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Covering Period September 30, 1982 Through June 30, 1982

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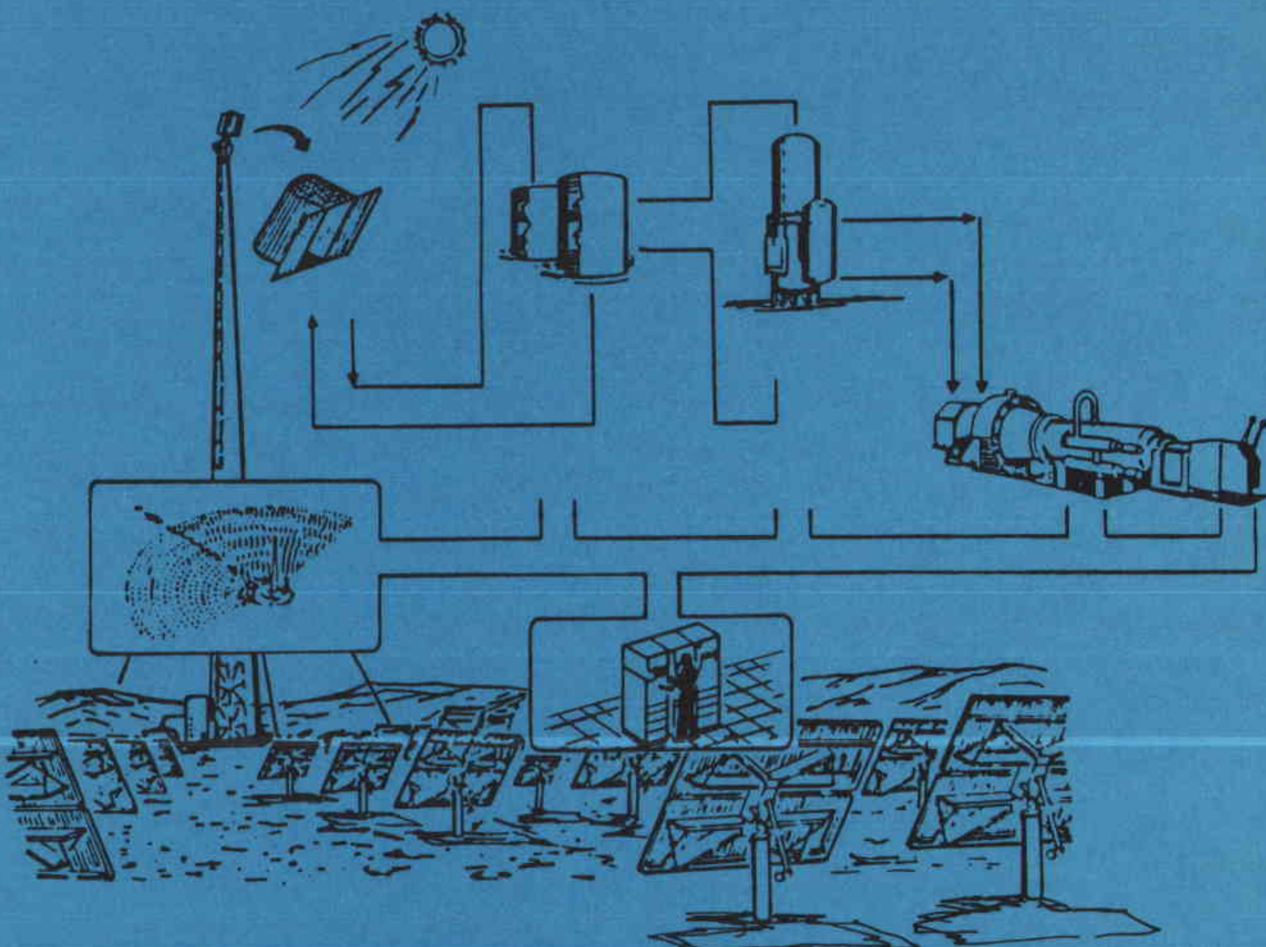

SIERRA PACIFIC POWER COMPANY REPOWERING ADVANCED CONCEPTUAL DESIGN

Final Technical Report

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

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CORPORATION

SAN/11568-1

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SIERRA PACIFIC POWER COMPANY REPOWERING ADVANCED CONCEPTUAL DESIGN

FINAL TECHNICAL REPORT

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Covering the period of September 30, 1981 through June 30, 1982

Prepared for the U.S. Department of Energy
Under Contract Number DE-AC03-81SF11568

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ABSTRACT

The Sierra Pacific Power Company (SPPCo) participated with the McDonnell Douglas team to refine 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 0.79 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 3 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 repowering of the plant is envisioned to take place in stages. A single collector/receiver module rated at 110 MW_t would be installed as a demonstration. Upon satisfactory completion of the demonstration, two additional collector/receiver modules would be constructed to complete the repowering.

The estimated annual average energy collection efficiency is 0.636. The plant annual energy output is about 93.5 GWhe, displacing the equivalent of 924×10^6 ft^3 natural gas per year.

Repowering was found to require a 60% subsidy to be economically attractive in today's economic climate. Legal and institutional barriers are minimal. A very aggressive repowering program should be pursued as a means for reducing dependence on foreign oil, demonstrating central receiver technology, and providing energy source diversification.

PREFACE

This report was prepared for the Department of Energy under Contract Number DE-AC03-81SF11568. It presents the results of a nine (9) month study to refine the site specific conceptual design for solar repowering of Sierra Pacific Power Company's Ft. Churchill Unit #1, located near Yerington, Nevada.

The guidance and support of the Department of Energy Program Manager, Keith Rose, and the technical assistance and support of Christine Yang of the Sandia National Laboratories, were of great benefit in the conduct of this study, and we acknowledge their contribution.

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Section 1

EXECUTIVE SUMMARY

This section contains an overview of the Sierra Pacific Power Company Repowering Advanced Conceptual Design study conducted under contract to Department of Energy, San Francisco Operations Office.

1.1 STUDY TEAM

The study team and their responsibilities are shown in Figure 1-1. 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 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 1-1.

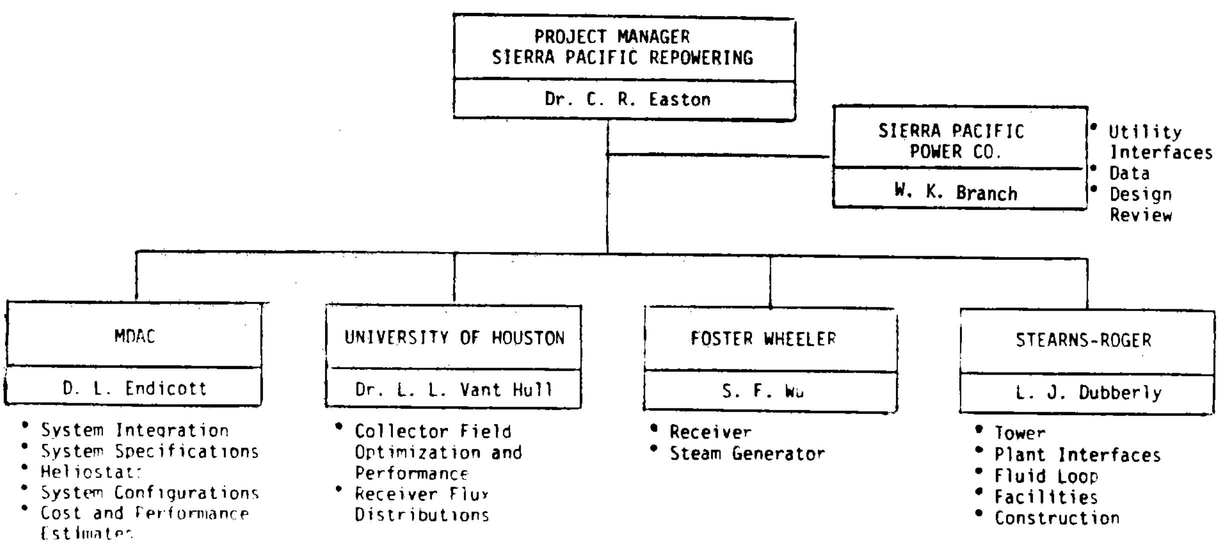


FIGURE 1-1 STUDY ORGANIZATION

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 #1 was selected for this study.

Table 1-1

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

Unit No.	Rating (MWe)	1982 Service	1986 Scheduled Service	Fuel
1. Tracy No. 1	53	Standby/Peak	Standby/Peak	Gas
2. Tracy No. 2	83	Standby/Peak	Intermediate	Gas
3. Tracy No. 3	110✓	Intermediate	Baseloaded	Gas
4. Ft. Churchill No. 1	110✓	Baseloaded	Baseloaded	Gas
5. Ft. Churchill No. 2	110✓	Intermediate	Intermediate	Gas
6. North Valmy No. 1	125*	Baseloaded	Baseloaded	Coal
7. North Valmy No. 2	125*	- - -	Baseloaded	Coal

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

✓ Potential for repowering.

The higher efficiency reheat units, Tracy 3 and Ft. Churchill Units #1 and #2, are excellent prospects for repowering. Ft. Churchill was preferred over Tracy because of higher insolation and more accessible land. Unit #1 entered service in 1968, and presently operates at a capacity factor of 0.79. Unit #1 will continue as baseload throughout the 1980s. Ft. Churchill Unit #2 is scheduled for load following duty (24-hour service power) in the winter and part of the summer with capacity factor ranging from 0.5 to 0.7. Typical of new units in the range of 100 MWe, those at Ft. Churchill, operate on a reheat cycle at 12.4MPa(1800 psia), 538°C (1000°F) high pressure turbine inlet and 538°C (1000°F) reheat.

The site is located 75 Km (47 miles) southeast of Reno, Nevada, in the high desert near Yerington, Nevada. It is 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% of daylight hours at Reno. The Reno weather factor (includes effects of insolation reduction for weather) is about 0.76. 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 was 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. The land to the immediate northwest is owned partially by SPPCo and partially by the Bureau of Land Management (BLM), as indicated in Figure 1-2. 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

One of the key issues in this study was to explore modularizing the collector field to reduce project cost and risk. One module, with its tower and receiver, would be built as a demonstration. Upon successful demonstration, two additional, identical collector/receiver modules would be added to complete the repowering. Table 1-2 shows a comparison of the previous design with the one module and three module systems. The second set of steam generator equipment will be installed with the second collector/receiver module. Output from the third collector/ receiver module will go completely to storage.

A summary of the significant design refinements accomplished under this study is shown in Table 1-3.

1.3.1 Trade Study Summary

The optimum size for repowering SPPCo's Ft. Churchill Unit #1 was developed considering programmatic and application constraints. A 110 MW_{th} collector/ receiver module was selected to go with a 59 MWe gross steam generator as the best combination to meet all constraints.

An erect (panels vertical) partial cavity receiver was found to have performance equal to that of a tilted receiver. A slight increase in tower height was required. However, the receiver becomes structurally simpler; hence, an erect configuration was chosen.

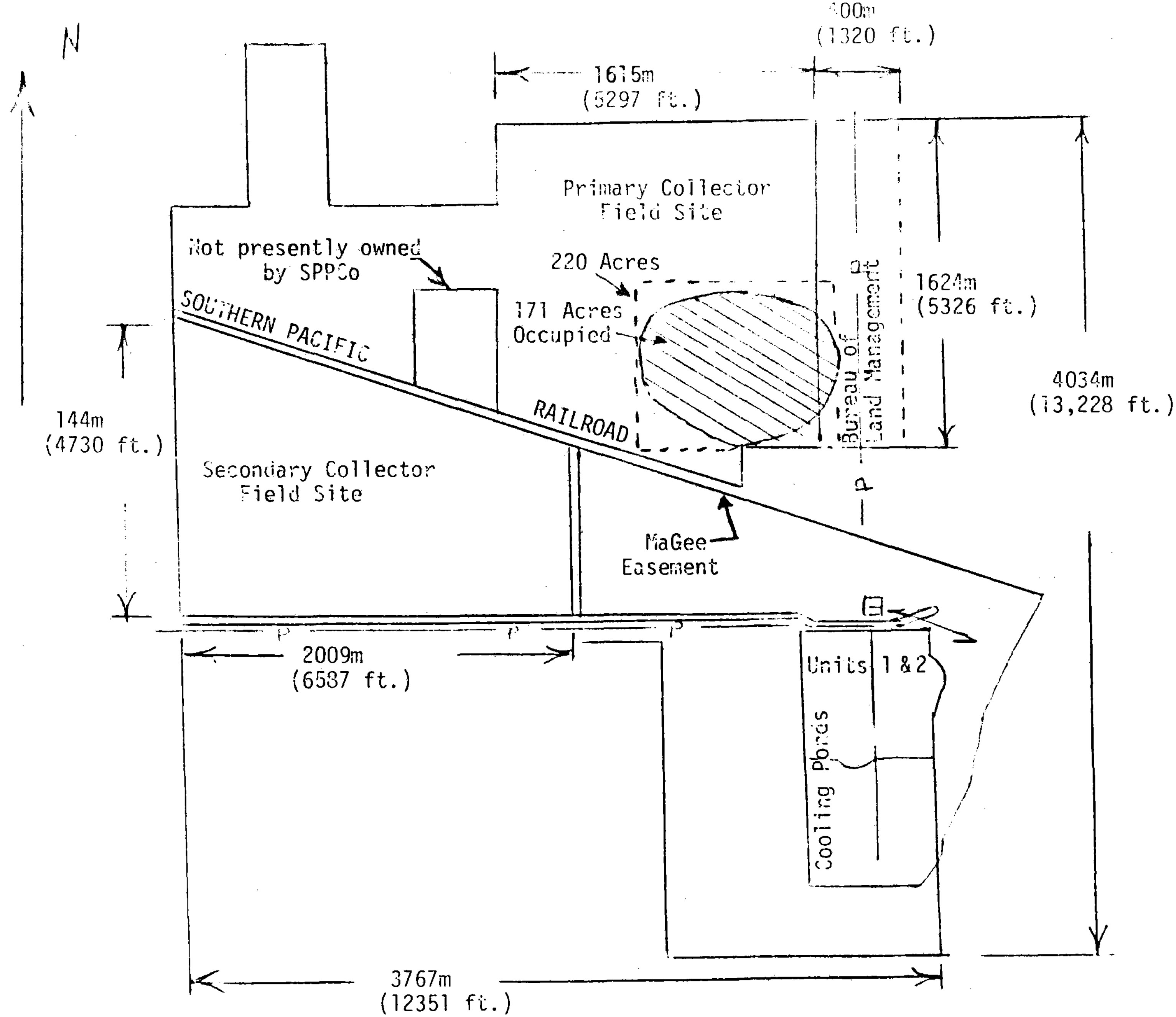


FIGURE 1-2 FORT CHURCHILL SITE PLOT

TABLE 1-2 ONE AND THREE MODULE SYSTEM CONFIGURATIONS

	PREVIOUS DESIGN	FIRST MODULE	THREE MODULES
COLLECTOR/RECEIVER DESIGN POINT POWER	330 MWe	110 MW_t	330 MW_t
NUMBER OF HELIOSTATS (AT 56.85 M^2 EACH)	8344	2565	7605
NUMBER OF TOWERS AND RECEIVERS	1	1	3
THERMAL STORAGE SIZE	1150 MW_{ht}	278 MW_{ht}	1150 MW_{ht}
STEAM GENERATOR SIZE	77 MWe	54 MWe	108 MWe

TABLE 1-3 DESIGN REFINEMENTS ACHIEVED

REFINEMENT	COMMENTS
<u>COLLECTOR</u>	
• MODULARIZED FIELD	REDUCED DEMONSTRATION COST AND RISK.
<u>RECEIVER</u>	
• VERTICAL PANELS	SIMPLIFIED SUPPORT AND ERECTION.
• REFINED GEOMETRY	EACH PANEL PLACED AS TO OPERATE AT PEAK HEAT FLUX, REDUCES ABSORBER AREA AND RECEIVER SIZE.
• CLOUD TRANSIENT CONTROL RESPONSE	EXTENSION OF PREVIOUS WORK INCLUDING SOLAR ONE AND MOLTEN SALT RECEIVER SRE.
• DOWNSIZED	RECONFIGURED TO SUIT 110 MW_t COLLECTOR MODULE.
<u>TOWER</u>	
• STRUCTURAL STEEL	LOWER COST AND SEISMIC LOADS ON RECEIVER.
<u>STEAM GENERATOR</u>	
• DOWNSIZED	50 MWe NET DESIGN FROM STEAM GENERATOR SRE USED.
<u>STORAGE TANKS</u>	
• REDUCED SIZE	RESIZED TO BE CONSISTENT WITH 110 MW_t COLLECTOR MODULE
• COOLED FOUNDATION	FOUNDATION COOLING ADOPTED BECAUSE OF GROUND WATER.
<u>MASTER CONTROL</u>	
• NO CHANGES	

A structural steel tower was found to be lower cost than a concrete tower for the 110 MW_{th} module. In addition, receiver seismic loads were substantially reduced. Hence, a steel tower was chosen.

An analytical model of the receiver controller was tested under transient cloud conditions. Satisfactory performance with a partially opaque cloud was obtained. Additional work is required to confirm control through cloud transients.

1.3.2 <u>Conceptual Design Summary</u>

The conceptual design of the repowered plant is summarized in Table 1-4. In the baseline mode, Unit #1 will be repowered for hybrid operation with the fossil side operated continuously. The solar will displace fossil steam at a rate of up to 37 MWe gross equivalent, when available, and during the high demand periods of the day. Capacity will be provided for up to 3-hours of thermal storage at 35 MWe net. The plant would thus deliver up to 37 MWe gross from solar for up to 12-hours in mid-summer, and would displace about 12% of the fossil fuel annually.

The 110 MWe collector/receiver module was planned as one of three modules to be used for complete repowering of Ft. Churchill, Unit #1.

Two additional collector/receiver modules can be added to bring the fuel displacement up to 37%. The baseline operating mode of the plant is hybrid operation. The repowered plant can also operate in a solar stand-alone mode at 54 MWe gross. A fossil only mode at full power is also always available.

The system schematic is shown in Figure 1-3 and the baseline is summarized in Table 1-4. The 130° north field is located to the northwest of the plant, and will occupy about 0.89 x 10^6 m^2 land area within the rectangle containing the field and tower. The collector field will contain 2565 MDAC second generation heliostats at 56.85 m^2 each for a total mirror area of 145,820 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. The receiver uses a molten salt working fluid. The front and side walls of the receiver are arranged in two parallel sets of seven panels each in series.

The thermal storage baseline is a two tank, externally insulated unit. The tanks are 15.2 m (50 ft) in diameter and 8.2 (27 ft) high. The four element steam generation heat exchanger use separate preheater, evaporator, superheater, and reheater units.

The center of the receiver aperture plane is 133 m above the ground, and the receiver is supported on a steel tower.

Table 1-4 (Page 1 of 2)

CONCEPTUAL DESIGN SUMMARY

		Comments
Prime Contractor	McDonnell Douglas Astronautics Company	
Associate Prime Contractor	Sierra Pacific Power Company	Associate prime contractor, design review, evaluation, approval and utility data
Major Subcontractors	Foster Wheeler Development Company	Receiver, steam generator
	Stearns-Roger, Inc.	Plant interfaces, facilities, A&E services
	University of Houston	Collector field optimization, layout and performance
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. Representative of 6800 GWe of systems in the 50-150 MWe range.
Site Location	Fort Churchill Plant	75km (47 miles) southeast of Reno, Nevada, near Yerington. Ideal operating conditions.
Design Point	Equinox Noon	Design point insolation is 1008 W/m^2, hybrid operation.
Design Mode	Hybrid Operation	
Receiver Design		
Fluid	Molten Salt	60/40 sodium and potassium nitrate, normal melting point 221°C (430°F), maximum safe operating temperature 649°C (1200°F).
Power Rating	110 MW_{th}	60 m^2 external absorber, 359 m^2 cavity absorber. Two parallel sets of seven panels in series.
Tube Size	28.6mm (1.1/8 in.) O.D.	Incoloy 800.
Inlet Temperature	288°C (550°F)	
Outlet Temperature	566°C (1050°F)	

Table 1-4 (Page 2 of 2)

CONCEPUTAL DESIGN SUMMARY

		COMMENTS
Heliostat		
Number	2565	MDAC Second Generation (mmets Sandia Specification Drawing A10772). Area 56.85 m^2 (612 ft^2), non-inverting.
Cost	$198/$m^2$	Installed price, including control.
Collector Field	North	130° azimuth angle in field with erect receiver.
Storage	3-hours	278 MWh_{th} storage capacity. Two tank.
Steam Generator	Four element, drum separator	Preheater, evaporator, superheater, reheater.
Project Cost	$99.4 x 10^6 '82$$	Includes owner's cost of $3.3M.
Construction Time	Four Years	
Capacity Factor - Solar	0.097	Corresponds to solar fraction of 0.12.
Fossil Fuel Saved	924 x 10^6 cf/year	Fuel savings is in natural gas. Includes boiler efficiency.
Annual Energy Produced	0.229 x 10^9 kWh_{th}	Thermal energy delivered to the turbine.
Ratio: Annual Energy Mirror Area	1.57 MWh_{th}/m^2	Fuel displacement is 1.86 MWh_{th}/m^2 because of boiler efficiency of 0.846.
Ratio: Capital Cost + Annual Fuel Displaced	$355 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.

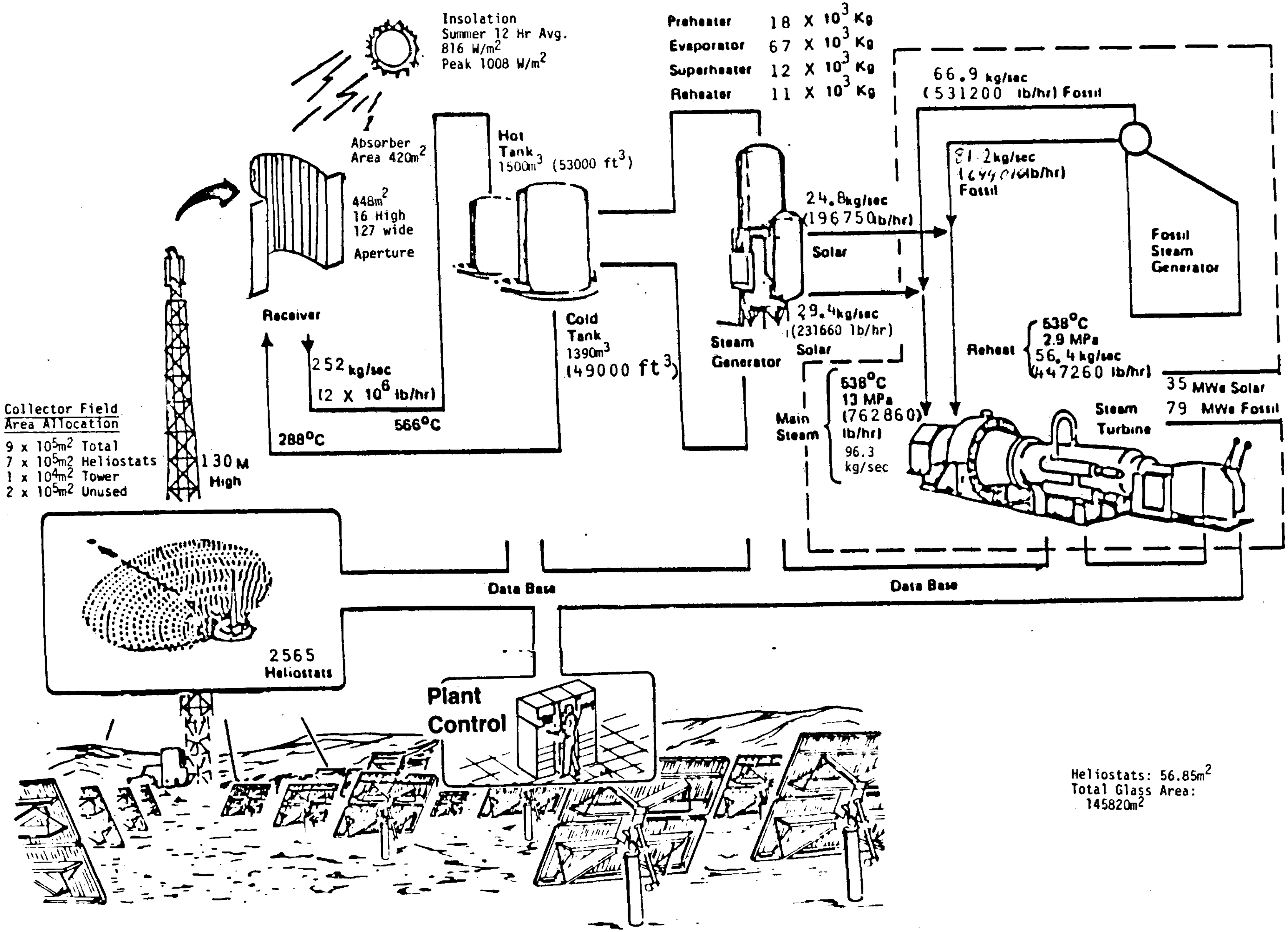


FIGURE 1-3 SIERRA PACIFIC POWER COMPANY FORT CHURCHILL NO. 1

The 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 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.

1.3.3 System Performance

The insolation data establish that the Ft. Churchill site has approximately 7.2 kWh/m^2/day average annual insolation. 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 historic Reno weather factor. Clear day total insolation levels and design point insolation levels are shown in Table 1-5, together with weather factors estimated from Reno weather data. The winter and summer design point insolation levels are off nominal design points used for receiver design.

Table 1-5

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 (at 9:00 am)	7.1	0.67	4.7
Spring	1008 (at Noon)	9.6	0.68	6.5
Summer	750* (at 7:00 am)	10.8*	0.85	9.2
Autumn	----	9.0*	0.92	8.3
ANNUAL	---	9.1	0.794	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. Annual is average weighted by insolation.

