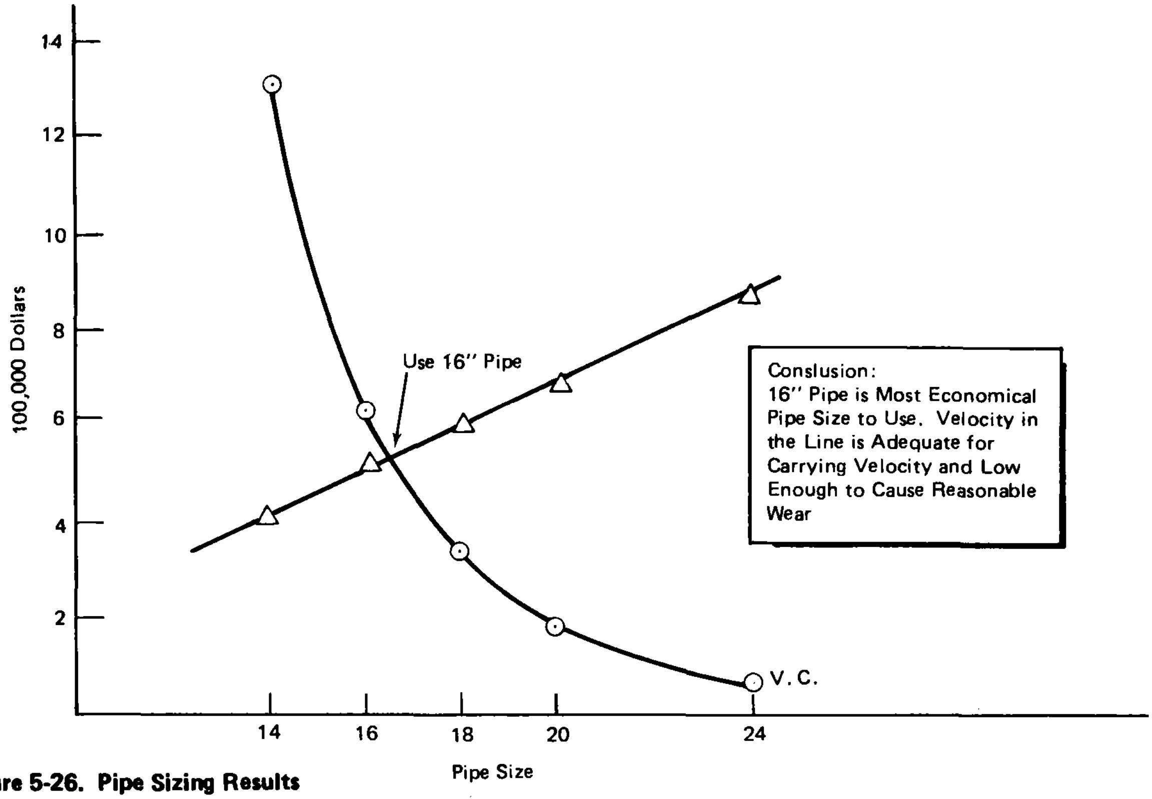


Figure 5-26. Pipe Sizing Results

across the drag valve pcv-1. Pcv- 1 is also utilized to maintain positive gauge pressure on the receiver as shown on the Piping and Instrumentation Diagram, Figure 4-3.

The piping material selected for the hot 565°C (1050°F) salt piping is type 316 stainless steel based on molten salt corrosion investigation work by Sandia National Laboratories*; however, this selection is considered preliminary for conceptual design.

The cold 288° (550°F) piping material selected is carbon steel A106-Grade B, which is compatible with molten salt at this operating temperature.

5.4.3.2 Salt Pumps

The design conditions for the receiver feed system are of .41 m^3/S (6500 GPM) at a pumping head of 364 m (1200 ft). The specific gravity of the molten salt is 1.87 at 288°C (550°F). It is proposed that two half capacity pumps operating in parallel be used to pump the liquid through the receiver feed system. The power required to drive each pump would be 1832 kW (2455 BHP) based on a pump efficiency of 75%.

* Work conducted by R. Carling, Sandia National Laboratory, Livermore, CA.

The design conditions for the steam generator feed system are a flow of .25 m^3/S (4050 GPM) at a pumping head of 91 m (300 ft). The specific gravity of the molten salt is 1.67 at 566°C (1050°F). It is proposed that two half capacity pumps operating in parallel be used to pump the liquid through the system. The power required to drive each pump would be 253 kW (339 BHP) based on a pump efficiency of 75%.

A special pump design is necessary to pump molten salt due to the high pressures and temperatures involved and the corrosive nature of the liquid involved. Byron Jackson pumps were selected to be used in this study due to their previous experience in the design and manufacture of pumps utilized for high temperature liquid metal applications.

A centrifugal, cantilever was recommended by Byron Jackson for both the receiver feed pumps and the steam generator feed pumps. Multi-staging is used to achieve the required pressure. The pump would feature hydrostatic bearings. The stuffing box is separated and sealed from the pumped liquid by means of a pressurized, inert gas. Seals and oil lubrication are used in the stuffing box. These seals are completely isolated from the hot salt and will not cause a safety problem.

It was also determined that Lawrence Pumps, Inc. and Rockwell International developed pumping equipment for similar applications.

Lawrence pumps have had experience in pumping molten salt with a vertical shaft centrifugal, cantilever pump. Their design is based on using a sump with controlled level to separate pumped liquid from the bearings and stuffing box area.

Rockwell International has developed a vertical pump to pump sodium that could possibly be adapted to pumping molten salt.

There is very limited experience in pumping molten salt at the design pressure and temperatures involved. Development and qualification may be necessary before a suitable, economical pump is obtained for this application.

5.4.3.3 Expansion Joints

A tradeoff study was conducted to determine the best method for dealing with the thermal expansion of the hot salt line from the receiver to the hot salt tank. The routing includes the vertical run within the tower and the horizontal run from the base of the tower to the tank.

The following methods were investigated:

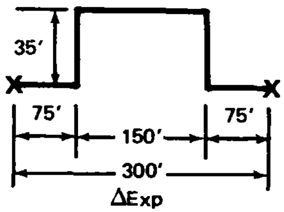
1) traditional pipe loop
2) universal bellows expansion joints with tie rods.
3] Hinged bellows expansion joints.
4) axial bellows expansion joints with no loops.

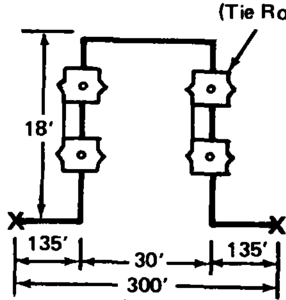
The study was based on 91.5m (300 ft) sections with rigid anchor supports to accommodate the 0.91m (3 ft.) thermal expansion per loop. For the horizontal pipe run these would be approximately sixteen 91.5m (300 ft) sections. Budget bid estimates from two different bellows joint manufactures were obtained. A comparison of the overall total cost per 91.5m (300 ft) section for the 4 different expansion methods is given in Table 5-4. Because of the concern for corrosion of the material at 565°C (1050°F) Incoloy was specified for the bellows. As indicated by the table, the cost per 91.5m (300 ft) section varied from approximately $116,000 to $140,000 with the pipe loop being the least costly. Based on 16 sections , an installed capital cost savings of at least $150,000 would be evident by using the pipe loop method as compared to the least expensive of the bellows joint applications. Furthermore, there is considerably more maintenance.required with a bellows design than with a pipe loop. Another cost not included for the axial expansion joint design is the axial thrust of 0.33MN (75,000 lb) that the bellows would have to withstand. An additional concern is the ability of the bellows designs to accommodate the required earthquake loading at the Ft. Churchill site. Therefore, on the basis of cost, maintenance, and safety, the traditional pipe loop method will be used to accommodate the pipe expansion. In the horizontal plane, there will be two 10.7m (35 ft) legs per 91.5m (300 ft) section. For the vertical run of hot salt pipe, three vertical 12.2m (40 foot) leg loops will be used.

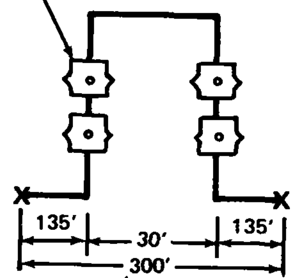
Table 5-4. Hot Salt Pipe Expansion Compensation, Cost Comparison (per 300 ft Section)

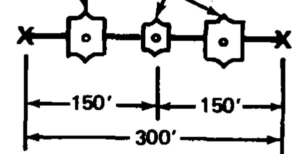
Pipe Specification
0.3m (12in.) Schxs
ASTM 312 (316SS)
Operating Conditions:
565°C (1050°F)
at 3.6m Pa (525 psig)

X = Fixed Ahcnor (Typical)
Δ Exp = 0.91m (36 in.) (Typical)









	Pipe Expansion Loop	Universal Expansion Joint with Tie Rods	Hinged Expansion Joint	Axial Expansion Joint
Number of Loops	1	1	1	0
Number of Expansion Joints	0	4 (2 Assemblies)	4 (Hinged)	5 (2 Doubles and 1 Single)
Total Pipe Length	(370 ft)	(336 ft)	(312 ft)	(~300 ft)
Cost of Pipe and Elbows	$82,594	$75,923	$71,214	$56,900
Cost of Expansion Joints	–	18,800	40,000	42,500
Cost of Insulation	33,300	30,800	28,640	28,083
Total Cost	$115,894	$125,523	$139,814	$127.483
Delta Cost	Base	$9,629	$23,920	$11,589
% Increase in Cost	Base	8.3	20.6	10

The cold salt piping runs from the cold salt storage tank to the tower and receiver. The cold salt is at an operating temperature of 288^{o}C (550^{o}F) and an operating pressure of 6.85 MPa (1000 Psi). However, the line would need to withstand the shutoff head of the cold salt. receiver pump, i.e., 9.3 MPa (1350 psig). Discussions with the bellows manufacturers indicated that it was not feasible.to design a bellows to withstand the high pressure and they would not even quote a budget bid figure. Therefore, the traditional pipe loop would also be used for the cold salt pipe expansion. The specifications of the cold salt pipe are:

Design Temperature	288^{o}C (550^{o}F)
Design Pressure	9.6 MPa (1400 psig)
Pipe Size (Nominal)	0.41m (16 in)
Schedule	80
Type	Carbon steel A106-Gr.B

For the horizontal pipe run, the expansion loops will have 5.5m (18 ft.) legs as compared to 10.7m (35 ft) legs for the hot salt loop. For the vertical pipe run in the tower, there will be two loops each with 7.6m (25 ft) legs.

5.4.4 Freeze Protection/Preheat

Electric trace heaters are provided on the receiver panels, headers, and all interconnecting salt piping. The trace heaters are sized to preheat and maintain the aforementioned receiver components at a temperature of 288° C (550°F). The heating elements on the salt piping are positioned along the pipe axis at locations dependent on the number of elements required. Heating elements for the receiver panels are mounted on a 304 stainless steel plate positioned approximately 51-76 mm (2-3 in.) behind the panels. Direct attachment of the elements to the receiver panel is not recommended because of the receiver tube thin wall (1.65 mm [0.065 in.]). The heating elements are positioned in loops traversing the panel width in order to uniformly heat all tubes within a given panel. A 480 volt power supply is required to operate the trace heaters. The electrical trace heater requirements for the receiver system are as follows:

Item	Number of Units	Length/Unit m (ft)	Power Watt/m	Power* Watt/ft
Downcomers:				
Pass 1-2	6	89 (196)	191	58
Pass 2-3	6	132 (290)	191	58
Pass 3-4	6	89 (196)	188	57
Transfer Pipe:				
Primary Riser	10	73 (160	327	99
Inlet	6	6 (13)	191	58
Outlet	6	6 (13)	188	57
Primary Downcomer	12	103 (227)	191	58
Feeders & Risers	320	42 (93)	148	45
Headers:				
Wing	32	11 (25)	330	100
Side	160	9 (20)	330	100
Rear	128	9 (19)	330	100
Panels:				
Wing	72	63 (140)	414	38
Side (L2, L3, R2, R3)	96	77 (170)	414	38
Side (L4, L5, L6, R4), R5, R6)	108	168 (370)	338	31
Rear (L9, L10, R9, R10)	64	77 (170)	272	25
Rear (L7, L8, R7, R8)	96	41 (90)	240	22

During normal steam generator operation on a calm day with 15.6°C (60°F) ambient temperature, the heat loss through the receiver insulation is approximately .54 MW_{th} (1.84 x 10^6). During an extended shutdown period with the electric trace heaters maintaining the system at 288°C (550°F), the heat loss from the receiver system is approximately 0.627 MW_{th} (2.14 x 10^6 B). with the aforementioned ambient conditions.

*Power required for foot of pipe length based on 17.8°C (0°F) ambient temperature with wind velocity factor included.

5.4.5 Control

The receiver control is presented in Section 5.5.

5.4.6 Receiver Door

The support structure will include the door tracks and door operating mechanisms for four, full width doors. The doors will be mounted in pairs which are counter-balanced within each pair. Two doors will open by moving upward and nesting on each other, while the second pair of two doors will open downward and these will also nest on each other. These doors will be similar to conventional hanger doors and the design was provided by the Ferguson Door Company.

5.4.7 Development Items

Receiver system items requiring further detailed analysis include the following:

- Receiver panel fabrication (continuous weld or braze, stitch weld, or loose tubes with support lugs welded or brazed on each tube).
- Creep relaxation analysis of receiver tubes having high temperature salt and high heat fluxes.
- Detailed analysis to determine tolerable heat flux variations across the panel width.
- Receiver door and guide track design.
- Detailed receiver support structure design.
- Detailed receiver roof and floor design.
- Seal arrangement for gap between receiver panels provided for panel lateral expansion.
- Detailed transient analysis of receiver panels.

Receiver subsystem items which require development or qualification testing includ

- Receiver absorber panel - CRTF.
- Receiver configuration - CRTF.
- Receiver feed pumps and seals - CRTF.

5.5 MASTER CONTROL SYSTEM (MCS)

The Master Control System for the Fort Churchill No. 1 Power Plant solar retrofit provides control of the collector, receiver, thermal storage and interfaces with the existing plant.

Design descriptions of the Master Control Subsystem for the Solar Repowering Retrofit System at Sierra Pacific Power Company are presented for the architecture, function, design, software and operation.

5.5.1 Architecture

The preferred design for this repowering system will use a modern process control architecture. This system will be physically and operationally independent of the plant fossil control system. The design incorporates the following general features:

- Distributed digital control of the solar plant processes.
- Remotely located controllers.
- Serial redundant digital control and data communications between the control center and the subsystem.
- Single operator for plant and subsystem control and monitoring.
- Control processor terminals used for plant and subsystem control and monitoring.
- Microprocessor based controller hardware used throughout.
- Maximum use of CRT display devices for monitoring plant status.
- Three modes of operation: 1) Automatic, 2) Semi-Automatic, 3) Manual.

The interconnections of these various controllers are shown on the P&ID, Figure 4-3.

The master control design for the solar parts of the repowered plant incorporates a centralized plant control center that links via a serial digital data bus to remote subsystem controllers. An overview of this design concept is shown in Figure 5-27. This design employs a distributed control system concept whereby the individual controller functions are accomplished close to the process while the integrated plant control is performed in the control center.

Master Control Subsystem - Block Diagram

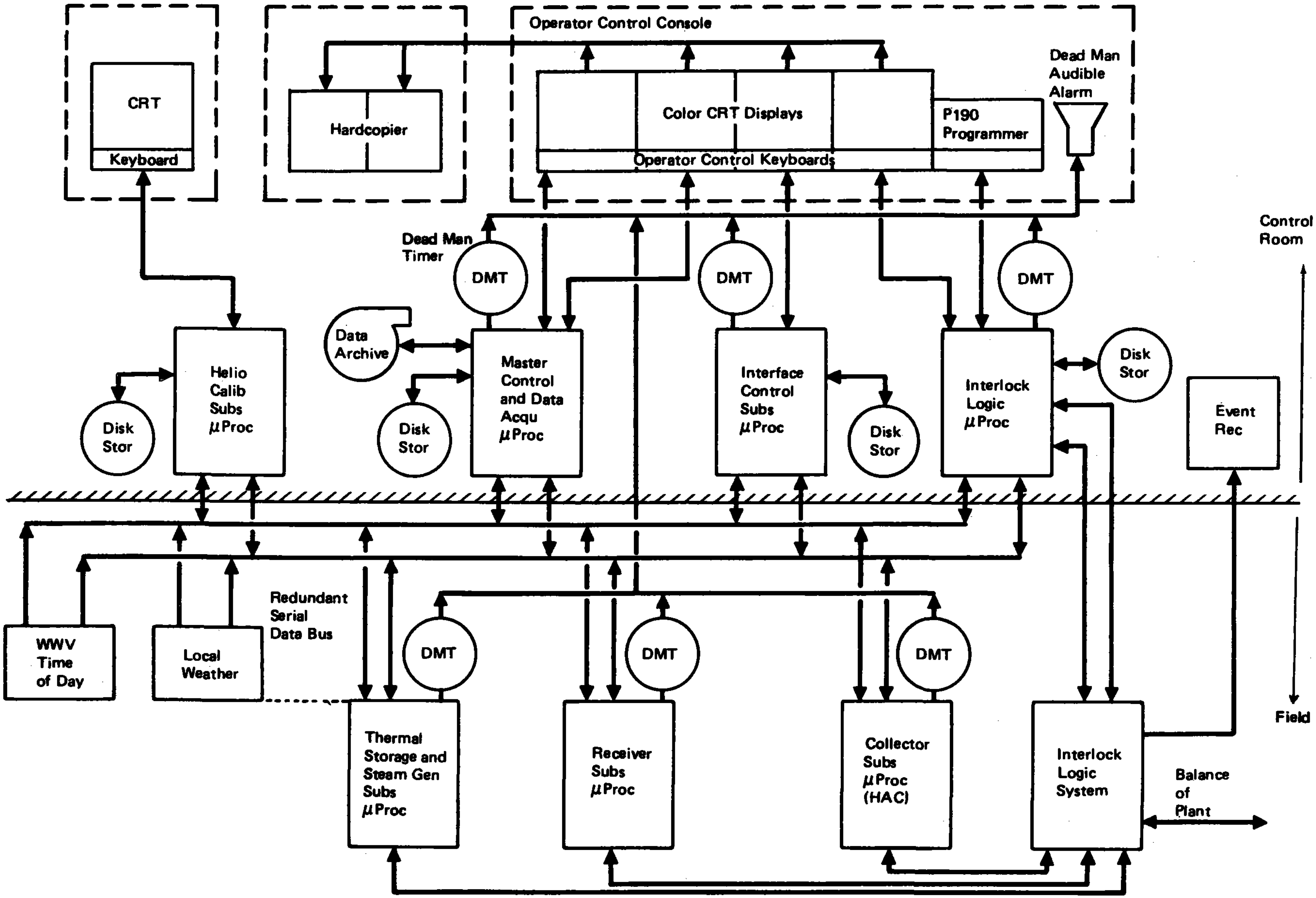


Figure 5-27. MCS Diagram

A vital part of the control system concept is the man-machine interface with control displays located in the control center. At this station,a single operator monitors and commands the operations of the plant. Programmed command sequences are initiated from the control consoles,and plant status and data are monitored, displayed on color CRT's and, if desired, recorded on hard copiers.

Supervisory Control Architecture

The design of control/monitoring system for the Solar Power Plant incorporates an integrated plant control center. This center connects master control and independent subsystem controls to the subsystem controllers, located remotely in the field, by a redundant serial transmission scheme.

Features of the plant control center include:

- Distributed control/monitoring functions with redundant fail over capability.
- Single communication bus architecture interfacing all solar control facilities.
- Automatic and manual safing and protection systems.
- Recording, logging and hard copy capabilities that preserve significant plant operation events.
- Heliostat calibration subsystem integrated into the plant control concept.
- Time of day, local weather and grid demand coordination connected to the communications bus.

A block diagram of the plant control hardware is shown in Figure 5-28.

The control/monitoring system design employs a combination of hardware and software to achieve plant monitoring and control functions. Specific control/ monitoring functions are distributed within 8 microprocess or based units that provide: 1) independent subsystem control and monitoring that supports automatic, semi-automatic and manual (cascade) modes of plant operation, and 2) a redundant fail over capability for plant control fucntions to minimize single point failures of computational control hardware and peripherals.

This design approach distributes a common set of interfaces, hardware components and software design disciplines across the subsystems, at the master control level, maintaining system integrity throughout. Significant cost and operational benefits of this implementation are obtained through: 1) development of simpler stand-alone software packages for each subsystem processor in preference to development of software packages for a single processor that are complicated by limited single CPU and peripheral resources that each subsystem task must compete for, 2) use of multiprocessor to provide tailored subsystem throughput capacity for control, display and operator interaction without the need for high performance and costly mini or maxi computer systems, and 3) the adoption of the multiprocessor configuration to minimize system monitor/control failures at the control center interface by providing failover to a redundant "look-alike" system rather than a wire-by-wire large control board with a unique combination of manual control and monitoring appliances.

The control center philosophy assigns an independent processing capability to the subsystems with a reserve capacity to absorb the monitoring and control operations of a companion processor that has failed. The failover techniques and operation are discussed in Section 5.5.5. Eight processors, each configured with memory, arithmetic and mass storage peripherals, will provide the total capacity to monitor and control the plant operating functions.

The individual controllers which make up the master control are summarized below and explained in more detail in the following paragraphs:

Master Controller (located in the Control room)

This controller is the primary interface between operator and the solar part of the plant. It also serves as the controlling element between the other subsystems, additional duties, data logging and report generation.

Solar/Fossil Interface Controll (located in the Control room)

This controller monitors temperatures and pressures and controls valves to regulate the proportion of steam from the solar and fossil boilers and reheaters for the various modes of operation.

Interlock Logic Controller (located in the field)

This controller monitors switches, valves and pumps and controls the sequence of operation in a pre-determined manner.

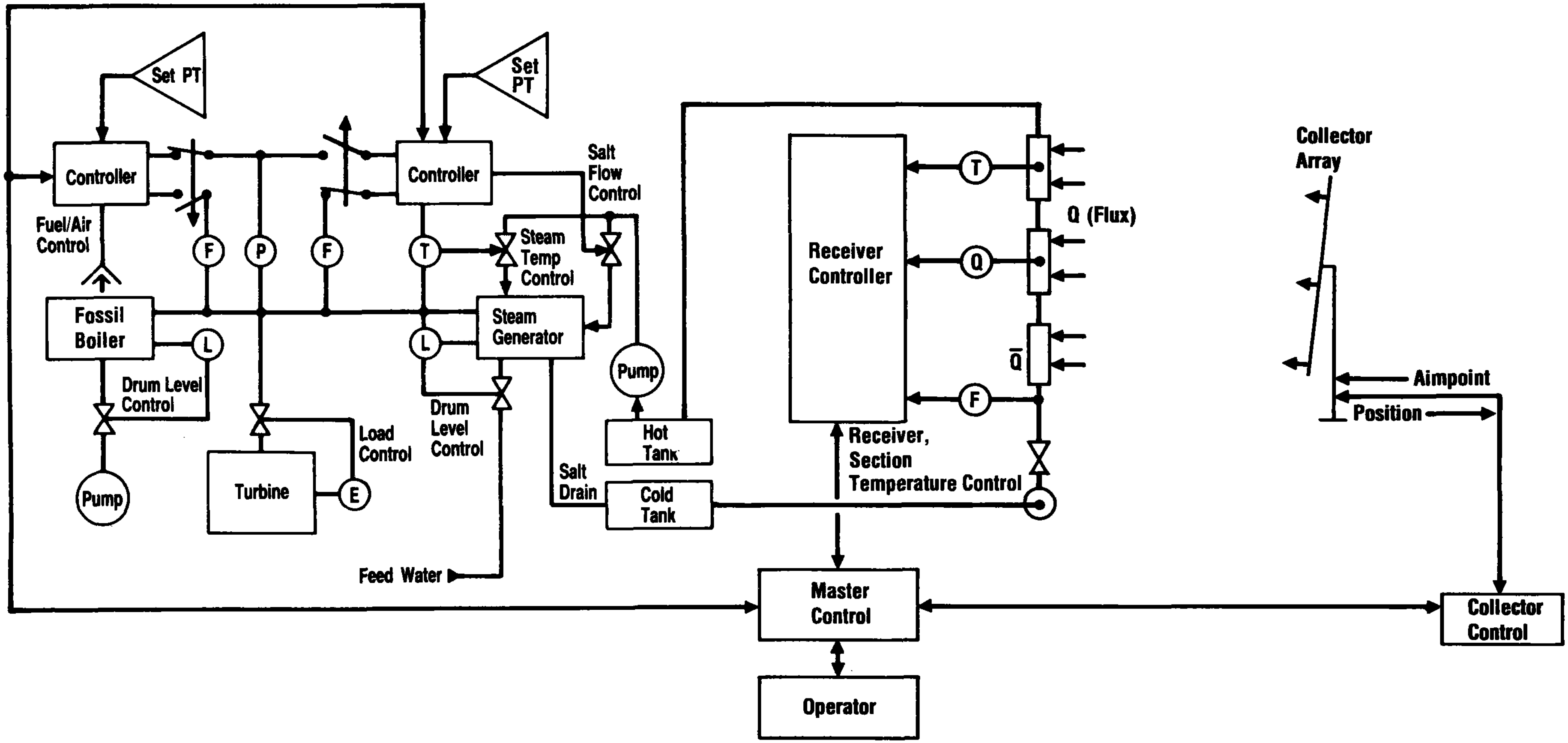


Figure 5-28. Block Diagram for Plant Operation

Collector Controller (located in the field)

This control subsystem directs heliostats on and off the receiver as directed by master control. It also provides master control with various heliostat status data.

Receiver Subsystem Controller (located in the field)

This controller monitors temperature, fluid flow, flux and pressure in the receiver. It controls the fluid flow through the various panels in a manner that prevents excessive local temperatures while maintaining the output at a constant temperature. It also provides requirements to master control for it to add or remove heliostats from the receiver.

Thermal Storage Subsystem Controller (located in the field)

This controller monitors temperatures, flows and pressures and controls valves and pumps to direct the flow of hot salt in a manner that provides the proper amount of superheated and reheated steam for the selected mode of operation (fixed flow rate for the boiler follower mode and constant pressure, variable flow rate for the turbine follower mode).

Heliostat Calibration Controller (located in the Control room)

This controller measures the beam characteristics of a heliostat when it is directed on a fixed target and generates alignment data for the collector controller data base. It also provides maintenance data to the operator.

5.5.2 Master Control Functional Description

5.5.2.1 Supervisory Control

The Master Controller, Interface Controller, and Interlock Logic controller are the main elements of the supervisory control for the plant. These controllers contain the modules that will coordinate the activities of all the controllers as well as monitor control, as required of specified functions of the balance of plant, solar/fossil interface and the interlock logic. Plant support systems (i.e., N_2 Argon, compressed air, etc.) will be monitored by this unit. Monitor and control modules executed by the master are:

- Master Control Coordination - This module will manage the input and output traffic of the other programmed controllers when using the redundant serial data bus or the shared peripherals (i.e., event recorders and hard copy loggers). The plant operations sequencing for automatic operation will be provided in this module.

- Master Data Base Manager - A master data base will be stored and updated in the master controller. This data base will be a composite of the other data bases managed in the other three program controllers. The contents of the master data base will be used for the generation of plant reports and the display of graphic and tabular plant data to the operator.

- Plant Report Generator - The generation of plant reports will be accomplished by this module, stored and output on the hardcopy loggers and visual operator display terminals. The report generator will obtain the information for reports from the master data base. Reports will be generated on a time basis or upon demand when requested by the operator.

- Redundant Bus Diagnostics - A diagnostic module will be used to test the redundant data bus integrity with the other programmed controllers, shared peripherals and remote subsystem interfaces. This module will automatically assign the programmed controllers to the functioning serial data bus. The failure of a serial data bus will post an alarm to the operation and the programmed controllers.

- Plant Start-up - The operator will be required to initiate the master control system startup following a power down incident or when required. A module will be required to initiate the program loading of the other programmed controllers and a functional test of master control when a system startup is required. This module will also report the startup status of master control upon request from the operator.

5.5.2.2 Collector Subsystem Controller

Two of the eight processors will be configured with the software modules to control and monitor the operation of the heliostat array. The solar plant will require this processor, called the Heliostat Array Controller (HAC), to perform the following collector field tasks:

- Heliostat Status - This major module will periodically request information about every heliostat in the field and maintain a status data base on a mass storage device (disk). This module can also be called as a subroutine to either store a status change in the data base or retrieve data about heliostat(s) from the disk for the requesting module. The operating mode will be represented as well as the last known azimuth and elevation angle positions.

- Emergency Slew - A single command from either the MCS or the operator at the HAC can trigger emergency slew. Emergency slew is a rapid movement of all heliostat reflector beams away from the receiver to a standby position.

- Mode Transition - This module will conduct all mode transition, except for an emergency slew request, and ensure that they are executed without violating beam safety requirements.

- Aim Point - This module will calculate a trajectory of aim points across the heliostat field hemisphere to move those heliostats selected for special moves. The beam safety subroutine will be called to advise this module on avoiding areas where beams are not permitted.

- Beam Safety - This module maintains a description of the topography of the heliostat field and surrounding air space where reflected solar beams are permitted and where they are not permitted. It will be necessary for this module to know the heliostat position (x, y, z) and the proposed beam path vector trajectory in order for the module to determine if the reflected beam will pass through a restricted zone.

- Calibrate Heliostats - This module interfaces with the heliostat calibration subsystem. This module will calculate gimbal angles which will result in the selected heliostat hitting an active calibration target. After the calibration target has obtained several measurements of image centroid from several mirror positions, the correction algorithms can be executed and new alignment constraints determined. This module may also be used to recover reference for a heliostat which has lost its reference.

- Data Collection - This module will collect data from heliostats in accordance with several predetermined data collection formats. The collection module will collect data either from the HAC's global data base or request the required information from the heliostats.

- Start-Up - This module will calculate the heliostat field to be used for cold and hot receiver start-ups. The determination of the requirements for start-up will be obtained from data supplied by the receiver programmed monitor/controller.

5.5.2.3 Receiver Subsystem Controller

A sixth controller will be assigned to the receiver subsystem. This controller will perform the following tasks:

- Startup Management - This module will determine the status of each receiver panel prior to a startup and solve the algorithms for the optimization of cold and hot receiver startups. Optimization data will be presented to the operator and used by the collector monitor/controller for the selection of the heliostats to be used for start-up.
- Receiver Shutdown - A module will be required for optimizing shutdown of the receiver to minimize thermal stresses and prevent the solidification of liquid salt. This module will also provide: 1) SET point command changes to the individual panel controllers initiated by the operator should they be required, 2) monitor tracking of panel status, and 3) formatting status change displays for alarm and operator interpretation.
- Receiver Steady State Operation - The decoupling of the receiver subsystem from the steam/water and power generation subsystems removes interacting subsystem coordination requirements. Consequently, the steady state module provides for the monitoring of receiver operating status and provides alarms and data to the operator. This module provides the capability for commanding controller setting changes if required.
- Receiver Data Collection - This module acquires monitoring/control measurement and status and formats these data for use by other monitor/control modules of the master control system.

- Receiver Diagnostics - The available time remaining within the programmed controller will continually be filled running diagnostics on programmed controller hardware and interpreting the availability of monitor and control hardware in the field.

5.5.2.4 Thermal Storage Subsystem Controller

A seventh controller monitors and controls the thermal storage and steam generation subsystems. This element of the power plant is, for the most part, typical of a conventional power plant. The tasks performed by this unit are:

- Energy Management - This module calculates the status for operating the solar plant based on the available stored energy, the energy, the energy requirements to maintain base load and operating plan for the day and the available energy storage replenishment. The data from these computations is formatted and displayed to the operator.
- Data Acquisition - Operational data in the form of digitized analog measurements and binary status are collected and formatted for recording, operator display and use by other modules in master control.
- Storage/Steam Control - This module provides the capability for the operator to command changes to control settings for the thermal storage and steam generators if required. Alarm and limit tests and display are performed by this module using data obtained from the data acquisition module.

5.5.2.5 Heliostat Calibration Controller

The eighth controller provides the capability of calibrating the heliostats in the collector field. This controller interfaces to the redundant digital data bus of master control to communicate and transfer information to and from the collector subsystem programmed controller. This controller also interfaces to a digital image radiometer, remotely located in the field, that measures the radiance patterns of the heliostat. A block diagram of this system is shown in Figure 5-29. The programmed controller in the beam characterization system performs the following tasks:

- Data Collection - This module will collect digitized video scanned irradiation data from a target reflection of a heliostat beam along with heliostat position and available light data. These data will be stored in raw form.

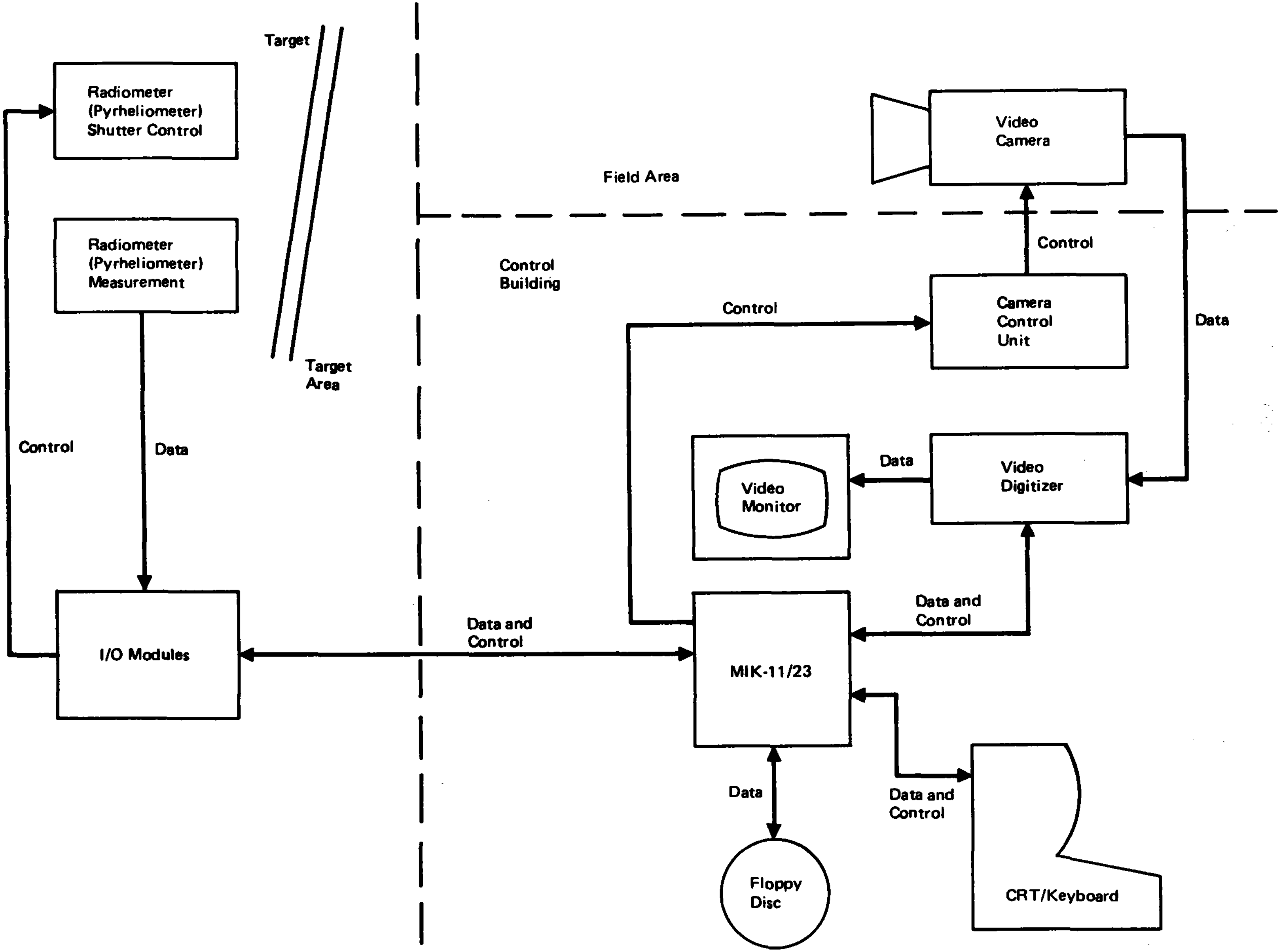


Figure 5-29. Heilostat Calibration Subsystem Block Diagram

- Data Reduction and Analyses - Beam reflectivity, irradiance, flux density comparisons, flux density distribution and beam centroid data reduction and analysis are performed by this module. Results of these analyses are used to determine the condition and alignment characteristics of each heliostat. These alignment and reflective characteristics are in turn transmitted to the collector subsystem programmed controller where heliostat alignment corrections and maintenance actions are programmed.
- Data Display - The display of calibration data for a heliostat will be provided by this module. Tabular and graphical presentations can be commanded from the display terminal.
- Diagnostics - This module will provide diagnostics that evaluate the programmed controller and irradiance system hardware. Hardware status and malfunction reports will be generated in this module.

5.5.3 Master Control Design Description

5.5.3.1 Central Control Console Desian

The central control console shown in Figure 5-30 where a unified control center designed for a single operator. The operator interfaces with the plant from this console through the use of color CRT displays and function keyboards. Recorders, printers, loggers and control processors support the plant monitoring and control functions. A safing control panel contains the plant emergency controls and the mode controls for switching from automatic to manual or vice versa.

The design of the control console connnects three processor units to the common digital data bus and the processor control terminals. A block diagram of this arrangement was presented in Figure 5-28, where master control system block diagram second figure back.

Each of the four processor control terminals can communicate with any of the processors. Thus, the operator can command and monitor the plant from one CRT/ keyboard or command and monitor each subsystem through an independent CRT keyboard.

Each processor contains the control and monitoring sequences for the entire plant. These programmed sequences are stored in separate secondary storage media and used by the processor as required. A program sequence exists for each subsystem. In addition, a master control program sequence provides overall

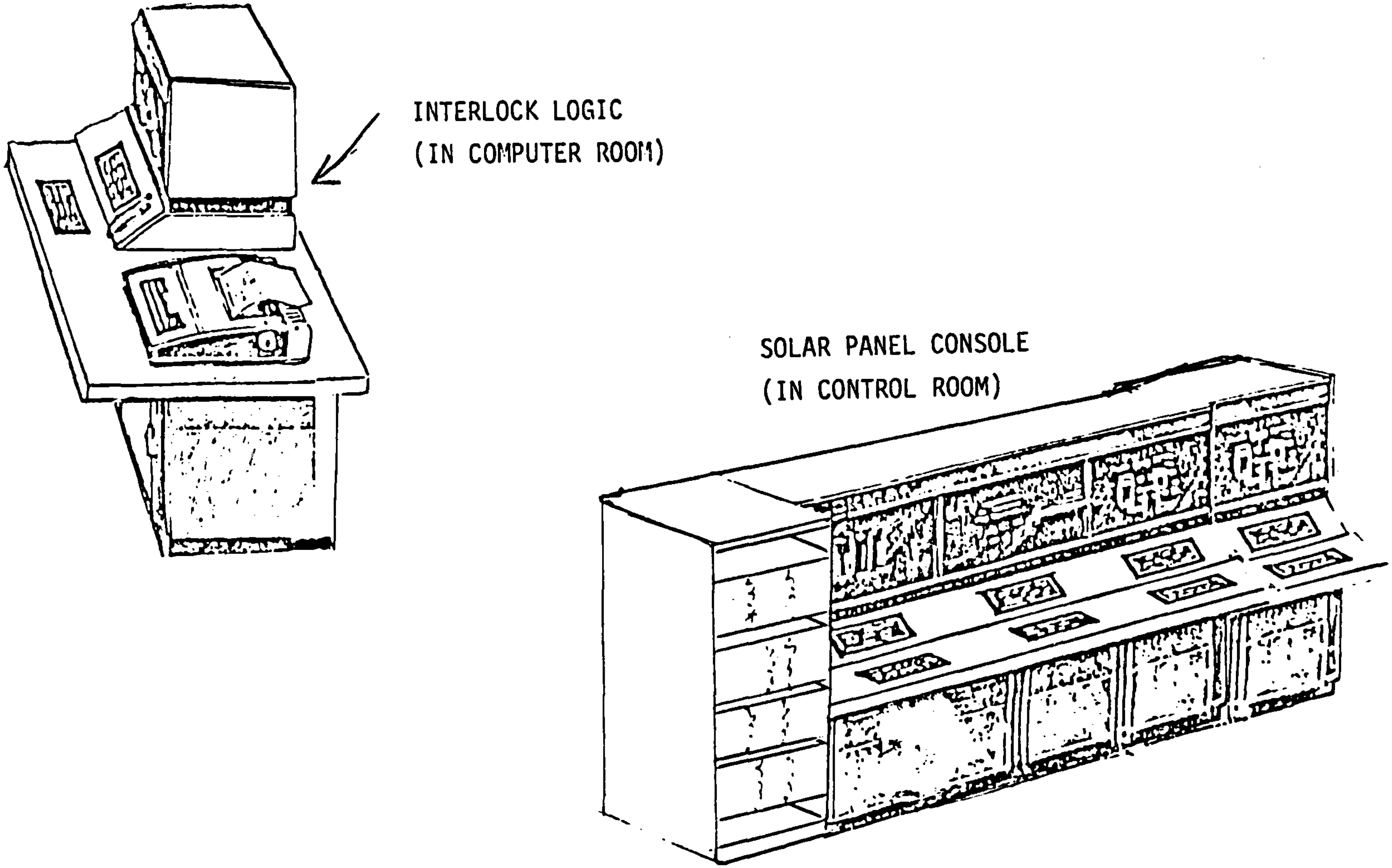


FIGURE 5-30 CONTROL CONSOLES

plant control and arbitrates the use of peripherals shared by all processor units.

The duplication of processor units, control units and shared peripherals in the central control console provides a high degree of redundancy that minimizes single point failures.

Data Communications Design

The common communications link between the central control console and the subsystem controllers consists of a redundant hardwire. A hardwire cable at present provides the most cost effective approach to the communications requirements. However, the high speed parallel transmission characteristics and superior electrical noise immunity available using fiber optics techniques are attractive. These techniques should be cost competitive with the hardwired approach in the 1980 and later time period.

The serial hardwired data link will transmit data between the central control console and subsystem controllers in a digital form. This technique is highly immune to external electrical noise perturbations and forms a totally compatible information interface with the central control console processors and the subsystem controllers.

Addressing schemes will be used to direct the data to the appropriate device and word bit patterns will accompany each transmission for the purpose of diagnosing single and multiple bit transmission errors. All information transfers will be sent over both the primary cable and the backup cable. A transmission line monitor continually tests the lines for loss of signal and alarms the central control console if this happens. Each device reads both lines and accepts the primary line if found to be error free. Should an error occur, or loss of signal occur on the primary line, the device uses the data from the backup line providing it is error free. Error flags are used to inform the central control that a transmission error has occurred and retransmission of the message is required.

Subsystem Controller Design

Subsystem controllers used by the Solar Plant will consist of the following types of devices:

- Microprocessors
- Discreet Controllers (digital output)
- Discreet Monitors (digital input)
- Analog Monitors (analog inputs)
- Analog Controllers (analog outputs)

The conceptual design of the control system provides for the distribution of computational and logic functions within each controller device. This is implemented through the integration of microprocessors into the hardware. Consequently, the central control processor functions are not complicated with requirements for complex software and the need for very high performance equipment.

In addition to the computation and logic functions of the subsystem controllers, the microprocessor provides capabilities to diagnose the hardware on a time available basis, store data for use by the central control processors, and communicate with the backup controller to provide automatic fail-over independent of central control.

If a plant upset should occur, this hardware will automatically initiate an emergency monitor mode. At this time, monitor and control data will be stored for a selected period of time or until the storage memory is full. Following the upset, central control can immediately interrogate these memories and log the data on a printer for analysis.

5.5.3.2 Collector Controller Design

There are four basic electronic components 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 functions of these components and the information flow between them is summarized in Figure 5-31. The specific equipment making up these components and the communication paths between them are illustrated in Figure 5-32.

The HAC functions are distributed between the Control Room and field location (building at receiver tower base). The HAC computer has dedicated peripherals

MCDONNELL DOUGLAS

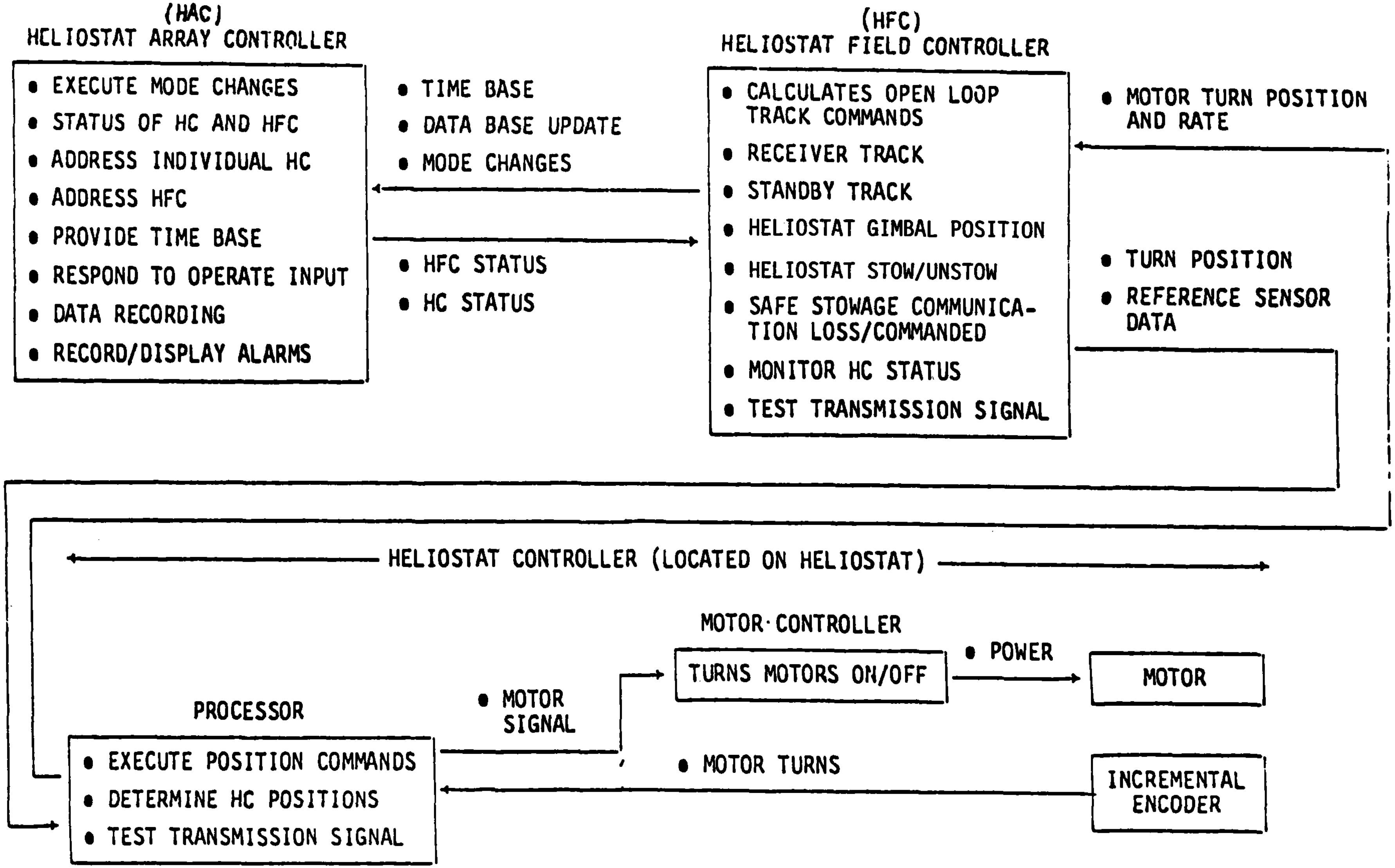


FIGURE 5-31 CONTROLS SUBSYSTEM

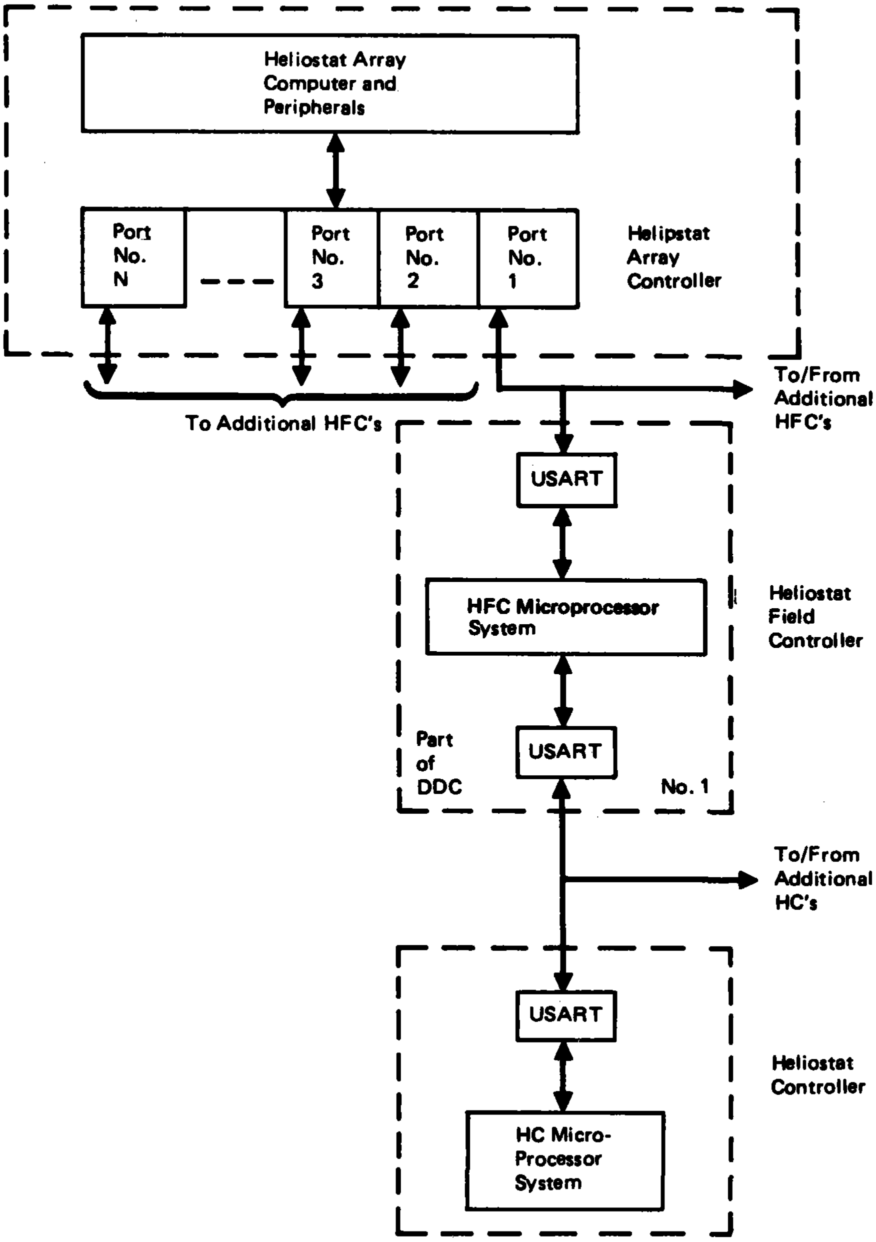


Figure 5-32. Collector Field Controller Hardware

which include a CRT, a printer and a removable disk pac. The HAC communicates with the HFC via a twisted poly bi-directional party line. The failure of an HFC will not affect the operation of any other HFC. Another microprocessor will be switched in as a backup HAC if the primary fails. It communicates on separate signal lines to the HFC's. Thus, failure of the primary HAC will not cause loss at the collector field.

The main functions of the HAC are:

1. Respond to commands from an operator at the control console.
2. Act as an executive controller of the heliostats.
3. Monitor the performance of the heliostats.
4. Conduct the heliostats in a test mode.

Groups of up to eight HFC controllers are housed in a common weatherproof container identified as the Data Distribution Center (DDC). DDC's are located at strategic points in the field. The field location of the DDC is optimized by placing the HFC groups adjacent to or in proximity of the secondary field power transformer in a strategic manner that (1) eliminates the effect of EMI from the transformer and (2) allows the laying of all cables (i.e., power and signal) along paths that require only one pass of the cable laying machinery.

Each HFC is microprocessor based with the capability to control up to 32 heliostat controllers. It receives all commands and data from HAC. A message error check is made of the received message and, if there are no errors, the HFC will echo back the received message or the received message with the requested data. The HAC will check the echo message against the transmitted message before declaring the transmission good.

The main functions of the HFC are:

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.
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 HFC is built around the 8085 central processing unit (CPU). It operates at 3.072 MHz. Memory consists of 2K bytes of ultraviolet erasable PROM and 16K bytes RAM. Features include a direct memory access (DMA), an arithmetic processing unit (APU), an interrupt controller, and a real time counter. Communication with the HAC's and HC's is handled by 3 universal synchronous/asynchronous receiver/transmitters (USART's) which are linked to the communication lines by transceivers. A Field Programmable Logic Array (FPLA) is used for certain decoding. The rest of the IC's consists of various gates, buffers, decoders, flip-flops, and counters.

The HC is located in a heliostat controller assembly mounted on the pedestal about 4 feet above the ground. This location was selected over a ground location in order to give added protection from the environment, and to minimize heliostat wiring.

The main functions of the HC are:

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 operating in the following control modes:
   a. Normal receiver tracking
   b. Standby position
   c. Special aimpoint
   d. Special gimbal angle
   e. Heliostat stow
   f. Heliostat unstow
4. Store motor turn position data and transmit each data upon request.

The HC is developed around an INTEL 8049 one-chip microcomputer which contains 2K ROM and 12A bytes of RAM. It provides the capability of communicating with the HFC (through the USART), inputting data from the detectors (incremental encoders and limit switches) and controlling the motors.

Motor control involves a motor control circuit and a contactor assembly. The motor control circuit is used to provide on/off control of 208 VAC three phase power and to provide a CW/CCW direction control signal to the contactor assembly. The contactor assembly has two contactors, one for each motor and rated for motor full load operation. Motor direction is reversed by switching the polarity of the direction signal into the contactor.

An incremental encoder is used to determine the position of the heliostat by counting the number of motor revolutions achieved from a known reference. Two identical incremental encoders will be used on the heliostat, one for each drive motor. 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 a slotted ferrous metal vane attached to the motor shaft which protrudes from the end of the motor. Each sensor assembly consists of a magnetic detector (Hall-effect device) and a permanent magnet separated by a gap. The sensor assembly and slotted metal vane are configured such that once each motor revolution each sensor detects the absence of the metal within the gap causing a change in the magnetic field. This change results in the Hall-effect sensor output to switch status (logic "0" to logic "1"). The orientation of the two sensor assemblies result in two channels of data with the phase relationship. A reversal in motor direction causes the sensor output waveform to change phase, sensor 2 waveform would lead sensor 1. Therefore, by noting the number of pulses and the phase relation between sensor 2 and 1, the net number of motor turns can be detected.

The controller assembly can be disconnected and a portable controller plugged in for local control of the heliostat. Local control isolates this heliostat without affecting the control of any other heliostat in the field.

5.5.3.3 Receiver Controller Design

The receiver controller is build around a MIK-11/23 microcomputer system with 128 K words of memory. Analog-to-digital (A/D) converters and digital-to-analog (D/A) converters allow the digital microcomputer to talk to the analog parts of the controls and sensors. The computer uses the inputs from thermocouples, flow meters, flux transducers, and pressure gauges to calculate the settings for the valves which control the amount of salt flow through the different panels.

The first two receiver passes are uncontrolled, as was indicated in Figure 4-3. The final two passes are arranged in series and controlled to regulate outlet temperature. The final pass fluid temperature controllers provide the salt outlet temperature control. Solar flux meters provide the controller with an average incident flux reading to be used in an anticipator loop. Tube metal temperature is measured on the back side of the tube to provide control of metal and fluid temperature during transient operation.

The pressure control drag valve Pcv-1 of Figure 4-3 serves a two-fold purpose. The first is to dissipate the static fluid pressure in the downcomer and prevent excessive pressure in the fluid entering the hot salt storage tank. The second, is to prevent a negative atmospheric pressure from occurring in the receiver, by supplying sufficient back pressure in the downcomer.

The flow control bypass of the supply pumps is controlled by the maximum open temperature control valves (V1, V2, V3, and V4). The pump bypass valves (VPH1 and VPH2) are adjusted to maintain the temperature control valves in the stowed position that most enhances the controllability of fluid flow. The pump bypass valve is also controlled to maintain these pumps in efficient operation. As can be seen the controller must make trade-offs between temperature control and pump characteristics.

5.5.3.4 Thermal Storage Controller Design

The thermal storage and steam generation control subsystem is built around a MIK-11/23 microcomputer system with 128K words of memory. Analog-to-digital (A/D) converters and digital-to-analog- (D/A) converters allow the digital microcomputer to talk to the analog parts of the controls and sensors. The computers use the inputs from thermocouples, flow meters, and pressure gauges to calculate the settings for the valves which control the amount of salt flow through the different heat exchangers, as well as the feedwater lines.

The controller has been broken into six (6) subunits for better clarity, as shown in Figure 5-33. Controller #1 is the main salt supply control. It controls the outlet steam flow (or pressure) by supplying the proper flow of

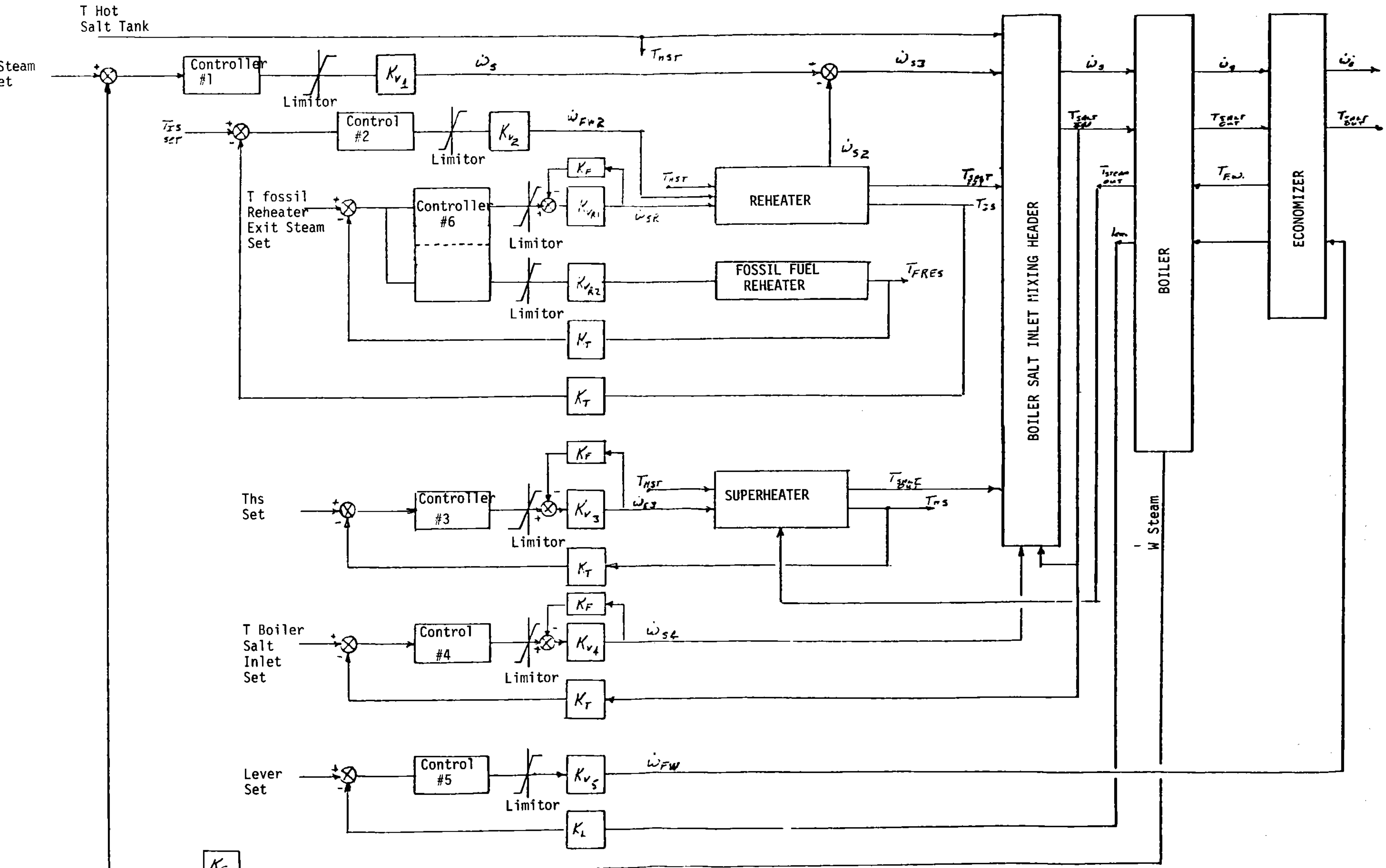


FIGURE 5-33 CONTROL BLOCK DIAGRAM

hot salt to the system. Controller #2 maintains the proper reheat steam temperature by controlling the feedwater supply to the spray attemperator, thus controlling the reheater steam inlet conditions.

Controller #3 adjusts the flow rate of hot salt through the superheater to maintain the proper superheat temperature.

Controller #4 is redundant but could supply very useful features. It prevents the salt temperature into the boiler from exceeding design limits and prevents the boiler from superheating the steam or giving a false drum water level reading caused by too rapid a change in boiling rate.

Controller #5 maintains proper boiler level by bypassing the feedwater around the feedwater pump.

Controller #6 splits the cold reheat steam between the fossil and solar reheaters. When the fossil boiler is turned down, its reheat section is not able to heat the steam to the proper temperature. An excess of steam is shunted to the solar reheater to maintain the hot reheat steam temperature.

5.5.4 Master Control Software

The programmed controller inputs and outputs commands, performs information transfers, and provides monitor and control data for the operator and the subsystem. Programmed instructions in the controller are executed in a prescribed sequence to perform tasks associated with the command, communication and data functions. These tasks or modules will be organized in each of the programmed controllers to perform a series of functions needed to monitor and coordinate the control of the subsystems.

5.5.5 Master Control Operation

Master control operates in any one of three modes from an integrated control console. These modes are:

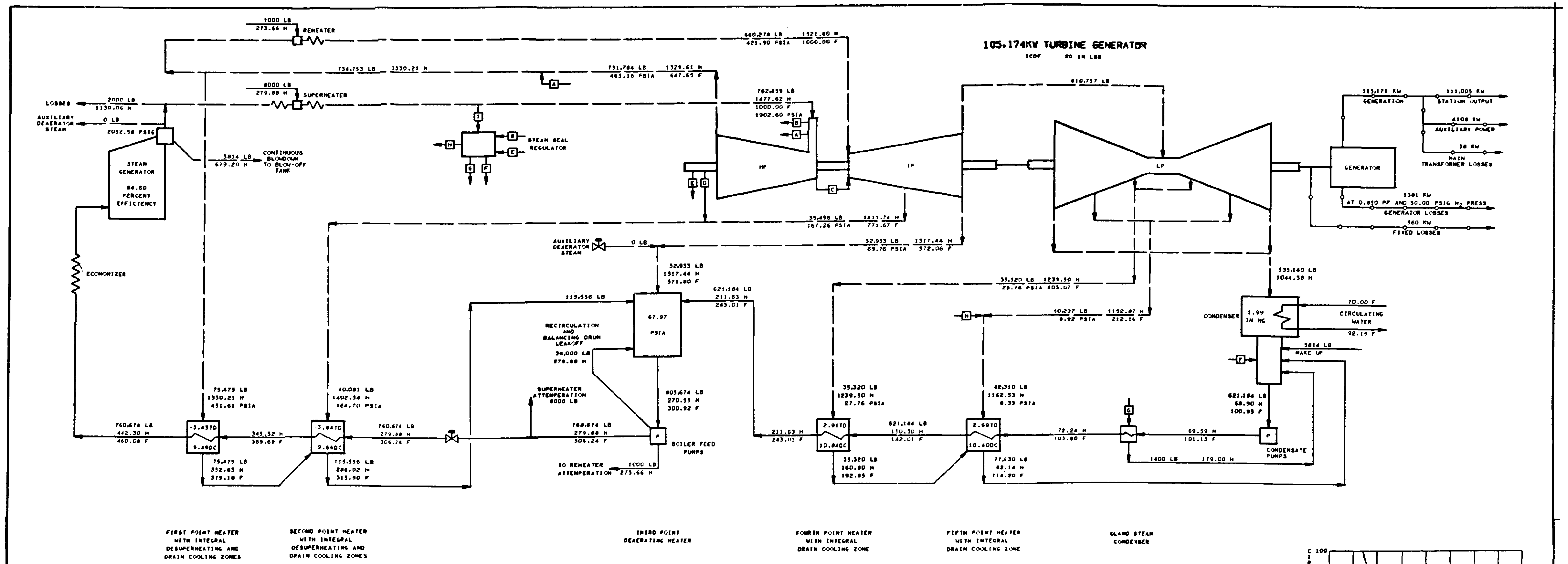
Manual	-	Subsystem Stand-Alone
Programmed-Auto	-	Semi-Automatic Operation with Operator Intervention required.
Automatic	-	Programmed Automatic Operation with Operator Monitoring

The control console design provides the man/machine interfaces with which to control the Plant and subsystems. Three individual terminals connected to the redundant serial data busses are used to control each of three subsystems independently (i.e., thermal storage, receiver and collector) or as an integrated plant system using master control.

5.6 FOSSIL ENERGY

The Ft. Churchill plant contains two generation units which are similar in size and rating. Unit No. 1 was placed in operation in 1968, Unit No. 2 in 1971. Both of these units were designed with boilers which could be connected to coal burners. The turbine/generators systems are similar with both units and these are discussed in Section 5 of Appendix A. These units are rated at a nominal 115 MW_e (gross) or 110 MW_e (net). The rated conditions are at 12.4 MPa (1800 psi) 538°C/538°C (1000°F/1000°F). Both of these units are normally operated at a 5% overpressure condition, hence, 13.0 MPa (1890 psi). The predicted nominal performance of Unit No. 1 is shown on the heat balance diagram, Figure 5-34. The performance of the installed equipment has been measured and while some slight differences were measured these were not significantly different from the predicted conditions.

Both Unit No. 1 and Unit No. 2 can be operated on either oil, gas or on a combination of both of these. However, each unit was optimized on one fuel only and this optimization produced different combinations in heat transfer surface areas within the boilers. The actual values of each are:



$$\text{TURBINE HEAT RATE} = \frac{\text{BOILER DUTY}}{\text{GENERATION}} = \frac{9.20938 \times 10^{+08}}{115{,}171} = 7996.24 \text{ BTU/KW-HR}$$

$$\text{STATION HEAT RATE} = \frac{\text{BOILER DUTY}}{\text{STATION OUTPUT} \times \text{BOILER EFF.}} = \frac{9.20938 \times 10^{+08}}{111{,}005 \times .8460} = 9807.06 \text{ BTU/KW-HR}$$

BASIS OF HEAT BALANCE CALCULATIONS

ELEVATION - APPROXIMATELY 4308 FT.
ATMOSPHERIC PRESSURE - 12.6 PSIA
FUEL - NATURAL GAS
BOILER BLOW DOWN - 0.50 PER CENT OF MAIN STEAM FLOW
STEAM LOSSES - 2000 LB, CONSTANT AT ALL LOADS
BOILER EFFICIENCY - CALCULATED AT A DAILY AVERAGE DRY BULB TEMPERATURE OF FIVE DEGREES LESS THAN THE CIRCULATING WATER INLET TEMPERATURE.
EXTRACTION PRESSURES SHOWN NEAREST THE TURBINE ARE TURBINE EXTRACTION CONNECTION PRESSURES. HEATER ENTRANCE PRESSURE IS SHOWN ADJACENT TO HEATER.
STEAM LINE PRESSURE DROPS ARE CALCULATED AT ALL LOADS.
MAX RATED LOAD HEAT BALANCE CALCULATED AT 1800 PSIG. ALL OTHER HEAT BALANCES CALCULATED AT 105 PERCENT OF RATED PRESSURE.

BALANCE DIAGRAMS WERE GENERATED AND DISPLAYED BY A GENERAL DYNAMICS SC-4020 HIGH SPEED MICROFILM RECORDER.

AUXILIARY POWER REQUIREMENTS ARE CALCULATED FOR ALL PIECES OF MAJOR EQUIPMENT LISTED BELOW.

REQUIREMENTS VARIABLE WITH LOAD

EQUIPMENT	IN OPERATION
2 BOILER FEED PUMPS	2
2 CONDENSATE PUMPS	2
1 FORCED DRAFT FAN	1

CONSTANT REQUIREMENTS

EQUIPMENT	KILOWATTS
2 CIRCULATING WATER PUMPS	292
1 DEEP WELL PUMP	110
MISC MECH EQUIP	180
BUILDING SERVICE	23
MISC + LIGHTING	120
TOTAL CONSTANT REQUIREMENTS	725

ALL HEAT BALANCE RESULTS WERE PRODUCED BY A COMPUTER PROGRAM PROCESSED ON A 7094 IBM COMPUTER.

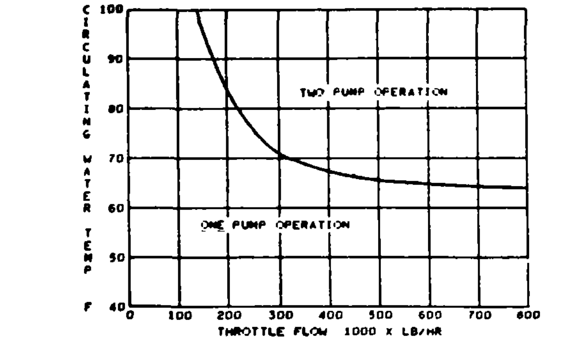
CIRCULATING WATER TEMPERATURE F	CONDENSER PRESSURE IN HG	BOILER EFFICIENCY PERCENT	LAST EXTRACTION FLOW LB/HR	TURBINE EXHAUST FLOW LB/HR	EXPANSION LINE END POINT BTU/LB	EXHAUST ENTHALPY BTU/LB	GENERATION KW	STATION OUTPUT KW	TURBINE HEAT RATE BTU/KWHR	STATION HEAT RATE BTU/KWHR
90.00	3.46	84.85	31,754	545,177	1051.82	1056.99	113,524	109,359	8112.29	9925.20
80.00	2.62	84.72	36,180	540,010	1038.27	1048.82	114,643	110,477	8033.07	9839.27
70.00	1.99	84.60	40,297	535,140	1025.21	1044.38	115,171	111,005	7996.24	9807.06
60.00	1.53	84.47	44,016	530,680	1013.01	1043.04	115,225	111,059	7992.51	9316.89

LEAKAGES

	FLOW	ENTHALPY
A	2969	1477.62
B	819	1477.62
C	10,908	1457.59
D	4586	1329.61
E	3794	1329.61
F	1200	1355.88
G	1400	1355.88
H	2013	1355.88
I	0	0.

LEGEND

— —	STEAM
——	WATER
—o—	POWER
LB	FLOW, POUNDS PER HOUR
H	ENTHALPY, BTU PER POUND
F	TEMPERATURE, DEGREES F
TD	TERMINAL DIFFERENCE
DC	DRAIN COOLER APPROACH
KW	KILOWATTS
IN HG	PRESSURE, IN OF MERCURY, ABS.
PSIA	PRESSURE, LB PER SQUARE IN, ABS.
(valve symbol)	CONTROL VALVE



PUMP SLECTION CURVE

CORR APPR DATE

HEAT BALANCE DIAGRAM
115171 KW LOAD MAXIMUM GENERATION
FORT CHURCHILL STATION UNIT NO 1
SIERRA PACIFIC POWER COMPANY
RENO, NEVADA
STONE + WEBSTER ENGINEERING CORPORATION
BOSTON, MASSACHUSETTS
DRAWING NUMBER 11087-FM-6A

Figure 5-34 HEAT BALANCE DIAGRAM

	Unit No. 1	Unit No. 2
Reheater	763 m^2 (8313 ft^2)	964 m^2 (10503 ft^2)
Superheater	1724 m^2 (18772)	2455 m^2 (26736)
Superheater	294 m^2 (3208)	294 m^2 (3208)
Economizer	1480 m^2 (16105)	1040 m^2 (11300)

It should be noted that Sierra Pacific Power Company has a third unit, Tracey No. 3, which is similar to the two units at Ft. Churchill. Tracey No. 3 uses oil/gas as a fuel, but this unit was not designed to accommodate a future coal conversion. Hence, Tracey No. 3 is a prime candidate for solar repowering and the data generated for the fossil energy system for Ft. Churchill No. 1 will be applicable to both Ft. Churchill No. 2 and Tracey No. 3. Tracey No. 3 and Ft. Churchill No. 2 are both on the computerized dispatch system and they are both controlled from the office in Reno. Ft. Churchill No. 1 is presently controlled by the plant operators, on site, and dispatched as requested by the Reno dispatcher. Depending on the final configuration of the Master Control System (Solar) for Unit No. 1, it may be possible to incorporate this unit into the overall computer network and place the dispatch operations for Unit No. 1 in the Reno office. This possibility will be evaluated further in the phase 2 design effort.

5.7 ENERGY STORAGE SUBSYSTEM

The energy storage subsystem consists of the Thermal Storage Unit, the Steam Generator Heat Exchangers and the circulation equipment. Each of these systems are presented in this section.

5.7.1 Thermal Storage

5.7.1.1 Thermal Storage Description

The thermal storage unit is designed to receive, store, and discharge molten salt as required by the receiver and steam generator. The thermal storage unit includes two (2) externally insulated, cylindrical storage tanks sized to store enough salt to operate the solar steam generator at full load for approximately 6 hours.

Figure 5-35 schematically illustrates the tank arrangement. Salt heated in the receiver to 566°C (1050°F) is directed to the hot tank. Depending upon steam generator load requirements, salt is pumped from the hot tank through the steam generator. Hot salt not directly required by the steam generator system remains in the hot tank. After passing through the steam generator, cold salt at approximately 288°C (550°F) is discharged into the cold tank. Cold salt not directly required by the receiver remains in the cold tank.

For steam generator start-up, the thermal storage subsystem is equipped with transfer lines which permit the blending of salt from the hot and cold storage tanks to the temperature required by the steam generator system. An external fired heater is provided for freeze protection, storage tank preheat, and to maintain the salt temperature in the respective tanks at a relatively uniform level in order to avoid thermal cycling of the tank materials.

The general layout of the thermal storage system is shown on the P&ID, Figure 4-3. The physical location of these components is shown on the site plot plan, Figure 4-5.

5.7.1.2 Storage Tank Description

Figures 5-36 and 5-37 illustrate the conceptual design of the hot and cold storage tanks, respectively. Significant design features include the following:

- Both tanks are designed with a 0.6 height-to-diameter ratio. Since the Fort Churchill plant site is classified a Seismic Zone 3, a low height-to-diameter ratio is required to reduce the overturning moment due to seismic accelerations. The low ratio also reduces the soil bearing load.
- Each tank roof is a self-supporting dome.
- Because of the high operating temperature of the hot tank (566°C [1050°F]), the tank material is 304 stainless steel. The cold tank operating temperature (288°C [550°F]) permits the use of carbon steel.

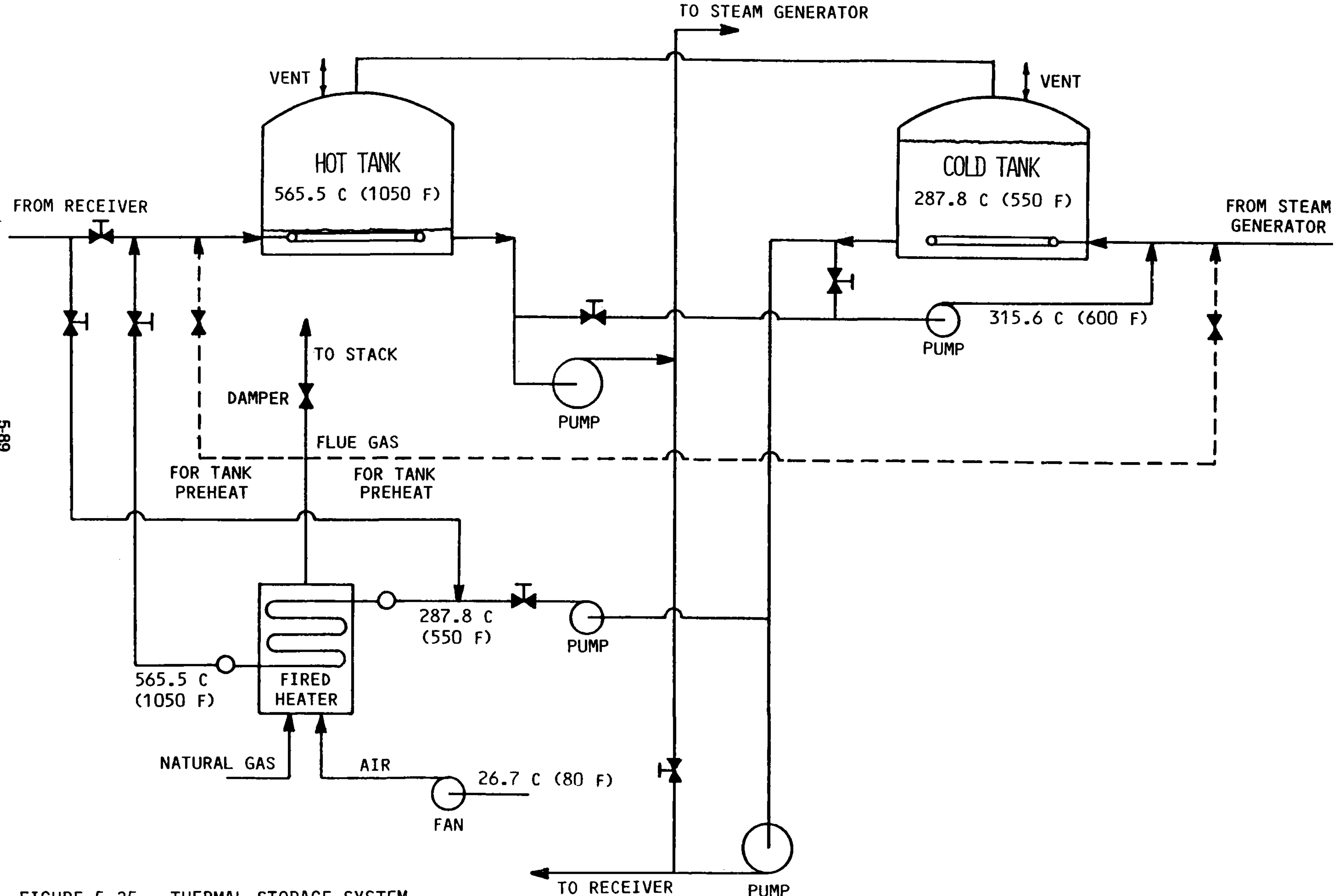


FIGURE 5-35 THERMAL STORAGE SYSTEM

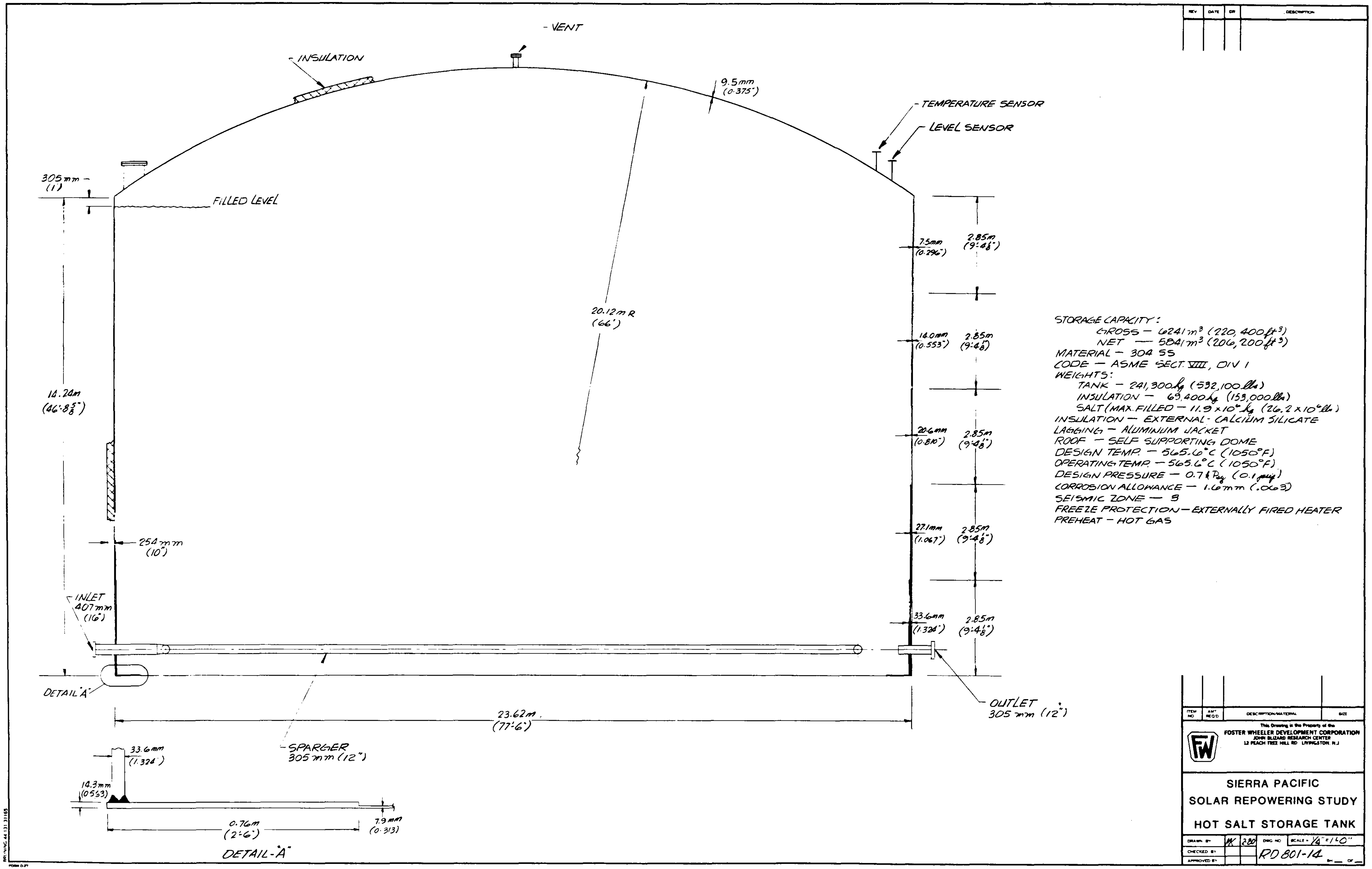


Figure 5-36 HOT SALT STORAGE TANK

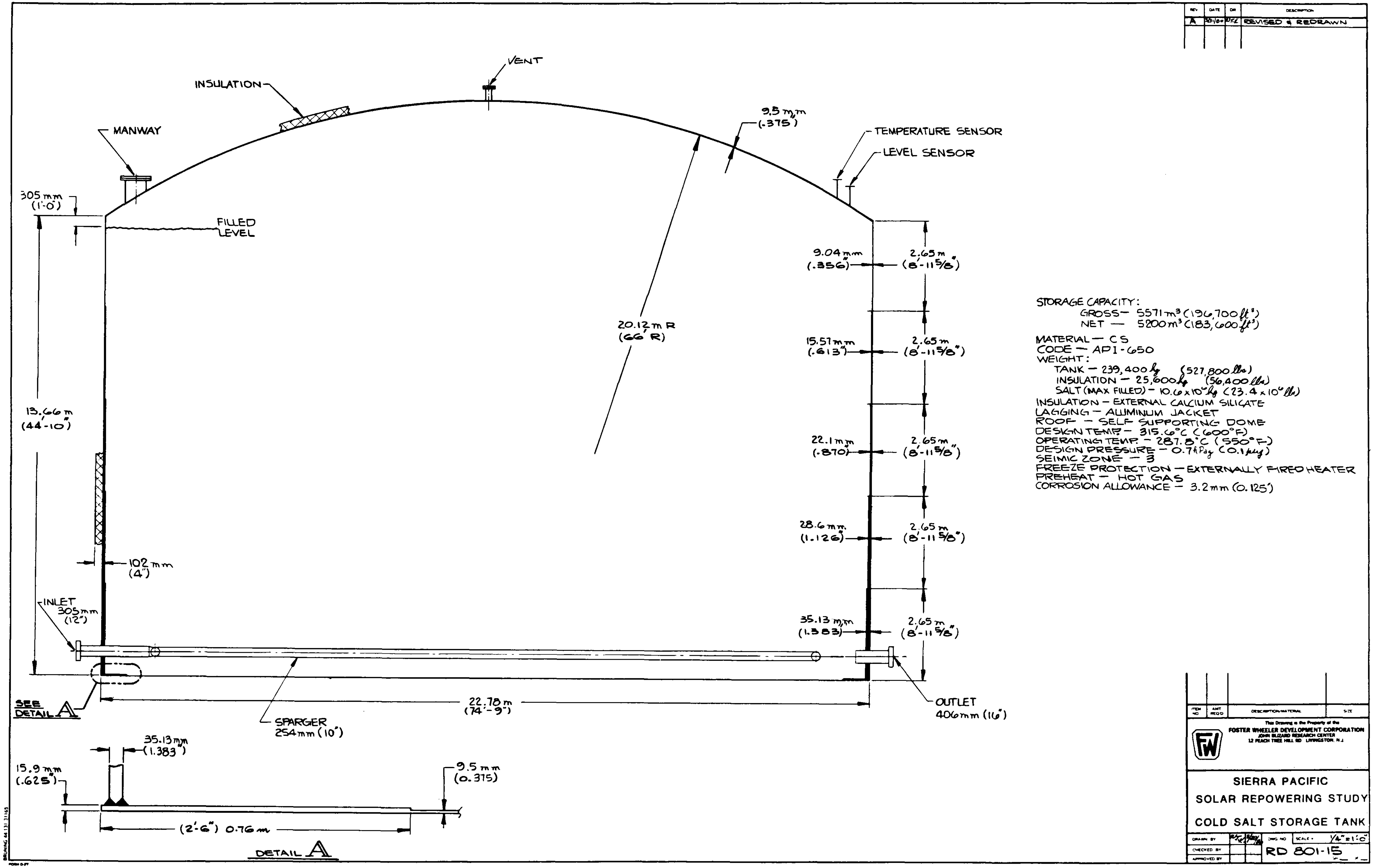


Figure 5-37 COLD SALT STORAGE TANK

- Each tank is designed with five (5) shell rings with variable thickness dependent upon the hydrostatic pressure at each level. Corrosion allowances of 1.6 mm (0.063 in.) and 3.2 mm (0.125 in.) were provided in the hot and cold tanks, respectively.

- Low stress levels in the floor permit the use of thin butt-welded plate material. However, in order to properly provide a double-sided full penetration weld where the shell meets the floor, the thickness of the outer 0.76 m (2.5 ft) floor plates was increased.

- Inlet and outlet nozzle penetrations are located approximately 0.61 m (2 ft) from the tank floor to reduce shell thermal and pressure stresses. Consequently, 0.61 m (2 ft) of unusable salt will remain in each tank. This residual salt will be maintained at the normal operating temperature by the tank trace heaters. Radiation and natural convection from this layer of salt will maintain the tank materials at a uniform temperature, avoiding thermal cycling.

- A freeboard zone of 0.3 m (1 ft) is provided above the filled salt level in each tank. When one tank is completely filled, waves generated during an earthquake may strike the roof. Pittsburgh Des-Moines Steel, who provided tank design information, indicated that the roof structure would not be adversely affected by waves striking it during an earthquake. If necessary the freeboard zone could be increased to prevent waves from striking the roof.

- In order to avoid designing the storage tanks as pressure vessels, cover gas must be added or discharged from the tanks as they are emptied or filled. Consequently a vacuum vent and a pressure relief vent are required on each tank to maintain the freeboard pressure between $\pm$0.7 Pag ($\pm$0.1 psig). In order to minimize the amount of cover gas added to or discharged from the system, the tank vents are interconnected so that as one tank is filled, the displaced cover gas is vented to the other tank which is being drained. As hot cover gas is displaced into the cold tank, the reduction in gas temperature will require cover gas to be added to the system. Conversely, as cold cover gas is displaced into the hot tank, the increase in gas temperature will require discharging cover gas from the system. Specific cover gas and salt purification requirements will be defined in the detail design portion of this program.

- External calcium silicate with aluminum lagging is used to insulate the storage tanks. The hot tank (shell and roof) requires 254 mm (10 in.) of insulation and the cold tank requires 102 mm (4 in.).
- During start-up and shutdown, salt at a temperature different from the tank salt inventory may be added. Consequently, a circular distribution sprager extends from each tank inlet in order to uniformly distribute salt as it enters, minimizing tank temperature variations.

5.7.1.3 Performance

Each storage tank is capable of storing 9.72 x 10^6 kg (21.43 x 10^6 lb) of usable salt as the tank normal operating temperature. This quantity of salt can provide 6.37 hours of continuous full load, hybrid solar steam generator operation.

Insulation on each tank was selected to provide personnel protection and minimize heat losses to ambient. With 26.7°C (80°F) ambient temperature on a calm day the aluminum jacket on each tank will be at or below 54.4°C (130°F). Heat losses from the storage tanks are as follows:

	Hot Tank	Cold Tank
Normal, MW (10^6 Btu/h)	0.249 (0.851)	0.216 (0.738)
%/day	0.27	0.48
Maximum, MW (10^6 Btu/h)	0.274 (0.936)	0.260 (0.887)
%/day	0.29	0.57

The normal values correspond to losses on a calm day with 15.6°C (60°F) ambient temperature. The maximum values correspond to losses with -16°C (2°F) ambient temperature and a 3.1 m/sec (7 mph) wind velocity. The maximum conditions were selected from the 1967 ASHRAE Handbook of Fundamentals. The ambient temperature corresponds to the temperature equalled or exceeded during 99% of the winter hours. The wind velocity occurs during less than 30% of the extreme cold hours. The percentage heat loss indicated corresponds to the ambient heat loss per day relative to the sensible heat of the usable salt stored.

5.7.1.4 Freeze Protection/Preheat

The recommended means for providing freeze protection during an extended plant shutdown is schematically illustrated in Figure 5-35. The salt temperature in each tank is monitored so that when the salt temperature in either tank falls 2.8-5.6°C (5-10°F), the freeze protection system will be activated in order to prevent the temperature from dropping further. Salt from the cold tank is pumped through the fossil fuel fired heater which heats the salt to 566°C (1050°F). The salt is then passed into the hot tank. As the salt level in the hot tank rises, salt is drained from the hot tank and blended with salt from the cold tank. With a blended temperature of approximately 316°C (600°F), the salt is pumped back into the cold tank.

Significant features of this system include the following:

- Salt in both the hot and cold tanks can be maintained at a relatively uniform temperature by limiting the permissible temperature drop in each tank. Consequently, excessive thermal cycling of the tank materials can be avoided, as well as the resultant thermally induced stresses.
- A single fired heater can be used to service both tanks.
- Conventional low temperature 316°C (600°F) pumps can be used to circulate salt through the system.
- The external fired heater will be designed for high heat-transfer rates as compared to immersion-type heater built into the tanks. Consequently, less heat transfer surface is required.
- The external fired heater provides improved salt temperature control and a faster temperature response time as compared to other systems.

For initial unit start-up the tanks must be preheated before salt is added in order to prevent salt from freezing on the tank floor and also to avoid thermally induced stressed between the tank shell, floor, and roof. The simplest method of supplying the preheat is to incorporate trace heaters around the outer circumference of the tanks. The heater area would extend from the bottom of the tank to a height of 1.2 M (4 ft) up the tank wall. These trace heaters will be operated at a rate that will permit heat conduction through the metal until the tank bottom and sides are heated to a temperature suitable for the start of the hot salt filling process. The hot salt added during the initial portion of the fill cycle will provide a satisfactory heat transfer fluid within the bottom of each tank and this will assist in stabilizing the thermal gradients between the walls and the bottom of the tank. The allowable stress level in the tank walls and bottom will be determined during the detail design portion of the repowering study (Phase 2). If it is found that the thermal stresses are excessive when using the external trace heaters at the lower portion of the tank another method of preheat will be investigated. The baseline design was selected using the trace heaters and these were included in the detail cost summary.

A second method of tank preheat was investigated on this program. This method was suggested by the tank supplier, Pittsburgh Des-Moines Steel Co., and this method would use hot gas in a manner similar to that used to cool cryogenic tanks, using a cold gas. The hot gas could be passed through the inlet sparger to uniformly distribute hot gas throughout the tank. Gas would be added at a rate that would increase the tank temperature 2.8-8.3°C (5-15°F) per hour. Temperature detectors would be located at significant locations on the tank shell, floor, and roof. As the tank temperature rises, the temperature difference between any two temperature detectors should not exceed approximately 55.5°C (100°F). If this temperature difference is exceeded, the introduction of hot gas will be stopped until the difference falls within the allowed difference.

The hot gas can be either flue gas from the natural gas fired heater, as shown in Figure 5-35, fired with a very high excess air, or air heated in a heater specifically provided for this purpose. The air heater can simply be a heat exchanger which utilizes molten salt heated in the natural gas-fired heater. A separate forced draft fan would also be required. Specific requirements for the preheat system are dependent upon the desired rate for tank preheat and the type system selected.

For the purpose of the conceptual design study, a cost estimate was obtained for a commercially available 1.76 MW (6 x 10^6 Btu/hr) natural gas-fired heater. The full load heat input to this heater is approxiamtely three times that required for tank freeze protection. If used with an oversized forced draft fan, it would require approximately 4 days to preheat each storage tank.

5.7.1.5 Foundation/Anchor Arrangement

Thermal Storage Tank Foundation Design

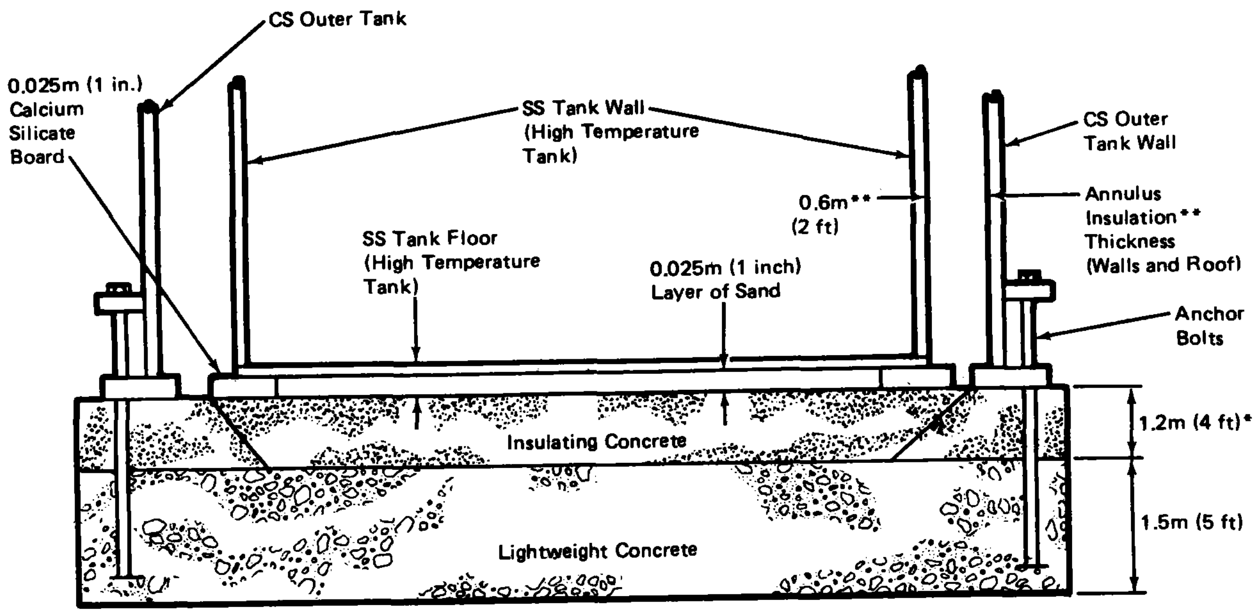
The thermal storage tank foundation design for the hot and cold cylindrical tanks are described below and also given on Figures 5-38 and 5-39.

Design Criteria

- Allowable Soil Bearing Pressure 0.24 MPa (5000 PSF)
- Seismic - UBC Zone 3
  - (0.25g Peak Ground Acceleration)
- Temperature
  - Hot Salt/Tank 566°C (1050°F)
  - Cold Salt/Tank 288°C (550°F)
- Total Heat Loss (Tank and Foundation) 1%/day (stored energy).

The cylindrical tank foundation is designed (1) to limit the heat loss through the foundation to the earth and (2) to withstand the seismic loading criteria. The structural foundation for the hot and cold tanks is the same except for the dimensions of the concrete. 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 refractory product, Marinete I, a calcium silicate board, is specified under the rigid tank shell bottom joint to provide (1) a non-combustible filler material between the tank and the irregularities in the concrete, and (2) to confine the one inch of sand. The Marinete 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°F (1200°F) in an unstressed condition for testing. The insulating concrete was therefore conservatively assumed to lose 50% of its initial strength due to high temperature exposure. Since the concrete will be heated while loaded in compression, it should, according to work done by Abrams*, retain more than one half its initial strength.

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



*0.6m (2 ft) Insulating Concrete Thickness for Low Temperature Salt Tank, ie 288°C (550°F) (Walls and Roof)
**0.38m (15in) Coarse Granular Expanded Perlite or Vermiculite for Low Temperature Salt Tank, ie 288°C (550°F)

Figure 5-38. Storage Tank Foundation and Seismic Anchor

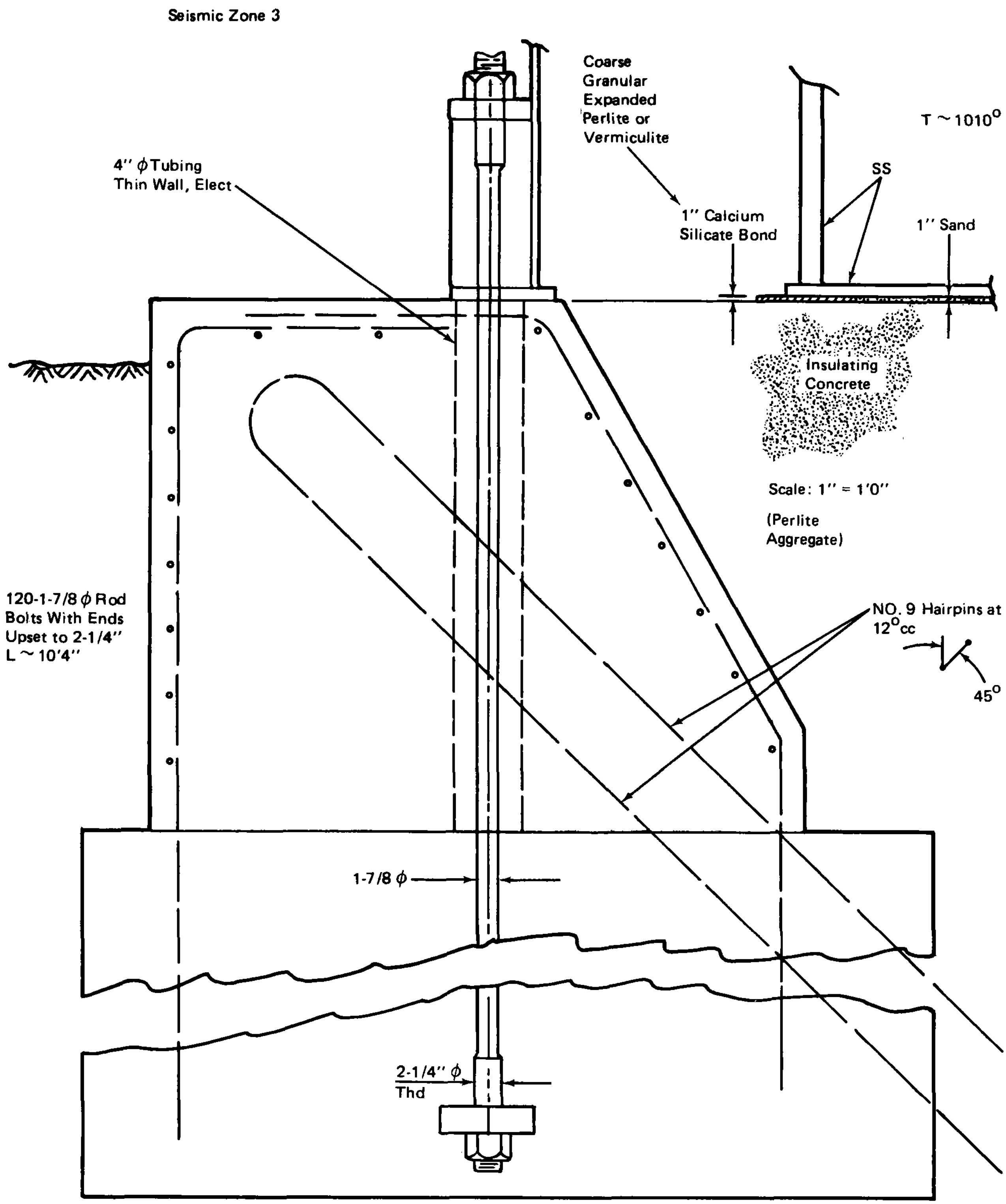


Figure 5-39. Anchor Bolt Arrangement

The concrete foundation is comprised of two cylindrical layers, the uppermost being insulating concrete and the lower layer being light weight concrete. For the hot tank, the insulating concrete is 1.2m (4 ft) thick and for the cold tank it is 0.6m (2 ft) thick. The lightweight structural concrete is 1.5m (5 ft) thick for both the hot and cold thermal storage tanks.

Anchor Arrangement

The seismic design criteria of 0.25g was used for the peak ground acceleration. Due to the seismic force the fluid (salt) would oscillate with a simple calculated amplitude of 2.4m (8 ft). The dynamic viscosity of the draw salt at 1050°F is almost identical to water at 70°F. Without heavy bottom reinforcement running from the tank wall radially inward, the tank will tend to alternately lift opposite sides in response to the earthquake forces. It is not practical to attempt to anchor the inner (hot) tank for three reasons (1) there would be a significant heat loss through the anchor bolts, (2) the bottom edge of the tank will expand radially about 0.1m (4 in.) from ambient to operating temperature, and (3) any initial bolt clamping force would tend to restrict radial movement of the bottom plate. Restraint limiting uplift from seismic forces is provided by anchoring the outside (lagging) els., tank with 120-0.05 mu (1 7/8ø")* bars with threaded (upset) 0.06 mø 2 1/4"ø ends. The 0.6m ** (2 ft) space between the inner (hot) tank and outer (lagging) tank or shell would be filled with expanded spherical perlite (or a vermiculite alternate). In the case of the perlite, the initial density of about $3\#/ft^3$ would be increased to approx. $4\#/ft^3$ as the inner shell or tank temperature increased from ambient to operating temperature.

During an earthquake, the inner tank movement would be dampened by contact with the confined insulation. Perlite can be added to or vacuumed out of the annular shell space and replaced as necessary.

** 0.38m (15 in.) for the low temperature or cold salt tank.

* The main body of the bolts have a smaller area (see Figure 5-39) than the thread area - improved ductibility.

ø Diameter

The rod bolts, attached to the outer shell, would enter the structural concrete ring outside the insulating concrete zone and would be anchored in the concrete mat below as shown in Figure 5-38.

Depending upon final evaluation of the seismic force magnitude, it may be advisable to provide several additional feet of freeboard which would in turn reduce the slashing upward on the tank roof. Because of the sharp angular change at this joint, a horizontal ring should be built into the joint opposite the shell and dome intersection. Both the shell and dome should be thickened in the vicinity of this joint to provide a substantial compression/tension ring to handle the horizontal component of the seismic force. This change will be investigated on the phase 2 design effort.

Piping connected to the inner (hot) tank must be flashed through the outer (lagging) tank in a manner to allow 0.3m (12") lateral movement, 0.15m (6") downward and 0.45m (18" $\pm$) upward movement without bearing on the lagging shell.

5.7.1.6 Development Items

Items requiring further analysis in Pahse II include the following:

- Detailed stress analysis of hot storage tank weld joints where the shell meets the floor and roof. The analysis would determine initial preheat requirements and permissible thermal cycling rates during normal operation.
- Optimization of storage tank insulation requirements relative to overall plant economics.
- Optimization of a cover gas/ullage control system.
- Selection of a salt polishing/purification system.

5.7.2 Steam Generator

5.7.2.1 System Description

The steam generator system is comprised of four (4) heat exchangers designed to generate 64.6 kg/sec (512,730 lbm/hr) of superheated steam at 541°C (1005°F), 13,478 kPag (1955 psig), and 54.5 kg/sec (432,850 lbm/hr) of reheat steam at 541°C (1005°F), 2933 kPag (425 psig). These design point steam conditions correspond to the Stearns-Roger turbine cycle for Case 26 operation (77 MWe solar). Figure 5-40 schematically illustrates the steam generator system.

Hot molten salt entering the system at 567°C (1045°F) flows in parallel through the superheater and reheater, then combines and passes in series through the evaporator and preheater with cold salt leaving the preheater at 288°C (550°F). All heat exchangers are oriented in a vertical position with all heated steam/water circuitry upflow. The preheater, superheater, and reheater are counter-flow, while the evaporator is parallel flow in order to improve natural circulation. A vertical steam drum is mounted on top of the evaporator. A recirculation pump is provided to maintain the feedwater at a temperature above the salt freezing point (221°C [430°F]) during start-up and part-load operation.

Final main steam temperature is controlled by a valve at the superheater outlet which controls the salt flow rate through the superheater. Reheat steam temperature is controlled by bypassing salt around the reheater. A spray attemperator is located at the reheater steam inlet for trim control. Since the salt side pressure drop through the superheater is greater than that through the reheater, a valve is located at the reheater salt outlet to balance pressure drop. The total salt flow rate through the system is controlled by a valve at the preheater outlet. The total salt flow rate is determined by the steam flow rate required.

5.7.2.2 Heat Exchanger Description

The heat exchangers are single-pass shell and tube exchangers with a floating head and triple segmental baffles. Expansion bellows are provided to absorb the differential expansion between the tube bundle and the shell.

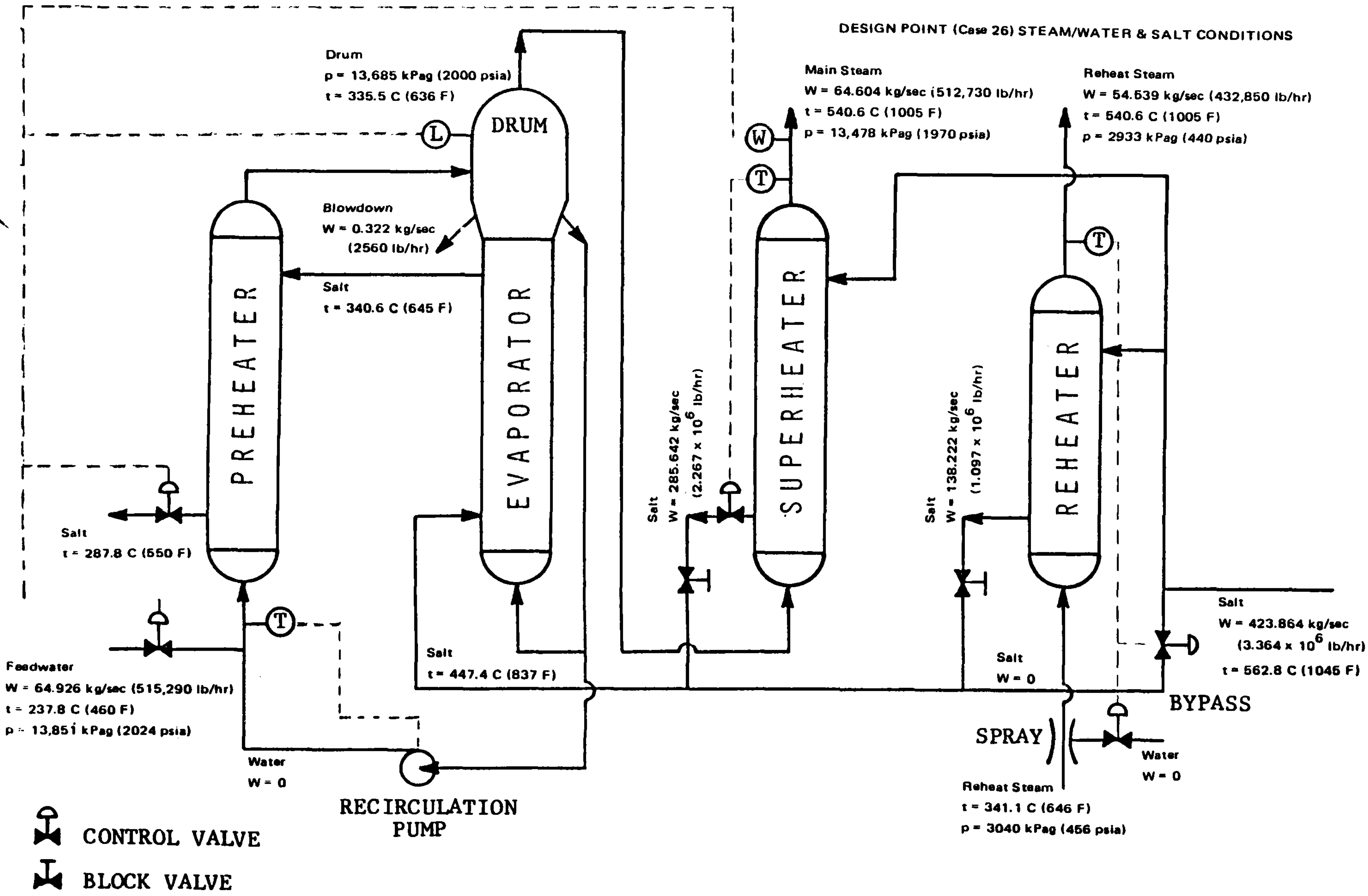


FIGURE 5-40 STEAM GENERATOR SYSTEM

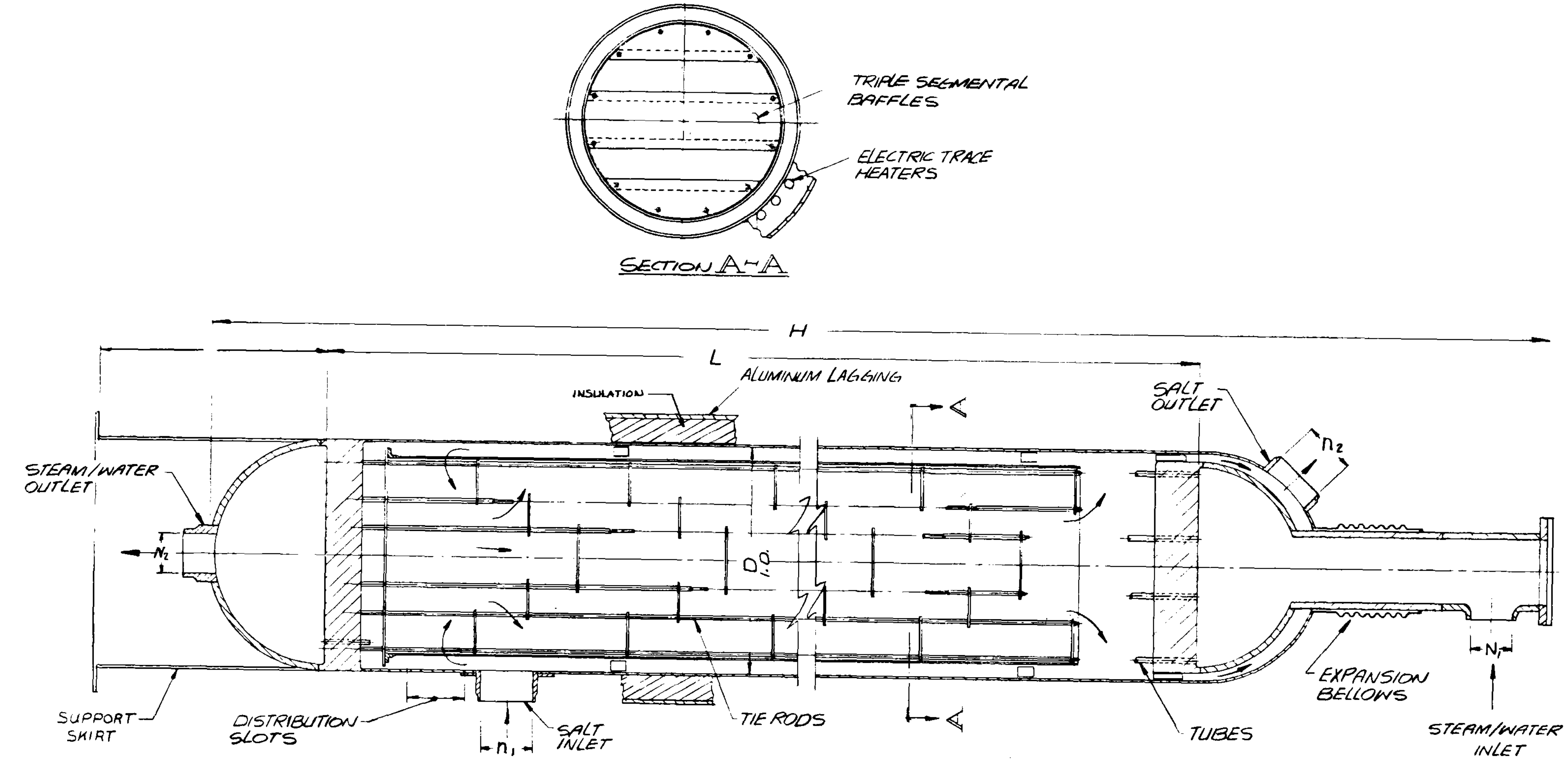
Figure 5-41 illustrates the conceptual design of the preheater, superheater, and reheater. Hot salt enters a nozzle located in the exchanger shell and passes through the annular space formed by a shroud which surrounds the tube bundle. The salt then flows through distribution slots in the shroud and then passes over the tube bundle. After passing through the tube bundle, the salt re-enters the annular space and flows out of the exchanger through a nozzle in the shell head. Steam or water enter and leave through nozzles in the shell heads. The system will incorporate standard safety venting provisions.

The design of the natural circulation evaporator is illustrated in Figure 5-42. The arrangement is similar to preheater, superheater, and reheater except for the following:

- Hot salt enters the lower nozzle located in the shell head and leaves through the upper nozzle located in the shell.
- Steam/water discharges into a vertical drum mounted on top of the evaporator.

The vertical steam drum, which is designed as an integral part of the evaporator, is equipped with 19 spiral arm separators and 14 box-type chevron driers to provide dry saturated steam. Feedwater enters the steam drum through a circular distribution pipe which is positioned below the drum water level. A blowdown line is provided to control feedwater impurity concentration levels in the evaporator.

The heat exchangers were sized using the Heat Transfer Research Institute (HTRI) computer program ST-4 for shell and tube heat exchangers. The program has the capability to determine structural requirements for the standard type shell and tube heat exchangers included in the Standards of the Tubular Exchanger Manufacturers Association (TEMA) for design temperatures and pressures up to 343°C (650°F) and 4138 kPag (600 psig). However, since the selected design is somewhat different from the standard TEMA configurations and since the design conditions for this application exceed the program limitations, head and shell thickness were determined from the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, while tubesheet thickness was estimated from equations included in the TEMA standards.



	PREHEATER	SUPERHEATER	REHEATER
H	18.14m (59'-6")	18.14m (59'-6")	13.26m (43'-6")
L	15.24m (50'-0")	15.24m (50'-0")	10.36m (34'-0")
D	1257mm (4'-1½")	953mm (3'-1½")	927mm (3'-0½")
n_1	356mm (14")	305mm (12")	203mm (8")
n_2	356mm (14")	305mm (12")	203mm (8)
N_1	203mm (8")	254mm (10")	406mm (16")
N_2	203mm (8")	305mm (12")	406mm (16")
TUBE SIZE	15.875mm O.D. x 1.651mm MW (5/8" O.D. x 0.065" MW)		
DRY WEIGHT ②	31,746 kg (70,000 lbs)	18,367 kg (40,500 lbs)	12,880 kg (28,400 lbs)
FILLED WEIGHT	58,685 kg (129,400 lbs)	30,701 kg (69,900 lbs)	20,726 kg (45,700 lbs)
INSULATION THICKNESS ③	127mm (5")	178mm (7")	178mm (7")
ELECTRICAL TRACE HEATERS:			
No OF UNITS	24	14	8
LENGTH OF UNIT	30.48m (100')	30.48m (100')	20.73m (68')
DESIGN CONDITIONS:			
TUBE SIDE			
PRESSURE	15,512 kPag (2250 psig)	15,340 kPag (2225 psig)	3,964 kPag (575 psig)
TEMPERATURE	371.1°C (700°F)	565.6°C (1050°F)	565.6°C (1050°F)
SHELL SIDE			
PRESSURE	2,068 kPag (300 psig)	2,068 kPag (300 psig)	2068 kPag (300 psig)
TEMPERATURE	371.1°C (700°F)	565.6°C (1050°F)	565.6°C (1050°F)
MATERIAL	CS	304 SS	304 SS
APPLICABLE CODE: ASME SECTION VIII, DIV 1			

KEY:
① NOMINAL NOZZLE SIZES
② INSULATION WEIGHT NOT INCLUDED
③ CALCIUM SILICATE
④ TUBES, FORGINGS, SHELL PLATES, SHELL HEADS

REV | DATE | DR | DESCRIPTION

ITEM NO | AMT REQD | DESCRIPTION MATERIAL | SIZE

This Drawing is the Property of the FOSTER WHEELER DEVELOPMENT CORPORATION
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FW

SIERRA PACIFIC POWER
SOLAR REPOWERING STUDY

PREHEATER, SUPERHEATER, REHEATER

DRAWN BY EP | DWG NO | SCALE
CHECKED BY
APPROVED BY

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Figure 5-41 COUNTER FLOW HEAT EXCHANGER

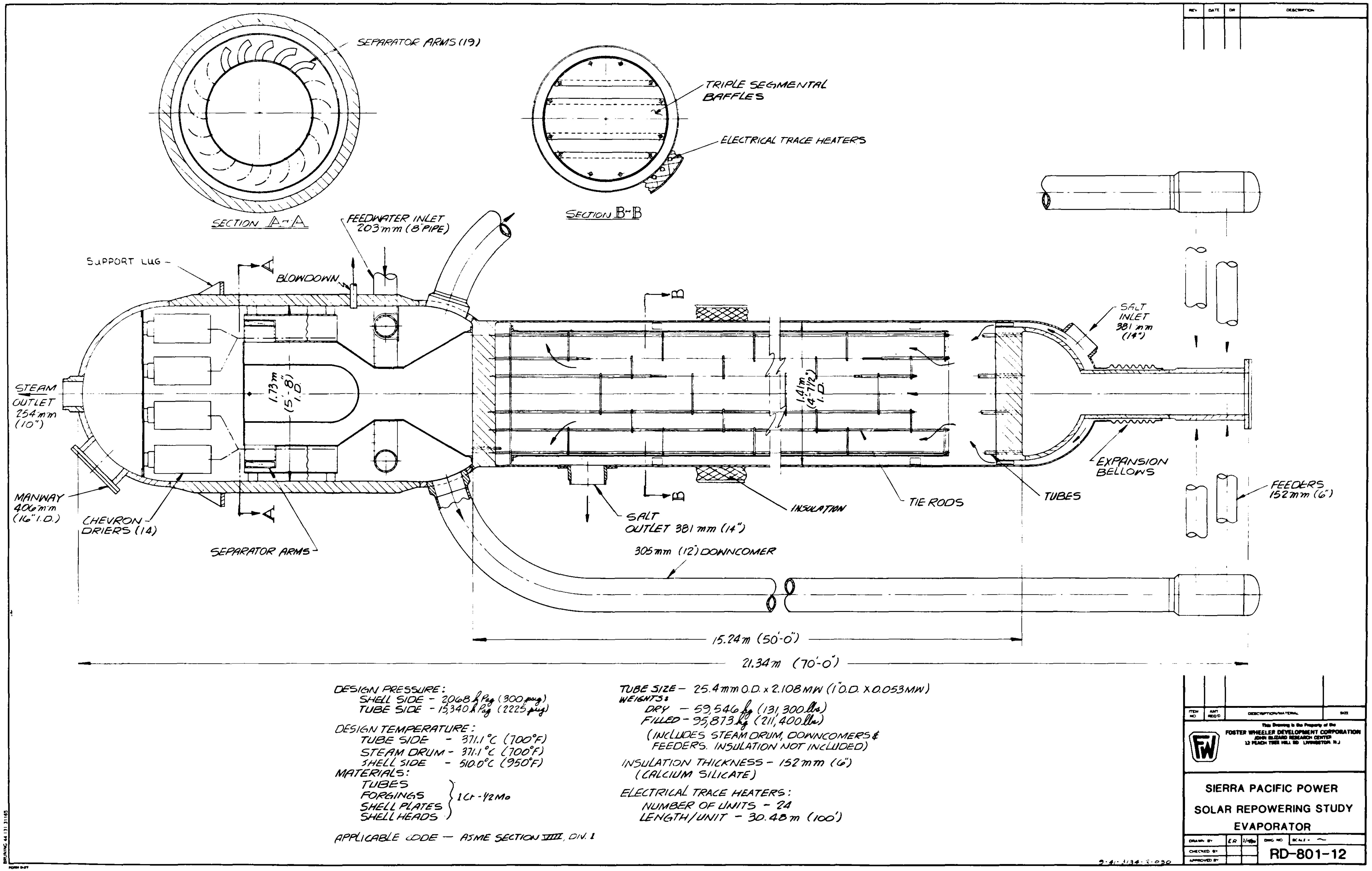

Figure 5-42 PARALLEL FLOW HEAT EXCHANGER

In sizing the heat exchangers, configurations were selected that result in reasonable overall heat transfer coefficients, shell and tubeside pressure drops, and length to diameter ratios. Significant arrangement details and design parameters for the heat exchangers are presented in Section of the SRS.

The materials selected for the preheater (carbon steel) and evaporator (1 Cr-1/2Mo) were based on recent studies conducted by Martin Marietta ("Solar Central Receiver Hybrid Power System," Martin Marietta Corporation, DOE-ET-2103801, September 1979). The materials selected for the superheater and the reheater (304 stainless steel) were based on favorable preliminary corrosion rate test results obtained by Sandia Laboratories, Livermore, California.

The floating head design, using a flexible bellows assembly, was selected for this application on the basis of lower system costs. The tube and shell design is a conventional state-of-the-art design. The final design selected is based on the design of a similar heat exchanger which was designed, and qualified, for the Clinch River Breeder Reactor Plant. A development program was completed by Foster Wheeler on the flexible bellows assembly that was to be used in the Breeder Reactor Plant. The results of that program were covered in a report titled, "Clinch River Breeder Reactor Plant, Intermediate Heat Exchanger, Phase III Expansion Bellows Development Program," FWBC Document No. NO/78/27, September 23, 1978. The configuration was shown on CRBRP-1HX Design Layout, Drawing #27-2538-6-0100. The favorable results obtained on the Breeder Reactor Design were instrumental in selecting this less expensive design for the Sierra Pacific application.

5.7.2.3 Performance

The Heat Transfer Research Institute (HTRI) computer program ST-4 for shell and tube heat exchangers was used to predict thermal and hydraulic heat exchanger performance. Table 5-5 lists estimated performance for hybrid full (Case 26) and part-load operation at 5% overpressure, and for solar stand-alone (Case 20) operation at the turbine design pressure. Of note are the following items:

TABLE 5-5 **STEAM GENERATOR PERFORMANCE**

	HYBRID (5% Overpressure)				SOLAR STAND-ALONE (Design Pressure)
LOAD, % Design	25	50	75	100 (Case 26)	91 (Case 20)
TEMPERATURES, C (F)					
Steam/Water:					
Feedwater	237.8 (460)	237.8 (460)	237.8 (460)	237.8 (460)	211.7 (413)*
Superheater Inlet	334.4 (634)	334.4 (634)	335.0 (635)	335.6 (636)	330.6 (627)
Final Steam	540.6 (1005)	540.6 (1005)	540.6 (1005)	540.6 (1005)	540.6 (1005)
Reheater Inlet	341.1 (646)	341.1 (646)	341.1 (646)	341.1 (646)	309.4 (589)
Reheater Outlet	540.6 (1005)	540.6 (1005)	540.6 (1005)	540.6 (1005)	540.6 (1005)
Salt:					
Superheater Inlet	562.8 (1045)	562.8 (1045)	562.8 (1045)	562.8 (1045)	562.8 (1045)
Superheater Outlet	378.9 (714)	404.4 (769)	428.9 (804)	447.4 (837)	432.8 (811)
Reheater Inlet	562.8 (1045)	562.8 (1045)	562.8 (1045)	562.8 (1045)	562.8 (1045)
Reheater Outlet	400.0 (752)	418.9 (786)	434.4 (814)	447.4 (837)	428.9 (804)
Evaporator Inlet	445.4 (833.7)	445.8 (834.4)	446.4 (835.6)	447.4 (837)	449.4 (841)
Evaporator Outlet	334.6 (634.3)	335.6 (636.1)	337.4 (639.4)	340.6 (645)	333.9 (633)
Preheater Inlet	334.6 (634.3)	335.6 (636.1)	337.4 (639.4)	340.6 (645)	333.9 (633)
Preheater Outlet	282.1 (539.7)	283.4 (542.2)	285.5 (545.9)	287.8 (550)	278.3 (533)
FLOWS, kg/sec (M lbm/hr)					
Steam/Water:					
Feedwater	16.23 (128.8)	32.46 (257.6)	48.69 (386.5)	64.93 (515.3)	57.12 (453.4)
Blowdown	.08 (0.6)	0.16 (1.3)	.24 (1.9)	0.32 (2.6)	.28 (2.2)
Main Steam	16.15 (128.2)	32.30 (256.3)	48.45 (384.6)	64.61 (512.7)	56.84 (450.5)
Reheater	13.63 (108.2)	27.27 (216.4)	40.90 (324.6)	54.54 (432.9)	48.20 (382.6)
Recirculation	0	0	0	0	13.56 (107.6)
Salt:					
Preheater	103.80 (824.0)	208.62 (1656.0)	314.94 (2500.0)	423.86 (3364.0)	391.66 (3109)
Evaporator	103.80 (824.0)	208.62 (1656.0)	314.90 (2500.0)	423.86 (3364.0)	391.66 (3109)
Superheater	44.60 (354.0)	107.08 (850.0)	183.93 (1460.0)	285.64 (2267.0)	219.20 (1740)
Reheater	24.50 (194.5)	55.48 (440.4)	93.22 (740.0)	138.22 (1097.0)	118.54 (941)
Bypass	34.70 (275.5)	46.06 (365.6)	37.79 (300.0)	0	53.92 (428)
PRESSURES, kPag (psig)					
Steam/Water:					
Feedwater	13,628 (1976)	13,676 (1983)	13,752 (1994)	13,851 (2009)	12,993 (1884)
Drum	13,497 (1957)	13,583 (1963)	13,600 (1972)	13,685 (1985)	12,821 (1859)
Final Steam	13,483 (1955)	13,483 (1955)	13,483 (1955)	13,483 (1955)	1,772 (1837)
Reheater Inlet	3,040 (441)	3,040 (441)	3,040 (441)	3,040 (441)	1,772 (257)
Reheater Outlet	3,034 (440)	3,014 (437)	2,979 (432)	2,933 (425)	1,634 (237)
Salt:					
Superheater Inlet	503 (73)	607 (88)	869 (126)	996 (145)	924 (134)
Reheater Inlet	503 (73)	607 (88)	869 (126)	996 (145)	924 (134)
Preheater Outlet	717 (104)	717 (104)	717 (104)	717 (104)	717 (104)

*NOTE: Before mixing with recirculated water from Evaporator.

- A 2.8°C (5°F) steam temperature drop was assumed in both the main and reheat steam lines from the heat exchangers to the turbine. The resultant steam temperature leaving the superheater and reheater is 540.6°C (1005°F).
- A 2.8°C (5°F) salt temperature drop was assumed in the hot salt line feeding the steam generator system. Consequently, the molten salt temperature entering the superheater and reheater is 562.8°C (1045°F).
- Molten salt properties for Partherm 430 were used.
- Main and reheat steam temperature can be controlled by bypassing hot salt to the evaporator.
- A blowdown rate of 0.5% was used.
- For solar stand-alone operation (Case 20) with 211.7°C (413°F) feedwater, approximately 24% of the total flow is recirculated to the preheater inlet to maintain the feedwater temperature at 237.8°C (460°F).

Figure 5-43 illustrates the design point temperature profiles through the steam generator system.

5.7.2.4 Structural Design

The layout of the steam generator system is illustrated in Figure 5-44 . The preheater, superheater, and reheater are vertically hung from a support skirt which extends from the upper hemispherical head of each heat exchanger. The evaporator is vertically hung from the lugs on the steam drum.

The structural supports member sizes were based on the following:

- Dead load - 240,400 kg (530,000 lb)
- Seismic - 0.25 g (Seismic Zone 3)
- Wind - 40.2 m/sec (90 mph) at 9.1 m (30 ft)

The wind load is more critical than the seismic load. Consequently, the combined effect of the dead load and wind load were used to size the support structure members according to the Uniform Building Code. The resultant weight of structural steel is approxiamtely 110,500 kg (243,700 lb).

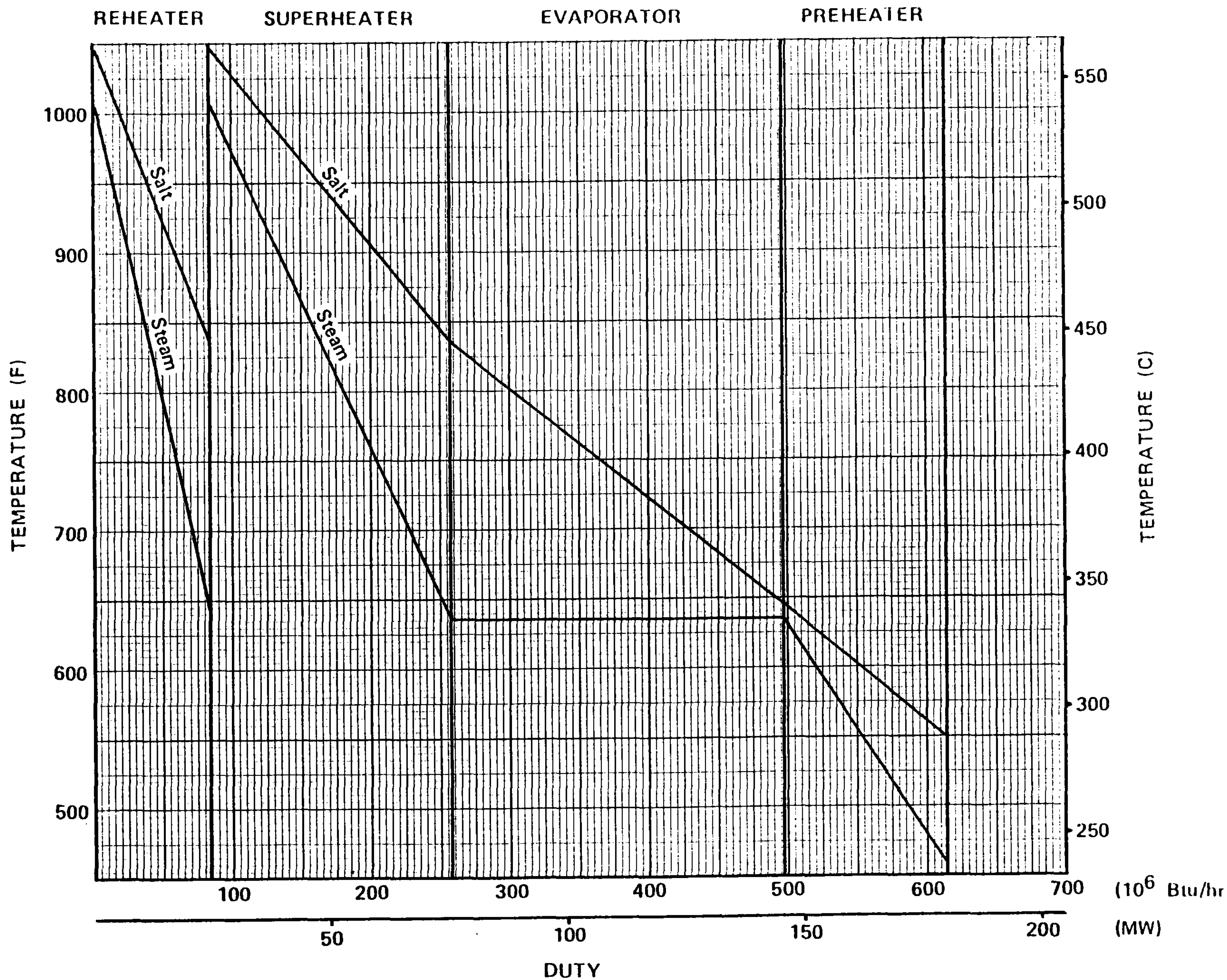

FIGURE 5-43 STEAM GENERATOR PERFORMANCE

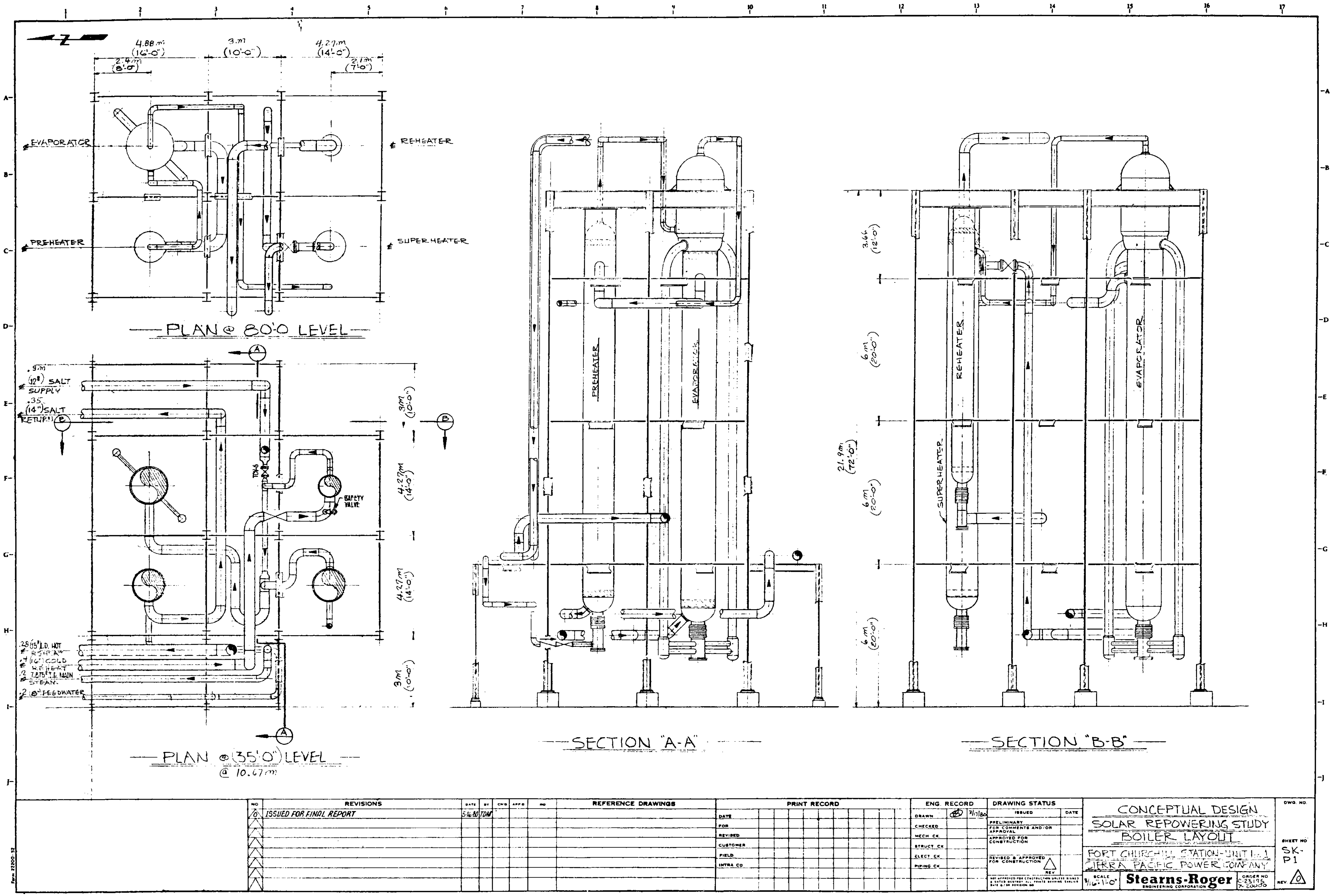

 Figure 5-44 STEAM GENERATOR LAYOUT

5.7.2.5 Steam Generator Foundation

Based on the soil boring logs at Fort Churchill, a mat type foundation was assumed for the steam generator, using an assumed allowable net bearing pressure of 0.24 MPa (5000 psf). The final selection of foundation type and depth will be based on a new foundation investigation (to determine the strength properties and settlement characteristics of subsurface meterials) and the magnitude of structural loads.

5.7.2.6 Start-Up

Recommended start-up procedures unique to the solar steam generator system are discussed below. Integration of these procedures into the existing fossil boiler, turbine, and feed cycles was determined by Stearns-Roger.

Initial Cold Start-Up

For initial unit start-up, the heat exchangers and interconnecting piping will be at ambient temperature. In order to prevent thermal shocking of the system and freezing of the salt, electrical trace heaters will be used to preheat the salt piping and heat exchanger shells to a temperature of 287.8°C (550°F). Because of the annular space between the heat exchanger shell and the shroud surrounding the tube bundle, it would not be practical to attempt to preheat the tube bundle, tubesheets, etc., by means of the external electrical trace heaters on the exchanger shell. Low pressure superheated steam can be passed through each exchanger tube bundle to bring the steam/water pressure parts up to temperature at a predetermined rate. Shell and tube bundle temperatures will be monitored to ensure that the electrical trace heaters preheat the shell at a rate comparable to the rate at which the superheated steam preheats the steam/water pressure parts. Preheating the reheater steam pressure parts will be limited by the reheater design pressure 3964 kPag (575 psig) and the corresponding saturation temperature 251°C (484°F). Condensed steam in the superheater and reheater will have to be drained prior to unit start-up. Steam condensed in the preheater and evaporator can be used for initial filling. Additional saturated water can be added to fill the preheater and evaporator.

Solar Stand-Alone Start-Up

After a unit shut down the steam generator system will be bottled-up and maintained at a temperature no lower than 287.7°C (550°F) by means of electrical trace heaters on each heat exchanger shell and on all interconnecting salt piping (the saturation pressure at 287.7°C [550°F] is 7204 kPa [1045 psia]). In order to prevent salt from freezing in the preheater when cold feedwater is admitted, the following procedure can be used to restart the unit:

- With the feedwater valves closed, start the recirculation pump with a preestablished flow rate and recirculate saturated water through the preheater and evaporator.
- Isolate the superheater and reheater by closing the block valves located at the salt outlet of each exchanger.
- Blend hot and cold salt from the storage tanks to some predetermined temperature (between 288°C [550°F] and 454°C [850°F] and pass the salt through the reheater bypass into the evaporator and through the preheater. Since all the heat exchangers were initially 288°C (550°F), salt will leave the preheater at or above 288°C.
- With the superheater steam outlet valve closed, continue to circulate low temperature salt through the evaporator and preheater to raise drum pressure. Monitor drum level as the saturation temperature and pressure are increased and blowdown if necessary.
- When at full pressure (approximately 13.8MPa [2000 psia]) open superheater outlet steam valve and admit cold feedwater (104°C [220°F]) into the preheater.
- Put the recirculation pump on feedwater temperature control in order to maintain the feedwater temperature at or above 238°C (460°F).
- At some predetermined steam flow rate open the salt valves at the superheater outlet and circulate salt through the superheater in order to generate superheated steam.
- When reheat steam flow is established, open the salt valve at the reheater outlet.
- Put the superheater and bypass control valves on temperature control and increase unit load as required.

Hybrid Start-Up

The procedure used for solar stand-alone start-up can be used for hybrid start-up. Since the feedwater temperature will initially be at 238°C (460°F) the recirculation pump can be stopped after feedwater flow is established.

5.7.2.7 Control Requirements

The control requirements for the steam generator system were discussed in Section 5.5 Master Control System.

5.7.2.8 Auxiliary Equipment

5.7.2.8.1 Recirculation Pump

The recirculation pump is provided to maintain the feedwater temperature above the salt freezing point (221°C [430°F]) during start-up and part-load solar stand-alone operation. The pump circulates saturated water from the evaporator inlet to the preheater inlet. The pump selected is as follows:

Type:	Union Pump 6 x 6 x 8-1/2 VTK or equivalent
Design Flow Rate:	14.49 kg/sec (115,000 lb/hr)
Operating Pressure:	13,685 kPag (1985 psig)
Operating Temp.:	335.6°C (636°F)
Head Developed:	207 kPa (30 psi)
Design Pressure:	17,241 kPag (2500 psig)
Design Temp.:	343.3°C (650°F)
Motor:	22.4 kw (30 hp), 3600 rpm, 460 volt/3 phase/ 60 cycle

5.7.2.8.2 Safety Valves

Safety valves required for the steam generator system based on the ASME Boiler and Pressure Vessel Code, Section I are as follows:

Location	Number	Crosby Designation	Relieving Capacity kg/sec (lb/hr)	kPag (psig)
Drum	1	2-1/2 K6 HE86W	24.0 (190,817)	15,345 (2225)
Drum	1	2-1/2 K_26 HE86W	34.4 (272,701)	15,743 (2290)
Suphtr. Out.	1	2 J 6 HCA88W	12.3 (97,511)	14,138 (2050)
Rhtr. In	1	4 Q 8 HC36W	28.7 (228,000)	3,966 (575)
Rhtr. Out	1	4 Q 8 HCA36W	26.9 (213,381)	3,724 (540)

5.7.2.8.3 Freeze Protection

Electric trace heaters are provided on the heat exchanger shells and all interconnecting salt piping. The trace heaters are sized to preheat and maintain the salt piping and exchanger shells at a temperature of 287.8°C [550°F]. The heating elements on the salt piping are positioned along the pipe axis at approximately six (6) locations around the pipe surface. Heating elements on the heat exchanger shells are positioned parallel to the exchanger axis in single loops. The heat exchangers and all interconnecting piping are insulated with calcium silicate and covered by aluminum lagging. For preheat the trace heaters require a 240 volt power supply. For freezing protection a 120 volt power supply is required. The electrical trace heater requirements for the steam generator system are as follows:

Salt Pipe	Length/Unit m (ft)	Number of Units	Power* watt/m (watt/ft)
Superheater to Tee	15.8 (52)	6	187 (57)
Reheater to Tee	34.4 (113)	4	171 (52)
Tee to Evaporator	28.3 (93)	6	230 (70)
Evaporator to Preheater	25.3 (83)	6	230 (70)

Heat Exchangers	Length/Unit m (ft)	Number of Units	Power§ watt/m (watt/ft)
Preheater	30.5 (100)	24	49 (15)
Evaporator	30.5 (100)	24	43 (13)
Superheater	30.5 (100)	14	36 (11)
Reheater	20.7 (68)	8	36 (11)

* Per unit length

§ Per shell surface area

During normal steam generator operation on a calm day with 15.6°C [60°F] ambient temperature, the steam generator system heat loss is approximately 0.112 MW (0.381 x 10^6 Btu/hr). During an extended shutdown period with the electric trace heaters maintaining the system at 288°C [550°F], the heat loss from the steam generator system is approxiamtely 0.067 MW (0.299 x 10^6 Btu/hr) with the aforementioned ambient conditions.

5.8 ELECTRICAL POWER GENERATING SYSTEM/INTERFACES

The total repowered plant will consist of the existing fossil fired plant, the new solar equipment and the interfaces between the two subsystems. The description of the existing fossil plant is presented in Section 5, Appendix A. The various subsystems of the solar plant are presented in Sections 5.1 to 5.7.

The primary interfaces of these two subsystems are presented in this section. These interfaces include the following:

Boiler Feedwater	-	Water Line
Main Steam	-	Steam Line
Hot Reheat	-	Steam Line
Cold Reheat	-	Steam Line
Control Systems	-	Electrical Terminals
Auxiliary Power	-	Electrical Terminals

5.8.1 Water/Steam Interfaces

The four water/steam interfaces are shown schematically on the P&ID, Figure 4-3. The actual routing of these lines are shown on Figures 5-44, 5-45 and 5-46. The design characteristics of these four lines are shown in Table 5-6. The design rationale for these selections are as follows:

New Main Steam Line

This line was treated as a "boiler external piping," as follows:

(a) From Superheater Outlet through the Second Stop Valve:
Design Pressure: The lowest set pressure of the new superheater. outlet safety valves (2050 psig [same as existing superheater outlet]).

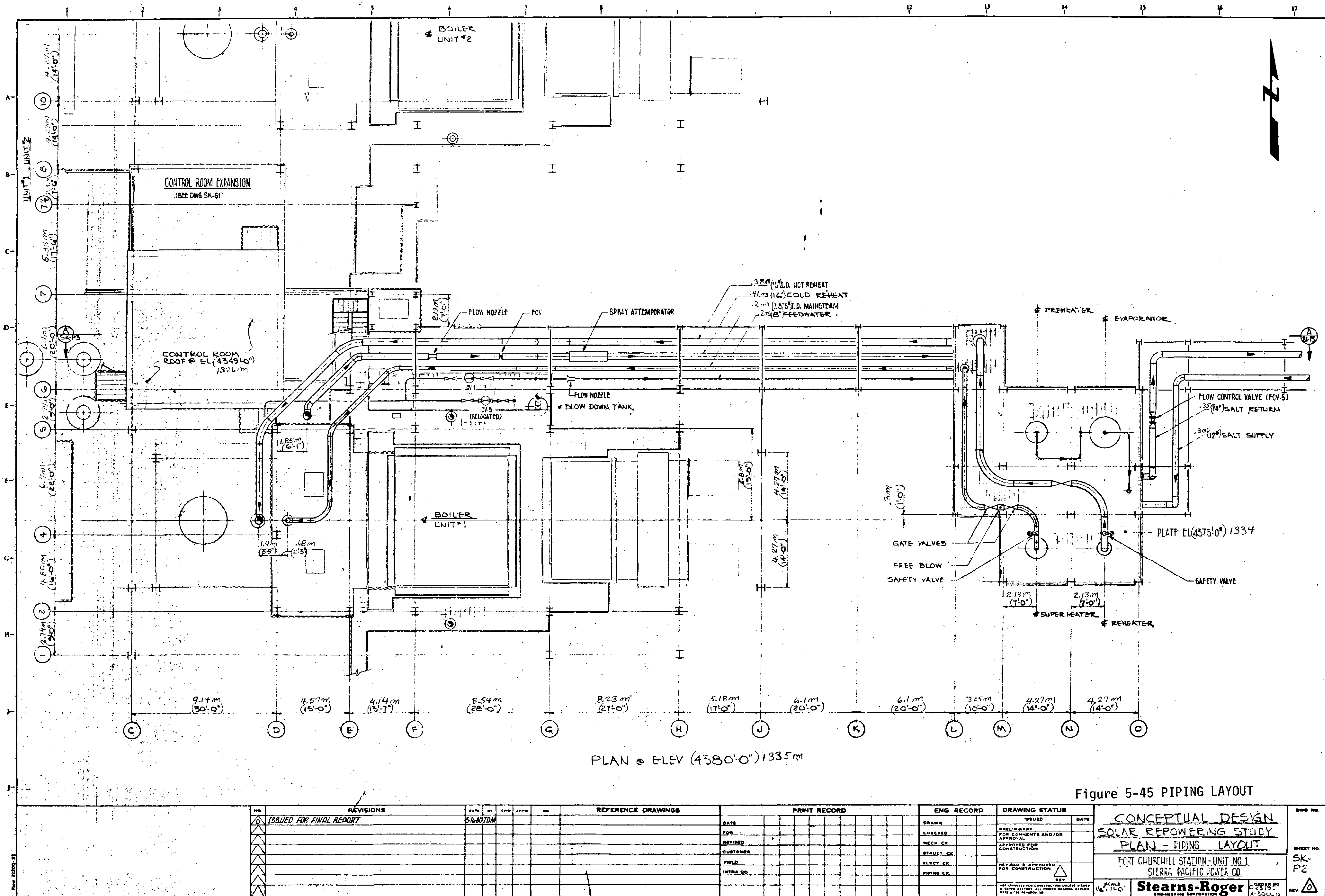

Figure 5-45 PIPING LAYOUT

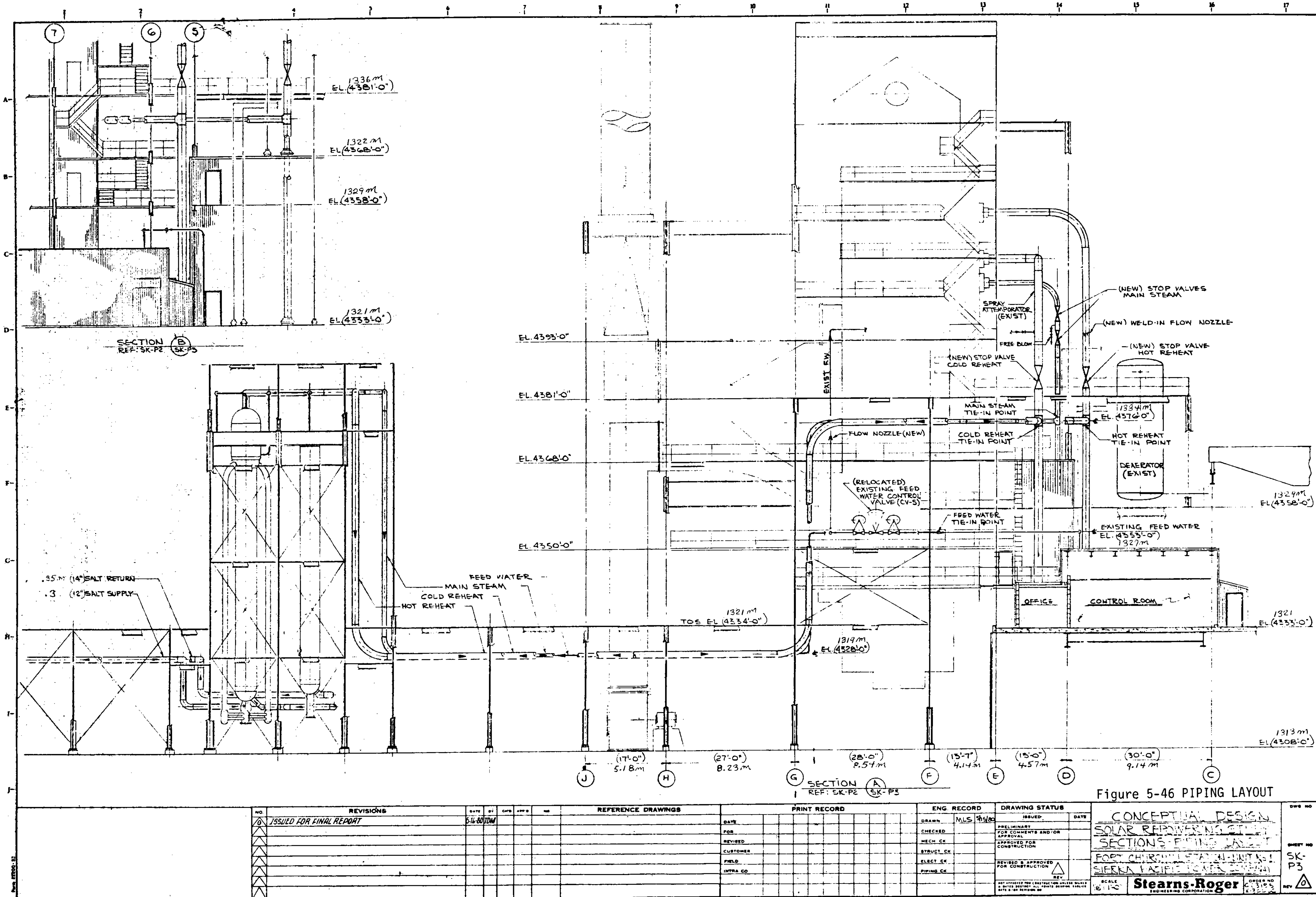

Figure 5-46 PIPING LAYOUT

TABLE 5-6

SOLAR STEAM AND FEEDWATER PIPING

FORT CHURCHILL - UNIT NO. 1

		MAIN STEAM	HOT REHEAT	COLD REHEAT	BOILER FEED
Design Pressure	MP_a	14.1	3.95	3.95	17.2
Design Temperature	°C	546	546	377	238
Material	-	A335-P22 2-1/4 CR-1 MO Seamless	A335-P22 2-1/4 CR-1 MO Seamless	A106-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 I.D.	M	.20	.38	.41 Sch. 40	.2 Sch. 160
Mimimum Wall	MM	31.6	15.7		
Nom. O.D.	M	.27	.42	.41	.22
Weight/M	Kg/M	197	165	124	112
Insulation	-	Calcium Silicate	Calcium Silicate	Calcium Silicate	Calcium Silicate
Ins. Thickness	M	.15	.15	.128	.076

Design Temperature: The expected continuous superheater outlet temperature plus the guaranteed tolerance, from the new or existing superheater, whichever is greatest 540°C + 6°C (1005 + 10°F).

(b) From the Second Stop Valve to Tie-in with Existing Main Steam Line:

Design Pressure: The maximum expected operating pressure (excluding the set pressure of superheater safety valves) or 85% of lowest set pressure of the evaporator steam safety valves, whichever is greater.

1) Maximum expected operating pressure: 13 MPa (1890 psig) (throttle) + .5MPa (70 psi) (friction) = 13.5 MPa (1960 psig).
2) 85% x 15.5 MPa (2225 psig) = 13.1 MPa (1892 psig).

Design Temperature: Same as Item (a).

New Hot Reheat Line

Design Pressure: Same as reheater design pressure 4 MPa (575 psig [same as existing reheater]).

Design Temperature: The expected continuous reheater outlet temperature plus the guaranteed tolerance, from new or existing reheater, whichever is the greatest 540°C + 6°C (1005 + 10°F)

New Cold Reheat Line

Design Pressure: Same as reheater design pressure 4 MPa (575 psig).

Design Temperature: Our normal procedure is to follow the recommendation set forth in HEI Standards for Closed Feedwater Heaters for heater shell skirt design temperature (same as extraction to first point heater). Enter the Mollier diagram at the normal operating steam temperature and pressure and follow a constant entropy line to the maximum operating pressure, read temperature at that point and round off to next higher six degrees C. This procedure results in a design temperature of 377°C (710°F).

Existing Piping Design Pressure and Temperature

The existing main steam, hot and cold reheat and boiler feed piping at Fort Churchill - Unit No. 1 was designed for the following pressures and temperatures obtained from Stone & Webster Piping Specifications.

	Main Steam	Hot Reheat	Cold Reheat	Boiler Feed*
Design Press. MPa (psig)	13.8 (1985)	3.5 (500)	3.5 (500)	15.6 (2250)
Design Temp. OC (°F)	540 (1005)	540 (1005)	349 (660)	237 (458)

*1st point heater to boiler stop and check valve.

Since solar requires tie-ins with existing piping systems previous designed under applicable Code rules having jurisdiction at that time, a detailed study of current Code rules applicable to this case is required. We have not attempted to resolve all the apparent differences in design pressures and temperatures during our conceptual design study.

5.8.2 Control System Interface

The interfaces between the solar control system and the fossil plant system will occur at a number of common points. The common points are shown schematically on the P&ID, Figure 4-3. The discussion of these points was presented in Section 5.5, Master Control System.

5.8.3 Auxiliary Electric Power Interface

The auxiliary electric power for the basic solar repowering system will be taken from an unused leg of an existing transformer (4160 V) tertiary unit located in the switch yard on the west side of the plant. This unit is expected to handle all requirements except for the starting power for the large receiver feed pumps. The starting power requirements will be handled by the same system which now starts the boiler feed pump, however, the exact interconnect points have not been established on this study. The remaining electrical power will require an available capacity of 6.0 MVA. This power is available from the existing transformer.

This remaining electrical system consists of a line up of 4160 volt switchgear supplying large motors, a heat tracing feeder, four heliostat field feeders, and a load center. A 900 KW emergency engine generator will be provided to supply the heliostat field for safe shutdown in the event of power system failure.

The load center supplies medium sized motors and a motor control center. The motor control center supplies motors of 100 horsepower and smaller, and miscellaneous electrical service for the solar system.

The heliostat field will be supplied by four 4160 volt feeders. Pad mount transformers will step 4160 volts down to 208 V/120 volts for the heliostats. It is anticipated that the heliostat transformers will be 112.5 KVA. The heliostat transformers will be distributed throughout the heliostat field.