Collection efficiency is defined as the ratio of the thermal energy delivered to thermal storage 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 and their waterfall charts are shown in Figure 1-4. The collection efficiency at the equinox noon design point is 0.746. The annual average collection efficiency for clear days is 0.636.

The plant cycle efficiency includes conversion of heat energy to electricity and efficiency reductions due to plant auxiliary loads. The net turbine-generator cycle efficiency is 0.426. The solar parasitic loads will reduce the plant output by about 1% during daylight hours. Overnight load must be provided for thermal conditioning. Hence, a solar parasitic factor of 0.98 is used in addition to the fossil parasitic factor of 0.957. The average net annual plant efficiency is 0.257 for solar. With the average annual insolation of 7.2 kWh/m^2/day from Table 1-3 and the predicted plant availability of 0.958, the annual energy production from soalr is 93.5 GWhe delivered to the grid. The solar capacity factor is about 0.097 and the fuel savings is about the equivalent of 3.0×10^{15}J (924MM x 10^6 cf gas) per year.

1.4 ECONOMIC FINDINGS

Project capital cost data are summarized in Table 1-6. In the previous study, repowering was found to be competitive with continued operation on oil at the Ft. Churchill plant. Several economic factors, as outlined in Table 1-7, have combined to reverse this picture at the present time. Fuel savings and capital costs are for 3-modules of repowering to keep the estimates on a common footing. The principal changes are due to:

a. The availability and low cost of natural gas.
b. The high interest rates and fixed charge rates.
c. The high discount rates for the value of future fuel savings.

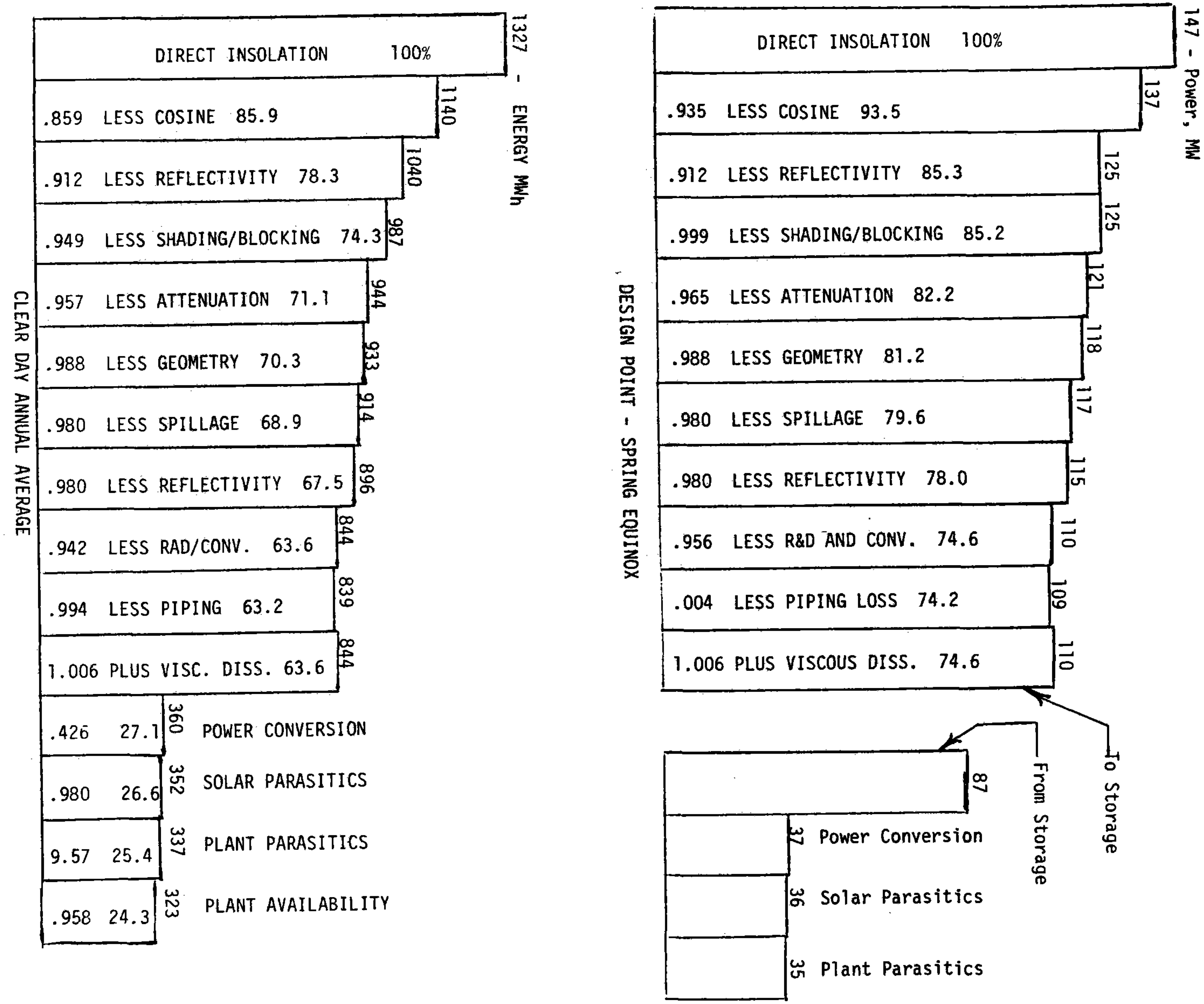


FIGURE 1-4 COLLECTOR/RECEIVER PERFORMANCE

TABLE 1-6

PROJECT CAPITAL COST SUMMARY

CBS	DESCRIPTION	COST ESTIMATES (10^6 1982 DOLLARS)	
5100	Design Cost		23.9
5200	Owner's Cost		3.3
5300	Construction Cost		70.6
5311	Site Improvements	(1.5)	
5312	Buildings and Structures	(0.3)	
5321	Collector System ($198/$m^2$)	(34.9)	
5322	Receiver System	(9.9)	
5323	Horizontal Piping	(5.9)	
5324	Plant Control	(1.8)	
5325	Heat Transfer Media	(1.4)	
5326	Energy Storage System	(3.2)	
5327	Heat Exchanger System	(9.7)	
5350	Accesory Electrical	(1.6)	
5360	Misc. Power Plant Equipment	(0.4)	
5400	Startup and Testing		1.6
	Total		99.4

Table 1-7

ECONOMIC PARAMETER COMPARISON

- All Costs and Values in 1982 Dollars -

	Previous Study	Current Study
Primary Fuel	Residual Fuel Oil	Natural Gas
Cost, 1982 $/GJ ($1/MM Btu)	6.18 (5.86)	4.64 (4.4013)
Escalation Rate	12%/Year	10%/Year
Levelized Fixed Charge Rate	15%/Year	20.4%/Year
Capital Escalation Rate	7%-'82, 6% after	10%-'82, 8% after
O&M Escalation Rate	9%/Year	10%/Year
Cost of Capital (Discount Rate)	11.6%/Year	17%/Year
Present Value Fuel Displaced ($M)	577	113 (3 Modules)
Present Value Capital Cost ($M)	287	259 (3 Modules)

The major impact of these changes is in the high ratio of discount rate to fuel escalation rate. This ratio appears in formulae for present value. When the discount rate is high and substantially larger than the fuel escalation rate, the present value of future fuel savings is very minimal.

In today's volatile economic climate, it is very difficult to forecast the trends of significant economic parameters. It is therefore, interesting to speculate on what might happen to make the project economically attractive.

Factors Reducing Cost - The project cost can be reduced by a significant amount in several ways:

- Direct subsidy by the Federal Government.
- R&D expensing by the utility and regulatory agency.
- Third party financing utilizing investment and energy tax credits.
- Consortium contributions anticipating direct benefit from the demonstration.

Of these ways, the only one currently in place is the tax credits resulting from third party financing. The effect of investment tax credits would be similar to a 25% to 36% reduction of capital cost, depending on whether the credits and depreciation are sold on a lease back arrangement or taken by the third party investor. However, the $4M annual revenue generated by the plant for steam sales would not approach the level necessary for an attractive third party financed project. A major investment from the federal government would be required to make the project viable under present economic conditions.

Factors Improving Value - The two factors which could improve the value of the project are an increased fuel cost and a decreased cost of money. Fuel costs are unlikely to increase by an amount which would make the project viable because of the constraining influence of coal prices. Repowering Ft. Churchill with coal will remain an alternative to use of oil/gas should prices escalate rapidly.

A decreased cost of money affects also the levelized fixed change rate and the discount rate. This is the most likely near-term change which may affect the viability of the project.

1.5 DEVELOPMENT PLAN

A summary of the development plan is shown in Figure 1-5. A total of 45 months is indicated from the start of preliminary design to the completion of acceptance test. The final design begins 6 months after the project start.

There are two critical paths in the plan. One path flows from the soils and topographic data through site construction operations. The second flows through the software development and integration for the plant control The receiver, a critical path in the former development plan, is no longer critical because of the development work accomplished in the receiver SRE.

1.6 SITE OWNER'S ASSESSMENT

1.6.1 Sierra Pacific System Characteristics

Sierra Pacific Power Company's (SPPCo) service territory covers northern Nevada and a portion of eastern California surrounding Lake Tahoe. There are a total of 175,000 customers in this service territory. The mid summer peak demand for 1982 is forecast to be 683 MWe.

SPPCo has a dual peaking load profile. The 1981/1982 winter peak was 645 MWe. In the past, the winter peak has been higher than the summer peak. As air conditioning loads have grown, the gap between the summer and winter peaks has reduced. Our forecast now shows a small excess of summer peak over the previous winter peak.

The total system installed capacity is 689 MWe. Power purchase contracts with neighboring utilities, primarily Utah Power and Light, provide additional available capacity. The system has a high percentage of capacity (466 MW) in oil and gas. Hence, we have forecast that the repowering project will displace only oil or natural gas.

Nevada's only abundant energy resources are in solar and geothermal. SPPCo is proceeding with a geothermal demonstration project, and will be willing to consider solar when demonstrated and economically feasible.

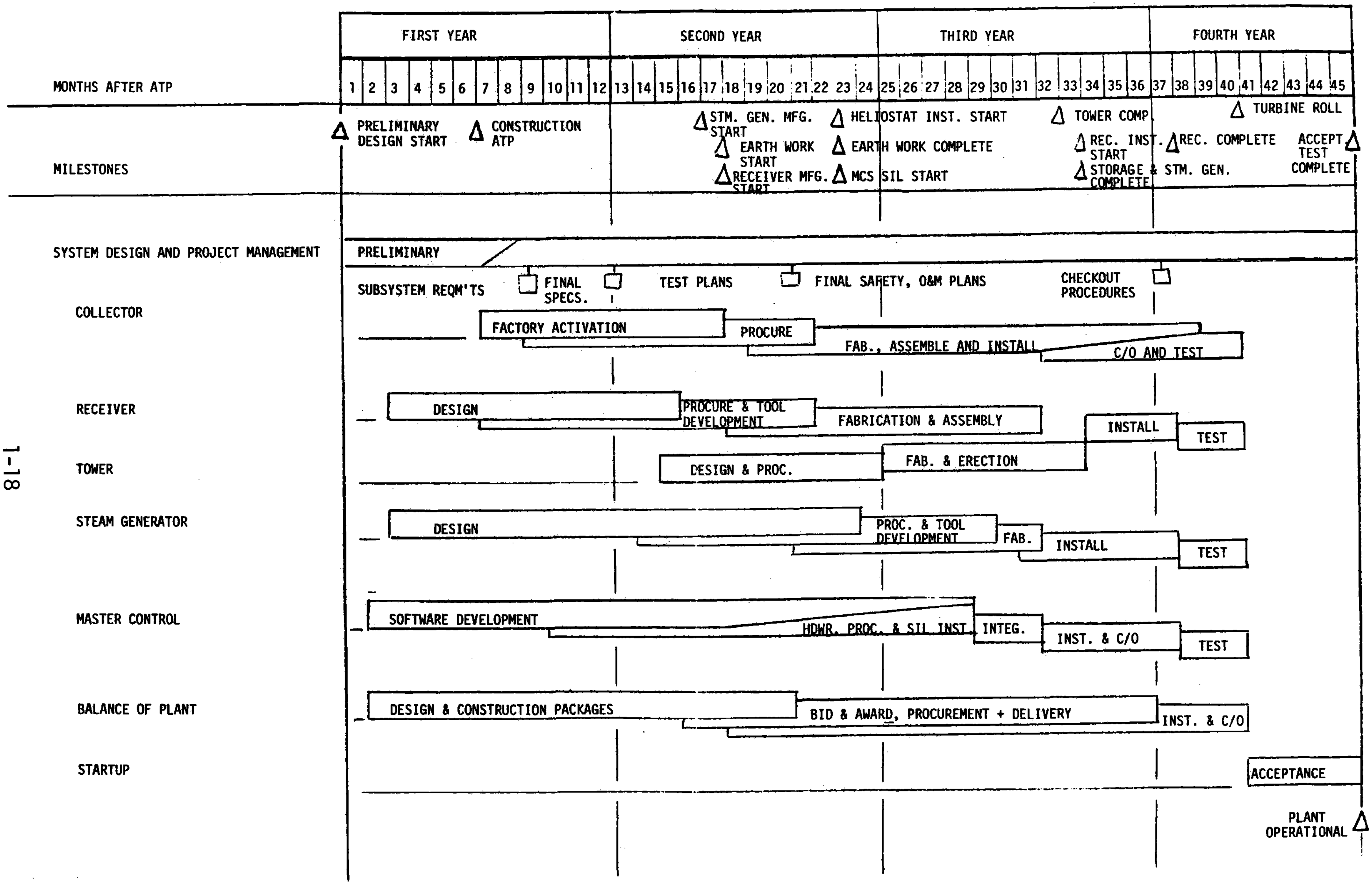


FIGURE 1-5 DEVELOPMENT PLAN SUMMARY

1.6.2 Overview of Repowering Advanced Conceptual Design

In today's uncertain natural gas and petroleum market conditions, alternative energy repowering concepts for existing oil and gas-fired plants are becoming attractive for their ability to reduce dependence on oil and gas. 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 SPPCO's Ft. Churchill station project describes a practical and operationally acceptable repowering system. The projected oil or gas displacement of about 924 x 10^6 cubic feet of natural gas (160,000 barrels of oil) equivalent energy per year is perhaps the most dramatic indicator of the national significance of the Solar Thermal Repowering Program.

Solar repowering with utility funding does not now appear to be economically competitive with continued operation on oil/gas. It is understood that first unit economic competitiveness was never a goal nor an expectation of the government. A significant cost-sharing by the government will be necessary for a repowering demonstration. The modular approach of this repowering Advanced Conceptual Design will reduce both the technical and economic risk of a demonstration.

SPPCo believes that two technology developments are needed before a repowering demonstration is appropriate. First, the testing of Solar 1 at Barstow should be completed. The data collected during the operational test on system operation, performance, reliability, and related issues should be available to influence the design of a repowering demonstration. Second, molten salt SRE's or a full system experiment should be conducted to reduce uncertainties and technical risk.

1.6.3 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. The relatively short design and construction period projected for solar projects would also be a significant consideration in evaluating this option. Industrial demonstration of new technologies provides essential hard operational data for energy system decisions.

1.6.4 System Repowering Potential

Sierra's two plant repowering potential represents slightly over 460 MWe. 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, 220 MWe for intermediate service, and 110 MWe for baseload service. This diversity should yield reasonable flexibility in developing repowering schedules.

If Ft. Churchill Units 1 and 2 were repowered with coal, solar repowering could make up the derated boiler capacity fo 35 MWe equivalent. This option was a consideration in the sizing of the repowering conceptual design.

SPPCo does not plan to repower Ft. Churchill with coal or solar at this time. The current economic circumstances do not make either option attractive as privately funded ventures. Coal repowering will be reevaluated by the direction of the Nevada Public Service Commission. SPPCo will continue to evaluate solar repowering and stand-alone applications by participation on Utility Advisory Board and monitoring progress.

!.6.5 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 cateqories.

Section 2

INTRODUCTION

2.0 INTRODUCTION

The Sierra Pacific Power Company (SPPCo) Repowering Advanced Conceptual Design has been conducted for the DOE under contract number DE-AC03-815F 11568. 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 30, 1981 through June 30, 1982. The total cost was $227,000. This study is a continuation of the Sierra Pacific Utility Repowering Study reported in SAN-06091, dated June 1980.

2.1 STUDY OBJECTIVE

The objective of the original study was to develop a site specific conceptual design for repowering SPPCo'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 capacity should be available for all insolation conditions so that oil/gas combustion is 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 repowered.

2. Be able to be constructed and operating in 1986. The four year design, development and construction program implied by 1986 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.

The DOE has sponsored pilot plant, SRE, and laboratory scale tests on central receiver systems and components. The primary objective of the present study is to refine the conceptual design by incorporating the most recent technical development and ensuring that performance estimates are based, to the maximum extent possible, on the performance of commercially available equipment.

2.2 TECHNICAL APPROACH AND UNIT SELECTION

SPPCo's Ft. Churchill Unit No. 1 was selected for this study. The selection criteria derived from the study objective are compared to the updated findings of the present 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 Ft. 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 0.65×10^6 m^2 (160 acres), which should be available for collector field siting.

TABLE 2-1 UNIT SELECTION

CRITERION	STUDY FINDINGS
Useful Increment of Capacity	Projected Solar Capacity Factor is 0.097, Projected Plant Capacity Factor is 0.79 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 0.14 for the First Module, and may Grow to 0.43 for Three Modules.
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 $kW/m^2/day$.
Available Lnad	Adequate Land is Available at the Site.
High Fraction of Capacity in Oil/Gas	80% of the Projected 1985 Capacity is Currently in Oil/Gas.
High Degree of User Interest	SPPCo is Studying Alternate Energy Projects and Plans to Implement Projects in Geothermal and Solar Thermal when Economically Feasible.

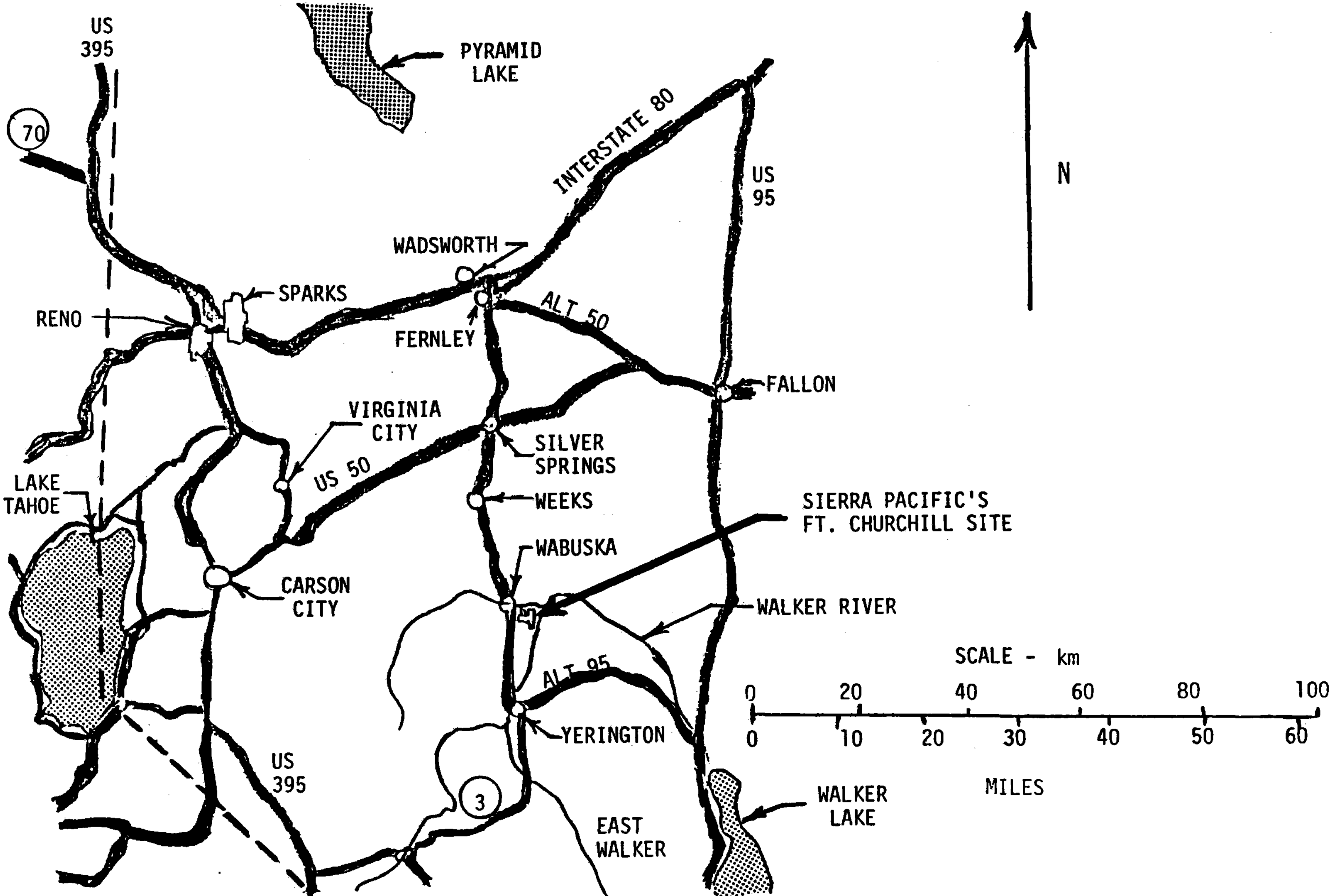


Figure 2-1 Site Location

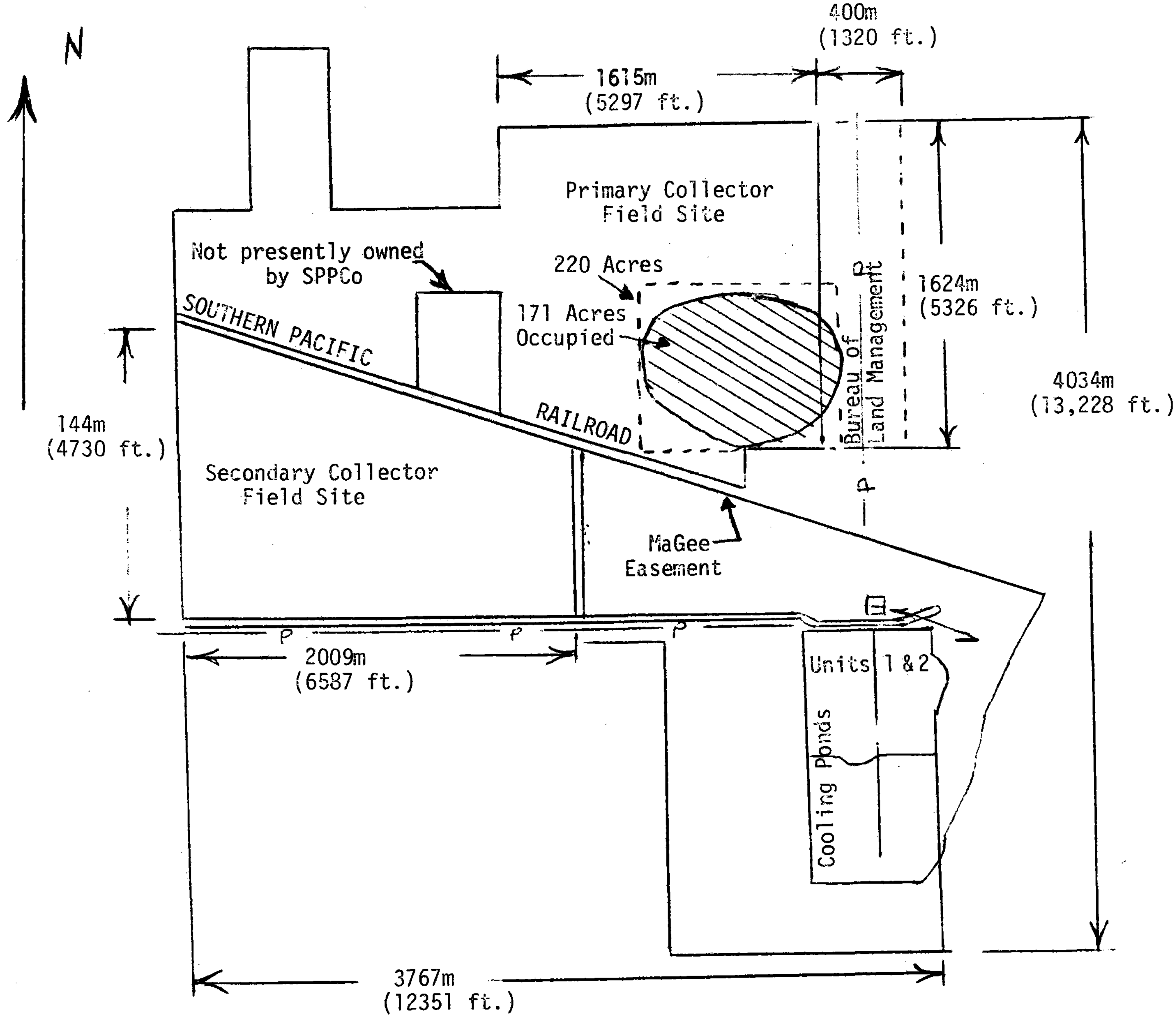


FIGURE 2-2 FORT CHURCHILL SITE PLOT

The baseline collector field required a rectangular area of 900m (2950 ft) deep by 1km (3280 ft) wide (220 acres), with about $0.69 \times 10^6 m^2$ (171 acres) actually occupied by heliostats. Hence, the collector field can be easily fitted into the 3.3×10^6 m^2 (810 acres) parcel (including BLM land) northwest of the plant. A second and third module for Unit 1 could also fit into this parcel. Two additional modules could be fitted into the secondary site in the west of the plant. Hence, there is adequate land available at the site and currently owned by SPPCo to repower Ft. Churchill Unit 1.

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

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.

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	
(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.

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.

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

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 (Figure 4-2) 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.

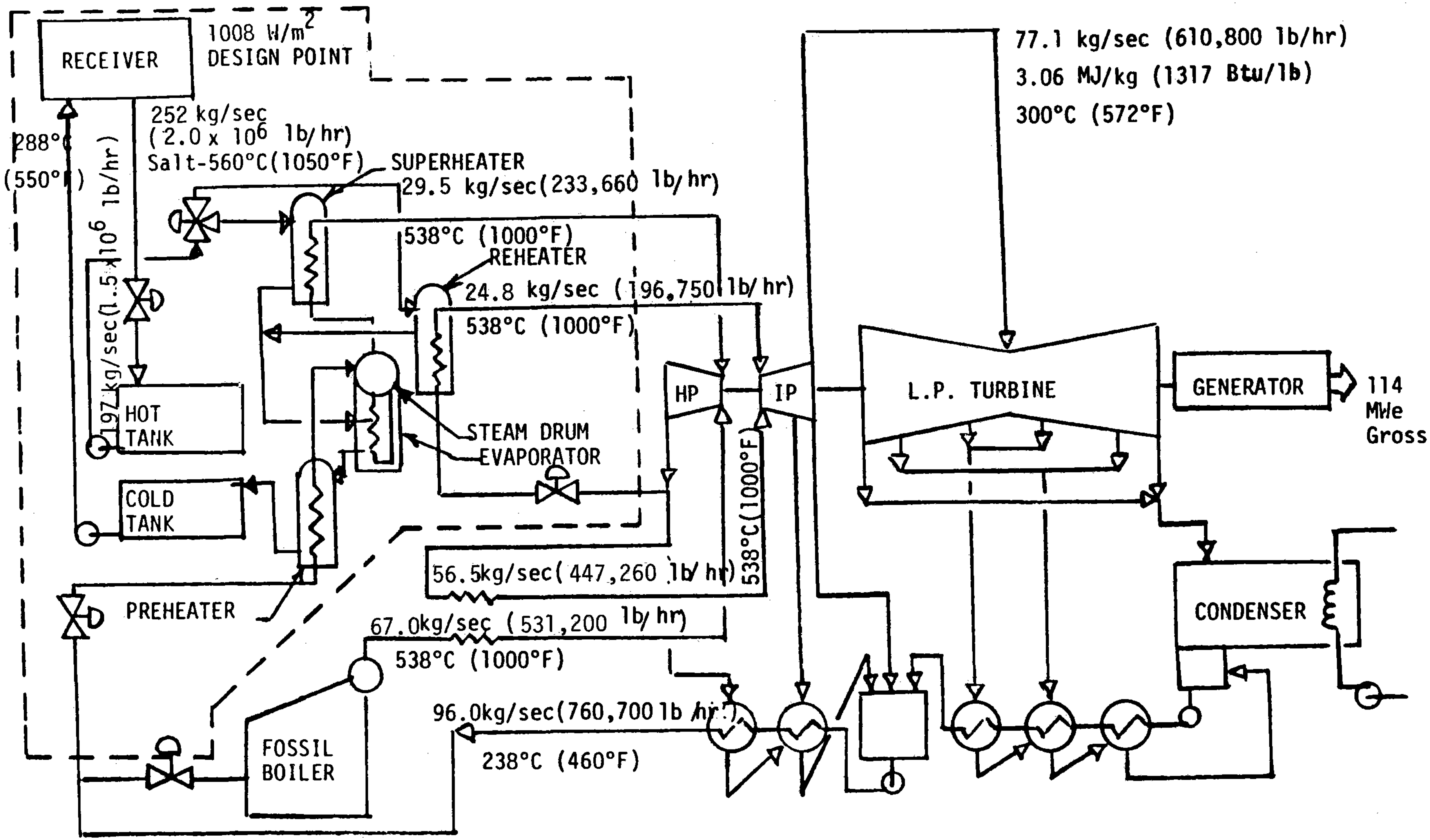


FIGURE 2-3 PLANT CYCLE SOLAR-FOSSIL HYBRID

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.

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 0.79 capacity factor, and is considered to be baseload. The annual electrical energy production is about 750 GWh. The scheduled operation for 1985 and beyond is as a baseload capacity factor plant. The capacity factor was estimated at 0.79 by SPPCo.

At the current usage, the plant consumes the heat equivalent of 0.2×10^6 m^3 ($1.27\ 10^6$ bbl) of oil.

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 nonrepowered plant are shown in Table 2-3. The economic parameter set uses 10% per year fuel escalation and 17% per year discount rate. Capacity factor continues at 0.79. Operations and maintenance costs escalate at 10% per year.

2.8 PROJECT ORGANIZATION

The functional organization chart for the SPPCo, Solar Repowering Study, is shown in Figure 2-4.

MDAC and SPPCo, 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 three subcontractors (Foster Wheeler, Stearns-Roger and University of Houston) 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. The key personnel assigned to this study and their specific responsibilities by task, are also shown on Figure 2-4.

TABLE 2-3 OPERATIONS AND MAINTENANCE (O&M) COSTS FOR NON-REPOWERED PLANT
(10^6 1982 DOLLARS)

CURRENT FIXED O&M	0.9
PRESENT WORTH 30 YEARS O&M	11.2
FUEL COSTS, PRESENT YEAR ESTIMATE	32.7
PRESENT WORTH, 30 YEARS	393.8
PRESENT WORTH O&M PLUS FUEL	405.0
LEVELIZED FIXED O&M COST	1.9
LEVELIZED FIXED FUEL COST	67.6
TOTAL LEVELIZED FIXED CHARGE VALUE OF FUEL PLUS O&M	69.5

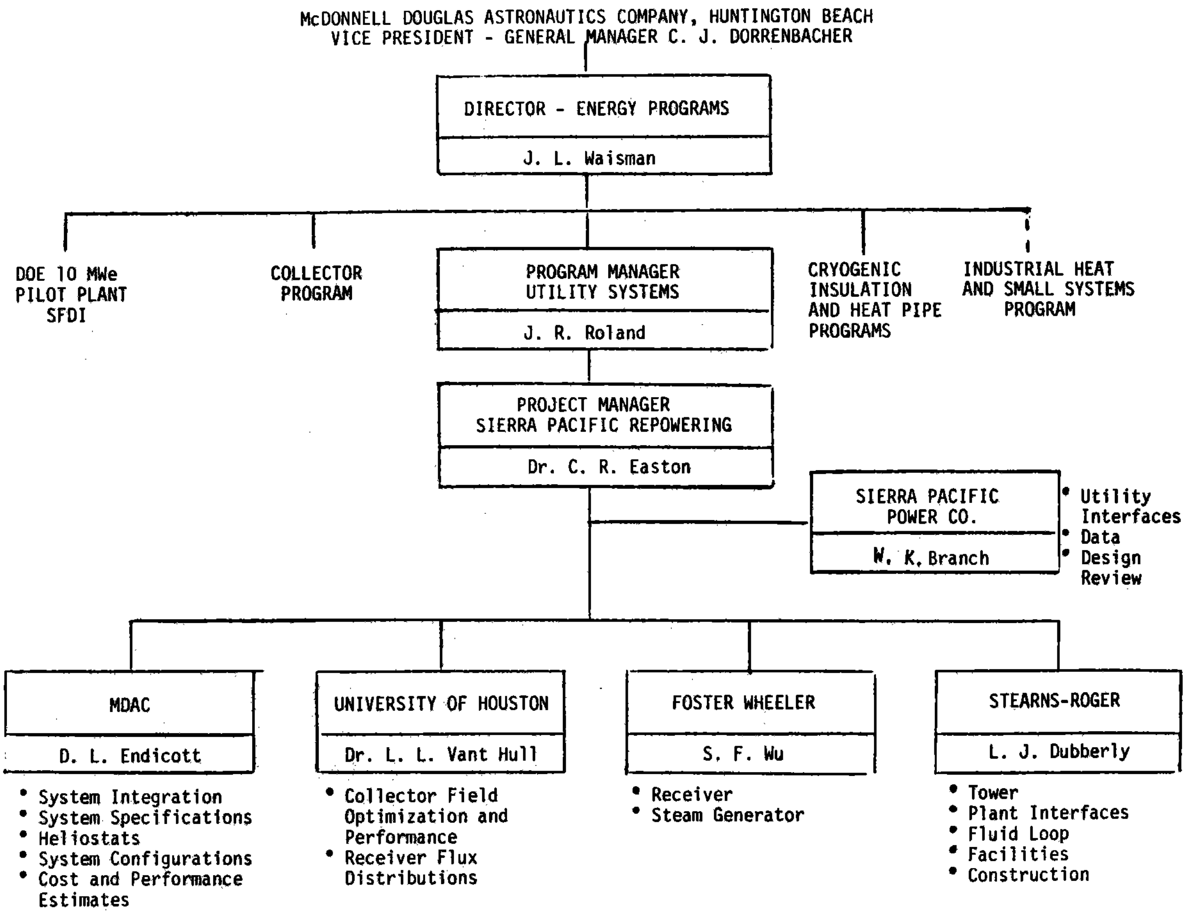


FIGURE 2-4 - SIERRA PACIFIC POWER CO. REPOWERING ADVANCED CONCEPUTAL DESIGN ORGANIZATION

Section 3

SELECTION OF REFINED BASELINE CONCEPTUAL DESIGN

This section contains a summary of the trade studies performed as a part of Task 1, "Refined Baseline Conceptual Design." The original repowering study developed a design for a large solar repowering field for the Ft. Churchill Unit No. 1. The full-sized system contained a single solar field of 8411 heliostats ($56.4m^2$) which had a rating of $330MW_t$. The large system included a large thermal storage system which permitted up to 6 hours operation at 77 MWe after sundown. The large size of the original design resulted in some questions relating to both technical and economic issues. Hence, the first step on this Phase 2 study was to determine if a modular version of the large field was feasible and if so, what size module was preferred. This evaluation was completed by conducting four trade studies. The description of these studies and the results of each are presented in this section.

3.1 SYSTEM LEVEL TRADE STUDIES

The system level trade study completed on the Phase 2 effort was related to the selection of the optimum unit size for a modular system. The details of this trade study are presented in Appendix B.

This trade study was proposed to examine the effect of constraints on the optimum size for a modular repowering unit for Sierra Pacific's Ft. Churchill Unit 1.

Constraints arise from the DOE published requirements and indicated objectives for repowering. Additional constraints arise from the unit itself, and the SPPCo operating plans.

The objective of this trade study was to identify sizes for the collector/receiver and the steam generator which were consistent with these constraints. The analysis reveals that no size is consistent with all constraints. The best compromise appears to be a 110 MW_{th} collector/receiver and a 50 MW_e steam generator. These sizes are selected for the refined baseline conceptual design. The one-third size module design will permit the installation of a single module as a first step in the repowering of the Ft. Churchill unit. After the output, performance and value of the first module has been established, the second and third modules can be added.

If all three modules were installed, the expected performance would be consistent with the large field arrangement studied on the basic repowering study. The 110 MW_t module would permit operating the plant in the hybrid mode at 79 MW_e on fossil fuel and 35 MW_e on solar. The proposed configuration is suitable for operating in the solar stand-alone mode with a power output rating of 35 MW_e to 50 MW_e. This combination gives the best results when the solar field, receiver, receiver feed system and storage tanks are sized for the 35 MW_e (110 MW_t) rating while the steam generator and steam generator feed system are sized at the 50 MW_e rating. This combination was selected as the baseline configuration for the Phase 2 study.

3.2 SUBSYSTEM TRADE STUDIES

Three subsystem trade studies were completed in support of the design selection and performance evaluations for the 110 MW_t size system. These three studies evaluated the redesign indicated for the smaller receiver, for the shorter tower and for the cloud transient effects on receiver performance when a small solar field/receiver was incorporated.

3.2.1 Receiver Design

The original 330 MW_t receiver was a partial cavity "omega" design with 1100 m^2 of absorber area. The large unit had a four pass, series/parallel flow arrangement and the entire absorber was tilted down at a angle of 25° from the vertical. This tilt angle resulted in a complicated mounting arrangement for the absorber panels and a corresponding heavy receiver support system. With the smaller 110 MW_t receiver, the arrangement with a 25° tilt angle and a new vertical arrangement (which stairsteps up at a 25° angle to the rear) were evaluated. The performance loss with the simpler stairstep arrangement was found to be relatively small and the higher performance of the tilted arrangement did not justify the extra mounting complications. The vertical receiver, with a two-pass/fourteen panel arrangement was selected for the Phase 2 baseline. The details of this trade study are presented in Appendix C.

3.2.2 Tower Design

The single field, full size plant had a slip formed concrete tower which was 198.5m high. The optimum tower height for the smaller one-third size module was found to be 120m. With the shorter tower and with a greatly reduced receiver weight, the optimum type of construction was not known.

A trade study was completed to compare a slip formed concrete tower with a conventional steel tower at the 120m height. The results of this study showed a lower cost for the steel tower ($1,590,000 for steel, $1,815,000 for concrete) and a significant improvement in seismic response for the steel tower (g's at receiver centerline were 0.19 for steel and 0.64 for concrete). The steel tower was selected for the Phase 2 baseline design. The details of the tower selection study are presented in Appendix D.

3.2.3 Cloud Transient Response

The original repowering study of Ft. Churchill Unit 1 included performance estimates for steady state operating conditions, but very little transient response data. One of the studies completed on the Phase 2 effort was to expand this data base for receiver response to cloud transients. The study was completed by developing a computer model of the response characteristics of the 14 panel, 110 MW_t size receiver and then using this program to evaluate the receiver response. The results of the study indicate that the Phase 2 receiver design should operate satisfactorily under the worst case studied. This worst case consisted of a sharp edge cloud, traveling west-to-east at 13 M/W (43 ft/sec) with the receiver at the power level corresponding to a clear day at equinox noon. The results indicate that the present design and control strategy would hold the outlet temperature excursion of the hot salt to a value of $\pm$ 6°C. The details of the computer model and the performance estimates are presented in Appendix E.

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 with a one-third-size solar module. Detailed subsystem-level descriptions are contained in Section 5.

4.1 SYSTEM DESCRIPTION

4.1.1 Modular Repowering Approach

The 110 MW_t collector/receiver module selected through the trade studies is envisioned as the first of three such modules. The comparison in Table 1-2 shows the single module, three modules, and original repowering concepts.

The baseline operating mode for the repowered plant is hybrid operation. With a fully repowered system of three collector modules, Unit No. 1 would be repowered for hybrid operation with the fossil side operated continuously at at least 37 MWe (gross), and the solar will provide 77 MWe (gross) when energy from solar is available. Solar capacity may be provided for up to six hours from 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 40% of the fossil fuel annually. The repowered plant can also operate in solar stand-alone and fossil-only modes.

The full-size solar repowering system was defined in the phase 1 conceptual study and the results were reported in report SAN 0609-1, dated June 1980. The present phase 2 effort included the refinement of the basic configuration. One of the major refinements identified consisted of modularizing the large single solar field into one-third size modules. This modularized arrangement will permit the solar system to be installed sequentially, starting with a single one-third size module. With all three modules installed, the total output would be similar to the performance expected for the large single field. The plant performance which can be expected for a single one-third module field was determined in this effort.

4.1.2 First Module Description

In the discussions that follow, the first 110 MW_t module and its associated storage and steam generator will be discussed. Additional collector/receiver modules will be essentially identical to the first. One additional steam generator module will be required for full repowering, as well as an enlarged thermal storage.

The modular arrangement will permit the generation of about 37 MWe (gross) from solar while the plant is operating in the hybrid mode. The fossil-fired output would be set at 77 MWe (gross) for a total plant output of about 114 MWe. The solar stand-alone mode could be conducted from the normal 37 MWe hybrid rating up to the 54 MWe SGS capability. The steam generation/storage tank sizing determines the stand-alone output level. Since the DOE-sponsored SRE steam generator program is producing a steam generator design suitable for a 50 MWe output level, the use of the SRE equipment was considered for the SPPCo application.

The system schematic is shown in Figure 4-1, 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 $6.9 \times 10^5 m^2$ (171 acres) land area. The collector field will contain 2565 MDAC second generation heliostats at 56.85 m^2 (612 ft^2) each for a total mirror area of 145,870 m^2. The University of Houston has optimized the collector field layout as a radial staggered field.

The center of the receiver aperture is 133 m above the ground level, and the receiver is supported on a steel tower. The tower is 23.8 m (78.7 ft) in diameter at the base and 14.9 m (49.2 ft) in diameter at the top.

The partial cavity receiver design uses a molten salt working fluid. The front and side walls of the receiver are arranged in two-series sets of panels. The outlet temperature is controlled to 566°C (1050°F) by feedback of outlet temperature, pressure flux, and back wall metal temperature.

The receiver fluid is a 60/40 mixture of sodium and potassium nitrates by weight 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).

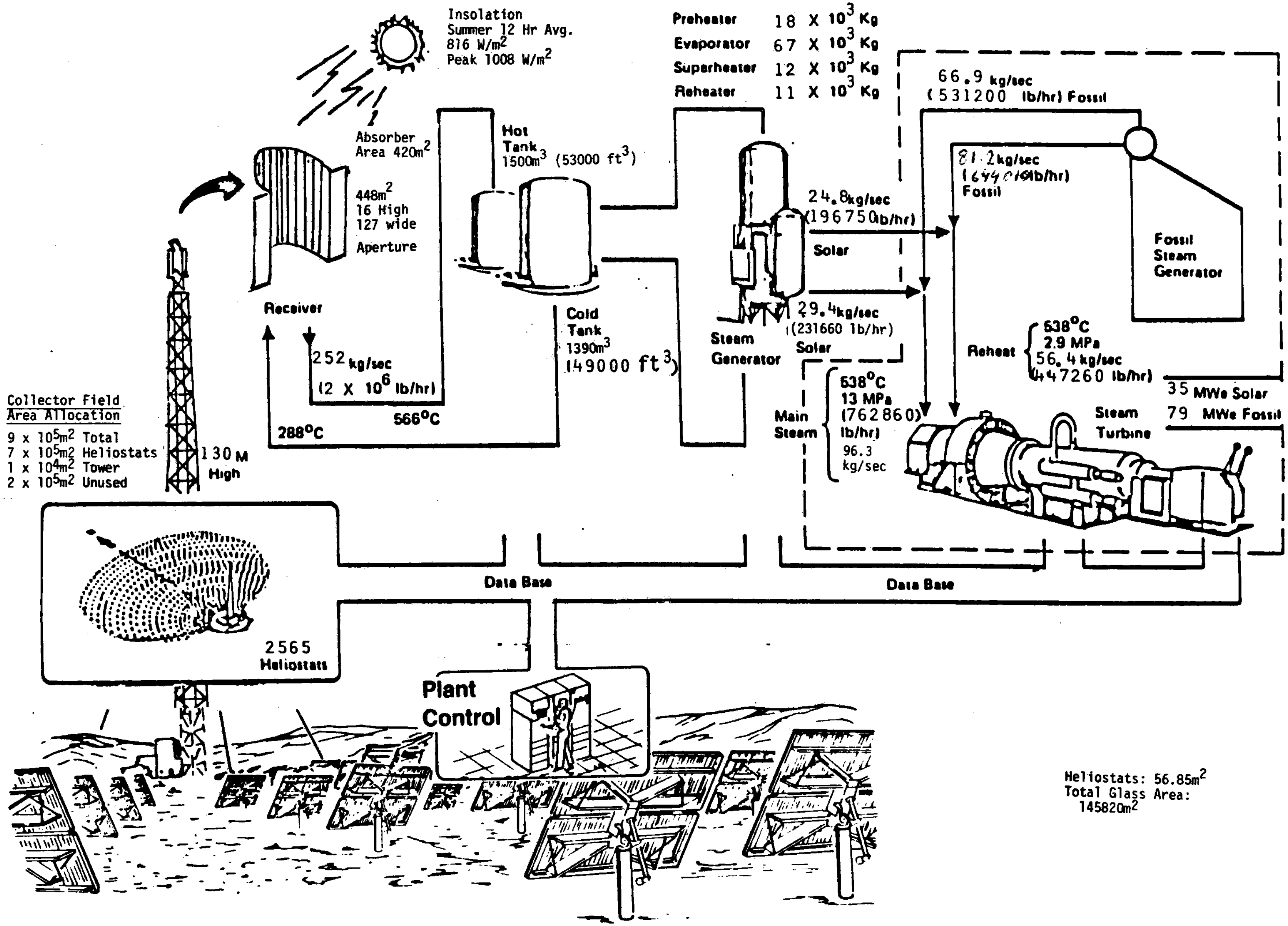


Figure 4-1 Sierra Pacific Power Co. Fort Churchill No. 1

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 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. (68,00 + GWe)
Receiver Fluid	Molten Salt	High performance with reheat system. No fossil fuel field re-heaters 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	Steel	Minimum risk, lower cost, best performance
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 thermal storage unit baseline is an externally insulated, two tank unit. The hot tank is 15.2m (50 ft) in diameter and 8.2m (27 ft) high. The tank is made of 347 stainless steel. The cold tank is carbon steel, 15.2m (50 ft) in diameter and 7.6m (25 ft) high. The cold salt line from the thermal storage cold tank to the receiver inlet is 0.3m (12 in.) in diameter. The hot salt line from the receiver outlet to the thermal storage hot tank is 0.25m (10 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.

4.2.1 Operating Requirements

The plant shall be capable of operating in hybrid, fossil only, and solar only modes. In the hybrid mode, the total gross power output shall be up to 114 MWe. The design point solar contribution in hybrid operation is 37 MWe gross equivalent. Output in the solar only mode shall be up to 54 MWe gross.

The system shall provide adequate thermal conditioning to maintain the equipment and piping containing molten salt of at least 288°C (550°F) under non-operating conditions. Startup, shutdown, and mode transitions shall be accomplished in such a manner as to prevent excessive thermal stress and temperatures on sensitive components. The receiver shall be provided with an operating mode which monitors an adequate flow to withstand insolation transients induced by cloud cover. A bypass loop recirculating salt to the warm tank shall be utilized as required to maintain the capability of producing rated steam conditions.

4.2.2 Performance Requirements

At the system design point, the collector shall direct 117 MW_{th} incident power on the receiver. The receiver shall absorb and retain 110 MW_{th}.

The receiver outlet temperature shall be maintained at 566°C (1050°F) ± 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 278 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 35 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 54 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 -	2565
Heliostat Mirror Area -	56.85m^2 (612 ft^2)
Total Mirror Area -	145,820 m^2 (1.57 x 10^6 ft^2)
Collector Field Ground Area -	6.9 x 10^5 m^2 (171 acres)
Tower Height to Receiver Centerline -	133 m (439 ft)
Average Parasitic Power -	225 kW
Peak Parasitic Power -	595 kVA
Receiver Characteristics	
Receiver Type -	Partial Cavity
External Absorber Area -	60 m^2 (651 ft^2)
Cavity Absorber Area -	359 m^2 (3910 ft^2)
Number of Absorber Panels -	14
Number of Controlled Circuits -	2
Control Parameters Measured -	Receiver Fluid Temperature, Metal Temperature, Pressure
Absorber Tube Diameter -	28.5 mm (1 1/8 in.)
Absorber Tube Wall Thickness -	1.65 mm (0.065 in.)
Absorber Tube Material -	Incoloy 800
Receiver Fluid -	Molten Salt, 60 Weight Percent $NaNO_3$ 40 Weight Percent KNO_3
Inlet Temperature -	288°C (550°F)
Outlet Temperature -	566°C (1050°F)
Maximum Film Temperature Goal -	593°C (1100°F)

TABLE 4-2 DESIGN/OPERATING CHARACTERISTICS

Design Point Salt Flow Rate -	252 kg/sec (2 x 10^6 lb/hr)
Receiver Feed Pump Type -	Two Half Flow, Motor-Driven Centrifugal Pumps
Peak Heat Flux Goal -	To design
Current Design Point Peak -	0.694 MW/m^2
Gross Receiver Unit Mass - (Includes Receiver Fluid)	347,500 kg (766,000 lb)
Support Structure Mass -	169,000 kg (374,000 lb)
Receiver Parasitic Power -	776 kW_e
<u>Thermal Storage Unit Characteristics</u>	
Thermal Storage Unit Type -	Two Tank, External Insulation
Energy Storage Capacity -	278 MWh_{th}
Storage Duration at Design Point -	3 hours at 37 MWe gross
Total Heat Transport Fluid Mass -	2.27 x 10^6 kg (5 x 10^6 lb)
Salt Flow Rate to Steam Generator -	202 kg/sec (1.6 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-	250 kW_e
<u>Steam Generator Characteristics</u>	
Number of Heat Exchangers -	Four (Superheater, Reheater, Evaporator, Preheater)

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 -	46 kg/sec (369,126 lb/hr) - at 54 MWe gross
Reheater Steam Flow Rate -	38.2 kg/sec (303,182 lb/hr) - at 54 MWe gross
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 -	304 S.S.
Evaporator/Preheater Tube Material -	1 1/4 CR - 1/2 Mo Steel
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
Existing Plant Characteristics	
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 4-2. 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.