The 4160 volt heat tracing feeder will supply 4160-208 V/120 volt pad mount transformers, which will supply the heat tracing system.

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

The electrical equipment requirements for the repowered Fort Churchill Unit No. 1 are:

Electrical Equipment List

12 Switchgear Units, 4.16 KV, 1200 ampere, 250 MVA
1 Load Center consisting of:
- 1 Transformer, 750 KVA 65°C rise, 4160-480 volt, 3 phase
- 1 Circuit Breaker, power, 600 volt, 1600 ampere
- 3 Circuit Breakers, power, 600 volt, 800 ampere

1 Motor Control Center
4 Transformers, pad mount, 3 phase, 500 KVA, 4160-208 V/120 volt, for heat tracing
50 Transformers, pad mount, 3 phase, 500 KVA, 4160-208 V/ 120 volt, for heliostat field.

Lot Lighting and Power Panels

1 Emergency Engine Generator, 900 KW (diesel)

1 Battery, lead acid, 60 cell, 125 V, 400 amperes hours

1 Battery Charger 480 VAC, 125 VDC, 50 amperes

1 Uninterruptible system, 45 KVA, 120/208 V, 3 phase, 125 VDC, consisting of inverter, blocking diode, rectifier power supply, and solid state transfer switch.

Section 6
ECONOMIC ANALYSIS

6.1 METHOD

The economic assessment of the solar repowered plant was completed by the Advanced System Technology group, Westinghouse Electric Corporation using a methodology developed for solar power electric utility systems.* The methodology was developed on EPRI and DOE funded programs and was modified slightly to fit the Sierra Pacific Power Company grid and the MDAC Solar arrangement.

The economic analysis was completed in two phases. The first phase was completed by Westinghouse using a preliminary set of cost figures which were supplied by SPPCo, MDAC and Westinghouse. These preliminary figures were based on known data, where available, and estimated data prepared using the algorithms supplied by Sandia National Laboratories, Westinghouse and others. These costs were incorporated into the Westinghouse program together with high and low estimates (± 30%) to show sensitivity to system cost.

Concurrent with the baseline economic analysis, the plant conceptual designs were being completed and refined cost estimates made for the actual designs selected. The final step in this program was completed by inserting the refined cost estimate values into the results generated parametrically and then comparing the final cost and value figures.

6.2 ASSUMPTIONS

The economic assumptions used in the Westinghouse study are shown on Table 6-1. The figures shown in column A were supplied by SPPCo. These figures are based on current book values. There are some obvious incongruities with 1980 economics

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* Day, J. T., "A Methodology for Solar-Thermal Power Plant Evaluation", EPRI Report ER-869, August 1978.

Table 6-1 Economic Data for Plant Value Analysis
(All Cost Numbers in 1985$)

	(SPPCo) Economics A	(MDAC) Economics B
Present Worth Discount Rate	11.6%	11.6%
Solar Fixed Charge Rate	15%	15%
Capital Costs, $/kWe Combustion Turbine, Combined Cycle, Cost	232, 433, 1091	232, 433, 1091
Fuel Cost, $/gJ ($/MBtu) (#6, #2, Coal, Gas)	6.94, 10.36, 2.00, 5.77 (6.58, 9.82, 1.90, 5.47)	8.68, 12.95, 2.5, 7.21 (8.23, 12.27, 2.37, 6.83)
Fuel Escalation (Oil, Coal, Gas)	10, 7, 10%	12, 9, 12%
Energy Purchases, $/MWh (Utah Power & Light, Pacific Gas and Electric)	15.77, 31.54	19.71, 39.43
Purchase Escalations (Utah Power & Light, Pacific Gas and Electric)	5.874, 2.195%	7.874, 4.195%
O&M Escalation	9%	9%
Capital Escalation	6%	6%

Note: Capital escalation was projected to change in the pre-study year as such:

1980	9%
1981	8%
1982	7%
1983	6%

Therefore, the factor to move 1980 capital costs to 1985 dollars is 1.41529.

in these numbers, and many will require update to reflect present economics or renegotiation between utilities. In anticipation of these revisions, the values shown in column B were generated. This column reflects the best estimates of MDAC, SPPCo. and Westinghouse for the future cost figures. Both sets of values (Column A and B) were used in the Westinghouse program. High, nominal and low costs were used with each set of economic parameters; hence, six different sets of system costs and values were generated.

The algorithms used for cost evaluation were in general agreement with the Sandia algorithms. The primary exceptions to this statement were in the tower cost estimates. The cost algorithms did not seem to produce reasonable cost estimates for the tower assembly, so Stearns Roger completed a preliminary design and cost estimate for the receiver tower. The Stearns Roger estimates were used used for the cost analysis.

The total cost with all allocations and factors used as the reference in the Westinghouse study was $\$156 \times 10^6$. This cost included heliostats at $\$178/m^2$ and early estimates for other solar equipment. The cost estimate from this study shows a fully factored cost of $\$196 \times 10^6$. The principal cost growth is in the heliostat cost, put in our cost estimates at about $\$220/m^2$.

The fuel cost estimations were made using known SPPCo data, Sandia suggested values and MDAC forecast values. In general, the Sandia suggested values are higher than the comparative values used by SPPCo but lower than the MDAC forecasts. These comparisons are as follows (in $1985):

	SPPCo	Sandia (a)	Sandia (a)	MDAC
Oil	6.94	7.04	9.16	8.68
Coal	2.00	2.01	2.41	2.50
Gas	5.77	4.21	6.9	7.21

(a) The Sandia figures used in this column are based on DOE estimated costs for 1980 and DOE inflation factors.

(b) This column is based on present, known fuel costs at the Ft. Churchill site and DOE inflation factors.

As can be seen from this table, the MDAC values used in the Westinghouse study are in good agreement with the Sandia estimates when allowances are made for the actual present cost of fuel at the plant. Therefore, the MDAC forecasts would appear to be most appropriate for the economic analysis of this specific plant. The MDAC figures are used in the Westinghouse study as Economic Model B.

The baseline heliostat cost estimate used in the economic evaluation was $\$178/m^2$. This value is consistent with the value used during the system and subsystem trade studies completed on the Task 2 effort. The Westinghouse study was made by establishing a reference cost (in 1980 dollars), escalating this cost to 1985 dollars and then generating a high and low figure to go with the reference costs. The high and low figures were generated by selecting values that were 30% higher and 30% lower than the reference figures. This ratio was selected so that the high heliostat cost estimate was $\$230/m^2$ (in 1980 dollars), the Sandia reference cost. The three cost levels then represent the following:

a. Reference cost, $\$178/m^2$ represents a cost for a 2nd generation heliostat produced with volume production rate tooling and equipment.
b. High cost, $\$230/m^2$ represents a 2nd generation heliostat produced on a limited production basis with limited tooling and equipment and agrees with the Sandia guideline.
c. Low cost, $\$125/m^2$ represents a 2nd generation heliostat made at high production rates on a continuing production basis or a heliostat which is subsidized to this cost level.

A capacity credit of $\$22 \times 10^6$ was assumed under all cases. This credit is based on the expected increase in the usable life of Unit No. 1 which will occur due to the solar repowering. The capacity credit is believed to be conservative and a higher credit should probably be applied. However, a more detailed system performance evaluation during the preliminary design phase is needed to produce a more accurate capacity credit.

It was further assumed that the operating profile selected for each of the cases evaluated would be based on the most desirable grid/load characteristics without regard to the mechanical feasibility of such load changes. The final cases investigated are described in Table 6-2. In general, the cases studied were:

a. Baseline Hybrid, 77 MW_e Solar
b. Alternate 1 Hybrid, 110 MWe Solar

Solar stand alone operation was estimated from the above cases by deducting the fuel cost from the fuel savings.

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Table 6-2

Economic Evaluation Case Descriptions

Case No.	Economic Parameter Set	Collector Field Area (M^2)	Steam Generator Size (MWe)	Storage Unit Size (Hours)	Operating Mode
7A	A	474,500	77	6	Hybrid
7B	B	474,500	77	6	Hybrid
8A	A	474,500	110	6	Hybrid
8B	B	474,500	110	6	Hybrid

6.3 PLANT AND SYSTEM SIMULATION MODEL

The plant model used for the economics analysis was the model used at the start of the conceptual design phase. After the first few runs, the model was updated as new data became available. The runs completed last (7 and 8), were made with a plant model which reflects the later results obtained on the Task 3, Conceptual Design. These parameters included:

a. 474,500 M^2 glass area (8411 heliostats).
b. Field efficiencies per final University of Houston calculations.
c. Receiver size, cost, efficiency per final MDAC design.
d. Two tank storage with capacity of 6 hrs. storage at a 77 MW_e level.
e. Plant parasitics and efficiency per Stearns Roger plant performance analysis.
f. Grid demand estimates per SPPCo planning estimates.
g. Purchase power availability/costs per SPPCo and MDAC estimates.
h. Economic factors discussed in 6.2
i. Standard Westinghouse format, modified to incorporate items a-h.

6.4 RESULTS AND CONCLUSIONS

6.4.1 Grid Dispatch Analysis Results

The study began with a non-solar baseline run to determine probable dispatch of all plants in the SPPCo grid plus the purchased power from adjacent utilities without repowering. The fuel savings for the solar repowered plant were found by tabulating the reductions in fuel consumed in all plants and the reductions in energy purchases from adjacent utilities. The solar repowered plant fuel displacement was evaluated for 1985 and 1995 and found to be:

	Oil/Gas	Coal	Purchased UPL	Purchased PG&E
1985	60%	0	0	40%
1995	45%	20%	0	35%

The study did not include a complete assessment of all of the potential configurations/combinations on the repowering of Ft. Churchill No.1. With the number of runs completed, it is unlikely that the optimum case has been identified or evaluated. However, the data generated on case 7 and case 8 are close to the optimum and indicate that the economics of repowering Unit No. 1 will be equal to or better than originally estimated. The results of case 7B (77 MWe Solar, Economics B) is shown in Table 6-3. The results for case 8B (110 MWe Solar, Economics B) is shown in Table 6-4. While neither of these represent a fully optimum case, it should be noted that the economics obtained with the reference cases ($178/m^2 heliostats and with solar plant costs obtained with the normal cost algorithms) are well within the range of interest for a potential solar repowering plant.

The value of total cost and project value from Tables 6-3 and 6-4 are plotted in Figure 6-1. This figure is presented to aid the reader in converting from 1980 capital cost dollars to 1985 life cycle cost dollars. The current estimate for the cost of the repowered plant is indicated, as are the plant values for the fuel cost and displacement model used by Westinghouse. As will be shown in section 6.4.3, the real values of displaced fuel are expected to be somewhat higher. However, the real message of Figure 6-1 and section 6.4.3 is that repowering is an economically attractive alternative energy capitalization.

The design studies completed on this conceptual design and those that will be completed on a preliminary design effort will be likely to increase the basic plant cost estimates, as compared to the estimated costs used in the Westinghouse economic analysis. However, since the effects of evaluating overall benefits, as compared to direct value, were not assessed in the time available for the conceptual design phase, it is expected that the effects of total plant benefits will tend to offset potential increases in plant cost estimates and that the favorable economic outlook will be retained as the program continues.

The typical load and output characteristics for the baseline plant are shown in Figure 6-2 and 6-3. These characteristics are for week 22 of 1995 and with the case 7 and case 8 conditions, respectively. These plots show that a changing mix of solar and fossil supplied power will be needed at various times during this week, depending on demand, estimated solar availability, etc. It should be noted that under some conditions, a significant economic gain can be generated if the response time (ramp rate) of the fossil system can be kept at a rapid rate. Lower solar and higher fossil power generation levels may also be used to levelize the fossil boiler load and minimize fossil boiler ramp rates. The feasibility of this type of fast ramp rates has not been completely

Table 6-3 Economic Evaluation for 110 MWe Solar Dispatch

ALL PEAKING CAPACITY CREDIT
FORT CHURCHILL REPOWERING
CASE 7. 110 MW SOLAR.
SOLAR PLANT VALUE AND COST TABLE ECONOMICS B METHOD 1
PRESENT WORTH OF REVENUE REQUIREMENTS 1985 MILLIONS

	LO- (30%)	REF*	HI (+ 30%)
SOLAR PLANT COST			
PLANT COST	194.7	278.1	361.6
PLANT O+M	21.4	30.5	39.7
TOTAL COST	216.1	308.7	401.2
SOLAR PLANT VALUE			
FUEL VALUE	629.5	629.5	629.5
VARIABLE O+M	0.0	0.0	0.0
SOLAR FUEL COST	-367.4	-367.4	-367.4
CAPACITY CREDIT	22.0	22.0	22.0
TOTAL VALUE	284.1	284.1	284.1
NET VALUE	68.1	-24.5	-117.1
BREAKEVEN $/KW 1985	1963.3	1894.8	1826.5
PLANTCOST $/KW 1985	1454.7	2078.1	2701.6
SOLAR ENERGY GWH/YR	397.7	397.7	397.7
CAPACITY FACTOR	.422	.422	.422
ENERGY COST MILLS/KWHR	176.7	204.8	232.8

CAPACITY DISPLACEMENT TABLES

	MEGAWATTS	VALUE RR
PEAKING	107.5	22.0
INTERMEDIATE	0.0	0.0
BASE LOADED	0.0	0.0
TOTAL	107.5	22.0

CAPACITY CREDIT TAKEN IN YEAR 1992

*Reference Case is for $178/m^2$ Heliostats

Table 6-4 Economic Evaluation for 77 MWe Solar Dispatch

ALL PEAKING CAPACITY CREDIT

FORT CHURCHILL REPOWERING
CASE 8. 77 MW SOLAR. 6 HR. 474.5K M**2
SOLAR PLANT VALUE AND COST TABLE ECONOMICS B METHOD 1
PRESENT WORTH OF REVENUE REQUIREMENTS 1985 MILLIONS

	LO(30%)	REF*	HI(+30%)
SOLAR PLANT COST			
PLANT COST	193.1	275.9	358.7
PLANT O+M	13.7	19.6	25.5
TOTAL COST	206.9	295.5	384.2
SOLAR PLANT VALUE			
FUEL VALUE	663.8	663.8	663.8
VARIABLE O+M	0.0	0.0	0.0
SOLAR FUEL COST	-394.9	-394.9	-394.9
CAPACITY CREDIT	22.0	22.0	22.0
TOTAL VALUE	290.9	290.9	290.9
NET VALUE	84.1	-4.6	-93.3
BREAKEVEN $/KW 1985	2071.0	2027.0	1983.0
PLANTCOST $/KW 1985	1443.0	2061.4	2680.0
SOLAR ENERGY GWH/YR	409.4	409.4	409.4
CAPACITY FACTOR	.435	.435	.435
ENERGY COST MILLS/KWHR	177.1	203.2	229.3

CAPACITY DISPLACEMENT TABLES

	MEGAWATTS	VALUE RR
PEAKING	107.5	22.0
INTERMEDIATE	0.0	0.0
BASE LOADED	0.0	0.0
TOTAL	107.5	22.0

CAPACITY CREDIT TAKEN IN YEAR 1992

* Reference Case is for $178/m^2 Heliostats

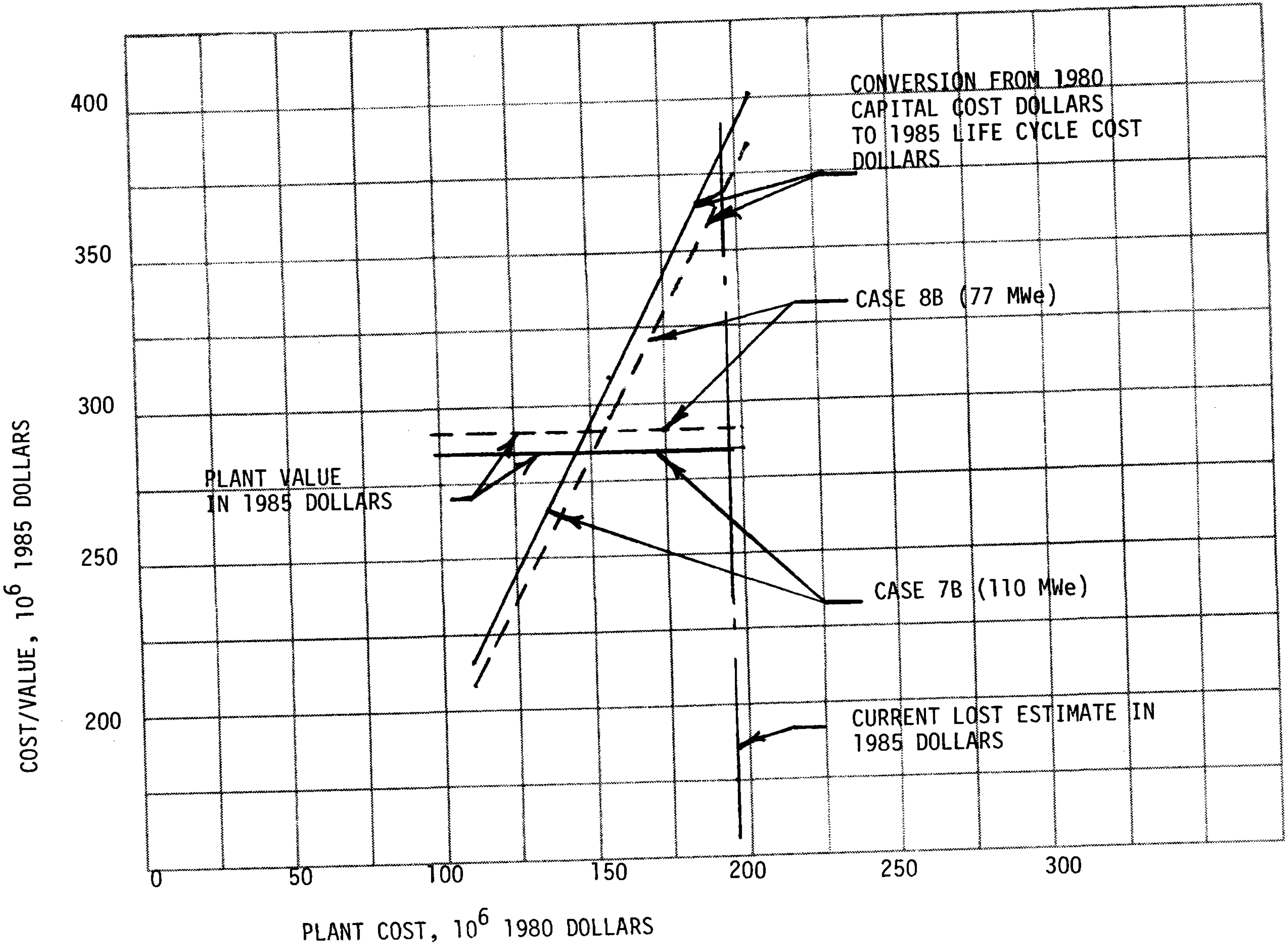


FIGURE 6-1 PLANT COST AND VALUE CONVERSIONS TO 1985 DOLLARS

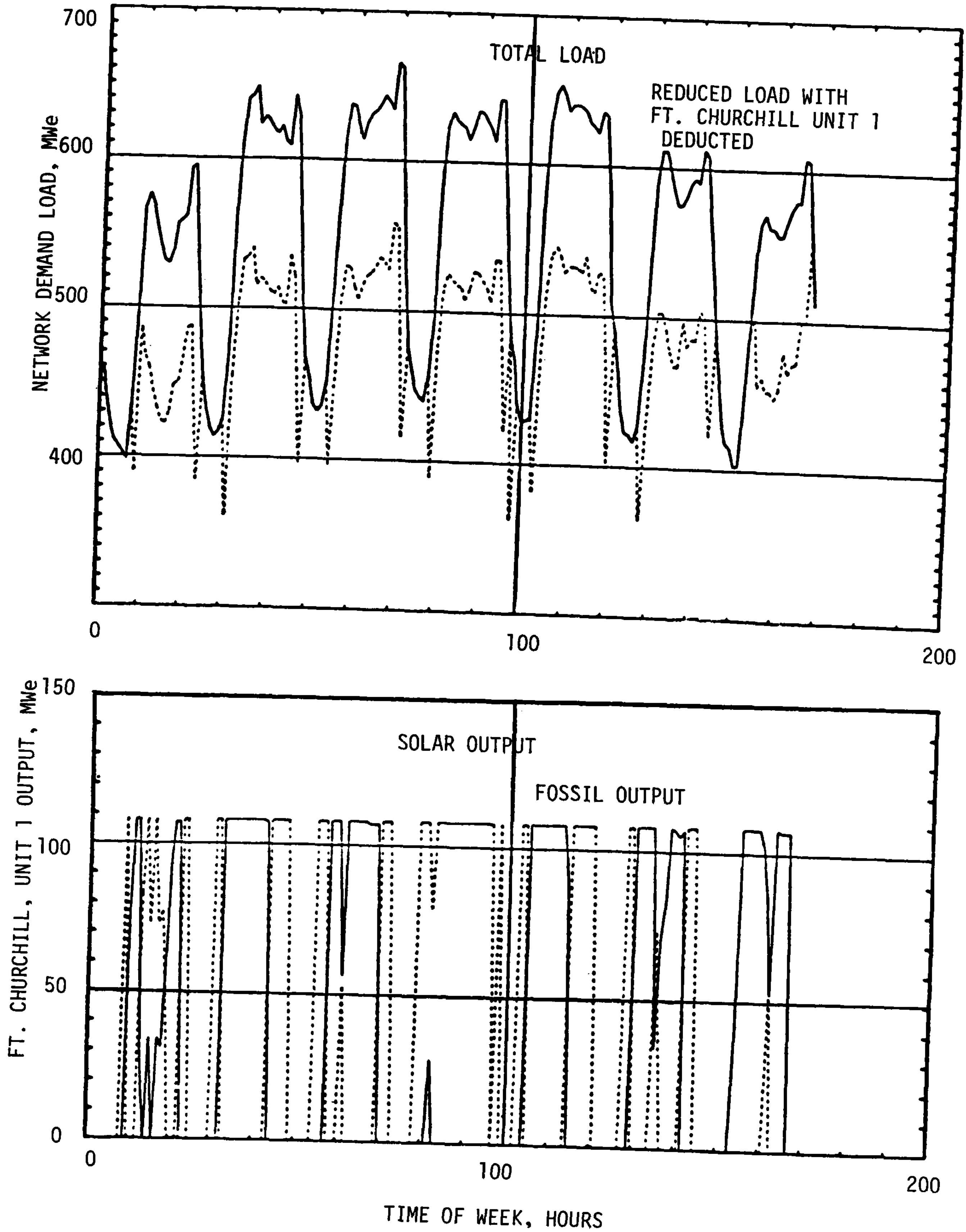
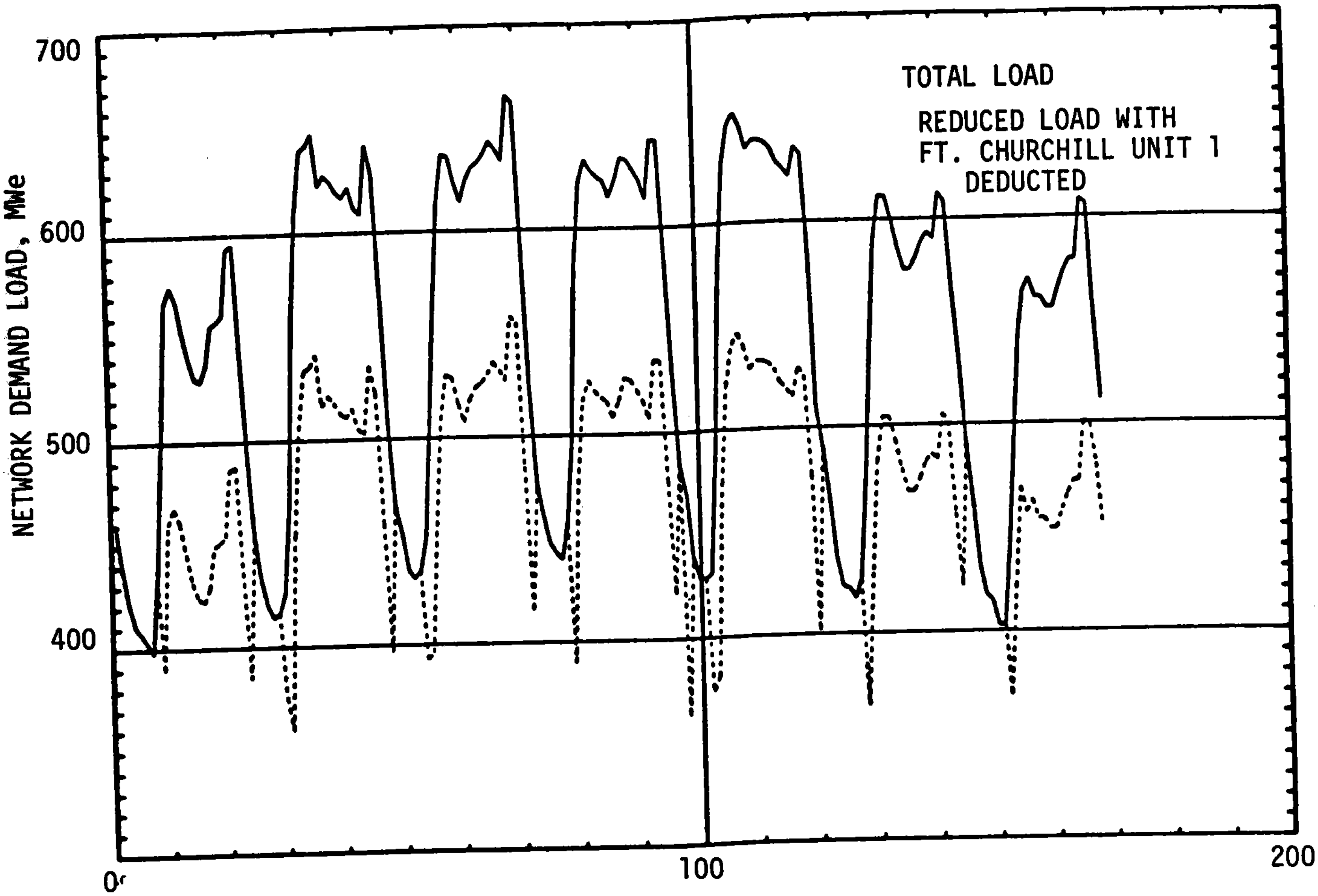


FIGURE 6-2, SOLAR AND FOSSIL OUTPUT PROFILES, CASE 7B (110 MWe), WEEK 22



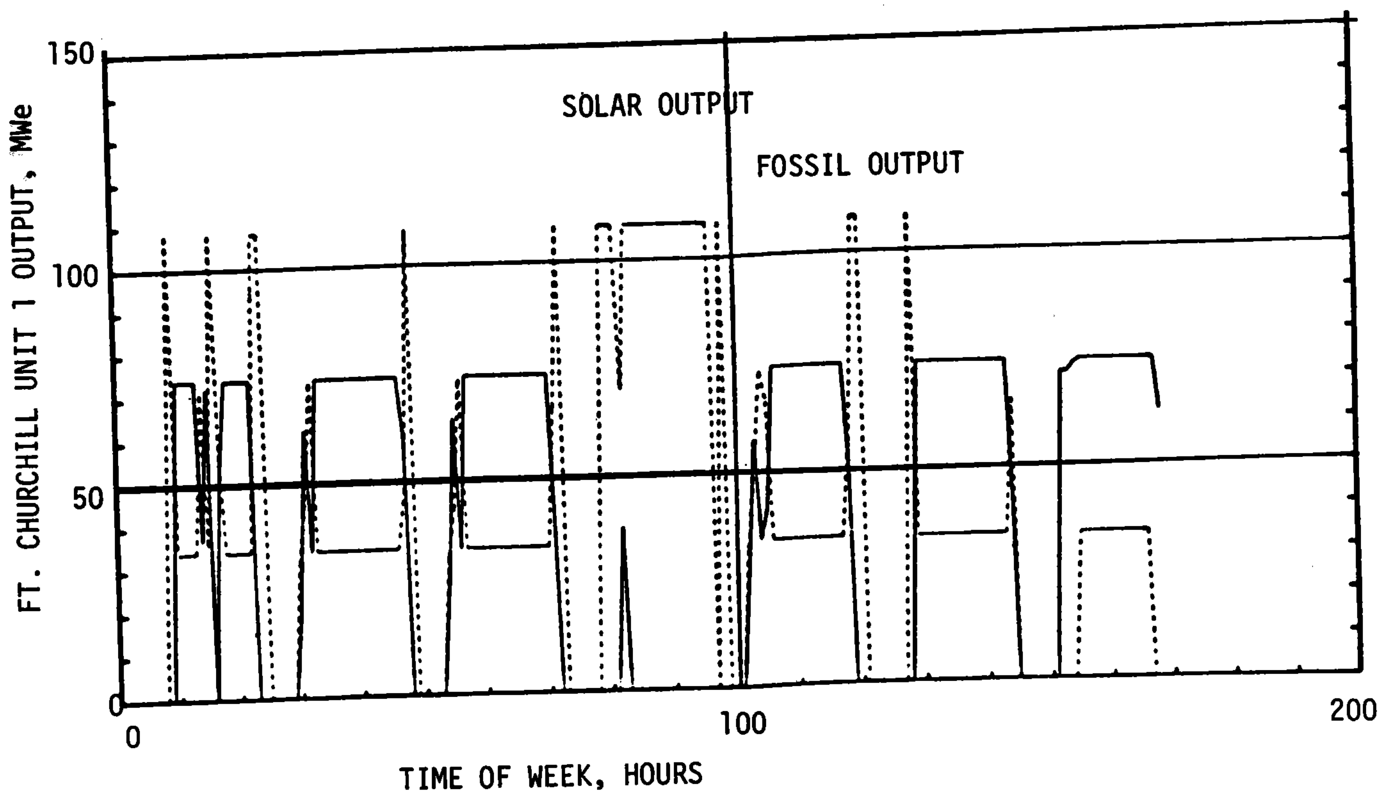


FIGURE 6-3 SOLAR AND FOSSIL OUTPUT PROFILES, CASE 8B (77 MWe), WEEK 22

determined. A preliminary study indicates that the load carrying capabilities of the solar steam generators may unload the fossil steam generators to such an extent that rapid time responses are practical. Since the turbine/generator remains at a constant output and only the steam generator load mix changes, the normal ramp rate limitations, based on turbine load changes, are not limiting. Fast response times may be practical and desirable.

The mechanical feasibility of meeting these economic dispatch rates will be evaluated in greater depth in the preliminary design phase.

6.4.2 Economic Analysis Impact on Preferred Design

The economic analysis completed to date does show that it is desirable to incorporate a significant amount of storage into the Ft. Churchill repowering plant and to utilize this storage capacity on a daily basis. It appears that storing solar energy up to the maximum storage capacity for use during those hours of the day when the cost of purchased power is the highest can make a significant improvement in the overall plant economics. This scenario will be investigated further on the preliminary design activity. This advantage of deferred operation is applicable to both the hybrid and a solar stand alone operating modes. The present study indicates that the baseline hybrid mode would be recommended during the early years of solar repowering operation but this will shift later and the solar stand alone mode will provide the better economics. To utilize the system to the best advantage it appears that the system should be rated at full output on solar power (110 MW_e gross) instead of the 77 MW_e level selected for the baseline hybrid model.

Designing the system for full output on solar will not present a serious problem since nothing will change except the size of the solar steam generator. These steam generators (heat exchangers) are of conventional design, and there should be no problem in scaling the units up to the 110 MW_e level. This change will be evaluated on the preliminary design effort. The cost for the larger solar steam generator used in case 7 at the economic analysis was based on existing cost algorithms. These algorithms are believed to be sufficiently accurate for a conceptual design study.

6.4.3 Economic Findings and Conclusions

There are five major conclusions which result from analysis of the economic findings of this study. These conclusions are listed below, followed by the supporting data and sensitivity analyses.

1. Repowering is Economically Preferable to Continued Oil/Gas Usage, Even at First Plant Costs - This conclusion is based on the finding that the present value of fixed charges against the capital cost of repowering is less than the present value of the fuel saved, if all of the fuel displacement is against oil and natural gas.
2. Repowering is Competitive with New Coal Capacity at First Plant Costs and Equal Capacity Factor - This conclusion is also based on present value comparisons. The present value of 30 years coal savings plus the fixed charge against plant cost is essentially equal to the present value cost of repowering.
3. Solar Repowering Requires Incentives for the First Plant to Compete With Coal Repowering - The retrofit of a plant like Ft. Churchill with new coal fired boilers is less expensive than a new coal plant. The lowered cost compared to the new coal plant would require lower solar repowering plant costs to be competative. Hence, incentives would be required for the first unit to be competative. Subsequent plants might become competative with no subsidies.
4. Solar Repowering is More Economic Than Coal Liquefaction - Because of the low conversion efficiency of coal liquefaction, the present value of coal saved is about equal to the present value of fixed charges against the capital cost of solar repowering. The capital cost of the coal liquefaction plant represents a substantial additional present value cost.
5. Solar Repowering is Economically Feasible - The first repowering plant will require some subsidies to be economically feasible. However, the plants are close enough to breakeven economics that cost/value ratios less than unity are virtually assured in subsequent plants.

One of the key parameters in all of the above conclusions is the present value of the capital cost of the repowering plant. There are four principal parameters in evaluating this present value; total plant cost including fees, interest during construction, and all other indirect and distributables; levelized fixed charge rate including equity, debt service, taxes, O&M costs, etc, expressed as an average percentage of capital cost over the lifetime of the plant; present worth discount rate; and the duration of the investment.

The present worth discount rate can be transformed into a multiplicative present value factor (PVF) by:

$$PVF = \frac{1}{1+i} \left[\frac{1 - x^n}{1 - x} \right] \quad (1)$$

when

- i is the present worth discount rate
- n is the number of years
- x is the ratio $\left(\frac{1+r}{1+i}\right)$, and
- r is the escalation rate

For the levelized fixed charge calculation, the escalation rate is taken to be zero. The present value factor dependence on discount rate and number of years is shown in Figure 6-4. The PVF is multiplied by the fixed charge rate and the capital cost of the plant. The present worth of the capital investment is given by:

$$PWC = C \times FCR \times PVF \times R \quad (2)$$

where C is the total capital cost
FCR is the fixed charge rate, and
R is a factor which provides for inflation.

$$R = \left(\frac{1+r}{1+i}\right)^m$$

where r is now the inflation rate, and
m is the number of years to project completion

The nominal example for SPPCo would use:

$C = \$196 \times 10^6$

FCR = 0.15

PVF = 8.30

R = 0.821

The present worth of the capital cost of the repowered plant would then be

$PW = \$180 \times 10^6$

This present worth cost would move up or down, depending on any of the above parameters.

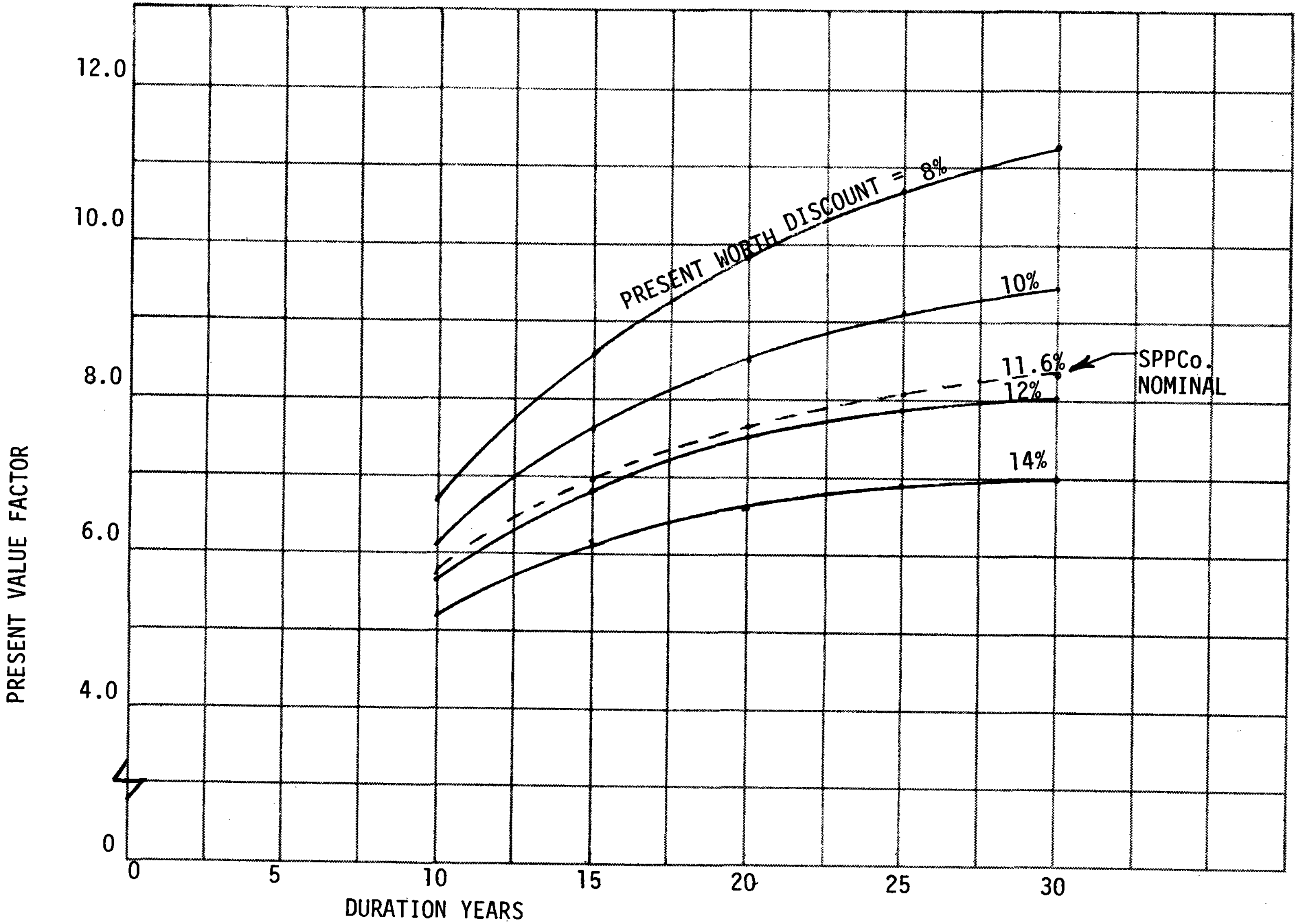


FIGURE 6-4 PRESENT VALUE FACTOR DETERMINATION

The next important value is that of fuel displacement. For all oil/gas, the present value factor is given by equation (1). However, the escalation rate is no longer zero. Figure 6-5 shows present value factors for 30 years and combinations of escalation and discount rates. The equation equivalent to equation (2) for the present value of fuel saved is:

$$PWF = AC \times PVF \times R, \quad (4$$

where AC is the annual cost of fuel saved in current year dollars, The nominal example for SPPCo for all savings in oil is

$AC = \$14.7 \times 10^6$

$PVF = 28.37$

$R = 1.022$

$PWF = \$425 \times 10^6$

Similar cases are worked out in Table 6-5 to support the conclusions listed above. The values shown on the Table are representative for the economic parameters used (escalation rates of 10 and 12%, discount rate of 11.67; current oil costs \$5/GJ, current coal costs \$1.50/GJ, current purchased power costs \$2.75/ GJ_{th} equivalent). As may be seen in Figures 6-4 and 6-5, the numbers on Table 6-5 may vary up or down by a factor of 2 or more as these parameters are varied. Hence, no specific conclusions may be drawn without detailed verification of the parameter set to be used.

One of the major factors in the economic evaluation by Westinghouse was a very low escalation rate for purchased power. Reducing the escalation rate for purchased power from 12% to the 4% in column B of Table 6-1 reduces the present worth cost of purchased power by a factor of 4. Hence, the Westinghouse grid dispatch analysis was driven to maximize the purchase of power from adjacent utilities. However, the circumstances of the adjacent utilities may not permit such large power purchases to continue. It also seems unlikely that power purchases can continue at such low prices. Hence, the final economic evaluation would have to consider the probable cost of power purchases from adjacent utilities in order to show the true economic worth of repowering.

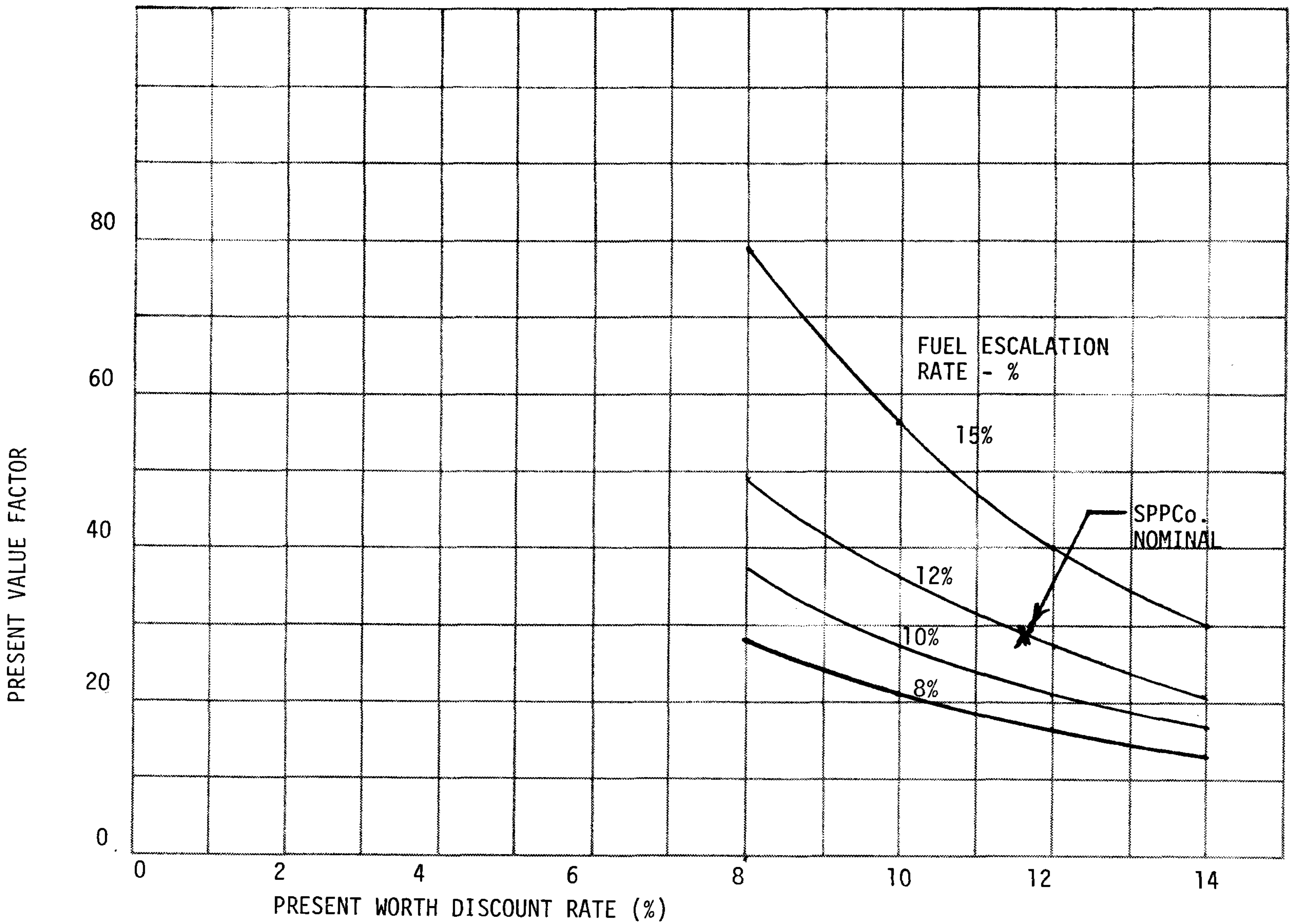


FIGURE 6-5 PRESENT VALUE FACTOR FOR FUEL

Table 6-5 Present Value Comparisons
(Values in 10^6 1980 Dollars)

Case	Comparison	Present Value of Fuel Displaced	Present Value of Capital	Total Present Value
1	<u>All Displacement in Oil/Gas</u>			
	12% Escalation	425	-	425
	10% Escalation	330	-	330
2	<u>New Coal Plant</u>			
	12% Escalation	123	102	225
	10% Escalation	95	102	197
3	<u>Coal Repowering at Ft. Churchill</u>			
	12% Escalation	130	50	180
	10% Escalation	100	50	150
4	<u>Coal Liquefaction</u>			
	12% Escalation	180	110	290
	10% Escalation	140	110	250
5	<u>Probable Displacement</u>			
	20% Coal } 12%	25	-	275
	40% Oil/Gas } 12%	170	-	
	40% Purchased } 12%	80	-	
	10% Escalation			210
6	<u>Probable Displacement</u>			
	20% Coal at 10% Escalation	15		205
	40% Oil/Gas at 12% Escalation	170		
	40% Purchased Power at 4%, Escalation	20		

Section 7

DEVELOPMENT PLAN

7.1 DESIGN PHASE

General

The MDAC Repowering Development Plan for the repowering of Ft. Churchill No. 1, as depicted by the Master Program Phasing Schedule (MPPS), shown in Figure 7-1, is totally responsive to published DOE established milestones, with two exceptions. These exceptions pertain to the authorization for Long Lead Procurement (1 February 1982), and Authorization for Construction (1 February 1983). Long Lead Procurement for the Collector Subsystem for the baseline plant design is scheduled to begin approximately 1 September 1981, and construction activities associated with preliminary earthwork is planned start 1 May 1982.

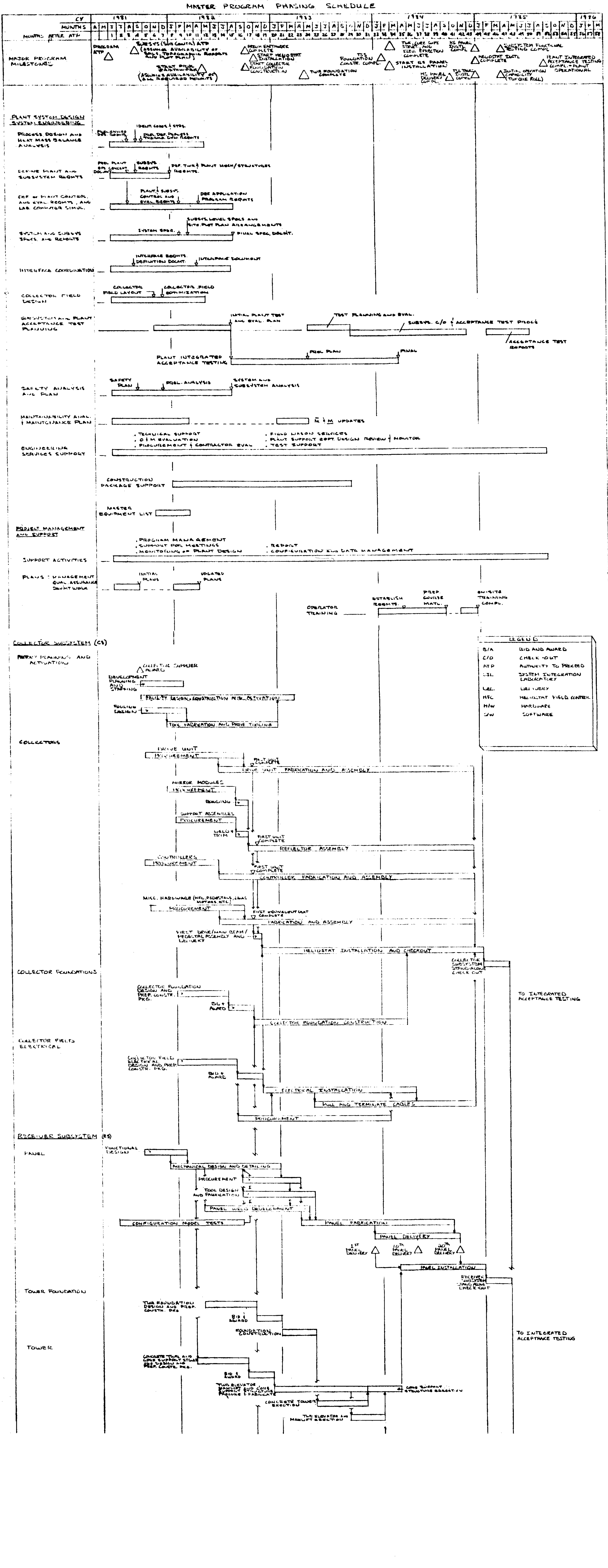
The overall program was reviewed, subsystem by subsystem, with each subcontractor drawing experience from the 10 MWe Barstow Program. These coordinated team efforts developed, in detail, the time-phasing and sequencing of activities to meet the basic DOE schedule objectives. Contract go-ahead is planned for 1 June 1981, at which time system engineering activities will start. Three months thereafter, the first contract for subcontractor activity is expected. With the earlier starts mentioned above, the remainder of activities will culminate in Initial Operations Capability (Turbine Roll) 1 April 1985, 46 months after program start.

This plan is realistically obtainable. However, there are several areas which will require special attention. These are explained in the critical path summaries and throughout the following text.

7.1.1 Design Phase

A primary objective of the design phase will be to establish system and subsystem requirements as early as possible, in order to minimize any overlapping of system and subsystem design activities. Furthermore, it appears

REPOWERING - FORT CHURCHILL
MASTER PROGRAM PHASING SCHEDULE



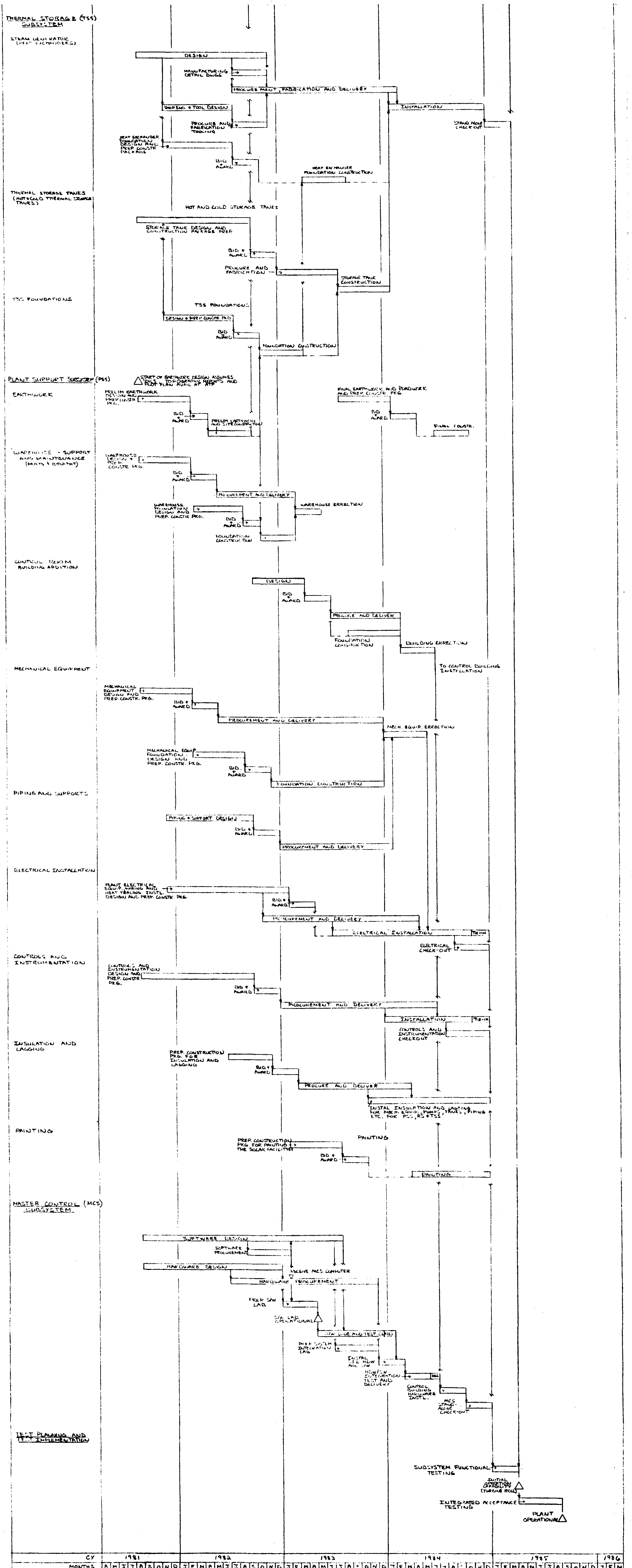


Figure 7-1. Repowering - Fort Churchill Master Program Phasing Schedule

that under the existing period of performance, little time is available in the specified period for the Preliminary Design Phase. It must become a part of the designated time allocated for design, which will practically necessitate, in some instances, a short or nonexistent transition from conceptual design. This is mainly the case in both the receiver and thermal storage subsystems. If subcontractor selection were accelerated to 1 January 1981, this problem would be partially alleviated.

A better solution, however, would be to establish a precontract activity for the development of preliminary design activities. An approximate nine (9) month period, with a proposed start of 1 September 1980, would be recommended. During this time, System Engineering could develop more definitive requirements, better system and subsystem specification, and would be able to establish a more orderly approach toward interface requirements, plot plans, layouts, and operating and maintenance requirements. This proposed preliminary design phase has been coordinated with SPPCo and potential cost sharing appears to be feasible.

The suggested preliminary design phase has not been considered in the schedule of Figure 7-1. If implemented, the preliminary design phase would shorten the front end of the schedule in Figure 7-1 by up to 3 months. The major benefit of the preliminary design would be in reducing the schedule risk and total program cost.

7.1.2 System Engineering

Significant milestones for System Engineering will be in the release of subsystem requirements (3) months after program start. This will provide subsystem contractors with early data, and with a follow-up of subsystem specifications (6) months thereafter. Other milestones include release of the Safety Plan and Site Plan arrangements at (3) months after program start date, Collector Field Layout at (5) months, and Interface Documents at (10) months.

7.1.3 Plant Support Subsystem (PSS)

Primary objective is to obtain the necessary soils and topographic data in order to start earthwork design on 1 September 1981, the start date for subcontract effort on PSS. Since earthwork design activity begins the chain of one critical path, it is essential that data be available in order to release preliminary plant layout drawings within four (4) months. Heliostat foundation design will begin upon the availability of this information. Tower structure and tower foundation designs will also require early inputs from soils and topographic reports.

The timely start of design activities for all areas requiring construction bid packages, and especially for mechanical equipment and controls and instrumentation, is of paramount importance and high on the objectives list. It is recommended that the soil and topographical data be obtained in the nine-month preliminary design phase proposed for this program.

7.1.4 Receiver Subsystem

Functional design of receiver panels will begin immediately upon subcontract go-ahead. Receiver sizing will be obtained early so that long-lead purchase orders for Incoloy material can be placed. Panel weld development activities are planned to start nine (9) months after subcontract approval. Design efforts to determine receiver weight are also essential early in the design cycle in order to assess tower foundation and structure requirements.

It is recommended that a separate technology program relative to Receiver Panel development and subsequent testing be conseeintiously pursued. This program should commence early, so that its derived benefits can be incorporated into the commercial program. This receiver technology work should be conducted concurrent with the preliminary design phase. The funding required may be through a separate technology development source or from the basic repowering study fund.

Tests of the MMC receiver panel and the G.E. receiver panel at the Central Receiver Test Facility (CRTF) are expected to provide adequate and timely data for the receiver panel design.. If these tests are completed with their present scope and schedule, no additional panel tests are envisioned to be required. A receiver configuration model test to verify flux distributions, flow and flow control, and efficiency is shown in Figure 7-1. This test would be appropriate for CRTF.

Definition of the configuration model test requirements, test plans, and test article configuration will begin at ATP. Actual model design and fabrication will follow with the subcontractor awards.

7.1.5 Collector Subsystem

Design activities for the collector subsystem are already complete as a result of MDAC's participation in the Second Generation Heliostat Program. No anticipated design changes are anticipated at this time. Operational activities will begin upon receipt of approved contract.

7.1.6 Master Control Subsystem

Both the software and hardware design efforts will begin 3 months after ATP on 1 September 1981. The concurrency of design will permit early hardware procurement on 1 July 1982 and software procurement on 1 September 1982, so that subsequent laboratory preparations can be accomplished to support start of the integration programs.

7.2 CONSTRUCTION PHASE

General

This phase is broken down into two sections, first, the procurement and fabrication functions of those subcontractors with possibly significant schedule impact implications, and second, the construction milestones of the more critical areas. The Development Plan, for this phase, assumes that all required permits will be obtained prior to the start of site construction. This will necessitate that the data gathering process for offset (operating permit) and environmental assessment and Cultural Resources Reports be completed prior to program start. With a separate preliminary design phase added to the overall program, the processing of the required permits would be started during the preliminary design phase.

7.2.1 Plant Support Subsystem

Preparation of construction bid packages will be as early as 1 March 1982, with earthwork, warehouse, and mechanical equipment. This activity will continue until the last construction bid package for painting is released on 1 November 1983.

Site construction activities (earthwork) are planned to start on 1 May 1982, and to be completed by 1 October 1982. This will then permit construction activities associated with the heliostat foundations to start as planned on 1 October 1982, and the warehouse, garage, and thermal storage tank foundation to start one month later. Installation activities on site will begin on 1 November 1982, for collector field electrical, and will end with electrical, and controls and instrumentation on 1 November 1984.

7.2.2 Receiver Subsystem

The currently planned program of panel weld development will start 1 April 1982, and will continue for one year. On 1 March 1983, panel fabrication will start and first panel delivery will occur on 1 December 1983. Activities performed concurrently with those above will be associated with fabrication and construction of tower foundation, structure, erection, and equipment installation. These are planned for completion on 1 March 1984--the same date delivery of the first receiver panel is expected on site. Panel installations will be completed on 31 December 1984. At that time, selected stand-alone tests will be conducted for three months, to fully check out the entire receiver subsystem.

7.2.3 Collector Subsystem

Long lead procurements for electronics on the controllers and for hardware drives on the drive units will occur on 1 September 1981. The MDAC plan is to fabricate, assemble and test three major subsystems prior to site delivery. Controllers, which will start fabrication on 1 June 1982, will be solely built and tested at MDAC. First delivery to site will be 1 October 1982. The second major subassembly consisting of pedestal drive unit with elevation jack and main beam will be delivered as an assembled unit. All of these components will be procured with the exception of the drive unit. MDAC intends to establish a in-house capability to produce approximately 50 percent of total program requirements. The third major subassembly consists of the reflector assemblies (batwings) which contain the mirror modules and structural supports. Again, all components will be procured. Bonding operations will also be split where 50 percent will be performed at MDAC. It is further planned that local (near site) industry be used to perform certain reflector structure welding operations and selected assembly operations.

Insatllation of the first heliostat is scheduled on 1 November 1982, one month following the completion of first foundation. Final installations and start of stand-alone testing will occur on 31 December 1984.

An alternate approach to ensure turbine roll by 1985 would permit the construction, installation and operational startup of the plant with a 1/2 size solar field module. With this approach, the tight schedule for early heliostat production can be improved will still start power production in 1985. Also, with this approach, the TSU, heat exchangers, controls, etc., would all be installed at full design capacity. The solar field would be split into two identical modules with both of equal size. The first field, tower and receiver would be installed and placed in operation before construction of the second module is started. While this approach is not shown on the development plan, it has been given a preliminary evaluation. The results of this preliminary analysis indicate that there should be little or no cost penalty incurred with this two module arrangement. However, a more detailed study is needed and is recommended to be included in the proposed preliminary design phase.

7.2.4 Master Control Subsystem

Upon the receipt of hardware, on 31 December 1982, it will be installed in MDAC's system integration laboratory and checked out prior to hardware and software integration. Also, during this time, software will be developed prior to integration with the Master Control Subsystem hardware. Starting on 1 March 1984, hardware and software will be integrated, using the MDAC developed plant simulator as a real-time plant representation. The Master Control Subsystem will be fully integrated and checked out prior to delivery to the site starting on 1 June 1984.

Other facts that add to MDAC's high confidence in meeting the integrated baseline of the master program phasing schedule are as follows:

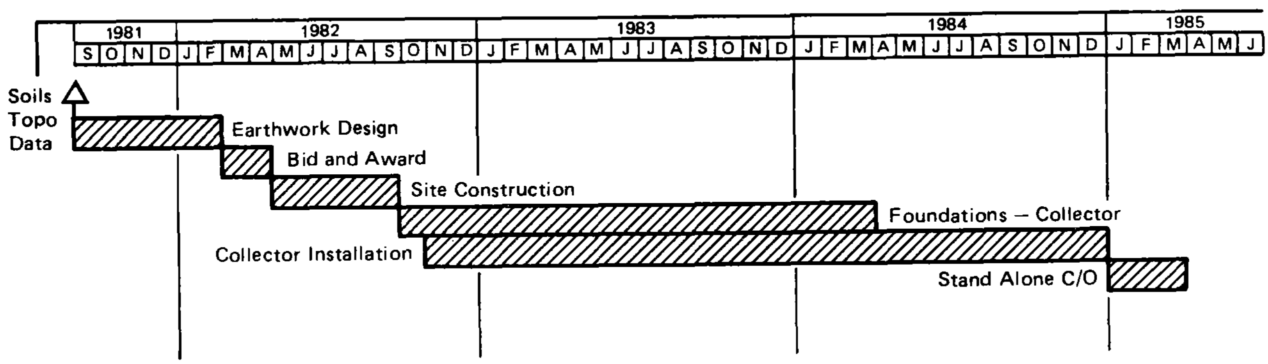
- The Master Control Subsystem will undergo plant simulations prior to delivery.
- We understand the Collector Subsystem and its interaction with the plant.

- We understand the construction activities and electrical power plant construction.
- We have planned utilization of experienced management, engineering, and manufacturing personnel.

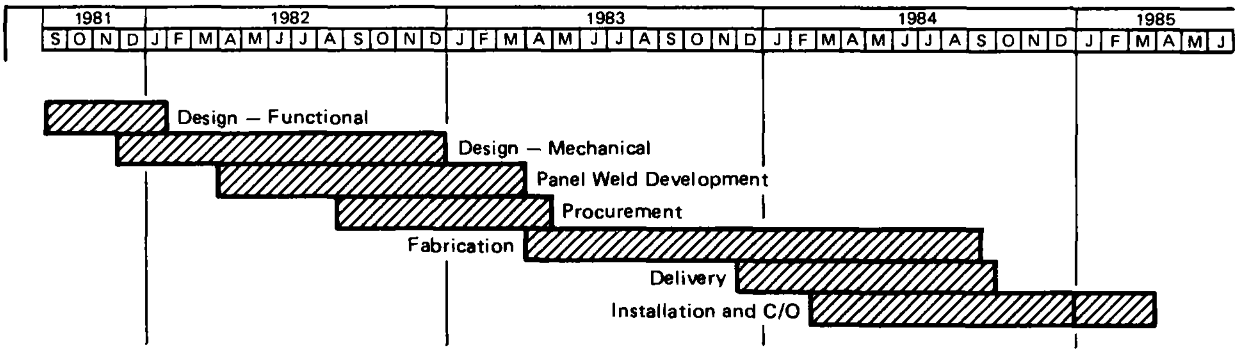
7.3 CRITICAL PATH ANALYSIS

The critical path analysis is based upon a detailed schedule evaluation of activity time spans and interactions compared to program milestones and MDAC's recent experience in performing related activities on the Barstow 10 MWe Program. There are no negative slack paths, but there are some paths more time-critical than others. The context in which "critical path" is used is not the classic meaning that a day-for-a-day slip occurs if any activity on the path is delayed. Rather, the meaning is twofold: (1) to improve management's view of the progress attained in reaching the program end dates, and (2) to focus attention on meeting schedule milestones. Two paths have been identified.

The first critical path involves the availability of soils and topographic data at the start of the subcontract, analysis of that data, design and preparation of earthwork bid package, bid and award cycle, site construction, collector foundations and installations, and stand-alone checkout. The element in this path is the availability of adequate soils and topographic data to allow collector foundations to start on 1 October 1982.



The second critical path involves functional design, mechanical design, procurement of Incoloy, weld development, panel fabrication, delivery, and installation and checkout of the receiver. Two of the most sensitive elements associated with this path are the development weld of panels and procurement of Incoloy. Replacement of orders for material may be accommodated prior to program start, if required, and the development processes, as mentioned before, should receive early program recognition.



Critical path analysis will continue throughout the program as program status information is collected and analyzed. Total program and subsystem critical paths will be reported to management as the program progresses to permit early identification of potential problems for management evaluation and action.

APPENDIX A

SYSTEM REQUIREMENTS SPECIFICATION

DRAWING 1D22600

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
A		[illegible]	[illegible]
B		[illegible]	[illegible]

SYSTEM REQUIREMENTS SPECIFICATION

SIERRA PACIFIC POWER CO. - FT. CHURCHILL NO. 1

MATERIAL	CONTRACT NO.	MCDONNELL DOUGLAS ASTRONAUTICS CO. HUNTINGTON BEACH, CALIF. MCDONNELL DOUGLAS
	ORIGINAL DATE OF DRAWING 79-10-26	
	FIRST RELEASE OF PRINTS	
DASH NUMBERS SHOWN E DASH NUMBERS OPPOSITE	PREPARED [illegible] [illegible] APPROVED [illegible] [illegible]	
PART OR IDENT NO.	CHECKED DESIGN ACTIVITY APPROVAL	SIZE A · CODE IDENT NO. 18355 · DRAWING NO. 1D22600
FOR USAGE DATA SEE ENGINEERING RECORDS	CUSTOMER APPROVAL	SCALE · SHEET 1 OF

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Section 1
GENERAL

1.1 SCOPE

This specification defines the characteristics, requirements, and environment for solar central receiver repowering of Sierra Pacific Power Company's (SPP Co) Ft. Churchill Unit No. 1 power plant. In addition, conceptual design data are provided for the clarification and evaluation of this application.

1.2 SYSTEM DESCRIPTION

The major elements of the solar repowered plant for SPP Co's Ft. Churchill, Unit No. 1 are shown in the hardware tree of Table 1.1. The pictorial system schematic of Figure 1.1 indicates interfaces and major new equipment to be added to repower Unit No. 1. The dashed line encloses the major existing equipment. Only those portions of the plant involved with Solar repowering are discussed in this section. A description of existing overall plant can be found in Section 5. The plot layout is shown in Figure 1.2.

The major subsystems of the repowered plant include the following:

a. Site Facilities

b. Collector

c. Receiver

d. Tower

e. Energy Storage

f. Steam Generators - Heat Exchangers

g. Master Control

h. Fossil

i. Electric Power Generation

j. Specialized Equipment

TABLE 1.1

SOLAR THERMAL POWER SYSTEM HARDWARE TREE

(Page 1 of 2)

SYSTEM

Central Receiver Solar Thermal Power System

SUBSYSTEM	ASSEMBLY
o Collector	o Heliostat o Field Electronics o Heliostat Array Controller
o Receiver	o Absorber o Tower o Receiver Fluid Piping (Shown in Table 5.1) o Structure o Control
o Energy Storage	o Thermal Storage Unit o Circulation Equipment o Steam Generators o Energy Storage Piping (Shown on Figure 5.18)

TABLE 1.1

SOLAR THERMAL POWER SYSTEM HARDWARE TREE

(Page 2 of 2)

SYSTEM

Central Receiver Solar Thermal Power System (continued)

SUBSYSTEM	ASSEMBLY
o Electric Power Generation	o Turbine Plant o Electric Plant o General Plant o Interface Piping (Shown in Table 5.3)
o Master Control	o Computer o Control Console
o Facilities	o Foundations o Site Improvements o Administrative o Operations and Maintenance

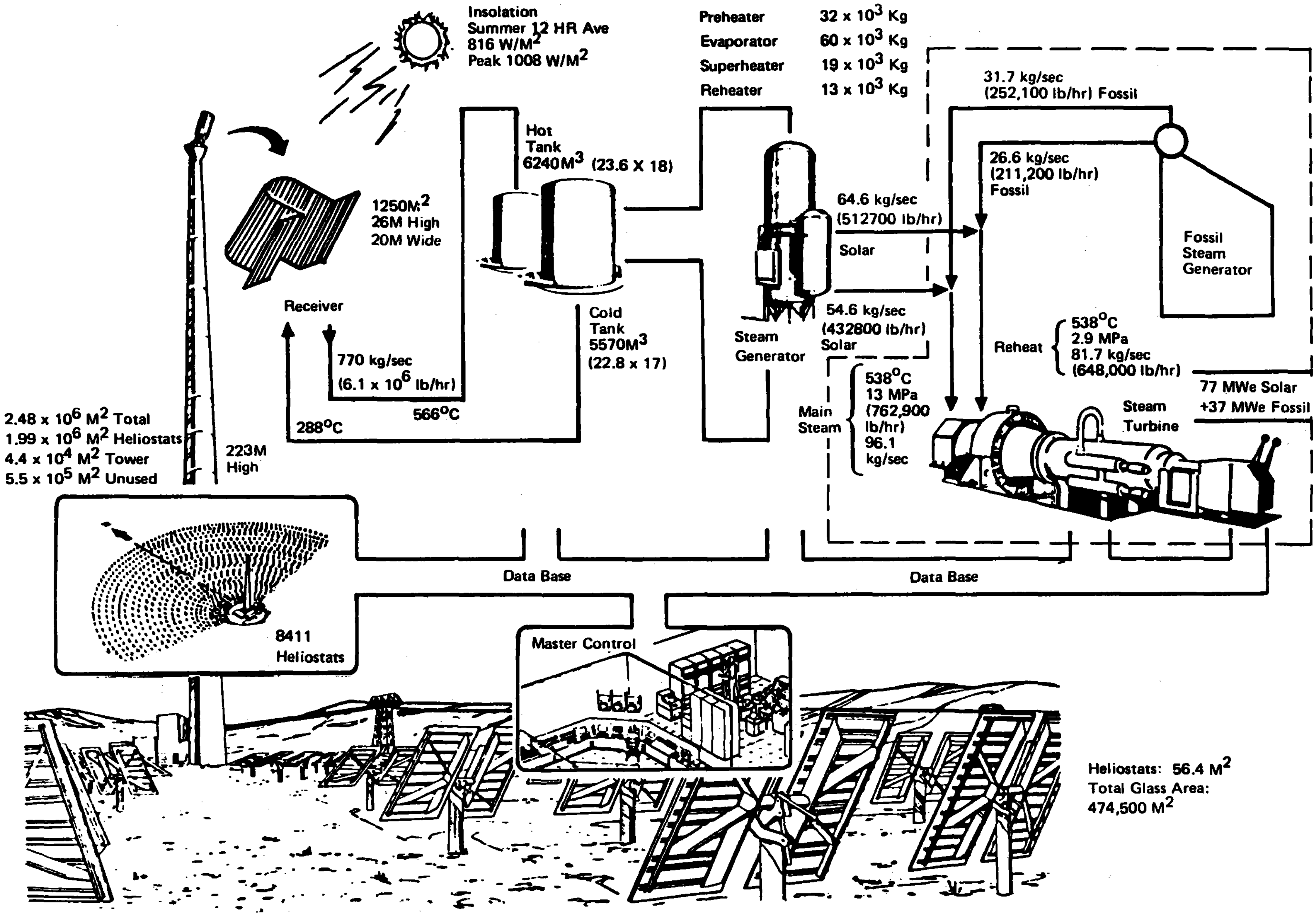

Figure 1.1 Sierra Pacific Power Co. Fort Churchill No. 1

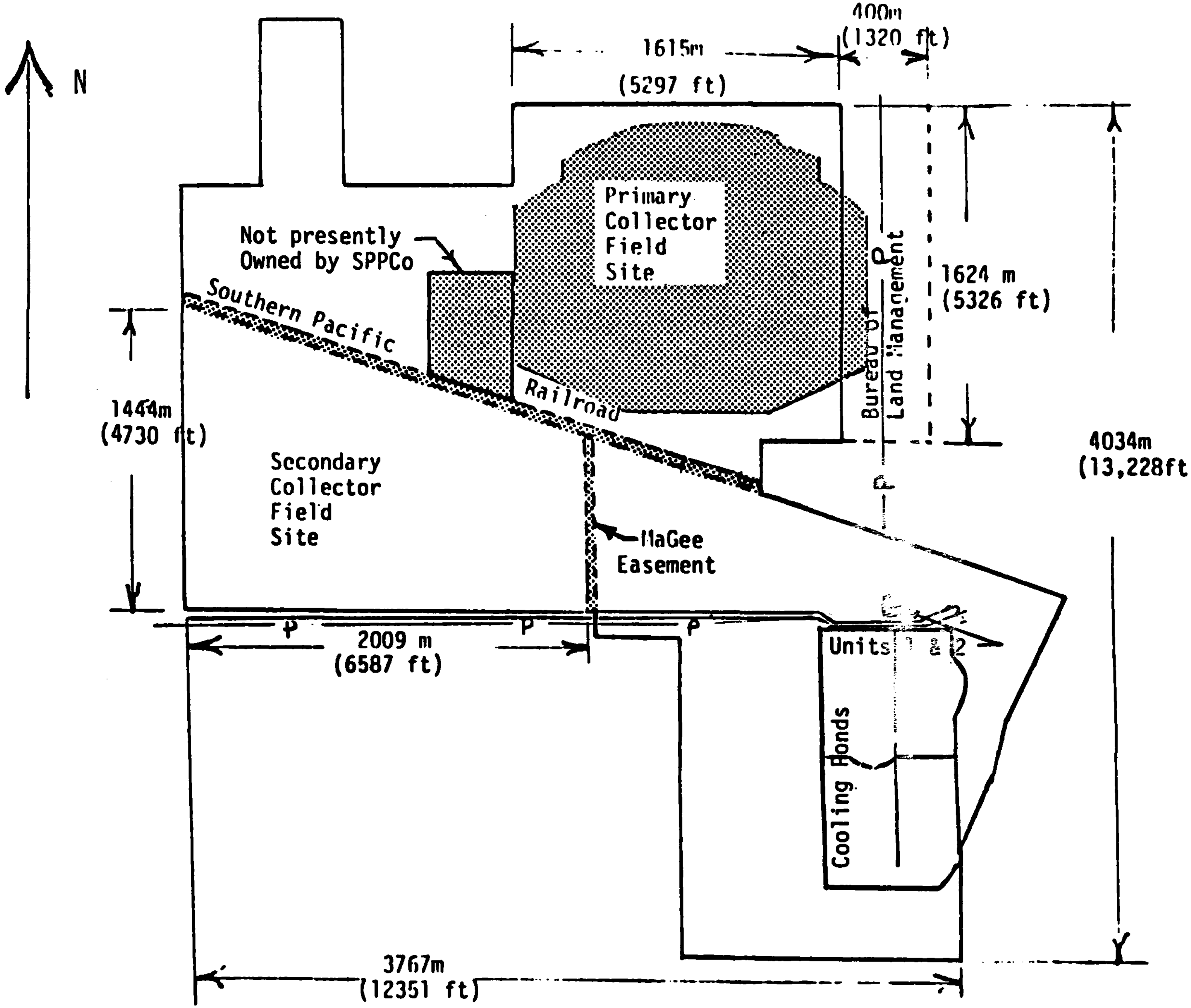

Figure 1.2 Fort Churchill Site Plot

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Issue: B
16 June 1980

1.2.1 Site

The site is located 75 kms southeast of Reno, Nevada. The terrain is typical of a high desert with an elevation of 1250 m. The land surrounding the plant is a combination of open desert (brush covered) and irrigated farm land. The terrain is relatively smooth and level and has a slight slope toward the east where the Walker River flows. The river is located further to the east than the eastern extreme of the solar repowering plant. The lands on the east side of the plant are used for cattle grazing, on the west is irrigated farm land, and open desert land is located north of the plant. The open desert in this location is sandy, may be marshy during the wet season, and requires gravel footings to provide a load bearing surface. One land drainage ditch runs across the land from the southwest to the northeast, through the prime location for the solar field. A southern Pacific railroad right of way is located to the immediate north of the Ft. Churchill site. Two spur lines connect the main line and the plant. Four large evaporative cooling ponds are located to the south of the plant.

1.2.2 Site Facilities

This section provides a description of the buildings and structures that will be added, or modified, for solar repowering. These areas are to include, but not be limited to, the following facilities:

Operations

The facilities required for the solar additions will include the addition of a new computer room adjacent to the present control room. Operational support will require a rerouting of the present county road, the addition of a paved road between the plant railroad siding and the tower sets and a paved road between the railroad siding and the salt unloading area. Additional roads will include an unpaved road (crushed rock) roadway around the periphery of the solar field and to key points within the solar field.

Security

The additional security provision will include the addition of a 1.8m (6 ft) chain link fence around the outer perimeter of the solar plant. Plant identification signs will be attached to this fence at intervals.

Storage and Maintenance

In general, the present plant has adequate storage and maintenance facilities, however, one additional area will be added. This combined storage and maintenance area will have a floor area of 367 m^2 (4000 ft^2) and will be suitable for the repair of heliostat drive systems, field electronics, and related equipment. A specific garage area will be provided for service and storage of the mobile equipment used on the solar equipment.

Visitor Center

The present plant office and reception area is adequate to handle the normal requirements of a visitor center, and these facilities will be used during the early years of solar operation. A separate visitor center will be added at a later time if the number of visitors warrant such an installation. The separate visitor center is not included in the basic plant costs.

1.2.3 Collector Subsystem

The collector subsystem consists of 8,411 heliostats of 56.4 m^2 each and associated electronics laid out in a field generally north of the tower. Each heliostat tracks in two axes such that its reflected light falls on the receiver. The total mirror area will be approximately 474,380 m^2,

1.2.3.1 Heliostat

Heliostats generally conform to the requirements of the DOE Second Generation Heliostat program and are covered under Collector Subsystem Requirements, specification A10772, Sandia Livermore Laboratory. Where specific characteristics are required, the MDAC Second Generation design with the non-inverting option will be used. That heliostat is functionally represented as follows:

Reflector Area: 56.4 m^2 (606 ft^2)
Reflector Shape: Rectangular, 8.65m wide, 6.87m high (28.4 ft x 22.5)
Normal Stowage Position: Reflector Vertical
Severe Wind Stowage Position: Reflector Face Up
Number of Panels: 14
Panel Dimensions: (1.22 x 3.66m) (4 ft x 12 ft)
Azimuthal Spacing Range: 13.3m (43.6 ft) minimum, 16.3m (53.4 ft) maximum

Minimum Spacing: 10.6m (35.5 ft)

Control: Open Loop

Power: 208 VAC 3 Phase 60 Cycle

1.2.3.2 Field Electronics

The collector field will be connected by buried cable. Field distribution centers will be used to communicate between groups of heliostats and the Heliostat Array Controller. Transformers will be located at the Field Distribution Centers to step down from 2.4 KV primary distribution voltage to 208 V/120 V secondary.