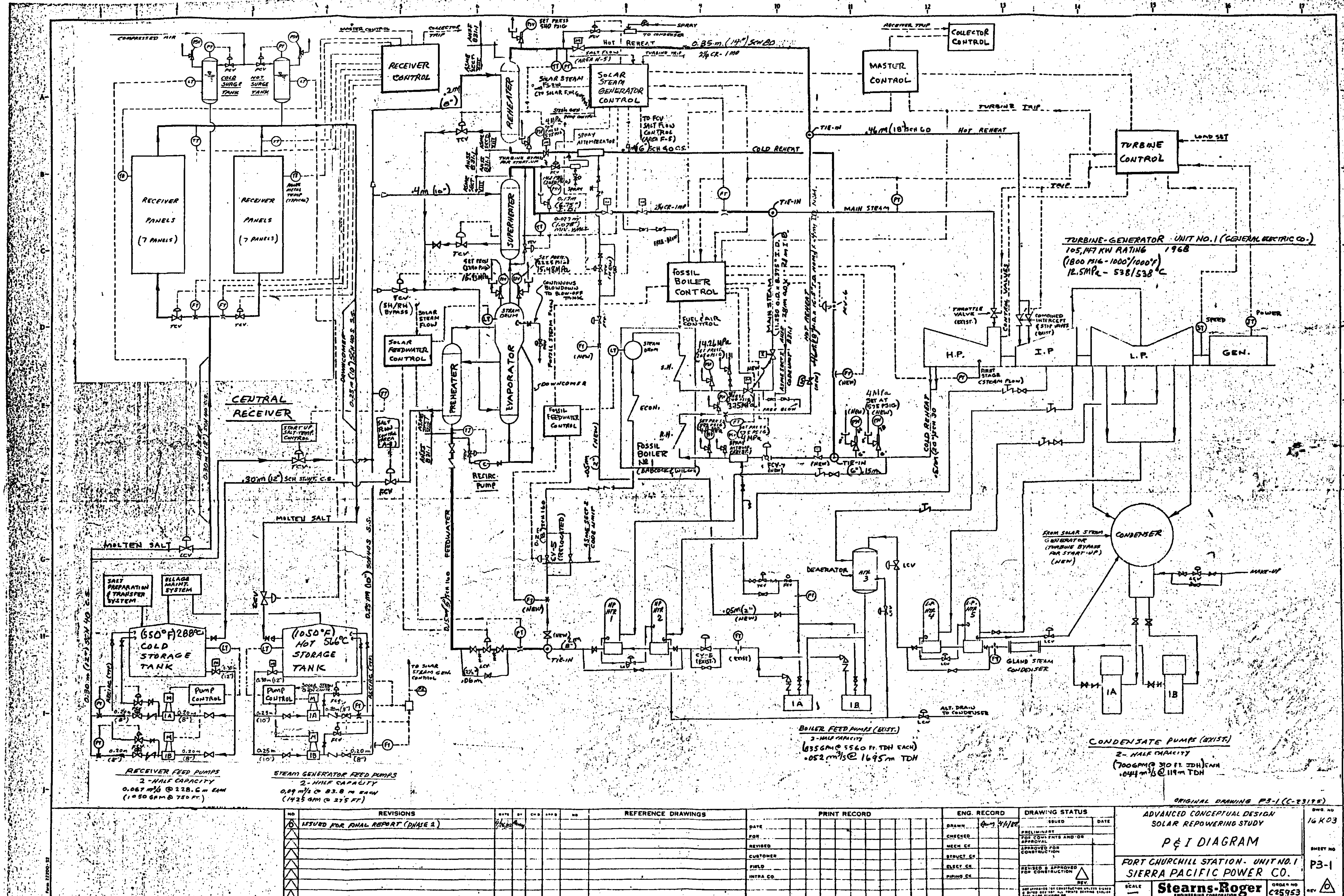


Figure 4-2 P&ID

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. The flow passes through the seven left panels in series and in parallel with the seven right panels.

Surge Tanks - An inlet surge tank is used to damp pressure surges in the warm salt line and to store a reservoir of salt to maintain receiver flow, in the event of a loss of flow, until safe shutdown can be achieved. An outlet surge tank, vented to ambient, is used to damp pressure surges in the hot salt line. The receiver fluid is brought to the ground in the downcomer. A drag valve is used to control the receiver outlet surge tank level 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 join 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 4-3 and described below:

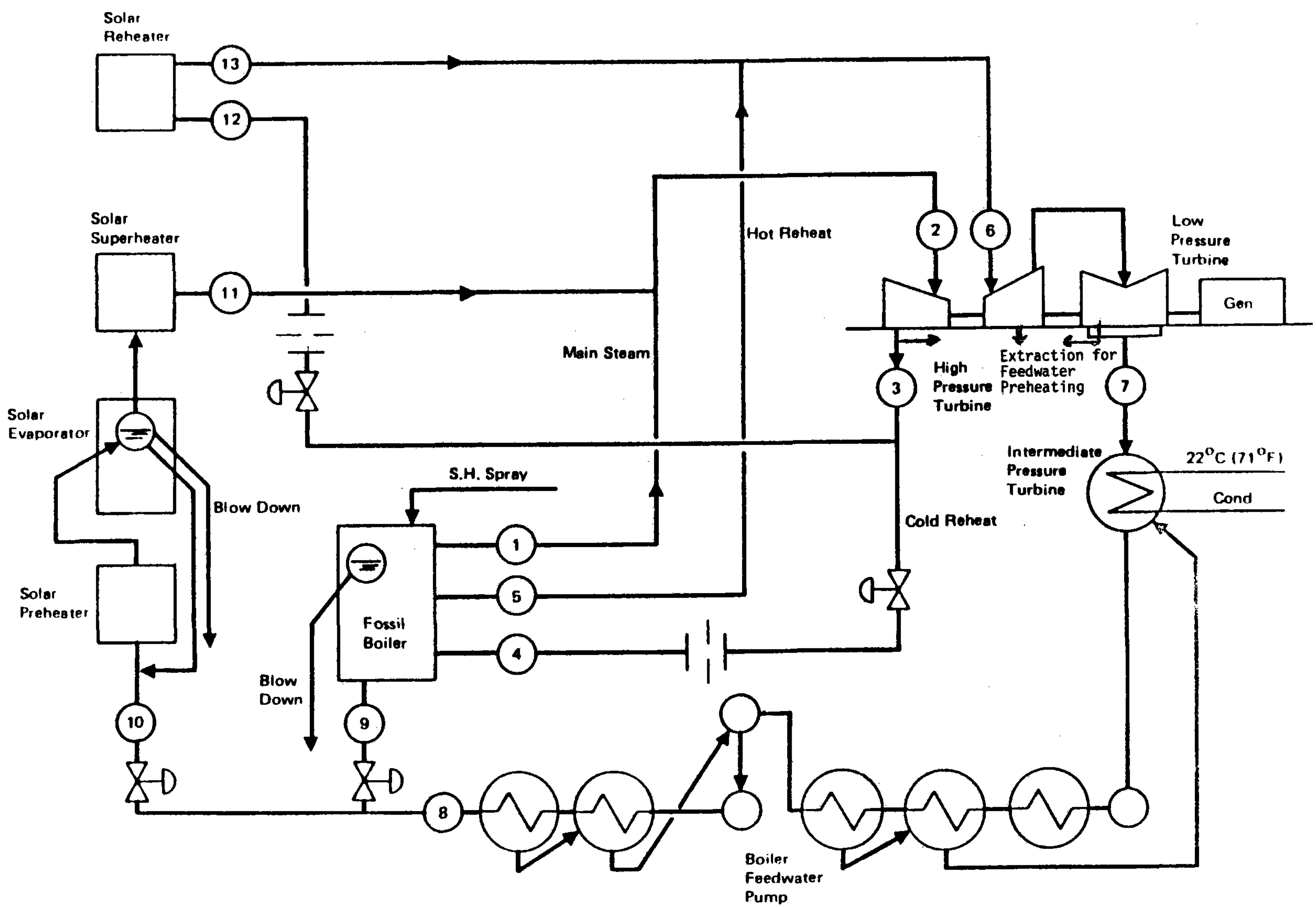


Figure 4-3 Heat Balance Data Points

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.

4.3.4 SOLTES Model of Repowered System

The SOLTES model of the repowered system is illustrated by Figure 4-4. Standard SOLTES models are used for most of the loop elements. The function of each element in the model is shown on Figure 4-4. The model identification and pertinent data are contained in Table 4-4.

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 (37 MWe SOLAR/79 MWe FOSSIL)													
Flow Kg/sec (LB/HR)	67 (531,200)	96.3 (762,800)	81.3 (644,010)	56.5 (477,260)	56.5 (447,260)	81.3 (644,010)	67.5 (534,515)	96.0 (760,670)	66.8 (525,850)	29.7 (234,820)	29.5 (233,660)	24.8 (196,750)	24.8 (196,750)
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 (54 MWe)													
Flow, Kg/Sec(LB/HR)	0	46.1 (365,300)	38.2 (303,182)	-	-	38.7 (306,612)	33.9 (268,794)	46.6 (369,126)		46.6 (369,126)	46.3 (367,300)	38.2 (303,182)	38.2 (303,182)
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)

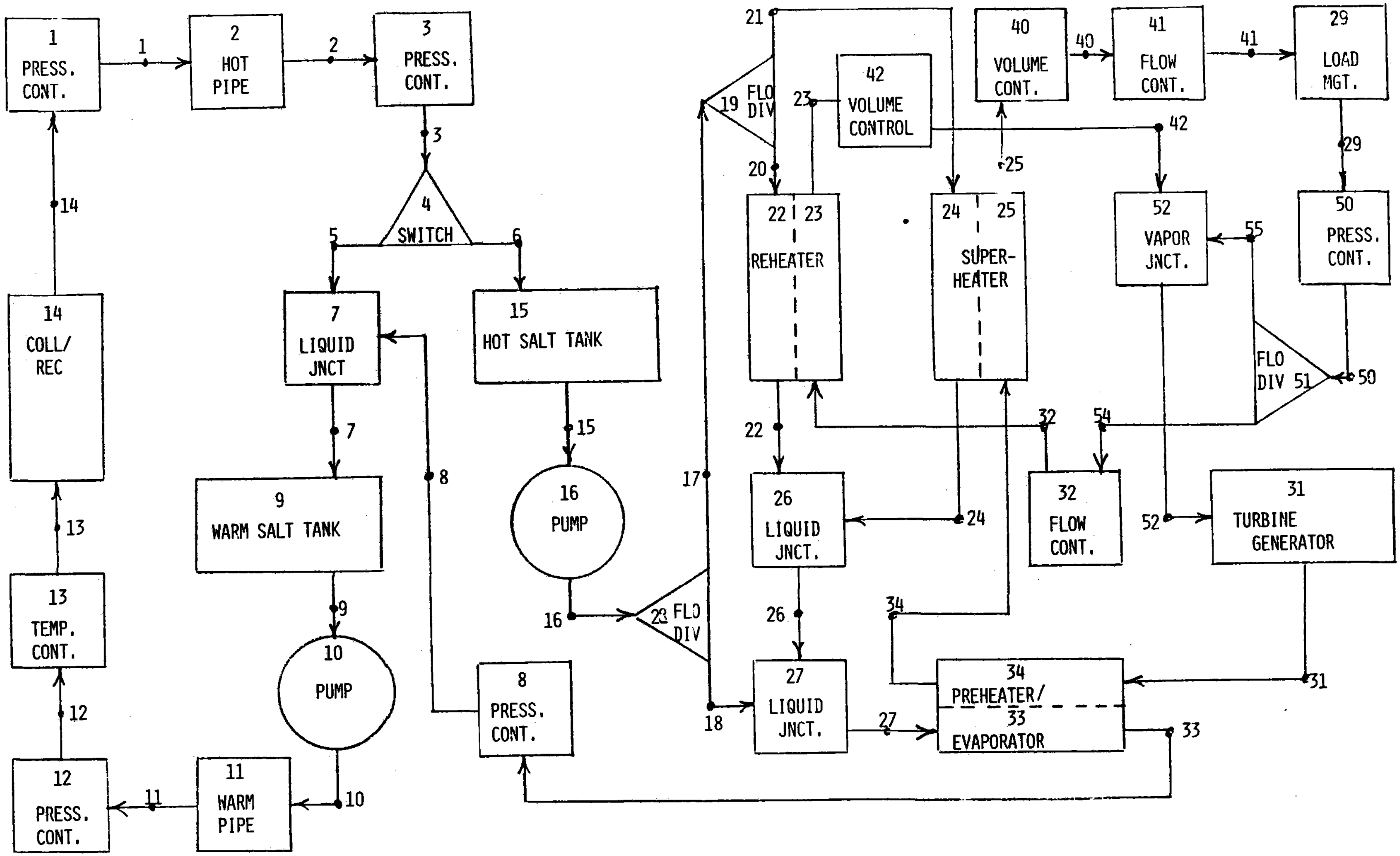


FIGURE 4-4 SOLTES SCHEMATIC OF SPPCo REPOWERING

TABLE 4-4 SOLTES INPUT DATA

Component Number	Component Type	Inlet State Number(s)	Outlet State Number(s)	Fluid	Additional Data
1	DUMCOM	14	1	Salt	Pressure = 1.015 E5 Pa
2	PIPE	1	2	Salt	Length = 1524M Diameter = 0.255M Thermal Res. = 0.08883°K/W Number of Pipes = 1 Maximum ΔP = 0.95 Roughness Ratio = 2000 Head Rise = 250M Loss Coefficient = 20
3	DUMCOM	2	3	Salt	Pressure = 1.015 E5 Pa
4	SWITCH	3	5(1), 6(2)	Salt	Reference State = 3 Low Temp. = 810°K High Temp. = 811°K Initial Outlet = 1
7	LIQJNT	5, 8	7	Salt	
9	STORE 5	7	9	Salt	Initial Volume = 110m^3 Initial Temp. = 552°K Ref. Temp. = 552°K Minimum Volume = 110m^3 Tank Th. Cap. = 24.3 x 10^{6}J/°K Ins. Th. Cap. = 6.8 x 10^{6}J/°K Heat Loss Coef. = 318 W/°K Variable Flow

TABLE 4-4 SOLTES INPUT DATA - Continued

Component Number	Component Type	Inlet State Number(s)	Outlet State Number(s)	Fluid	Additional Data
10	PUMP	9	10	Salt	Outlet Head = 229M Efficiency = 0.75 Variable Flow
11	PIPE	10	11	Salt	Length = 1524M Diameter = 0.303M Thermal Res. = 0.119°K/W Number of Pipes = 1 Maximum ΔP = 0.9 Roughness Ratio = 2000 Head Rise = 250M Loss Coefficient = 20
12	DUMCOM	11	12	Salt	Pressure = 1.015E5 Pa
13	TEMCO2	12	13	Salt	Reference State = 14 Reference Temp. = 838.9°K Error Tol. = 2.0°K Maximum Flow = 276.Kg/s Minimum Flow = 50.Kg/s
14	FOCOL	13	14	Salt	Number of Collectors = 1 Collector Area = 145692m^2 Collector Efficiency = 0.636
8	DUMCOM	33	8	Salt	Pressure = 1.015E5 Pa

TABLE 4-4 SOLTES INPUT DATA - Continued

Component Number	Component Type	Inlet State Number(s)	Outlet State Number(s)	Fluid	Additional Data
15	STORE 5	6	15	Salt	Initial Volume = $110m^3$ Initial Temperature = 838.9°K Reference Temperature = 838.9°K Minimum Volume = $110m^3$ Tank Thermal Cap. = 24.3×10^6J/°K Ins. Thermal Cap. = 13.4×10^6J/°K Heat Loss Coefficient = 207 W/°K Variable Flow
16	PUMP	15	16	Salt	Outlet Head = 83.8M Efficiency = 0.75 Variable Flow
28	FLODIV	16	17, 18	Salt	Reference State = 26
19	FLODIV	17	20, 21	Salt	Reference State = 22
22	THMBLR	21	22	Salt	Power Side Comp. = 23 Power Side Inlet = 32 Thermal Inlet ΔT = 27.78°K Thermal Outlet ΔT = 150°K
26	LIQJNT	22, 24	26	Salt	
27	LIQJNT	18, 26	27	Salt	

TABLE 4-4 SOLTES INPUT DATA - Continued

Component Number	Component Type	Inlet State Number(s)	Outlet State Number(s)	Fluid	Additional Data
33	THMBLR	27	33	Salt	Power Side Comp. = 34 Power Side Inlet = 31 Thermal Inlet ΔT = 111.1°K Pinch Point ΔT = 6°K
40	VOLVLV	25	40	Steam	Reference Comp. = 15 Shutoff Volume = 110M^3 Startup Volume = 450M^3 Maximum Volume = 1340M^3
41	DUMCOM	40	41	Steam	Flow Rate = 29.45Kg/s
29	LODMG	41	29	Steam	Power Operating Mode Follows Electrical Demand Demand Specified in Cpt. 31
42	VOLVLV	23	42	Steam	Reference Comp. = 15 Shutoff Volume = 110M^3 Startup Volume = 450M^3 Maximum Volume = 1340M^3
50	DUMCOM	29	50	Steam	Pressure = 2.91E6 Pa
51	FLODIV	50	54, 55	Steam	Reference State = 32

TABLE 4-4 SOLTES INPUT DATA - Continued

Component Number	Component Type	Inlet State Number(s)	Outlet State Number(s)	Fluid	Additional Data
32	DUMCOM	54	32	Steam	Flow Rate = 24.42 Kg/s
52	VAPJNT	42, 55	52	Steam	
31	DUMEL	52	31	Water/ Steam	Efficiency = 0.427 Inlet State = Steam Outlet State = Water Outlet Pressure = 15.19E6 Pa Outlet Temperature = 510.9°K Load = 35 MWe

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 3.0 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.

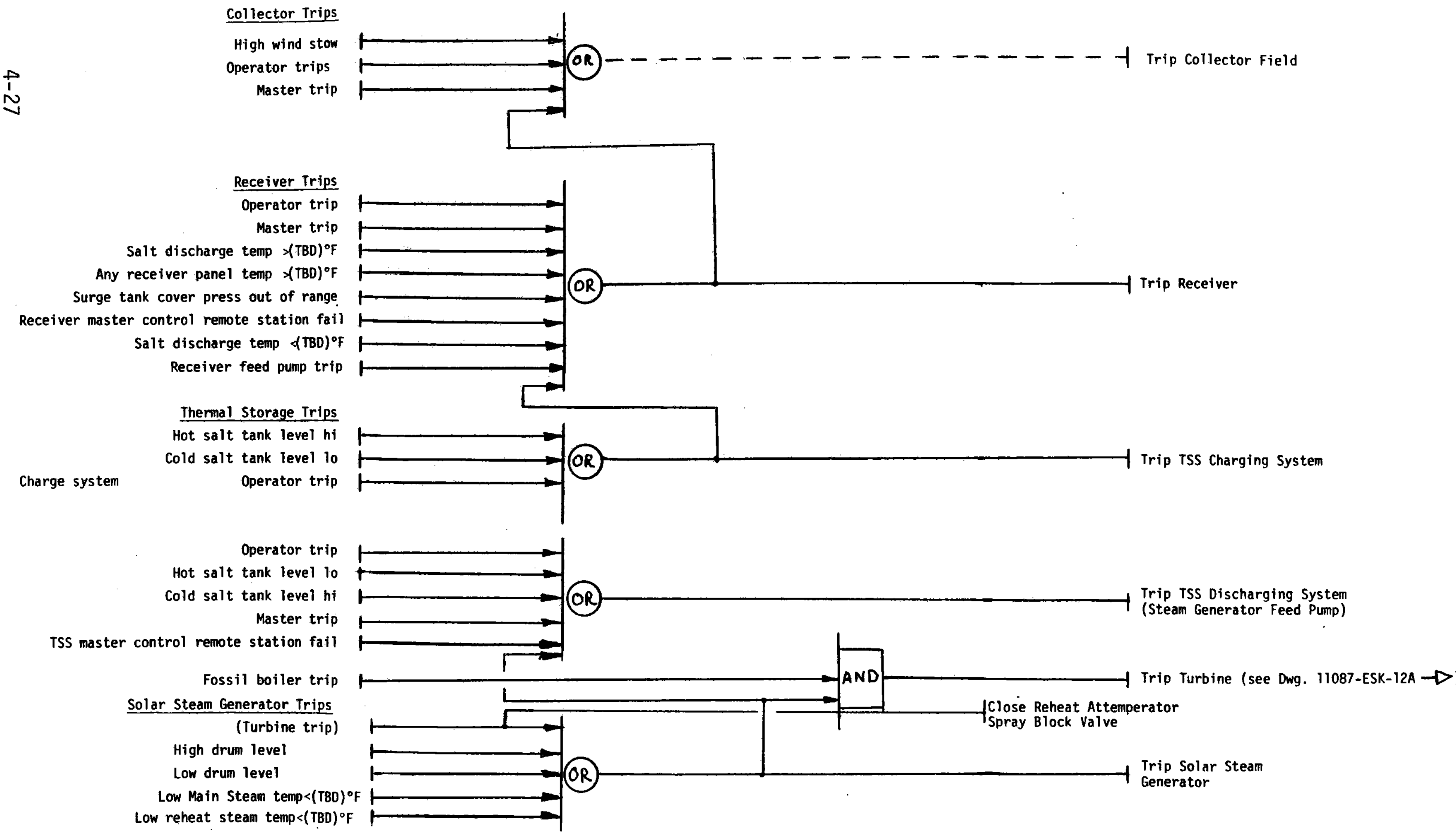
The solar master control interfaces with the existing plant controller primarily through the operator. Coordination of the two controllers is facilitated by providing selected plant operating data to the solar master control. The following parameters have been identified as required for coordinated control:

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

The interface between the main plant controller and the solar system was evaluated for plant trip condition. The data available from the "Solar One" plant, at Barstow, was used to develop an up-to-date plant trip logic. The results of this study are shown on Figure 4-5. The solar system trip functions which will lead to a plant turbine trip are shown on this diagram. Other parameters may be added as the master control subsystem definition is refined. As previously indicated, a 3,000-kVA tap into one of the main transformers is required to provide power to the solar equipment.

Figure 4-5 Solar Plant Trip Logic
(Ft. Churchill - Unit 1)

Note: Values labeled TBD will be set in final design.



4.4.4 Site Plot Plan

The site plot plan is shown in Figure 4-6. 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 1140 m (3750 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

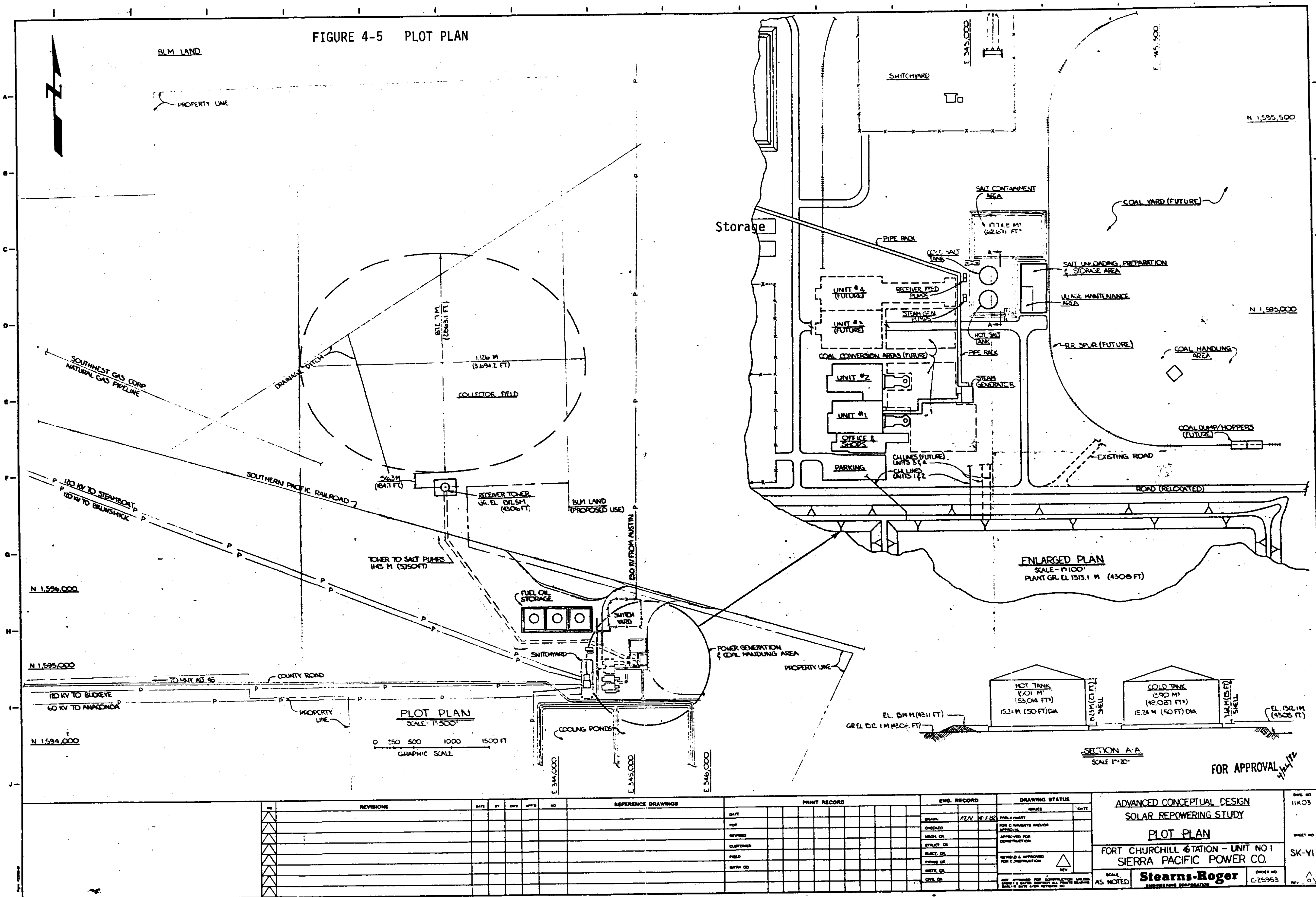


FIGURE 4-5 PLOT PLAN

estimated at .746 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 .636.

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 calculation 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 4-5. 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 4-6. 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 4-6 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 Desert 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 4-5 PARASITIC LOADS

(Loads in kW_e)

Load	Fossil Only	Hybrid Daytime	Hybrid Storage	Solar Daytime	Solar Storage
Receiver					
Feed Pumps	----	694	----	694	----
Trace Heating	550	----	550	----	550
Collector	----	224	----	224	----
Thermal Storage					
Circulation	----	210	210	308	308
Heating	180	----	----	----	----
Master Control	50	50	50	50	50
Variable Load	3441	3022	3022	2152	2152
Constant Load	775	775	775	775	775
Total	4996	4975	4607	4203	3835
Fraction of Gross Power	0.043	0.043	0.040	0.078	0.071

TABLE 4-6   PLANT AVERAGE ANNUAL 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	0.636	0.636	0.636	0.636
Turbine Generator	0.426	0.425	0.425	0.42	0.42
Parasitic Factor, Fossil	0.957	0.957	0.957	N/A	N/A
Parasitic Factor, Solar	N/A	0.990	0.990	0.922	0.929
Net Fossil Efficiency	0.345	0.345	0.345	N/A	N/A
Net Solar Efficiency	N/A	0.267	0.267	0.246	0.248

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 4-7. A consistent trend toward measurements of direct normal insolation 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 $kWh/m^2/day$.

Figure 4-8 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 $kWh/m^2/day$.

No clear days were recorded in January. Figure 4-9 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 $kWh/m^2/day$.

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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.

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

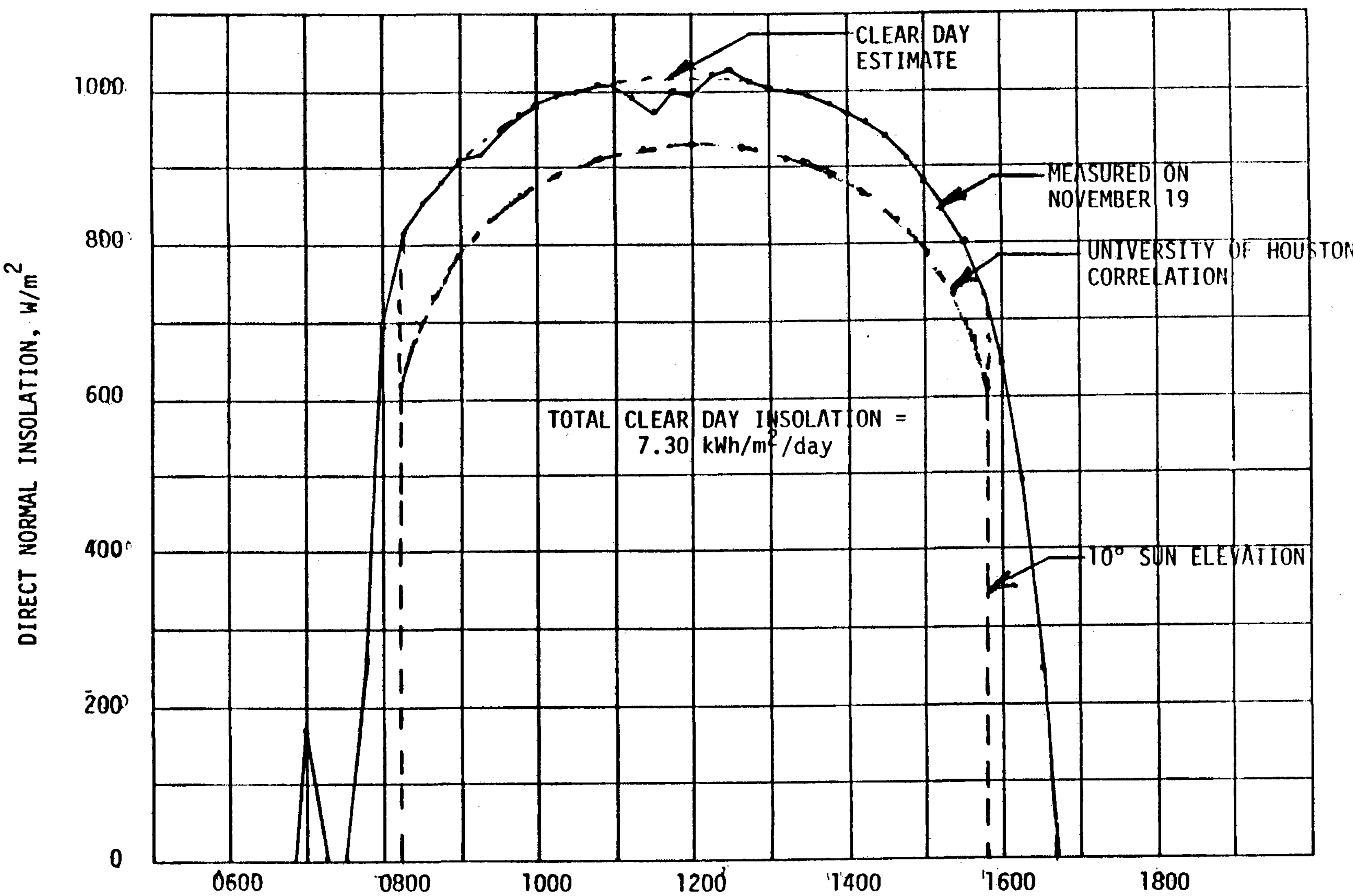

FIGURE 4-7 CLEAR DAY INSOLATION FOR NOVEMBER

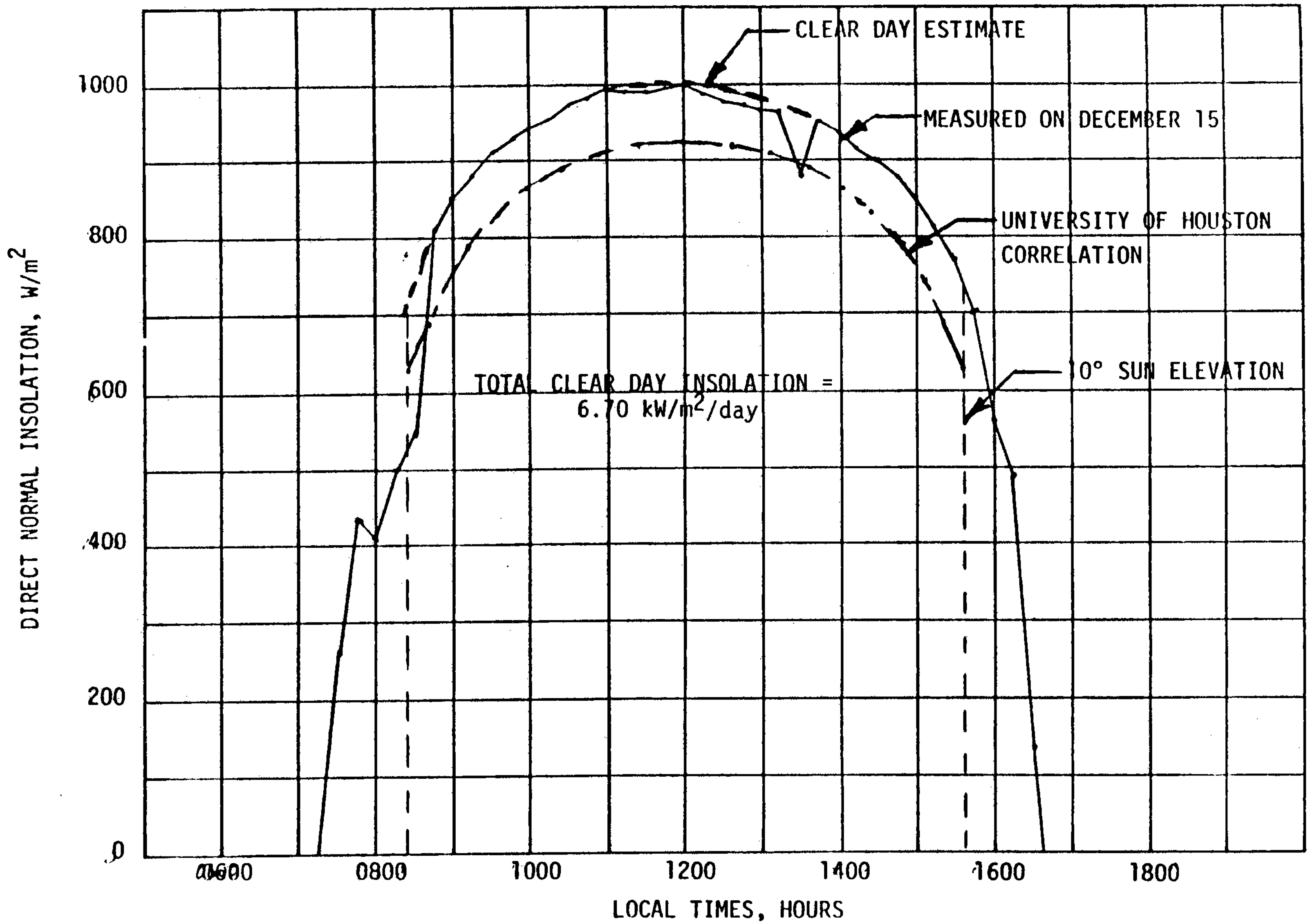

FIGURE 4-8 CLEAR DAY INSOLATION FOR DECEMBER

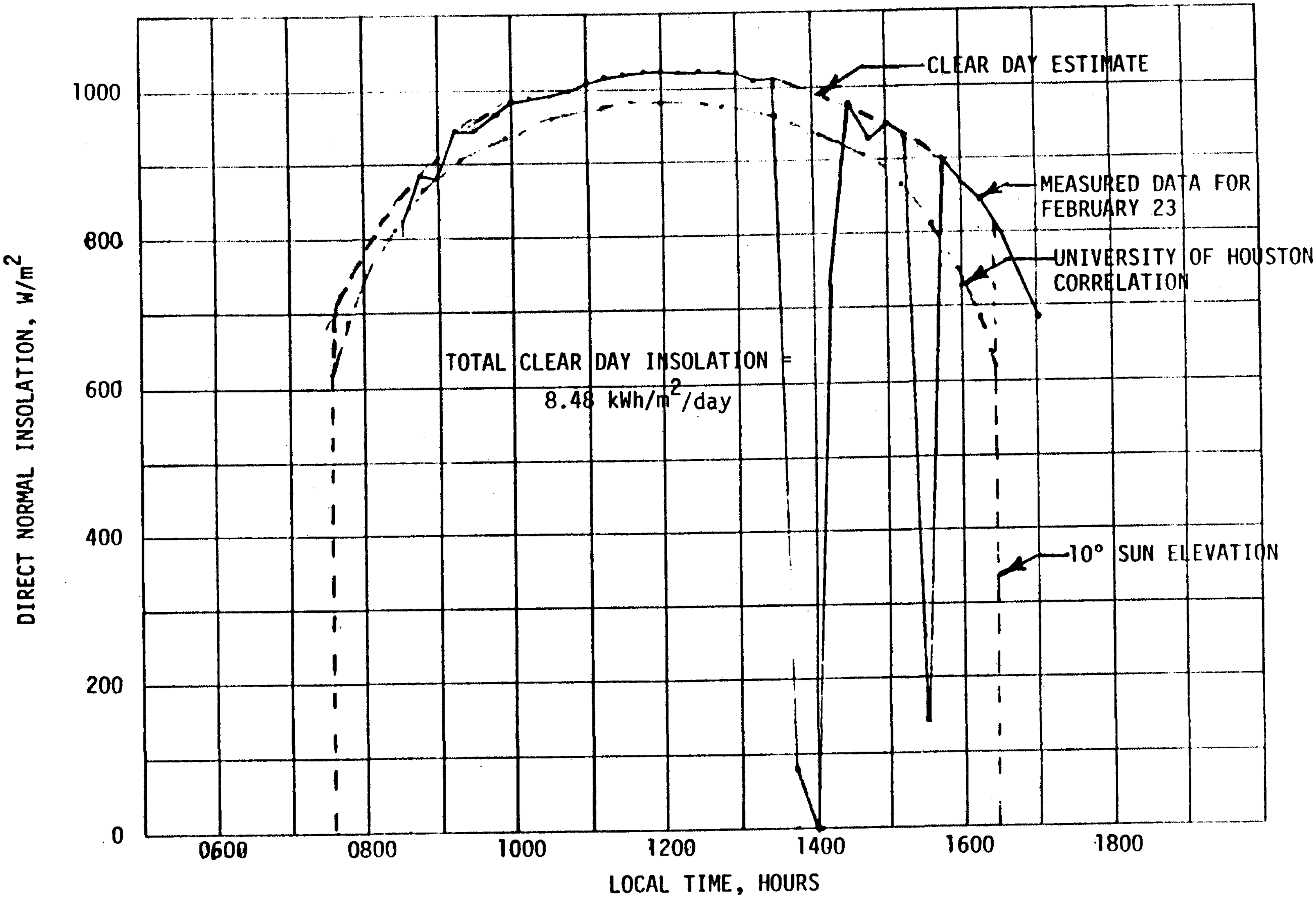

FIGURE 4-9 CLEAR DAY INSOLATION FOR FEBRUARY

The March clear day estimate is shown in Figure 4-10. 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 4-11. 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 4-12. The average Reno weather factor is 0.76.

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 4-12. The average weather factor is .783, and the insolation weighted average is 0.794.

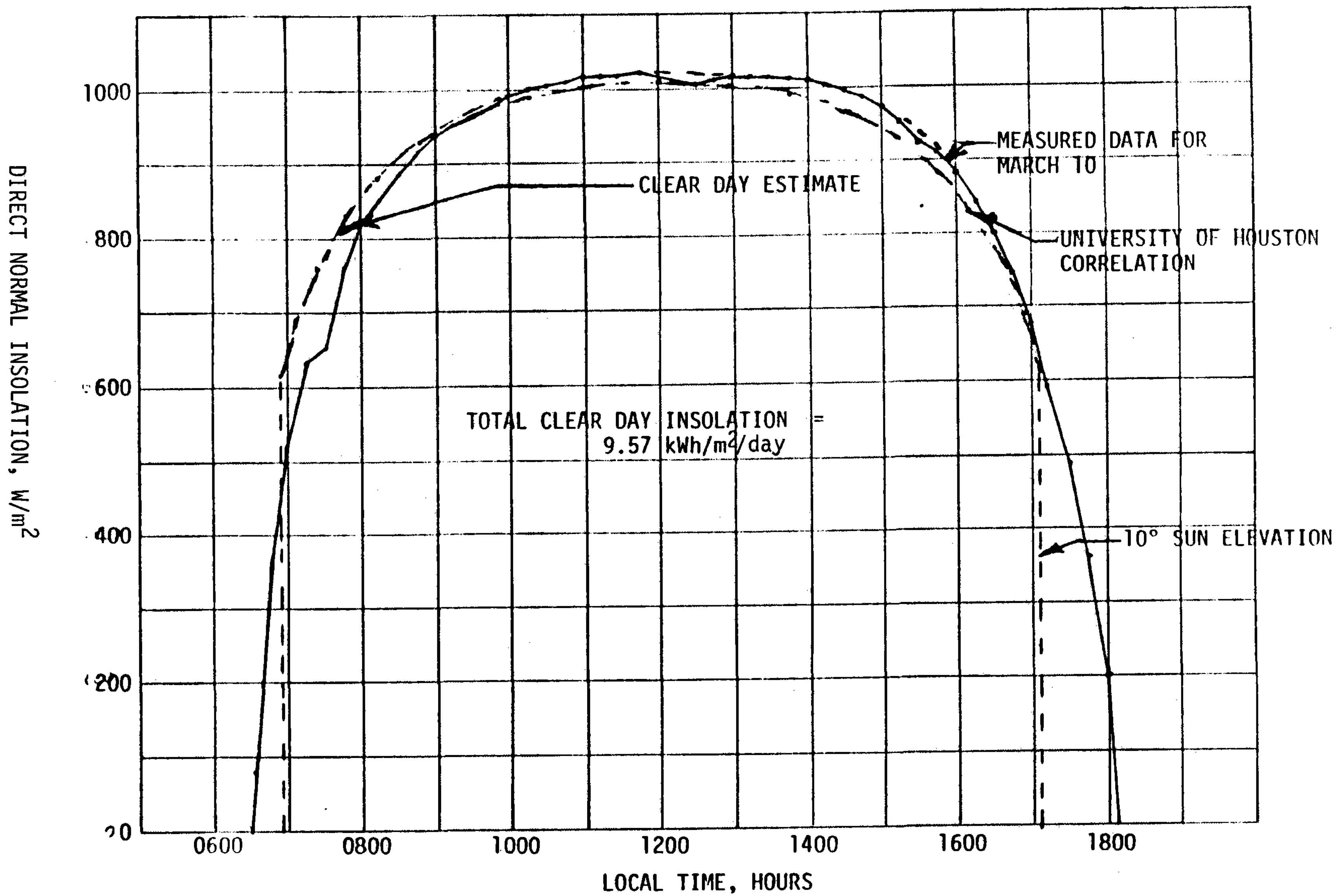

FIGURE 4-10 CLEAR DAY INSOLATION FOR MARCH

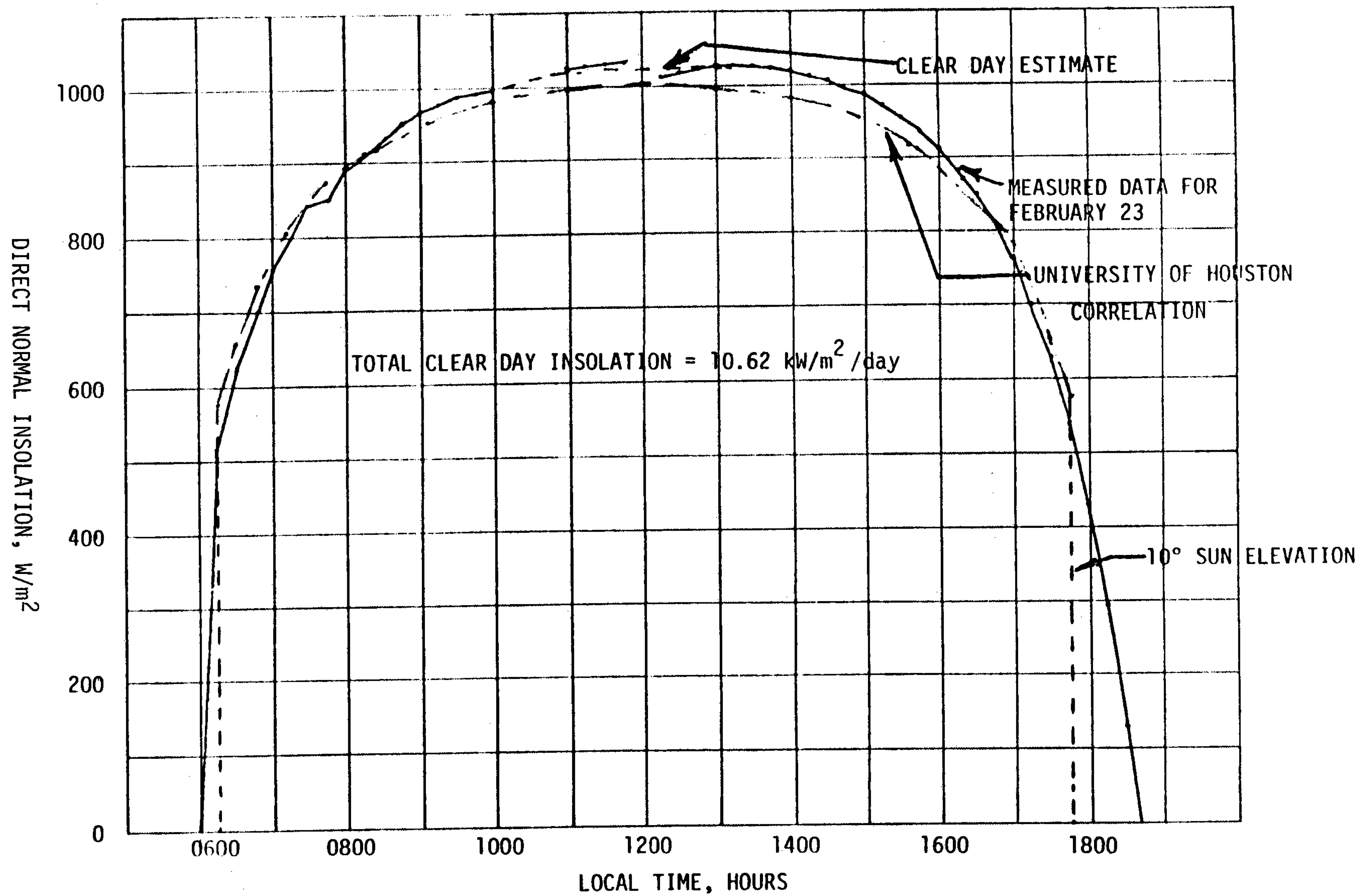

FIGURE 4-11 CLEAR DAY INSOLATION FOR APRIL

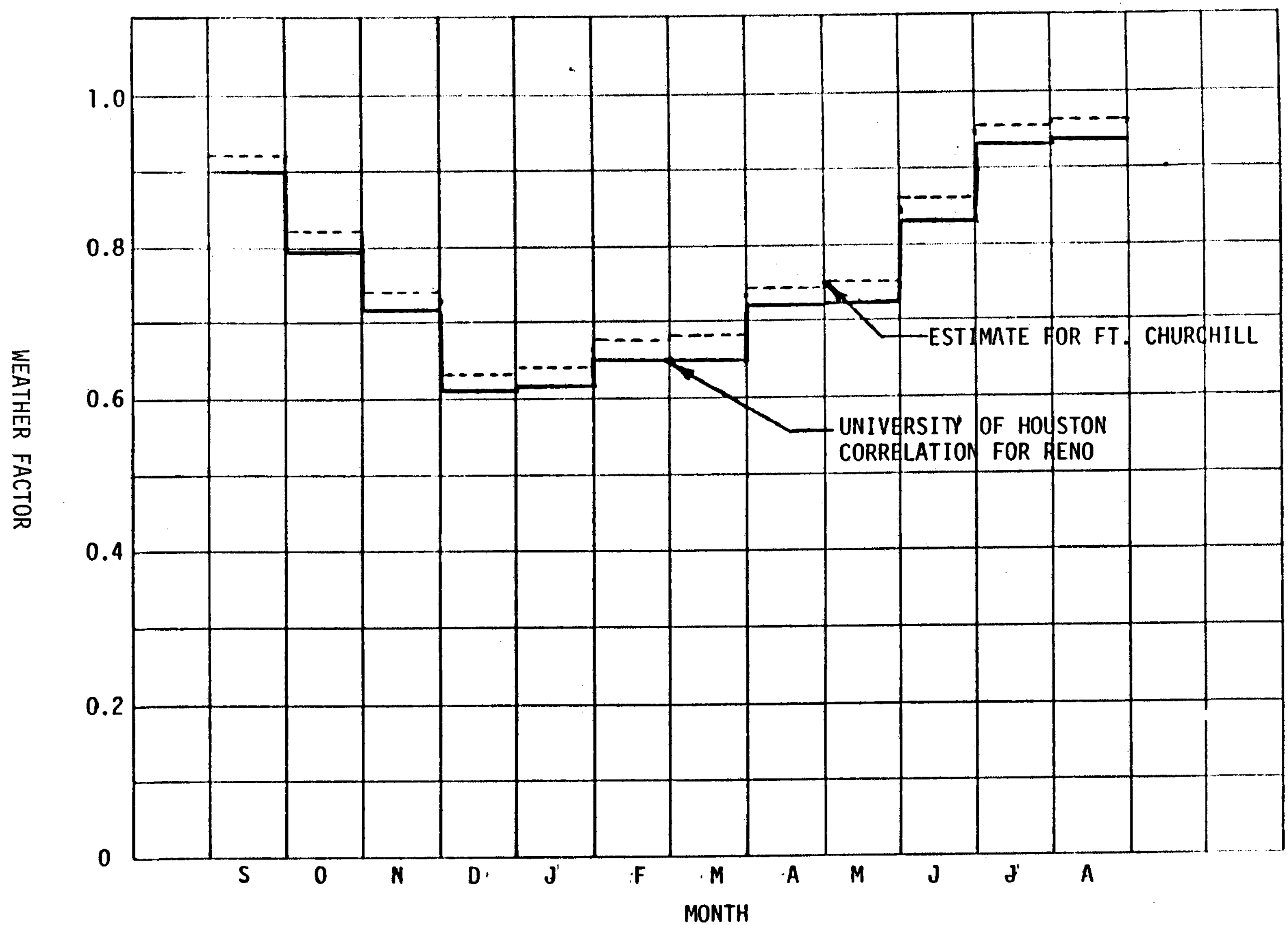

FIGURE 4-12 MONTHLY WEATHER FACTOR

4.5.3.3 Monthly and Annual Average Insolation

The clear day total direct normal insolation is plotted by month in Figure 4-13. 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 4-13.

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 (0.636).

(2) Multiply by heliostat area (56.8 m^2).

(3) Multiply by number of heliostats (2565).

(4) Multiply by days per year (365.25)

(5) Multiply by weighted parasitic factor (0.981*).

(6) Divide by boiler efficiency (0.848).

(7) Multiply by plant availability factor (0.958 including solar outage)

The result is an estimated 271 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 25,400 m^3 (159,300 bbl) per year. At 1000 Btu/ft^3, the displacement is the equivalent of 924 Mcf of natural gas.

*The weighted parasitic factor is comprised of about 66%, direct solar and 34% solar storage from Table 4-6. The resultant is divided by the fossil parasitic factor from Table 4-5 without the trace heating load.