The Heliostat Array Controller will be used as the interface between the Collector subsystem and Master Control Subsystem. Heliostat mode commands and time updates will be provided by Master Control. Return communication will be routed to the sequence of events recorder and interface control.

1.2.3.3 Collector Field

The collector subsystem consists of a collector field containing 8411 individual heliostats and their controls, power supplies, and field wiring. The collector field is located to the west and north of the plant.

The collector field is located north of the tower and is a 128° north field layout. The collector field was optimized in a radial staggered layout which contains 40 individual cells.

The collector field is divided into four separate zones which have different aim strategies. These four zones shown on Figure 1.3 are as follows:

Zone 1 - An outer zone, where the beam is larger than the aperture, the aim point will be on the center of the aperture. Where the beam is smaller than the aperture, the aim will be tangent to the top of the aperture and on the vertical centerline. This zone contains 2640 heliostats.

Zone 2 - This zone will use a divided high/low aim strategy with both points on the vertical centerline. The low aim point will be high enough to minimize

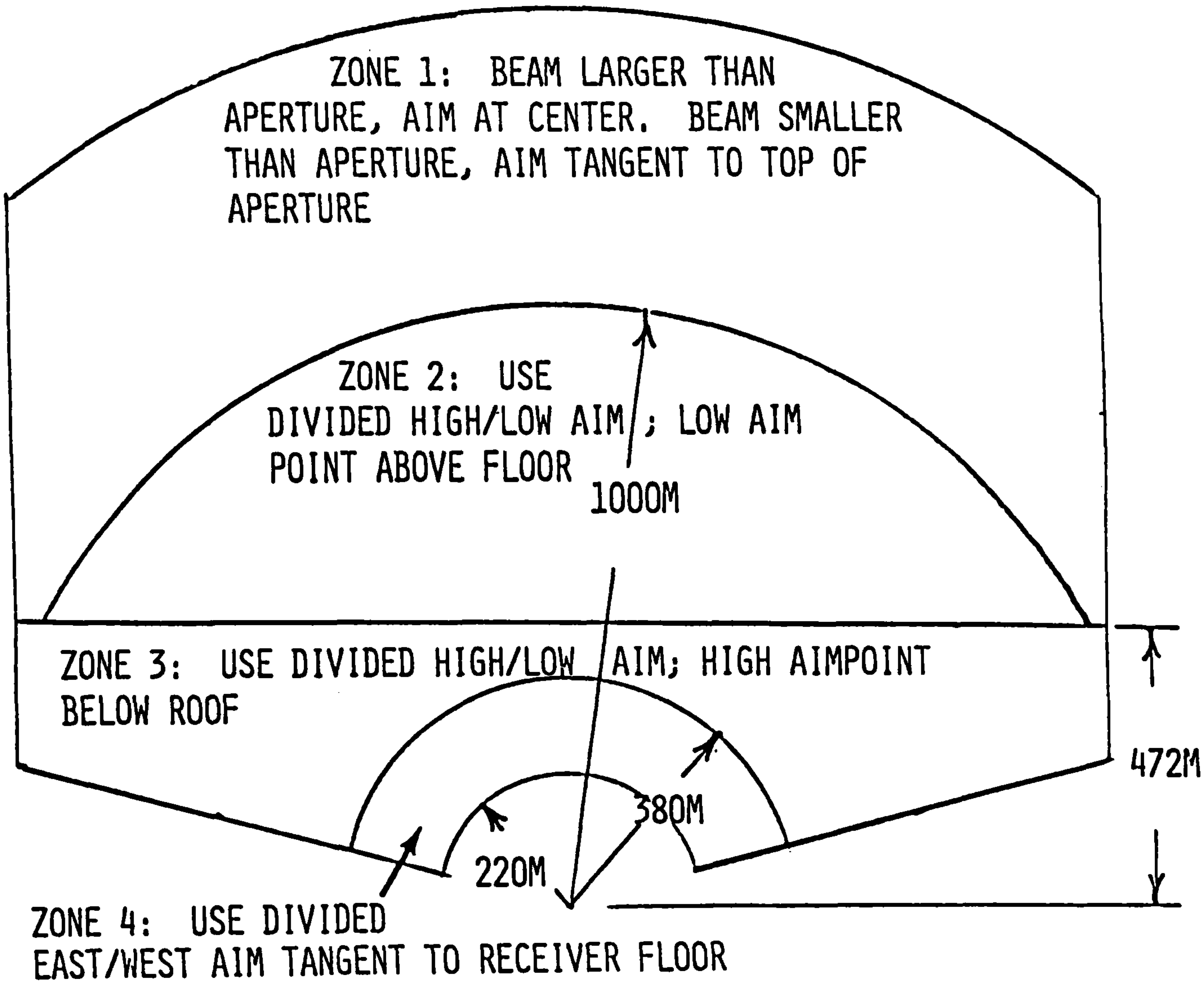

Figure 1.3 RECEIVER AIM STRATEGY

impingement of radiation on the floor. This zone will contain 2438 heliostats.

Zone 3 - This zone uses a divided high/low aim strategy with the high aim point low enough to minimize impingement on the receiver celing. This zone contains 897 heliostats.

Zone 4 - The inner zone uses a divided east/west aim strategy with both sets high enough to minimize impingement on the receiver floor. This zone contains 897 heliostats.

1.2.4 Receiver Subsystem

The receiver subsystem absorbs the redirected sunlight in its absorber panel assemblies. The sunlight is converted to heat in the heat transfer fluid within the absorbers panels. The receiver is generally arranged in a partial cavity configuration.

The receiver shall be an omega-shaped, partial cavity design consisting of two (2) external wing panels, then (10) internal side panels, and eight (8) internal rear panels. The aperture plane shall be tilted 25° from vertical to face the north collector field. Molten salt entering the receiver will be heated from 288°C (550°F) to 566°C (1050°F). The design point (equinox noon) thermal rating of the receiver is 330 MW_{th}.

The absorber panels are mounted to the receiver structure, which is in turn mounted to the tower top. Receiver piping connects the absorber panels to the heat transfer fluid flow to each panel such that the outlet temperature from each panel is regulated to acceptable limits.

The twenty absorber panels are arranged in a four pass series parallel configuration. This arrangement is as follows:

Stage	Panels	Flow
Primary preheat	L1, L2, L3, R1, R2, R3	Parallel
Secondary preheat	L4, L5, L6, R4, R5, R6	Parallel
Intermediate	L8, L10, R8, R10	Parallel
Final	L7, L9, R7, R9	Series/Parallel

1.2.4.1 Absorber Panel

The absorber panels will consist of panels which are 26 meters long and which will be of three different widths. The tubing used will be 25.4 MM (1") x 1.65 MM (.065") made from Incolloy 800. the panel width data will include the following:

2 panels - 3 meters wide with 118 tubes
10 panels - 2.4 meters wide with 95 tubes
8 panels - 2.34 meters wide with 92 tubes

1.2.4.2 Receiver Structure

The receiver support structure will consist of an open type steel truss structure which will support the receiver at an angle of 25° from the vertical underall conditions of wind, weather and earthquakes. The support structure will include the door tracks and door operating mechanisms for four, full width doors. The doors will be mounted in pairs which are counterbalanced within each pair. Two doors will open by moving upward and nesting on each other, while the second pair of two doors will open downward and these will also nest on each other.

1.2.4.3 Receiver Fluid

PARTHERM 430 (or equivalent), salt. 47% sodium nitrate--53% potassium nitrate.

1.2.4.4 Receiver Piping

The receiver piping will consist of the flow control distribution manifolds, flow control valves and the interface with the riser and downcomer. The riser will be a .4M x 9.5 MM (16" x .375") carbon steel pipe which will be fitted with 16" bellows. The downcomer will be a .3 M x 9.5 MM (12" x .375") pipe made of 304 CRES. Expansion hooks will be used on both the riser and downcomer.

1.2.4.5 Receiver Controller

The receiver controller will be an integral control unit which will be tower mounted. The control will sense both bulk salt temperatures and incident solar flux and will control both the flow distribution between panels and the total mass flow of salt.

1.2.4.6 Receiver Tower

The receiver tower will be slip formed concrete tower that is 198.5 M in height (ground level to tower top). The top of the tower will be 20.2 M in diameter with a base that is 24 M diameter. The tower taper is 1/2° and the wall thickness varies from .25 M (.833 ft) at the top to 0.33 M (1.083 ft) at the base. The tower will set on a mat which has a diameter of 45.5 M (150 ft) and a thickness of 4.24 M (14 ft). The tower will be steel reinforced.

1.2.5 Master Control Subsystem (MCS)

The Master Control Subsystem provides the manual and coordinated control of the collector, receiver, thermal storage and interface subsystems of the retrofit plant. A centrally located single control console with displays, and switches forms the operator interface to monitor and manually control retrofit plant processes. A distributed microcomputer software based system provides the coordinated control capabilities and the independent loop and interlock control functions. The major elements of the master control subsystem include:

a. Operator Interface - (CRT and Operator Keyboard)
b. Interlock Logic System (Programmable Logic Controller - Microprocessor Based)
c. Receiver Subsystem Control (Microprocessor Based)
d. Collector Subsystem Control (Heliostat Array Controller (HAC), Heliostat Field Controllers (HFC), Heliostat Controllers (HC)).
f. Interface Subsystem Control (Microprocessor Based)
g. Thermal Storage Steam Generation Subsystem Control (Microprocessor Based).
h. Heliostat Aimpoint Alignment Subsystem (Microprocessor Based).

The Master Control Susbystem shall operate in the following modes:

a. Steady State
   1. Fossil only
   2. Hybrid
   3. Solar only

b. Transition
   1. Solar plant startup
   2. Solar plant shutdown
   3. Solar/fossil transition

c. Non-Operational
   1. Solar standby - hot
   2. Solar shutdown - cold
   3. Solar emergency stop

The steady state plant operating modes will adapt to sun following and load following submodes utilizing the fossil and solar systems as required.

1.2.6 Fossil Energy Subsystem

The fossil energy subsystem consists of the present "El Paso" type boiler system. This system includes provisions for both oil and gas burning, either separately or with both types simultaneously. The present system will be modified to separate the feed water supply to the fossil boiler and solar steam generator, to split the turbine cold reheat steam flow and to join the dual sources of hot reheat steam at the turbine inlet, the present fossil energy control system will be integrated into the total Master Control System; however, the present system will retain the capability to operate as a separate unit for fossil only operations.

1.2.7 Energy Storage Subsystem

The Energy Storage Subsystem receives hot heat transfer fluid from the receiver and stores this heat in a sensible heat storage unit. The heat required to satisfy turbine demand is taken directly from the hot storage tank. Excess heat is allowed to accumulate in the hot storage tank. The hot heat transfer fluid is flowed in parallel into superheater and reheater heat exchangers and then in series into an evaporator heat exchanger and preheater. The cold heat transfer fluid is collected and stored in the cold storage tank for recirculation to the receiver.

1.2.7.1 Thermal Storage Unit

The thermal storage unit will consist of a single hot tank and a single cold storage tank. The hot storage tank will be fabricated from 304 CRES and will be covered with external insulation. The cold storage tank will be fabricated from carbon steel and will have external insulation. Both tanks will be equipped with auxiliary heating provisions and both will have liquid level sensors.

1.2.7.2 Circulation Equipment

The cold salt flow to the receiver will be pumped with two receiver feed pumps. These pumps will be half capacity each. Each pump will have a capacity of .178 m^3/s (2825 GPM) when operating with a head of 261 M (861 ft). These pumps will be powered with electric motors of approximately 1305 KW (1750 HP).

The hot salt flow to the steam generators will be pumped with two, half capacity, heat exchanger feed pumps. These pumps will have a capacity of .106 M^3/s (1700 GPM) at a head of 31.5 M (104 ft). The heat exchanger feed pumps will be of stainless steel construction. The two pumps will be powered with an electric motor of 112 KW (150 HP) each.

1.2.7.3 Heat Exchange

The heat exchangers used for the steam generation from solar energy will include the following:

a. Preheater, counterflow, tube and shell

b. Evaporator, parallel flow, tube and shell

c. Superheater, counterflow, tube and shell

d. Reheater, counterflow, tube and shell

These units will be fabricated as four separate items and they will be mounted vertically and in close proximity to each other.

1.2.7.4 Thermal Storage Control

The thermal storage controller monitors temperatures, flows and pressures and controls valves and pumps to direct the flow of hot salt in a manner that provides the proper amount of superheated and reheated steam for the selected mode of operation.

1.2.8 Electrical Power Generating Subsystem Interfaces

The solar system will interface with the existing power generating subsystems at the following points:

a. High pressure steam to turbine (main stream). The point of interconnection with the main steam line will be a new tee in the existing 11-1/4" O.D. main stream header.

b. Steam from H.P. turbine to reheaters (cold reheat). The point of interconnection with the cold reheat line will be a new tee in the existing 20" cold reheat header, located between the 1st point heater extraction and the existing attemperator.

c. Steam from reheaters to I.P. turbine (hot reheat). The point of interconnection with the hot reheat line will be a new tee in the existing 10" O.D. hot reheat header.

d. Feedwater feedline (boiler feed). The point of interconnection with the boiler feedline will be a new tee in the existing 8" boiler feed header, downstream of the 1st point heater (highest pressure heater).

e. Solar System controller to existing controller - The interfaces for the solar system controller and the present plant continually will be located in the present plant control room and in the new solar control room and computer room. The location of each electrical/electronic interfaces will be located in this specific area and in the circuits shown on this plant P&ID.

f. Plant electrical power supply - The electrical power supply for the solar system will be supplied from the existing 120-60 KV auto transformer tertiary auxiliary power supply, for normal operation and from the 900 KW emergency diesel generator for emergency conditions. The 900 KW diesel generator package is a new unit that will be included in the solar repowering package.

1.2.9 Specialized Equipment

The following items of specialized equipment will be required for this installation:

a. Mobile installation machine - heliostat pedestals
b. Mobile trailer - heliostat pedestals
c. Mobile installation machine - heliostat mirror panels
d. Mobile trailer - heliostat mirror panels
e. Mobile heliostat washing machine (two required)
f. Freeze protection heater

1.3 DEFINITIONS OF TERMS

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

Busbar Cost - Levelized revenue requirements of a generating option divided by the annualized kilowatt hour output (levelized over the life of the unit) in mills per kilowatt hour.

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

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

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

Conversion Efficiency, Gross - Gross output provided by a conversion device divided by total input oower at specified conditions.

Conversion Efficiency, Net - Actual net output (after deducting parasitics) provided by a conversion device divided by the required input power at specified conditions.

Design Point - The time and day of the year at which the system is sized with reference insolation, wind speed, temperature, humidity, dewpoint and sun angles.

Field Receiver Power Ratio - Maximum heliostat field power output divided by maximum receiver power absorption capability.

Direct Insolation - Non-scattered solar flux falling on a surface oriented normal to the sun (watts/m^2):

Fluid, Receiver - The fluid used to cool the solar receiver and distribute the absorbed solar energy to other parts of the system; heat transport fluid.

Fluid, Working - The fluid used in the turbine or other prime mover.

Geometric Concentration Ratio - The ratio of the projected area of a reflector system (on a plane normal to the insolation) divided by absorber area.

Receiver Efficiency - Ratio of thermal power output at receiver base to incident solar power upon receiver.

Repowered/Industrial Retrofit Plant - A repowered/industrial retrofit plant that uses solar energy to partially replace a non-renewable fuel source.

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

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

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

Solar Multiple - Defined at the design point as thermal power from receiver(s) after downcomer and piping losses divided by Thermal Power, Prime Mover

Storage Capacity - The amount of net energy which can be delivered from a fully charged storage subsystem (MWh_e or MWh_t).

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

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

*Note: For utility applications MWh electrical, net, from respective source.

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

Section 2
REFERENCES

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

2.1 STANDARDS AND CODES

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

b. OSHA Regulations

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

   2) OSHA Title 29, Part 1926 - Safety and Health Regulations for Construction

c. ASME Boiler and Pressure Vessel Code

   1) Section I - Power Boilers, including: ANSI B31.1-1977 Power Piping

   2) Section II - Materials Specifications

   3) Section III - Unfired Pressure Vessels

d. NRC Regulatory Guide 1.60

e. NRC Regulatory Guide 1.61

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

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

h. Human Engineering Design Criteria - MIL-STD-1472

i. SAN 0501-01 "Pattern of Health and Safety Responsibility," April 21, 1976

j. SAN 0499-6 "Summary Safety Plan (RADL 2-24)," June 1979

k. Design, Construction and Fabrication Standards

   1) Standard of AISC (American Institute of Steel Construction)

   2) Standards of ACI (American Concrete Institute)

   3) Standards of TEMA (Tubular Exchanger Manufacturer's Assn)

   4) Standards 650 of API (American Petroleum Institute)
      - Welded Steel Tanks for Oil Storage

2.2 OTHER PUBLICATIONS AND DOCUMENTS.

Collector Subsystem Requirements - Sandia Specification A10772

Collector Field Optimization Report (RADL Item 2-25) Report SAN/0499-22 dated October 1979.

2.3 PERMITS & LICENSES

The permits required for the Solar Repowering are:

a. Construction order, Public Service Commission
b. Offset, operating permit, Division of Environmental Protection
c. Environmental Assessment and CRR, Bureau of Land Management
d. Cultural Resource Clearance SHPO
e. Aviation Hazard Permit, Federal Aviation Authority

2.4 APPLICABLE LAWS AND REGULATIONS

The applicable laws and regulations are:

a. Construction Order - Utility Environmental Protection Act Rule 25

b. Offset - Operating Permit - Clean Air Act Amendments 1977
Title I Section 127 Prevention of Significant Deterioration
- 128 Visability protection
- 129 Nonattainment areas
Code of Federal Regulations
Title 40 Part 51 Appendix S - Emission Offset

c. Environmental Assessment and Cultural Resource Report -
CFR Title 40 Part 6 - Environmental Assessment
Historic Preservation Act 1966-Public Law 89-665 80 Stat. 915

d. Cultural Resource Clearance
Historic Preservation Act 1966-Public Law 89-665 80 Stat. 915
(Duplicate copy of CRR is sent to State Historic Preservation Officer)

e. Aviation Hazzard Permit - Federal Aviation Regulations Part 77 Subchapter B

Section 3
REQUIREMENTS

The solar repowered plant shall be designed to meet the requirements of this section. These requirements are applicable only to the new or modified portions of a solar repowered plant.

The solar retrofit design shall make maximum use of completed or on-going DOE solar R&D activities. The solar/non-solar interfaces shall be designed so that the plant can still be operated in a fossil only mode without degradation of performance or availability.

The operating modes for the repowered plant shall be:

a. Fossil only 115,171 KW (gross)
b. Hybrid 77,000 KW Solar/36,875 KW Fossil
c. Solar only 77,000 KW

3.1 SITE PREPARATION

Based on the available soils data, a maximum allowable net soil bearing pressure of 250 KPa (5 ksf) will be assumed for foundation design for the general field. A value of 375 KPa (7.5 ksf) will be assumed for areas which are backfilled and compacted.

In general, site grading will be limited to a minimum amount of stripping and cut and fill to provide for drainage in the collector field area. Very little, if any, grading is required at the proposed steam generator and thermal storage tank areas, except as required for foundations.

A paved road will be built from the end of the existing paved area at the railroad siding and extend to the tower location. This road shall be capable of supporting heavy duty construction vehicles.

A general road will be built around the perimeter of the solar collector field. This road will be located inside the security fence and will be capable of supporting heavy duty construction vehicles.

3.2 SITE FACILITIES

The facility modification/addition required for the solar repowering portion of the plant will include the following:

a. Computer Room - New Addition
b. Washer Room/Kitchen - New Addition/relocated
c. Office - New Addition/relocated
d. Storage and Maintenances - New
e. Garage and Service Area - New

3.3 COLLECTOR SUBSYSTEM

The Collector Subsystem shall reflect solar radiation onto the Receiver Subsystem in a manner which satisfies receiver incident heat flux requirement. The Collector Subsystem shall meet the requirements listed in this paragraph.

3.3.1 Layout

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

a. Heliostat capital cost
b. Operating and maintenance cost
c. Field wiring cost
d. Tower cost
e. Receiver cost
f. Land availability
g. Land cost
h. Heliostat performance
i. Receiver size
j. Shading and blocking
k. Atmospheric attenuation
l. Latitude
m. Terrain contour
n. Tower height

The optimization shall be by methods developed by and currently in use at the University of Houston Energy Laboratory. The RCELL Code, as described in RADL 2-25, will be used for this program.

The collector field will be capable of supplying 330 MWth (absorbed) or 345 MWth (incidence) to the receiver at equinox noon at the site latitude of 39^{o} north. The peak flux delivered to the receiver absorber surface shall be .6 MW/m^2.

3.3.2 Heliostats

The heliostats shall meet the requirements of "Collector Subsystem Requirements, A10772," Sandia Livermore Laboratories except for the following deviations:

2.1 Standards

Soil and Foundation Investigation Report, 5 MW STTF, Sandia Labs.
N/A

3.1.1 Collector Subsystem Diagram (Figure 3 in A10772) implies a DAS and a BCS. We may elect to use neither.

3.1.2.1 Anticipates a procurement of an installed system. It is more likely to be a hardware buy w/Contractor installation. Will certainly be to contractor determined heliostat locations. Hence, contractor must determine arrangement and boundaries.

3.1.2.2 Collector/Receiver Subsystem. The collector subsystem shall concentrate its redirected energy onto the receiver. The receiver is an "omega" shaped partial cavity receiver which is mounted at an angle of 25^{o} from the vertical. The front aperture opening for the receiver will be approximately 20 meters wide and 26 meters high.

3.1.2.5 Heliostat Array Controller (HAC)/Data Acquisition System (DAS) -- not applicable.

3.1.2.6 Heliostat Array Controller (HAC)/Beam Characterization System (BCS) -- not applicable.

3.2.1 Performance

a. Temperature - 5^{o} to 33^{o}C (23^{o}F to 92^{o}F)
Azimuth Angles - at all angles (Note: Gimbal lock does not occur within the proposed field boundaries.)

b. Temperature - -5^{o} to 33^{o}C (23^{o}F to 92^{o}F)

c. Not Applicable

3.2.2 Entry D - Delete entry - not applicable

3.2.4 Fault isolation should not be designed into the HC, HFC, HAC chain. At most, it should be designed into a mobile repair van.

3.2.6.2 Temperature - -5° to 33°C (23° to 92°F)
-30°C to 40°C (-22°F to + 104°F)

3.2.6.4 Delete Survival hail

3.4.4 Delete entry - not applicable

Appendix 1

3.1.5 Sandstorm Environment. The plant shall be able to operate after a dust storm with maximum dust flux up to 10^{-4} grams/cm^2/sec, particle sizes of 50 micrometers or less, for durations of up to 36 hours, and at wind speeds up to 18 M/S.

3.2 Temperature. Ambient air temperatures range from -30°C to +40°C (-22°F to 104°F)

3.3.1 Rain. Average annual: 133 mm (5.23 in); maximum 24 hour rate 51 mm (2.02 in).

3.3.4 Snow. Maximum 24 hour rate 152 mm (6 in); maximum loading: 250 Pa (5 lbs/ft^2)

3.6 Soil Properties. The soil properties which will be used for designing the heliostat foundation are site specific, hence the actual characteristics of the soil at the Ft. Churchill site will be used.

3.3.3 Operation

The collector subsystem operating modes can be commanded either automatically or manually through the Master Control Subsystem, or manually in the field. The following modes are required.

3.3.3.1 Normal Tracking (Mode C-1)

Each operational heliostat tracks the sun so that its reflected beam strikes the receiver at its preassigned aim point. Tracking is by articulation of gimbal axes to computed positions based on a computed, apparent sun position.

3.3.3.2 Normal Stow (Mode C-2)

The normal heliostat stow position shall be with its reflector surface nearly vertical. This position shall be preferred for night time stow and for periods when the system is not operating and no threat of damage to the heliostats due to severe weather exists. Heliostats can be stowed in groups of approximately 256 while the remainder of collector subsystem is in normal tracking.

3.3.3.3 Severe Weather Stow (Mode C-3)

The heliostats shall stow with their reflective surfaces horizontal and reflector side up during periods of weather severe enough to otherwise threaten damage to the heliostats.

3.3.3.4 Cleaning and Maintenance

The heliostats shall be able to be manually positioned, either singly or in groups, to positions which facilitate corrective maintenance and/or cleaning. (No scheduled maintenance actions are contemplated.) Such manual control can be commanded either locally in the field or remotely by the Master Control Subsystem.

3.3.3.5 Transition Modes

The heliostats have six basic mode transitions: Normal Tracking to Normal Stow, Normal Tracking to Severe Weather Stow and Normal Stow to Severe Weather Stow, together with the reverse transitions for each of the above. Each of the above mode transitions must be accomplished in such a manner as to preclude unsafe beam conditions on the ground or in the air space surrounding the site, and to prevent unsafe conditions for personnel, equipment, and facilities within the site.

A set of standby tracking points may be specified for the heliostats as a staging point during on and off target mode transitions. When the shutdown command is given, the heliostats must move off target rapidly and in such a way as to preclude excessive heat flux on the receiver or the tower and support structure. When returning to target, the heliostats must stage their transition to provide a controlled receiver startup.

3.3.4 Collector Subsystem Interface

The collector subsystem interfaces with Electrical Power Generation Subsystem through a transformer and distribution panel. 4160V three-phase power is delivered to field transformers. The peak power requirement is 2525 KVA (1675 KW) for emergency stow with a duration of 20 seconds. The average power during normal operation is 550 KVA.

3.4 RECEIVER SUBSYSTEM

The Receiver Subsystem shall provide a means of transferring the incident radiation from the Collector Subsystem into the receiver working fluid and transport of the heated fluid to the bottom of the tower. The receiver subsystem consists of the receiver unit, including absorber panels, structure, piping, and controls, and the receiver working fluid and the receiver tower.

The receiver subsystem has a single operating mode, independent of the several fossil plant and solar plant modes. The receiver delivers energy at rated temperature to the bottom of the tower. Energy collection is discontinued at the fractional power level where it is no longer possible to deliver rated temperature. The receiver shall have a Hot Standby and a Hot Shutdown non-operating mode. These non-operating modes shall be maintained by trace heating.

3.4.1 Structural Design

The receiver support structure shall attach the receiver to the tower structure such that the geometrical center of the receiver will be installed within 1.0 m of a fixed point in space under all operating conditions and under the specified environmental conditions. The support structural weight shall not exceed 680000 Kg (1.5×10^6 lbs.). The uncooled support structure shall be adequately protected from the solar energy of the collector field irradiance falling off the absorber surfaces. The receiver structure shall be able to withstand stray solar irradiance at a level of 1000 W/M^2, at any location, and for time intervals of 12 hrs.

3.4.2 Receiver

The receiver configuration shall be a partial cavity, combining both external absorber and cavity regions in the optimum manner. The receiver design and operating parameters will be:

a.	Receiver active surface area	1267 m^2	13,798 (ft^2)
b.	Design flux limit of receiver	.6 MW_t/m^2	1.88×10^5 ($Btu/hr\text{-}ft^2$)
c.	Average operating flux limit	.35 MW_t/m^2	1.1×10^5 ($Btu/hr\text{-}ft^2$)
d.	Thermal power - receiver output	331 MW^t	1.1×10^9 (Btu/hr)
e.	Receiver coolant fluid	Partherm 430* (or equivalent)	

Consideration shall be given to ease of maintenance. Adequate provisions shall be made to ensure crew safety at all times for required operations, inspection, maintenance and repair. The receiver design shall be consistent with the intent of appropriate ASME Boiler codes.

The receiver subsystem will deliver, at the bottom of the tower, the following performance:

	Design Point	Maximum	Minimum
Energy (MWt)	331	347	50
Temperature (°C)	566	566	566
Efficiency	0.93	0.93	

The maximum energy output estimated at 105% of design will occur on an extremely bright day. The minimum, estimated at 20% of design, could occur under conditions of partial cloudiness, haze, thin clouds or early and late day operation.

The receiver subsystem will operate and/or survive under the environmental conditions specified in paragraph 4.0.

*Contamination limit is 1% total.

The receiver will interface with the remainder of the system through the following interfaces:

Mechanical:	Riser, Downcomer, Tower
Electrical:	Electrical Power for Pumps, Valves, etc.
Control:	Master Control

3.4.3 Receiver Fluid Loop

3.4.3.1 Piping

The design conditions for the receiver fluid piping shall be as follows:

Downcomer:
- Design Pressure 4 MPa (575 psi)
- Design Temperature 593°C (1100°F)
- Pipe Material ASTM A312 (316 SS)
- Code ANSI B31.1

Hot Fluid Horizontal Piping:
- Design Pressure 4 MPa (575 psi)
- Design Temperature 593°C (1100°F)
- Pipe Material ASTM A312 (316 SS)
- Code ANSI B31.1

Riser:
- Design Pressure 9.6 MPa (1400 psig)
- Design Temperature 302°C (575°F)
- Pipe Material ASTM A106-GR.B
- Code ANSI B31.1

Cold Fluid Horizontal Piping:
- Design Pressure 9.6 MPa (1400 psi)
- Design Temperature 302°C (575°F)
- Pipe Material ASTM A106-GR.B
- Code ANSI B31.1

3.4.3.2 Pumps

The Receiver Fluid Loop shall contain two receiver feed pumps which are rated for one-half the total requirements each. These pumps shall meet the following requirements:

a. Capacity	.41 m^3/S (6500 GPM)
b. Head	364 m
c. Efficiency (minimum)	75%
d. Type Drive	Electric Motor
e. Motor Power	1832 Kw
f. Motor Speed	880 rpm

g. Pump Type	Vertical
h. Pump Material	Carbon Steel
i. Shaft Seals	None Used

The steam generator system shall contain two, half capacity, feed pumps which have the following requirements:

a. Capacity	.25 m^3/S (4050 GPM)
b. Head	91 m
c. Efficiency, Minimum	75%
d. Type Drive	Electric Motor
e. Motor Power	253 KW
f. Motor Speed	1800 RPM
g. Pump Type	Vertical
h. Material	Stainless Steel
i. Shaft Seals	None Used

3.4.4 Receiver Tower

The receiver tower shall support a total receiver weight of 1,000,000 KG (2200 KIPS) at a height of 222.5m (receiver center line to ground level).

The tower will survive wind loads resulting from a 40 M/S (90 mph) wind, from any direction and will survive an earthquake having a simultaneous .05g vertical and .25g horizontal acceleration. Additional tower design requirements are:

a. The tower shall be equipped with aircraft warning lights and lightning protection as required.

b. The tower shall be designed to provide access for maintenance and inspection of the receiver, instrumentation and controls, piping, and other equipment mounted on the tower.

c. The tower foundation shall be designed to meet the tower specification when mounted on a soil capable of supporting 250 KPa (5 kps per ft^2).

3.5 MASTER CONTROL SUBSYSTEM

3.5.1 Operating Modes

The Master Control Subsystem shall control the operation of the plant in the following ranges:

a. Steady State

1.	Fossil only @	37 MWe to 115 MWe
2.	Hybrid	37 MWe to 115 MWe fossil, 20 MWe to 77 MWe Sol ar
3.	Solar only	20 MWe to 77 MWe

b. Transition

1.	Solar plant startup	60 minutes (max)
2.	Solar plant shutdown	30 minutes (max)
3.	Solar/fossil transition	10 minutes (max)
4.	Emergency Defocus	2 minutes (max)

c. Non-Operational- The following non-operational modes will be provided:
   1. Solar standby - hot
   2. Solar shutdown - cold
   3. Solar emergency stop

The steady state plant operating modes will adapt to sun following and load following submodes utilizing the fossil and solar systems as required.

3.5.2 Design Criteria

The master control subsystem is a computerized supervisory system which incorporates the following features:

a. Distributed digital control of the solar plant processes

b. Remotely located subsystem controllers

c. Serial redundant digital control and data communications between the control center and the subsystems

d. Single operator for plant and subsystem control and monitoring

e. Control processor terminals used for plant and subsystem control and monitoring

f. Microprocessor based controller hardware

g. Use of CRT display devices for monitoring plant status

h. Semi-automatic and manual modes of operation

The control system architecture consists of the following hardware divisions: (1) Operator Station (2) Data bus, (3) Field process control electronics, (4) Heliostat aimpoint alignment subsystem.

A centrally located single operator control station will provide the operator interface and supervisory control and monitoring of the retrofit solar subsystems and the conventional fossil system processes.

The control station is linked to the field remote subsystem process control electronics using a common, redundant data bus. The data bus links all of the remote subsystem control facilities to their respective central control and monitoring processor.

Specific control and interlock logic functions are distributed within the field process control electronics to control and monitor the receiver, collector, thermal storage, beam characterization and solar interface subsystems.

The master control system will contain the following elements:

I Operator Station Hardware Components.

1. Subsystem supervisory processor - 3.
2. Operator color CRT display(s) - 4.
3. Audible alarms(s) - 1
4. Hardcopy data logger(s) - 2
5. Time of day clock - 1
6. Console - 5
7. Data bus interface controller - 5
8. Sequence of events recorder - 1
9. Mass storage disk(s) and coltroller(s) - 5
10. Strip charts - 4

II Field Process Control Electronics.

A. Receiver Subsystem

1. PID controller processors - 1
2. Digital input controller module(s) - 1
3. Digital output controller module(s) - 2
4. Analog input controller module(s) - 4
5. Analog output controller module(s) - 3
6. Data bus interface controller - 1
7. Power supply - 1
8. Termination panel - 1

B. Collector Subsystem

1. Heliostat control processors - 2
2. Heliostat controllers - 8411
3. Incremental encoder circuit assemblies - 8411
4. Mother board circuit assemblies (for HFC) - 33
5. Heliostat field controllers - 263
6. Cabling harnesses - 8411
7. Data bus interface controller - 2
8. Power supply - 2
9. Termination panel - 2

C. Thermal Storage and Steam Generation Subsystem

1. PID controller - 1
2. Digital input controller modules - 2
3. Digital output controller modules - 2
4. Analog input controller modules - 3
5. Analog output controller modules - 2
6. Data bus interface controller(s) - 1
7. Power supply - 1
8. Termination panel - 1

D. Interface Control Subsystem

1. PID controller processors - 1
2. Analog input controller module(s) - 1
3. Analog output controller module(s) - 1

4. Data bus interface controller - 1
5. Power supply - 1
6. Termination panel - 1

E. Interlock Logic System

1. Programming unit - 1
2. Data bus interface controller
3. Digital input controller module(s) - 4
4. Digital output controller module(s) - 2
5. Analog input controller module(s) - 4
6. Analog output controller module(s) - 2
7. Power supply - 1
8. Termination panel - 1

III Heliostat Aimpoint Alignment Subsystem Components.

1. Camera(s) and amplifier(s) - 1
2. Target(s) - 1
3. Power supply - 1
4. Termination panel - 1
5. Video monitor - 1
6. Alignment processor - 1
7. Analog input controller module(s) - 2
8. Digital output controller module(s) - 1
9. Operator color CRT display - 1
10. Mass storage disk and controller - 1

3.6 FOSSIL ENERGY SUBSYSTEM

3.6.1 Interface

The fossil energy/solar interfaces are shown on Figure 3.1. The piping and valves used in the solar energy feed system will be made from the same materials as are presently used on the fossil energy system and will be in accordance with the applicable sections of the ASME Boiler Code. Safety vent and relief capability will be incorporated into the solar steam system as appropriate.

The operational interfaces between the fossil and solar systems will include the following, as shown in Figure 3.1.

a. Feedwater supply
b. High pressure turbine inlet
c. Reheater inlet - high pressure turbine outlet
d. Intermediate turbine inlet
e. Master control and instrumentation
f. Auxiliary electric power to solar field

3.7 ENERGY STORAGE SUBSYSTEM

The Thermal Storage Subsystem receives hot receiver fluid at the flow rate governed by the receiver power level. The subsystem supplies heat transfer fluid to heat exchangers and generates steam at state points and rates demanded by the Power Generating Plant. Heat input from the receiver in excess of the Power Generating Plant demand is stored in the Thermal Storage Subsystem. Excess demand by the Power Generating Plant over the heat available from the receiver is made up from stored heat in the Thermal Storage Subsystem.

The Thermal Storage Subsystem will include the following items:

a. Hot storage tank
b. Cold storage tank
c. Hot and cold salt pumps and piping
d. Tank ullage and control system
e. Tank heaters/trace heaters

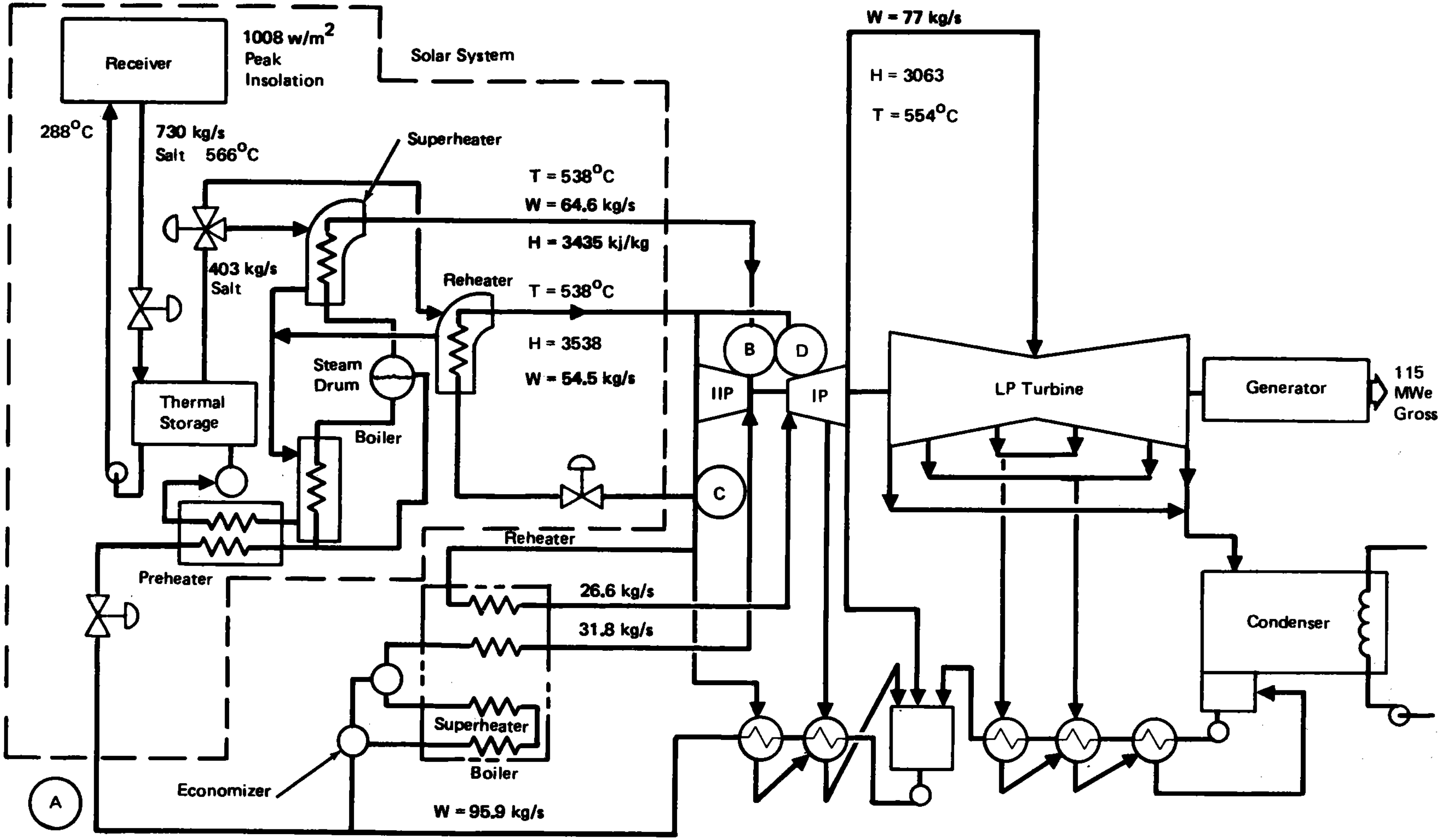

Figure 3.1. Interfaces

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f. Level sensing instrumentation
g. Preheater (Solar)
h. Evaporator/steam drum (Solar)
i. Superheater (Solar)
j. Reheater (Solar)
k. Foundation
l. Insulation
m. Operation/monitoring instrumentation
n. Salt clean up system
o. Salt loading/liquefication system
p. Salt drainage sump/sump pump

3.7.1 Operations

There are only three operating modes required for the Thermal Storage Subsystem.

3.7.1.1 Charging/Discharging Operation

In this mode, the Thermal Storage Subsystem receives heated fluid from the receiver at a rate ranging from no flow up to the maximum capability of the receiver. Steam is dispatched to the turbine at rates ranging from no flow up to the maximum design output of the steam generators. The Thermal Storage Subsystem shall be capable of charging and discharging independently.

3.7.1.2 Hot Standby Operation

When the thermal storage unit is depleted, or is otherwise in an extended period of hot standby, the Thermal Storage Subsystem will maintain the steam generating heat exchangers in hot standby condition and provide blanketing and sealing steam to the Power Generating Plant, as required. Trace heating will be supplied, as required, to prevent freezing of the receiver working fluid.

3.7.1.3 Transitions

In transitioning from Charging/Discharging to Hot Standby, the steam flow rate from the Thermal Storage Subsystem must be reduced in a controlled manner which allows the Power Generation Plant to increase fossil steam generation and maintain constant load. The nominal duration of this transition is 30 minutes.

3.7.2 Design

The thermal storage system will consist of a thermal storage unit (TSU) and a steam generation unit. The specific requirements of these units follows:

a.	Storage capacity	1150 MWH_{th}
b.	Type	Two tank - hot and cold
c.	Receiver fluid	Partherm 430
d.	Field Quantity	9.72×10^6 Kg (21.43×10^6 lb)
e.	Hot fluid temperature	566°C (1050°F)
f.	Cold fluid temperature	288°C (550°F)
g.	Pressure	690 ± 690 Pa (.1 ± .1 P SIG)
h.	Charging Rate - Max.	330 MW_{th}/HR
i.	Discharging Rate - Max.	220 MW_{th}/HR
j.	Thermal Leakage Rate	1% per day
k.	Track heating rate-max	1.2 MW (2×10^6 BTU/HR)
l.	Ullage volume (fully charged)	5%
m.	Ullage medium	Dry air

3.7.2.2 Steam Generation Unit

a. Preheater

1.	Type	Counterflow	Tube and Shell
2.	Heat Exchanger area - min.	1560 M^2	(16795 ft^2)
3.	Weight - max. (wet) - max. (dry)	60300 kg 32000 kg	(133000 lbs) (70000 lbs)
4.	Heat Exchanged (rated)	34.69 MW	(118.4×10^6)
		Shell Side	Tube Side
5.	Fluids	Paratherm 430	Water
6.	Temperature - inlet	340.6°C (645.1°F)	237.8°C (460°F)
7.	Pressure	2068 KPPG (300 PSIG)	15512 KPag (2250 PSIG)
8.	Temperature - outlet	287.8°C (550°F)	335.8°C (635.8°F)
9.	Flow rate - max.	423.86 Kg/Sec	64.9 Kg/Sec

		$(3.364 \times 10^6$ lbs/Hr	(515,290 lbs/Hr)
10.	Flow rate - min.	103.8 Kg/S (824,000 lbs/hr)	16.23 Kg/s (128,800 lbs hr)
11.	Thermal efficiency - min	99.9%	

b. Evaporator

1.	Type	Parallel flow	Tube and Shell
2.	Heat exchanger area-min.	1381.7 M^2	(14873 ft^2)
3.	Thermal efficiency-min	99.9%	
4.	Weight-max (wet) -max (dry)	96000 Kgs 60000 Kgs	(217,900 lbs) (133000 lbs.)
5.	Heat Exchanger	70 MW	$(239 \times 10^6$ BTU/HR)
		Shell Side	Tube Side
6.	Fluids	Partherm 430	Water/Steam
7.	Temperature - inlet	447.4°C (837°F)	335.5°C (635.8°F)
8.	Pressure	2068 KPag (300 Psig)	15340 KPag (2225 PSig)
9.	Temperature - outlet	340.6°C (645.1°F)	335.5°C (635.8°F)
10.	Flow Rate - max.	423.86 Kgs/Sec $(3.364 \times 10^6$ lbs/ hr	64.93 Kgis (515,300 lbs/hr)
11.	Flow Rate - min.	103.8 Kg/s (824,000 lbs/hr)	16.23 Kg/s (128,800 lbs/hr)

c. Superheater

1.	Type	Parallel Flow	Tube and Shell
2.	Heat Exchanger area-min.	810.7 M^2	(8726.6 ft^2)
3.	Thermal efficiency-min.	99.9%	
4.	Weight - max. (wet) (dry)	31000 kg 18500	(70000 lbs) (41000 lbs)
5.	Heat Exchanger (rated)	51.1 MW	(174.3×10^6) (BTU/HR)
		Shell Side	Tube Side
6.	Fluids	Partherm 430	Water/Steam
7.	Temperature	562.8°C(1045°F)	335.5°C (635.8°F)

8.	Pressure	2068 KPag (300 PSIG)	15340 KPag (2225 PSIG)
9.	Temperature - outlet	447.4°C (837.2°F)	
10.	Flow Rate-Max.	285.64 Kg/Sec (2.267×10^6 lb/hr)	4.6 Kg/Sec (512730 lb/hr)
11.	Flow Rate - min.	44.6 Kg/s (354,000 lb/hr)	16.15 Kg/s (128,200 lb/hr)

d. Reheater

1.	Type	Counterflow	Tube and Shell
2.	Heat Exchanger area-min.	629.5 M^2 (6775.5 Ft^2)	
3.	Thermal efficiency-min.	99.9%	
4.	Weight-max (wet) (dry)	22000 Kgs (48500 lbs) 12900 Kgs (28500 lbs)	
5.	Heat Exchanged (rated)	24.7 MW (84.36×10^6 BTU/HR)	
		Shell Side	Tube Side
6.	Fluids	Partherm 430	Steam
7.	Temperature	562.8°C(1045°F)	341.1°C(646°F)
8.	Pressure	2068 KPag (300 PSIG)	3964 KPag (575 PSIG)
9.	Temperature-outlet	447.4°C (837.2°F)	540.6°C (1005°F)
10.	Flow Rate- max	138.2 Kg/Sec (1.097×10^6 (lbs/hr)	54.54 Kgs/Sec (432,850 Lbs/Hr)
11.	Flow Rate - min	24.5 Kg/s (194,500 lbs/hr)	13.63 Kg/s (108,200 lb/hr)

3.8 ELECTRICAL POWER GENERATING SUBSYSTEM

The present EPGS at Ft. Churchill No. 1 will be unchanged except for the following items.

3.8.1 Solar/Fossil Mechanical Interfaces

The solar/fossil interfaces are shown on Figure 3.1.

3.8.2 Electrical Power in Solar Field

The auxiliary electrical power equipment required by the Solar Field and Master Control System are:

Electrical Equipment List

12 Switchgear Units, 4.16 KV, 1200 ampere, 250 MVA
1 Load Center consisting of:
  - 1 Transformer, 750 KV OA, 65°C rise, 4160-480 volt, 3 phase
  - 1 Circuit Breaker, power, 600 volt, 1600 ampere
  - 3 Circuit Breakers, power, 600 volt, 800 ampere

1 Motor Control Center
4 Transformers, pad mount, 3 phase, 500 KVA, 4160-208 V/120 volt, for heat tracing
50 Transformers, pad mount, 3 phase, 500 KVA, 4160-208 V/120 volt, for heliostat field.

Lot Lighting and Power Panels

1 Emergency Engine Generator, 900 KW (diesel)
1 Battery, lead acid, 60 cell, 125 V, 400 amperes hours
1 Battery Charger 480 VAC, 125 VDC, 50 amperes
1 Uninterruptible system, 45 KVA, 120/208 V, 3 phase, 125 VDC, consisting of inverter, blocking diode, rectifier power supply, and solid state transfer switch.

This equipment will provide power for:

a. Solar field operation
b. Solar field control
c. Receiver fluid pumps and control
d. Heat exchanger hot salt fluid pumps and control
e. Emergency backup power

3.9 SERVICE LIFE

The solar equipment to be added to repower the SPPCO. Ft. Churchill, Unit No. 1 shall have a design service life of 30 years.

3.10 RELIABILITY/AVAILABILITY

The design should be such that the plant will start up satisfactorily and operate with minimum forced outages attributable to design deficiencies and hardware failures.

The solar equipment shall be designed to a 94.4% availability of generation of rated steam, exclusive of insolation conditions. The preliminary unavailability allocation is:

Subsystem	Forced Outage (%)	Planned Outage (%)
Collector	0.01	0
Receiver	1.17	1.4
Thermal Storage	2.78	1.4
Master Control	0.1	0
Facilities	0.23	1.15
Total	34.29	3.55
*Adjust Planned Outages	4.29	1.28
Total Unavailability - 5.6%		
Total Availability - 94.4%		

*Note: Planned outages will be scheduled for simultaneous accomplishments 64% of the time. Therefore, only 36% of planned outage is charged to the solar equipment.

3.11 MAINTAINABILITY

The solar equipment shall be designed to a MTTR as follows:

Subsystem	*MTTR (Hours)
Collector	4
Receiver	4
Thermal Storage	26
Master Control	1
Facilities	9

*Note: Mean Time To Repair (MTTR) is based exclusively on critical failures.

3.12 SPECIALIZED EQUIPMENT

The following items of specialized equipment will be required.

a. Mobile installation machine for heliostat drive system/pedestal installation. This unit will consist of a special support/alignment crane fixture mounted on a four wheel vehicle. This vehicle will have tire loading valves low enough to permit vehicle operation on the normal site terrain (sandy) without requiring special preparation of the surface soil.

b. Mobile installation machine for the heliostat mirror panel assemblies. This unit will consist of a special support/alignment crane fixture mounted on a four wheel vehicle. This vehicle will be capable of carrying 2 (or more) mirror panels from the railroad siding to the heliostat pedestal location. This vehicle will have tire loading values low enough to permit the vehicle to operate on the normal site terrain without requiring special soil preparation.

c. Mobile heliostat washing machines. Two separate heliostat washing machines will be mounted on two trucks. The first truck will spray a conditioning/cleaning fluid on each heliostat mirror surface, then the second truck will spray deimized water on the mirror panels. The two trucks shall be capable of washing 5600 heliostats in a normal working month, and will wash the 8411 heliostats at Ft. Churchill in intervals of approximately six weeks.

d. Freeze protection heater. A gas fired salt heater will be utilized as the primary freeze protection device for the hot salt system. This heater will be located in the piping of the thermal storage system. It will be designed to operate in two operating modes. The primary operating mode will consist of heating a recirculating flow of hot salt from the cold tank through the hot tank and back to the cold tank. This heater will operate as a tank preheater during the original salt loading operation. This last function will be accomplished by ducting the hot stack gases from the heater through each storage tank and out through the tank vent just prior to the initial charging of the salt into the storage tank system.

The gas heater will have a rating of 176 KW (6 x 10^6 BTU/HR) and it will include a self contained forced air flow.

3.13 SPECIALIZED REQUIREMENTS

3.13.1 Transportability

Sizing and Weight Limitations

System elements shall be designed for transportability with applicable Federal and State regulations by highway and railroad carriers using standard transport vehicles and materials handling equipment.

3.13.2 Human Engineering

The system shall be designed to facilitate manual operation, adjustment, and maintenance as needed, and to provide the optimum allocations of functions for personnel or automatic control. MIL-STD-1472, Human Engineering Design Criteria, shall be used as a guide in designing control stations and equipment.

3.13.3 Logistics

a. Operating and Maintenance Personnel

Operation and maintenance personnel requirements shall be satisfied by contractor personnel and from the established servicing or utility labor pools.

b. Training

System uniqueness and utility interfaces dictate a need for training, but do not establish a need for new skills or trades. The types of training and number of personnel requiring training shall be determined for each major subsystem.

c. Documentation

Documentation of subsystem design, performance, operating, test characteristics, instructions, construction drawings, procedures and parts lists and related information shall be prepared for each subsystem.

d. Spares and Interchangeability

Consideration for spares and interchangeability shall be given for common items such as heliostat reflective panels, drive instrumentation, wiring, connectors, attachment bolts, support brackets, etc. Components with common functions shall be produced with standard tolerances and connector locations to permit interchange for servicing. Quantities of spares and repair parts to be available shall be specified for each subsystem.

e. Maintenance

Servicing at the site will be preferred for all permanently installed equipment. Minor plant equipment (such as instrumentation, valves, heaters, fluid lines, electrical lines, switches, etc.) will be serviced at the site using standard equipment and parts.

Maintenance activities shall be categorized as follows:

Level 1 - On-line maintenance
Level 2 - Off-line, on-site maintenance
Level 3 - Off-line, off-site maintenance.

Maintenance actions for each subsystem shall be identified, and a maintenance plan for the solar equipment shall be prepared.

f. Field Installation

Installation of the subsystems at the field site shall be accomplished using standard transportation and handling equipment (including the possible use of helicopters for receiver assembly installation). Component breakdown shall be such that the equipment and labor for field installation (structural, fluid, electrical, instrumentation and control interfaces) are minimal.

The system shall be installed so as to minimize susceptability to electromagnetic interference and to minimize the generation of conducted or related interference. Also, plant operation shall not be adversely affected by external or internal power line transients caused by normal switching or fault clearing.

3.13.4 Safety

The safety requirements for the solar and solar/fossil hybrid systems shall meet the intent of SAN 0501-01 "Pattern of Health and Safety REsponsibilities" April 21, 1976. To implement this objective, the applicable portions of "System Safety Plan (RADL 2-24), SAN/0499-6, June 1979 (10 MWe Solar Thermal Central REceiver Pilot Plant") will be applied to the Solar Repowering program.

Section 4
ENVIRONMENTAL CRITERIA

4.1 PLANT ENVIRONMENT DESIGN REQUIREMENTS

4.1.1 Operating Environment

The repowered plant shall be capable of operating in and surviving appropriate combinations of the following environments.

a. Temperature: The solar plant equipment shall be able to operate in the ambient air temperature range from -9 to 50°C (16 to 122°F). Performance requirements shall be met throughout an ambient air temperature range of 0 to 50 °C (32 to 122°F).

b. Wind: The plant shall be able to operate in winds up to 15.5 m/s (35 mph). Performance requirements shall be met for winds up to 15.5 m/s (35 mph) throughout the temperature range from 0 to 50 °C. Wind analyses shall satisfy the requirements of ANSI A58.1-1972.

   The above wind speeds are at a reference height of 10m. Wind speed at other heights are determined from $V/V_{10} = (Z/10)^{0.15}$.

4.1.2 Survival

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

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

b. Wind rise rate: A maximum wind rise rate of .01 m/s^2 (.02 mph/sec shall be used in calculating wind loads during heliostat stowage. In addition, the plant should withstand, without catastrophic failure, a sudden wind of 22 m/s (50 mph) from any direction, such as might result from severe thunderstorm gust fronts.

c. Sand/dust: The plant shall be able to operate after a dust storm with maximum dust flux up to 10^{-4} grams/cm^2/sec, particle sizes of 50 micrometers or less, for durations of up to 36 hours, and at wind speeds up to 18 m/s.

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

e. Snow: The plant shall survive a static snow load of 250 Pa (5 lb/ft^2) and a snow deposition rate of (.3) m (1 ft) in 24 hours.

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

Average annual - (135 mm) (5.3 in)

Maximum 24-hr rate - (52 mm) (2.05 in)

g. Ice: The plant shall survive freezing rain and ice deposits in a layer 50 mm (2 in) thick.

h. Earthquake: Peak ground accelerations shall be as presented below per applicable UBC zone. This peak ground acceleration is combined with the response spectrum given by NRC Reg Guide 1.60 and the damping values given for the operating base earthquake in NRC Reg Guide 1.61. Zone III values should be used for the baseline design

Maximum Survival Ground Accelerations

UBC Zone	Peak Ground Acceleration Average or Firm Conditions
III	0.2 g horizontal 0.05 g vertical

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

Diameter: (25 mm) (1 in)

Specific Gravity: 0.9

Terminal Velocity: (23 m/s) (75 fps)

4.2 ENVIRONMENTAL STANDARDS

4.2.1 Air Quality Standards

The Air Quality Standards are listed in section 2.4.

4.2.2 Water Quality Standards

The Water Quality Standards are listed in section 2.4.

Section 5
CONCEPTUAL DESIGN DATA

This section presents the conceptual design data used to establish the baseline cost estimates and additional data covering the material presented in Sections 1-4 but which are not formal requirements of this specification.

5.1 SOLAR PLANT CHARACTERISTICS AND PERFORMANCE

The following data will be used in determining the technical characteristics and related plant performance for the Solar repowered utility plant.

5.1.1 Collector Data

The collector subsystem consists of a collector field of 1.99 x 10^6 m^2 area which contains 8411 heliostats. The control system will include:

- 8411 Heliostat Controls (HC)
- 263 Heliostat Field Controllers (HFC)
- 1 Heliostat Array Controller (HAC)
- 2 Power Supplies
- 8411 Field Wiring Harness
- 2 Data Bus Interface Controllers

The collector field is located to the west and north of the plant as shown on the plot plan (Figure 5.1).

5.1.1.1 Collector Field Layout

The collector field is located north of the tower and is a 128° north field layout shown in Figure 5.2. The collector field was optimized in a radial staggered layout. The optimization was conducted for 40 individual cells. The optimum number of heliostats for each cell is shown on this illustration. The location of the 277 heliostats in a typical cell is shown on Figure 5.3.

5.1.1.2 Aim Strategy

The collector field is divided into four separate zones which have different aim strategies. These four zones were shown on Figure 1.3.

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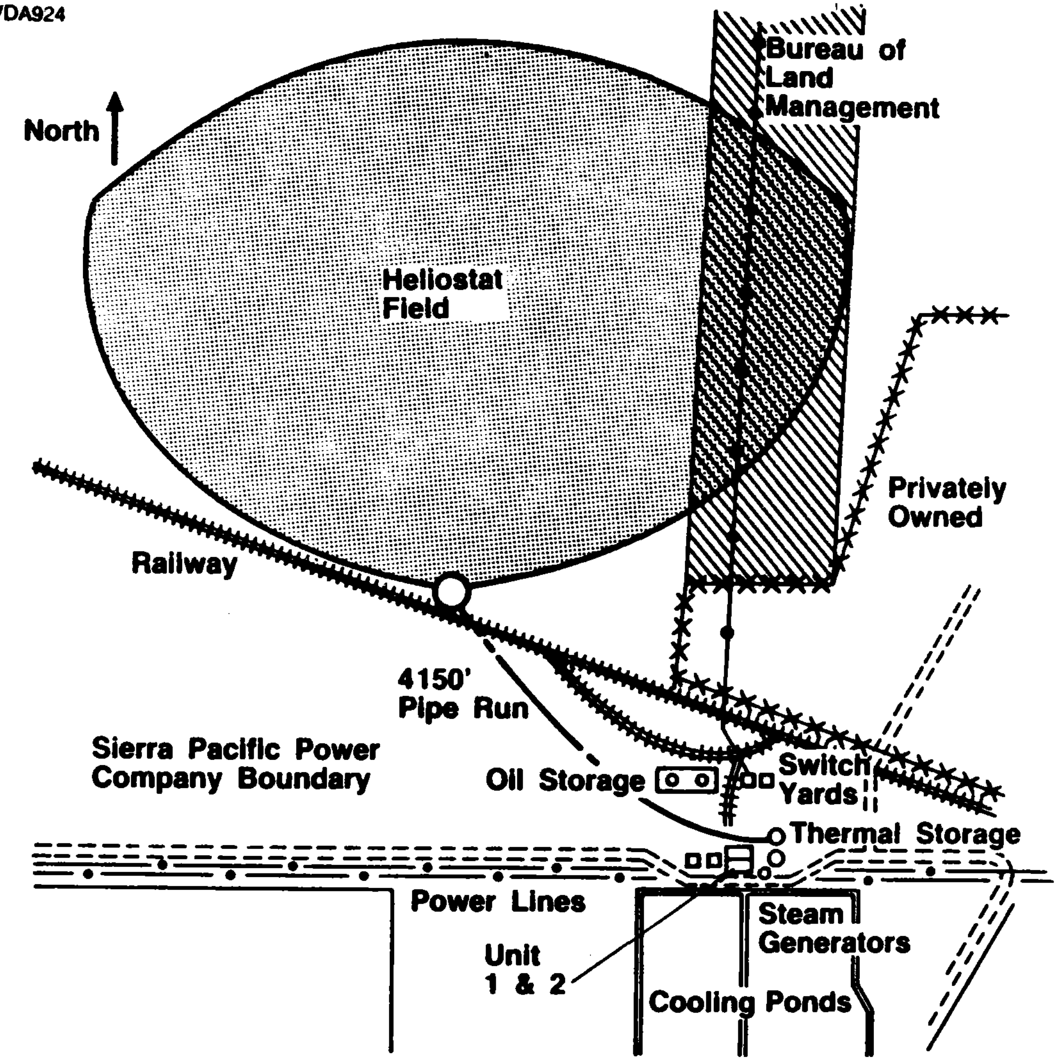
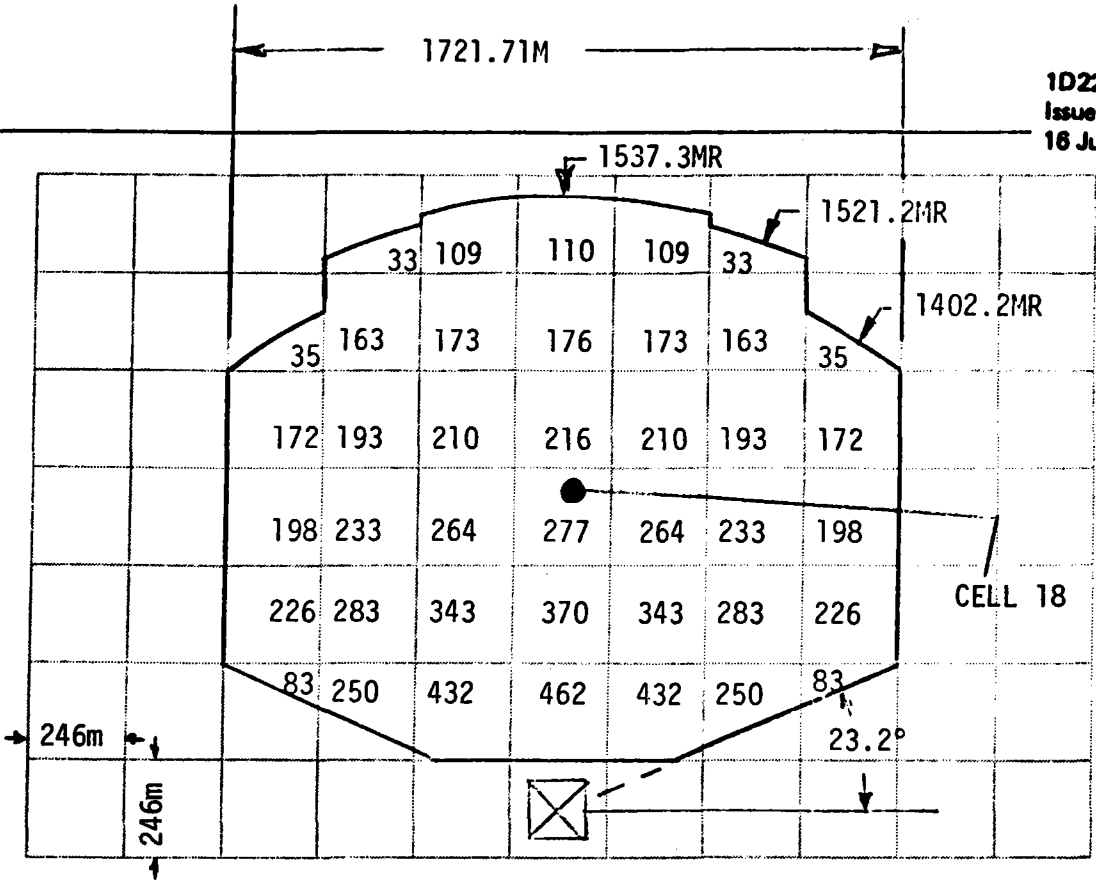
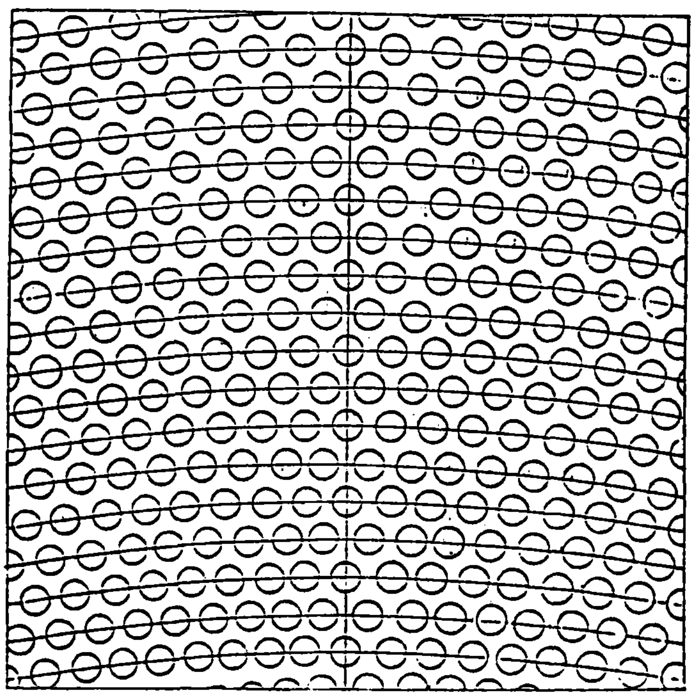


Figure 5.1 Plot Layout



5.2 Collector Field Layout



5.3 Heliostat Spacing in Cell 18

Each zone contains the following number of heliostats:

Zone 1	2640 Heliostats
Zone 2	2438 Heliostats
Zone 3	897 Heliostats
Zone 4	897 Heliostats

5.1.1.3 Heliostats

The heliostat selected for this application is based on the DOE Second Generation Design. Each heliostat contains 56.4 m^2 of reflector mirror area. Normal stow is with the reflector surface vertical. Survival stow for high winds is with the reflector face up. Inverting stow is not provided.

The electrical requirements for these heliostats are estimated to be as follows:

	(Each)		Total Power	
	Power Watts	Volts Amps	Kilowatts	Kilovoltamp
a) Tracking Mode				
Motors	2 watts	3VA		
Electronics	33 watts	69VA		
Total	35 watts	72VA	294 KW	605 KVA
b) Slew Mode (Emergency Defocus)-Sequential Program				
Motors	302 watts	432VA		
Electronics	33 watts	69VA		
Total	335 watts	501VA	800 KW	1196 KVA
c) Stow Mode, Normal				
Motors	624 watts	864VA		
Electronics	33 watts	69VA		
Total	657 watts	933VA	131 KW	186 KVA
d) Stow Mode, Emergency, High Wind				
Motors	347 watts	480VA		
Electronics	33 watts	69VA		
Total	380 watts	549VA	798 KW	1153 KVA

The heliostats will be mounted on tapered concrete pedestals. The details of this heliostat design (shown on Figure 5.4) include the following:

Mirror Module

1.23 m x 3.38 m Glass cut - 2.36 mm Float mirrored - 4.76 mm Back light.

PVB Pinched rolled - autoclaved to white backing paint

Painted Hot Sections - bonded to primed back light

Galvanized Edge Member with butyl/silicone

Silicone Grommet

Butyl/Silicone Beads

Reflector Support Structure	
Beam thickness	2.75 mm
Material	Galvanized Steel
Main Beam	
Size	.41m x .506 Box ~1.57 m Long
Material	Galvanized Steel
Pedestal	
Size	.0508 m OD Tube ~ 3.61 m Long
Fit.	Slip fit 1.22 m, flare
Estimated Weights	
Mirror Modules	1206 Kg
Support Structure	773
Dual Units	192
Pedestal	218
Total	2389

5.1.1.4 Collector Field Performance

The estimated collector field performance is shown on Figures 5.5 - 5.8.

5.1.2 <u>Receiver Data</u>

5.1.2.1 Description

The receiver shall be an omega-shaped, partial cavity design consisting of two (2) external wing panels, ten (10) internal side panels, and eight (8) internal

REFLECTOR SHAPE	RECTANGULAR (8.66 M x 6.87 M)
MIRROR AREA	56.42 M^2
NUMBER OF MIRROR MODULES	14
MIRROR MODULE SIZE	1.22 M x 3.35 M
REFLECTIVITY	0.87 - 0.92 (DEPENDANT ON IRON CONTENT AND OXIDATION STATE)
REFLECTOR CONFIGURATION	CANTED AND FOCUSED
BEAM ERROR (AS USED IN PERFORMANCE CALCULATIONS)	2.83 MR
SLEW RATE	15 DEGREES/SEC.
DRIVE	AZIMUTH: HARMONIC DRIVE; ELEVATION: LINEAR ACTUATORS
CONTROL SIGNAL DISTRIBUTION	HARD WIRE

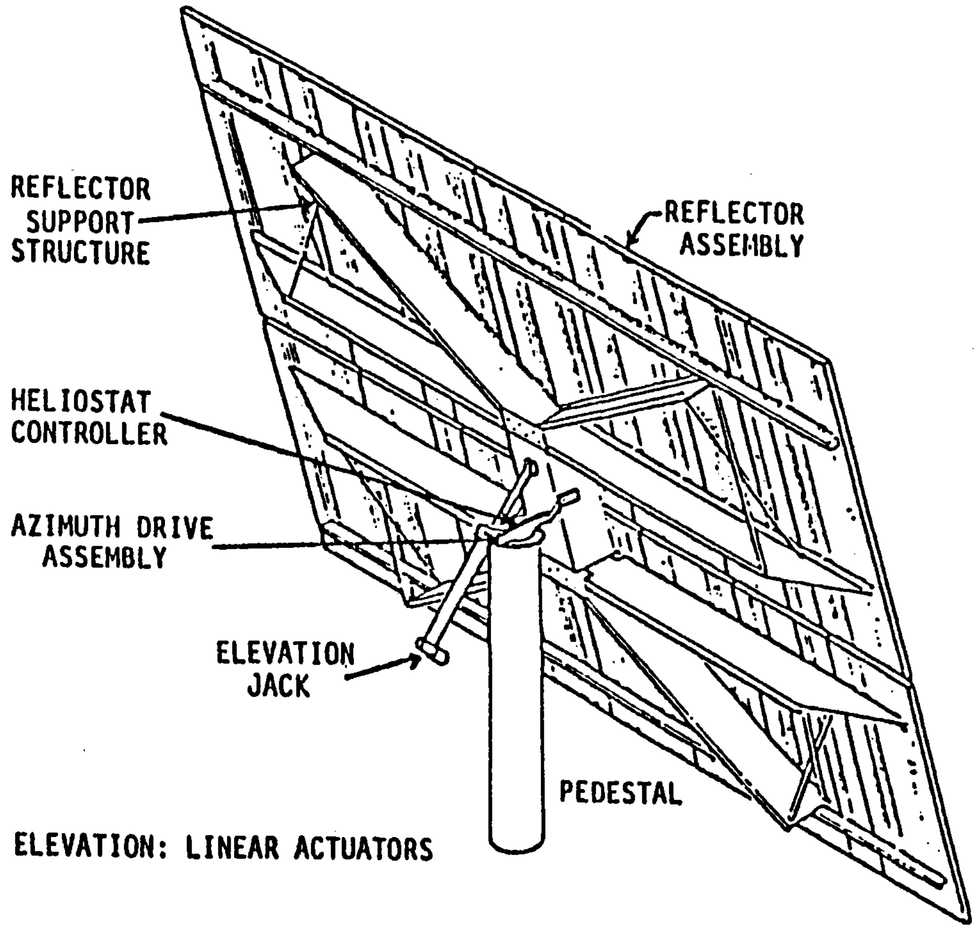


Figure 5.4 MDAC Second Generation Heliostat

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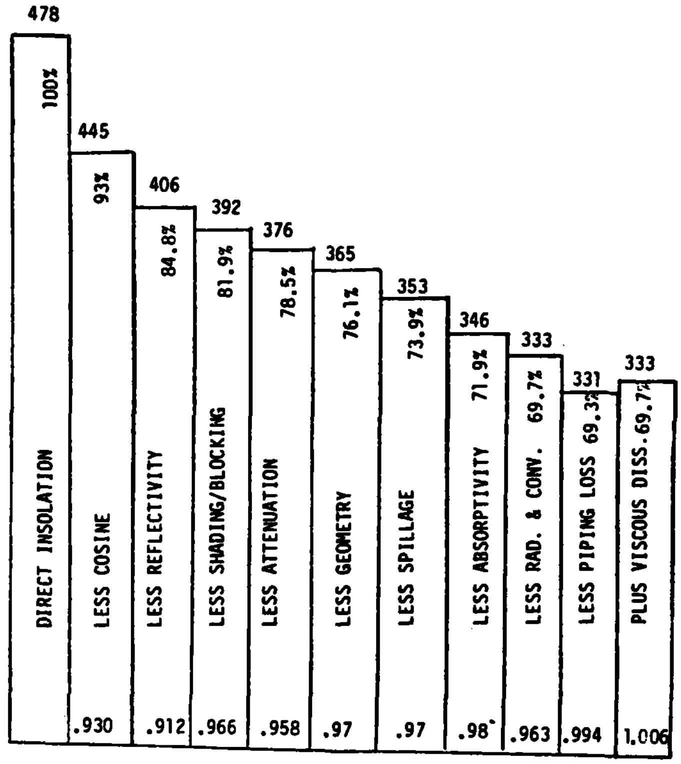


Fig. 5.5 Design Point--Spring Equinox

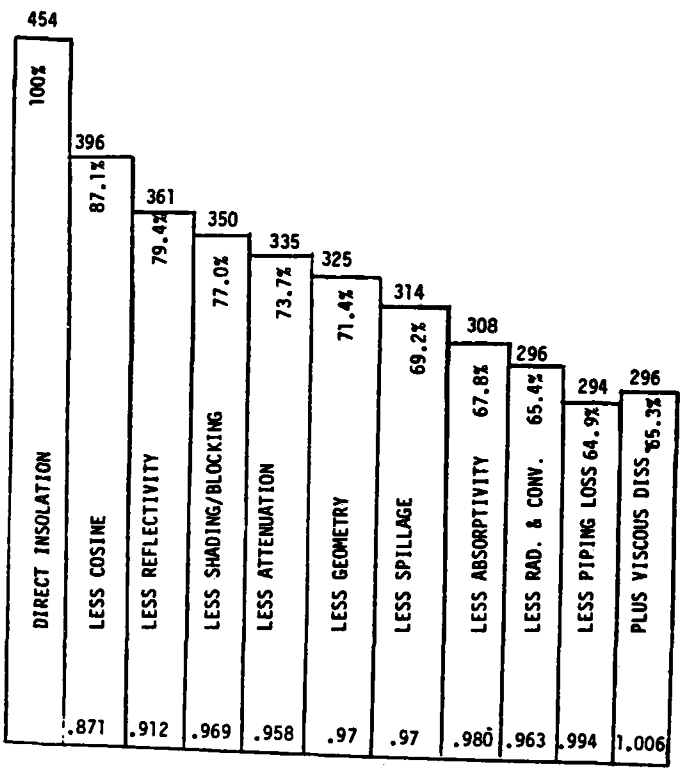


Fig. 5.6 Summer Solstice Noon Performance

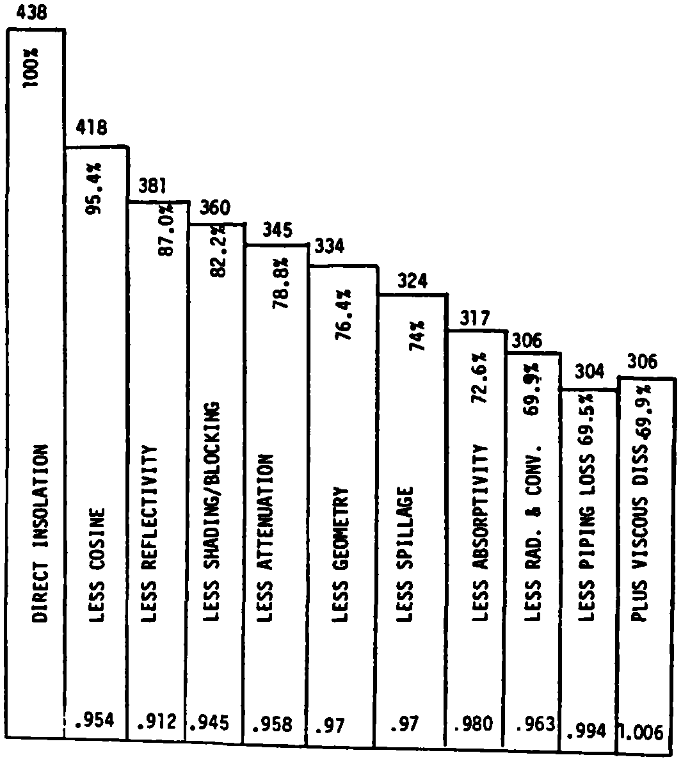


Fig. 5.7 Winter Solstice Noon Performance

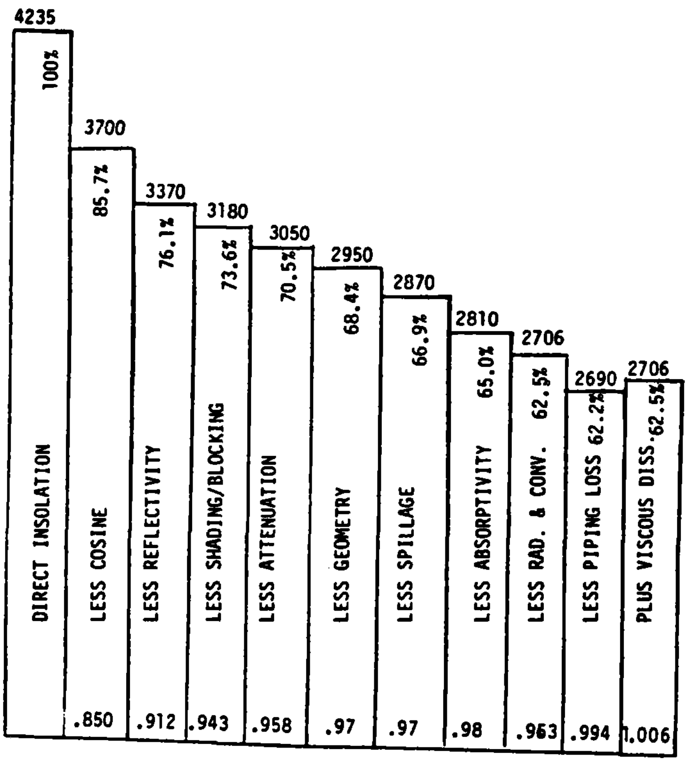


Fig. 5.8 Clear Day Annual Average

rear panels. The aperture plane shall be tilted 25° from vertical to face the north collector field. Molten salt entering the receiver will be heated from 288°C (550°F) to 566°C (1050°F). The design point (equinox noon) thermal rating of the receiver is 330 MW_{th}.