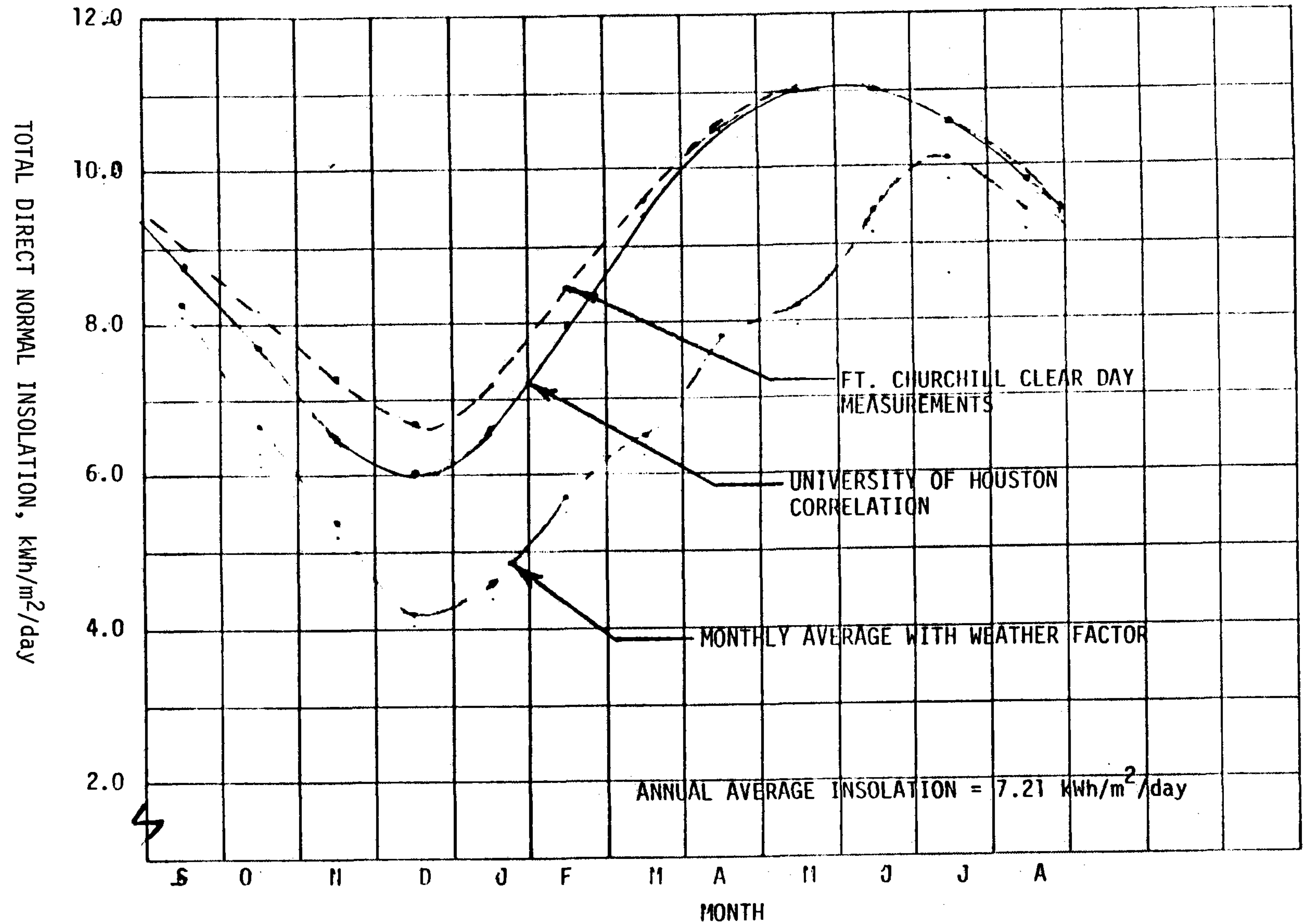

FIGURE 4-13 MONTHLY CLEAR DAY AND AVERAGE TOTAL INSOLATION

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 4-2) and the plot plan (Figure 4-6).

On the plot plan, Figure 4-6, 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 4-2 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 4-7. Detailed cost estimates are provided in the SRS, Section 5. The heliostat costs shown represent results of a detailed manufacturing study of the second generation heliostat design. The major uncertainty of heliostat costs is expected to be in the firm commitments to purchases available at the time of production.

TABLE 4-7

FT. CHURCHILL NO. 1 REPOWERING CAPITAL COST SUMMARY

CBS	DESCRIPTION	COST ESTIMATE (10^6 '82 DOLLARS)		3 MODULE SYSTEM COST MULTIPLIERS
5100	Design Cost	23.9		1.5
5200	Owner's Cost	3.3		3 x 2.1 + 1.2
5300	Construction Cost	70.6		---
5311	Site Improvements		1.5	2
5312	Buildings and Structures		0.3	2
5321	Collector System*		34.9	3
5322	Receiver System		9.9	3
5323	Horizontal Piping		5.9	4
5324	Plant Control System		1.9	1.5
5325	Heat Transfer Media		1.4	1154/278
5326	Energy Storage System		3.2	1154/278
5327	Heat Exchanger System		9.7	2
5350	Accessory Electrical		1.6	3
5360	Misc. Power Plant Equipment		0.4	1.5
5400	Startup and Testing Cost	1.6		3
	TOTAL	99.4		256.5

*Heliostats estimated at $198/m^2$

4.7 OPERATING AND MAINTENANCE COSTS AND CONSIDERATIONS

The operating and maintenance staff requirements for the new solar equipment are shown on Table 4-8.

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. Personnel already available onsite (especially operators and supervisory) are counted, only if additional personnel must be hired. Collector working is assumed to be a contracted service, as working requirements would not justify a specified crew.

TABLE 4-8 FIRST YEAR OPERATING AND MAINTENANCE STAFF

CATEGORY	ASSIGNMENT	STAFF LEVEL
SUPERVISORY	COLLECTOR MAINTENANCE AND REPAIR	1
ELECTRICAL TECHNICIAN	COLLECTOR MAINTENANCE	2
	COLLECTOR REPAIR	1
	OTHER SOLAR EQUIPMENT	1
MECHANICAL TECHNICIAN	COLLECTOR MAINTENANCE	1
	COLLECTOR REPAIR	0
	OTHER SOLAR EQUIPMENT	1
DRIVER	COLLECTOR WASHING	0*
OPERATOR	SOLAR MASTER CONTROL (1 PER SHIFT)	0+
TOTAL		7

*Assumes contracted service.

+Solar plant assumed to be operated by regular plant operators.

The operating and maintenance cost summary is shown in Table 4-9. 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 4-9 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 4-9

OPERATING AND MAINTENANCE COST SUMMARY

Cost Estimate	Annual Cost (10^3 1982 Dollars) First Year Labor	First Year Other	First Year Total	Average Year Labor	Average Year Other	Average Year Total
Collector System	176	208	384	101	137	238
Receiver System			87			87
Master Control			30			30
Energy Storage System			53			53
Heat Exchanger System			71			71
Site and Structures			49			49
Other			6			6
			680			534

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. A Failure Modes and Effects 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. The fossil heater provided to maintain salt temperature during periods of extended shutdown will be controlled to 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 heliostat cleaning will use a biodegradable, environmentally acceptable detergent.

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 the solar repowered plant with the one-third size field module 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 4-6, 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 contains the receiver tower and the collector field appear to be similar 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 (collector field will not be graded).

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 4-6.

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 4-6.

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 4-6, north of the switch yard on the west side of Units 1 and 2.

5.2.3 Garage and Service Building

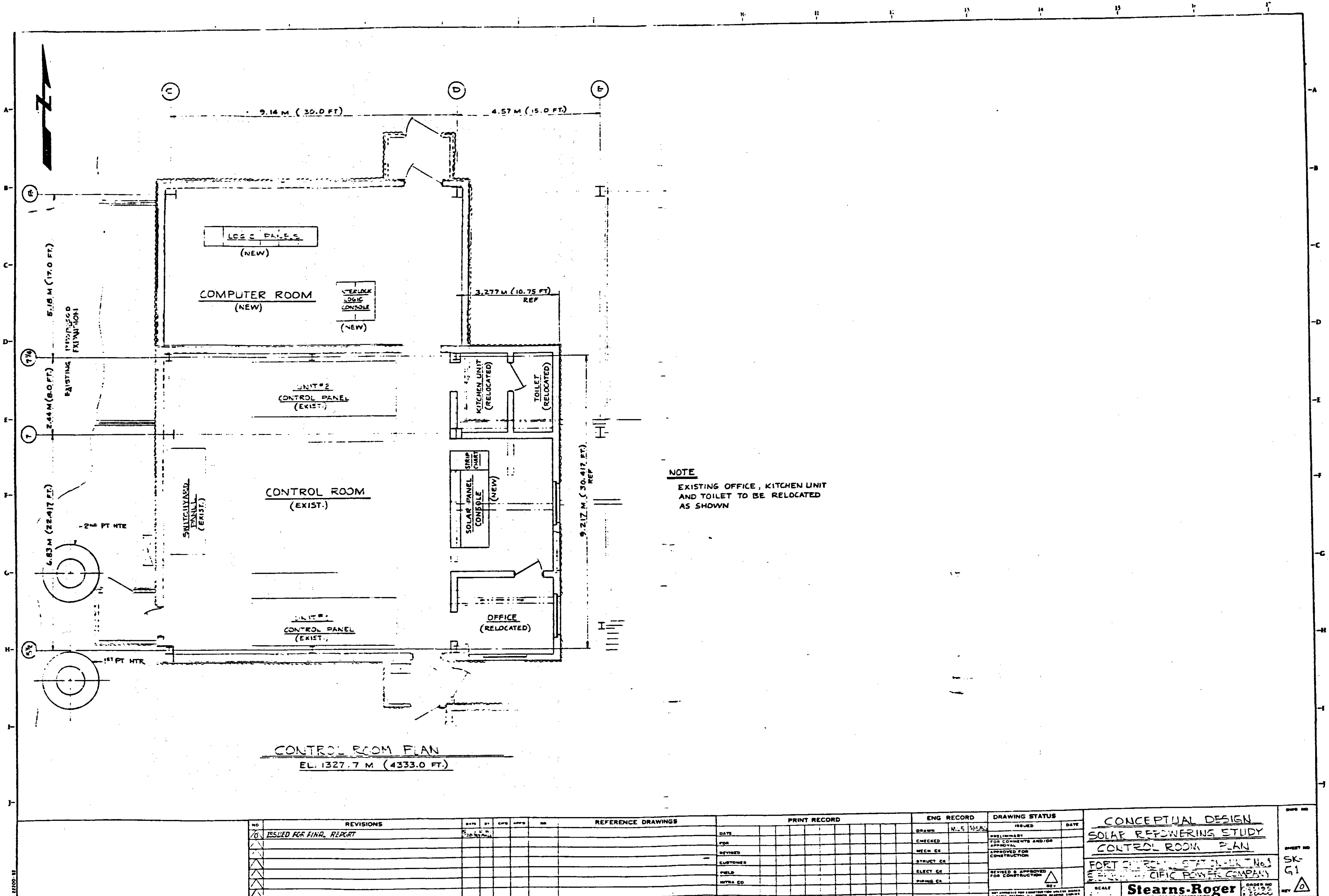
A garage and service building will be provided to support the mobile equipment used for the maintenance of the solar plant. This building will handle the service and parking of the two (2) washing trucks and additional mobile equipment that will be defined during the next phase of the program. This building 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 2565 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 4-6).

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 layout of the solar field is shown in 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
UNIT #2 CONTROL PANEL (EXIST.)
KITCHEN UNIT (RELOCATED)
TOILET (RELOCATED)
CONTROL ROOM (EXIST.)
SWITCHYARD PANEL (EXIST.)
STRIP CHART
SOLAR PANEL CONSOLE
(NEW)
9.217 M (30.417 FT.) REF
2ND PT HTR
1ST PT HTR
UNIT #1 CONTROL PANEL (EXIST.)
OFFICE (RELOCATED)
NOTE
EXISTING OFFICE, KITCHEN UNIT AND TOILET TO BE RELOCATED AS SHOWN
CONTROL ROOM PLAN
EL. 1327.7 M (4333.0 FT.)
REVISIONS
ISSUED FOR FINAL REPORT
REFERENCE DRAWINGS
PRINT RECORD
ENG RECORD
DRAWING STATUS
CONCEPTUAL DESIGN
SOLAR REPOWERING STUDY
CONTROL ROOM PLAN
FORT CHURCHILL STATION - UNIT No. 1
SIERRA PACIFIC POWER COMPANY
Stearns-Roger
SK-G1

5-5 Figure 5-1

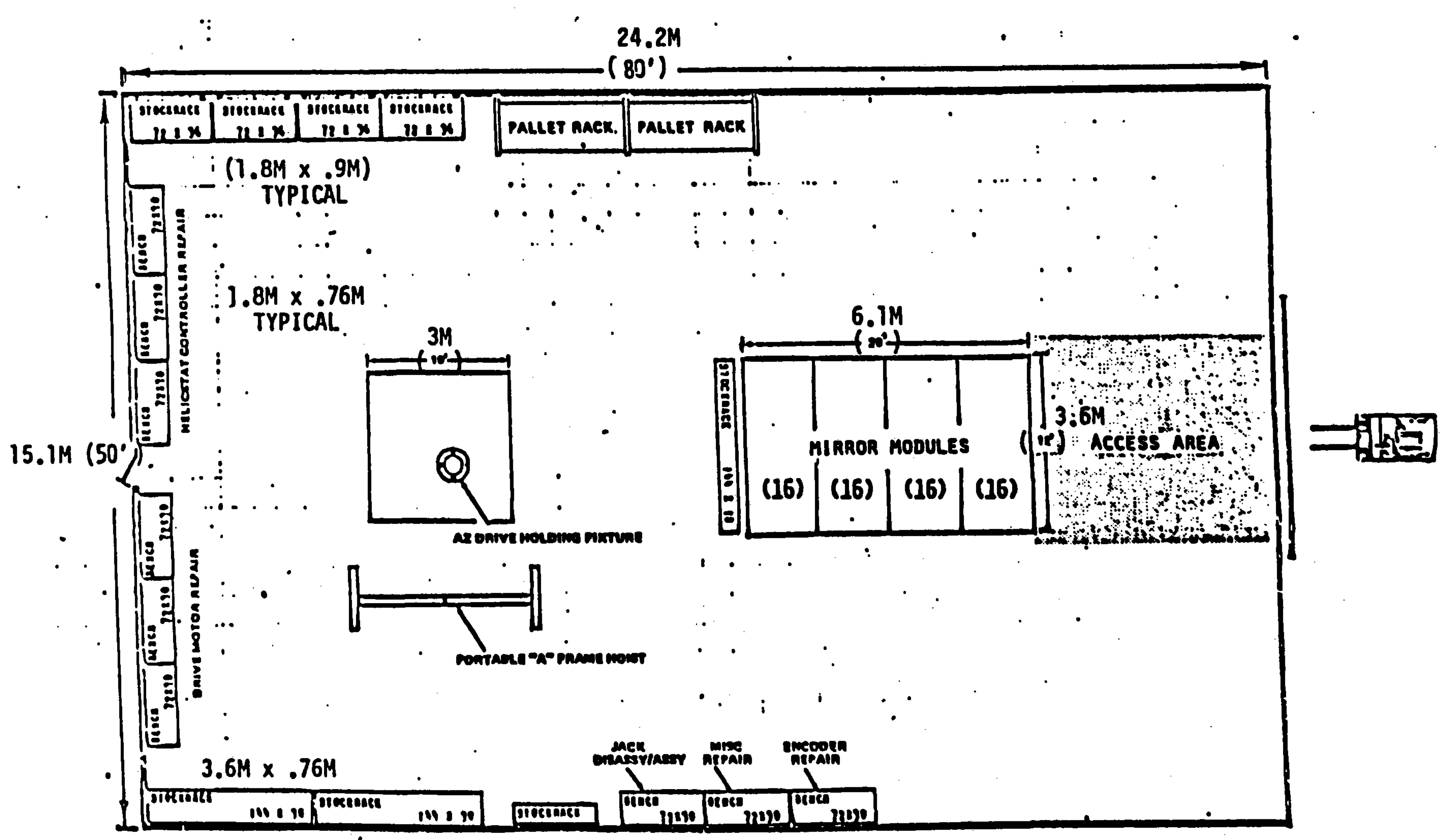


Figure 5-2 REPAIR AND STORAGE FACILITY

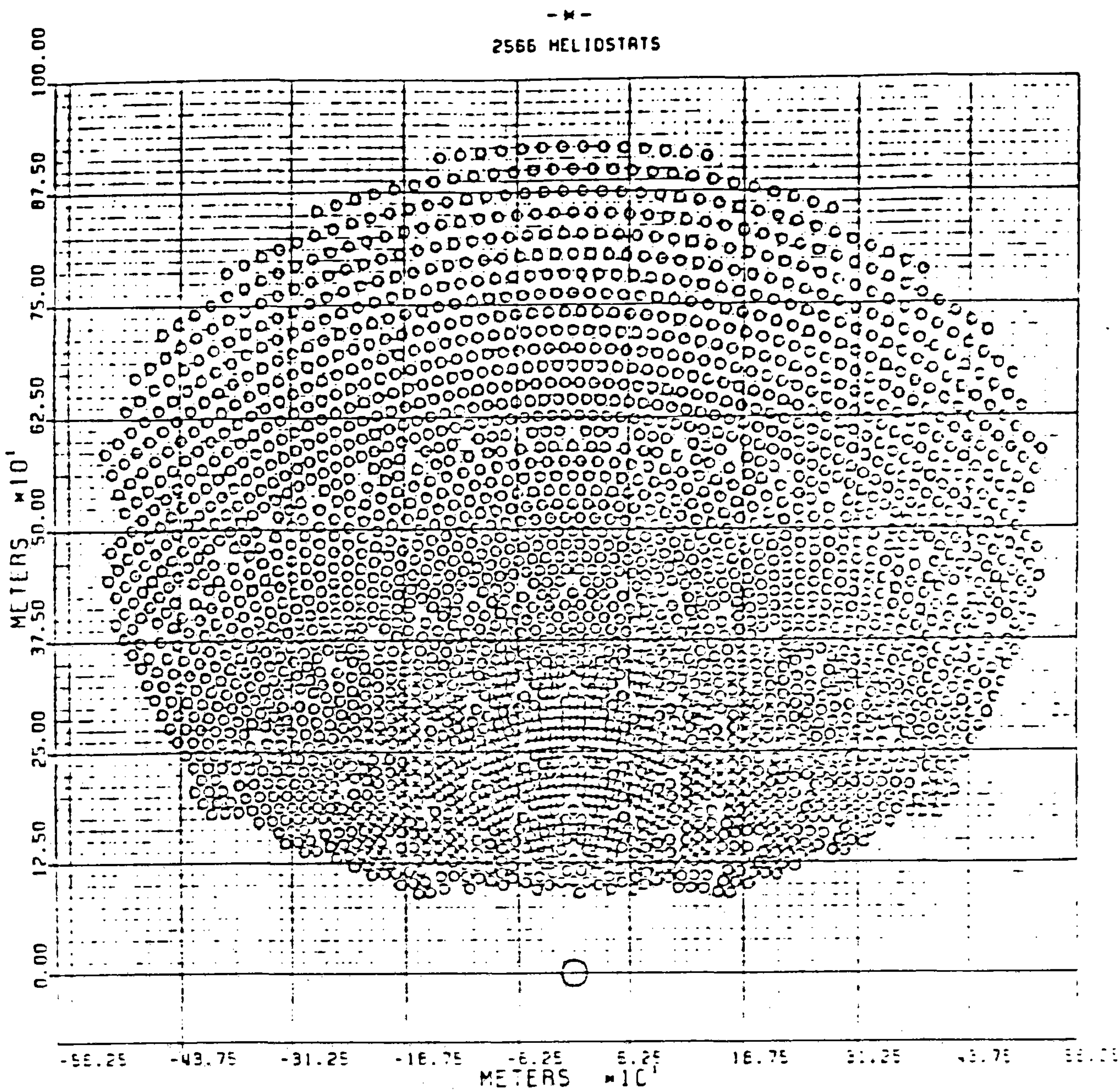


Figure 5-3 Collector Field Layout

5.3.2 Aim Strategy

The small one-third size field module is arranged as a single homogeneous field which uses a simplified aim strategy. All heliostats are aimed at the receiver aperture plane in a high/low, right/left pattern. The displacements are set so that each beam is tangent to the top or bottom and to the right or left side of the absorber surface.

5.3.3 Heliostats

The heliostat selected for this application is based on the MDAC Second Generation design. Each heliostat contains 56.85m^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 electrical requirements for these heliostats are estimated to be as follows:

	Power For Each Heliostat		Power For Total Field	
	Watts	Volt-Amp	KW	KVA
a) Tracking Mode				
Motors	2.0 W	3 VA		
Electronics	51.3 W	52 VA		
Total	53.3 Watts	55 VA	223 KW+	364 KVA+
b) Slew Mode (Emergency Defocus) - Sequential Program				
Motors	453.7 W	709 VA		
Electronics	51.3 W	52 VA		
Total	505.0 Watts	761 VA	416 KW++	595 KVA++
c) Stow Mode, Normal				
Motors	624.0 W	864 VA		
Electronics	51.3 W	52 VA		
Total	675.3 Watts	916 VA	131 KW++	186 KVA++
d) Stow Mode (Emergency, High Wind)				
Motors	422.0 W	659 VA		
Electronics	51.3 W	52 VA		
Total	473.3 W	711 VA	445 KW++	613 KVA++

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

\+ Includes HFC power.

++Sequential startup reduces total field load.

The basic configuration of the heliostat used in this study is shown on Figure 5-4. 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 nominal cost forecast for each production was used in this study. Collector field optimization used a cost of $\$220/m^2$. Economic evaluations are based on a heliostat cost of about $\$198/m^2$.

5.3.4 Collector Control

The collector control system is included in the collector cost. The operator of the collector control is discussed in Section 5.5.

5.3.5 Collector Field Performance

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

The results of the field performance prediction are shown on Figures 5-5 to 5-7 for a clear day at spring equinox, summer and winter solstice, in MW_t. Annual daily average performance is shown in Figure 5-8, in MW_t-Hr/Day.

The collector field performance data of Figures 5-5 to 5-8 were generated using the following data sources:

- Cosine Losses - University of Houston RCELL series.
- Reflectivity - Estimate for second generation heliostat 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 - Estimate based on Solar One 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 Reradiation - Multiple reflection analysis by MDAC program TRASYS using calculated surface temperatures.
- Receiver Convection - Estimate based on Abrams and Greif model for natural convection and cylinder data for forced convection.

REFLECTOR SHAPE	RECTANGULAR (8.66 M x 6.87 M)
MIRROR AREA	56.85 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	12°/MIN, ELEVATION, 15°/MIN AZIMUTH
DRIVE	AZIMUTH: HARMONIC DRIVE; ELEVATION: LINEAR ACTUATORS
CONTROL SIGNAL DISTRIBUTION	HARD WIRE

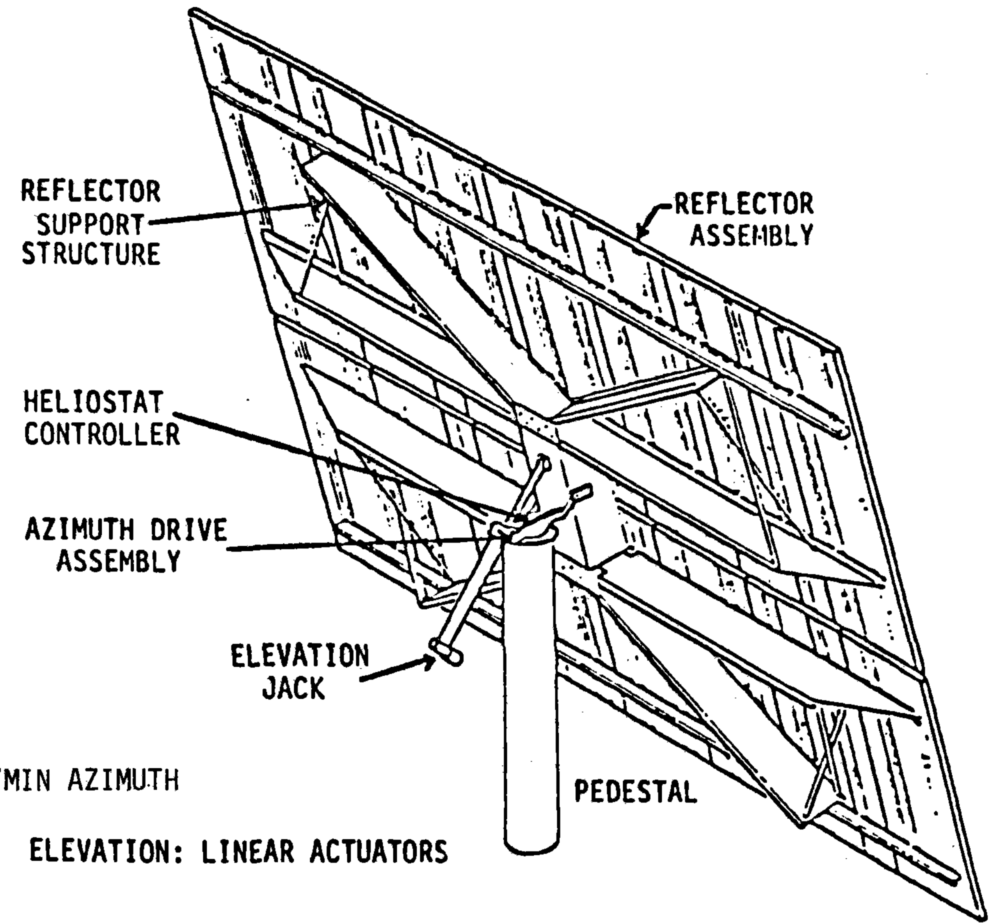


Figure 5-4 MDAC SECOND GENERATION HELIOSTAT

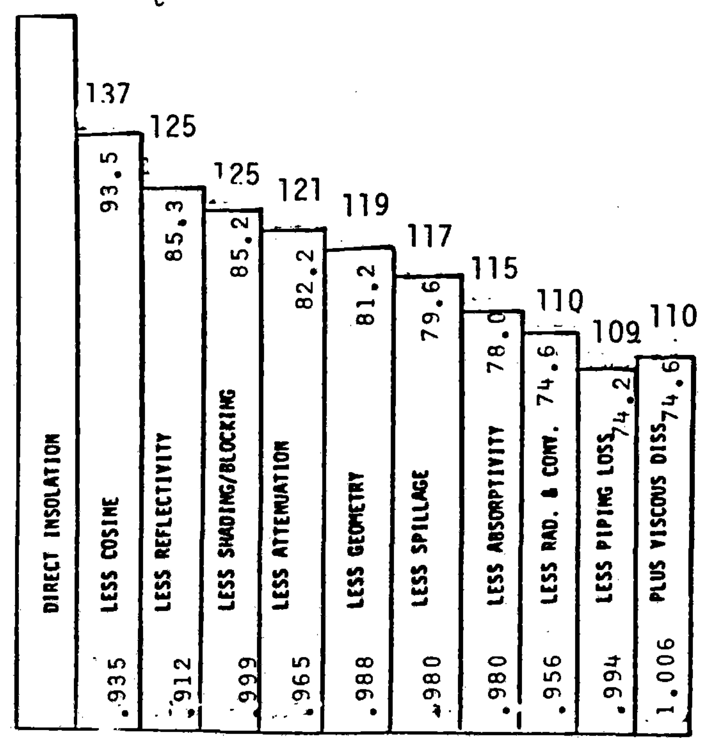


Fig. 5-5 Design Point--Spring Equinox

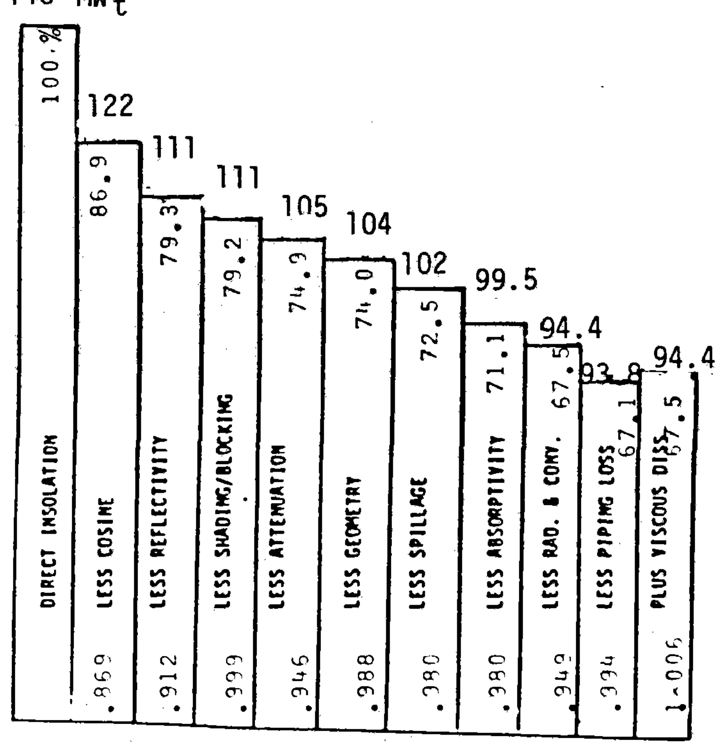


Fig. 5-6 Summer Solstice Noon Performance

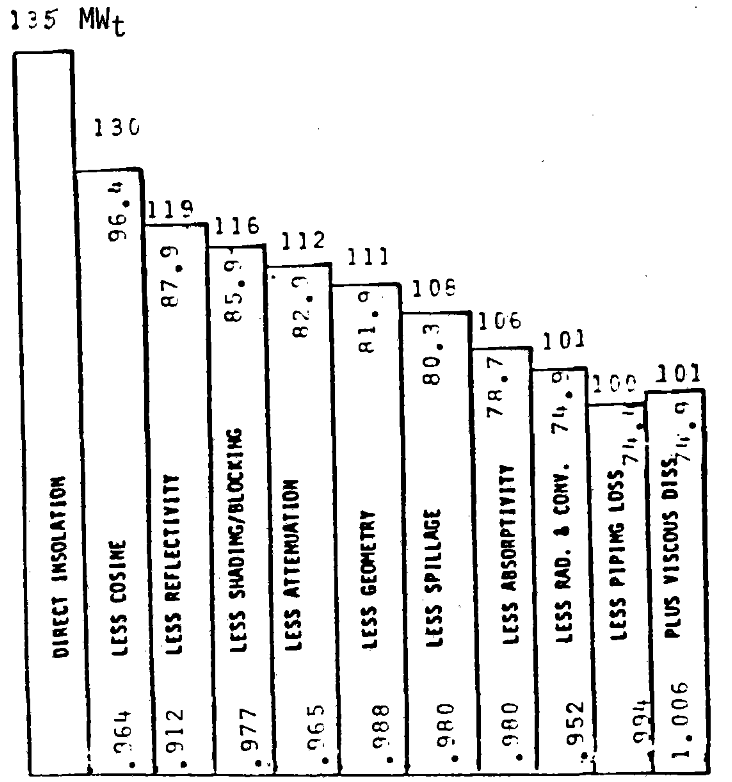


Fig. 5-7 Winter Solstice Noon Performance

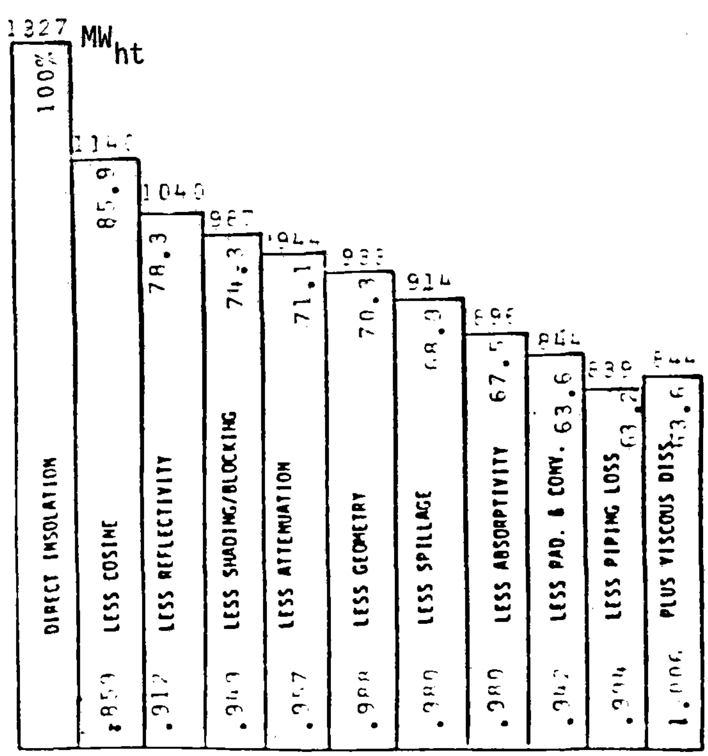


Fig. 5-8 Clear Day Annual Average

- 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 the receiver assembly, the receiver tower, and the fluid loop. These are described in the following section.

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 and ten (10) internal side panels as shown in Figure 5-9. The aperture plane is vertical and faces 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 110 MW_{th}.

The absorber portion of a receiver panel consists of 28.6mm (1.125 in.) O.D. Incoloy 800 tubes with 1.65mm (0.065 in.) minimum wall thickness. The tubes are parallel, in a vertical plane, and continuously welded to the adjacent tubes on 31.8mm (1.25 in.) centers by fins of 3.18mm (0.125 in.) width. The heated length of each panel is 16m (52.5 ft.). The number of tubes per panel varies from 54 to 66 as noted in Figure 5-9. The heated face of each panel is coated with a high temperature absorptive paint (Pyromark).

Panels are grouped in a seven (7) pass arrangement. Low and medium temperature passes 1 through 4 are positioned toward the front of the receiver, while high temperature passes 5 through 7 are positioned toward the rear of the receiver to minimize ambient heat losses. Outlet pass 7, with the highest salt temperature, was positioned in the central portion of the side wall with the lowest peak heat flux levels.

The arrangement of the receiver circuitry is schematically illustrated in Figure 5-10. The arrangement was designed for salt to flow up through each panel. The left and right valves 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. Two control valves are used to maintain the salt outlet temperature at 566°C (1050°F) by controlling the amount of salt flow through each half of the receiver.

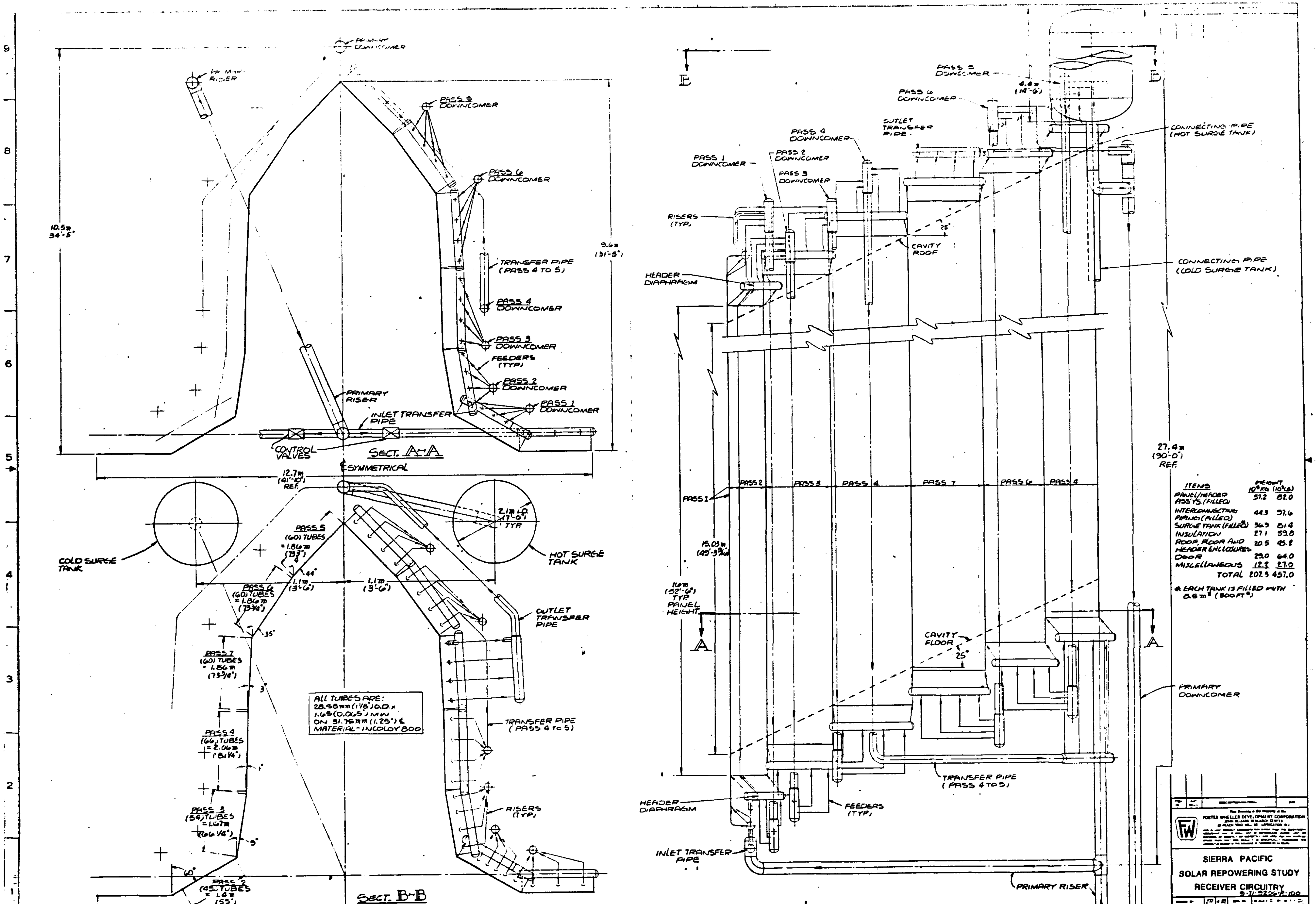


FIGURE 5-9 RECEIVER DESIGN

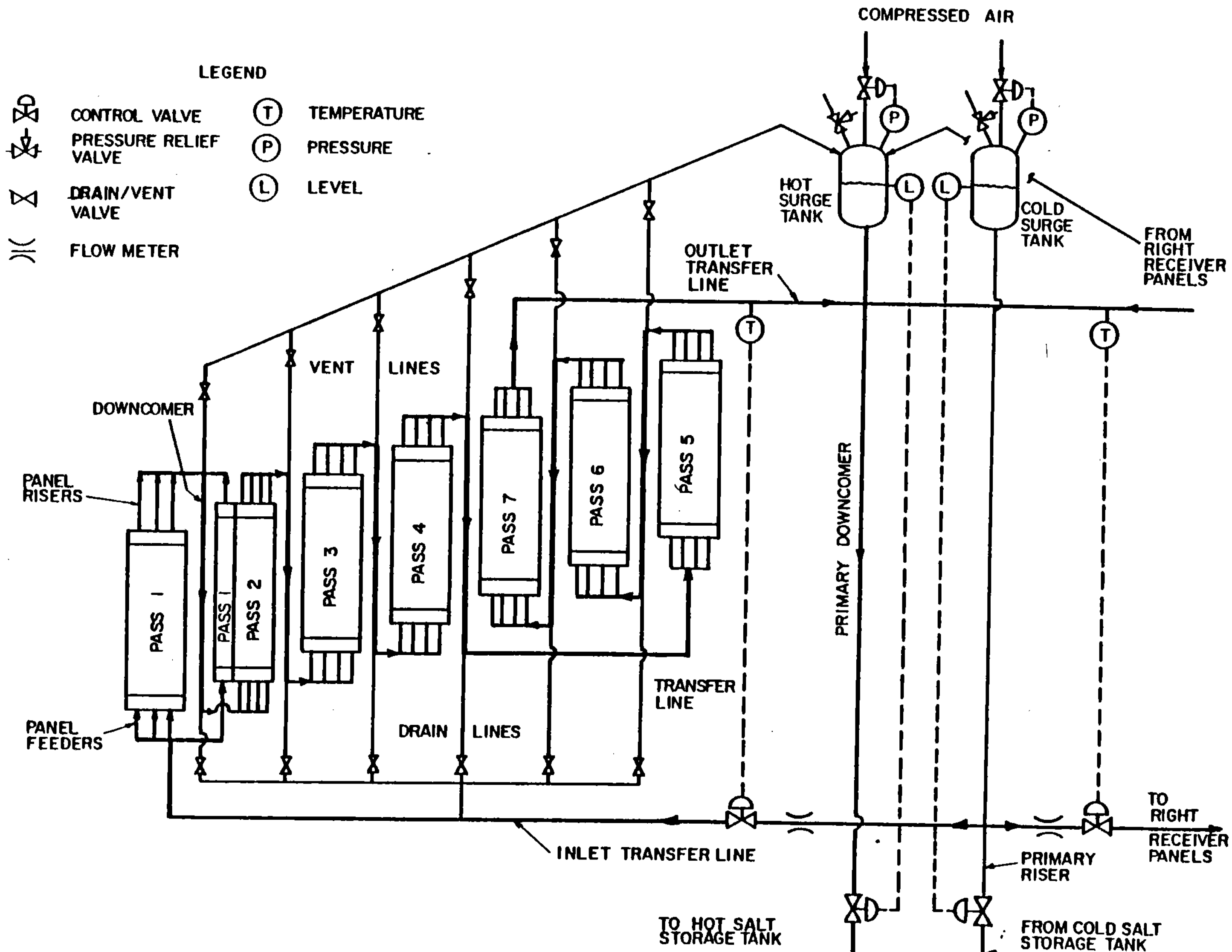


FIGURE 5-10 RECEIVER DESIGN CIRCUITRY

The receiver circuitry consists of seven (7) passes in series. This flow arrangement was selected to minimize the pressure drop through the receiver while keeping tube wall temperatures and front-to-back temperature differences within the design limits. For each half of the receiver, the number of tubes per pass varies from 75 to 45 dependent upon the heat flux levels and distributions on tube panels. Each half of the pass 1 consists of an external panel and a portion of the adjacent internal side panel. The remaining portion of this internal side panel forms the heating surface of pass 2. All other passes are separated panels. Flowing upward through each pass, the heated molten salt is collected at the upper header and transferred to the lower inlet header of the next pass via four risers, a downcomer and four feeders. Salt flow from pass 4 downcomer is connected by a transfer pipe to pass 5 which is located at the rear of the receiver. Salt is further heated successively in passes 5, 6, and 7 until it reaches its specified outlet temperature. Salt leaving pass 7 from both halves of the receiver is carried by two outlet transfer pipes to the primary downcomer.

Figures 5-9 and 5-10 also illustrate the relationship of surge tanks to the receiver circuitry. The cold surge tank at the inlet to the receiver isolates the receiver from the dynamics of the pump and primary riser. It also provides an emergency 1-minute of salt flow to protect the receiver in case of a feed pump or power failure. The hot surge tank at the outlet isolates the primary downcomer and drag valve from the receiver dynamics. The sizes and materials selected for the surge tanks are shown as follows:

ITEMS	I. D. m	(ft)	THICKNESS mm	(in.)	HEIGHT m	(ft)	MATERIAL
Cold Tank	2.1	(7)	13	(0.5)	4.4	(14.5)	C. S.
Hot Tank	2.1	(7)	10	(0.375)	4.4	(14.5)	304 SS

The piping layout was arranged so that the receiver system is completely drainable. The arrangement of all interconnecting salt piping is shown in Figure 5-9. The sizes and materials chosen for all piping and headers are shown in Table 5-1.

The cavity ceiling and floor are tilted downward 25 degrees from horizontal toward the aperture. The ceiling is formed by two staggered layers of ceramic fiberboard, 12.7 mm (0.5 in.) and 25.4 mm (1 in.) thick. The ceramic fiberboard is anchored to a 6.4 mm (0.25 in.) thick, reinforced carbon steel plate rigidly supported from the receiver support structure. The floor is formed by a layer of castable concrete atop two staggered layers of ceramic fiberboard, both of which are anchored to a carbon steel plate.

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:

TABLE 5-1 RECEIVER PIPING AND HEADERS

Items	Size mm	(in)	Schedule	Material
1. Primary Riser	305	(12)	20	C. S.
2. Inlet Transfer Pipe	203	(8)	20	C. S.
3. Feeders	102	(4)	40	C.S. (Passes 1 to 4) P-22 (Passes 5 & 6) 304 SS (Pass 7)
4. Risers	102	(4)	40	C.S. (Passes 1 to 3) P-22 (Passes 4 & 5) 304 SS (Passes 6 & 7)
5. Downcomers	203	(8)	20	C.S. (Passes 1 to 3) P-22 (Passes 4 & 5) 304 SS (Pass 6)
6. Transfer Pipe (Pass 4 to 5) →	203	(8)	20	P-22
7. Outlet Transfer Pipe	203	(8)	20	304 SS
8. Primary Downcomer	254	(10)	20	304 SS
9. Headers	203	(8)	40	Incoloy 800

- The receiver design point is equinox noon with 110 MW_t absorbed, heating 252 kg/s (2 x 10^6 lb/h) of molten salt from 288°C (550°F) to 566°C (1050°F).
- The absorbed heat flux distribution at the design point is shown in Figure 5-11 which was provided by MDAC. The flux distribution at this condition is symmetrical about the receiver center line. 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. The receiver heat flux for winter is shown in Figure 5-12.
- Flow sensitivity to heat flux variations across the panel width was checked for pass 1 which is subject to the most severe flux distribution. Total pressure drop (frictional and gravity heat) was computed for the coldest tube (41% of the average tube heat load), the hottest tube (164% of the average heat load), and the average tube as a function of flow multiplier. The flow multiplier is defined as a fraction of the average flow rate. Results are plotted in Figure 5-13. As noted in the figure, the coldest tube has approximately 2% less flow than the average tube. Consequently, salt flow through each pass is very insensitive to heat flux variations across the pass width and each tube within the same pass will have essentially the same salt flow rate.
- Design point frictional pressure drops through the receiver circuitry are as follows:

	Pressure Drop KPa	Pressure Drop (Psi)
Inlet Piping	9.7	(1.4)
Pass 1	68.9	(10.0)
Downcomer	17.2	(2.5)
Pass 2	157.9	(22.9)
Downcomer	17.2	(3.5)
Pass 3	112.4	(16.3)
Downcomer	17.2	(2.5)
Pass 4	77.9	(11.3)
Downcomer and Transfer Piping	24.1	(3.5)
Pass 5	90.3	(13.1)
Downcomer	17.2	(2.5)

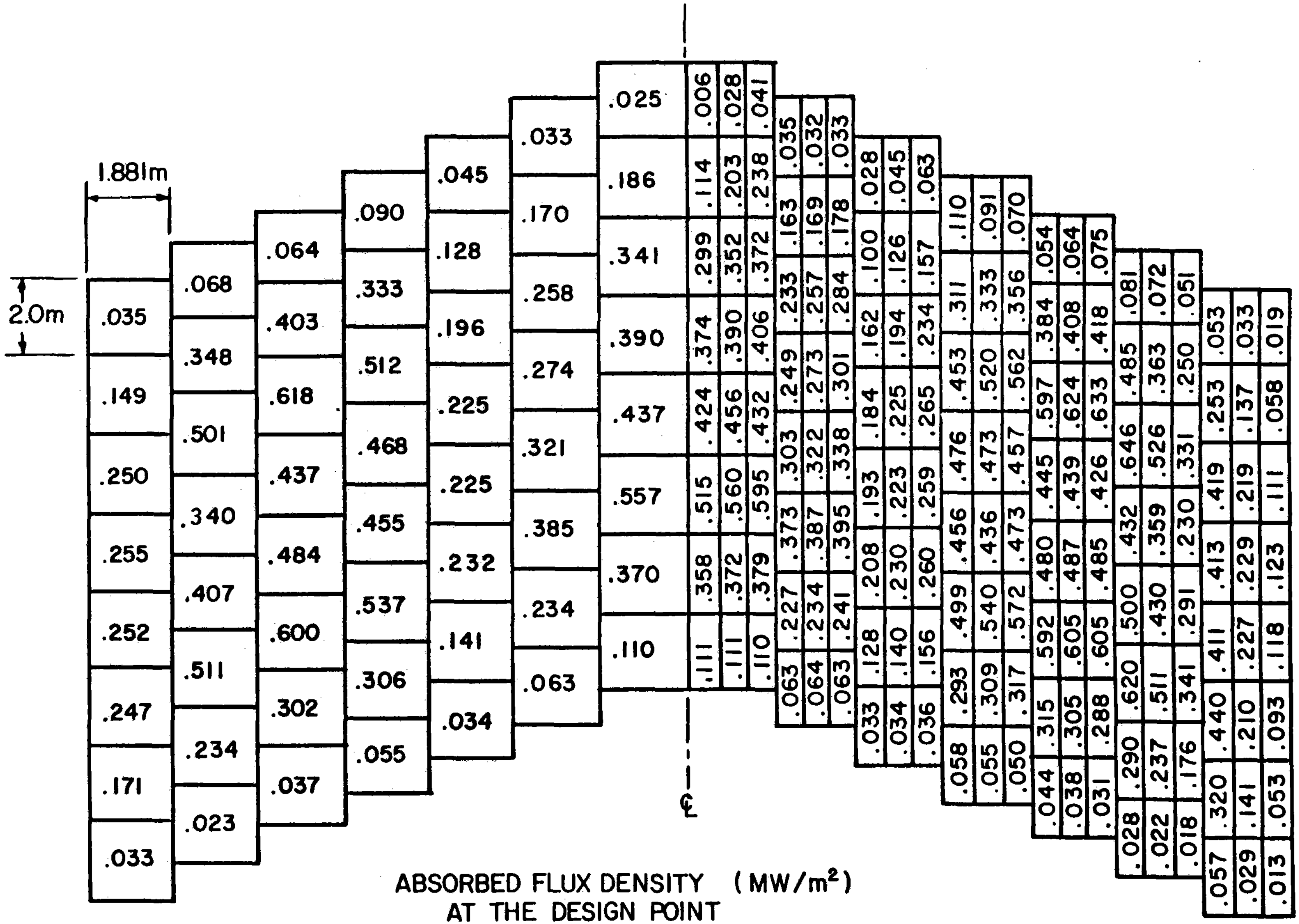


Figure 5-11 Receiver Absorbed Flux - Equinox

.011	.048	.086	.111	.116	.105	.064	.018
.026	.126	.192	.210	.213	.204	.126	.031
.051	.284	.397	.375	.379	.384	.231	.050
.017	.158	.319	.294	.249	.326	.240	.053
.020	.210	.450	.389	.329	.467	.329	.066
.026	.258	.550	.456	.395	.577	.390	.075
.028	.259	.545	.447	.394	.572	.380	.069
.035	.277	.554	.454	.410	.572	.374	.063
.041	.290	.549	.451	.419	.553	.354	.059
.047	.294	.533	.445	.428	.523	.329	.062
.052	.289	.506	.438	.439	.484	.305	.077
.055	.275	.469	.426	.438	.436	.282	.090
.033	.146	.245	.238	.243	.218	.141	.051
.033	.132	.217	.208	.207	.182	.113	.036
.031	.120	.196	.181	.172	.152	.091	.023
.060	.227	.372	.320	.286	.268	.163	.029
.061	.220	.361	.304	.260	.241	.153	.028
.060	.213	.347	.286	.238	.218	.145	.028
.105	.356	.556	.458	.386	.348	.213	.035
.106	.350	.524	.433	.372	.328	.182	.024
.106	.337	.485	.405	.355	.304	.148	.014
.106	.337	.485	.405	.355	.304	.148	.014
.106	.350	.524	.433	.372	.328	.182	.024
.105	.356	.556	.458	.386	.348	.213	.035
.060	.213	.347	.286	.238	.218	.145	.028
.061	.228	.361	.304	.260	.241	.153	.028
.060	.227	.372	.320	.286	.267	.162	.029
.031	.120	.196	.181	.172	.151	.091	.023
.033	.132	.217	.208	.207	.182	.113	.036
.033	.146	.245	.238	.243	.218	.141	.051
.055	.275	.469	.426	.438	.436	.282	.090
.052	.289	.506	.438	.439	.484	.305	.077
.047	.294	.533	.445	.428	.523	.329	.062
.041	.290	.549	.451	.419	.553	.354	.059
.035	.277	.554	.454	.410	.572	.374	.063
.028	.259	.545	.447	.394	.572	.380	.069
.026	.258	.550	.456	.395	.557	.390	.075
.020	.210	.450	.389	.329	.467	.329	.066
.017	.158	.319	.294	.249	.326	.240	.052
.051	.284	.397	.375	.379	.384	.187	.050
.026	.126	.192	.210	.213	.204	.126	.031
.011	.048	.086	.111	.116	.105	.064	.018