The absorber portion of a receiver panel consists of 25.4 mm (1.0 in.) O.D. Incoloy 800 tubes with 1.65 mm (0.065 in.) minimum wall thickness. The tubes are parallel, in plane, and continuously welded to the adjacent tubes on 25.4 mm (1.0 in.) centers. The heated length of each panel is 26 m (85.3 ft.) Panel widths vary from 2.34 m (7.67 ft.) to 3 m (9.84 ft.)
The heated face of each panel is coated with a high temperature absorptive paint (Pyromark).

Panel	Width	No. of Tubes
L1, R1	3 m	118
L2, L3, L4, L5, L6	2.4 m	94
R2, R3, R4, R5, R6	2.4 m	94
L7, L8, L9, L10	2.34 m	92
R7, R8, R9, R10	2.34 m	92

Panels are grouped in a four (4) pass arrangement. Low temperature inlet passes 1 and 2 are positioned toward the front of the receiver, while high temperature passes 3 and 4 are positioned toward the rear of the receiver to minimize ambient heat losses. Outlet pass 4, with the highest salt temperature, was positioned in the rear portion of the receiver with the lowest peak heat flux levels (panels L7, L8, R7, R8).

The arrangement of the receiver circuitry is schematically illustrated in Figure 5.9. The arrangement was designed for salt to flow up through each panel. The left and right halves of the receiver operate as independent parallel flow circuits with the flow through each dependent upon the total heat absorbed in the respective half of the receiver. Pass 1 and pass 2 of each circuit have three (3) uncontrolled parallel flow panels. Each pass 1 and pass 2 tube in a given circuit receives approximately the same salt flow. Flow leaving the pass 1 and pass 2 panels mix in a downcomer which delivers salt at a uniform

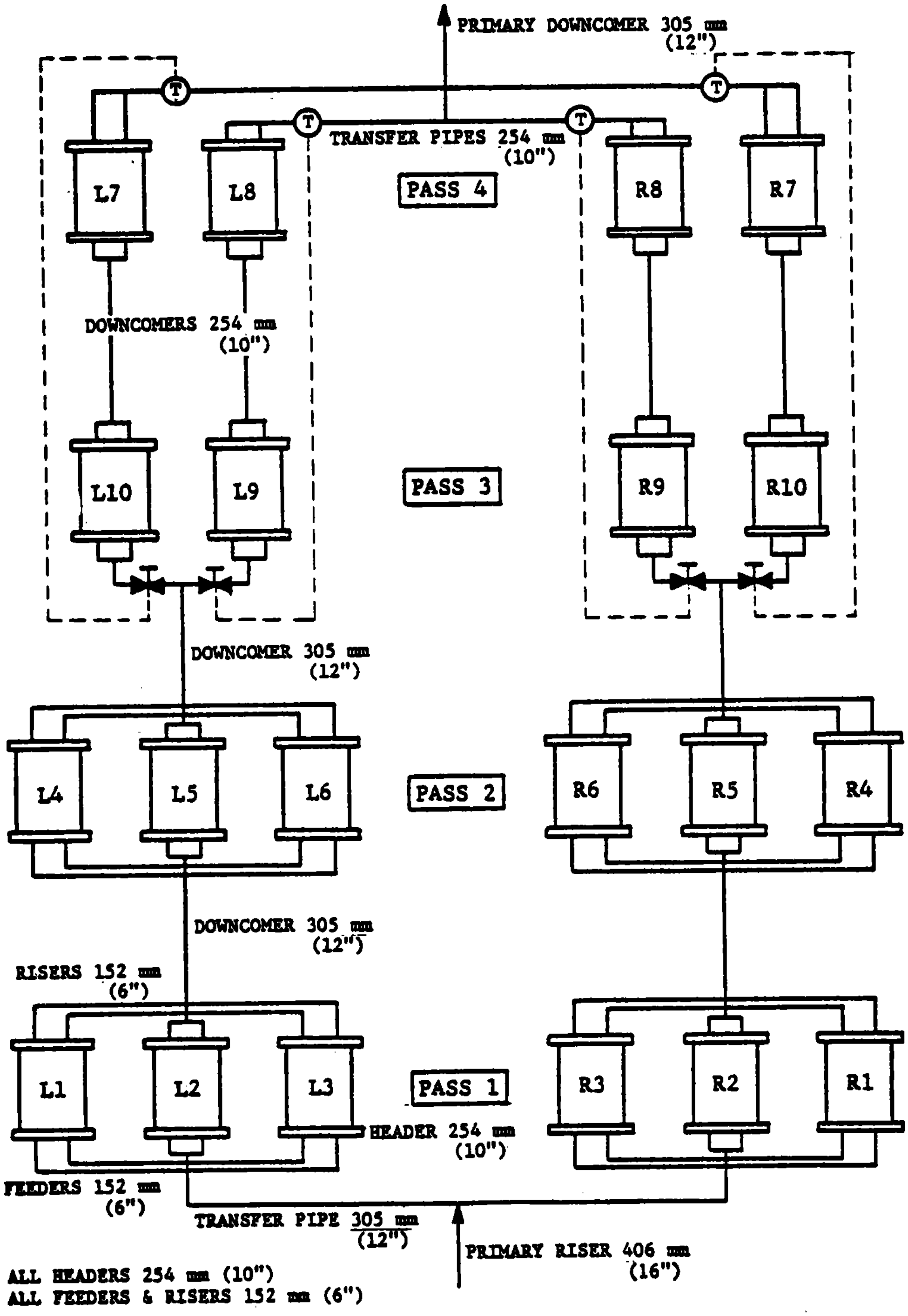


Figure 5.9 Receiver Circuitry Arrangement

temperature to the downstream panels. Pass 3 of each circuit has two (2) panels in parallel connected in series to specific pass 4 panels. The salt flow rate through each series of panels is controlled to maintain the leaving salt temperature at 566°C (1050°F). High absorption panels in pass 3 were connected in series to low absorption panels in pass 4 in order to minimize the variation in flow rate through each of the outlet pass panels.

All headers, feeders, and risers are 0.254 m (10 in.), 0.152 m (6 in.) and 0.152 m (6 in.) schedule 40 pipe, respectively. Sizes were selected to minimize header flow imbalance, pressure drop, and length required for flexibility. The layout of all interconnecting salt piping is illustrated in Figure 5.10. The piping layout was arranged so that the system is completely drainable.

The receiver floor and roof are uncooled relective surfaces, insulated from behind. For the purpose of the conceptual design study, a waffled 304 stainless steel floor and roof (supplied by Glitsch Cryogenics) were selected since a surface is required that can expand within the bounds of the receiver panels.

All panels, headers, and interconnecting salt piping are electrically trace heated to preheat and maintain the receiver circuitry at a temperature of 287.8°C (550°F). A four (4) panel door assembly is provided to minimize ambient heat losses when the unit is not in operation. The receiver panels are insulated with calcium silicate. This arrangement was selected in order to provide personnel protection as well as minimize ambient heat losses. All insulation is covered with aluminum lagging.

The receiver headers and valve sizes are shown on Figure 5.9 and Figure 5.10. The central valves will be of stainless steel construction and suitable for continuous operation at 588°C. The receiver shall be designed to meet the standards for a non-boiler type solar receiver. The receiver shall operate and survive under the environmental conditions listed in Section 4. The absorptivity and emissivity factors for the surface coatings on the absorber panels shall equal or exceed the values for the Pyromark coating.

5.1.2.2 Performance

Significant receiver performance characteristics include the following:

- o The receiver design point is equinox noon with 330 MW_{th} absorbed, heating 767 kg/sec (6.09 x 10^6 lb/hr) of molten salt from 288°C (550°F) to 566°C (1050°F).

- o Heat absorbed in each receiver panel was determined from the product of the receiver panel flat projected heated area and the panel's average absorbed heat flux obtained from Figure 5.11 for equinox (noon and 4:00 p.m.) and from Figure 5-12 for winter solstice 9:00 a.m.).

The predicted receiver flux map is shown in Figure 5.13 for the design point condition. The desired receiver efficiency values are shown on Figure 5.14. The receiver shall be designed with a peak metal temperature of 760°C, a working stress limit of 308,070 KPa, for 20,000 cycles and with an estimated life of 100,000 hrs.

5.1.3 Receiver Tower and Foundation

a. Design Characteristics - The tower that supports the receiver, piping, and other elements of the receiver subsystem shall be designed in accordance with the following design and operating requirements:

1. Support a receiver subsystem weight of 10^6 Kgs, and provide access for maintenance and inspection of the receiver, instruments and controls, piping and other equipment mounted on tower.

2. Provide aircraft warning lights and lightning protection as required.

3. Evironmental design data.
   Design Wind per Section 4.
   Design Seismic per Section 4.

4. Soil data.
   Design Bearing Capacity -- .24 MPa (5000 lb/ft^2)

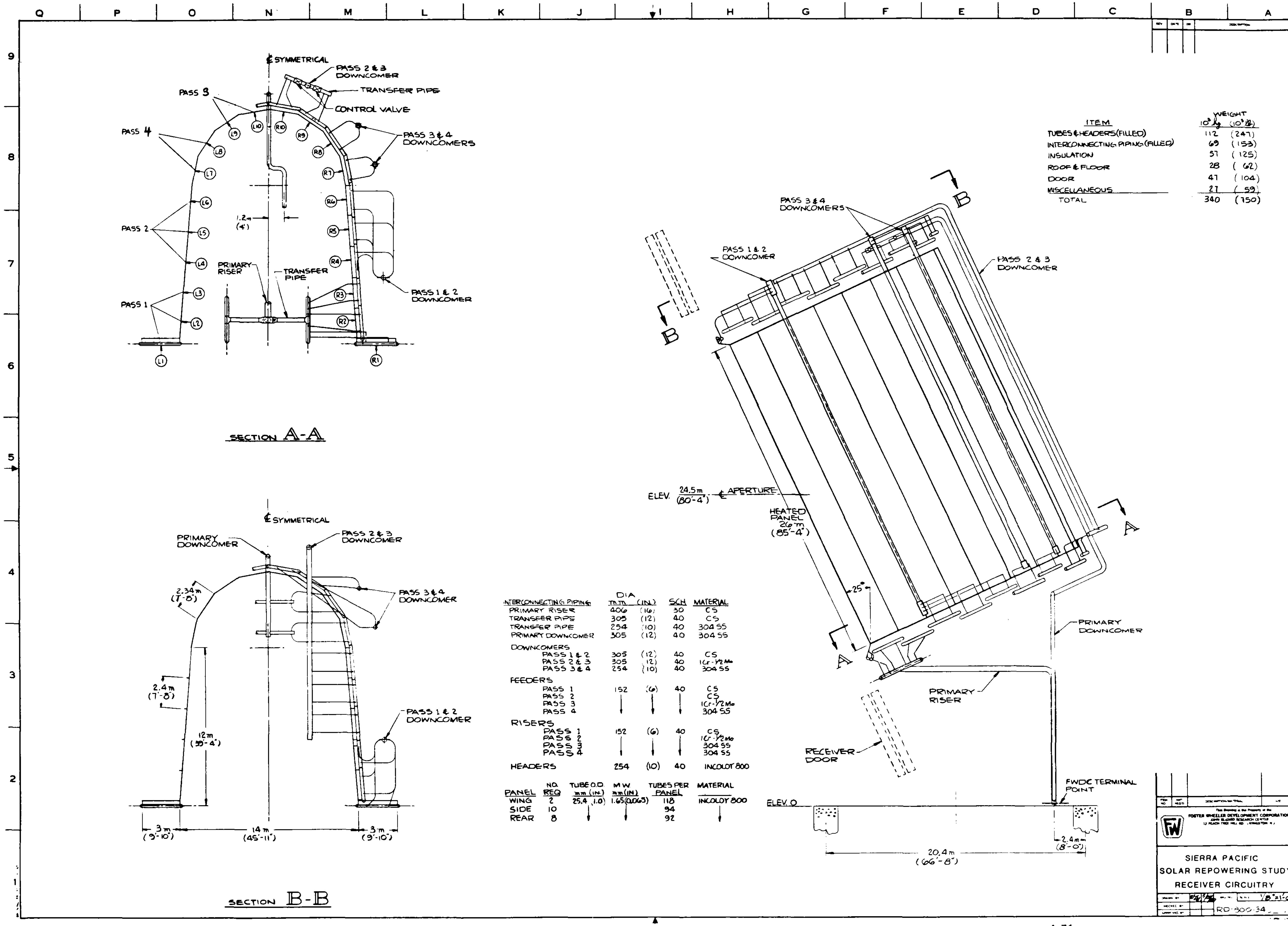
5. Tower height. -- 198.5 m

6. Type of construction. -- Concrete - reinforced

7. Tower dimensions -- 20.3 m top, 24.2 m bottom--.5° tap

8. Tower foundation dimensions. -- 45.7 m Dia. x 4.3 m thick

9. Weights. -- Receiver system, 10^6 Kg



ITEM	WEIGHT 10^3 kg	(10^3 lb)
TUBES & HEADERS (FILLED)	112	(247)
INTERCONNECTING PIPING (FILLED)	69	(153)
INSULATION	57	(125)
ROOF & FLOOR	28	(62)
DOOR	47	(104)
MISCELLANEOUS	27	(59)
TOTAL	340	(750)

INTERCONNECTING PIPING	DIA mm	(IN)	SCH	MATERIAL
PRIMARY RISER	406	(16)	30	CS
TRANSFER PIPE	305	(12)	40	CS
TRANSFER PIPE	254	(10)	40	304 SS
PRIMARY DOWNCOMER	305	(12)	40	304 SS
DOWNCOMERS				
PASS 1 & 2	305	(12)	40	CS
PASS 2 & 3	305	(12)	40	1Cr-1/2Mo
PASS 3 & 4	254	(10)	40	304 SS
FEEDERS				
PASS 1	152	(6)	40	CS
PASS 2	↓	↓	↓	CS
PASS 3	↓	↓	↓	1Cr-1/2Mo
PASS 4	↓	↓	↓	304 SS
RISERS				
PASS 1	152	(6)	40	CS
PASS 2	↓	↓	↓	1Cr-1/2Mo
PASS 3	↓	↓	↓	304 SS
PASS 4	↓	↓	↓	304 SS
HEADERS	254	(10)	40	INCOLOY 800

PANEL	NO. REQ	TUBE O.D. mm (IN)	MW mm (IN)	TUBES PER PANEL	MATERIAL
WING	2	25.4 (1.0)	1.65 (0.065)	118	INCOLOY 800
SIDE	10	↓	↓	94	↓
REAR	8	↓	↓	92	↓

Figure 5.10 Receiver Design

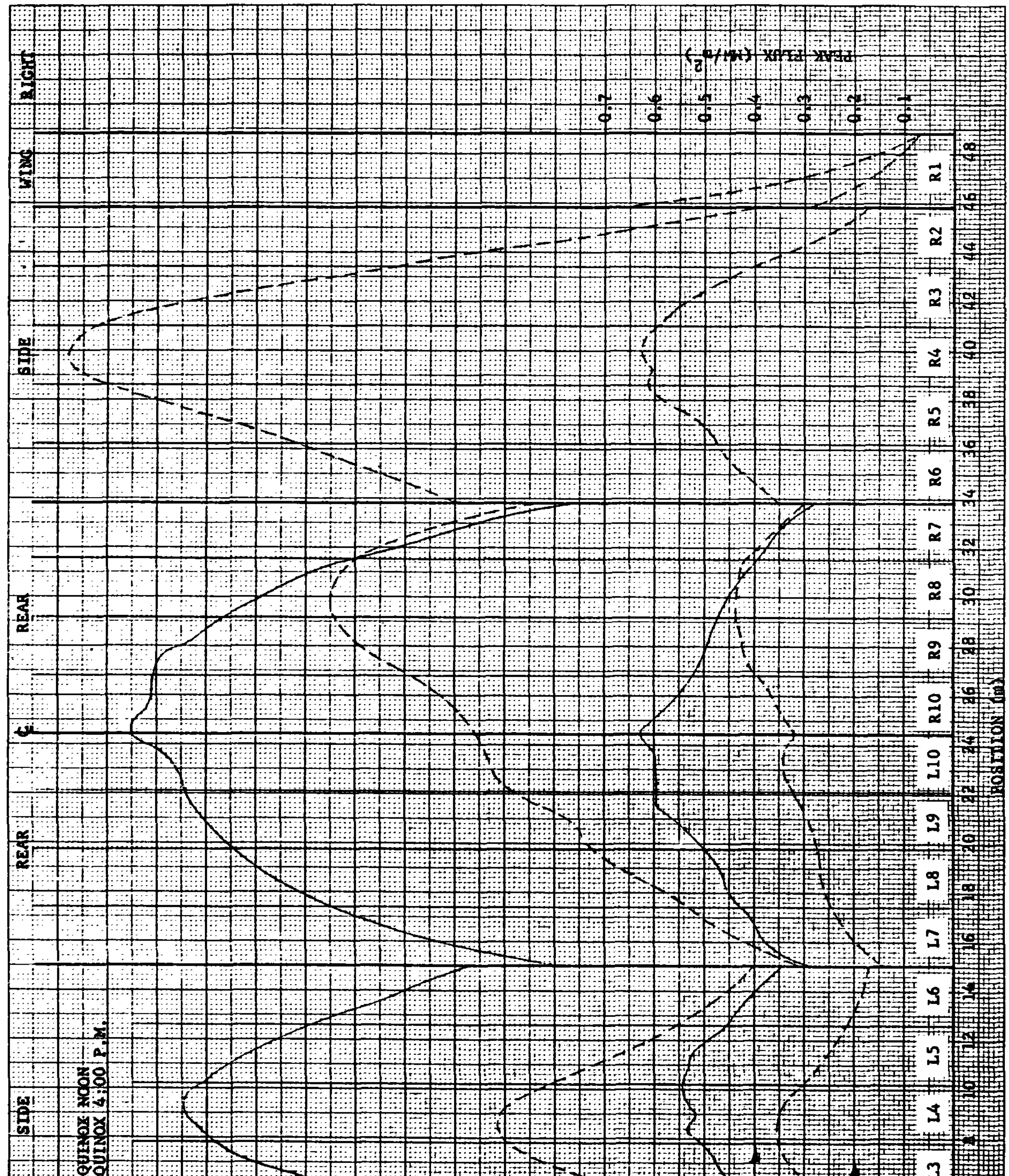


Fig. 5.11 Receiver Absorbed Flux - Equinox

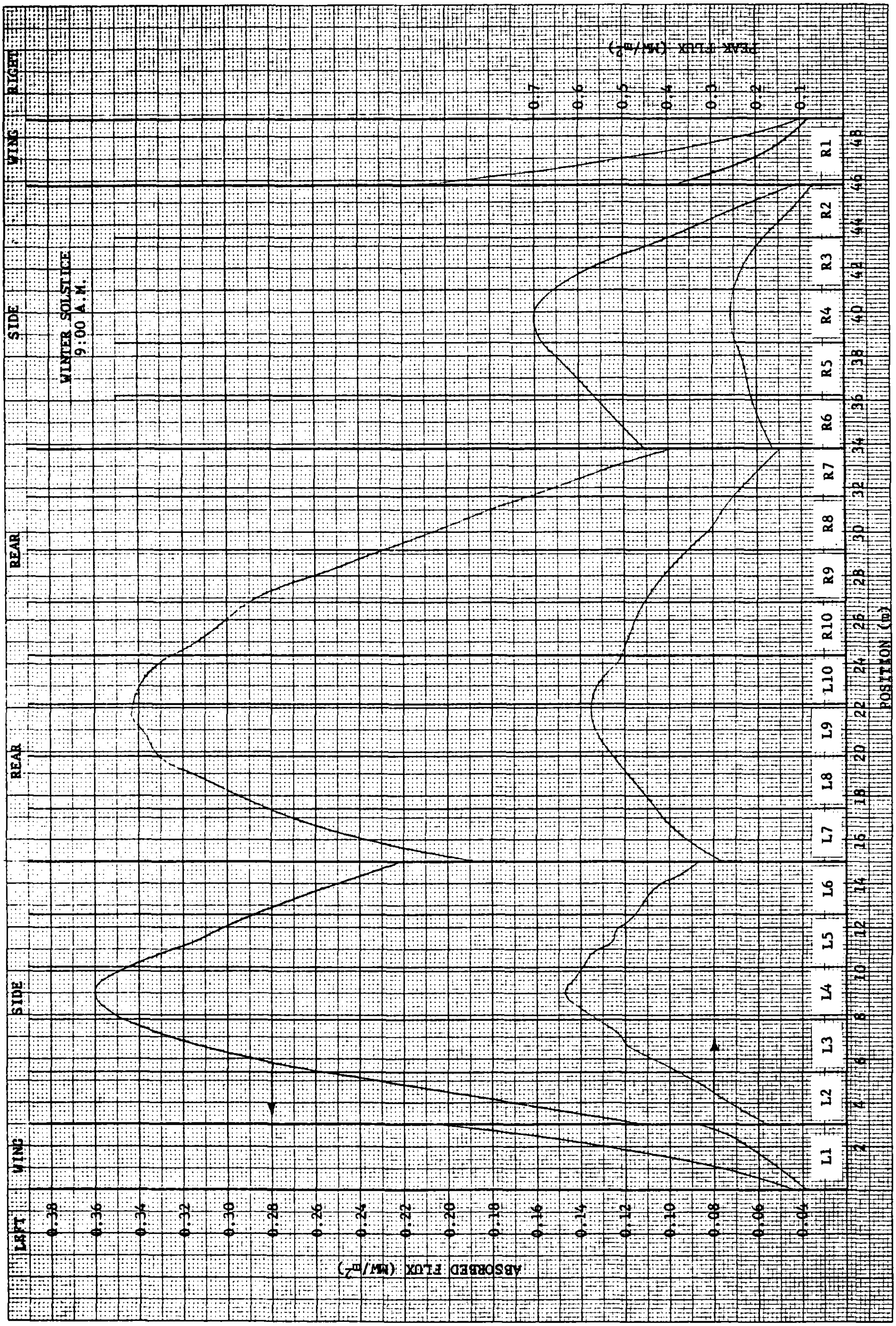


Fig. 5.12 Receiver Absorbed Flux - Winter Solstice

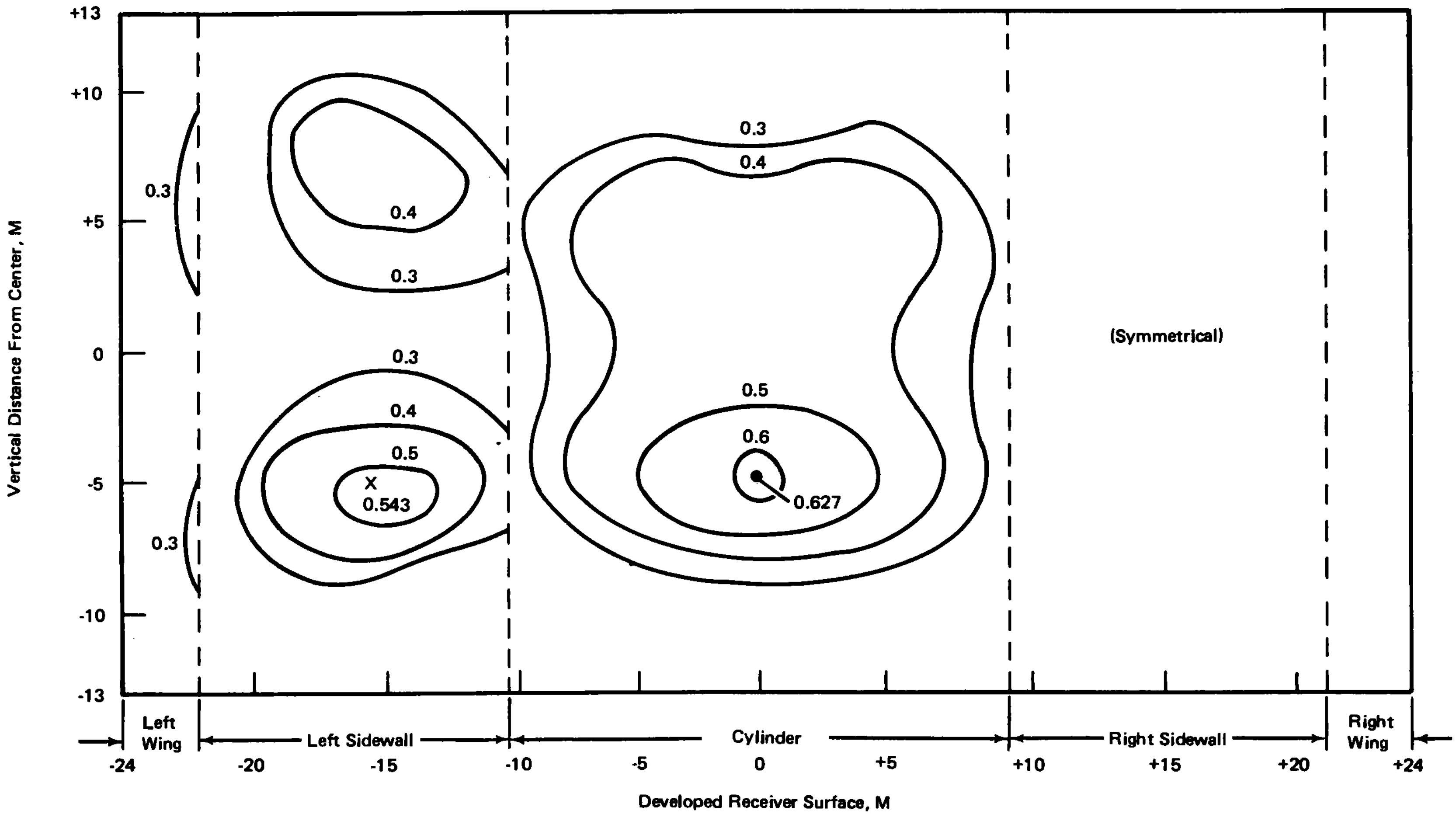


Figure 5-13. Receiver Flux Map Equinox Noon

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Figure 5.14

DESIRED RECEIVER EFFICIENCY

CONSTITUENT EFFICIENCY	VALUE
INTERCEPTION FACTOR	0.970
ABSORPTIVITY	0.980
EMMISION	0.984
CONVECTION	0.979
OVERALL	0.916

b. Operating Characteristics

1. Tower deflections -- Max. 0.686 m, Centerline w/40.2 m/s wind

2. Tower acceleration -- 0.46 g's top, 0.57 g's centerline

5.1.4 Receiver Fluid Loop

a. The design condition for the receiver working fluid piping shall be as shown on Table 5.1.

b. Molten Salt Pumps:

	Receiver Feed	Steam Generator
Quantity	2	2
Capacity, total	.41 m^3/S (6500 gpm)	.25 m^3/S (4050 gpm)
Head, each	364 m	91 m
Pumping temperature	288°C	566°C
Spec. gravity	1.87	1.67
Pump efficiency	.75	.75
Pump Power	1832 KW	253 KW
Motor rating, hp	---	---
Motor speed, rpm	880	1800 rpm
Pump type	---	---
Horiz/vert	Vertical	Vertical
Pump material		
Casing	Carbon steel	CRES
Impellers	Carbon steel	CRES
Shaft	Carbon steel	CRES

5.1.5 Energy Storage Data - Final List

5.1.5.1 Storage Tank

a. Design Characteristics

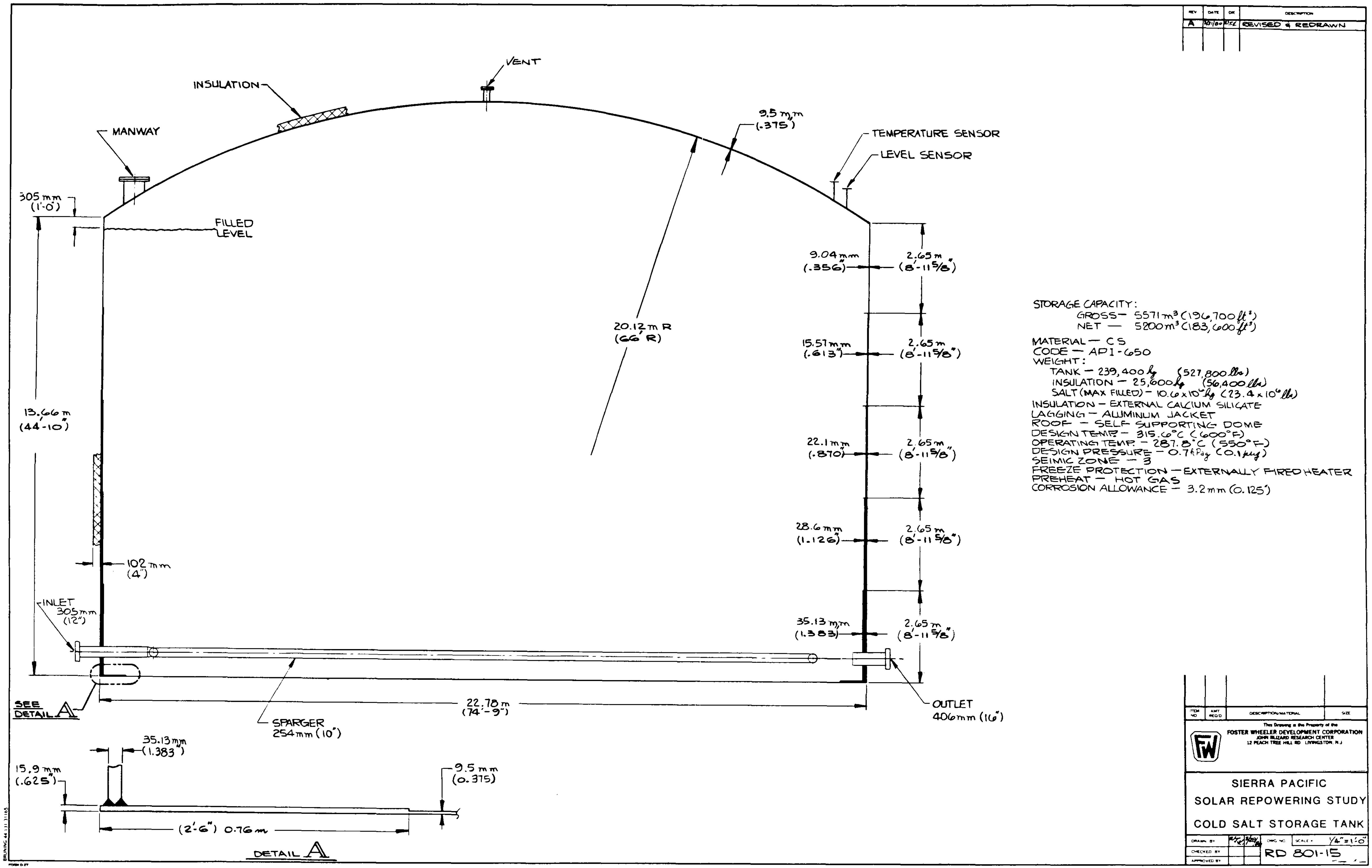
1. Storage Media

	Cold Tank	Hot Tank
Media	--- Partherm 430 (or equivalent)	
Density	1.87	1.67
Temperature	288°C	566°C

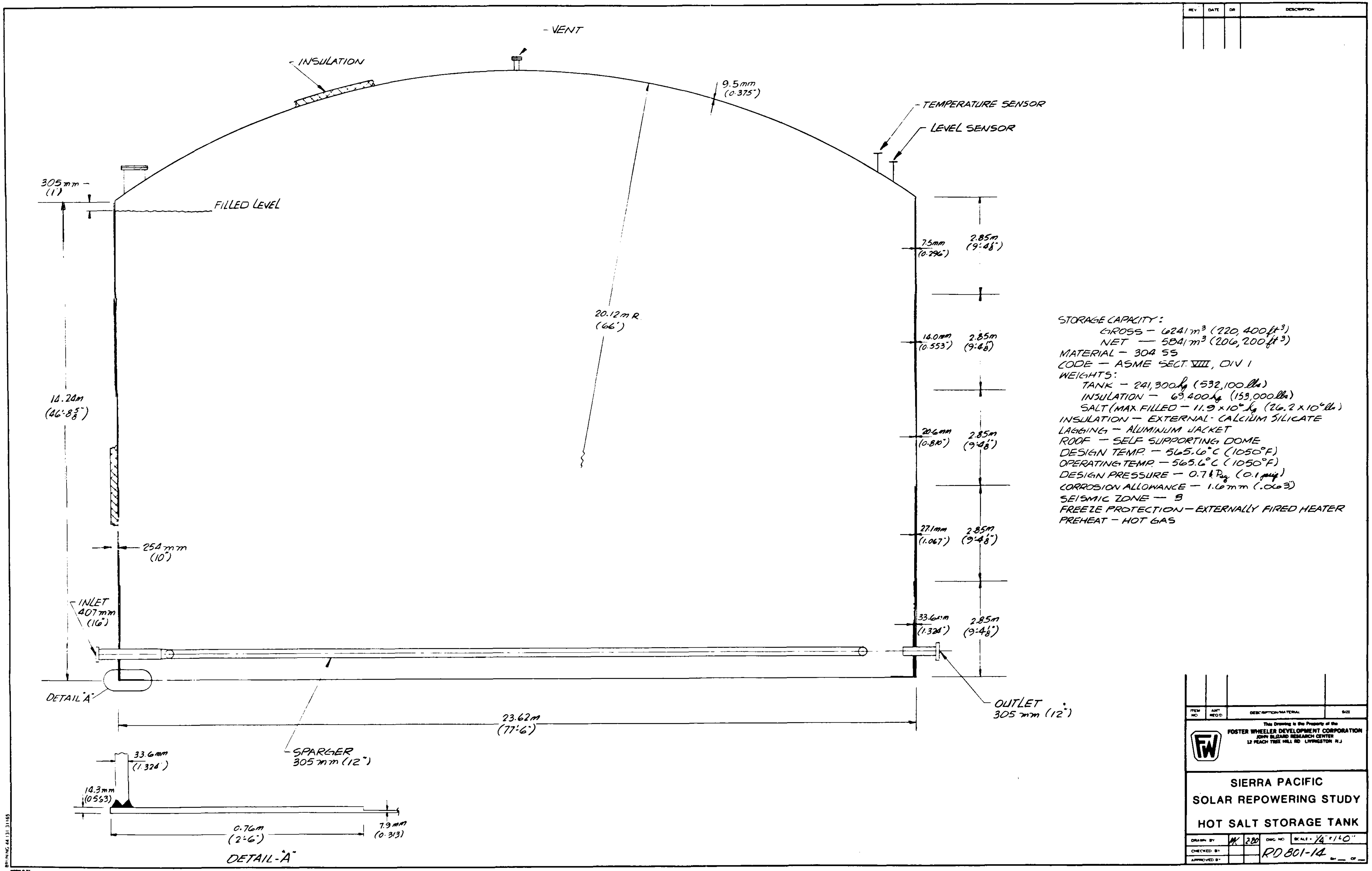
Table 5.1

Receiver Fluid Piping Characteristics

	HOT SALT Downcomer and Horizontal Piping	COLD SALT Riser and Horizontal Piping
Design Pressure	4.0 MPa (575 psig)	9.6 MPa (1400 Psig)
Design Temperature	593°C (1100°F)	302°C (575°F)
Pipe Material	ASTM A312- (304 SS)	ASTM A106-Gr.B
Code	ANSI B31.1	ANSI B31.1
Pipe Size	0.3m (12 in) Nominal Sch. X s	0.41m (16 in) Nominal Sch 80
	0.0127m (0.5 in) Nom. Wall	0.070m (0.843 in.) Nom. Wall
Wt. Per Meter (Ft)	97 kg (65 lb)	204 kg (137 lb)
Approx. Length	2057 m (6750 ft.)	1875 m (6150 ft)
Insulation Type	Calcium Silicate	Calcium Silicate
Ins. Thickness	0.15 m (6 in)	0.20 m (8 in.)



A-79/80 Figure 5.15 Cold Salt Tank



A-81/82 Figure 5.16 Hot Salt Tank

2. Tankage

   a. The cold tank configuration is shown on Figure 5.15.

   b. The hot tank configuration is shown on Figure 5.16.

1. Extractable energy capacity and duration of output.

   1150 MW Hr_{th} for 6 hours.

2. Rates

	Charge	Discharge
Maximum	330 MW_{th}/hr	180 MW_{th}/hr
Minimum	66 MW_{th}/hr	36 MW_{th}/hr
Design	330 MW_{th}/hr	180 MW_{th}/hr

3. Heat Loss Rate - Both Tanks --- less than 1%/day.

5.1.5.2 Steam Generators

a. Design Characteristics

The steam generator system is shown on Figure 5.17. The design parameters for the preheater, evaporator, superheater and reheater are shown on Figures 5.18-5.21. The design configuration for the counterflow preheater, superheater and reheater are shown on Figure 5.22. The parallel flow evaporator is shown on Figure 5.23.

b. Operating Characteristics

The operating characteristics are shown on Table 5.2 and Figure 5.24.

5.1.5.3 Steam Drun

The steam drum is an integral part of the evaporator assembly and is covered in Section 5.1.5.2.

5.1.6 Piping Data, Miscellaneous

a. Piping Data

The data for the new piping required in the EPGS system is presented in Table 5.3.

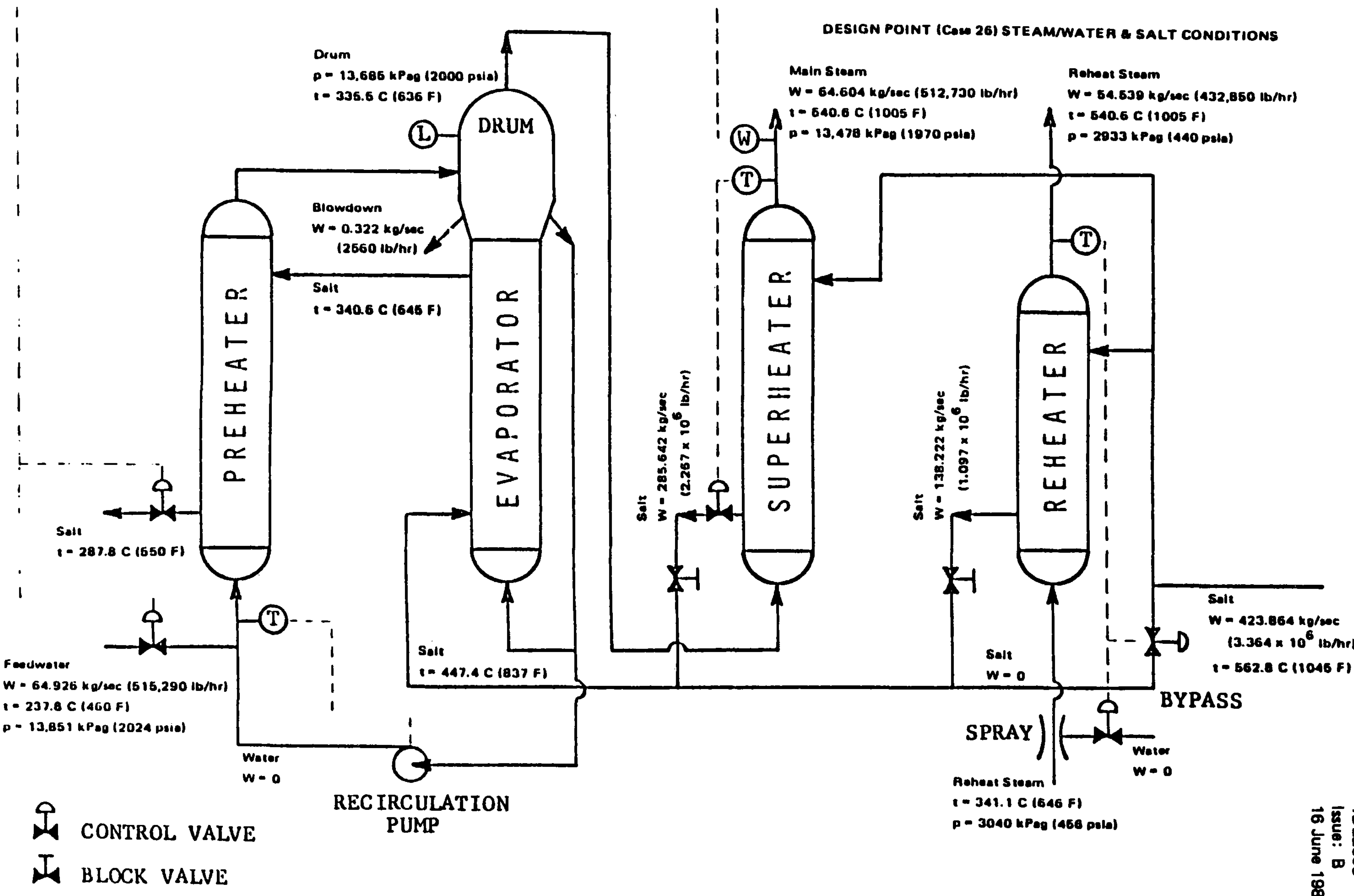


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FIGURE 5.17 STEAM GENERATOR SYSTEM

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CLIENT McDonnell Douglas	CONTRACT NO.	REQUISITION NO.		DATE
SITE Yerington, Nevada	ITEM NO.			
MATERIAL SHELL & TUBE HEAT EXCHANGER		C1	C4	
SERVICE Superheater		C2	C5	
		C3	C6	

1	Size	Type Counter Flow (~~Horizontal~~/Vertical)	Connected In.	Parallel	Series
2	Surf/Unit (Gross/~~Eff.~~) 832 Sq m	Shells/Unit	Surf/Shell (~~Gross~~/Eff.) 810.7 Sq. m		

		Shell Side In	Shell Side Out	Tube Side In	Tube Side Out
3	PERFORMANCE OF ONE UNIT				
4	Fluid Allocation	In	Out	In	Out
5	Fluid Name	Molten Salt		Steam	
6	Fluid Quantity, Total kg/sec				
7	Vapor (In/Out)				
8	Liquid	285.642	285.642		
9	Steam			64.604	64.604
10	Water				
11	Noncondensable				
12	Temperature °C	562.8	447.4	335.5	540.6
13	Specific Gravity				
14	Viscosity, Liquid Cp				
15	Molecular Weight, Vapor				
16	Molecular Weight, Noncondensable				
17	Specific Heat (Liq) (Vap) kJ/kg °C				
18	Thermal Cond (Liq) (Vap) kcal/m hr °C				
19	Latent Heat kcal/kg @ °C				
20	Pressure kPag	996	1165	13623	13478
21	Velocity m/sec				
22	Pressure Drop, Allow./Calc. (fric.) kPa	/ 75.32		/ 75.84	
23	Fouling Resistance (Min.) m^2 hr °C/kcal	0.0001		0.0001	
24	Heat Exchanged 51.056 MW_{th} ; MTD (Corrected) °C				
25	Transfer Rate, Service	Clean		kcal/m^2 hr °C	

	CONSTRUCTION OF ONE SHELL		Shell Side	Tube Side	Sketch (Bundle/Nozzle Orientation)
27			Shell Side	Tube Side	
28	Design/Test Pressure kPag		2068 /	15,340/	
29	Design Temperature °C		565.6	565.6	
30	No. Passes per Shell		1	1	
31	Corrosion Allowance mm				
32	Connections	In		236.5	
33	Size &	Out		281.0	
34	Rating	Intermediate			

35	Tube No. 1095 OD 15.875mm ; Thk (Min/~~Avg~~) 1.651mm ; Length 15.24 m ; Pitch 20.625 mm ◁30 ▲60 □90 ◇45	
36	Tube Type	Material 304 SS
37	Shell 953 ID OD mm	Shell Cover (Integ.) (Remov.)
38	Channel or Bonnet	Channel Cover
39	Tubesheet-Stationary	Tubesheet-Floating
40	Floating Head Cover	Impingement Protection
41	Baffles-Cross 47 Type Triple Segmental	% Cut (Diam/Area) Spacing: c.c Inlet mm
42	Baffles-Long	Seal Type
43	Bypass Seal Arrangement	Tube-Tubesheet Joint
44	Expansion Joint	Type
45	ρv² – Inlet Nozzle Bundle Entrance	Bundle Exit
46	Gaskets-Shell Side	Tube Side
47	-Floating Head	
48	Code Requirements ASME Section VIII, Div. 1	TEMA Class
49	Weight: Dry 18,367 Filled 31,701 (With insulation 33,600)	kg
50	REMARKS: Pathway Bellows BB20-300-14	
51		
BY	P O NO.	VENDOR

FORM NO. 135-201

Figure 5.18 Superheater Data Sheet

FOSTER WHEELER ENERGY CORPORATION

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CLIENT McDonnell Douglas	CONTRACT NO.	REQUISITION NO.	DATE
SITE Yerington, Nevada	ITEM NO.		
MATERIAL SHELL & TUBE HEAT EXCHANGER		C1	C4
SERVICE Evaporator		C2	C5
		C3	C6

1	Size	Type Parallel Flow ~~(Horizontal/~~Vertical)		Connected In. Parallel	Series
2	Surf/Unit (Gross/~~Eff.~~) 1425 Sq m	Shells/Unit One (1)		Surf/Shell (~~Gross~~/Eff.) 1381.7	Sq. m
3	PERFORMANCE OF ONE UNIT				
4	Fluid Allocation	Shell Side In	Shell Side Out	Tube Side In	Tube Side Out
5	Fluid Name	Molten Salt		Steam/Water	
6	Fluid Quantity, Total kg/sec				
7	Vapor (In/Out)				
8	Liquid	423.864	423.864		
9	Steam				64.604
10	Water			284.224	219.620
11	Noncondensable				
12	Temperature °C	447.4	340.6	335.5	335.5
13	Specific Gravity				
14	Viscosity, Liquid Cp				
15	Molecular Weight, Vapor				
16	Molecular Weight, Noncondensable				
17	Specific Heat (Liq) (Vap) kJ/kg °C				
18	Thermal Cond (Liq) (Vap) kcal/m hr °C				
19	Latent Heat kcal/kg @ °C				
20	Pressure kPag	945	593	13685	13685
21	Velocity m/sec				
22	Pressure Drop, Allow./Calc. (fric.) kPa	/ 95.51		/	
23	Fouling Resistance (Min.) m^2 hr °C/kcal	0.0001		0.0001	
24	Heat Exchanged 69.998 MW_{th}	MTD (Corrected) °C			
25	Transfer Rate, Service	Clean		kcal/m^2 hr °C	

				Sketch (Bundle/Nozzle Orientation)
26	CONSTRUCTION OF ONE SHELL			
27		Shell Side	Tube Side	
28	Design/Test Pressure kPag	2068 /	15,340 /	
29	Design Temperature °C	510.0	371.0	
30	No. Passes per Shell	1	1	
31	Corrosion Allowance mm			
32	Connections Size & Rating — In	336.6	188.9	
33	Out	336.6	236.5	
34	Intermediate			

35	Tube No. 1172 OD 25.4 mm; Thk (Min/~~Avg~~) 2.108 mm; Length 15.24 m; Pitch 31.75 mm ◁30 ▲60 □90 ◇45	
36	Tube Type	Material 1 Cr - 1/2 Mo
37	Shell 1517 ID OD mm	Shell Cover (Integ.) (Remov.)
38	Channel or Bonnet	Channel Cover
39	Tubesheet-Stationary	Tubesheet-Floating
40	Floating Head Cover	Impingement Protection
41	Baffles-Cross 46 Type Triple Segmental	% Cut (Diam/Area) Spacing: c/c Inlet mm
42	Baffles-Long	Seal Type
43	Bypass Seal Arrangement	Tube-Tubesheet Joint
44	Expansion Joint	Type
45	ρv² — Inlet Nozzle Bundle Entrance	Bundle Exit
46	Gaskets-Shell Side	Tube Side
47	-Floating Head	
48	Code Requirements ASME Section VIII, Div. 1	TEMA Class
49	Weight: Dry 59,546 Filled 95,873 (With insulation 98,800) kg	
50	REMARKS: Pathway Bellows 3B20-300-10; Weights include steam drum, downcomers, feeders	
51		
	BY P O NO	VENDOR

FORM NO. 135-201

Figure 5.19 Evaporator Data Sheet

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SITE Yerington, Nevada	ITEM NO.		
MATERIAL SHELL & TUBE HEAT EXCHANGER		C1	C4
SERVICE Preheater		C2	C5
		C3	C6

1	Size	Type Counter Flow ~~Horizontal~~/Vertical)	Connected In.	Parallel	Series
2	Surf/Unit (Gross/~~Eff.~~) 1603 Sq m;	Shells/Unit One (1)	Surf/Shell (~~Gross~~/Eff.) 1560.3 Sq. m.		
3	PERFORMANCE OF ONE UNIT				
4	Fluid Allocation	Shell Side In	Shell Side Out	Tube Side In	Tube Side Out
5	Fluid Name	Molten Salt		Water	
6	Fluid Quantity, Total kg/sec				
7	Vapor (In/Out)				
8	Liquid	423.864	423.864		
9	Steam				
10	Water			64.926	64.926
11	Noncondensable				
12	Temperature °C	340.6	287.8	237.8	335.5
13	Specific Gravity				
14	Viscosity, Liquid Cp				
15	Molecular Weight, Vapor				
16	Molecular Weight, Noncondensable				
17	Specific Heat (Liq) (Vap) kJ/kg °C				
18	Thermal Cond (Liq) (Vap) kcal/m hr °C				
19	Latent Heat kcal/kg @ °C				
20	Pressure kPag	555	717	13851	13706
21	Velocity m/sec				
22	Pressure Drop, Allow., Calc. (fric.) kPa	/ 104.74		/ 17.24	
23	Fouling Resistance (Min.) m^2 hr °C/kcal	0.0001		0.0001	
24	Heat Exchanged 34.685 MW_{th} ; MTD (Corrected) °C				
25	Transfer Rate, Service Clean kcal/m^2 hr °C				

	CONSTRUCTION OF ONE SHELL			Sketch (Bundle/Nozzle Orientation)
27		Shell Side	Tube Side	
28	Design/Test Pressure kPag	2068 /	15,512 /	
29	Design Temperature °C	371.1	371.1	
30	No. Passes per Shell	1	1	
31	Corrosion Allowance mm			
32	Connections Size & Rating: In	336.6	188.9	
33	Out	336.6	188.9	
34	Intermediate			

35	Tube No. 2109 OD 15.875 mm; Thk (Min/~~Avg~~) 1.651 mm; Length 15.24 m; Pitch 20.625 mm ◁30 ▲60 □90 ◇45	
36	Tube Type	Material CS
37	Shell 1257 ID OD mm	Shell Cover (Integ.) (Remov.)
38	Channel or Bonnet	Channel Cover
39	Tubesheet-Stationary	Tubesheet-Floating
40	Floating Head Cover	Impingement Protection
41	Baffles-Cross 47 Type Triple Segmental	% Cut (Diam/Area) Spacing: c/c Inlet mm
42	Baffles-Long	Seal Type
43	Bypass Seal Arrangement	Tube-Tubesheet Joint
44	Expansion Joint	Type
45	ρv² – Inlet Nozzle Bundle Entrance	Bundle Exit
46	Gaskets-Shell Side	Tube Side
47	-Floating Head	
48	Code Requirements ASME Section VIII, Div. 1	TEMA Class
49	Weight Dry 31,746 Filled 58,685 (With insulation 60,300)	kg
50	REMARKS Pathway Bellows 3B20-300-6	
51		
BY	P. O. NO.	VENDOR

FORM NO. 135-201

Figure 5.20 Preheater Data Sheet

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CLIENT McDonnell Douglas	CONTRACT NO.	REQUISITION NO.	DATE
SITE Yerington, Nevada	ITEM NO.		
MATERIAL SHELL & TUBE HEAT EXCHANGER		C1	C4
SERVICE Reheater		C2	C5
		C3	C6

1 Size Type Counter Flow ~~(Horizontal/~~Vertical) Connected In. Parallel Series

2 Surf/Unit (Gross/~~Eff.~~) 642 Sq m: Shells/Unit Surf/Shell (~~Gross~~/Eff.) 629.5 Sq. m.

3 PERFORMANCE OF ONE UNIT

#		Shell Side In	Shell Side Out	Tube Side In	Tube Side Out
4	Fluid Allocation	In	Out	In	Out
5	Fluid Name	Molten Salt		Steam	
6	Fluid Quantity, Total kg/sec				
7	Vapor (In/Out)				
8	Liquid	138.222	138.222		
9	Steam			54.539	54.539
10	Water				
11	Noncondensable				
12	Temperature °C	562.8	447.4	341.1	540.6
13	Specific Gravity				
14	Viscosity, Liquid Cp				
15	Molecular Weight, Vapor				
16	Molecular Weight, Noncondensable				
17	Specific Heat (Liq) (Vap) kJ/kg °C				
18	Thermal Cond (Liq) (Vap) kcal/m hr °C				
19	Latent Heat kcal/kg @ °C				
20	Pressure kPag	996	1127	3040	2933
21	Velocity m/sec				
22	Pressure Drop, Allow./Calc. (fric.) kPa	/	19.49	/	107.55
23	Fouling Resistance (Min.) m² hr °C/kcal	0.0001		0.0001	

24 Heat Exchanged 24.708 MW$_{th}$; MTD (Corrected) °C

25 Transfer Rate, Service Clean kcal/m² hr °C

26 CONSTRUCTION OF ONE SHELL — Sketch (Bundle/Nozzle Orientation)

#			Shell Side	Tube Side
27			Shell Side	Tube Side
28	Design/Test Pressure kPag		2068 /	3964 /
29	Design Temperature °C		565.6	565.6
30	No. Passes per Shell		1	1
31	Corrosion Allowance mm		203	381
32	Connections	In	203	381
33	Size &	Out		
34	Rating	Intermediate		

35 Tube No. 1243 OD 15.875 mm ; Thk (Min/~~Avg~~) 1.651 mm ; Length 10.36m; Pitch 20.625 mm ◁30 ▲60 □90 ◇45

36 Tube Type Material 304 SS

37 Shell 927 ID OD mm | Shell Cover (Integ.) (Remov.)

38 Channel or Bonnet | Channel Cover

39 Tubesheet-Stationary | Tubesheet-Floating

40 Floating Head Cover | Impingement Protection

41 Baffles-Cross 32 Type Triple Segmental | % Cut (Diam/Area) Spacing: c/c Inlet mm

42 Baffles-Long | Seal Type

43 Bypass Seal Arrangement | Tube-Tubesheet Joint

44 Expansion Joint | Type

45 ρv² – Inlet Nozzle Bundle Entrance Bundle Exit

46 Gaskets-Shell Side | Tube Side

47 -Floating Head

48 Code Requirements ASME Section VIII, Div. 1 TEMA Class

49 Weight Dry 12,880 Filled 20,726 (With insulation 22,000) kg

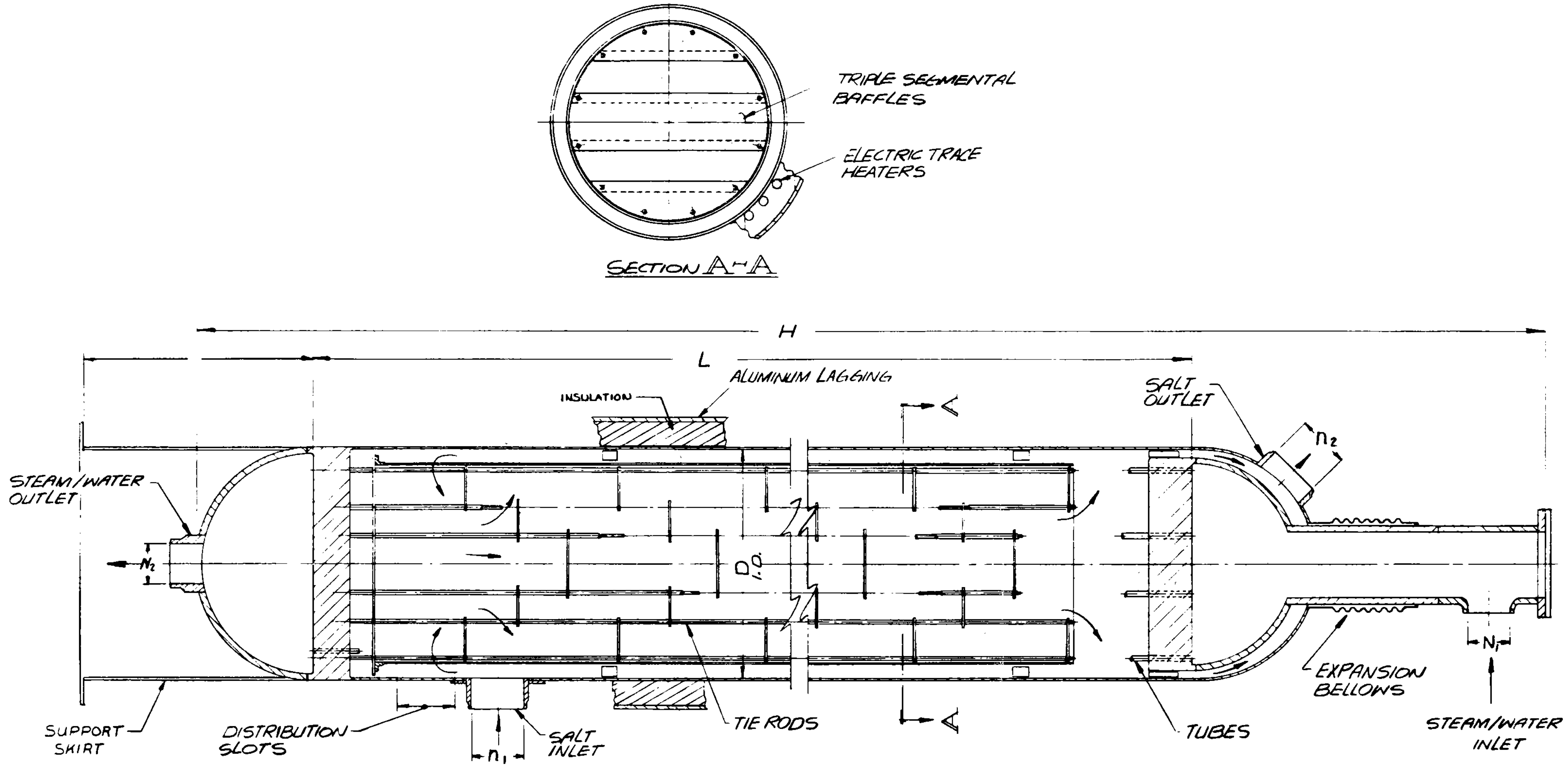
50 REMARKS Pathway Bellows B320-300- 10

51

BY | P O NO | VENDOR

FORM NO. 135-201

Figure 5.21 Reheater Data Sheet



	PREHEATER	SUPERHEATER	REHEATER
H	18.14m (59'-6")	18.14m (59'-6")	13.26m (43'-6")
L	15.24m (50'-0")	15.24m (50'-0")	10.36m (34'-0")
D	1257mm (4'-1½")	953mm (3'-1½")	927mm (3'-0½")
n_1	356mm (14")	305mm (12")	203mm (8")
n_2	356mm (14")	305mm (12")	203mm (8)
N_1	203mm (8")	254mm (10")	406mm (16")
N_2	203mm (8")	305mm (12")	406mm (16")
TUBE SIZE	15.875mm O.D. x 1.651mm MW (5/8" O.D. x 0.065" MW)		
DRY WEIGHT ②	31,746kg (70,000lbs)	18,367kg (40,500lbs)	12,880kg (28,400lbs)
FILLED WEIGHT	58,685kg (129,400lbs)	30,701kg (69,900lbs)	20,726kg (45,700lbs)
INSULATION THICKNESS ③	127mm (5")	178mm (7")	178mm (7")
ELECTRICAL TRACE HEATERS:			
No OF UNITS	24	14	8
LENGTH OF UNIT	30.48m (100')	30.48m (100')	20.73m (68')
DESIGN CONDITIONS:			
TUBE SIDE			
PRESSURE	15,512 kPag (2250 psig)	15,340 kPag (2225 psig)	3,964 kPag (575 psig)
TEMPERATURE	371.1°C (700°F)	565.6°C (1050°F)	565.6°C (1050°F)
SHELL SIDE			
PRESSURE	2,068 kPag (300 psig)	2,068 kPag (300 psig)	2068 kPag (300 psig)
TEMPERATURE	371.1°C (700°F)	565.6°C (1050°F)	565.6°C (1050°F)
MATERIAL	CS	304 SS	304 SS
APPLICABLE CODE: ASME SECTION VIII, DIV 1			

KEY:
① NOMINAL NOZZLE SIZES
② INSULATION WEIGHT NOT INCLUDED
③ CALCIUM SILICATE
④ TUBES, FORGINGS, SHELL PLATES, SHELL HEADS

This Drawing is the Property of the FOSTER WHEELER DEVELOPMENT CORPORATION, JOHN BLIZARD RESEARCH CENTER, 12 PEACH TREE HILL RD LIVINGSTON, N.J.

SIERRA PACIFIC POWER
SOLAR REPOWERING STUDY
PREHEATER, SUPERHEATER, REHEATER

DRAWN BY ER
RD-801-13

9-41-3134-2-C30

Fig. 5.22 Counterflow Heat Exchanger Design

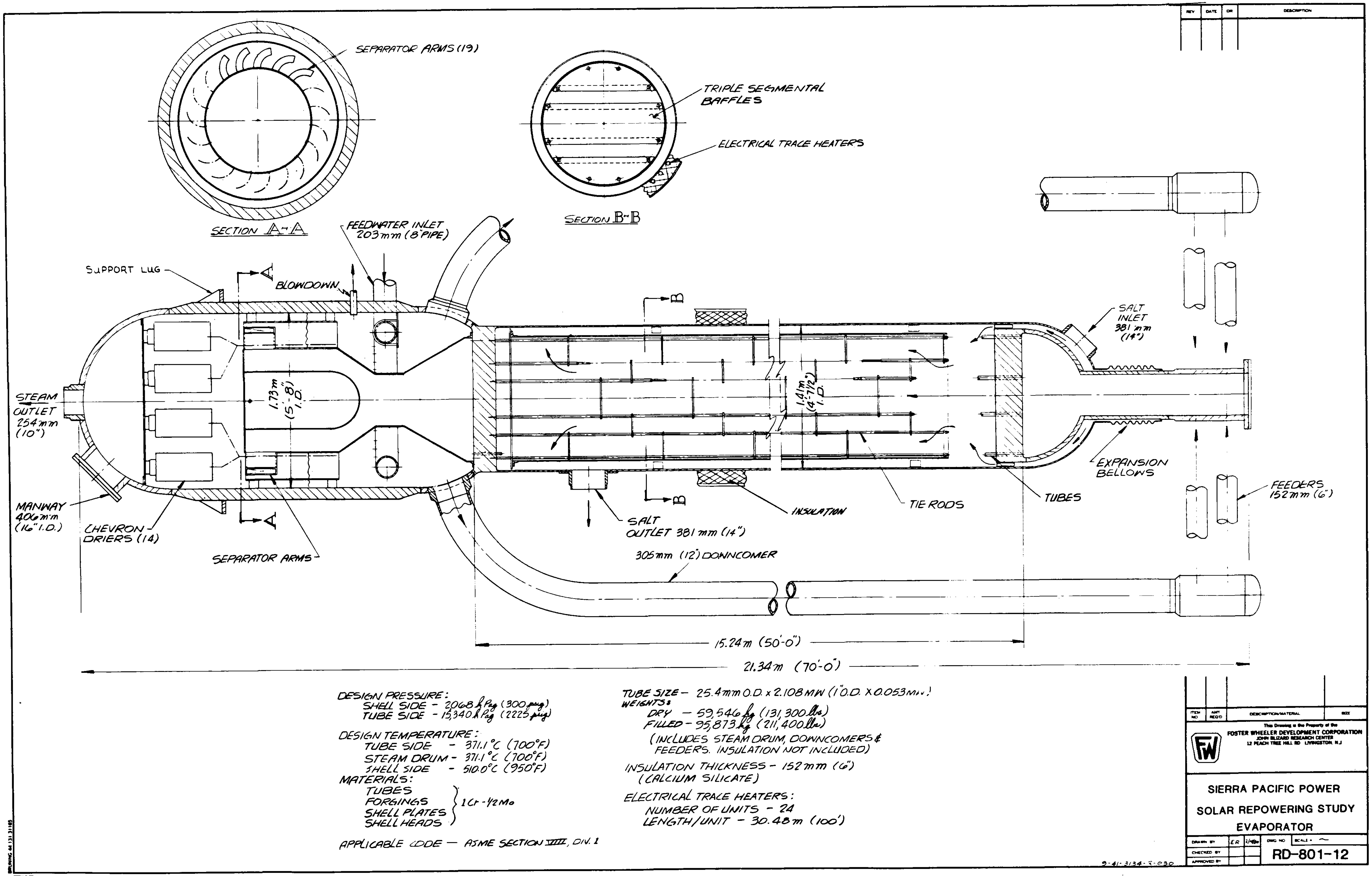


Figure 5.23 Parallel Flow Heat Exchanger Design

TABLE 52 STEAM GENERATOR PERFORMANCE

	HYBRID (5% Overpressure)				SOLAR STAND-ALONE (Design Pressure)
LOAD, % Design	25	50	75	100 (Case 26)	91 (Case 20)
TEMPERATURES, C (F)					
Steam/Water:					
Feedwater	237.8 (460)	237.8 (460)	237.8 (460)	237.8 (460)	211.7 (413)*
Superheater Inlet	334.4 (634)	334.4 (634)	335.0 (635)	335.6 (636)	330.6 (627)
Final Steam	540.6 (1005)	540.6 (1005)	540.6 (1005)	540.6 (1005)	540.6 (1005)
Reheater Inlet	341.1 (646)	341.1 (646)	341.1 (646)	341.1 (646)	309.4 (589)
Reheater Outlet	540.6 (1005)	540.6 (1005)	540.6 (1005)	540.6 (1005)	540.6 (1005)
Salt:					
Superheater Inlet	562.8 (1045)	562.8 (1045)	562.8 (1045)	562.8 (1045)	562.8 (1045)
Superheater Outlet	378.9 (714)	404.4 (769)	428.9 (804)	447.4 (837)	432.8 (811)
Reheater Inlet	562.8 (1045)	562.8 (1045)	562.8 (1045)	562.8 (1045)	562.8 (1045)
Reheater Outlet	400.0 (752)	418.9 (786)	434.4 (814)	447.4 (837)	428.9 (804)
Evaporator Inlet	445.4 (833.7)	445.8 (834.4)	446.4 (835.6)	447.4 (837)	449.4 (841)
Evaporator Outlet	334.6 (634.3)	335.6 (636.1)	337.4 (639.4)	340.6 (645)	333.9 (633)
Preheater Inlet	334.6 (634.3)	335.6 (636.1)	337.4 (639.4)	340.6 (645)	333.9 (633)
Preheater Outlet	282.1 (539.7)	283.4 (542.2)	285.5 (545.9)	287.8 (550)	278.3 (533)
FLOWS, kg/sec (M lbm/hr)					
Steam/Water:					
Feedwater	16.23 (128.8)	32.46 (257.6)	48.69 (386.5)	64.93 (515.3)	57.12 (453.4)
Blowdown	.08 (0.6)	0.16 (1.3)	.24 (1.9)	0.32 (2.6)	.28 (2.2)
Main Steam	16.15 (128.2)	32.30 (256.3)	48.45 (384.6)	64.61 (512.7)	56.84 (450.5)
Reheater	13.63 (108.2)	27.27 (216.4)	40.90 (324.6)	54.54 (432.9)	48.20 (382.6)
Recirculation	0	0	0	0	13.56 (107.6)
Salt:					
Preheater	103.80 (824.0)	208.62 (1656.0)	314.94 (2500.0)	423.86 (3364.0)	391.66 (3109)
Evaporator	103.80 (824.0)	208.62 (1656.0)	314.90 (2500.0)	423.86 (3364.0)	391.66 (3109)
Superheater	44.60 (354.0)	107.08 (850.0)	183.93 (1460.0)	285.64 (2267.0)	219.20 (1740)
Reheater	24.50 (194.5)	55.48 (440.4)	93.22 (740.0)	138.22 (1097.0)	118.54 (941)
Bypass	34.70 (275.5)	46.06 (365.6)	37.79 (300.0)	0	53.92 (428)
PRESSURES, kPag (psig)					
Steam/Water:					
Feedwater	13,628 (1976)	13,676 (1983)	13,752 (1994)	13,851 (2009)	12,993 (1884)
Drum	13,497 (1957)	13,583 (1963)	13,600 (1972)	13,685 (1985)	12,821 (1859)
Final Steam	13,483 (1955)	13,483 (1955)	13,483 (1955)	13,483 (1955)	1,772 (1837)
Reheater Inlet	3,040 (441)	3,040 (441)	3,040 (441)	3,040 (441)	1,772 (257)
Reheater Outlet	3,034 (440)	3,014 (437)	2,979 (432)	2,933 (425)	1,634 (237)
Salt:					
Superheater Inlet	503 (73)	607 (88)	869 (126)	996 (145)	924 (134)
Reheater Inlet	503 (73)	607 (88)	869 (126)	996 (145)	924 (134)
Preheater Outlet	717 (104)	717 (104)	717 (104)	717 (104)	717 (104)

NOTE: Before mixing with recirculated water from Evaporator.

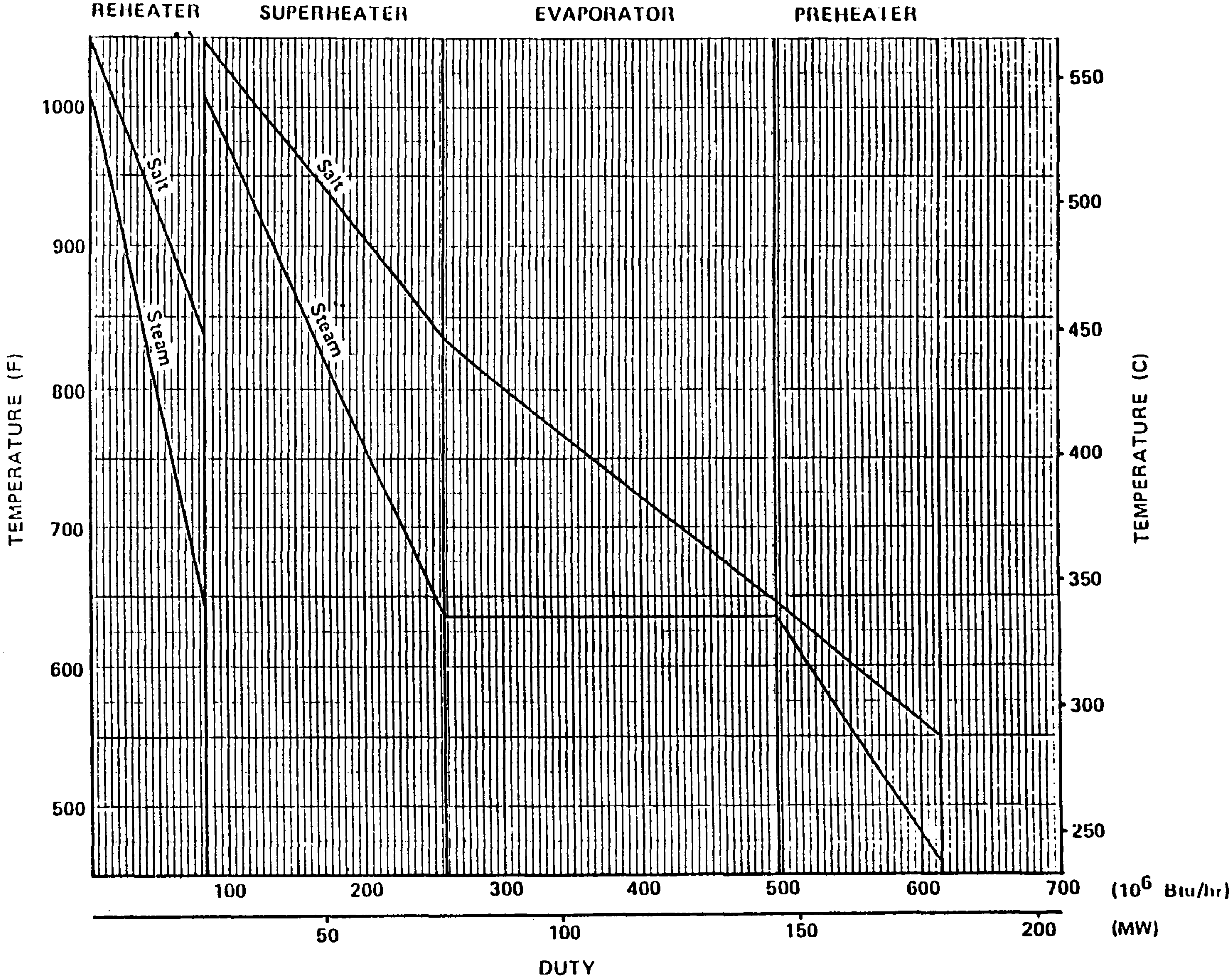


FIGURE 5.24 STEAM GENERATOR PERFORMANCE

1D22600
Issue: B
16 June 1980

TABLE 5.3

SOLAR STEAM AND FEEDWATER PIPING

FORT CHURCHILL - UNIT NO. 1

		MAIN STEAM	HOT REHEAT	COLD REHEAT	BOILER FEED
Design Pressure	MP_a	14.1	3.95	3.95	17.2
Design Temperature	°C	546	546	377	238
Material	-	A335-P22 2-1/4 CR-1 MO Seamless	A335-P22 2-1/4 CR-1 MO Seamless	A106-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 I.D.	m	.20	.38	.41 Sch. 40	.2 Sch. 160
Mimimum Wall	m	31.6	15.7		
Nom. O.D.	m	.27	.42	.41	.22
Weight/M	Kg/m	197	165	124	112
Insulation	-	Calcium Silicate	Calcium Silicate	Calcium Silicate	Calcium Silicate
Ins. Thickness	m	.15	.15	.128	.076

b. Turbine Performance Summary

The turbine performance summary for the Hybrid (case 26) and solar standalone (case 29) operating modes are shown in Table 5.4.

TABLE 5.4 TURBINE PERFORMANCE SUMMARY FORT CHURCHILL-UNIT NO. 1

Operating Mode	Season	Gross Generation Fossil	Gross Generation Solar	Gross Generation Total	Throttle Pressure	Throttle Temp	Reheat Temp	Condenser Pressure	Feedwater Temp.	Gross Heat Rate
		kWe	kWe	kWe	MPa (psia)	°C (°F)	°C (°F)	kPa (in.Hg A)	°C (°F)	kJ/kW-h (BTU/kW-h)
Hybrid (Case 26)	Equinox	37,564	77,000	114,564	13.1(1903)	538(1000)	538(1000)	6.4 (1.90)	238(460)	8470 (8028)
Solar Only (Case 29)	Summer	0	77,000	77,000	13.1(1903)	538(1000)	538(1000)	6.7 (2.00)	219(427)	8575 (8128)

TURBINE DATA

Manufacturer	General Electric
Rating	105,147 kW
Type	TC2F-20 LSB Reheat
Rated Steam Conditions	12.4 MPa (1800 psig)-538°C (1000°F)/538°C (1000°F)

1D22600
Issue: B
16 June 1980

5.2 EXISTING PLANT DESCRIPTION

The performance level of the existing power plant is shown on the Heat Balance Diagram, Figure 5.25. This diagram reflects the theoretical performance and not the actual delivered performance. The acceptance test on the Ft. Churchill No. 1 unit indicated minor variations in delivered performance (under actual operation), however the differences were not significant.

a. Boiler - The Babcock & Wilcox radiant type reheat, pressurized furnace steam generating unit has a maximum guaranteed continuous capacity of 97 kg/s (770,000 lb/hr) of steam at 13.6 MPa (1,960 psig) 540°C (1,005°F) at the superheater outlet with reheat of 83 kg/s (658,000 lb/hr) of steam to 540°C (1,005°F) at the reheat outlet, when supplied with feed-water at 235°C (456°F) at the economizer. The unit has a maximum 2 hr. peak of 102 kg/s (810,000 lb/hr) of steam. The unit was designed to allow for future conversion to coal firing.

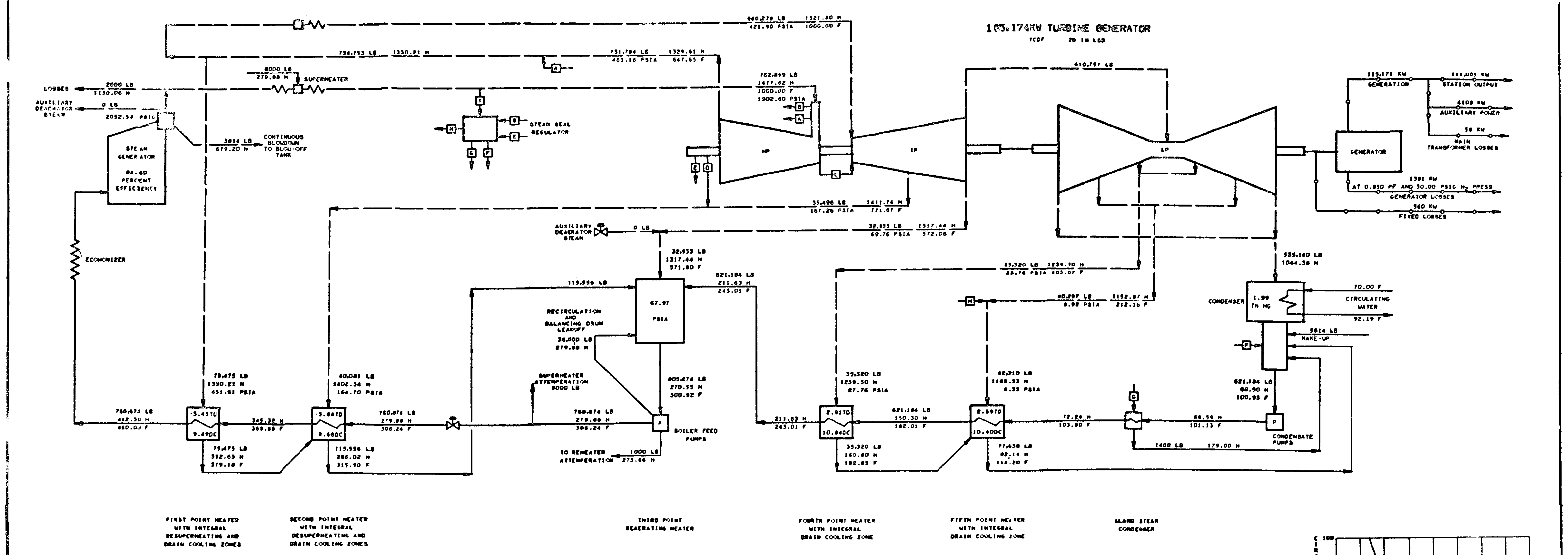
   The steam generating equipment includes: one regenerative type air preheater, superheater, reheater, economizer, steam temperature control equipment, duct work, insulation and aluminum casing.

   The boiler is arranged to fire with either gas or oil. The boiler is equipped with eight gas burners and eight mechanical atomizing oil guns.

b. Turbine - The General Electric tandem compound, reheat, double flow condensing, 3,600 rpm turbine with .5m (20 in.) last row blades, is designed for operating conditions of 12.5 MPa (1,800 psig) 538°C (1,000°F) with reheat to 538°C (1,000°F) with five uncontrolled preheater extraction p rts, and exhausting to 6754 Pa (2.0 Hg abs.) pressure. The turbine has a maximum capability of 11,5000 KW when operating at 13.1 MPa (1,890 psig) at the throttle.

c. Generator - The hydrogen cooled, 3 phase, 60 cycle, 13,800 v, 3,600 rpm generator rated at 135,300 KVA at 0.85 pf and .2 MPa (30 psig) hydrogen pressure.

d. Condenser - The 4420m^2 (47,500 sq. ft.) two pass steam surface condenser equipped with 7.9 m (26 ft) long, 22.2 mm (7/8 in.) OD tubes.



BASIS OF HEAT BALANCE CALCULATIONS

ELEVATION - APPROXIMATELY 4310 FT.
ATMOSPHERIC PRESSURE - 12.6 PSIA
FUEL - NATURAL GAS
BOILER BLOW DOWN - 0.50 PER CENT OF MAIN STEAM FLOW
STEAM LOSSES - 2000 LB. CONSTANT AT ALL LOADS
BOILER EFFICIENCY - CALCULATED AT A DAILY AVERAGE DRY BULB TEMPERATURE OF FIVE DEGREES LESS THAN THE CIRCULATING WATER INLET TEMPERATURE.
EXTRACTION PRESSURES SHOWN NEAREST THE TURBINE ARE TURBINE EXTRACTION CONNECTION PRESSURES. HEATER ENTRANCE PRESSURE IS SHOWN ADJACENT TO HEATER.
STEAM LINE PRESSURE DROPS ARE CALCULATED AT ALL LOADS.
MAX RATED LOAD HEAT BALANCE CALCULATED AT 1800 PSIG. ALL OTHER HEAT BALANCES CALCULATED AT 105 PERCENT OF RATED PRESSURE.

BALANCE DIAGRAMS WERE GENERATED AND DISPLAYED BY A GENERAL DYNAMICS SC-4020 HIGH SPEED MICROFILM RECORDER.

AUXILIARY POWER REQUIREMENTS ARE CALCULATED FOR ALL PIECES OF MAJOR EQUIPMENT LISTED BELOW.

REQUIREMENTS VARIABLE WITH LOAD

EQUIPMENT	IN OPERATION
2 BOILER FEED PUMPS	2
2 CONDENSATE PUMPS	2
1 FORCED DRAFT FAN	1

CONSTANT REQUIREMENTS

EQUIPMENT	KILOWATTS
2 CIRCULATING WATER PUMPS	292
1 DEEP WELL PUMP	110
MISC MECH EQUIP	180
BUILDING SERVICE	23
MISC + LIGHTING	120
TOTAL CONSTANT REQUIREMENTS	725

ALL HEAT BALANCE RESULTS WERE PRODUCED BY A COMPUTER PROGRAM PROCESSED ON A 7094 IBM COMPUTER.

$$\text{TURBINE HEAT RATE} = \frac{\text{BOILER DUTY}}{\text{GENERATION}} = \frac{9.20938 \times 10^{+08}}{115,171} = 7996.24 \text{ BTU/KW-HR}$$

$$\text{STATION HEAT RATE} = \frac{\text{BOILER DUTY}}{\text{STATION OUTPUT} \times \text{BOILER EFF.}} = \frac{9.20938 \times 10^{+08}}{111,005 \times .8460} = 9807.06 \text{ BTU/KW-HR}$$

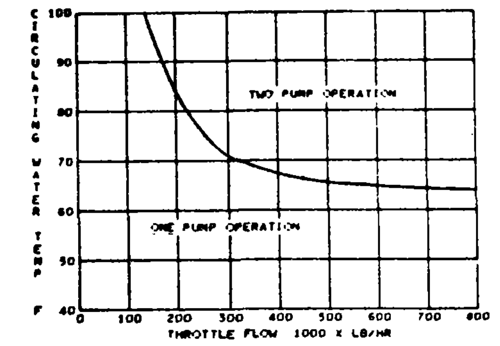
CIRCULATING WATER TEMPERATURE F	CONDENSER PRESSURE IN HG	BOILER EFFICIENCY PERCENT	LAST EXTRACTION FLOW LB/HR	TURBINE EXHAUST FLOW LB/HR	EXPANSION LINE END POINT BTU/LB	EXHAUST ENTHALPY BTU/LB	GENERATION KW	STATION OUTPUT KW	TURBINE HEAT RATE BTU/KWHR	STATION HEAT RATE BTU/KWHR
90.00	3.46	84.85	31,754	545,177	1051.82	1056.99	113,524	109,359	8112.29	9925.20
80.00	2.62	84.72	36,180	540,010	1038.27	1048.82	114,643	110,477	8033.07	9839.27
70.00	1.99	84.60	40,297	535,140	1025.21	1044.38	115,171	111,005	7996.24	9807.06
60.00	1.53	84.47	44,016	530,680	1013.01	1043.04	115,225	111,059	7992.51	9916.89

LEAKAGES

	FLOW	ENTHALPY
A	2969	1477.62
B	819	1477.62
C	18,908	1457.59
D	4586	1329.61
E	3794	1329.61
F	1200	1355.88
G	1400	1355.88
H	2013	1355.88
I	0	0.

LEGEND

— —	STEAM
——	WATER
—o—	POWER
LB	FLOW, POUNDS PER HOUR
H	ENTHALPY, BTU PER POUND
F	TEMPERATURE, DEGREES F
TD	TERMINAL DIFFERENCE
DC	DRAIN COOLER APPROACH
KW	KILOWATTS
IN HG	PRESSURE, IN OF MERCURY, ABS.
PSIA	PRESSURE, LB PER SQUARE IN, ABS.
⋈	CONTROL VALVE



PUMP SLECTION CURVE

HEAT BALANCE DIAGRAM
115171 KW LOAD MAXIMUM GENERATION

FORT CHURCHILL STATION UNIT NO 1
SIERRA PACIFIC POWER COMPANY
RENO, NEVADA

STONE + WEBSTER ENGINEERING CORPORATION
BOSTON, MASSACHUSETTS
DRAWING NUMBER 11087-FM-6A

CORR	APPR	DATE
		6/1/67

Figure 5.25 Heat Balance Diagram

e. Pumps-Boiler Feed - Two half size motor driven boiler feed pumps, each a capacity of 54 kg/s (430,000 lb/hr) at 1905m (6,250 ft.) total head deliver feedwater through the second and first preheaters to the boiler economizer.

f. Pumps-Condensate - Two half size motor driven vertical type condensate pumps each with a capacity of 44 kg/s (350,000 lb/hr) at 119m (390 ft.) total dynamic head draw condensate from the condenser hot well and pump it through the gland steam condenser and the fifth and fourth preheaters to the third deaerating heater.

g. Controls - The control room contains gage boards for boiler, turbine, and boiler feedwater and others which have annunciator alarm systems. The control board includes the turbine control console for bringing the turbine up to speed. Remote burner controls are located on the control board for lightoff of the boiler. Floor space was allotted for adding controls for future coal firing.

There are complete pneumatic control systems for:

System temperature control, combustion and feedwater control, boiler feed pump recirculation, condensate recirculation, hydrogen and lubrication oil temperature control, feedwater heater drain control, and condensate make up control.

h. Emergency Power - A 250 KW, 480 V, 3 phase, 60 cycle Diesel engine driven generator for critical loads such as turning gear drive, bearing and seal oil pump, fire pumps, and battery charger.

i. Chemical Treatment - Chemical Feed Equipment - Prepares and feeds sodium phosphate and caustic soda to the boiler drum, hydrazine and neutralizing amine to the condensate pump discharge.

j. Chemical Treatment - Chlorination Equipment - Includes a liquid chlorine evaporator with controls, vacuum type chlorine solution feed equipment, a one-ton liquid chlorine cylinder complete with valves and manifold, solution piping with control valves and diffusers, and a chlorination water booster pump (capacity .45 m 3/s (120 gpm) at 60m (197 ft.) total dynamic head).

k. Cooling Pond - Cooling pond has a surface area of about 809 388 m^2 (200 acres) and an average depth of 3m (10 ft.). It serves cooling purposes for both units 1 and 2.

l. Plant Auxiliaries

1. Draft System - One forced draft fan having a maximum capacity of 146 m^3/s (310,000 cfm) driven by a 1120 kw (1,500 hp) constant speed induction motor.
2. Circulating Water Pumps - Two half size vertical, wet pit type motor driven circulating water pumps are located in an intake structure at the cooling pond. Each pump has a capacity of 1.52 m^3 /s (24,600 gpm) at a total dynamic head of 7.3m (24 ft.) and is driven by a 150 kw (200 hp) 440V motor.
3. Building Services - Include the following:

   (a) Service water and air for chlorinator room

   (b) Water treatment regenerant waste discharge

   (c) Water treatment sump overflow and water tank drains

   (d) Main boiler blow-off tank drain

   (e) Storm sewer system

   (f) Sanitary waste systems

   (g) Plumbing systems

   (h) Gas piping

   (i) Compressed service air piping

   (j) Fire protection

   (k) Ventilation

(l) Air conditioning

(m) Auxiliary boiler heating

m. Switchyard - 120 KW switchyard consists of a main and transfer bus with two 120 KV lines. The switch yard includes six 120 KV oil circuit breakers with associated disconnecting switches, two pole top switches with ground blades, five potential transformers and six 97 KV lightning arresters.

n. Transformers and Switches - A 290 KW, 375V static excitation and voltage regulator system consists of a 3 phase power potential transformer, connected directly to the generator leads, saturable current transformers in generator terminal leads, and a set of excitation switchgear, including water cooled silicon diode rectifiers, field circuit breaker, and all components for static volage regulator.

5.3 PLANT COST DATA

5.3.1 Basis For Owner's Cost Estimate

The following costs will be considered owner's costs for this conceptual design study.

a. Land and land rights and cost of right of ways.

b. Consulting services for site studies.

c. Archeological search for artifacts.

d. Other environmental studies required for permits.

e. Costs of obtaining all necessary licenses and permits including preparation of environmental impact statements.

f. Dealings with public agencies, long range community relations, etc.

g. Owner's managerial, engineering, financing, and accounting, procurement, labor relations, general services, estimating, planning and scheduling, coordnation, construction, construction management and other home office services directly associated with the project.

h. Plant consumable supplies and startup costs.

i. Property taxes and insurance costs on the land and plant during construction.

j. Cost of money, AFDC (Allowance for Funds During Construction).

5.3.2 Construction Cost Estimate

a. Structure of construction costs estimate will be:

1. Construction cost codes details shown in 5.3.3

2. Construction cost accounts shown in 5.3.3

3. Construction cost backup sheets shown in 5.3.3

b. A/E performs as an engineer and constructor and is the Prime Contractor responsible for:

Plant Design
Quality Control
Construction
Subcontracting Construction
Procuring Major Equipment Construction Management

c. Labor wages rates = base wage rate at job location, 1980.

d. Labor manhours per U.S. Gulf Coast (Houston).

e. Adjustments for labor productivity from U.S. Gulf Coast to job location to be included in productivity (Acct U). Productivity factor = 1.08.

f. Material priced to job location, 1980.

g. Field indirects and engineering shown in 5.3.3.

h. The following two items are not to be included in construction costs:

   1. Sales Tax

   2. Cost of money, AFDC (Allowance for Funds During Construction).

i. Design contingency not to be included in total for construction cost.

j. All unique equipment, not built at the construction site, was costed at the site of manufacture.

5.3.3 Cost Breakdown Structure

5000 PLANT COST

NOTE: Required land for Project to be provided by owner.

5100 Site modifications, roads, landscaping, etc.

5200 Site Facilities (Operations, Security, Storage and Maintenance)

5300 Collector Subsystem

5400 Receiver Subsystem

5500 Master Control Subsystem

5600 Fossil Energy Subsystem (included in 5800)

5700 Energy Storage Subsystem

5800 Electric Power Generating Subsystem

5.3.4 - INDIRECT COSTS

Account

L Temporary Construction Facilities

Includes: Temporary buildings, sheds, trailers, work areas, bays, roads, walks, parking, signs, railroads, unloading docks, utilities, personnel protection, camps, cleaning services, maintenance services, utility bills, and site mainntenance.

M Construction Services, Supplies and Expenses

Services:

Includes cleanup, nonproductive time, medical examinations, doctor's fees, move on and off, and construction equipment maintenance and servicing.

Supplies:

Includes welding rod, oxygen, acetylene, rags and other consumables.

Field Office Supplies:

Includes office machines, telephone, telegraph, postage, computer rental, stationary, furniture.

N Field Staff, Subsistence and Expense

Field Staff:

Includes superintendents, field engineers, cost engineers, field administration, warehouseman, purchaser, nurse, safety engineer, timekeeper, accountant, clerks, Q/A control, watchmen, and security service.

Field Staff Subsistence:

Includes travel, subsistence, transportation, and relocation for field staff.

Field Staff Burdens:

Includes vacation, sick leave, and holiday allowance.

P Field Craft Benefits, Payroll Burdens and Insurance

Field Craft Benefits:

Includes required contributions to funds for vacation, welfare, education, apprentice, retirement, holidays, etc.

Field Craft Travel, Transportation or Subsistence

Payroll Burdens for Field Craft and Field Staff:

Includes social security, workman's compensation, comprehensive PL & PD, state unemployment insurance, federal unemployment insurance.

Insurance:

Includes builder's risk, performance bonds, and marine insurance.

Q Construction Equipment Rental

Special Equipment Rental

Small Tools

NOTE: Special rigging equipment included in the Direct Field Accounts

R Plant Engineering - prime contractor to design plant, subcontract construction, and startup plant.

R&D - for anticipated research and development required to design and produce special equipment which is not currently manufactured.

S <u>Equipment Procurement by Prime Contractor</u>

T <u>Construction Management by Prime Contractor</u>

U <u>Labor Productivity</u>

Includes adjustment for the difference in labor efficiency in Houston to the jobsite.

V <u>Contingency</u>

Construction Cost Contingency - This represents normal construction uncertainties in an estimate which is based on a given design.

Design Contingency - This is an allowance for possible design alternatives and used for project budgetary input.

W <u>Prime Contractors Fee</u>

Material Markups

Fee on Labor and Indirects

Fee on Subcontracted Work

Exclude Design Contingency

COST SUMMARY

5100	Site	$ 2,278,600
5200	Site Facilities	325,700
5300	Collector	136,563,000
5400	Receiver	32,699,200
5500	Master Control	4,990,000
5700	Energy Storage	14,994,200
5800	Electrical Power Generation	3,806,600
	Total (Reno)	$ 195,657,300

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5.3.5 CONSTRUCTION COST ESTIMATE

CLIENT ____

DESCRIPTION Grand Total
5000 Plant Cost

OCATION ____

PROJECT Sierra Pacific Repowering Study

CONT. NO. ____
MADE BY ____
APPROVED ____

A/C NO.	ITEM & DESCRIPTION	MAN HOURS	ESTIMATED COST LABOR	SUBCONTRACTS	MATERIALS	TOTALS
A	Excavation & Civil		375.3	1705.1		2080.4
B	Concrete		1931.2	3101.5	3162.3	8195.0
C	Structural Steel		1150.3	6158.6	1298.3	8607.2
D	Buildings			236		236
E	Machinery & Equipment		2467.0	350.0	93557.0	96374.0
F	Piping		1377.6	.4	7913.1	9291.1
G	Electrical		2427.5	100	5945.5	8473.0
H	Instruments		3.8		11	14.8
J	Painting		2.3			2.3
K	Insulation		101.8	1074.0	47	1222.8
	DIRECT FIELD COSTS		9836.8	12725.6	111934.2	134496.6
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					8322.0
	TOTAL FIELD COSTS					142818.6
R	Engineering					24071.6
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Major Equipment Procurement					2927.0
T	Construction Management					3602.7
	TOTAL OFFICE COSTS					30601.3
	TOTAL FIELD & OFFICE COSTS					173419.9
U	Labor Productivity					1369.5
V	Contingency					14413.6
W	Fee					6454.3
	TOTAL CONSTRUCTION COST					195657.3

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w/o cont. (181,243.7)

CONSTRUCTION COST ESTIMATE

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CLIENT Sierra Pacific
LOCATION Repowering Study
PROJECT

DESCRIPTION 5100 Site

CONT. NO.
MADE BY
APPROVED

A/C NO.	ITEM & DESCRIPTION	MAN HOURS	ESTIMATED COST LABOR	SUBCONTRACTS	MATERIALS	TOTALS
A	Excavation & Civil			1650.7		1650.7
B	Concrete					
C	Structural Steel					
D	Buildings					
E	Machinery & Equipment					
F	Piping			.4		.4
G	Electrical					
H	Instruments					
J	Painting					
K	Insulation					
	DIRECT FIELD COSTS			1651.1		1651.1
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					--
	TOTAL FIELD COSTS					
R	Engineering					363.3
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Major Equipment Procurement					
T	Construction Management					41.3
	TOTAL OFFICE COSTS					404.6
	TOTAL FIELD & OFFICE COSTS					2055.7
U	Labor Productivity					--
V	Contingency					165.1
W	Fee					57.8
	TOTAL CONSTRUCTION COST					2278.6

DATE REVISION NO. REVISION DATE PAGE NO.

(2113.5)

JOB NO. ______ PROJECT Sierra Pacific Repowering Study (Dollars in Thousands) ______ LOCATION ______ CLIENT ______

DATE ______ TAKE-OFF ______ PRICED ______ CALC. CHKD ______ APPROVED ______ SHEET ______ OF ______

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	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5100 Site Work									
A	Excavation & Civil									
A1	Removal of Brush, Rock, etc.									867.6
A2	Grading									272.7
A3	Yard Drainage									9.5
A4	Berm Ground Salt Tanks									9.1
A5	Soil Testing									5.0
A6	RR Spur									66.3
A7	Fencing									217.4
A8	Roads - Gravel									109.9
	Paved									66.0
	Relocate & Pave									14.5
A9	Paved Area									12.7
	Total A									1650.7
F	Piping									
	Sanitary Sewer									.4
	Total F									.4
R	Eng.									
R1	Startup									198.1
R2	A&E									82.6
R3	Solar Integrator									82.6
T	Constr. Mgt.									41.3
V	Contingency									165.1
W	Fee									57.8
CODE										

CONSTRUCTION COST ESTIMATE

1D22600
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CLIENT ____

DESCRIPTION 5200 Site Facilities

LOCATION Sierra Pacific

PROJECT Repowering Study

CONT. NO. ____

MADE BY ____

APPROVED ____

A/C NO.	ITEM & DESCRIPTION	MAN HOURS	ESTIMATED COST LABOR	SUBCONTRACTS	MATERIALS	TOTALS
A	Excavation & Civil					
B	Concrete					
C	Structural Steel					
D	Buildings			236		236
E	Machinery & Equipment					
F	Piping					
G	Electrical					
H	Instruments					
J	Painting					
K	Insulation					
	DIRECT FIELD COSTS			236		236
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					--
	TOTAL FIELD COSTS					236
R	Engineering					51.9
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Major Equipment Procurement					
T	Construction Management					5.9
	TOTAL OFFICE COSTS					57.8
	TOTAL FIELD & OFFICE COSTS					293.8
U	Labor Productivity					
V	Contingency					23.6
W	Fee					8.3
	TOTAL CONSTRUCTION COST					325.7

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w/o (302.1)

JOB NO. PROJECT Sierra Pacific Repowering Study LOCATION CLIENT

(Dollars in Thousands)

DATE TAKE-OFF PRICED CALC. CHKD APPROVED SHEET OF

	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
5200 Administrative Areas										
B	Buildings									
B1	Warehouse	4000	SF	23.00						92
B2	Garage	4800	SF	30.00						144
	Total B									236
R	Eng.									
R1	Startup									28.3
R2	A & E									11.8
R3	Solar Integrator									11.8
	Total R									51.9
T	Contr. Mgt.									5.9
V	Contingency									23.6
W	Fee									8.3
CODE										

CONSTRUCTION COST ESTIMATE

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CLIENT

DESCRIPTION 5300 Collector

LOCATION Sierra Pacific

PROJECT Repowering Study

CONT. NO.

MADE BY

APPROVED

A/C NO.	ITEM & DESCRIPTION	MAN HOURS	ESTIMATED COST LABOR	SUBCONTRACTS	MATERIALS	TOTALS
A	Excavation & Civil	22400	366		--	366
B	Concrete	58800	960		2195	3155
C	Structural Steel					
D	Buildings					
E	Machinery & Equipment	122300	2050		88484	90534
F	Piping					
G	Electrical	132400	2160		4946	7106
H	Instruments	200	2		11	13
J	Painting					
K	Insulation					
	DIRECT FIELD COSTS		5538		95636	101174
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		4154		874	5028
	TOTAL FIELD COSTS					106202
R	Engineering					11373
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Major Equipment Procurement				440	440
T	Construction Management					2674
	TOTAL OFFICE COSTS					14487
	TOTAL FIELD & OFFICE COSTS					120689
U	Labor Productivity					777
V	Contingency					10697
W	Fee					4400
	TOTAL CONSTRUCTION COST					136563

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(w/o cont. 125866)

JOB NO. ______ PROJECT SIERRA PACIFIC REPOWERING STUDY LOCATION ______ CLIENT ______

(DOLLARS IN THOUSANDS)

DATE ______ TAKE-OFF ______ PRICED ______ CALC. CHKD ______ APPROVED ______ SHEET ______ OF ______

	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5800 COLLECTOR									
A	ESCAVATION AND CIVIL									
A1	HELIOSTAT FOUNDATIONS	22.41	hrs		16.32			366		366
	TOTAL A									
B	CONCRETE									
B1	HELIOSTAT & MISC FOUNDATION	58.8 K	hrs.		16.32		2195	960		3155
	TOTAL B									
C	STRUCTURAL STEEL									
D	BUILDINGS									
E	MACHINERY AND EQUIPMENT									
E1	REFLECTOR PANEL INCLUDING MIRROR PACKING STRUCTURE					X	35980			35980
E2	DRIVE UNIT (PEDESTAL DRIVE, SHORT MAIN GEAR AND ELECTRONICS						52504			52504
E3	FIELD ASSY, C/O AND ALIGNMENT	122.3K	hrs		16.76			2050		2050
	TOTAL E						88484	2050		90534
G	ELECTRICAL									
G1	ELECTRICAL DISTRIBUTION						4946			4946
G2	ASSY, INSTAL AND C/O	132.4K	hrs.		16.32			2160		2160
	TOTAL G						4946	2160		7106

CODE

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JOB NO. ______ PROJECT Sierra Pacific Repowering Study LOCATION ______ CLIENT ______

DATE ______ TAKE-OFF (Dollars in thousands) PRICED ______ CALC. CHKD ______ APPROVED ______ SHEET ______ OF ______

	5300 Collector ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
H	Instruments									
H1	Sensor/Calib. Eq.						11			11
H2	Install & Calibrate	.7k	hrs	-----	16.32			2		2
	Total H						11	2		13
J	Painting (Heliostats prepainted)									
K	Insulation									
I-Q	Indirect Field Costs									
	Distributables									4154
	Initial spares & c/o spares									874
	Total I-Q									5028
R	Engineering									
	A & E									5349
	Field layout									50
R3	Solar/Integ/Startup									5974
	Total R									11373
S	Major Equipment									
S1	Service links									16
S2	Slings									24
S3	Washing Vehicles									254
S4	Repair Equipment									48
S5	Other Equipment									- 98
	Total S									440

CODE

CONSTRUCTION COST ESTIMATE

1D22600
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CLIENT ______________

DESCRIPTION 5400 Receiver

LOCATION ______________ Sierra Pacific

PROJECT Repowering Study

CONT. NO. ______________

MADE BY ______________

APPROVED ______________

A/C NO.	ITEM & DESCRIPTION	MAN HOURS	ESTIMATED COST			
			LABOR	SUBCONTRACTS	MATERIALS	TOTALS
A	Excavation & Civil			39.0		39.0
B	Concrete		639.2	3101.5	693.3	4434.0
C	Structural Steel		536.8	6158.6		6695.4
D	Buildings					
E	Machinery & Equipment		7.7	350.0	800.0	1157.7
F	Piping		932.6		6449.1	7381.7
G	Electrical		3.7	100.0	13.0	116.7
H	Instruments					
J	Painting					
K	Insulation		83.3	954.6		1037.9
	DIRECT FIELD COSTS		2203.3	10703.7	7955.4	20862.4
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					1594.5
	TOTAL FIELD COSTS					22456.9
R	Engineering					5605.5
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Major Equipment Procurement					64.0
T	Construction Management					569.0
	TOTAL OFFICE COSTS					6238.5
	TOTAL FIELD & OFFICE COSTS					28695.4
U	Labor Productivity					303.9
V	Contingency					2276.1
W	Fee					1423.8
	TOTAL CONSTRUCTION COST					32699.2

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30,423.1

JOB NO. ______ PROJECT SIERRA PACIFIC REPOWERING STUDY ______ LOCATION ______ CLIENT ______

(DOLLARS IN THOUSANDS)

DATE ______ TAKE-OFF ______ PRICED ______ CALC. CHKD ______ APPROVED ______ SHEET ______ OF ______

	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5400 RECEIVER									
A	ESCAVATION AND CIVIL									
A1	TOWER (EXCAVATION & BACKFILL)								39.0	
	TOTAL A									39.0
B	CONCRETE									
B1	TOWER FOUNDATION						688.3	634.6		
B2	TOWER ERECTION SUBCONTRACT								3101.5	
B3	SYSTEM PIPING						5.0	4.6		
	TOTAL B									4434.0
C	STRUCTURAL STEEL									
C1	RECEIVER EQ									
	RECEIVER UNIT							320.8	5713.6	
	SUBASSEMBLY ERECTION							202.2		
	DOOR							13.8	175.0	
	ERECTION/RECEIVER								270.0	
	TOTAL C									6695.4
E	MACHINERY AND EQUIPMENT									
E1	RECEIVER FEED PUMP						800.0	7.7		
E2	ELEVATOR, PLATFORM, LADDER								350.0	
	TOTAL E									1157.7
CODE										

JOB NO. ______ PROJECT SIERRA PACIFIC REPOWERING STUDY ______ LOCATION ______ CLIENT ______

(DOLLARS IN THOUSANDS)

DATE ______ TAKE-OFF ______ PRICED ______ CALC. CHKD ______ APPROVED ______ SHEET ______ OF ______

	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5400 RECEIVER									
F	PIPING									
	RECEIVER (WITHIN							91.7		
	SYSTEM PIPING						6449.1	840 9		
	TOTAL F									7381.7
G	ELECTRICAL									
	TOWER (LIGHT, GRIND, OBSTR., MISC)								100.0	
	RECEIVER - TRACE HEAT						6.0	.9		
	SYSTEM PIPING						7.0	2.8		
	TOTAL G									116.7
K	INSULATION									
k1	RECEIVER							83.3		
K2	SYSTEM PIPING								954.6	
S	INITIAL SPARES									64 0
L-Q	INDIRECT									1594.5
R	ENG.									
R1	REC.									1413 5
R2	TOWER									322.7
R3	STARTUP									2731.3
R4	A&E									1138.0
R5	SOLAR INTEG.									1138.0
T	CONSTR. MGT.									569.0
11	LABOR PROP.									297.2
V	CONTINGENCY									2276.1
CODE	FEE									1433.8

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CONSTRUCTION COST ESTIMATE

CLIENT

DESCRIPTION 5500 Master Control

LOCATION Sierra Pacific

PROJECT Repowering Study

CONT. NO.
MADE BY
APPROVED

A/C NO.	ITEM & DESCRIPTION	MAN HOURS	ESTIMATED COST			
			LABOR	SUBCONTRACTS	MATERIALS	TOTALS
A	Excavation & Civil					
B	Concrete					
C	Structural Steel					
D	Buildings					
E	Machinery & Equipment	3522	62		1137	1199
F	Piping					
G	Electrical	2336	41		12	53
H	Instruments					
J	Painting					
K	Insulation					
	DIRECT FIELD COSTS		103		1149	1252
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		77		81	158
	TOTAL FIELD COSTS					1410
R	Engineering					3345
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Major Equipment Procurement					--
T	Construction Management					35
	TOTAL OFFICE COSTS					3380
	TOTAL FIELD & OFFICE COSTS					4790
U	Labor Productivity					6
V	Contingency					142
W	Fee					52
	TOTAL CONSTRUCTION COST					4990

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W/O C 4848

JOB NO. ______ PROJECT SIERRA PACIFIC LOCATION ______ CLIENT ______

(DOLLARS IN THOUSANDS)

DATE ______ TAKE-OFF ______ PRICED ______ CALC. CHKD ______ APPROVED ______ SHEET ______ OF ______

	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5500 MASTER CONTROL									
E	EQUIPMENT									
E1	COMPUTERS AND PERIFERALS						440			440
E2	SYS CONTROL ELEMENTS						44			44
E3	S/SYS OPER CONTROL ELEMENTS						438			438
E4	CONSOLES, CRATES AND EVAL						12			12
E6	FIELD INSTALLATION	3512 hrs			17.52			62		62
	TOTAL E						1137	62		1194
G	ELECTRICAL									
G1	INTRA-SYS WIRE (XHELIO)						12			12
G2	FIELD INSTALLATION	2336 hrs			17.52			41		41
	TOTAL G									53
L-Q	INDIRECTS									
	DISTRIBUTABLES									77
	INITIAL SPARES									181
	TOTAL L-Q									158
R	ENGINEERING									
R1	A&E									71
R2	MCS DESIGN AND ENGINEERING									
	HARDWARE									856
	SOFTWARE									1987
	SYS INT LAB									190
R3	SOLAR INT & STARTUP									241
	TOTAL R									3345
CODE										

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CONSTRUCTION COST ESTIMATE

CLIENT ______

LOCATION ______

PROJECT ______

DESCRIPTION 5700 Energy Storage Subsystem

CONT. NO. ______

MADE BY ______

APPROVED ______

A/C NO.	ITEM & DESCRIPTION	MAN HOURS	ESTIMATED COST LABOR	SUBCONTRACTS	MATERIALS	TOTALS
A	Excavation & Civil		9.3	15.4		24.7
B	Concrete		332.0		274.0	606.0
C	Structural Steel		613.5		1298.3	1911.8
D	Buildings					
E	Machinery & Equipment		347.3		3136.0	3483.3
F	Piping		165.6		636.9	802.5
G	Electrical		138.9			138.9
H	Instruments		7.8			7.8
J	Painting		2.3			2.3
K	Insulation		18.5	72.1	47.0	137.6
	DIRECT FIELD COSTS		1629.2	87.5	5372.2	7108.9
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					1137.5
	TOTAL FIELD COSTS					8246.4
R	Engineering					2754.3
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Major Equipment Procurement (Media			29.0	2394.0	2423.0
T	Construction Management					211.7
	TOTAL OFFICE COSTS					5389.0
	TOTAL FIELD & OFFICE COSTS					13635.4
U	Labor Productivity					221.3
V	Contingency 846.77					846.8
W	Fee					290.7
	TOTAL CONSTRUCTION COST					14,994.2

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19,147.4

JOB NO. ________ PROJECT SIERRA PACIFIC REPOWERING STUDY ________ LOCATION ________ CLIENT ________

(DOLLARS IN THOUSANDS)

DATE ________ TAKE-OFF ________ PRICED ________ CALC. CHKD ________ APPROVED ________ SHEET ________ OF ________

	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5700 ENERGY STORAGE									
A	EXCAVATION AND CIVIL									
A1	HEAT EXCHANGERS UNIT							19.3		
A2	HOT TANK								8.4	
A3	COLD TANK								7.0	
	TOTAL A									24.7
B	CONCRETE									
B1	HEAT EXCHANGER FOUNDATION						30.0	59.3		
B2	HOT TANK FOUNDATION						134.0	150.5		
B3	COLD TANK FOUNDATION						110.0	122.2		
	TOTAL B									606.0
C	STRUCTURAL STEEL									
C1	HEAT EXCHANGER							81.5		
C2	HOT TANK									
	INNER SHELL							203.2	792.0	
	OUTER SHELL							78.4	131.9	
	ANCHOR BOLTS							19.5	24.0	
C3	COLD TANK									
	INNER SHELL							141.1	208.0	
	OUTER SHELL							70.3	118.4	
	ANCHOR BOLTS							19.5	24.0	
	TOTAL C									1911.8

CODE

JOB NO. PROJECT SIERRA PACIFIC REPOWERING STUDY LOCATION CLIENT

(DOLLARS IN THOUSANDS)

DATE TAKE-OFF PRICED CALC. CHKD APPROVED SHEET OF

	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5700 ENERGY STORAGE									
E	EQUIPMENT									
E1	Heat Exchangers						2636.0	341.2		
E2	FEED PUMPS						900.0	6.1		
	Total E									3483.3
F	PIPING									
F1	HEAT EXCHANGER							28.0		
F2	HOT TANK - SPARGER						17.0	4.4		
F3	COLD TANK - SPARGER						5.1	3.1		
F4	INTERCONNECTING SYSTEM PIPING						614.8	130.1		
	TOTAL F									802.5
G	ELECTRICAL									
G1	HEAT EXCHANGER							138.9		
	TOTAL G									138.9
H	INSTRUMENTS									
H1	HEAT EXCHANGER							1.8		
	TOTAL H									1.8
J	PAINTING									
J1	HEAT EXCHANGER							2.3		
	TOTAL J									2.3

CODE

JOB NO. ______ PROJECT SIERRA PACIFIC REPOWERING STUDY ______ LOCATION ______ CLIENT ______

(DOLLARS IN THOUSANDS)

DATE ______ TAKE-OFF ______ PRICED ______ CALC. CHKD ______ APPROVED ______ SHEET ______ OF ______

	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5700 ENERGY STORAGE									
K	INSULATION									
K1	HEAT EXCHANGER							15.5		
K2	HOT TANK						30.0	1.9		
K3	COLD TANK						17.0	1.1		
K4	INTERCONNECTING PIPING								72.1	
	TOTAL K									137.1
L-0	INDIRECT									1137.5
R	ENG									
R1	HEAT EXCHANGERS									891.4
R2	STARTUP									1016.1
R3	A& E									423.4
R4	SOLAR INTEGRATOR									423.4
S	Major Eq. Proc									
S1	INITIAL SPARES									29.0
S2	MEDIA									2394.0
T	CONSTR. MGF.									211.7
U	LABOR PRODUCTIVITY									221.3
V	CONT.									846.8
W	FEE									587.1
CODE										

CONSTRUCTION COST ESTIMATE

1D22600
Issue: B
16 June 1980

CLIENT ____

DESCRIPTION 5800 Electrical Power Generation

LOCATION ____

CONT. NO. ____

PROJECT Sierra Pacific Repowering Study

MADE BY ____

APPROVED ____

A/C NO.	ITEM & DESCRIPTION	MAN HOURS	ESTIMATED COST LABOR	SUBCONTRACTS	MATERIALS	TOTALS
A	Excavation & Civil					
B	Concrete					
C	Structural Steel					
D	Buildings					
E	Machinery & Equipment					
F	Piping		279.4		827.1	1106.5
G	Electrical		83.9		974.5	1058.4
H	Instruments					
J	Painting					
K	Insulation			47.3		47.3
	DIRECT FIELD COSTS		363.3	47.3	1801.6	2212.2
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					404.0
	TOTAL FIELD COSTS					2616.2
R	Engineering					578.6
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Major Equipment Procurement					
T	Construction Management					65.8
	TOTAL OFFICE COSTS					644.4
	TOTAL FIELD & OFFICE COSTS					3260.6
U	Labor Productivity					61.3
V	Contingency					263.0
W	Fee					221.7
	TOTAL CONSTRUCTION COST					3806.6

DATE ____ REVISION NO. ____ REVISION DATE ____ PAGE NO. ____

JOB NO. ______ PROJECT SIERRA PACIFIC REPOWERING STUDY LOCATION ______ CLIENT ______

(DOLLARS IN THOUSANDS)

DATE ______ TAKE-OFF ______ PRICED ______ CALC. CHKD ______ APPROVED ______ SHEET ______ OF ______

	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5800 EPGS									
E	PIPING									
E1	MAIN STEAM PIPING						376.3	119.8		
E2	HOT REHEAT PIPING						280.1	94.6		
E3	COLD REHEAT PIPING						170.8	65.0		
	TOTAL E									1106.5
G	ELECTRICAL									
G1	EMERGENCY ENGINE GENERATOR	1					200			
G2	SWITCHGEAR UNITS	12					260			
G3	LOAD CENTER	1					34			
G4	MOTOR CONTROL CENTER	1					19			
G5	TRANSFORMERS	4					19			
G6	LOT LIGHTING / POWER PANELS						12			
G7	BATTERY	1					10			
G8	BATTERY CHARGER	1					3			
G9	UNINTERRUPTIBLE SYSTEM	1					50			
G10	WIRING, CONDUIT, SUPPORTS						270			
G11	INSTALLATION							56.5		
F1	TRANSFORMER, AUX						12.0	3.7		
F2	SWITCHGEAR						85.5	23.7		
	TOTAL F									124.9
K	INSULATION									
K1	SYSTEM INSULATION								47.3	
	Total K									47.3

CODE

JOB NO. ______ PROJECT SIERRA PACIFIC REPOWERING STUDY LOCATION ______ CLIENT ______

(DOLLARS IN THOUSANDS)

DATE ______ TAKE-OFF ______ PRICED ______ CALC. CHKD ______ APPROVED ______ SHEET ______ OF ______

ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
5800 EPGS									
INDIRECT									404.0
ENG.									
STARTUP									315.6
A&E									131.5
SOLAR INTEGRATOR									131.5
CONSTR. MGR.									65.8
LABOR PRODUCTIVITY									61.3
CONTINGENCY									263.0
FEE									227.7
CODE									

A-128

SIERRA PACIFIC OWNER'S COST

COST ELEMENT	Private Land	Private and Public Land
a. Land and land rights and right of ways.		$ 800,000*
b. Consulting services for site studies. c. Archeological search for artifacts. d. Other environmental studies. e. Licenses, permits and statements. f. Public relations, etc.	$ 15,000	61,000
g. Owner's Home Office Services.	445,000	445,000
h. Plant consumable supplies and startup costs.		
i. Property taxes and insurance costs during construction.	2.52%** 0.75%***	2.52%** 0.75%***
j. Cost of money, AFDC (Allowance for Funds During Construction).	12.8%, 10%	12.8%, 10%
TOTAL (Excluding "i" and "j")- - - - - - - - - - - -	$460,000	$1,306,000

* Value of land already owned by Sierra Pacific.

** Property taxes on Assessed Value (35% Project Total Cost).

*** Project Insurance applied on Project Total Cost.

5.3.6 - SOLAR PLANT OPERATIONS AND MAINTENANCE COSTS

- OM100 Operations
  - OM110 Operating Personnel
  - OM120 Operating Consumables
  - OM130 Fixed Charges
- OM200 Maintenance Materials
  - OM210 Spare Parts
    - OM211 Turbine and Electrical Plant
    - OM212 Collector Equipment
    - OM213 Receiver Equipment
    - OM214 Thermal Storage Equipment
    - OM215 Non-Solar Energy Subsystem Equipment
  - OM220 Materials for Repairs
  - OM230 Other
- OM300 Maintenance Labor
  - OM310 Scheduled Maintenance
  - OM320 Corrective Maintenance

O & M SUMMARY

1ST YEAR COSTS - ($ IN 1000'S)

OM 100 Operation *	
OM 200 Maintenance Materials	
OM 210 Spare Costs	110.4
OM 220 Materials for Repairs	161.5
OM 230 Other	663.2
OM 300 Maintenance Labor	
OM 310 Scheduled Maintenance	105.9
OM 320 Corrective Maintenance	443.7
TOTAL	$1,484.7

* The Solar plant operators are assummed to be regular plant operators.

O & M SUMMARY - 1st YEAR - ($ in 1000's)

	NON LABOR			LABOR		
	SPARES	REP. PTS.	OTHER	CORRECT	SCHED.	TOTAL
HELIOSTAT EQUIPMENT	109.8	160.9	160.2	439.3	105.9	$ 976.1
MASTER CONTROL EQ.	.6	.6	19.2	4.4	---	24.8
RECEIVER SUBSYSTEM			287.4			287.4
THERMAL STORAGE SUBSYSTEM			148.4			148.4
ELECTRICAL POWER GENERATING			43.3			43.3
SITE AND STRUCTURE			4.7			4.7
TOTAL						$ 1,484.7

5.4 ECONOMIC DATA

The economic data presented in this section will be used to judge the value of this site-specific conceptual design and to make an assessment of the incentives that would make this plant more attractive to the user. This value determination will include a capital construction cost estimate, O&M costs and an estimate of the amount of oil or natural gas which will be displaced over the life of the solar plant.

The economic assumptions and data presented will permit the determination of a levelized busbar energy cost (BBEC) in mills/KW and user value assessment.

Two parameters have been set: (1) The solar repowered plant must be ready for operation by 1985 and (2) The solar contribution must be at least 20%.

5.4.1 Economic Parameters

The economic analysis will be completed using the economic parameters applicable to the Ft. Churchill Plant, Sierra Pacific Power Co. These parameters are as follows:

a.	Interest during construction:	None	
b.	System life:	Unit 1	30 years
		Unit 2	30 years
c.	Debt fraction:	0.5	
d.	Return on debt:	8.5%	
e.	Stock fraction:	Preferred stock	0.1
		Common equity	0.4
f.	Return on stock:	Preferred stock	8.5%
		Common equity	15.0%
g.	Cost of capital:	10.7% (before tax)	
h.	Income tax rate:	48%	

i.	Annual insurance/other taxes:	Insurance: 0.24%
		General Taxes: 1.20%
		1.44%
j.	Description method:	Straight Line

NOTE: Depreciation used for tax purposes was declining balance switching to straight line

j.	Depreciation life:	Unit 1	23 years
		Unit 2	27 years
l.	Fixed charge rate:	Unit 1	14.827%
		Unit 2	14.641%
m.	Rate of general inflation:	None used	
n.	Capital escalation rate:	6%	
o.	O&M escalation rate:	6%	
p.	Referfence year:	1977	

5.4.2 Site Owners Alternate Fuel Cost Estimates

The study relaated to the use of alternate fuels for the Ft. Churchill Plants have been completed and estimates of the cost of each alternate supplier determined. The estimates are as follows:

a. Direct Coal Conversion of Units 1 and 2

Capital Costs:	$630/net KWe	
O&M Cost:	$3.2/MWh	
Fuel Cost:	13.8 cents/Therm	
Fuel Escalation:	6%	
Fuel Rate:	Gross	10,400 Btu/KWh
	Net	11,400 Btu/KWh
Construction Period:	Unit 1	4 years, 5 months
	Unit 2	3 years, 9 months

b. Coal/Oil Mixture Conversion

Capital Cost:	$270/Net KWe
O&M Cost:	Coal $3.2/MWh
	Oil $2.4/MWh
Fuel Cost:	Coal 13.8 cents/Therm
	Oil 27.9 cents/Therm
Fuel Escalation Rate:	6%
Heat Rate:	Gross 9,400 Btu/KWh
	Net 10,000 Btu/KWh
Construction Period:	Unit 1 4 years, 5 months
	Unit 2 3 years, 9 months

5.4.2.2 Cost Factors

The factors used in this estimation include:

a. Residual Fuel Oil: (#6)	$4.65/MMBtu
Escalation Rate:	10%
b. Coal Escalation Rate	$1.49 MMBtu
	7%
c. Natural Gas:	3.86/MMBtu
Escalation Rate:	10%

5.4.3 DOE Supplied Fuel Cost Assumptions

Fuel Costs (1980 $/MBTU)

o Nuclear	.85
o Coal	1.25
o Oil	4.00
o Natural Gas	2.50

NOTE: Fuel costs are based on delivered prices.

Fuel Escalation Rates

o General Inflation	8% per year.
o Nuclear	1% per year above General Inflation
o Coal	2% per year above General Inflation
o Oil	4% per year above General Inflation
o Natural Gas	3% per year above General Inflation

Capital Cost (1980 $/KWe) -

Nuclear	1000
Coal	860
Combined Cycle (oil)	360
Combustion Turbine (oil)	190

5.5 SIMULATION MODELS

5.5.1 Insolation

The solar insolation model for determining the plant performance will consist of the following:

a.	Peak flux, clear day, equinox noon	1008 Watts/m^2
b.	Average flux, clear day, spring equinox	9.6 KWHR/m^2/day
c.	Average flux, spring, (w/weather)	6.5 KWHR/m^2/day
d.	Average flux, summer, (w/weather)	9.2 KWHR/m^2/day
e.	Average flux, fall, (w/weather)	8.3 KWHR/m^2/day
f.	Average flux, winter, (w/weather)	4.2 KWHR/m^2/day
g.	Annual average flux, (w/weather)	7.2 KWHR/m^2/day

NOTE: The values for this model will be determined by comparing direct solar isolation measurement taken at the Ft. Churchill site with available long term insolation values from other data sources in the general area of the repowered plant.

Trade studies and performance evaluations will use Typical Week Per Season insolation models. Those models will have the following characteristics:

a. All four seasons will be represented.

b. Seven actual days of historic data will be chosen for each season.

c. For each season, the days will be selected such that:

   1. Average daily total energy will equal the best projections for the Ft. Churchill site,

   2. The frequency distribution of isolation level will closely match that projected for Ft. Churchill, and

   3. The frequency distribution of total daily energy will closely match that projected for Ft. Churchill.

Actual days for the Typial Week Per Season models will be selected from sites close to Ft. Churchill as possible, and having weather, humidity, turbidity and elevation characteristics which match Ft. Churchill as closely as possible.

5.5.2 Plant Performance

The plant performance/heat balances will be determined using the codes developed by Stearns Roger.

The gross heat rate (GHR) will be determind for:

a. Design Point = 1800 psi, $1000^{o}F/1000^{o}F$
b. Off Design Point = 1800 psi, $950^{o}F/950^{o}F$
c. Off Design Point = 1800 psi, $950^{o}F/940^{o}F$
d. Off Design Point = 1890 psi, $1000^{o}F/1000^{o}F$
e. Off Design Point = 1890 psi, $950^{o}F/950^{o}F$
f. Off Design Point = 1890 psi, $950^{o}F/940^{o}F$

These points will be determined for the following conditions:

a.	Hybrid	70 MWe Solar	45 MWe Fossil
b.	Hybrid	77 MWe Solar	38 MWe Fossil
c.	Solar Standalone	70 MWe (gross)	
d.	Solar Standalone	77 MWe (gross)	

5.5.3 Plant Economic Model

Utility economic evaluations will be performd by Westinghouse using their STPM computer code. MDAC and Westinghouse will make plant cost estimates and an economic analysis of the Ft. Churchill repowering design. Capital and O&M costs (including cost of plant modification and down-time) will be developed from the DOE 10 MWe Barstow plant, the second generation Heliostat and other studies. Where new cost data must be developed, specific task and hardware requirements will be determined from the conceptual design. The economic analysis will integrate system design and performance estimates, utility operating parameters, and fuel, capital and O&M costs in order to provide:

- Annual and cumulative fuel saving

- Project worth, net value and cost/benefit ratios to Sierra Pacific Power Co.

- Comparative annual and cumulative cost for the repowered plant and alternate options (and other advantages/disadvantages).

The approach to be used is illustrated in Figure 5.26.

The specific fuel costs and escalation rates in this region have been assessed by Sierra Pacific and will be documented and used in the economic analysis. Sierra Pacific Power will also document financial parameters; i.e., weighted cost of capital, tax rates, depreciation methods and schedules, and other annual expenses, such as insurance.

The economic analysis will consider Sierra Pacific operating parameters, such as its existing and projected generating mix, load profile, reliability requirements, and dispatch strategies. A unique methodology developed by the Westinghouse Advanced Systems Technology Division in the performance of EPRI RP 648-1, "Requirements Definition and Impact Analysis of Solar Thermal Power Plants," is directly applicable to this type of analysis and will be used in this study. The methodology includes a system of computer models and economic procedures for the overall grid system which specifically integrates the solar plant concept into the final assessment and economic impact analysis.

The principal economic measures of solar plants using this methodology are:

- Levelized busbar energy cost with and without solar
- Cost/benefit of the solar plant
- Net economic impact upon utility

The Fort Churchill plant with and without solar repowering, and the other Sierra Pacific plants (Tracy and North Valmy), will be modeled on the Westinghouse computer program, together with the grid connections. The grid operation will be simulated for a projected year's load and insolation. Fuel displacement of all types from all plants and from the grid connection is estimated from the difference in fuel expended in the total system with and without the solar repowering of Fort Churchill Unit No. 1. Almost all of the

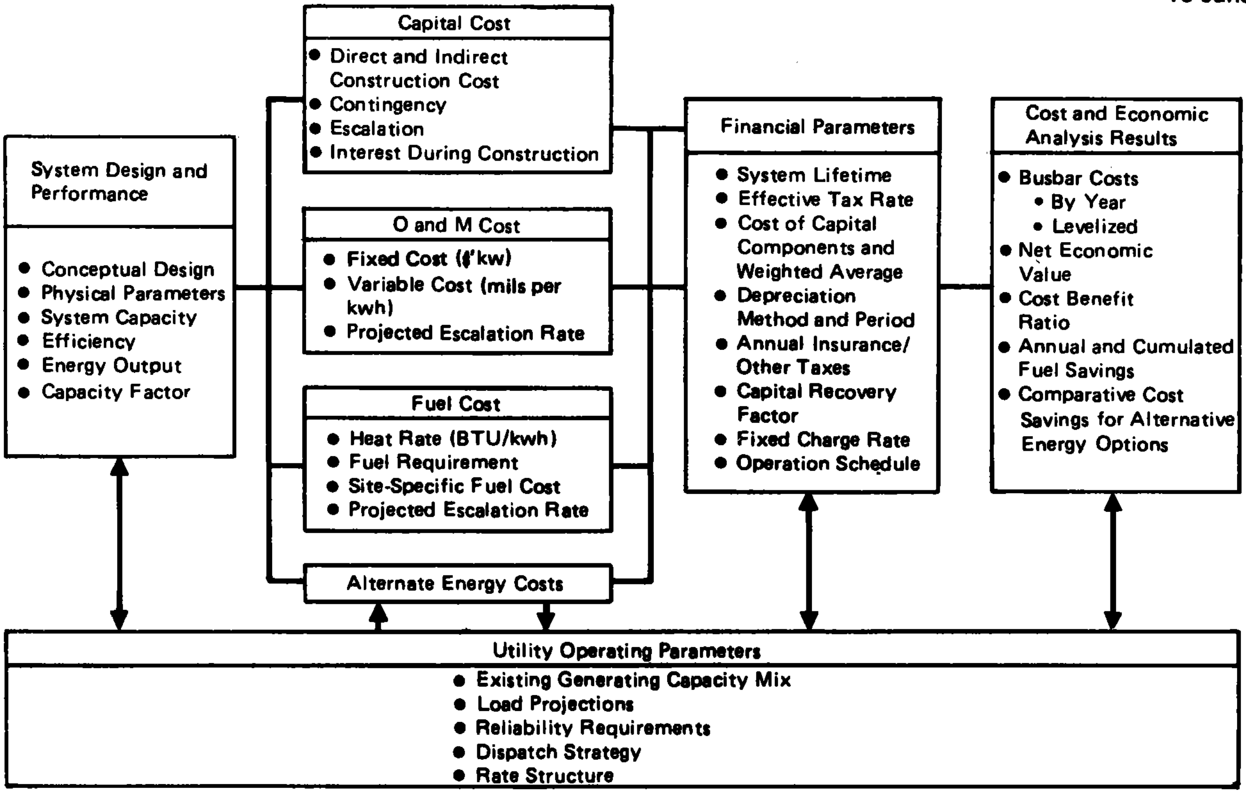


Figure 5-26. Ecomonic Assessment Diagram

fuel displaced is expected to be oil, because of the preponderance of oil in the generation capacity mix.

The levelized busbar cost methodology is consistent with the EPRI economic evaluation guidelines stipulated in the August 1977 EPRI "Technical Assessment Guide," and is a function of solar plant costs, electric energy production, and the financial parameters described earlier.

APPENDIX B CONTENTS

SIERRA PACIFIC UTILITY SOLAR REPOWERING
TASK 2 TRADE STUDY REPORT
RECEIVER FLUID SELECTION

1.0 OBJECTIVE AND SCOPE

This trade study compares two generic types of receiver fluids; molten salt as representative of receivers heating an intermediate fluid and water/steam as representative of the direct generation of steam for admission to the turbine in the receiver.

Since the turbine operates on a reheat cycle, and there is no acceptable means for using solar energy to reheat the steam, this trade study may seem unnecessary. However, a fossil fuel fired reheater, as an additional piece of equipment, does permit reheating. The expenditure of fossil fuel for this auxiliary reheater is less than 20% of that required to operate the complete cycle. Moreover, this arrangement allows for limited use of thermal storage for buffering solar energy collection. Hence, it is not necessary, in general, to operate the primary boiler in order to utilize solar energy. Hence, the two major objections to water/steam are circumvented.

The selection, then, rests on the traditional issues of system economics, user acceptability, and technology readiness. Table 1 summarizes the trade study objectives and approach.

2.0 SIZING AND PERFORMANCE ESTIMATES

Two system concepts (water/steam and heat transfer salt) were considered. The water/steam system was considered with buffer storage, only. The heat transfer salt system was considered with solar multiples (ratio of solar heat collected at the design point to turbine heat flow) of 1.0, 1.4 and 1.8. These solar multiples correspond to buffer storage, 2.7 hour storage and 6.5 hour storage, respectively.

Table 1

RECEIVER FLUID SELECTION (TS-1)

OBJECTIVE: To select the receiver heat transfer fluid.

CANDIDATES: Baseline - Heat transfer salt
Alternates - Water/steam

SELECTION CRITERIA: System cost, value of fuel displaced, solar fraction, operational considerations, user acceptance.

APPROACH: Estimate system from system cost estimating relationships as a function of solar multiple, annual electric energy generation, and operating costs including cost credit for fuel displaced. Estimate operational impact of reduced power output from storage with water/steam on plant performance in grid. Display prominently any site/application specific findings which play a significant rôle in the system selection. Factor in user acceptance of approaches, including O&M requirements and effects of development schedule.

EXPECTED RESULTS: Higher solar fraction and the cost of a long steam line from the collector/tower to the plant will weigh in favor of the baseline system.

INPUT DATA:
- First commercial unit cost data from the pilot plant
- Heliostat cost estimates from the Second Generation Heliostat Program
- Molten salt equipment cost estimates from MDAC and DOE/Sandia Advanced Concepts Program
- Reno insolation data
- Project 1985 plant usage and capacity factor

PARTICIPATING ORGANIZATIONS: MDAC - lead
SPPC - User acceptance, plant usage

2.1 WATER/STEAM SYSTEM CONCEPT DESCRIPTION

The existing reheat plant requires 1000°F in the reheat. Solar reheat is not adequate or effective for this purpose. However, a fossil fired reheater can be used to suppliment the solar boiler. Figure 1 shows a schematic of such a system.

Steam generated in the receiver is mixed with fossil boiler steam and expanded through the high pressure turbine. A proportional control divides the steam outlet from the high pressure turbine through the fossil boiler reheater and the auxiliary reheater. The two streams are then merged and reinjected into the intermediate pressure turbine.

The fossil reheat hybrid requires that ∿ 13 percent of the total heat added be supplied by fossil, or that the supplemental fossil heat be about 15 percent of the solar.

Positive features of the fossil reheat cycle include:

- Water steam application to existing reheat equipment
- Capability of operating without the existing fossil boiler
- Compatibility with storage for extended operation

As diagrammed, the system uses the TSU to regenerate steam. The steam is superheated to 1000°F in the fossil reheater and injected into the intermediate pressure turbine. The efficiency when operating in this mode is 80 percent of that for the system with the high pressure turbine in operation.

A heat transfer salt topping storage unit could be used in order to reduce the fossil fuel consummed in superheating steam from storage. However, it is doubtful that this complexity would be warranted.

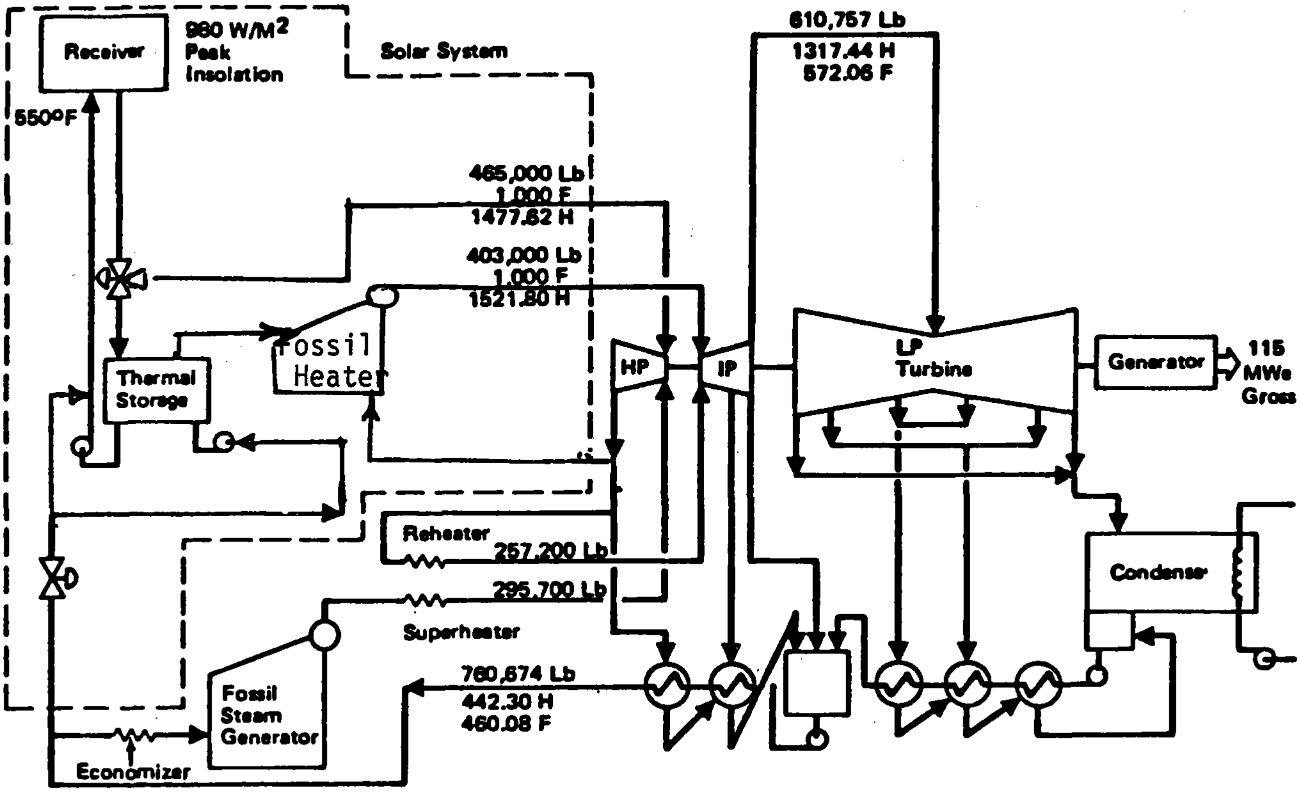


FIGURE 1 WATER/STEAM REPOWERING SCHEMATIC

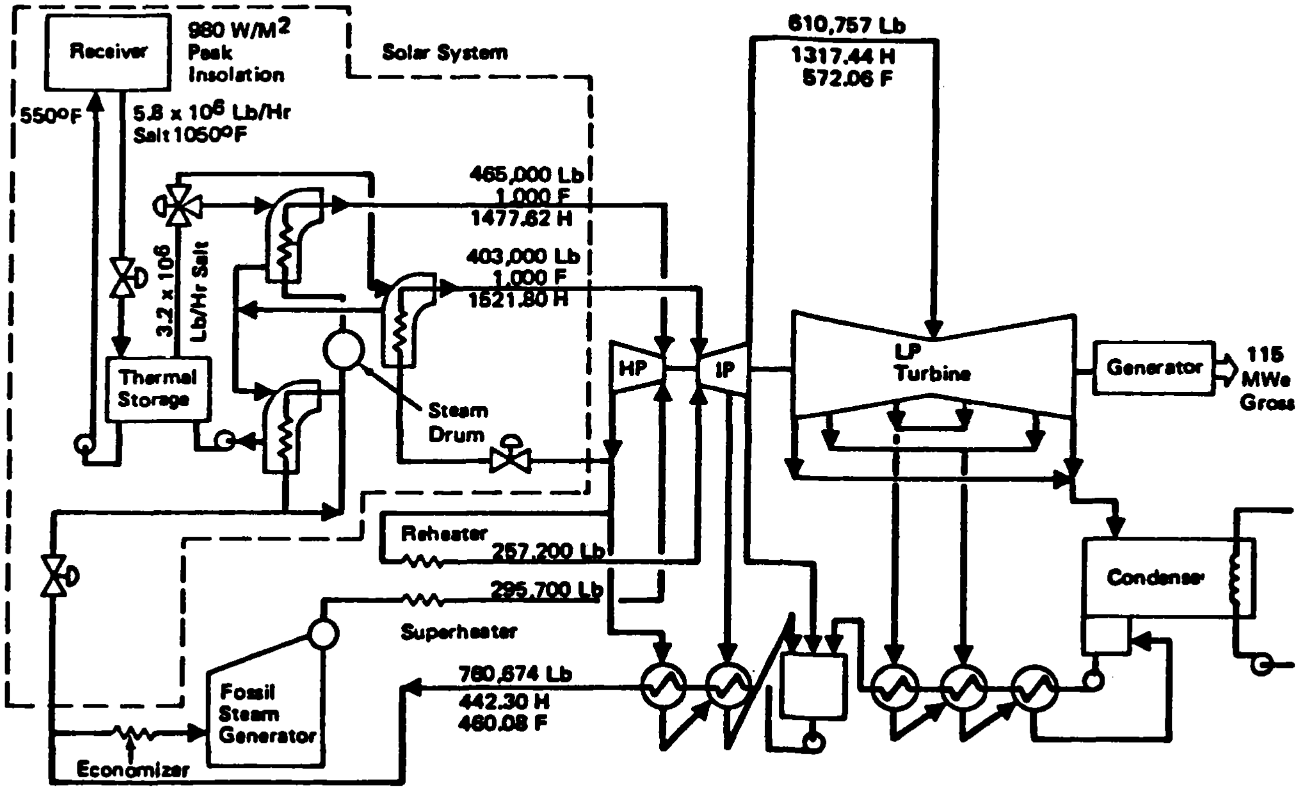


FIGURE 2 MOLTEN SALT REPOWERING SCHEMATIC

2.2 MOLTEN SALT CONCEPT DESCRIPTION

The molten salt concept baseline description is illustrated in the schematic of Figure 2. Molten salt is heated in the receiver and stored in the thermal storage unit. The salt is then withdrawn from the thermal storage and used to generate steam. Three separate heat exchangers perform boiler, superheater, and resuperheater functions.

Steam from the superheater is mixed with steam from the fossil boiler and expanded through the high pressure turbine. The outflow from the high pressure turbine is divided between the fossil resuperheater and the molten salt resuperheater. The reheated steams are merged and injected into the intermediate pressure turbine.

2.3 SYSTEM SIZING

The solar retrofit system is sized to provide 70 MWe of generator output. In this sizing study, considerable use was made of the values previously calculated for the proposals. Wherever possible, proposal values were scaled to provide the appropriate subsystem size for varying solar multiple. Sizing parameters are shown in Table 2.

The field size, number of heliostats, and the receiver area were all scaled linearly from the proposal as a function of solar multiple. Furthermore, since the receiver thickness is relatively small compared to its diameter, the receiver volume and mass were also scaled linearly with solar multiple.

For the salt system, three solar multiples were considered: 1.8, 1.4 and 1.0. For the water/steam system, a solar multiple of 0.85 was considered since an auxiliary fossil reheater was used to provide 13 percent of the energy at boiler efficiency of 0.87. Thus, both the salt system, with a solar multiple of 1.0, and the water/steam system, with a solar multiple of 0.85, would provide sufficient energy to generate 70 MWHe at summer solstice noon.

Tower height was determined by maintaining an average heliostat spacing of

TABLE 2 SYSTEM SIZING DATA, RECEIVER FLUID SELECTION

	WATER/STEAM SOLAR MULT 1.0	HEAT TRANSFER SALT SOLAR MULTIPLE 1.0	1.4	1.8
NUMBER OF HELIOSTATS	4795	5575	7800	10040
TOWER HEIGHT, m	99	107	127	144
RECEIVER AREA, m^2	430	430	602	774
WEIGHT, Kg		$2.7X10^5$	$3.8X10^5$	$4.9X10^5$
THERMAL STORAGE TANK VOLUME, m^3(HRS)	300(0.5)	315 (0.5)	1700(2.7)	4050(6.5)
HEAT EXCHANGER AREA & TYPE	2708 m^2 HOT GAS/STEAM	UNCHANGED FROM PROPOSAL		
PIPING LENGTH,	2470	2470	2590	2650
DOWNCOMER DIAMETER, M	0.25	0.35	0.41	0.46
WT/UNIT LENGTH, Kg/m	155	68	93	122
RISER DIAMETER, m	0.17	0.35	0.41	0.46
WT/UNIT LENGTH, Kg/M	68	68	93	122

22.4 heliostats/acre (at 49 M^2 of area per heliostat) and limited the view angles to a maximum of 52° and a minimum of 8°. Thus, tower height was expressed as a function of the field size and limiting angles, which ultimately reduces to the following simple expression:

$$\text{Tower height (m)} \cong \sqrt{2.05\ N}$$

where N is the number of heliostats.

Thermal storage requirements were sized by integrating an insolation profile typical of the plant location (at various solar multiples) in order to define the maximum storage time at each condition. Storage volume was based on a dual media thermocline system using drawsalt and iron ore which requires 625 m^3/hr capacity. Storage for the water/steam system is a high pressure water tank providing buffer storage only. High pressure water would be expanded from storage to provide 422 psi steam which would be reheated in the auxiliary fossil heater for the intermediate pressure turbine.

For the salt system, the heat exchanger would remain unchanged from the configuration in the proposal, while a fossil-fired reheater is needed for the water/steam system. Foster Wheeler has designed and built a larger version of such a furnace. The heat exchanger surface area used on this study was scaled down from the Foster Wheeler unit.

Piping length remains virtually unchanged for the variations in field size. However, pipe diameter was a direct function of the maximum flow rate. For the salt, an average flow velocity of 2.5 m/sec was used while for water 4.6 m/sec was used, and for the steam 40 m/sec.

3.0 COST AND ECONOMIC ANALYSES

3.1 COST ANALYSES

Costs were estimated on the subsystem or assembly level using cost estimating relationships. For solar peculiar equipment, MDAC relationships derived from the pilot plant, advanced concepts, and hybrid systems cost analyses were used. For more standard equipment, industry estimating guide lines were used.

Cost estimate results are shown in Table 3 for three assumed heliostat costs. The \$230/m^2 is a number suggested by Sandia as a result of the 2nd Generation Heliostat studies. The \$165/m^2 is the best current estimate of the average cost for the first 11,000 units produced for the current MDAC Second Generation model. The \$79/m^2 is estimated for Nth plant deployment of second generation heliostats. Receiver and tower costs anticipate the commercial form of the DOE 10 MWe pilot plant receiver (external absorber modular construction).

Thermal storage costs for the molten salt systems anticipate a dual medium, thermocline storage. A pressurized water buffer storage is envisioned for the water/steam system, as illustrated in Figure 1.

The heat exchangers for the molten salt systems include a boiler, a primary superheater, and a resuperheater, as shown in Figure 2. The water/steam heat exchanger is the auxiliary fossile fired resuperheater of Figure 1. The cost of the fossile fired resuperheater was bracketed by costs for a primary boiler/superheater at the same steam flow rate and a fired gas heat exchanger at the same heat flow rate.

Piping costs are estimated from construction cost guides and reflect differences in diameter, gage, length, and materials.

3.2 PERFORMANCE

Estimates of the annual energy displaced by the systems analyzed were made based on the average daily insolation estimated for the Fort Churchill site and the estimated system efficiencies. Results are shown in Table 4.

The average insolation was chosen to be slightly higher than the values for Reno, because of an alledged lower cloud cover at the Fort Churchill site. System average efficiencies were estimated from results of the commercial system studies performed during the pilot plant preliminary design.

TABLE 3 SYSTEM COST DATA RECEIVER FLUID SELECTION
COSTS IN 10^6 1980 DOLLARS

	WATER/STEAM	HEAT TRANSFER SALT		
	SM = 0.87	SM = 1.0	SM = 1.4	SM = 1.8
COLLECTOR ($230/$M^2$)	54	62.8	87.9	113.2
($165/$M^2$)	38.8	45.1	63.1	81.2
($ 79/M^2)	18.5	21.6	30.2	38.9
RECEIVER	8.9	8.9	11.1	13.0
TOWER	2.1	2.6	3.6	4.5
STORAGE	0.2	0.4	1.9	4.3
HEAT EXCHANGER	3.0-13.8	6.4	6.4	6.4
PIPING	4.0	3.2	4.0	4.7
TOTAL @ $230/$M^2$	72.2 82.0	84.3	114.9	146.1
@ $165/$M^2$	57.0 66.8	66.6	90.1	114.1
TOTAL @ $ 79/M^2	36.7 46.3	43.1	57.2	71.8

TABLE 4 - SYSTEM PERFORMANCE

SEASON	AVERAGE INSOLATION* KWh/m^2/day	WATER STEAM (SM=0.85)		HEAT TRANSFER SALT (mm btu/day)		
		SOLAR mm Btu/day	FOSSIL mm Btu/day	SM=1.0	SM=1.4	SM=1.8
SUMMER	8.2	4393	656	5113	7151	9207
FALL	6.9	3578	535	4162	5831	7501
WINTER	5.8	2907	434	3378	4720	6080
SPRING	7.6	3941	589	4586	6415	8252
YEARLY AVERAGE	7.125	3705		4310	6029	7760
YEARLY TOTAL FUEL DISPLAYED (10^{12} Btu/yr)		1.35		1.57	2.20	2.82

* INCLUDES WEATHER EFFECTS

The yearly fuel displacement is marginally less than that reported in the November 5th Project review because of more accurate system efficiency model.

3.3 ECONOMIC ANALYSIS

System economics was considered in two different ways. A figure of merit was developed by forming the ratio of the fuel savings to system cost. In forming this ratio, the fuel savings was taken as the present value (1980 dollars) of 20 years of fuel savings at the rates indicated in Table 4. A current fuel cost (1980 dollars) of $4.14/MM Btu was assumed as a value anticipating decontrol of oil and gas. This value corresponds to the current OPEC cost of $24/bbl. No. 6 fuel oil is assumed to be available at the site at this same cost. Fuel costs are then assumed to escalate at two rates: a high rate of 12% per year and a low rate of 10% per year. A weighted 9.23% discount rate is taken to find the present value for 20 years operation. (This is conservative, as the projected life of the repowered plant is 25-30 years).

Present value ratioed to capital cost is shown in Table 5. The most optimistic water/steam figure of merit (FOM) is seen to be essentially equal to the FOM for the heat transfer salt at a solar multiple of one (no extended operation from storage).

A second comparison is shown by computing an average return on investment (ROI). The annual ROI is plotted in Figure 3 for the two water/steam and three molten salt cases with the heliostat cost as a parameter. The ROI is seen to range from about 13% for the water/steam system with $230/m^2$ heliostats, the higher heat exchanger cost estimate, and the lower (10%) fuel escalation rate to as high as 31%* for Nth unit heliostat costs ($79/m^2$), molten salt, and 12% fuel escalation.

Two factors in the data of Figure 3 appear to be important. First, the ROI is significant for all cases and appears to be high enough to be of interest. Second, the cost of the heliostats and the fuel escalation rate are by far more significant than the type of system chosen. There is a small, probably significant improvement in ROI from water/steam to salt, and a further improvement with extended storage. The apparent optimum at SM=1.8 (6.5 hours

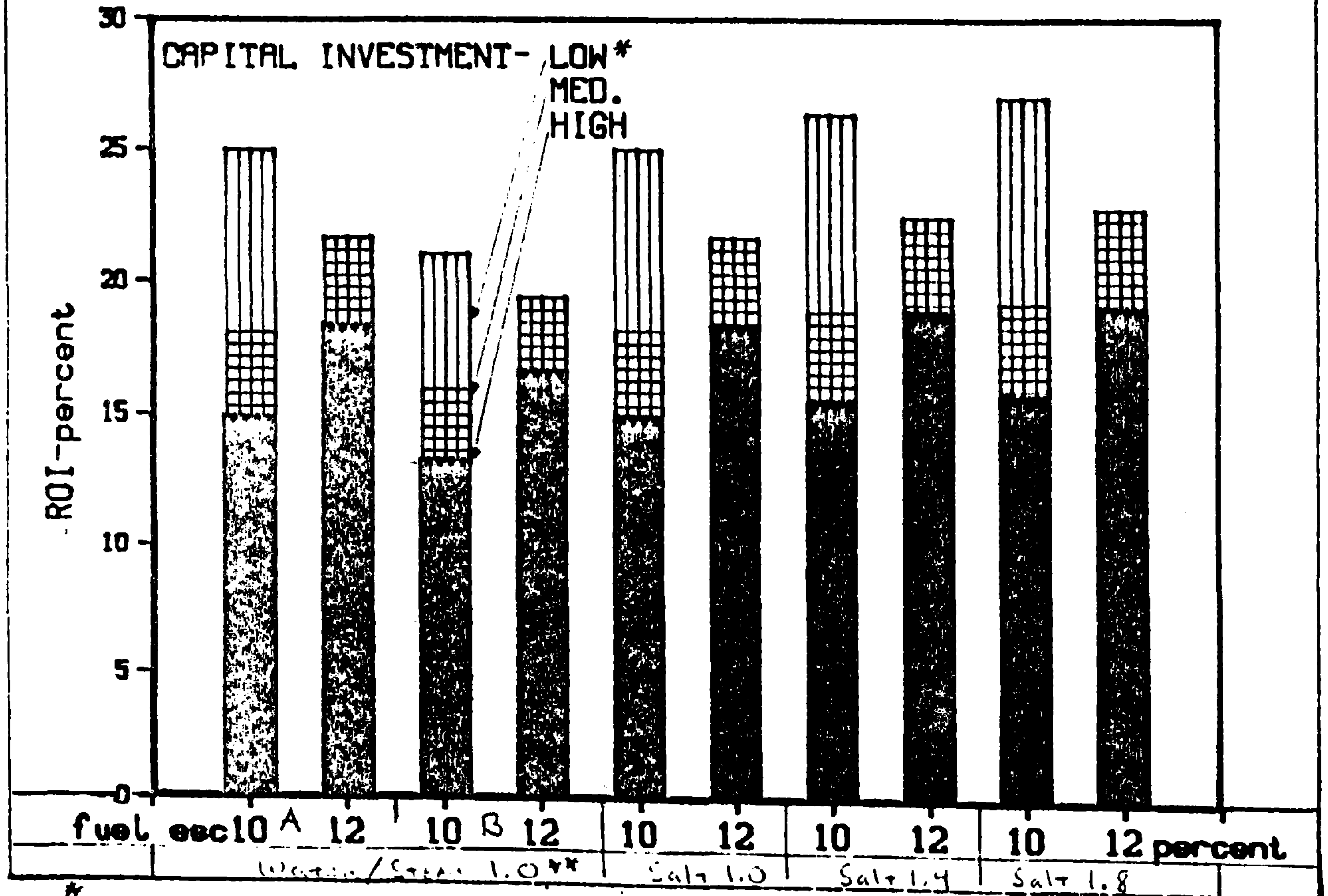
*Not shown in Figure 3

TABLE 5 - FIGURE OF MERIT FOR RECEIVER FLUID SELECTION

$$\left(\text{FOM} = \frac{\text{PRESENT VALUE OF 20 YEARS FUEL SAVINGS}}{\text{INITIAL SYSTEM CAPITAL COST}}\right)$$

FUEL ESCALATION RATE	SYSTEM COST	WATER STEAM (SM=0.85)		HEAT TRANSFER SALT		
		LOW	HIGH	SM=1.0	SM=1.4	SM=1.8
HIGH (12%/YR)	HIGH	3.54	3.12	3.52	3.61	3.66
	MED.	4.48	3.83	4.45	4.61	4.69
	LOW	6.96	5.50	6.88	7.26	7.45
LOW (10%/YR)	HIGH	2.50	2.16	2.45	2.51	2.55
	MED.	3.11	2.66	3.11	3.20	3.27
	LOW	4.83	3.83	4.80	5.05	5.19

FIGURE 3 RETURN ON INVESTMENT



* Low Capital Investment ROI for 12% Fuel Esc. not computed.

** A = Low Cost Steam Gen. ; B. = High Cost Steam Gen.

storage) is not felt to be significant.

The full output of the computer program for system economics is included for two cases. Figure 4 shows output for the case of water/steam, $165/m^2 heliostat costs, and the lower heat exchanger cost and fuel escalation rate. Figure 5 shows the output for comparable salt cost at SM=1.4 (2.7 hours storage).

4.0 ADDITIONAL CONSIDERATIONS

As indicated above, the molten salt receiver fluid shows a marginal economic advantage over water/steam. To be compete, we must also examine the operational aspects of the two systems. Important factors are discussed below and listed in Table 6.

Fuel Displacement - From Table 4, the molten salt system can displace more than twice the amount of fuel that the water/steam system can displace.

System Control - The essentially decoupled operations of heat collection and steam generation make the molten salt system substantially easier to control.

Maintenance - No significant difference are anticipated between the two systems.

Operations - The capability for solar only operation and for somewhat deferred operation with the use of storage favor the molten salt system. Since no direct flow of steam from the receiver to the turbine occurs, there is no direct danger of water carry over during cloud cover transients, Hence, operation of the molten salt receiver, with partial cloud cover, is simplified. Water/steam is slightly favored by a lesser danger of freezing during extended downtime. However, with trace heating provided, this disadvantage is not felt to be significant. The molten salt system is preferred, on balance.

TABLE 1

SUMMARY

* INTERNAL RATE OF RETURN (%)	18.057
* PAYBACK PERIOD - YEARS	6.269
* LEVELIZED CASH INFLOW - DOLLARS PER MBTU	8.603
* LEVELIZED COST - DOLLARS PER MBTU	6.811
* COST OF CAPITAL	.09900
* CAPITAL RECOVERY FACTOR	.11666

$165/m^2 HELIOSTATS

LOW HEAT EXCHANGER COST

10% FUEL ESCALATION RATE

FIGURE 4 WATER/STEAM ECONOMICS SUMMARY

TABLE I

SUMMARY

* INTERNAL RATE OF RETURN (%)	18.891
* PAYBACK PERIOD - YEARS	6.047
* LEVELIZED CASH INFLOW - DOLLARS PER MBTU	8.573
* LEVELIZED COST - DOLLARS PER MBTU	6.632
* COST OF CAPITAL	.09900
* CAPITAL RECOVERY FACTOR	.11666

$165/m^2 HELIOSTATS

1.4 SOLAR MULTIPLE

10% FUEL ESCALATION RATE

FIGURE 5 MOLTEN SALT ECONOMICS SUMMARY

TABLE 6 PROGRAMMATIC AND OPERATIONAL CONSIDERATIONS - RECEIVER FLUID SELECTION

CONSIDERAION	WATER/STEAM	MOLTEN SALT
SYSTEM ECONOMICS		SLIGHTLY FAVORED
FUEL DISPLACEMENT		SUBSTANTIALLY FAVORED
SYSTEM CONTROL		SUBSTANTIALLY SIMPLER
MAINTENANCE	ABOUT EVEN	ABOUT EVEN
OPERATIONS		SIMPLER, LESS RESTRICTIVE
SAFETY		SOME PRECAUTIONS REQUIRED
DEVELOPMENT STATUS	PREFERRED	
TECHNICAL FEASIBILITY	FOSSILE REHEATER	NO MAJOR ISSUES
RECOMMENDATION		NO MAJOR ISSUES

Safety - The molten salt system presents some unique safety issues. In industrial practice, minor leaks do not represent a hazzard. However, when leaks occur in the presence of organic material, a fire or explosion hazzard does exist. Precautions must be taken to prevent contact with organic material in the event of a salt leak. Other precautions appropriate to handling and piping a hot liquid under pressure must also be observed. Working crews should also be protected against inhalation or ingestion of the salt.

Development Status - The water/steam system is preferred because of its development status both because of its long term use in utilities, and because of its use in the DOE 10 MWe Pilot Plant. However, additional development work would still be required for the receiver and fossile fueled resuperheater with the water/steam systems. The molten salt system requires development in the receiver and potentially on the piping and thermal storage.

Technical Feasibility - There are two major feasibility issues with the water/-steam system. The fossile fueled reheater has no liquid water wall to absorb high heat fluxes in the radiant portion of the heat exchanger, and this results in difficulty in controlling the operating temperatures in several critical areas during transient operation. This difficulty has been found to be moderate (to severe) in past applications and will vary as a function of the ramp rate required. In addition, the operation of the intermediate and low pressure turbines at full steam flow with the high pressure turbine at partial flow has both operational and technical feasibility issues.

5.0 RECOMMENDATIONS

On balance, the salt system appears to be the better choice. Either choice could be justified, but in the absence of compelling reasons to choose water/-steam, the greater fuel displacement potential and operational flexibility of the salt system should dominate the selection. A molten salt system with extended storage is recommended.

SOLAR REPOWERING STUDY
SIERRA PACIFIC POWER UTILITY
TASK 2 TRADE STUDY REPORT
COLLECTOR FIELD CONFIGURATION

1.0 OBJECTIVE AND SCOPE

This trade study compares north and surround field configurations. A surround field has heliostats completely around the tower and a receiver which can accept sunlight from all directions. The north field has heliostats predominately to the north of the tower and a receiver which accepts sunlight only from the north.

In general, the north field has a generic advantage of more efficient heliostats, due to lower cosine losses on the mirrors. The receiver may be readily configured to a partial cavity arrangement to further increase effiency. The surround field generally has generic advantages of a shorter, less expensive tower and a smaller, less expensive receiver.

In the past, system trade studies for fields the size of the Ft. Churchill field have favored surround configurations. However, two factors differ for the site specific trade performed:

1) The tower is not at the power plant, and a significant piping cost is incurred in transporting the receiver fluid to the power plant location.

2) The latitude is 6° further north than that for which previous trade studies were made. Thus a surround field tends to be more north biased, and receiver cost savings for this field may be negated. The selection, then, rests on system economics with site specific factors included. Table 1 summarizes the trade study objectives and approach.

2.0 SIZING AND PERFORMANCE ESTIMATES

A Sandia Livermore computer program, DELSOL, was used to develop optimum surround and north field for the Sierra Pacific Power Company site.

TABLE 1 COLLECTOR FIELD CONFIGURATION (TS-2)

OBJECTIVE:	To select the general collector field/receiver configuration.
CANDIDATES:	Baseline - 360° surround field with external receiver Alternate- Single or modular north field options with cavity or partial cavity receiver
SELECTION CRITERIA:	System cost, value of fuel displaced
APPROACH:	Generate optimum surround and north fields using DELSOL. Estimate system cost from system cost estimating relationships, including costs of the line from the collector field to the turbine generator plant. Calculate annual energy collected with DELSOL. Select the more cost effective system approach.
EXPECTED RESULTS:	Lower capital costs for the 360° field with external receiver will lead to its selection.
INPUT DATA:	o Heliostat cost estimates from the Second Generation Heliostat Program o Tower costs from Sandia/Stears-Roger study o Molten salt equipment cost estimates from MDAC and DOE/Sandia Advanced Concepts Program o Reno insolation and geological data
PARTICIPATING ORGANIZATIONS:	MDAC

The DELSOL program can be used for first cut optimizations of solar fields. It has the capability of optimizing over discrete tower heights, discrete receiver dimensions including aspect ratio, and for discrete power levels. The most optimum field is selected based on lowest cost of energy.

In searching over discrete receiver sizes, a comparison of peak flux to the design point peak flux is made. If the design point flux is exceded, the program then proceeds with the next larger receiver size. Automatic aiming strategy is used.

For the surround field optimization the way in which DELSOL originally searched over receiver sizes was in error and favored a north field. This problem was discussed with the authors of the program and corrections recommended by Sandia were implemented to provide an optimum surround field.

Optimization results for the north and surround fields are shown in Figures 1 and 2, respectively. Both fields fill 11 computational cells to the north of the tower and give rim angles of about 8°. Computational cells are normalized to tower height. Data from the optimizations are shown in Table 2.

The two fields at the same rated power should be evaluated on the basis of annual energy. However, DELSOL does not provide for seasonal dependence of weather factor. Cloudy days are projected to occur much more frequently in the winter than in the summer at the Ft. Churchill site. The higher annual energy expected of the north field on the basis of unifrom weather factor is offset by more frequent cloudiness when its performance advantage is greatest. For this trade study, the annual energies are considered to be essentially equal.

3.0 COST ANALYSES

Costs were estimated on the subsystem or assembly level using cost estimating relationships. For solar peculiar equipment, MDAC relationships derived from the pilot plant, advanced concepts, and hybrid systems cost analyses were used. For more standard equipment (eg. piping and associated equipment)

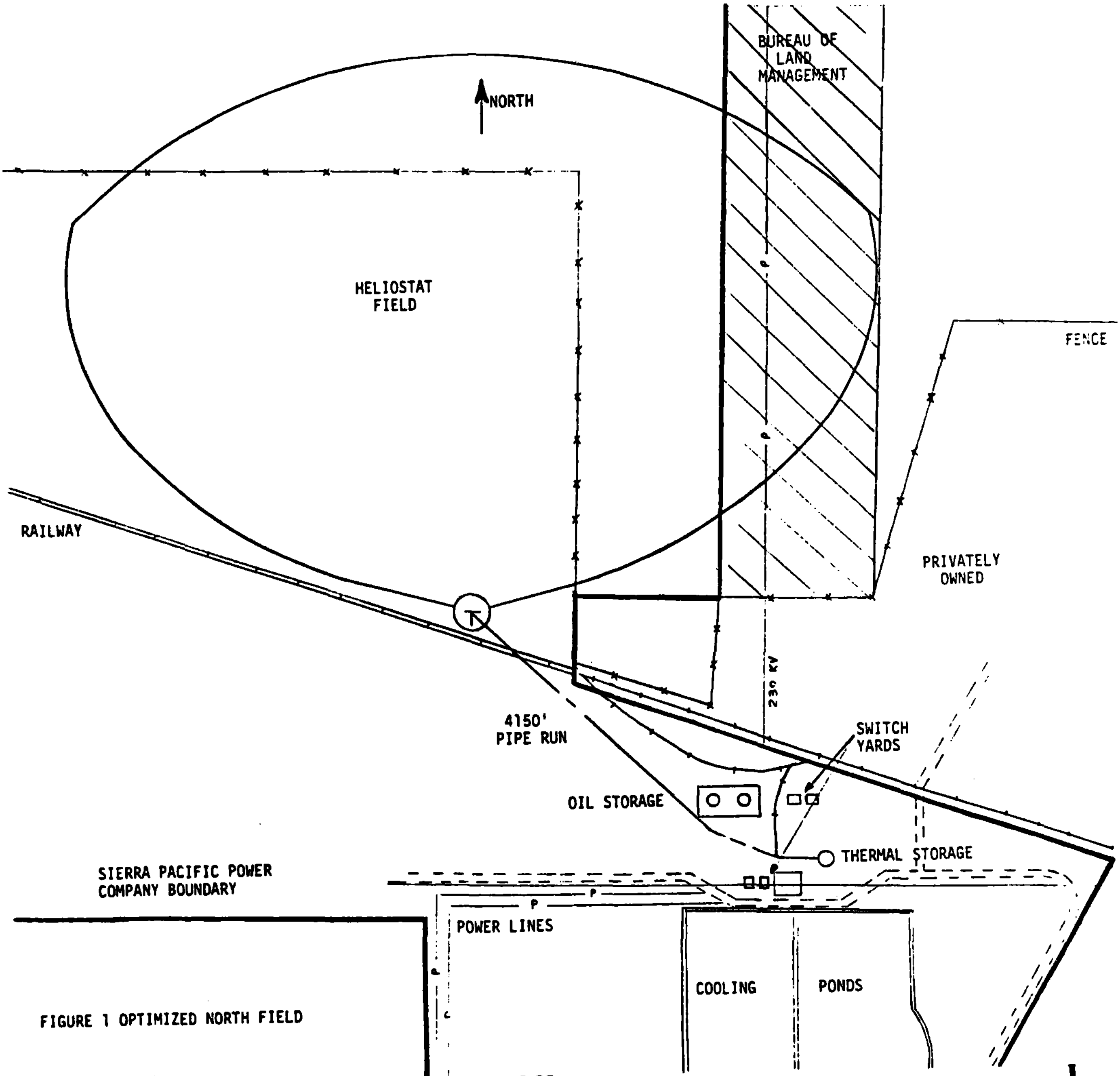


FIGURE 1 OPTIMIZED NORTH FIELD

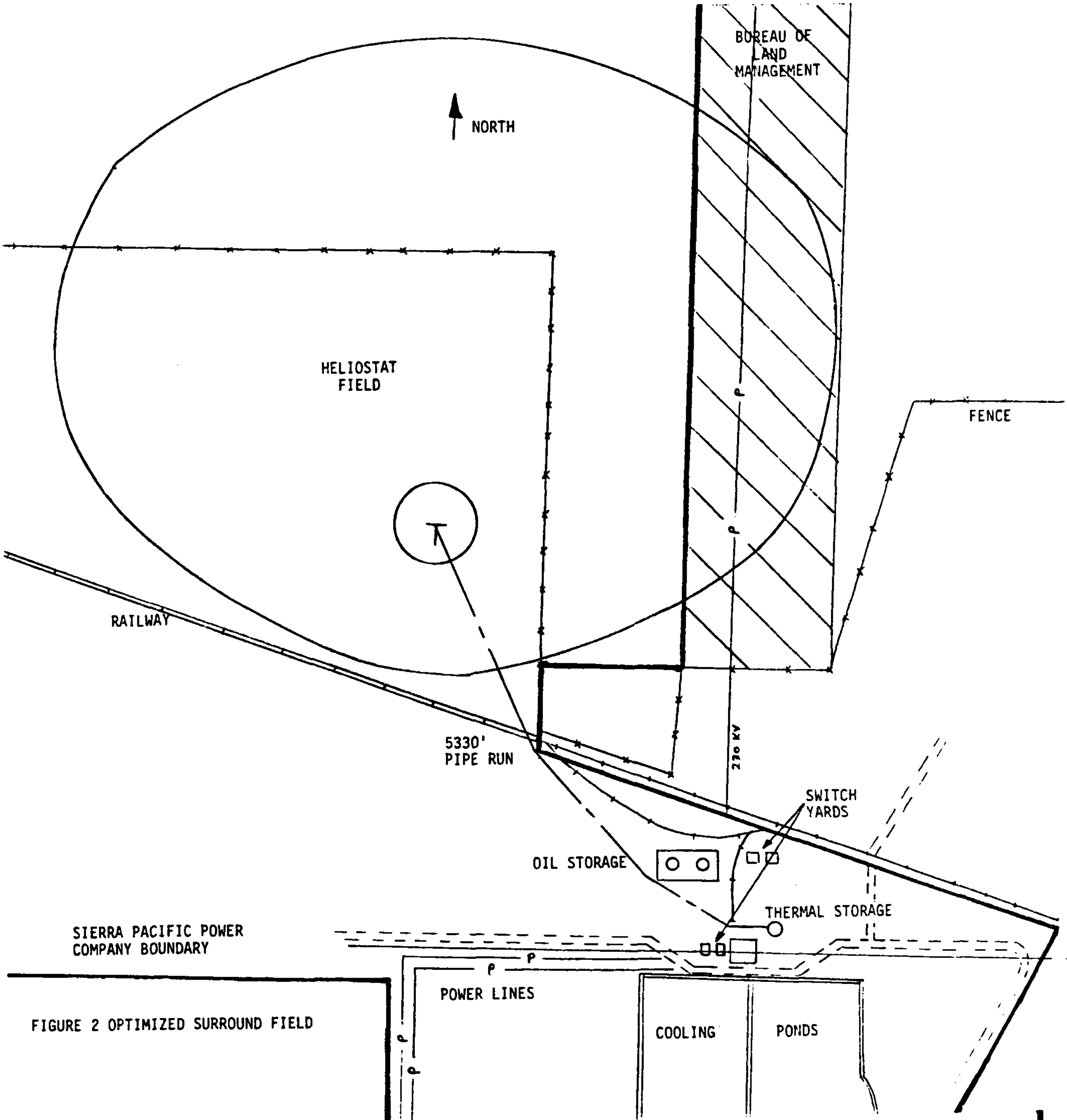


FIGURE 2 OPTIMIZED SURROUND FIELD

Table 2

COMPARISON OF OPTIMUM NORTH AND SURROUND FIELDS, 80 MWe SOLAR

		NORTH FIELD	SURROUND FIELD
NUMBER OF HELIOSTATS		9,980	10,880
TOWER HEIGHT	M (Ft.)	220 (722)	200 (656)
PIPING RUN LENGTH	M (Ft.)	1,265 (4150)	1,625 (5330)
RECEIVER DIMENSIONS	M (Ft.)	PARTIAL CAVITY 20 (65) Wide 22 (71) High	CYLINDER 15 (49) Diam 26.25 (86) High
RECEIVER ABSORBER AREA	M^2	1,100	1,237
ESTIMATED RECEIVER WEIGHT	10^6 Kg	0.386	0.459
DISTANCE FROM TOWER TO NORTH NORTH EDGE OF FIELD	M (Ft.)	1,622 (5320)	1,457 (4780)

industry estimating guidelines were used.

Cost estimate results are shown in Table 3 for three assumed heliostat costs. The $\$230/m^2$ is a number suggested by Sandia as a result of the 2nd Generation Heliostat studies. The $\$165/m^2$ is the best current estimate of the average cost for the first 11,000 units produced for the current MDAC Second Generation model. The $\$79/m^2$ is estimated for N^{th} plant deployment of second generation heliostats. Receiver costs are scaled from the commercial form of the DOE 10 MWe pilot plant receiver (external absorber, modular construction). Tower costs were estimated from Sandia algorithms.

The cost estimates in Table 3 show an economic advantage to a north field. Since this conclusion differs from all previous studies, a review of the probable reasons for the variation is in order. The following differences from previous optimizations are noted:

Shorter Piping Run To Plant - The piping run to the plant is shortened by 1200 ft., resulting in an estimated savings of $0.7M.

Higher North Latitude - The latitude of 39° causes some significant, but undetermined bias toward a north field.

150° Azimuthal Extent of Field - For the north field, the east and west segments were allowed to fill in to form a 150° field. This was accomplished by using taller tower, and by tilting the receiver down at a 30° angle from verticle. Heliostats were now able to pack closer into the tower, the distance to the north edge of the field was shortened, and the resulting smaller beam from the furthest heliostats enabled a smaller receiver to be optimum. The resulting field has a maximum distance to the north edge of the field of 1622 meters, opposed to 1457 meters for the surround field.

Partial Cavity Receiver - The assumption of a partial cavity receiver leads to performance comparable to that of a full cavity receiver, thus requiring less absorber area and less weight. Hence, receiver costs for the north field are less than for previous analyses, and equal to or less than the costs for a 360° receiver.

The above factors in combination appear to have resulted in slightly lower

Table 3
COST COMPARISON OF OPTIMUM
SURROUND FIELDS, 80 MWe SOLAR
10^6 1980 DOLLARS

		NORTH FIELD	SURROUND FIELD
HELIOSTAT COST	$230/M^2	112.5	122.6
	$165/M^2	80.7	88
	$ 79/M^2	38.6	42.1
TOWER COST		5.2	4.4
PIPING COST		2.4	3.1
RECEIVER COST		26.3	28.1
TOTAL COST	$230/M^2	146.4	158.2
	$165/M^2	114.6	123.6
	$ 79/M^2	72.5	77.7

cost estimates for the north field. We note from Table 3 that the cost savings varies with the heliostat cost assumption. However, realistic estimated costs between $165/m^2$ and $230/m^2$ clearly favor a north field. The significant factor in this study is the improved partial cavity receiver coupled with the north field and hence fewer heliostats required for the north configuration.

4.0 RECOMMENDATION

Based on the lower cost estimated, it is recommended that a north field be selected. This recommendation anticipates that a satisfactory partial cavity receiver design can be developed.

Previous results of MDAC studies for Sandia and JPL on small central receiver systems have shown the feasibility of partial cavity receivers. Hence, the risk of developing a suitable design is assessed to be low.

SOLAR REPOWERING STUDY
SIERRA PACIFIC POWER UTILITY
TASK 2 TRADE STUDY REPORT
RECEIVER CONFIGURATION SELECTION

1.0 OBJECTIVE AND SCOPE

This trade study compares three general receiver configurations; external, full cavity, and partial cavity. Each of the receiver concepts is arranged for the north field collector configuration chosen in Trade Study 2.

In general, a cavity receiver has the advantage of the highest efficiency. However, its absorber area tends to be large, its weight tends to be high, and there are operational disadvantages due to accessibility.

A major objection to cavity receivers in the past has been an imposition of limitations by the receiver on the collector field. For the SPP Co. site specific application, this limitation is less important because the collector field optimization tends to favor north field at comparable performance.

A cylindrical external receiver has the advantages of lower weight and size, ready accessibility for maintenance procedures, and operational flexibility. The external receiver efficiency is somewhat lower than that of a cavity receiver.

The partial cavity receiver uses an external absorber in the low flux regions and cavity region for the high flux. Overall efficiency is expected to equal that of a full cavity receiver, while the absorber area, size and weight should be significantly reduced.

The three candidate receiver configurations are described in this study and compared on a cost/performance basis. The trade study objectives and approach are summarized in Table 1.

TABLE 1 - RECEIVER CONFIGURATION SELECTION (TS-3)

OBJECTIVE:	To establish the receiver configuration for a north field receiver.
CANDIDATES:	Baseline - Fully external absorber Alternates - • Full cavity • Partial cavity
SELECTION CRITERIA:	System cost, energy collection efficiency, operations and maintenance considerations.
APPROACH:	Estimate system cost from cost estimating relationships, including effects of improved receiver efficiency on collector field and receiver cost and performance.
EXPECTED RESULTS:	Higher performance will outweigh additional costs and select some variant of a cavity receiver.
INPUT DATA:	• Heliostat costs from Second Generation Heliostat Program. • Tower costs from Sandia/Stearns-Roger tower cost study. • Receiver costs from MDAC and DOE/Sandia Advanced Concepts Program.
PARTICIPATING ORGANIZATIONS:	MDAC - Lead Foster-Wheeler - Requirement characteristics SPCC - O&M considerations

2.0 RECEIVER CONCEPTS

The three receiver concepts are described in this section, and general characteristics are shown in Table 2.

2.1 External Receiver

The external receiver is illustrated in Figure 1. The configuration is approximately cylindrical, with 36 sides. Each side is a factory assembled absorber panel which is complete and ready for installation.

A typical absorber panel is shown in Figure 2. The panel consists of a top and a bottom manifold with parallel flow tubes connecting the two manifolds. Each panel is mounted on a support structure, which also serves as a transportation fixture. The panel has factory applied insulation. Attachment flanges for inlet and outlet piping are prepared. Instrumentation for control and data output is installed. Since several panels will be connected in series, flow control valves are not installed.

For a surround field, each panel would normally be identical. For the present north field configuration, 21 panels will be actively flowing receiver fluid (210° of the cylinder). The remaining 15 panels will be dummy panels which are used strictly for aerodynamics on the receiver configuration.

The panels are supported on a steel framework. The upper end of each panel is fixed. The panel is restrained from motion in both horizontal directions, but allowed to expand freely in the vertical or lengthwise direction.

The panel absorber surface is coated with a high temperature, absorptive paint. The paint has a measured solar absorptivity of 0.95. Hence, about 95% of the energy incident on the panel will be absorbed.

Additional losses will be incurred by reradiation, free and forced convection, and interception. MDAC has estimated these additional losses for a molten salt receiver fluid at about 14% average. Hence, the expected receiver efficiency is 0.86 x 0.95, or 0.821.

TABLE 2 - COMPARATIVE RECEIVER DATA

	EXTERNAL	FULL CAVITY	PARTIAL CAVITY
Effective Absorptivity	0.95	0.986	0.98
Reflection Loss (MW)	20	5	7
Interception Factor	0.99	0.995	.983
Interception Loss (MW)	4	2	6
Active Absorber Area (m^2)	1340	1900	1100
Radiation Loss (MW)	22	8	6
Convection Loss (MW)	26	9	9
Total Efficiency	0.821	.933	.922
Required Field Power (MW)	402	354	358

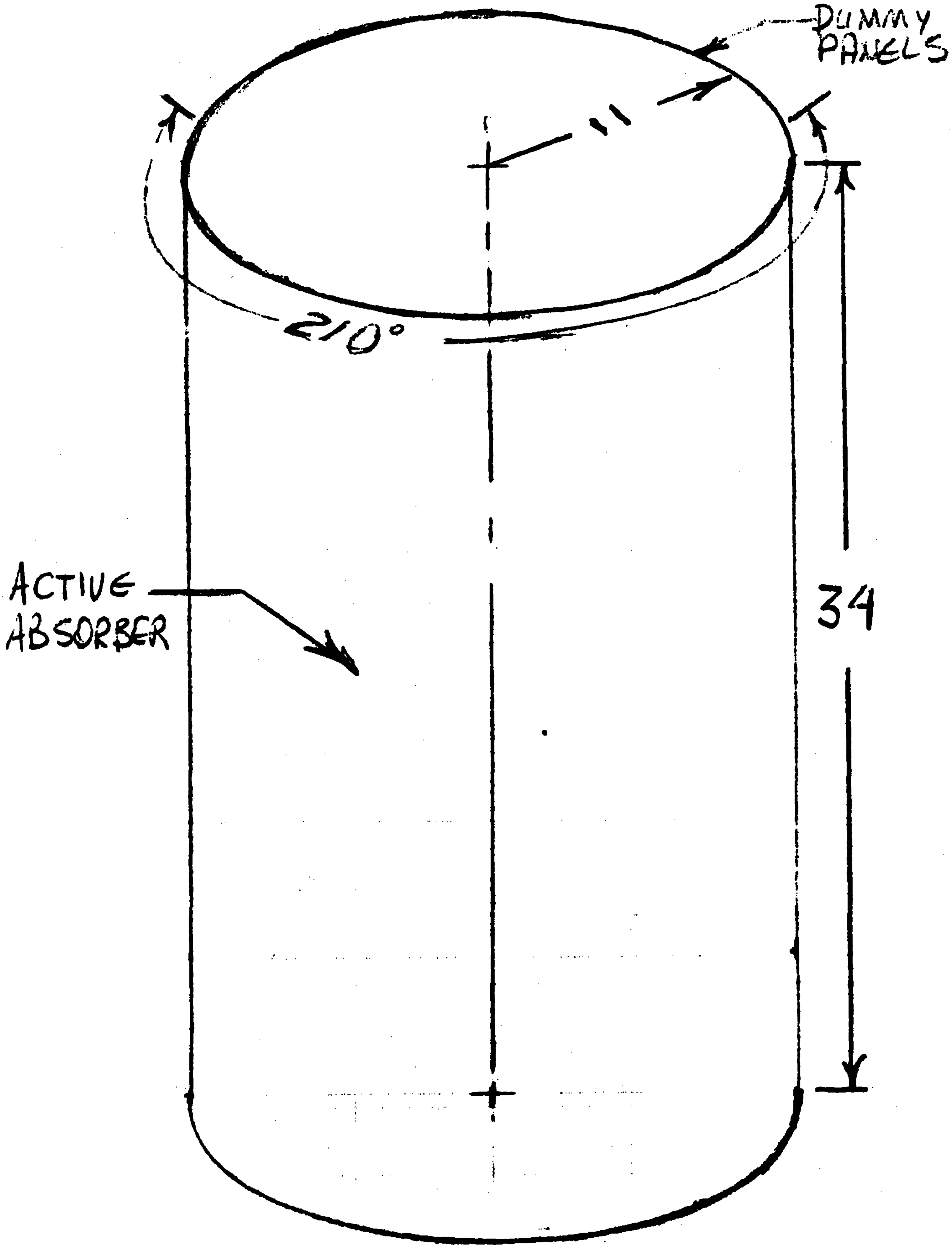


FIGURE 1 EXTERNAL ABSORBER RECEIVER

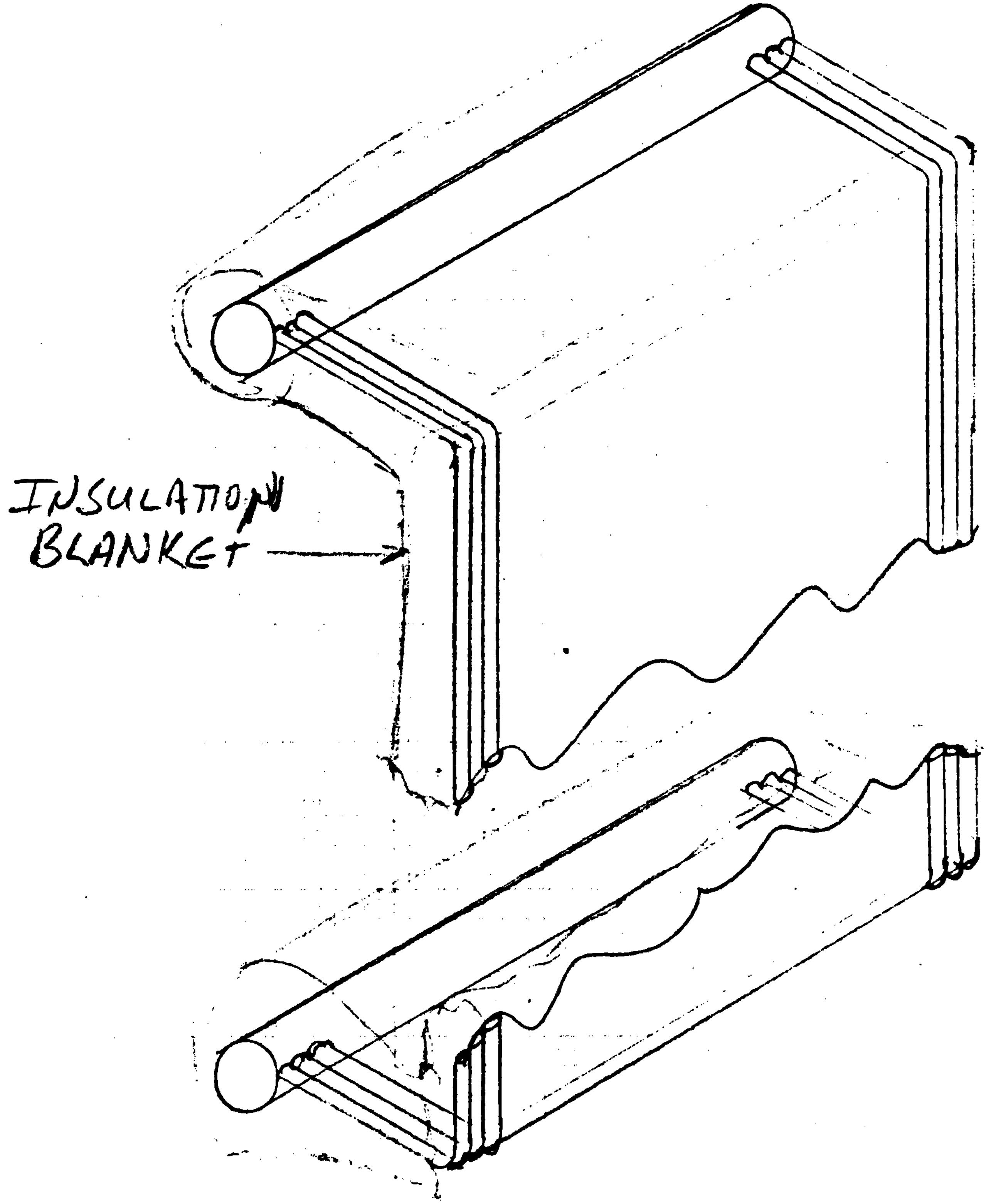


FIGURE 2 ABSORBER PANEL

2.2 Cavity Receiver

A cavity receiver is illustrated in Figure 3. The aperture is sized for the Sierra Pacific application. The cutoff flux was taken to be 20 kW/m^2, or about the maximum flux level which can be radiantly cooled. The box configuration has an inactive, adiabatic section near the inlet and continuing back to the point that heat can be usefully collected. The active absorber section is made of panels similar to those of the external receiver. An aim strategy is assumed for close-in heliostats which will selectively impinge their heat on the sides of the box to prevent excessive heat load on the back panel.

The overall cavity receiver efficiency is estimated to be 0.933.

2.3 Partial Cavity Receiver

The premise of a partial cavity receiver is that the portions of the frontal area of the receiver which have sufficiently low heat flux should be external absorbing. The coldest receiver fluid should be circulated through these portions to minimize losses.

The aperture of a cavity receiver must be sized to prevent excessive heat load on the structure surrounding the aperture. The extra area which must be added is rather poorly utilized, and adds substantially to the receiver cost. Making the edge a low temperature, external absorber reduces the receiver cost substantially at little overall efficiency penalty.

The central region of a partial cavity receiver is recessed to reduce the flux, both by increasing the absorber area and by allowing defocus of the reflected sunlight behind the aperture plane.

The partial cavity configuration selected is shown in Figure 4. The receiver is tilted down at an angle of 30° from vertical. The external absorber, side walls, and cylindrical rear wall are all made of nominally identical panels. The top and bottom of the cavity are insulated, adiabatic surfaces.

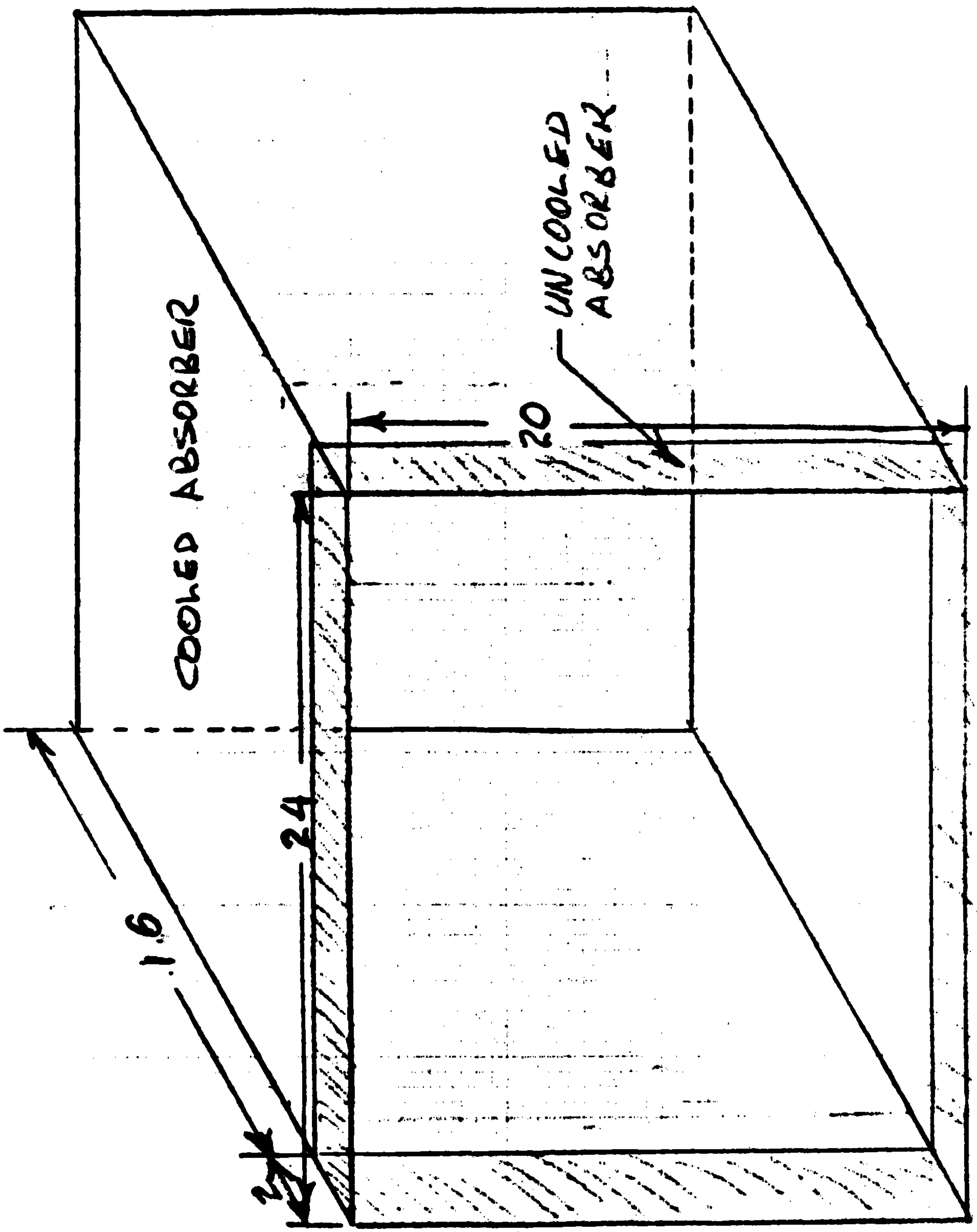


FIGURE 3 CAVITY RECEIVER

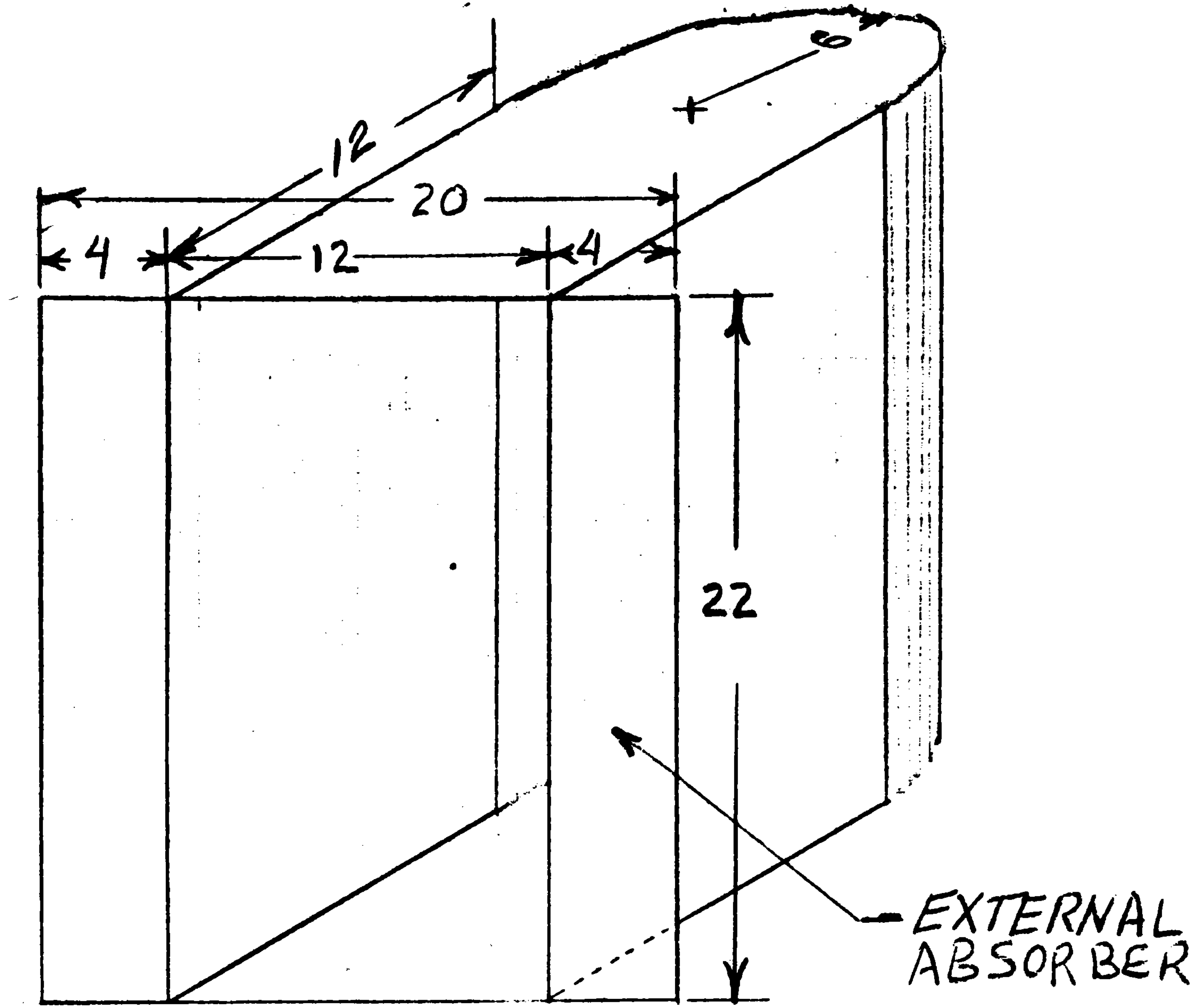


FIGURE 4 PARTIAL CAVITY RECEIVER

An aim strategy is required which impinges the incident light on active absorber surfaces. Heliostats toward the outer edge of the field need to be aimed slightly above the center of the aperture plane. Close-in heliostats are aimed below the midpoint of the aperture plane.

The overall efficiency of the partial cavity receiver is estimated to be 0.922.

3.0 COST ESTIMATES

Receiver costs were estimated to be proportional to active absorber area. In addition, tower and collector costs were assumed to be directly proportional to the required field power.

Comparative cost estimates for the three receiver types are shown in Table 3. The partial cavity receiver is seen to lead to lower system costs, independent of assumed heliostat costs. We also note that there is a reversal between external and full cavity, with external being preferred for the lower heliostat costs, and cavity preferred for higher heliostat costs.

No significant O&M considerations were identified. Hence, the receiver configuration may be chosen on cost considerations alone.

4.0 RECOMMENDATION

The partial cavity receiver is chosen on the basis of substantially lower projected system cost.

TABLE 3 - COMPARATIVE RECEIVER CONFIGURATION COST DATA

	EXTERNAL	FULL CAVITY	PARTIAL CAVITY
Receiver Cost ($M)	31.1	45.4	26.3
Tower Cost ($M)	5.8	5.2	5.2
Collector Cost ($M)			
$230/M^2	126.3	111.2	112.5
$165/M^2	90.7	79.8	80.7
$ 79/M^2	43.3	38.2	38.6
Total Cost ($M)			
$230/M^2	163.2	161.8	144.0
$165/M^2	127.6	130.4	112.2
$ 79/M^2	80.2	88.8	70.1

SIERRA PACIFIC UTILITY SOLAR REPOWERING

TASK 2 TRADE STUDY REPORT

RECEIVER TOWER SELECTION

1.0 OBJECTIVE AND SCOPE

The objective of this 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 foundations only; tower design, engineering, accessories and appurtenances are considered a stand-off and are not included.

Table 1 summarizes the trade study objective and approach.

2.0 ANALYTICAL PROCEDURE

2.1 STRUCTURAL MODEL

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 included 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.

The receivers were also modeled by beam elements. For concrete towers, the receiver stiffness was assumed equal to 0.2 times that of the adjacent tower element. For steel towers, the receiver stiffness was specified to be equal to that of the top of the tower, and so the receiver was modeled using equivalent beam elements having more or less the same length as the topmost tower element. The receiver mass was lumped at the receiver centroid.

TABLE 1

RECEIVER TOWER SELECTION

OBJECTIVE:	To select the receiver tower configuration.
CANDIDATES:	Baseline - Conventional steel Alternates - Reinforced concrete - Tubular steel
SELECTION CRITERIA:	Tower cost, construction considerations, operational considerations.
APPROACH:	Determine tower configuration meeting specified site-specific environmental 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.
EXPECTED RESULTS:	The initial baseline tower (150 m) was selected as a conventional steel tower due to seismic considerations. However, new tower height (200 m) may favor a concrete tower due to wind considerations.
INPUT DATA:	•Site: Yerington, Nevada •Environmental Design Data •Wind 40 m/s (90 mph) @ 10 m (30 ft.) •Seismic 0.25 g peak ground accel. (UBC Zone 3) •Soil Bearing 36,600 kg/m^2 (7500 psf) •Tower Height 200 m (656 ft.) •Receiver Weight 453,600 kg (1,000,000 lb.) •Current construction cost factors for material and labor.
PARTICIPATING ORGANIZATIONS:	S-R - lead MDAC - receiver design, tower height SPPC - site data

2.2 MODAL ANALYSIS

All horizontal and vertical (i.e., transverse and longitudinal) 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.

2.3 ANALYSIS FOR EARTHQUAKE

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 0.25 g maximum ground accelleration.

Modal damping ratios for the towers were obtained from Regulatory Guide 1.61, "Damping Values for Seismic 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.

2.4 ANALYSIS FOR DRAG WIND

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)".

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

$$F_r = C_f K_z G_f q_{30} A_r, \text{ where}$$

C_f = net pressure coefficient. For the concrete towers C_f was obtained using the values given in Table 15 for moderately smooth round shapes.

For the conventional steel tower, C_f was obtained for each node using the values given in Table 18. For the tubular steel tower, these values of C_f were modified using Table 19. C_f for the receiver was assumed equal to 1.2.

K_z = velocity pressure coefficient. Values for K_z were obtained using Fig. A2 of appendix A6.3.4.1 for exposure type C (flat, open country).

G_f = gust factor. Values of G_f were obtained using the provisions of Appendix A6.3.4.1. 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 feet.
= $0.00256\, V_{30}^2$, 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 tributary 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.

2.5 LOAD FACTORS

I. 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; .9D + 1.43E

II. Steel Towers

a) Wind Loads

W = maximum wind
Load Combination: .75D + .75W

b) Seismic Loads

Load Combination: .75D + .75E

2.6 DESIGN PROCEDURE

I. Design of Reinforced Concrete Tower

Minimum shell wall thickness and minimum circumferential reinforcement were determined in accord 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)".

II. Design of 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 Edidiiton.

III. Design of Foundation Mats

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

a) 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 1761 kg/m^3 (110 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.

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

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

2.7 ADDITIONAL PARAMETERS

Piping was assumed to add a dead load 227 kg (500 lb) per vertical foot.

3.0 RECEIVER DESCRIPTION

The preliminary receiver configuration used in the analysis is shown in Figure 1. The total receiver mass located above the top of the tower is 453,600 kg (1,000,000 lb), which was located at the assumed c.g. of the receiver.

4.0 TOWER DESCRIPTIONS

Sketches of the concrete, conventional steel and tubular steel towers and foundations are shown in Figures 2, 3 and 4 respectively.

As indicated in Figure 2, the reinforced concrete tower has a height of 200 m (656 ft.) above the top of the 36.6 m (120 ft.) diameter mat which corresponds to grade elevation. The diameter of the top and base of the tower is 12.2 m (40 ft.) and 19.2 m (63 ft.), respectively. The tower taper is 1° and the wall thickness varies from 0.25 m (0.833 ft.) at the top to 0.33 m (1.083 ft.) at the base. The mat thickness is 3.65 m (12 ft.).

Figure 3 shows the 200 m (565 ft.) conventional steel tower constructed of standard constructural steel shapes in an 8-legged structure. The dimensions across the flats is 13.7 m (45 ft.) at the top and 27.4 m (90 ft.) at the base. The mat dimensions are 37.5 m (123 ft.) diameter by 3.8 m (12.5 ft.) thick.

The tubular steel tower, Figure 4, is similar to the conventional steel tower in size and is also an 8-legged structure. The mat size is 36.3 m (119 ft.) diameter by 3.6 m (12 ft.) thick. The tubular steel tower is constructed of pipe or rolled plate members with bolted connetions. Column sizes are 0.61 m (24 in) O.D., with wall thickness varing from 0.009 m (0.375 in) to 0.52 m (2.06 in).

5.0 SUMMARY OF RESULTS

Table 2 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. As expected wind governs the steel tower design and seismic the concrete tower. Also the results show the accelerations at the top of the tower to be nearly identical for all three towers.

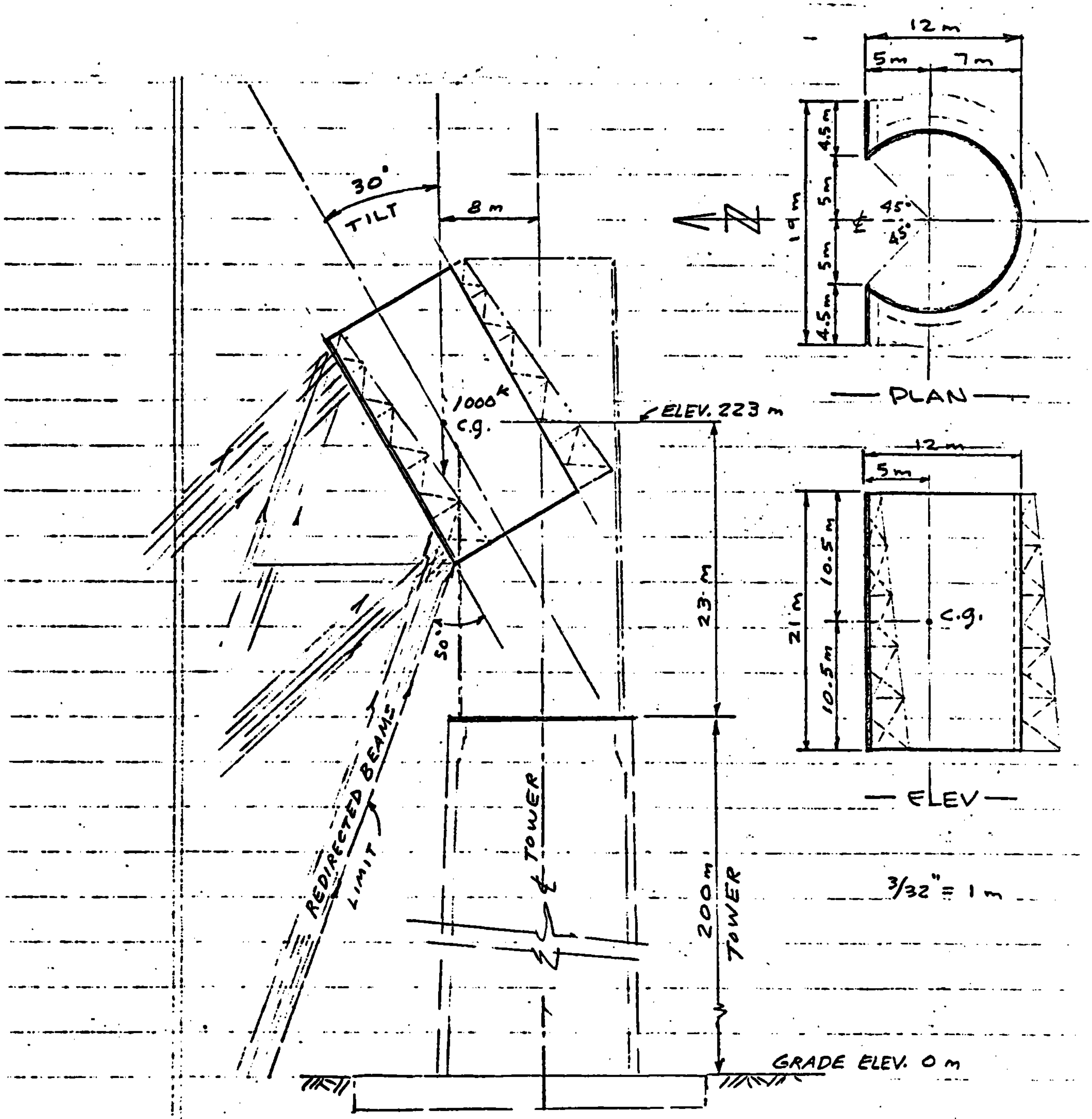


FIGURE 1 MOLTEN SALT RECEIVER (PRELIM.)

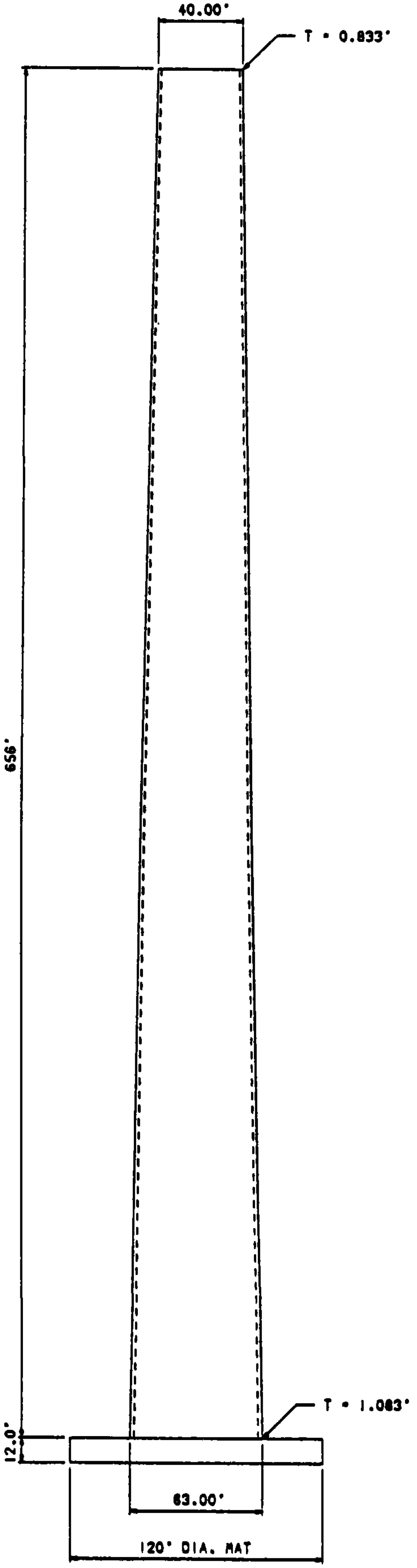


FIGURE 2 - CONCRETE TOWER

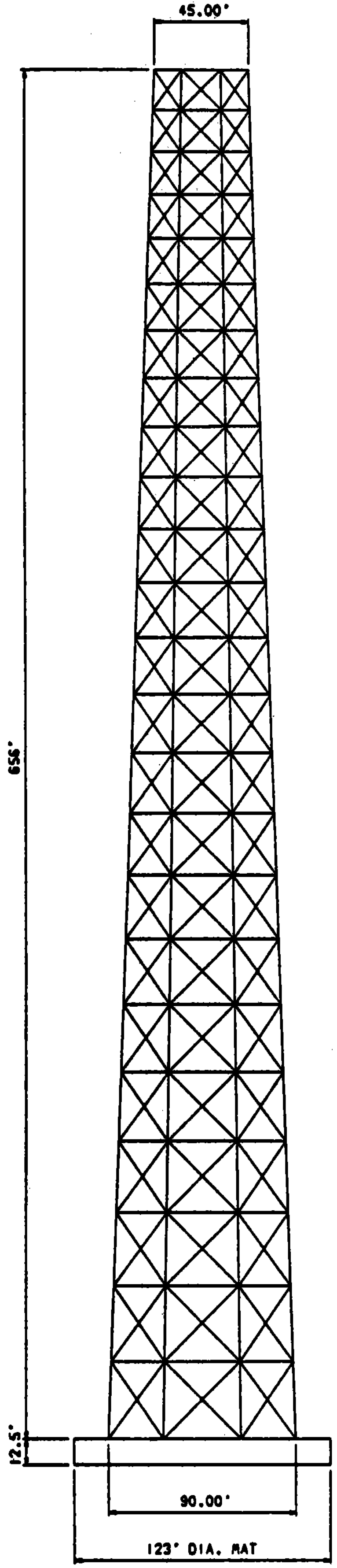


FIGURE 3 - CONVENTIONAL STEEL TOWER

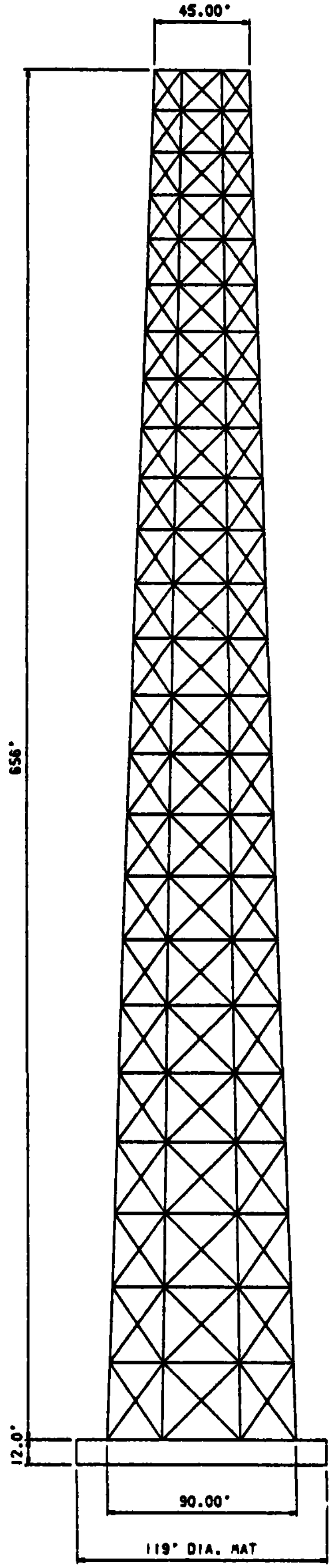


FIGURE 4 - TUBULAR STEEL TOWER

TABLE 2

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	0.061 (2.40)	0.116 (4.58)	0.114 (4.51)
Center Line Receiver	0.073 (2.89)	0.114 (5.68)	0.141 (5.57)
b. 40.2 m/s (90 mph) Wind			
Top of Tower	0.569 (22.41)	1.107 (43.58)	1.099 (43.27)
Center Line Receiver	0.686 (27.02)	1.375 (54.13)	1.358 (53.47)
c. 0.25 g Seismic			
Top of Tower	0.546 (21.52)	0.327 (12.89)	0.337 (13.27)
Center Line Receiver	0.657 (25.86)	0.421 (16.58)	0.430 (16.92)
MAX. ACCELERATION, g's			
a. Top of Tower	0.46	0.51	0.46
b. Center Line Receiver	0.57	0.21	0.19
MAX. WIND SHEAR, 10^3 kg (lb)			
a. Bottom of Tower	528.0 (1164)	674.9 (1488)	550.2 (1213)
b. Top of Tower	144.7 (319)	147.0 (324)	148.3 (327)
SEISMIC SHEAR, 10^3 kg (lb)			
a. Bottom of Tower	908.5 (2003)	274.9 (606)	228.2 (503)
b. Top of Tower	259.4 (572)	95.7 (211)	88.0 (194)

Plots of the tower frequencies, drag wind deflection, shear and moment for the concrete, conventional steel and tubular steel towers are shown in Figures 5, 6 and 7 respectively.

6.0 COST ANALYSIS

The cost analysis for the towers were prepared by Stearns-Roger's Cost Estimating Department using current material prices and labor rates for Yerington, Nevada.

6.1 MATERIAL QUANTITIES

The material quantities used in the cost estimates for the three tower configurations are shown in Table 3.

6.2 COST ESTIMATES

The comparison of tower costs are presented in Table 4. Indirect field cost has been assumed to be 75 percent of the direct labor cost 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 low. The steel towers were assumed to be erected entirely by the general contractor. These are "preliminary" cost estimates with an order of accuracy of ± 20%.

The cost estimate summaries and work sheets are attached to this report.

7.0 RECOMMENDATION

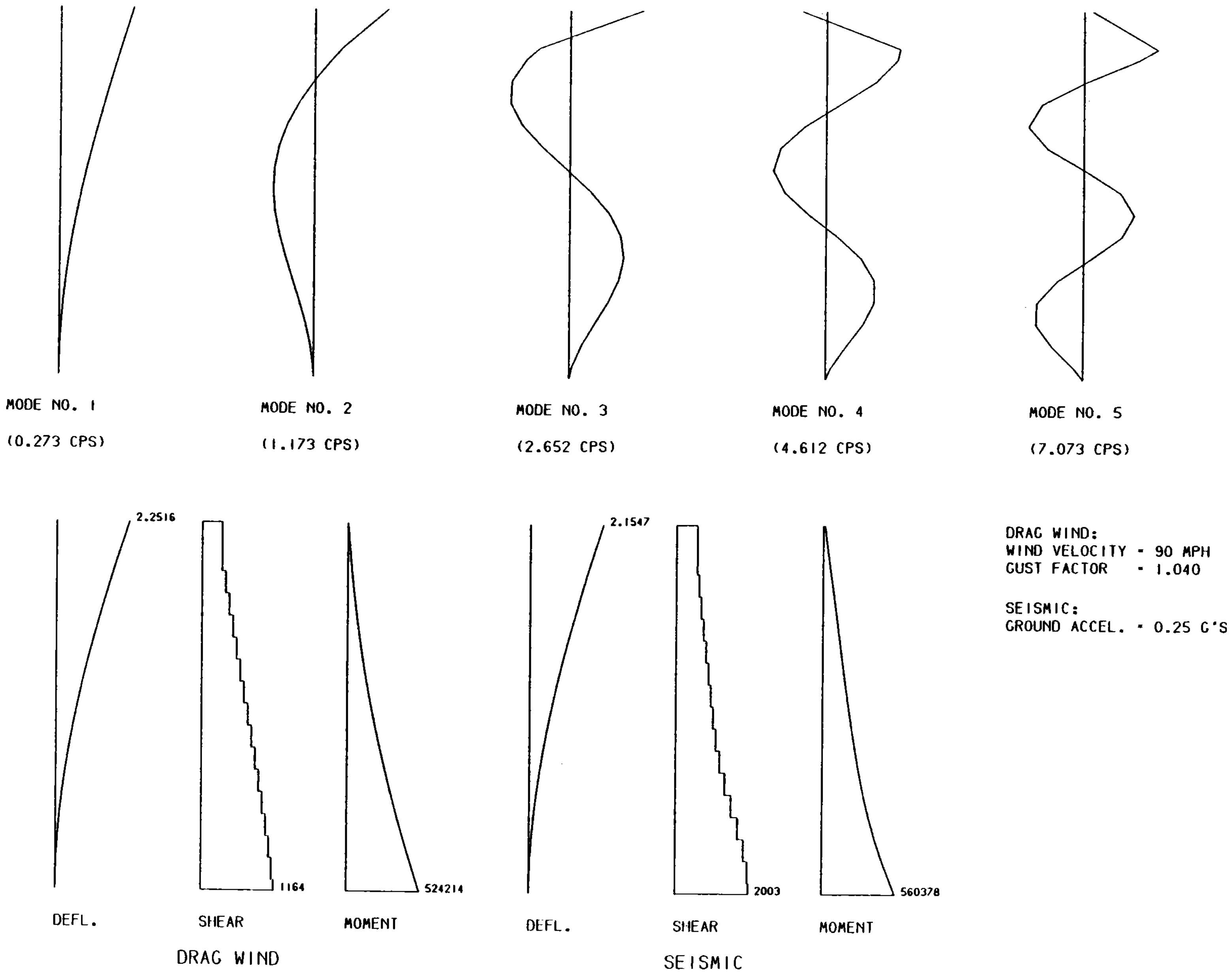
A reinforced concrete receiver tower is recommended for the baseline conceptual design. This recommendation is made for the following reasons:

1. From a cost standpoint, all three types of tower construction have the same capital cost, considering the accuracy of the cost estimate. Maintenance costs are expected to be higher for the steel towers.

2. Considerable more experience has been gained with tall concrete structures of this type, e.g., power plant chimneys, compared to the steel towers.

3. From an operational standpoint the wind and seismic induced accelerations and shears at the top of the tower are not considered significantly different for the concrete or steel towers. However, deflections due to wind are considerably higher for the steel towers.

SOLAR REPOWERING STUDY - FT. CHURCHILL UNIT NO. 1 - CONCRETE TOWER



UNITS: FEET.KIPS

FIGURE 5 - CONCRETE TOWER RESPONSE PLOT

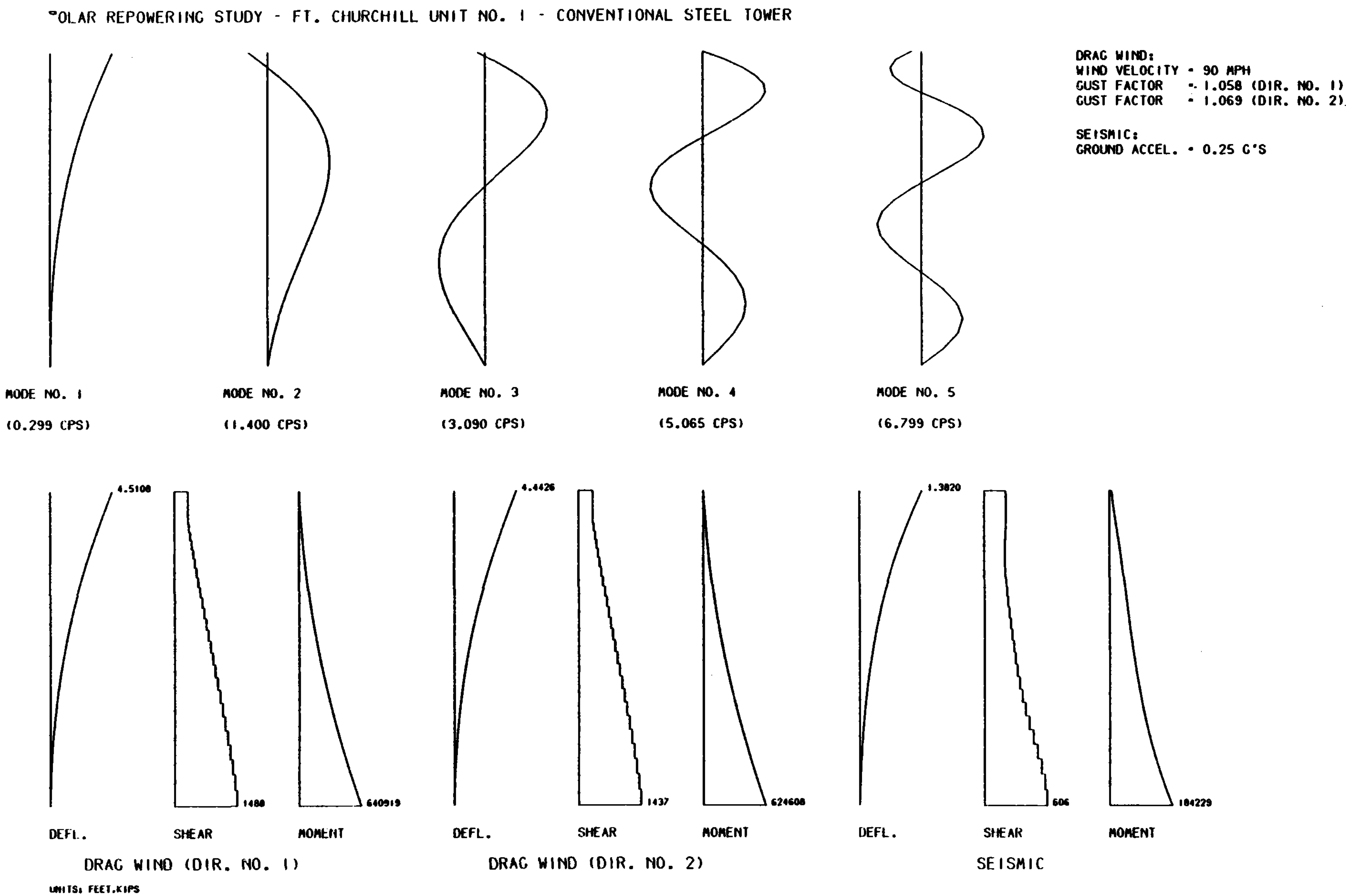


FIGURE 6 - CONVENTIONAL STEEL TOWER RESPONSE PLOT

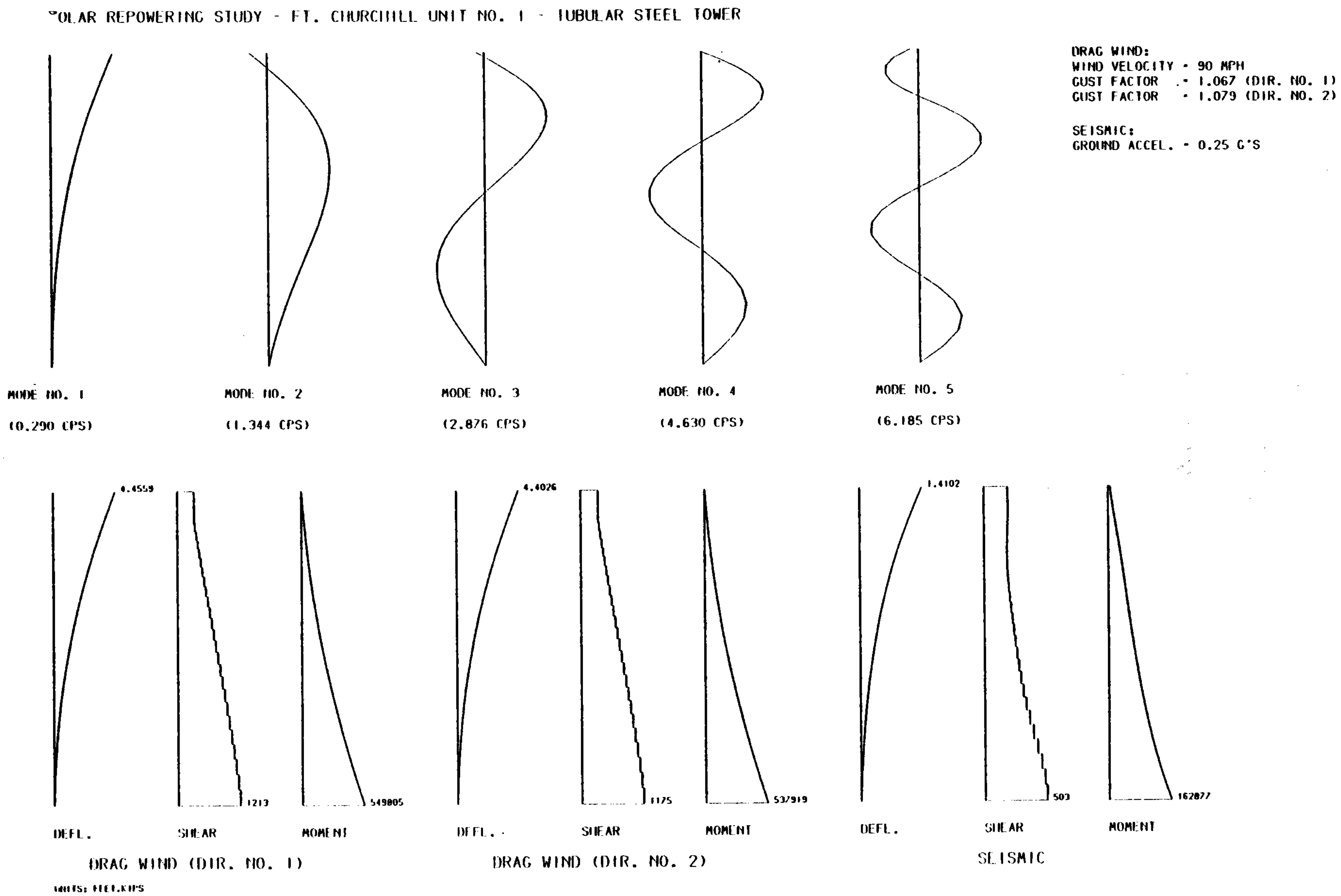


FIGURE 7 - TUBULAR STEEL TOWER RESPONSE PLOT

TABLE 3

MATERIAL QUANTITIES

200 m (656 ft.) TOWERS

	UNITS	CONCRETE	CONVENTIONAL STEEL	TUBULAR STEEL
1. TOWER				
a. Concrete (4000 psi)	m^3 ($yd.^3$)	2854 (3734)	N/A	N/A
b. Rebar (60,000 psi)	kg (ton)	317,520 (350)	N/A	N/A
c. Columns (A440 Conv.; A36 or equiv. Tubular)	kg (ton)	N/A	636,854 (702)	623,246 (687)
d. Bracing & Connections (A36 Steel)	kg (ton)	N/A	760,233 (838)	496,238 (547)
2. FOUNDATION MAT				
a. Concrete (3000 psi)	m^3 (yd^3)	3842 (5027)	4204 (5501)	3778 (4943)
b. Rebar (60,000 psi)	kg (ton)	171,460 (189)	186,883 (206)	167,832 (185)
3. SOIL EXCAVATION	m^3 (yd^3)	5392 (7055)	5898 (7717)	5317 (6957)

TABLE 4

TOWER COST COMPARISON

200 m (656 ft.) TOWERS

(1980 DOLLARS)

	CONCRETE	CONVENTIONAL STEEL	TUBULAR STEEL
Direct Field Cost	2,724,000	2,307,400	2,564,700
Indirect Field Cost	290,900	521,100	555,000
TOTAL FIELD COST	3,014,900	2,828,500	3,119,700
% Over Base	+ 6.59	Base	+ 10.29

Notes

1. Cost estimate is for tower and foundation only. Tower design, engineering, accessories and appurtenances are not included.

2. Labor rates for Yerington, Nevada.

Stearns-Roger INCORPORATED

BUDGET ESTIMATE SUMMARY

CUSTOMER	MDAC/SPPCo	PROP NO.	
LOCATION	YERINGTON, NEV	JOB NO.	C 23197 X 30000
PROJECT	SOLAR TOWER, CONCRETE, 40' OD X	DATE	1-8-80
	65' OD X 656' HIGH	BY	RHF
REV. NO.	REV. DATE	BY	

ACT	DESCRIPTION	CRAFT HOURS	LABOR	MATERIAL	OTHER	TOTAL
A	EARTHWORK				18 165	18 165
B	CONCRETE		387 770	377 255	1 940 855	2 705 880
C	BUILDINGS & STRUCTURES					
D	PROCESS EQUIPMENT					
E	PIPING					
F	ELECTRICAL					
G	PAINTING					
L	PLANT ITEMS					
N	INSTRUMENTS & CONTROLS					
P	INSULATION					
	DIRECT FIELD COST		387 770	377 255	1 959 020	2 724 045
H	FIELD EXPENSE					
H	ALL RISK, PR TAX, BOND					
K	CONSTRUCTION SUPPLIES					
M	STARTUP					
S	TEMPORARY FACILITIES					
V	CRAFT BENEFITS					
V	CONSTRUCTION CAMP.					
W	CONSTRUCTION EQUIP.					
	INDIRECT FIELD COST		75% OF D.L.			290 855
	TOTAL FIELD COST					3 014 900
J	ENGINEERING					
	TOTAL FIELD & ENG. COST					
Q	SALES TAX					
R	PREMIUM PAY					
	ESCALATION					
	CONTINGENCY					
	SUB TOTAL					
Y	FEE					
	TOTAL					

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Stearns-Roger

CLIENT MDAC/SPPCo

ORDER NO. C23197 LOCATION YERINGTON, NEV

X 30000

SHEET NO.

BY RHF

DATE 1-8-80

ACCOUNT	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L UNIT COST	MANHOURS UNIT	MANHOURS TOTAL	MANHOURS $/MH	LABOR	MATERIAL	OTHER	TOTAL
"A"	EXCAVATION	7055	CY							14110	14110
	BACKFILL	2028	CY							4055	4055
											18165
B	CONCRETE FOUNDATION	5027	CY	57^{60}	3.6	18100	15^{50}	280550	289555		570105
	REBAR "	189	T	464	36.6	6917	"	107220	87700		194920
								387770	377255		765025
B	TOWER ERECTION SUB CONTRACT										
	CONCRETE	3734	CY	57^{60}	11	41074	"	636650	215080		851730
	REBAR	350	T	464	36.6	12810	"	198555	162400		360955
	OH & P 25%										303170
	RENTAL EQUIP										250,000
	JUMP FORMS (COST)										175000
											1,940,855

Stearns-Roger INCORPORATED

BUDGET ESTIMATE SUMMARY

CUSTOMER	MDAC / SPPCo	PROP NO.	
LOCATION	YERINGTON, NEV	JOB NO.	C 23195 X 30000
PROJECT	SOLAR TOWER STRUCTURAL STEEL	DATE	1-8-80
	45' OD X 90' OD X 656' HIGH	BY	RHE
REV. NO. ⚠1 1-15-80	REV. DATE	BY	

ACT	DESCRIPTION	CRAFT HOURS	LABOR	MATERIAL	OTHER	TOTAL
A	EARTHWORK				19 865	19 865
B	CONCRETE		423 830	412 445		836 275
C	BUILDINGS & STRUCTURES		190 960	1 260 300		1 451 260
D	PROCESS EQUIPMENT			⚠1		
E	PIPING					
F	ELECTRICAL					
G	PAINTING					
L	PLANT ITEMS					
N	INSTRUMENTS & CONTROLS					
P	INSULATION					
	DIRECT FIELD COST		614 790	1 672 745	19 865	2 307 400
H	FIELD EXPENSE					
H	ALL RISK, PR TAX, BOND					
K	CONSTRUCTION SUPPLIES					
M	STARTUP					
S	TEMPORARY FACILITIES					
V	CRAFT BENEFITS					
V	CONSTRUCTION CAMP.					
W	CONSTRUCTION EQUIP.					
	INDIRECT FIELD COST		75% OF D.L.			461 100
	SPECIAL RENTAL EQUIP					60 000
	TOTAL FIELD COST					2 828 500
J	ENGINEERING					
	TOTAL FIELD & ENG. COST					
Q	SALES TAX					
R	PREMIUM PAY					
	ESCALATION					
	CONTINGENCY					
	SUB TOTAL					
Y	FEE					
	TOTAL					

FORM 62 - 11D REV. 10-76

Stearns-Roger

CLIENT MDAC / SPP CO

ORDER NO. C 23197 LOCATION YERINGTON, NEV

X 30000

SHEET NO.

BY RHF

DATE 1-8-80

ACCOUNT	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L UNIT COST	MANHOURS UNIT	MANHOURS TOTAL	MANHOURS $/MH	LABOR	MATERIAL	OTHER	TOTAL
"A"	EXCAVATION	7717	CY							15435	15435
	BACKFILL	2216	CY							4430	4430
											19865
"B"	CONCRETE	5501	CY	51.60	3.6	19804	15.50	306960	316860		623820
	REBAR	206	T	464	36.6	7540	"	116870	95585		212455
								423830	412445		836275
C	STRUCTURAL										
	COLUMNS A440	702	T	900	8	5616	"	87050	631800		718850
	△ BRACING A36	838	T	750	8	6704	"	103910	628500		732410
								190960	1,260,300		1,451,260

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FORM 22-288 REV 1/79

Stearns-Roger INCORPORATED

BUDGET ESTIMATE SUMMARY

CUSTOMER	*MDAC / SPPCO*	PROP NO.	
LOCATION	*YERINGTON, NEV*	JOB NO.	*C 23197 X 30000*
PROJECT	*SOLAR TOWER, TUBULAR STEEL*	DATE	*1-8-80*
	55' OD x 90' OD x 656' HIGH	BY	*RHF*
REV. NO.	REV. DATE	BY	

ACT	DESCRIPTION	CRAFT HOURS	LABOR	MATERIAL	OTHER	TOTAL
A	EARTHWORK				*17 945*	*17 945*
B	CONCRETE		*380 775*	*370 555*		*751 330*
C	BUILDINGS & STRUCTURES		*191 270*	*1 604 200*		*1 795 470*
D	PROCESS EQUIPMENT					
E	PIPING					
F	ELECTRICAL					
G	PAINTING					
L	PLANT ITEMS					
N	INSTRUMENTS & CONTROLS					
P	INSULATION					
	DIRECT FIELD COST		*572 045*	*1 974 755*	*17 945*	*2 564 745*
H	FIELD EXPENSE					
H	ALL RISK, PR TAX, BOND					*131 570*
K	CONSTRUCTION SUPPLIES					*97 250*
M	STARTUP					*31 460*
S	TEMPORARY FACILITIES					*—*
V	CRAFT BENEFITS					*54 250*
V	CONSTRUCTION CAMP.					*—*
W	CONSTRUCTION EQUIP.					*—*
						115 370
	INDIRECT FIELD COST		*75% OF DIRECT LABOR*			*430 000*
	SPECIAL RENTAL EQUIP					*125 000*
	TOTAL FIELD COST					*3 119 745*
J	ENGINEERING					
	TOTAL FIELD & ENG. COST					
Q	SALES TAX					
R	PREMIUM PAY					
	ESCALATION					
	CONTINGENCY					
	SUB TOTAL					
Y	FEE					
	TOTAL					

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Stearns-Roger

CLIENT MDAC / SPPCo

ORDER NO. C23197 LOCATION YERINGTON, NEV

x 30000

SHEET NO.

BY RHE

DATE 1-8-80

ACCOUNT	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L UNIT COST	MANHOURS UNIT	MANHOURS TOTAL	MANHOURS $/MH	LABOR	MATERIAL	OTHER	TOTAL
A	EXCAVATION	6957	CY							13915	13915
	BACKFILL	2014	CY							4030	4030
B	CONCRETE 119' ϕ x 12' THICK	4943	CY	57.60	3.6	17795	15.50	275825	284715		560540
	REBAR	185	T	464	36.6	6771	"	104950	85840		190790
								380775	370555		751330
C	STRUCTURAL A-36										
	COLUMNS 24" ϕ	687	T	1300/T	10 MH/T	6870	"	106485	893100		999585
	BRACING 8" ϕ TO 16" ϕ	547	T	"	"	5470	"	84785	711100		795885
		1234				12340		191,270	1,604,200		1795470

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SIERRA PACIFIC UTILITY SOLAR REPOWERING
TASK 2 TRADE STUDY REPORT
THERMAL STORAGE UNIT UTILIZATION

1.0 OBJECTIVE AND SCOPE

This trade study compares storage for extended operation to storage for system buffering.

Buffer storage is considered to be required for system operation. Extended operation storage is desirable if the marginal cost of collecting and storing additional solar energy is less than the cost of fuel. Some extended storage is also desirable if periods of solar, only, operation are anticipated. The extended storage gives the plant operator some discretionary control over the time of day that power is generated, and allows the plant to operate in an optimum peak shaving mode.

The selection is expected to be more a function of operational characteristics than of economics. Table 1 summarizes the trade study objectives and approach.

The primary objective of this study is to determine whether extended storage is cost effective. If so, a secondary objective is to determine the approximate optimum duration of storage. (A complete network integration analysis is required to finally optimize storage duration.)

To aid in estimating the optimum storage duration, three values of solar multiple are used: 1.0 for buffer storage only; 1.4 corresponding to 2.7 hours of storage; and 1.8 corresponding to 6.5 hours of storage. In addition, sensitivity to the type of thermal storage is examined. Candidates considered are thermocline, two tank, and multitank. This latest study will help focus Trade Study 6, "TSU Thermocline Versus Two Tank".

Table 1

THERMAL STORAGE UNIT UTILIZATION (TS-5)

OBJECTIVE:	To determine whether thermal storage should be used for extended operation or for buffer storage only
CANDIDATES:	Baseline - Extended operation storage Alternate - Buffer
SELECTION CRITERIA:	System cost, value of fuel displaced, benefits of storage to energy collection, compatibility with operating characteristics of existing plant equipment
APPROACH:	Estimate marginal cost of increasing thermal storage unit capacity. Use optimum collector field size as variable with storage unit size. Estimate marginal fuel displacement resulting from increased TSU capacity. Examine effects of TSU capacity on operations. Select approximately optimum TSU size
EXPECTED RESULTS:	Extended storage is expected to be preferred with the exact size to be determined
INPUT DATA:	o System costs as for previous trade studies o Operating characteristics of plant equipment from SPPC o Modified Reno insolation data
PARTICIPATING ORGANIZATIONS:	MDAC - lead SPPC - power equipment requirements
SCHEDULE:	Start 11/5/79 Complete 11/21/79

2.0 STORAGE CONCEPTS

Three candidate storage concepts are described in this section. It is recognized that there are technical feasibility issues involved with two of the concepts. However, all three are displayed to show effects of the storage method selected on the economic evaluation of extended storage. The questions of technical feasibility and risk will be considered in Trade Study TS-6, "TSU Thermocline Versus Two Tank".

2.1 THERMOCLINE STORAGE

The dual medium thermocline storage unit is illustrated in Figure 1. For simplicity, a single tank is shown. The tank is packed with pelletized iron ore in either a single size or in two sizes which differ by roughly a factor of 10 in linear dimension. A single size is preferred for this application. With a single aggregate size, approximately 60% of the tank volume is occupied by aggregate. The remaining 40% is occupied by heat transfer salt.

Heated salt from the receiver enters the tank through the inlet side of the upper manifold. Hot salt exits the tank from the outlet side of the upper manifold. The hot salt inlet flow rate is determined by the receiver thermal power level. The outlet flow rate is determined by the steam generator demand. Differences between these flow rates are made up by flow into or out of the storage tank.

A similar flow pattern occurs with "cold" salt flowing through the lower manifold.

As the molten salt flows through the fixed iron ore bed, heat is exchanged with the bed material. The heat exchange in a properly designed bed occurs in such a way as to maintain a rather sharply defined change in temperature with height within the tank. The zone of rapid change in temperature with height is termed a thermocline layer, and the storage method is a dual medium thermocline.

In charging and discharging the thermal storage tank, the temperature of the receiver fluid exiting the tank will remain constant until the thermocline layer reaches the manifold. Non-equilibrium processes occurring within the tank cause the thermocline layer to grow in time. This growth is limited by extracting a portion of the layer at the top and/or bottom of the tank during discharge/charge cycles.

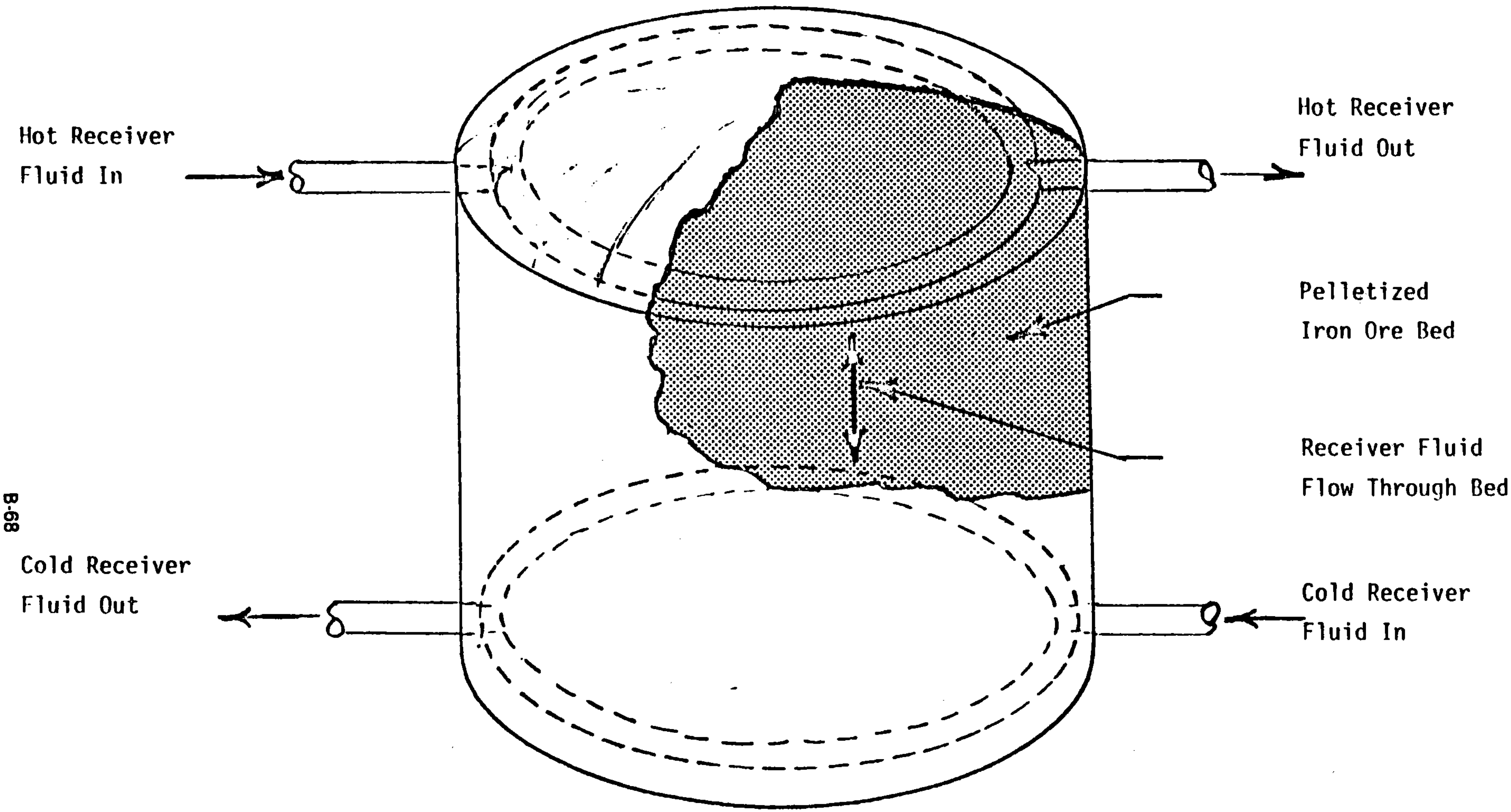


Figure 1 DUAL MEDIUM THERMOCLINE STORAGE UNIT

The thermocline layer during repeated full charge cycles is expected to make at least 90% of the total tank volume and stored energy usable. The remaining 10% is not a system loss, but rather remains permanently captive in the thermal storage tank.

2.2 TWO TANK - INTERNAL INSULATION

A two tank system, illustrated in Figure 2, employs a "hot" tank which receives all receiver fluid returned from the receiver at the maximum temperature (1050-1100^{o}F). A "cold" tank receives all of the low temperature fluid (550^{o}F) returned from the steam generator.

As with the thermocline tank, flow out of the cold tank and into the hot tank is regulated by receiver thermal power, and flow out of the hot tank and into the cold tank is controlled to meet the steam generation demand.

Two tank systems with external insulation have always appeared to be more costly than single tank systems. The external insulation means that the tank material must withstand the stresses at high temperature and the corrosive environment of the receiver fluid. Moreover, the tank must be larger than an equivalent dual medium thermocline tank because of a lower volumetric heat capacity. The combination of a larger tank plus a second, lower temperature tank has lead to a more expensive system.

By using internal insulation, the hot tank can have an ambient temperature pressure shell which is not in contact with the salt. Hence, the direct tank cost is greatly reduced. The insulation must be rigid, non-organic, and load bearing. Moreover, the insulation must allow for thermal cycling. A corrosion resistant liner must be used, and that liner must be leak free.

If the technical difficulties of an internal insulation - two tank system can be resolved on a schedule which supports the Sierra Pacific Repowering, the cost should be substantially reduced over that of a two tank - external insulation system.

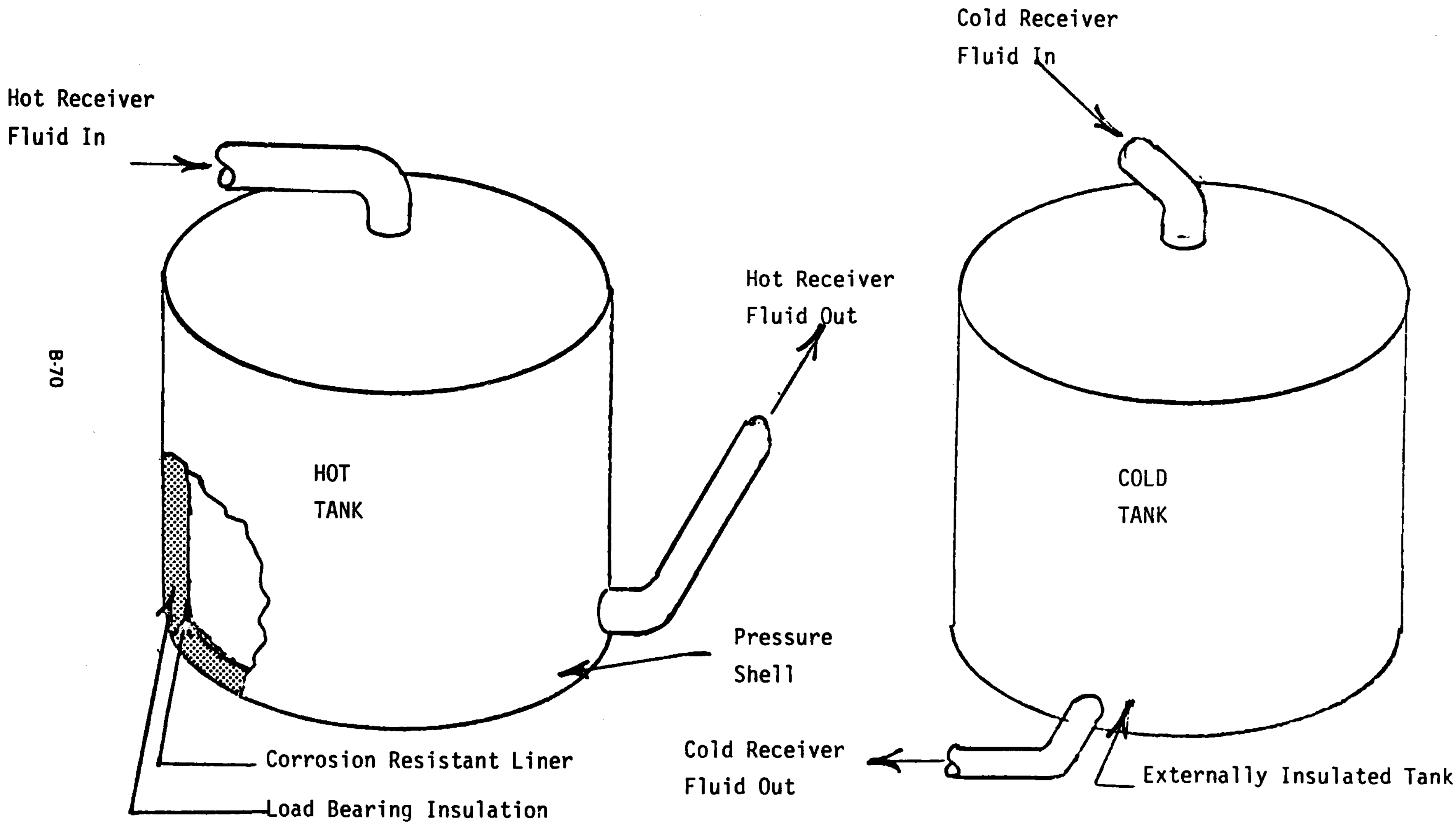


Figure 2 TWO TANK, INTERNAL INSULATION STORAGE UNIT

2.3 SERIES CONNECTED MULTI-TANK

A series connected multi-tank system is considered for reference. The system uses factory manufactured tanks which can be transported by common carrier. The arrangement is shown in Figure 3.

As with the other systems, all hot receiver fluid flows to the inlet to the first tank. Excess fluid above steam generator demand flows into the top of the first tank, and displaces fluid at the bottom of the tank. The displaced fluid flows up a standpipe in the center of the tank and over to the second tank. Subsequent tanks are series connected such that hot fluid flowing into the first tank causes cold fluid to flow into the surge tank, and subsequently back to the receiver.

The above process reverses when steam generator demand exceeds receiver fluid supply from the receiver.

At some point in the string of tanks, a thermocline exists. The thermocline is not expected to remain sharp at all times. However, it appears that a relatively poorly defined thermocline will not be deleterious to system operation in the operating modes envisioned. This question will be further explored only if the multi-tank system shows attractive economics.

3.0 SYSTEM COST ESTIMATES

System costs were estimated for the three storage concepts described in Section 2, and for buffer storage, 2.7 hour storage, and 6.5 hour storage. Sizing characteristics are shown in Table 2. Costs were estimated at the subsystem or assembly level using both cost estimating relationships and vendor quotations.

Subsystem costs are presented in Table 3 in 1980 dollars and include material and labor. The thermal storage tank and piping costs are estimated from construction cost estimating guides and reflect adjustments for diameter, gage, length and material type. Media (Partherm 430 @ \$.30/lb., iron ore @ \$36/ton) and insulation (Tank - mineral wool insulation, Piping - Calcium Silicate) costs are based on JPL Small Central Receiver Proposal Vendor quotes. Installation costs for these components have been derived using cost estimating relationships, and foundation costs are based on the PDR proposal with appropriate sizing adjustments.

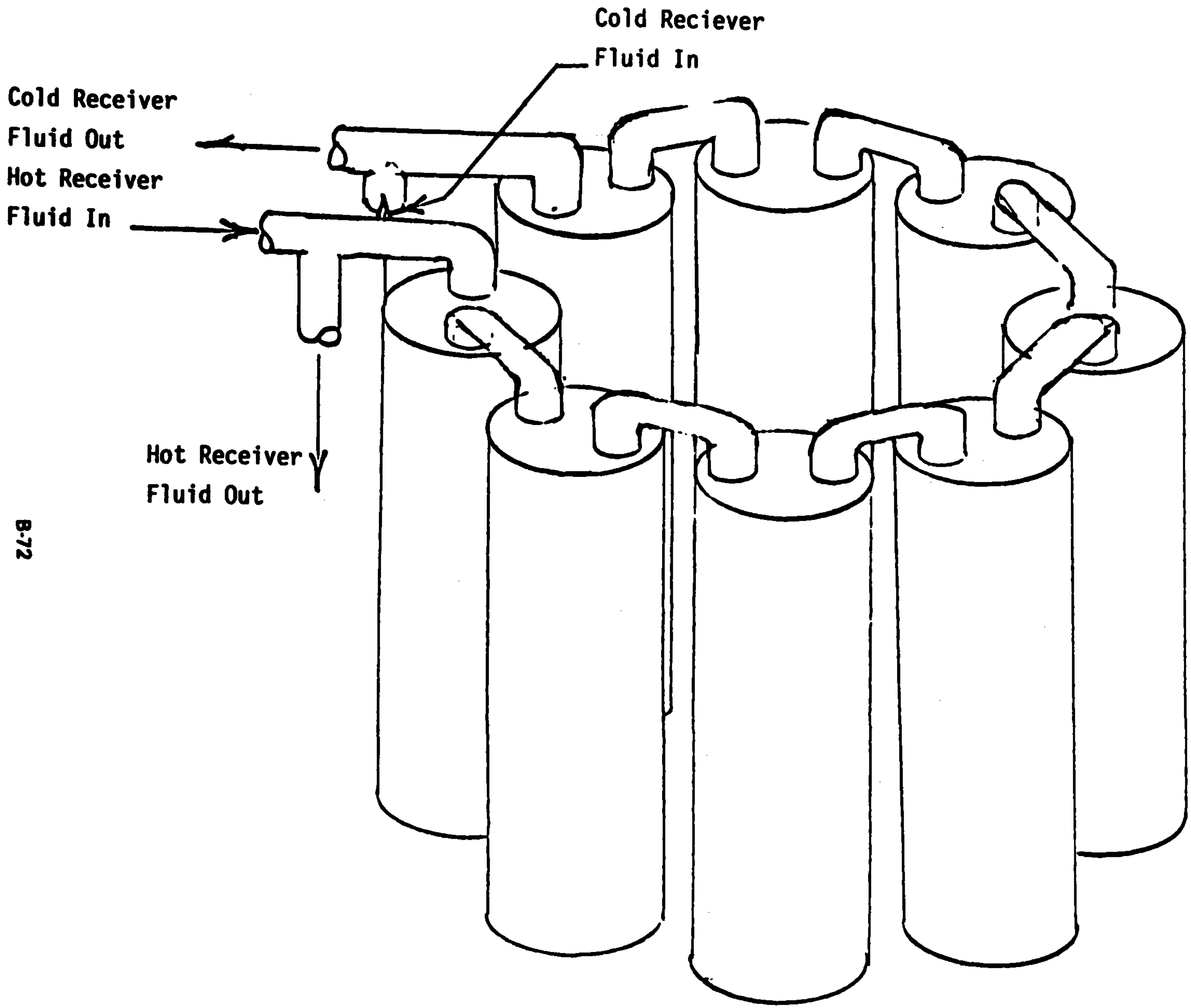


Figure 3 MULTITANK STORAGE UNIT

TABLE 2

TANKAGE SIZING CHARACTERISTICS

Tank Type	Solar Multiple	Tank Volume (ft^3)	Representative Dimensions (Ft.)	Hydrostatic Pressure At Base (PSIG)
THERMOCLINE	1.0	12,000	25 DIA. x 25 HIGH	44
	1.4	64,000	43 DIA. x 43 HIGH	74
	1.8	154,000	58 DIA. x 58 HIGH	100
TWO TANK INTERNAL INSULATION	1.0	15,000	26 DIA. x 26 HIGH	26
	1.4	79,000	46.5 DIA. x 46.5HIGH	45
	1.8	190,000	62 DIA. x 62 HIGH	59
MULTITANK	1.0	4 Tanks	12 DIA. x 38 HIGH	37
	1.4	19 Tanks	12 DIA. x 38 HIGH	37
	1.8	45 Tanks	12 DIA. x 38 HIGH	37

Table 3

TANK COST ESTIMATES (10^3, 1980)

Tank Type	Solar Multiple	Tankage	Foundation	Insulation	Media	Total TSU Cost	Balance of System Cost ($M)	Total System Cost ($M)
	1.0	506	17	73	199	795	66.2	67.0
THERMOCLINE	1.4	1,357	52	214	1,062	2,679	88.2	90.0
	1.8	2,357	95	389	2,553	5,394	109.8	115.2
TWO TANK	1.0	424	41	130	490	1,085	66.2	67.3
INTERNAL	1.4	958	128	417	2,649	4,152	88.2	92.4
INSULATION	1.8	1,454	223	742	6,048	8,467	109.3	118.3
	1.0	725	31	172	577	1,505	66.2	67.7
MULTITANK	1.4	3,433	148	820	2,827	7,228	88.2	95.4
	1.8	8,147	350	1,944	6,493	16,934	109.8	126.7

The balance of system costs are brought forward from Trade Study 1. Only the $165/M^2$ heliostat costs are shown.

The fuel displacement depends on the collector solar multiple and system storage size. Fuel displacement for the optimum combination of solar multiple and storage size was previously calculated for Trade Study 1 "Receiver Fluid Selection". As for that study, a figure of merit was computed for each case of solar multiple and storage system type. The figure of merit is the ratio of the present value of 20 years fuel displacement to the intial capital cost of the system. A fuel escalation rate of 10% per year from an initial (1980) value of $4.14/MMBTU was assumed. The 20 years fuel displacement is again felt to be conservative because the repowered plant's useful life is expected to be extended to 25 to 30 years by the lower loads placed on the fossile boiler.

Fuel displacement and figure of merit are shown in Table 4 for each combination of thermal storage type and solar multiple. In addition an annual return on investment is shown for each case. The return on investment is computed for a 10% fuel escalation rate and $165/M^2$ heliostat costs.

The figure of merit and the ROI are both greater for the thermocline storage unit than for the two tank. This result stems directly from the higher cost estimate for the two tank system in Table 3. Multi tank systems are substantially more expensive, and are excluded from further consideration.

The most important difference between system costs for the thermocline and two tank systems is seen from Table 3 to be in the cost of the storage media. Previous analyses have used costs as low as $.10/lb for the salt. These costs may be realistic, but tests of material properties and compatibility should be conducted to verify that the lower cost salts are acceptable. Such tests could be required individually on each batch.

Dual medium thermocline storage using pelletized iron ore and molten salt should be preferred on the basis of lower thermal storage system cost. Particularly for early deployment, the thermocline system should be preferred to the two tank, internal insulation approach on the bases of lower technical and schedule risk.

Table 4

EFFECT OF STORAGE DURATION ON SYSTEM ECONOMICS

[FOM = $\frac{\text{Present Value of 20 Years Fuel Savings}}{\text{Initial System Capital Cost}}$ (1)]

Solar Multiple	Fuel Displacement bbl Oil/Year	THERMOLLINE			TWO TANK			MULTITANK		
		Cost	FOM	ROI	COST	FOM	ROI	COST	FOM	ROI
1.0	271,000	67.0	3.13	18.4	67.3	3.12	18.4	62.7	3.10	18.3
1.4	379,000	90.9	3.19	19.1	92.4	3.14	18.8	95.4	3.04	18.3
1.8	486,000	115.2	3.30	19.8	118.3	3.21	19.2	126.7	3.00	18.2

NOTE: 1) 10%year Fuel Escalation

The thermocline tank will probably have to be modularized in order to stay within allowable soil bearing pressure limits. Hence, some cost risk may be incurred. This aspect will be explored in greater detail in Trade Study 6 "TSU Thermocline Versus Two Tank".

The figure of merit in Table 4 shows a steady increase with solar multiple for both the thermocline and two tank approaches. While the increase in FOM and ROI is small, the increase in fuel displacement is quite substantial. The conclusion reached is that thermal storage is economic up to the point that 24-hour-per-day operation or displacement of fuels other than oil is reached. Therefore, a nominal storage capacity of 6 hours at a nominal solar multiple of 1.74 will be chosen. This result will be either conformed or refined by the detailed network optimization to be conducted in Task 5.

4.0 RECOMMENDATIONS

It is recommended that thermal storage be included for extended system operation. A storage unit size of 1130 MWth (6 hours' capacity) will be used for the nominal size with a solar multiple of 1.74.

SIERRA PACIFIC UTILITY SOLAR REPOWERING
TASK 2 TRADE STUDY REPORT
TSU THERMOCLINE VERSUS TWO TANK

1.0 OBJECTIVE AND SCOPE

This trade study compares three types of thermal storage units:

1) Dual Medium Thermocline storage which uses a fixed bed of low cost, inert solids exchanging heat with the receiver fluid.

2) Two Tank, External Insulation which uses separate tanks for storing hot and cold receiver fluid. Both tanks have external insulation and the tank is also a pressure shell.

3) Two Tank, Internal Insulation which is similar to (2). The hot tank has an external pressure shell, internal load bearing insulation, and a corrosion resistant liner next to the fluid.

The selection is expected to be driven by system performance and economic issues. Volumetric efficiency of the thermocline tank and molten salt cost are issues of primary importance. In addition, there are development risks associated with both the thermocline and the internal insulation approaches. Table 1 summarizes the trade study objectives and approach.

2.0 STORAGE CONCEPTS

The storage concepts were previously described in detail under Trade Study 5, "Thermal Storage Unit Utilization". The discussion in this section will focus on limitations, operations and risk issues.

2.1 DUAL MEDIUM THERMOCLINE

Three areas of concern in dual medium thermocline storage remain somewhat uncertain. These areas are impact of materials compatibility, volumetric efficiency and thermocline degradation, and soil bearing pressure.

TABLE 1

TSU THERMOCLINE VERSUS TWO TANK (TS-6)

OBJECTIVE:	To select a thermal storage unit configuration
CANDIDATES:	Baseline - Thermocline storage in a dual medium tank(s) Alternate - Hot and cold storage in two or more separate tanks, with internal or external insulation
SELECTION CRITERIA:	System cost, operations and maintenance considerations
APPROACH:	Estimate cost of single tank and two tank systems from system cost estimating relationships. Consider development risk. Verify operational acceptability of each approach. Select the lower cost system with acceptable O&M characteristics
EXPECTED RESULTS:	A properly defined single tank, thermocline system is expected to be more cost effective.
INPUT DATA:	• MDAC and DOE/Sandia cost estimates for molten salt tankage and associated equipment • System size estimate from TS-5
PARTICIPATING ORGANIZATIONS:	MDAC - lead Foster-Wheeler - support
SCHEDULE:	Start 11/12/79 Complete 11/20/79

2.1.1 Materials Compatibility

Materials compatibility is being investigated in several DOE programs. Preliminary results indicate that pelletized iron ore can be used with molten salt up to at least 1100°F. Moreover, the salt appears to be compatible with type 304 stainless steel, provided it is well vented to dry, CO_2-free air.

Based on the above results, the thermocline analyses use pelletized iron ore as the bed medium and both Incoloy 800 and Type 304 stainless steel as the container materials. The Type 304 stainless steel will be baselined in anticipation of further favorable test results. However, it must be remembered that a higher grade alloy may be required after the test program is concluded.

2.1.2 Thermocline Volumetric Efficiency

Experience with DOE 10MWe Pilot Plant is showing a continuous degradation of the thermocline. Usable volumetric efficiencies as low as 60% are predictable on the basis of experimental data and analyses. The volumetric efficiency is increased to about 90% by re-establishing the thermocline during a full charge in the pilot plant. However, it is desirable to eliminate this requirement for the repowering application.

MDAC undertook an analysis of the several heat and mass transfer mechanisms which can be present in a packed bed. The conclusion reached in this analysis is that all previous analyses have ignored the controlling mechanism for thermocline degradation. Order of magnitude analyses predicted the actual measured data without adjustments of any constants. Previous analyses have required adjustment of empirical parameters by a factor of 4 to 5 from predicted values in order to match measured data.

Based on the success of the MDAC analysis of the thermocline, it is believed that a dual medium thermocline tank can be configured with a volumetric efficiency in excess of 90%. More detailed calculations are required to verify this conclusion.

2.1.3 Soil Bearing Pressure

The bearing stress on the soil becomes a potential problem for large thermal storage tanks. The soil at the Sierra Pacific Ft. Churchill site is probably limited to 7500 psf bearing pressure, even with compaction. The high density of the iron ore bed limits the usable bed height to about 31 feet.

The bed height limitation leads to either a very large diameter tank or multiple tanks. The thermocline layer is defined as the thickness of bed over which the temperature changes from the lowest usable temperature for steam generation to the highest usable temperature for input to the receiver. In the case of a single tank or tanks arranged in parallel flow, each foot of thermocline layer thickness leads to a loss of 3.2% of the bed height. The thermocline layer must be kept to about 3-ft. thickness in order to achieve 90% volumetric efficiency. Two or three thermocline tanks may be arranged in series, giving effective bed heights of 62 and 93 feet, respectively. The thermocline layer thickness could then grow to 6 or 9 feet.

The preferred arrangement has not yet been determined. More detailed analyses will be required to complete the configuring of the thermal storage tanks. Therefore, cost estimates will be developed for one, two, and three tank systems. The detailed arrangement will be left to be determined. Pertinent sizing data are shown in Table 2.

2.2 TWO TANK - EXTERNAL INSULATION

Material compatibility considerations are the only identified concern for the two tank system with external insulation. A baseline of Type 304 stainless steel will be carried, together with an Incoloy 800 alternate for the hot tank. The cold tank will be Type 304 stainless steel.

The salt cost is an important uncertainty. The major U.S. supplier of heat transfer salt, Park Chemical, indicates a price of 30¢/lb for the delivered salt. Other estimates for procuring the individual constituents and mixing on site range from 10¢/lb to 25¢/lb. The salt must be relatively free of impurities, and there are indications that the lower cost sources do not control the impurities as carefully as Park Chemical does. For this reason, the 30¢/lb

TABLE 2

THERMOCLINE SYSTEM SIZING DATA

No. of Tanks	Diameter (Ft.)	Wall Material	Wall Thickness (In.)	Height (Ft.)
1	76.4	Incoloy 800	1.75	31
		304 SS	3.2	
2	54	Incoloy 800	1.2	31
		304 SS	2.25	
3	44.1	Incoloy 800	1.0	31
		304 SS	1.85	

40% salt, 60% iron ore by volume

number appears to be more believable.

2.3 TWO TANK - INTERNAL INSULATION

With internal insulation and a corrosion-resistant liner, the pressure shell of the hot tank can be made of lower grade steel. For this study, 2 1/4 Cr. 1 Mo steel is assumed. The liner is assumed to be Type 304 stainless steel.

Sizing data for both two tank systems are shown on Table 3.

There are several technical questions which relate to the two tank system with internal insulation. These questions may all have valid and possibly even obvious answers. They are posed here for the sake of completeness.

1) Thermal cycling will occur on the empty or partially empty tank. Does the cycling break down the insulation?

2) How does the tank bottom behave when the hydrostatic load is cycled from the empty to the full tank daily in conjunction with thermal cycling?

3) The ground will be the major insolator for the tank bottom. Will the ground tend to buckle or scrub and abrade the tank bottom as it is cycled in load and temperature?

4) Can the insulation withstand minor liner leaks?

5) How is the system fabricated in the field?

6) Can the development problems attendant with the internal insulation task be solved in time to support a 1985 operational date?

If a two tank, internal insulation system is to be selected, these questions must be resolved.

TABLE 3

TWO TANK SYSTEM SIZING DATA

	Diameter (Ft)	Wall Material	Wall Thickness (In)	Height (Ft)
COLD TANK	68.6	304 SS	1.62	51.4
HOT TANK EXTERNAL INS.	68.6	Incoloy 800	1.4	51.4
		304 SS	2.6	
HOT TANK INTERNAL INS.	70.6	2 1/4 Cr, 1 MO	1.33	51.4

3.0 SYSTEM COST ESTIMATES

Costs were estimated for each of the systems and options discussed in Section 2. The cost estimates are shown in Table 4.

The tankage costs for the thermocline and the two tank systems are similar and not greatly different. The preponderance of difference in cost is seen to be in the media.

Note that if Type 304 stainless steel is acceptable as a tank material, the two tank, external insulation unit is only $0.36M (or 4%) more expensive than the two tank, internal insulation unit. It is questionable that this small potential gain would warrant the required development program. Hence, the lower risk, two tank system with external insulation is the preferred choice between these two options.

On the basis of the cost estimates of Table 4, the dual medium thermocline storage would be clearly preferred. However, there are several cost/risk issues to be addressed, as well.

4.0 RISK ASSESSMENT

Commerical grade salt can be produced for a much lower cost than the MIL STD grade used for the above cost analyses. A rather inexpensive compatibility test can be run to assure the suitability of the lower cost material.

The pelletized iron ore has about 40% void fraction, and the pullet size is too large to be optimum for dual medium storage. For the small quantities of ore required, there is some question that ore of a suitable size, purity, and solid fraction can be made available.

The steel container material in the dual medium tank has a higher thermal coefficient of expansion than the iron ore. When the tank is hot, the iron ore will settle to the bottom of the tank. As the tank cools, the ore will remain in place, and an additional hoop stress will be added to the tank wall. If the hoop stress were to exceed the yield stress of the material, racheting would occur and the tank would eventually rupture.

TABLE 4

THERMAL STORAGE UNIT COST ESTIMATES

	Thermocline Tanks			Two Tank**	
Cost Element	One Tank	Two Tanks	Three Tanks	External Ins.	Internal Ins.
Tank 304 SS	1.24	1.38	1.49	2.38	2.00*
Incoloy	2.26	2.29	2.39	3.45	--
Foundation	0.16	0.16	0.16	0.26	0.27
Insulation	0.38	0.45	0.50	0.84	0.84
Media	2.50	2.50	2.50	5.90	5.90
Piping	--	0.04	0.07	--	--
TOTAL 304 SS	4.28	4.53	4.72	9.38	9.02*
Incoloy	5.30	5.44	5.62	10.46	

*2 1/4 Cr, 1 Mo steel pressure shell on Hot Tank

** Low carbon steel may be used on cold tank with external insolation and on hot tank with internal insolation.

The actual magnitude of the hoop stress is dependent on the bulk modulus of elasticity of the packed bed. No data for this bulk modulus or for the modulus of the solid iron ore have been found, to date. If the modulus is found to be high, the additional stress in the tank walls will require heavier walls and a more costly tank. Hence, there is a cost risk involved with the dual medium approach.

There is also a question of compatibility of the iron ore and salt over a long term. Preliminary indications are that there is no problem; however, verification is required.

On the positive side, a dual medium system can be run completely with cold side salt pumping. This may prove to be a major advantage to the pump development.

5.0 RECOMMENDATION

Because of the cost and technical risks associated with the dual medium thermocline system, the two tank system is presently preferred. It is further recommended that the development program necessary to verify the dual medium system be undertaken. It appears to be cost effective on a first unit basis to perform the subsystem development. Such development should be done on a schedule which will allow a baseline change for a system to be deployed in 1985. In anticipation of successful development, the dual medium thermocline system will be carried as an alternate.

SOLAR REPOWERING STUDY
SIERRA PACIFIC POWER UTILITY
TASK 2 TRADE STUDY REPORT
HEAT EXCHANGER DESIGN SELECTION

Objective and Scope

The object of this study was to determine the type of Heat Exchanger/Steam Generator Components which would provide the best configuration for the Ft. Churchill repowering task and to determine the merits of operating the generators with a 950°F steam temperature and a 1000°F steam temperature (bulk salt temperature 1050°F). The detailed trade study was completed by Foster Wheeler and their report is attached.

Recommendation

The following recommendations are made based on the Foster Wheeler Study.

a. The preheat, superheater and reheater will be counterflow type heat exchangers.

b. The evaporation will be a parallel flow design.

c. The heat exchangers will be sized to deliver steam at 1005°F at the superheater outlet and at the reheater outlet. This temperature allows for a 5°F drop in temperature between the steam generators and turbine inlet housing hence, a temperature of 1000°F will be supplied by the Solar System. (Note: Since the fossil system will be operated at a low power setting, the steam generated in the fossil section will be less than 1000°F. The combination of the two steam sources will provide steam at the turbine inlets at about 980 - 985°F at rated design conditions.)

d. Type. The straight tube and plate type of heat exchanger is recommended. This system utilizes a bellows for thermal expansion instead of a directional change (as used in the hockey stick design.)

SOLAR REPOWERING STUDY

SIERRA PACIFIC POWER UTILITY

TASK 2 TRADE STUDY REPORT

STEAM GENERATOR DESIGN CONDITIONS

1.0 OBJECTIVE AND SCOPE

The objective of this trade study is to compare the relative cost of designing the steam generator system to supply 538°C (1000°F) as compared to 510°C (950°F) main and reheat steam to both the high and low pressure turbine stages. The approach used was to size the heat exchangers for 538°C operation (Case 1) in sufficient detail in order to obtain an approximate cost estimate. Then, assuming the heat exchangers for 510°C operation (Case 2) have the same overall heat transfer coefficients, estimate the cost based on the change in heat transfer surface relative to Case 1 resulting from the change in log mean temperature difference (LMTD).

The study does not consider the cost advantage resulting from increased turbine cycle efficiency and the resulting reduction in the number of heliostats, receiver size, etc. In addition, performance calculations were based on the assumption that both the fossil and solar unit, operating in a hybrid mode, provide the same aforementioned steam conditions to the turbine. For hybrid operation with the fossil unit turned down to approximately 35 percent of its rated capacity, the unit can provide only about 510°C main and reheat steam. Consequently, for actual hybrid operation, the blended main and reheat steam will be at a temperature somewhat lower than 538°C for Case 1.

The designs selected for this study are for a relative cost comparison between Case 1 and Case 2 and should not be viewed as final designs. Final designs will be determined under Task 3.

2.0 SIZING AND PERFORMANCE ESTIMATES

2.1 DESIGN CONDITIONS

Table 1 lists the steam generator design conditions for Case 1 (538°C/538°C) and Case 2 (510°C/510°C). Items of note include the following:

Table 1. Design Conditions

	CASE 1	CASE 2
TEMPERATURES [°F/°C]:		
Steam/Water:		
Feedwater	460/237.8	460/237.8
Superheater Inlet	638/336.7	638/336.7
Final Steam	1005/540.6	955/512.8
Reheater Inlet	648/342.2	605/318.3
Reheater Outlet	1005/540.6	955/512.8
Salt:		
Superheater Inlet	1045/562.8	1045/562.8
Superheater Outlet	835/446.1	844/451.1
Reheater Inlet	1045/562.8	1045/562.8
Reheater Outlet	835/446.1	844/451.1
Evaporator Inlet	835/446.1	844/451.1
Evaporator Outlet	647/341.7	649/342.8
Preheater Inlet	647/341.7	649/342.8
Preheater Outlet	550/287.8	550/287.8
FLOWS [(M lbm/h)/(kg/sec)]:		
Steam/Water:		
Feedwater	523.7/ 65.9	523.7/ 65.9
Blowdown	2.6/ 0.3	2.6/ 0.3
Main Steam	521.1/ 65.6	521.1/ 65.6
Reheater	451.0/ 56.8	451.0/ 56.8
Salt:		
Preheater	3420./430.8	3330./419.5
Evaporator	3420./430.8	3330./419.5
Superheater	2290./288.4	2170./273.4
Reheater	1130./142.4	1160./146.1

Table 1. Design Conditions (Cont'd)

	CASE 1	CASE 2
*PRESSURES [psia/kPa]:		
Steam/Water:		
Feedwater	2065/14,241	2065/14,241
Drum	2035/14,034	2035/14,034
Final Steam	1975/13,261	1975/13,621
Reheater Inlet	463/3193	463/3193
Reheater Outlet	438/3021	438/3021
Salt:		
Superheater Inlet	100/690	100/690
Superheater Outlet	80/552	80/552
Reheater Inlet	100/690	100/690
Reheater Outlet	80/552	80/552
Evaporator Inlet	80/552	80/552
Evaporator Outlet	60/414	60/414
Preheater Inlet	60/414	60/414
Preheater Outlet	40/276	40/276
DUTIES[(10^6 Btu/h)/MW]:		
Evaporator	239.4/ 70.1	239.4/ 70.1
Superheater	178.4/ 52.3	161.8/ 47.4
Reheater	87.6/ 25.7	87.0/ 25.5
Preheater	122.5/ 35.9	122.5/ 35.9
TOTAL	627.9/184.0	610.7/178.9

*NOTE: Initial Estimates

- Main and reheat steam flows were estimated by proportioning values from the 5 percent overpressure maximum load turbine cycle diagram (Figure 1) for Fort Churchill Unit No. 1. The ratio 80MW/ 117.112 MW was used.

- Steam pressures were estimated from the Babcock and Wilcox summary performance data for the Fort Churchill Unit No. 1 steam generator and expected losses through steam generator system.

- Molten salt properties for Partherm 430 were used.

- As requested by MDAC, the selected steam flows were held constant for both Case 1 and Case 2. As a result, the superheater, reheater, and total duties were reduced by 9.3, 1.0, and 2.7 percent respectively, when lowering the steam temperatures from 538°C to 510°C. In actual operation the throttle steam flow will increase as throttle temperature is reduced for a fixed maximum throttle pressure (See Figure 2).

- A 2.8°C (5°F) steam temperature drop was assumed in both the main stream and reheat steam lines from the heat exchangers to the turbine. Consequently the steam temperature leaving the superheater and the reheater is 540.6°C (1005°F) and 512.8°C (955°F) for Case 1 and Case 2 respectively

- A 2.8°C molten salt temperature drop was assumed in the hot salt line feeding the steam generator system. Consequently the molten salt temperature entering the superheater and reheater is 562.8°C (1045°F).

- A blowdown rate of 0.5 percent was used. This is the same as indicated on the turbine cycle diagram (See Figure 1).

- The Case 2 cold reheat temperature was estimated as shown on Figure 3.

Figures 4 and 5 show plots of fluid temperature versus duty for Case 1 and Case 2 respectively. By holding the cold salt temperature at 267.8°C(550°F), the approach temperatures for both the evaporator and the preheater are relatively low 5°C (9°F) and 6.1°C (11°F) for Case 1 and Case 2 respectively.

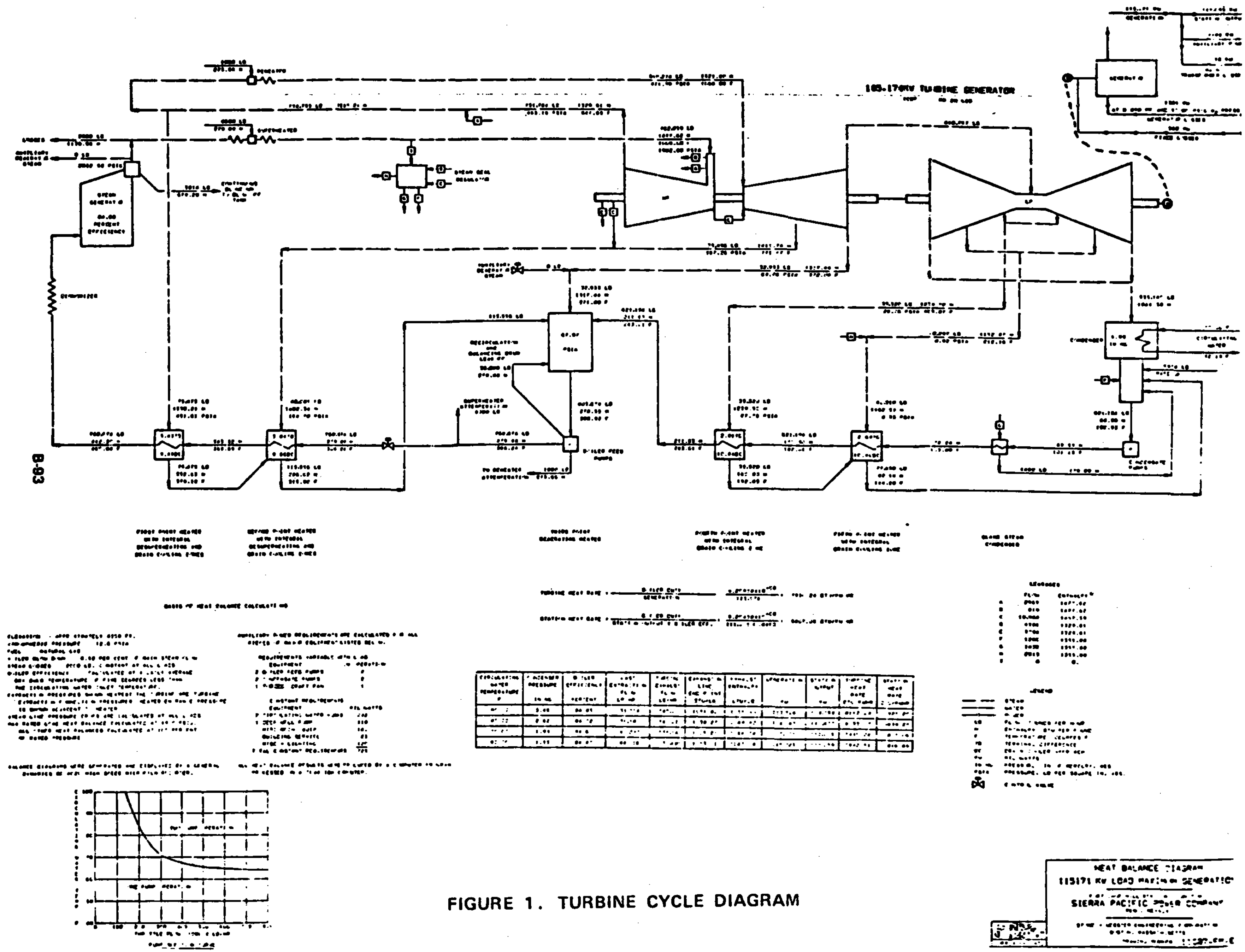


FIGURE 1. TURBINE CYCLE DIAGRAM

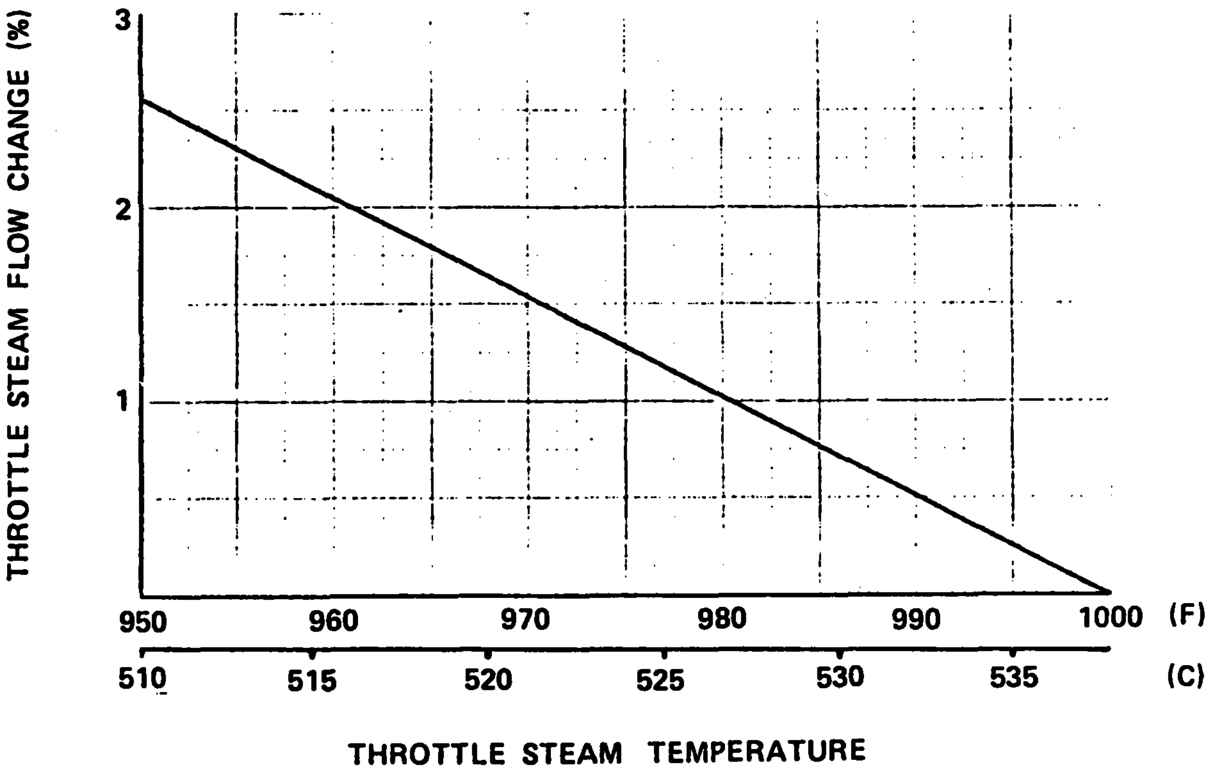
Throttle Flow Ratio (TFR)

$$TFR = \frac{W_C}{W_D} \left[\frac{(P/v)_D}{(P/v)_C} \right]^{1/2}$$

where, W = throttle steam flow (lbm/hr)
P = throttle steam pressure (psia)
v = throttle steam specific volume (ft^3/lbm)

Subscripts:

D = design
C = current



TFR = 1.0 (Valves wide open)

P_D = 13,121 KPa (1902.6 psia)

T_D = 538 C (1000 F)

W_D = 96.1 kg/sec (762,859 lbm/hr)

FIGURE 2. THROTTLE STEAM FLOW CHANGE VERSUS TEMPERATURE

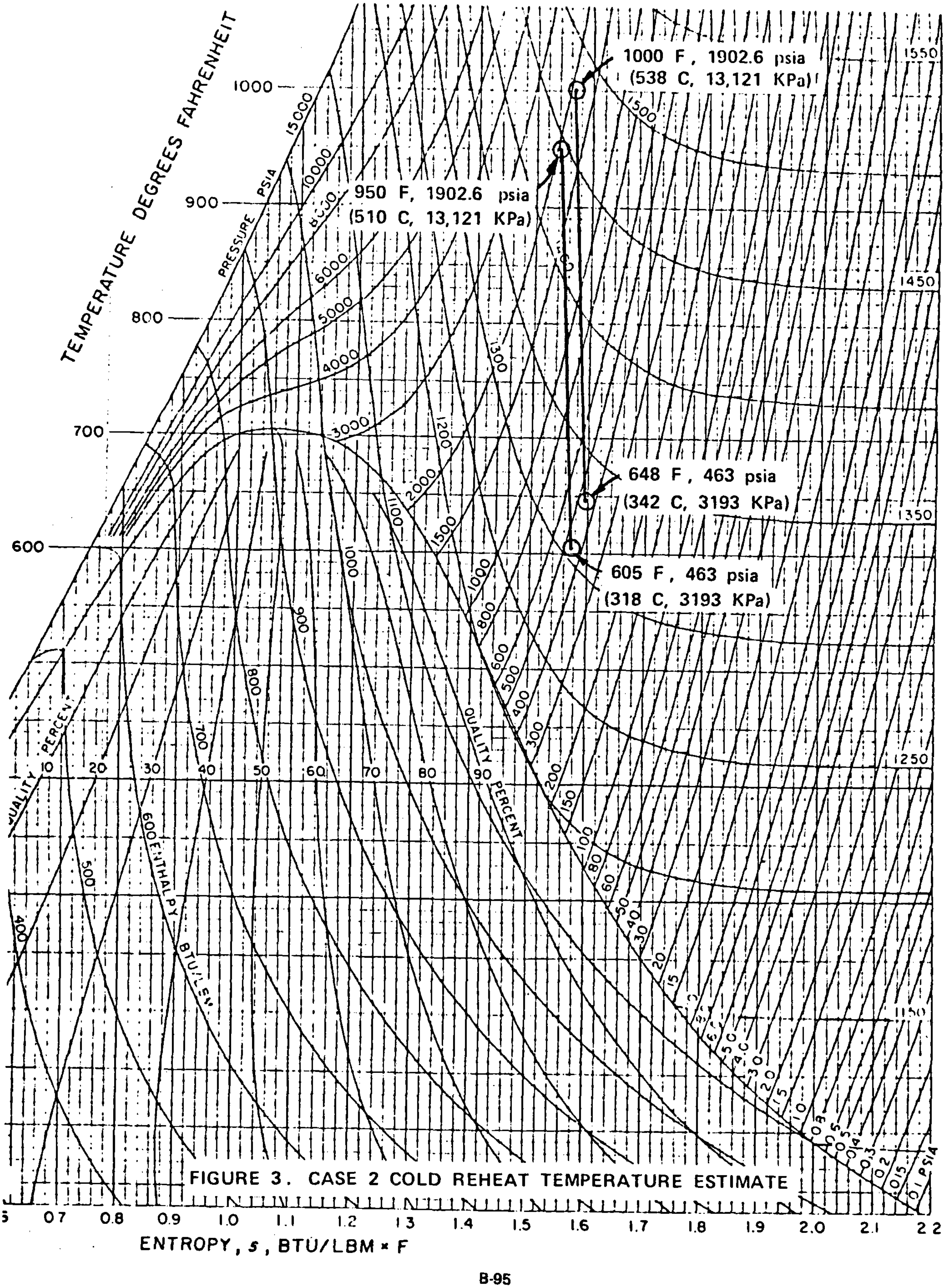


FIGURE 3. CASE 2 COLD REHEAT TEMPERATURE ESTIMATE

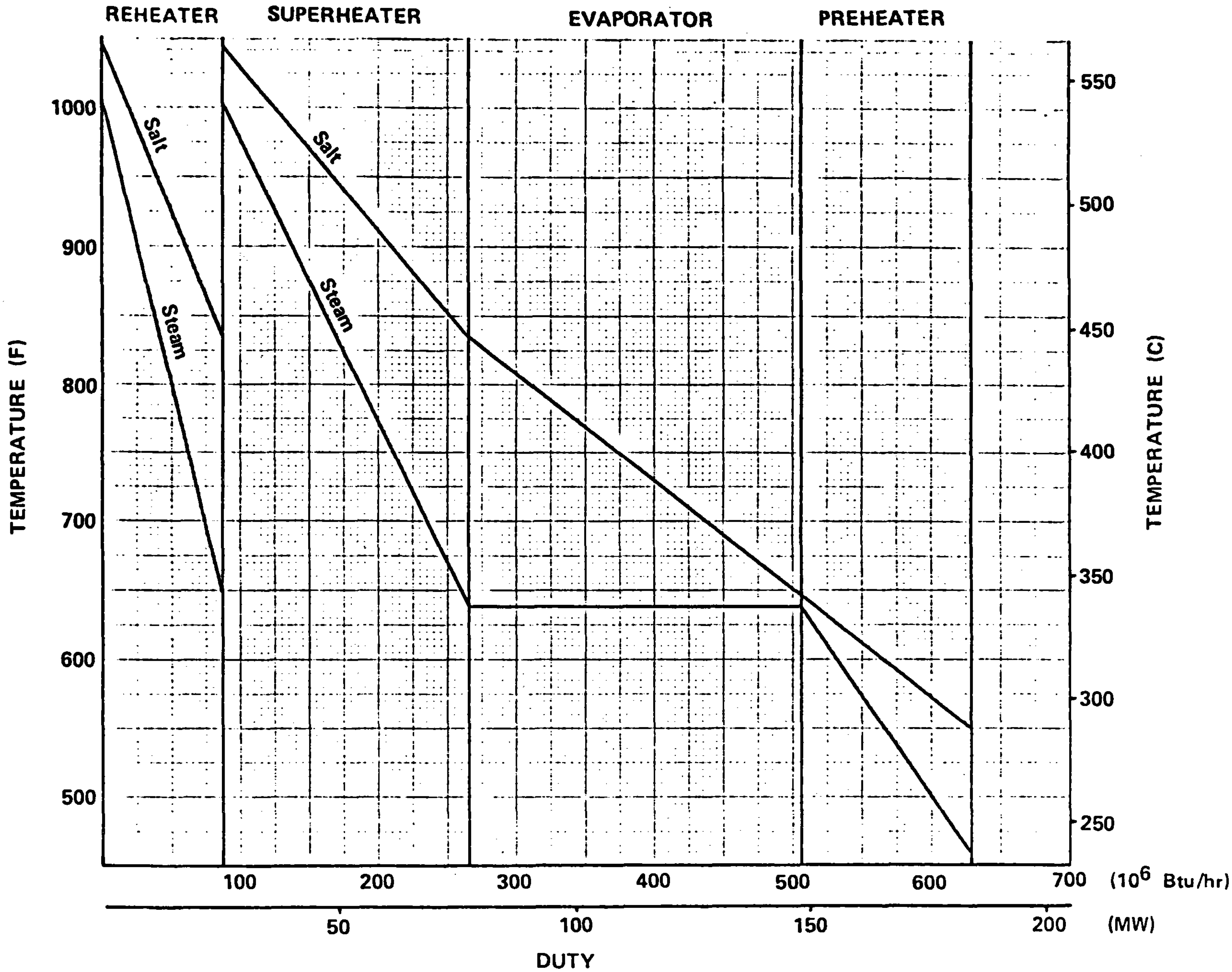


FIGURE 4. CASE 1 SALT AND STEAM/WATER TEMPERATURES VERSUS DUTY

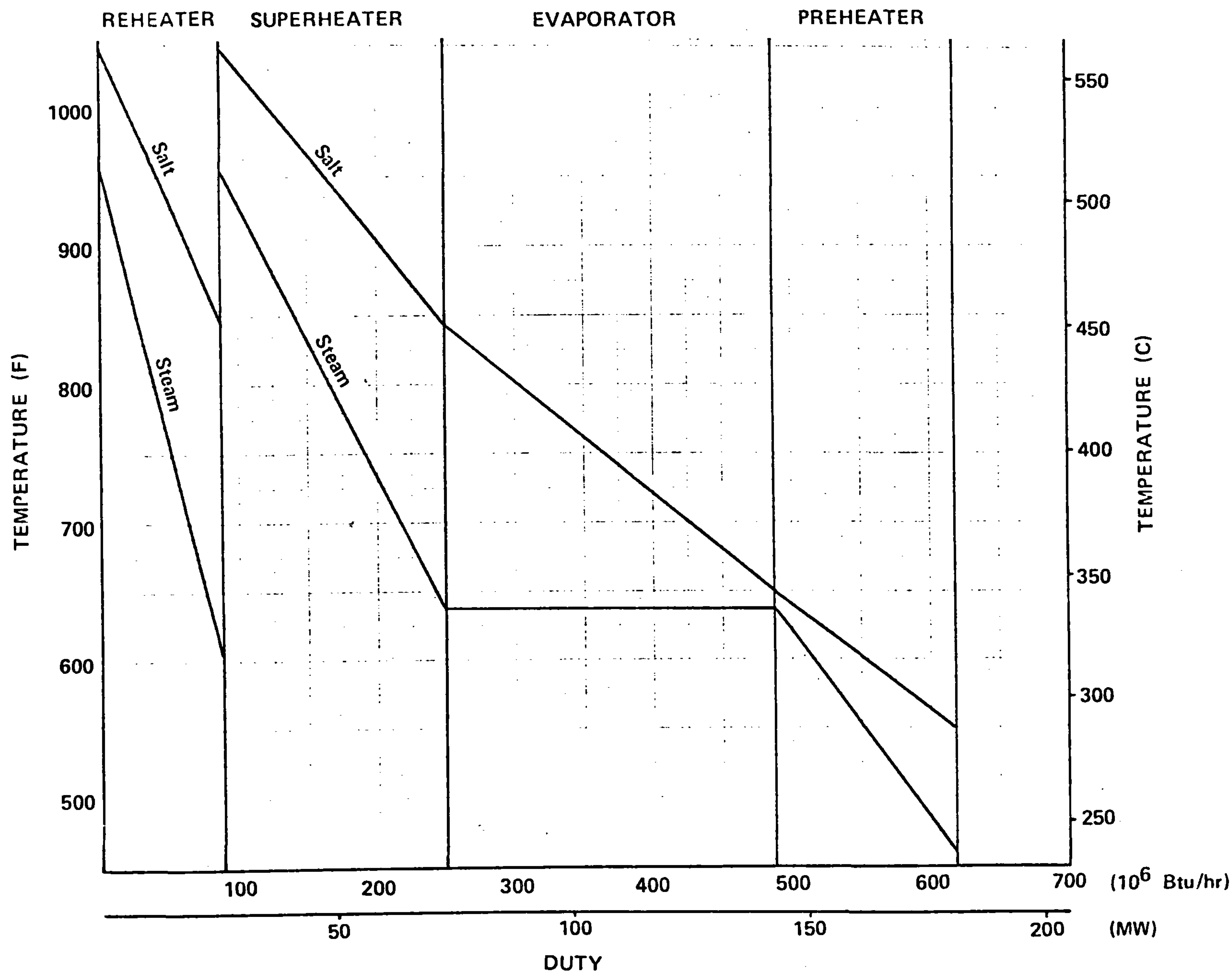


FIGURE 5. CASE 2 SALT AND STEAM/WATER TEMPERATURES VERSUS DUTY

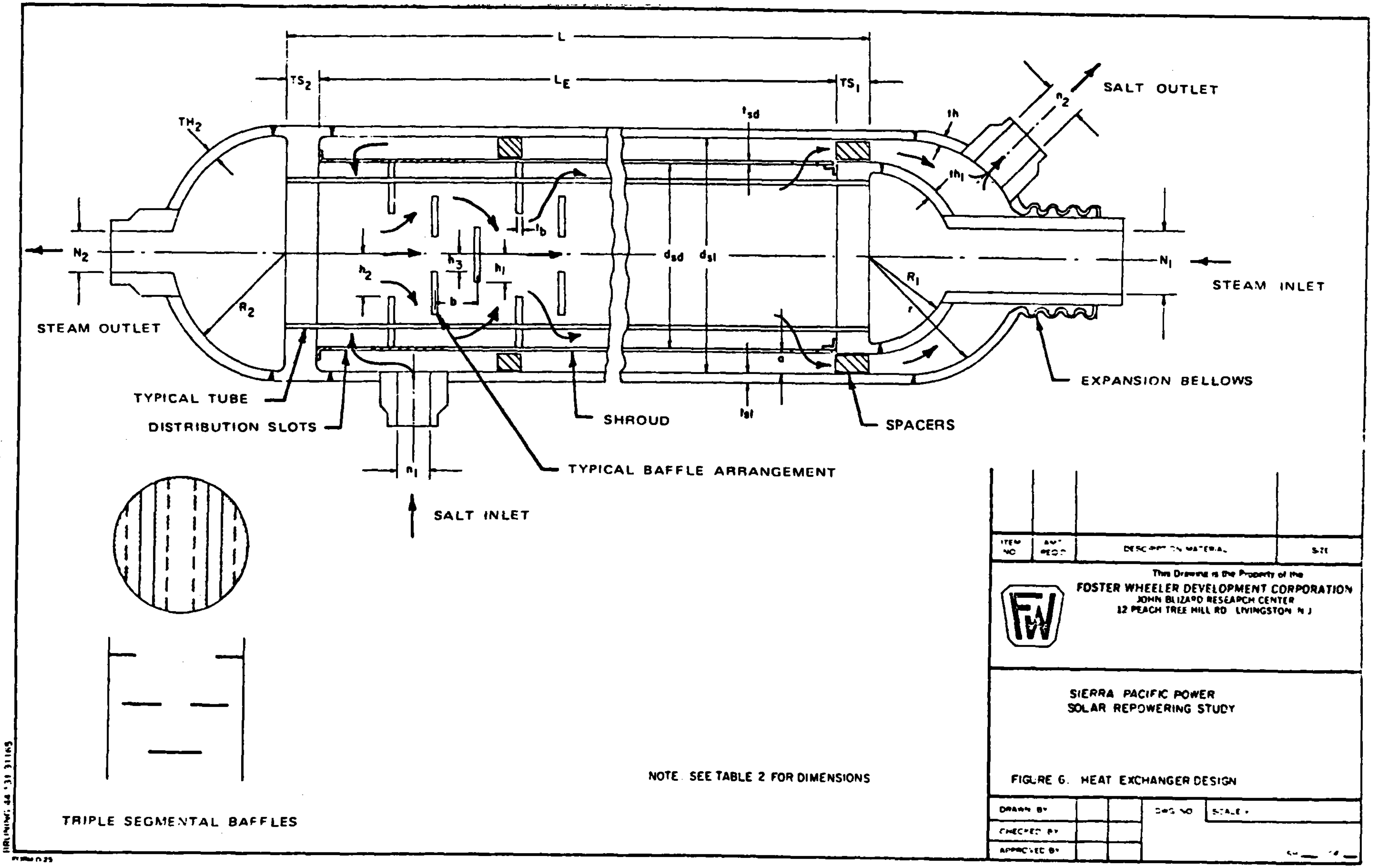
2.2 SIZING

The heat exchangers considered in this study are single-pass shell and tube heat exchangers with a floating head and triple segmental baffles. In order to absorb differential expansion between the tube bundle and the shell, the design includes an expansion bellows similar to that included in the intermediate heat exchanger design for the Clinch River breeder reactor. The preheater, superheater, and reheater are counterflow while the evaporator is parallel flow. A parallel flow evaporator was selected to improve natural circulation. Figure 6 schematically illustrates a typical heat exchanger design.

For initial calculations, the preheater, superheater, and reheater were assumed horizontal while the evaporator was vertical. For the purpose of this trade study, heat exchanger orientation is not a significant parameter since the same orientation was assumed for both Case 1 and Case 2. Optimum heat exchanger orientation will be determined in the Task 3 final design.

The Heat Transfer Research Institute (HTRI) computer program ST-4 for shell and tube heat exchangers was used to preduct thermal and hydraulic heat exchanger performance. The program has the capability to determine structural requirements for standard type shell and tube heat exchangers included in the Standards of the Tubular Exchanger Manufacturers Association (TEMA) for design temperatures and pressures up to 343°C (650°F) and 4138 kPa (600 psig). However, since the selected design is somewhat different from the standard TEMA configurations and since the design conditions for this application exceed the program limitations, head and shell thickness were determined from the ASME Boiler and Pressure Vessel Code, Section VIII, while tube sheet thickness was estimated from equations included in the TEMA standards.

In sizing the heat exchangers, configurations were selected that result in reasonable overall heat-transfer coefficients, shell and tube side pressure drops, and length-to-diameter ratios. Significant arrangement details for the Case 1 heat exchanger designs selected are listed in Table 2. The materials selected are based on recent studies conducted by Martin Marietta ("Solar Central Receiver Hybrid Power System," Martin Marietta Corporation, DOE-ET-2103801, September 1979).



L
TS_2
L_E
TS_1
SALT OUTLET
TH_2
t_{sd}
th
th_1
n_2
N_2
t_b
h_3
h_1
h_2
b
d_{sd}
d_{sl}
N_1
R_1
R_2
r
a
STEAM INLET
STEAM OUTLET
EXPANSION BELLOWS
TYPICAL TUBE
DISTRIBUTION SLOTS
SHROUD
t_{sl}
SPACERS
TYPICAL BAFFLE ARRANGEMENT
n_1
SALT INLET
TRIPLE SEGMENTAL BAFFLES
NOTE. SEE TABLE 2 FOR DIMENSIONS
This Drawing is the Property of the
FOSTER WHEELER DEVELOPMENT CORPORATION
JOHN BLIZARD RESEARCH CENTER
12 PEACH TREE HILL RD LIVINGSTON N J
SIERRA PACIFIC POWER
SOLAR REPOWERING STUDY
FIGURE 6. HEAT EXCHANGER DESIGN

Table 2. Case 1 (538°C/538°C) Heat Exchanger Arrangement Details

	Designation (See Figure 4)	Preheater	Evaporator	Superheater	Reheater
TUBES:					
O.D. (in./mm)		0.625/15.9	1.0/25.4	0.625/15.9	0.625/15.9
Wall Thickness (in./mm)		0.065/1.65	.083/2.11	0.065/1.65	0.065/1.65
Material		CS	1 Cr 1/2 Mo	347 SS	347 SS
Length (ft/m)	L	50/15.2	50/15.2	50/15.2	34/15.2
Effective Length (ft/m)	L_E	48.6/14.8	48.0/14.6	49.0/14.9	33.5/10.2
Pitch (in./mm)		0.812/20.6	1.25/31.8	0.812/20.6	0.812/20.6
Layout Angle (degrees)		60	60	60	60
Heat Transfer Surface (ft^2/m^2)		22,410/2082	17,650/1640	9,430/876	8,260/767
Number of Tubes		2,825	1,395	1,177	1,508
STEAM INLET HEAD:					
Type		Hemispherical	Hemispherical	Hemispherical	Hemispherical
Inside Radius (in./mm)	R_1	24.0/609.6	26.0/660.4	16.0/406.4	17.5/444.5
Thickness (in./mm)	TH_1	1.56/39.6	2.04/51.8	1.26/32.0	0.50/12.7
Material		CS	1 Cr 1/2 Mo	347 SS	347 SS
STEAM OUTLET HEAD:					
Type		Hemispherical	Hemispherical	Hemispherical	Hemispherical
Inside Radius (in./mm)	R_2	25.25/641.4	27.25/692.2	17.25/438.2	18.75/476.3
Thickness (in./mm)	TH_2	1.64/41.7	2.14/54.4	1.36/34.5	0.50/12.7
Material		CS	1 Cr 1/2 Mo.	347 SS	347 SS
SHELL HEAD:					
Type		Hemispherical	Hemispherical	Hemispherical	Hemispherical
Inside Radius (in./mm)	r	25.25/641.4	27.25/692.2	17.25/438.2	18.75/476.3
Thickness (in./mm)	th	0.50/12.7	0.50/12.7	0.50/12.7	0.50/12.7
Material		CS	1 Cr 1/2 Mo.	347 SS	347 SS
SHROUD:					
Inside Diameter (in./mm)		48.0/1219.2	52.0/1320.8	32.0/812.8	35.0/889.0
Thickness (in./mm)	d_{sd}	0.25/6.3	0.25/6.3	0.25/6.3	0.25/6.3
Material	t_{sd}	CS	1 Cr 1/2 Mo	347 SS	347 SS

Table 2. Case 1 (538°C/538°C) Heat Exchanger Arrangement Details (Cont'd)

	Designation (See Figure 4)	Preheater	Evaporator	Superheater	Reheater
SHELL:					
Inside Diameter (in./mm)	d_{s1}	50.5/1282.7	54.5/1384.3	34.5/876.3	37.5/952.5
Thickness (in./mm)	t_{s1}	0.50/12.7	0.50/12.7	0.50/12.7	0.50/12.7
Material		CS	1 Cr 1/2 Mo	347 SS	347 SS
BAFFLES:					
Type		Triple Segmental	Triple Segmental	Triple Segmental	Triple Segmental
Thickness (in./mm)	t_B	0.375/9.5	0.375/9.5	0.313/8.0	0.313/8.0
Number		47	46	48	32
Material		CS	1 Cr 1/2 Mo	347 SS	347 SS
Spacing (in./mm)	b	12.1/307.3	12.2/309.9	12.0/304.8	12.3/312.4
Cut Dimensions (in./mm)	h_1	7.1/180.3	7.9/200.7	4.9/124.5	5.3/134.6
	h_2	13.1/332.7	14.0/355.6	8.6/218.4	9.4/238.8
	h_3	6.2/157.5	6.7/170.2	4.1/104.1	4.5/114.3
TUBE SHEETS:					
Steam Outlet Thickness (in./mm)	TS_1	8.73/221.7	12.16/308.9	6.52/165.6	3.0/76.2
Material		CS	1 Cr 1/2 Mo	347 SS	347 SS
Diameter (in./mm)		53.78/1366.0	58.78/1493.0	37.22/945.4	38.26/971.8
Steam Inlet Thickness (in./mm)	TS_2	8.29/210.6	11.60/294.6	6.04/153.4	2.79/70.9
Material		CS	1 Cr 1/2 Mo	347 SS	347 SS
Diameter (in./mm)		48.5/1231.9	52.5/1333.5	32.5/825.5	35.5/901.7
SHROUD/SHELL CLEARANCE (in./mm)	a	1.0/25.4	1.0/25.4	1.0/25.4	1.0/25.4
APPROXIMATE WEIGHTS (10^3lb/10^3kg):					
Dry (pressure parts only)		111.3/50.5	125.2/56.8	58.5/26.5	43.9/19.9
Filled		147.3/66.8	171.1/77.6	74.6/33.8	57.8/26.2

In addition to the heat exchangers, a steam drum is required for the natural circulation steam generator system. For Case 1 and Case 2 the steam drum will be identical. As a result, for preliminary cost estimates a horizontal 1676 mm (66 in.) I.D. drum 5.5 m (18 ft) long with 44 horizontal separators and 16 Chevron driers was selected. For the Task 3 final design, a vertical drum built into the top of the evaporator will be considered.

2.3 PERFORMANCE

The steam/water and salt conditions to which the heat exchangers for Case 1 and Case 2 were designed are listed in Table 1. The resultant performance parameters for the Case 1 design are listed in Table 3.

As previously noted, the heat exchangers were sized to obtain reasonable overall heat-transfer coefficients, shell and tube side pressure drops, and length-to-diameter ratios. Shell side pressure drops per heat exchanger were kept below 138 KPa (20 psi) to minimize pump requirements while tube side pressure drops were kept sufficiently high to insure uniform flow distribution. As noted on Table 3, the preheater and superheater tube side pressure drops are relatively low and may require orificing to insure uniform flow distribution during reduced load operation. However, this is a detail that will be determined in the Task 3 final design. It should be noted that for hybrid operation, the fossil unit will be operated at its minimum turndown point resulting in minimum steam side pressure losses while the solar unit will be operating at its rated capacity. Therefore, to permit satisfactory turndown of the solar steam generator system, sufficient pressure drop must be provided at the design point condition. Consequently, the resultant pressure losses for the solar unit may be greater than those for the fossil unit which is at its minimum turndown point.

For an operating drum pressure of approximately 13,793 kPa (2000 psig), the minimum circulation ratio based on Foster Wheeler design standards is approximately 4 to 1. Based on the evaporator design selected for this study, the computed circulation ratio is approximately 6 to 1. The circulation ratio for the final design (Task 3) may vary from this value dependent upon the final evaporator and drum type (horizontal, vertical) selected.

Table 3. Performance Parameters for Case 1 (538°C/538°C) Heat Exchangers

	Preheater	Evaporator	Superheater	Reheater
Overall Heat Transfer Coefficient [(Btu/h·ft^2·°F)/(KCal/h·m^2·°C)]	158/771	240/1172	195/952	111/542
Fouling Resistance [(h·ft^2·°F/Btu)/(h·m^2·°C/KCal)]				
Shell Side	← 0.0005/0.0001 →			
Tube Side	← 0.0005/0.0001 →			
LMTD [°F/°C]	35.2/19.6	60.9/33.8	98.5/54.7	95.3/52.9
Pressure Drop [psi/kPa]				
Shell Side	12.9/89.0	13.9/95.9	10.9/75.2	2.7/18.6
Tube Side	0.8*/5.5	12.0/82.8	9.8*/67.6	15.0/103.4
Circulation Ratio	--	6.1/1	--	--

*NOTE: Orificing may be necessary to insure uniform flow distribution during reduced load conditions.

3.0 COST ANALYSIS

Based on the heat exchanger and steam drum design selected for Case 1, approximate costs were estimated for the steam generator components that will result in a significant cost difference between Case 1 and Case 2. Table 4 lists estimated material, fabricating, and shipping (Mountaintop, Pa. to Reno, Nev.) costs for the Case 1 preheater, evaporator, superheater, and reheater. For general reference the approximate material, fabricating, and shipping cost for the steam drum is also listed, however, it will be the same for both Case 1 and Case 2. The costs listed are not total costs and should not be viewed as such since the cost of engineering, drafting, management, erection, foundations, structural supports, insulation, heat tracing, interconnecting piping, etc., were not included and assumed the same for both Case 1 and Case 2. Total steam generator system cost will be determined in Task 3.

In order to estimate the material, fabricating, and shipping cost for Case 2, the following basic heat transfer equation was used to estimate the heat transfer surface required for Case 2:

$$Q = U_T A \Delta t_m$$

where,

Q = heat exchanger duty (MW)

U_T = overall heat transfer coefficient ($KCal/h \cdot m^2 \cdot °C$)

Δt_m = log mean temperature difference (°C)

A = effective heat transfer surface (m^2)

Since the flow rates for both Case 1 and Case 2 were assumed equal, the lower steam temperatures for Case 2 resulted in the reduction in heat exchanger duty. The change in steam temperatures also resulted in a reduction in LMTD (the correction factor for cross flow in a tube bundle was neglected for this analysis). Overall heat transfer coefficients were assumed the same as for Case 1 since design mass fluxes will be essentially the same. The resultant reductions in heat transfer surface for the Case 2 heat exchangers are listed in Table 5 along with the values for LMTD and duty reduction.

Table 4. Estimated Heat Exchanger Material, Fabricating, and Shipping Costs*

	COST (10^3\$)	
	CASE 1	CASE 2
Preheater	414.5	401.2
Evaporator	386.0	372.3
Superheater	344.7	269.8
Reheater	299.8	236.2
Steam Drum	180.6	180.6
Total	1,625.6	1,460.1
Cost Change	--	-165.5

*Note: Costs listed are not total costs. Cost of engineering, drafting, management, erection, stuctural supports, insulation, heat tracing, interconnecting piping, etc., are not included.

Table 5. Reduction in Heat Transfer Surface for Case 2 (510°C/510°C)

	Preheater	Evaporator	Superheater	Reheater
Basis for Area Reduction::				
Reduction in LMTD (%)	6.4	8.5	29.7	37.5
Reduction in Duty (%)	0	0	9.3	1.0
Reduction in Heat Transfer Surface for Case 2 (%)	6.4	8.5	36.2	38.1

Using the change in heat transfer surface for Case 2, appropriate material, fabricating, and shipping costs for Case 1 were proportioned to determine the costs for Case 2. Table 5 lists the resultant values. Also listed is the reduction in cost for Case 2 which is approximately $165,500.

4.0 CONCLUSIONS

The difference in heat exchanger cost between Case 1 (538°C/538°C) and Case 2 (510°C/510°C) operation does not appear to be significant ($165,500). However, the cost effectiveness for either case is a function of overall plant economics which is beyond the scope of this study.

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