Flux Density (MW/m^2) at Winter, Noon

Figure 5-12 Receiver Flux - Winter

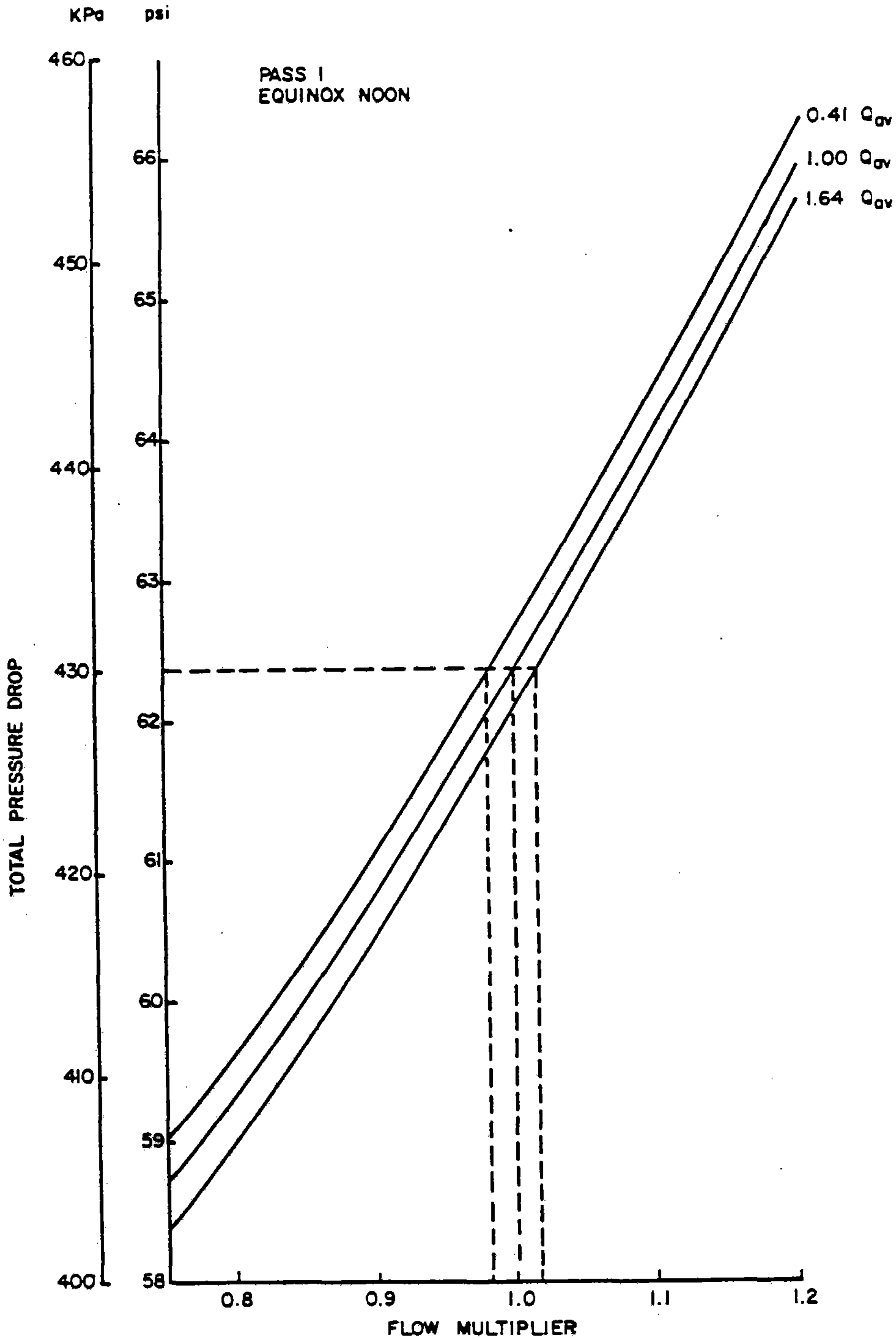


FIGURE 5-13 RECEIVER TUBE FLOW VARIATION WITH HEAT LOAD

	Pressure Drop KPa	(Psi)
Pass 6	89.6	(13.0)
Downcomer	17.2	(2.5)
Pass 7	89.6	(13.0)
Outlet piping	9.0	(1.3)
Total	815.4	(118.3)

As explained in the previous section, the number of tubes for each pass varies from 45 to 75 dependent upon the flux density level on the panel. Since the flux density in pass 1 (containing 75 tubes) is low (refer to Figure 5.12), a low mass velocity can be tolerated and consequently, the pressure drop through pass 1 is the lowest among seven passes. On the other hand, the flux density in pass 2 (containing 45 tubes) is very high, and a high mass velocity must be kept in this pass to keep the tube temperatures within design limits. Consequently, the pressure drop through Pass 2 is the highest among the seven passes

- A computer program was prepared to analyze individual receiver tubes. The heated portion [16 m (52.5 ft.)] of the receiver tube was broken down into eight (8) equal nodes, each of which was 2 m (6.56 ft.) long. The Dittus Boelter correlation was used to determine the salt film coefficient. For each receiver pass, the tube absorbing average heat flux and the tube absorbing the maximum heat flux were analyzed at the design point condition. The results of temperature profiles of the salt and tube wall along the length of the receiver are shown in Figures 5-14 through 5-17.

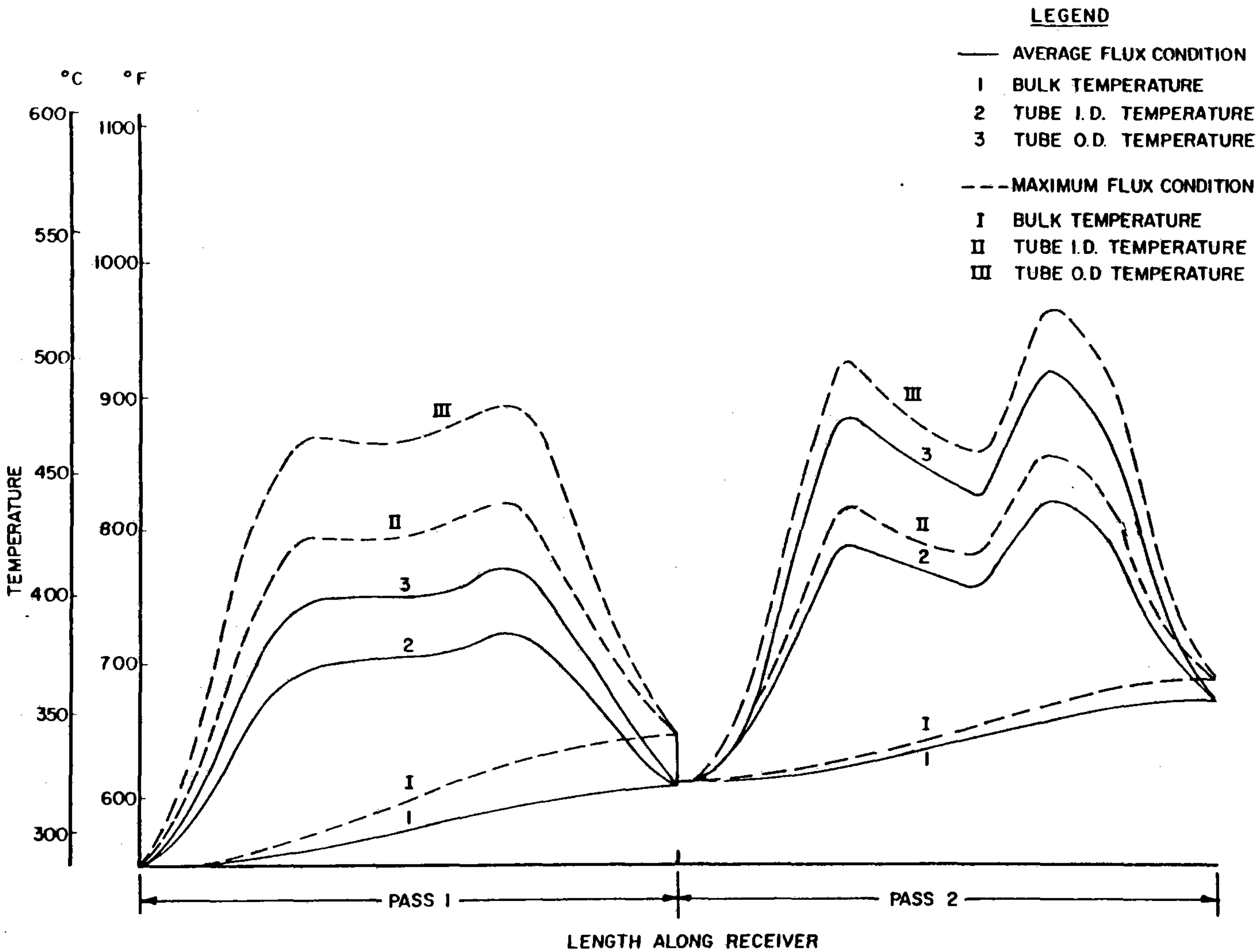


FIGURE 5-14 RECEIVER TEMPERATURES, PASS 1 AND PASS 2

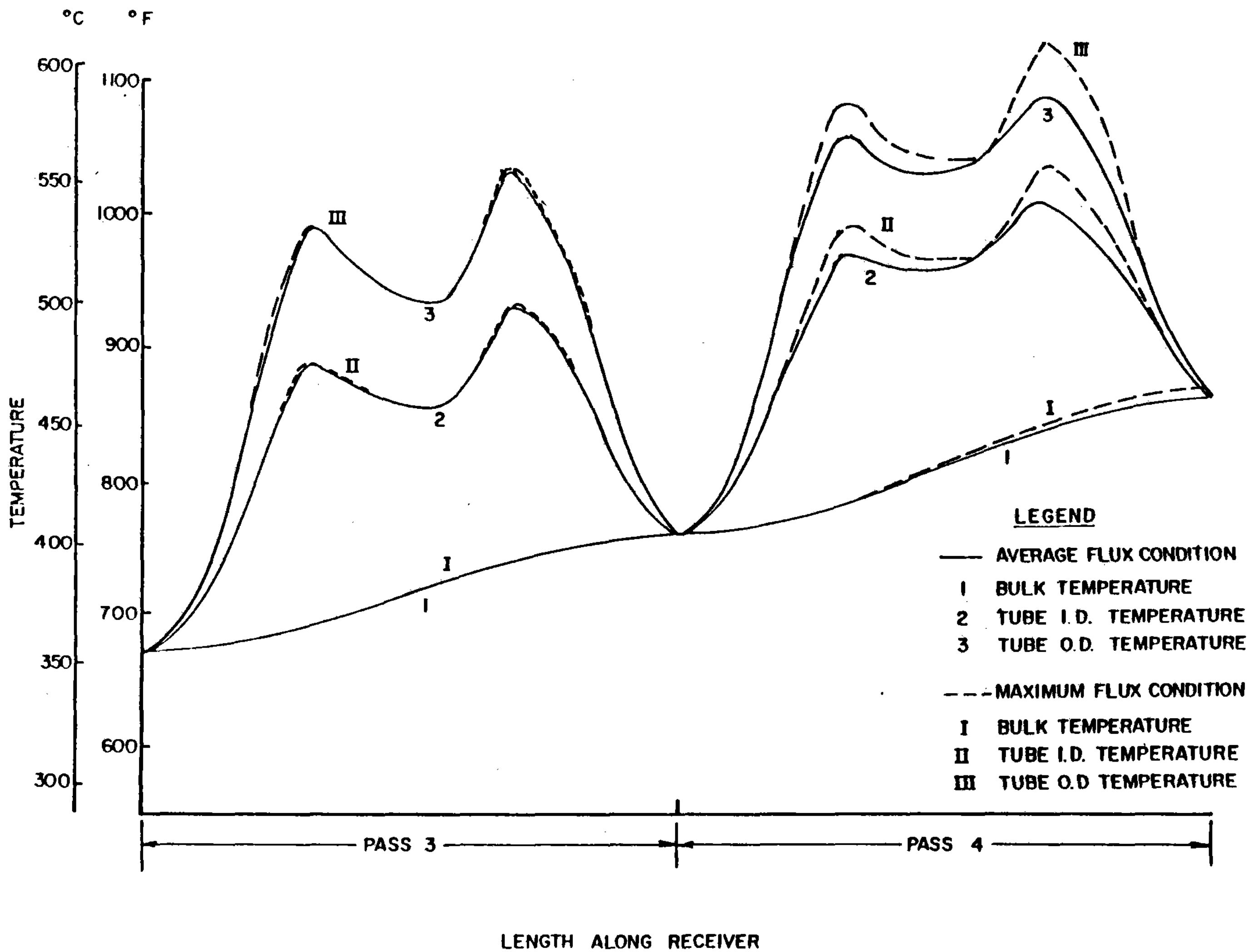


FIGURE 5-15 RECEIVER TEMPERATURES, PASS 3 AND PASS 4

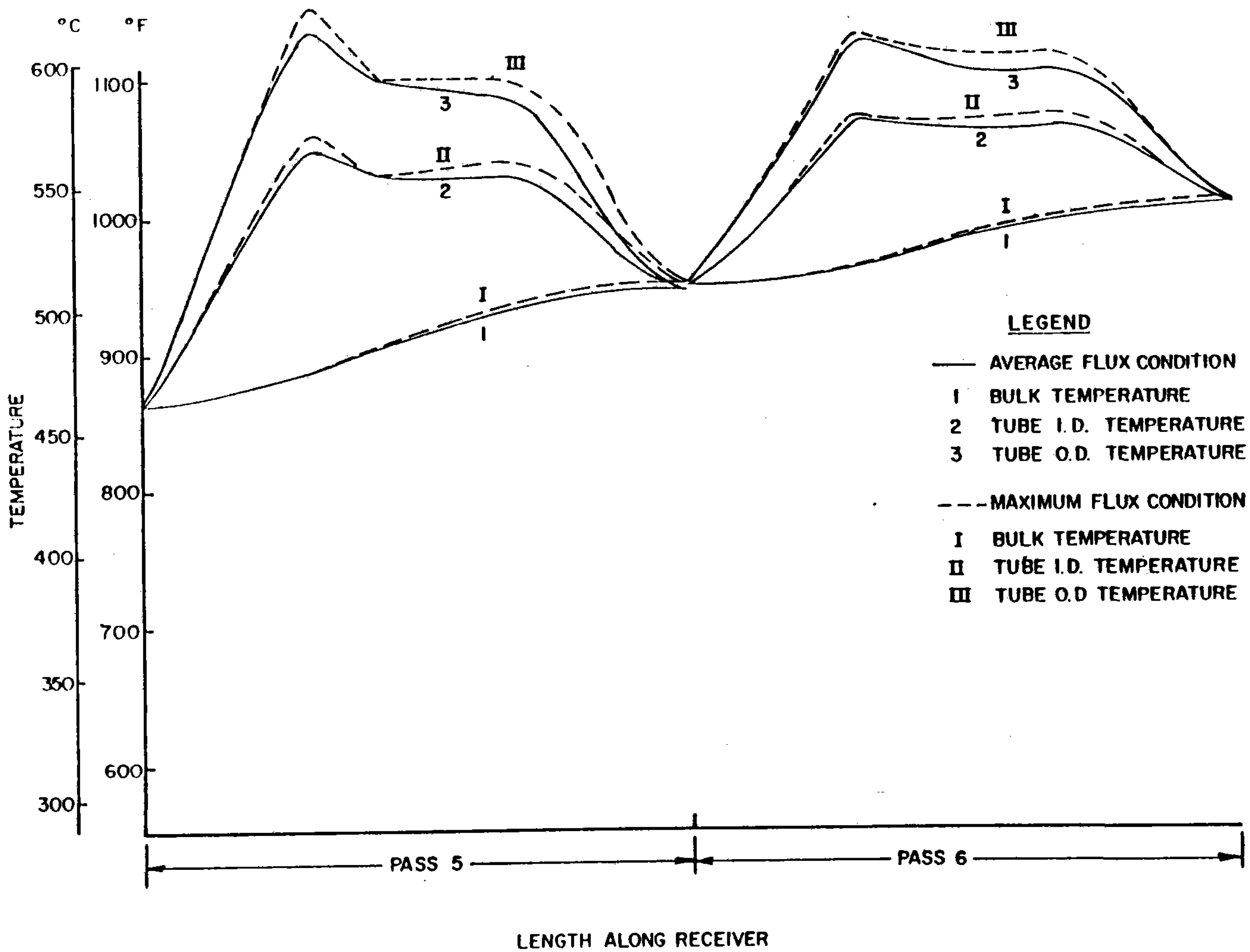


FIGURE 5-16 RECEIVER TEMPERATURES, PASS 5 AND PASS 6

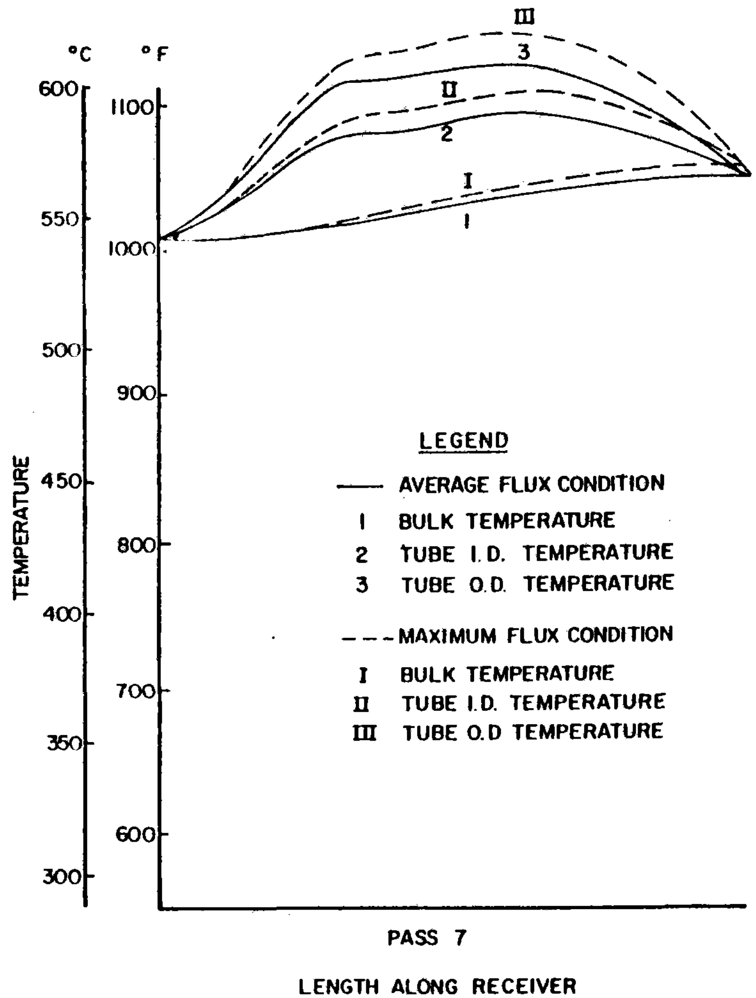
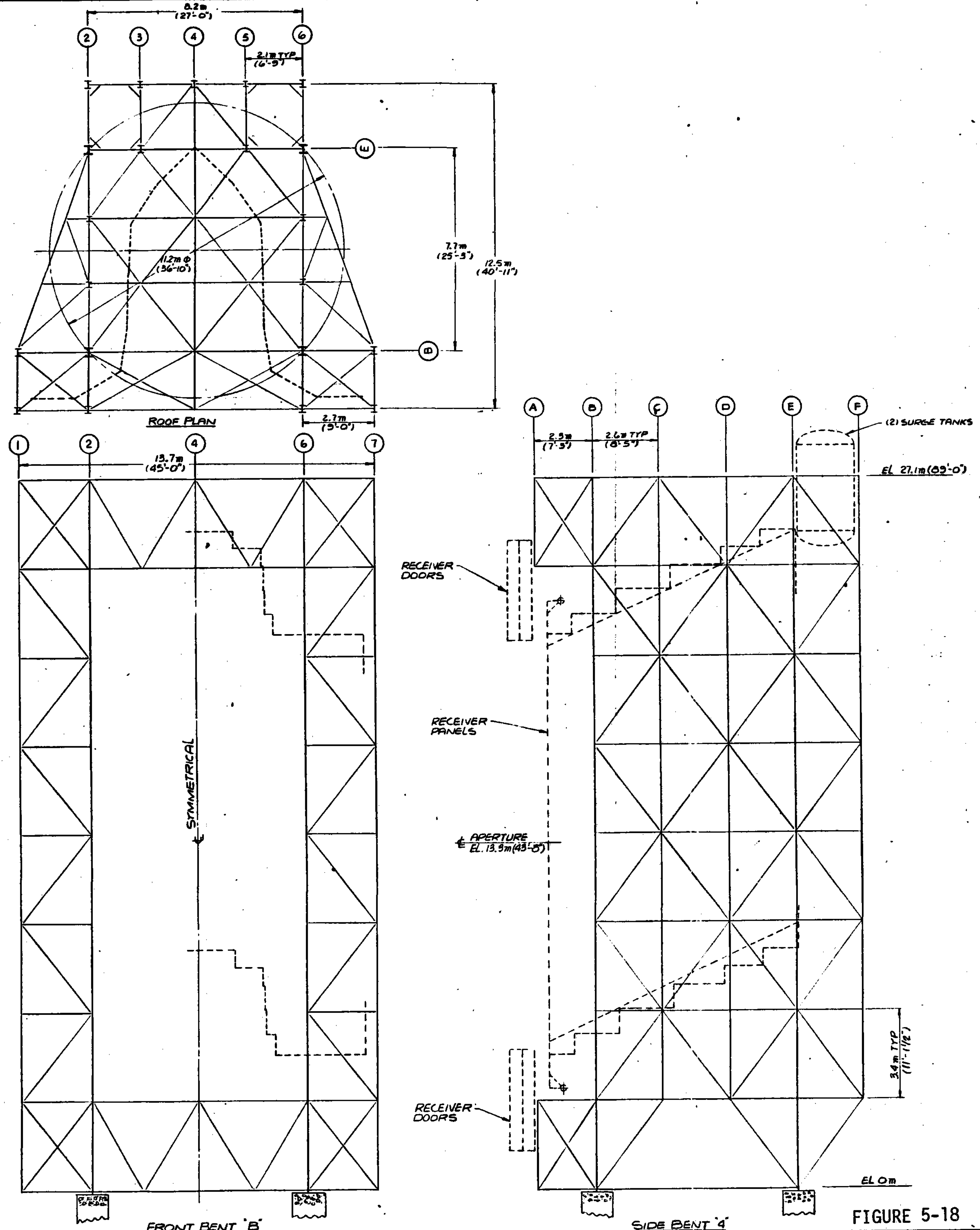


FIGURE 5-17 RECEIVER TEMPERATURE, PASS 7



ITEM	WEIGHT 10^3 KG	(10^3 LB)
COLUMNS	29.0	64
ROOF STEEL	7.3	16
BEAMS	69.9	154
BRACING	36.3	80
CONNECTIONS	15.4	34
PLATFORM&LADDERS	11.8	26
TOTAL	169.7	374

FIGURE 5-18 RECEIVER SUPPORT STRUCTURE

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
SOLAR REPOWERING STUDY
RECEIVER STRUCTURE
9-71-9206-R-100

DRAWN BY ER 4/82 DWG NO SCALE 3/16" = 1'-0"

RD-820-23

5.4.1.3.1 Support Structure Design

Figure 5-18 illustrates the structure required to support the 207,900 kg (457,000 lb) receiver. The structure was sized for a 0.32 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 horizontal 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 (E) 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 2 and 6.

The receiver gravity loads are taken to the roof via hangers and then transmitted to the base of the structure via bents 2, 6, B, and E. 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 6m (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.

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 5-18. Approximately 169,700 kg (374,000 lb) of structural steel is required to make the structure sufficiently stiff to sustain a 0.32 g seismic load.

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, 28.6 mm (1.125 in.) O.D. with 1.65 mm (0.065 in.) minimum wall thickness continuously welded on 31.8 mm (1.25 in.) centers. The number of tubes per panel varies from 54 to 66. Each panel is 16m (52.5 ft) long.
- Inlet and Outlet Headers - Incoloy 800, 0.203m (8 in.), schedule 40 each with four (4) 0.102m (4 in.) nozzle connections for feeders/risers.
- Unheated Inlet and Outlet Tubes ("Jumper Tubes") - Incoloy 800, 28.6mm (1.125 in.) O.D. with 1.65mm (0.065 in.) minimum wall thickness used to connected panel tubes to header.
- Support Lugs
- Buckstays

A typical panel is illustrated in Figure 5-19. 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 depend on the erection schedule requirements. Removable 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 arrangment is illustrated in Figure 5-19. A typical receiver panel is shown to illustrate the concept.

Support lugs are welded between every fifth panel tube and vertically spaced 1.25m (4.08 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.

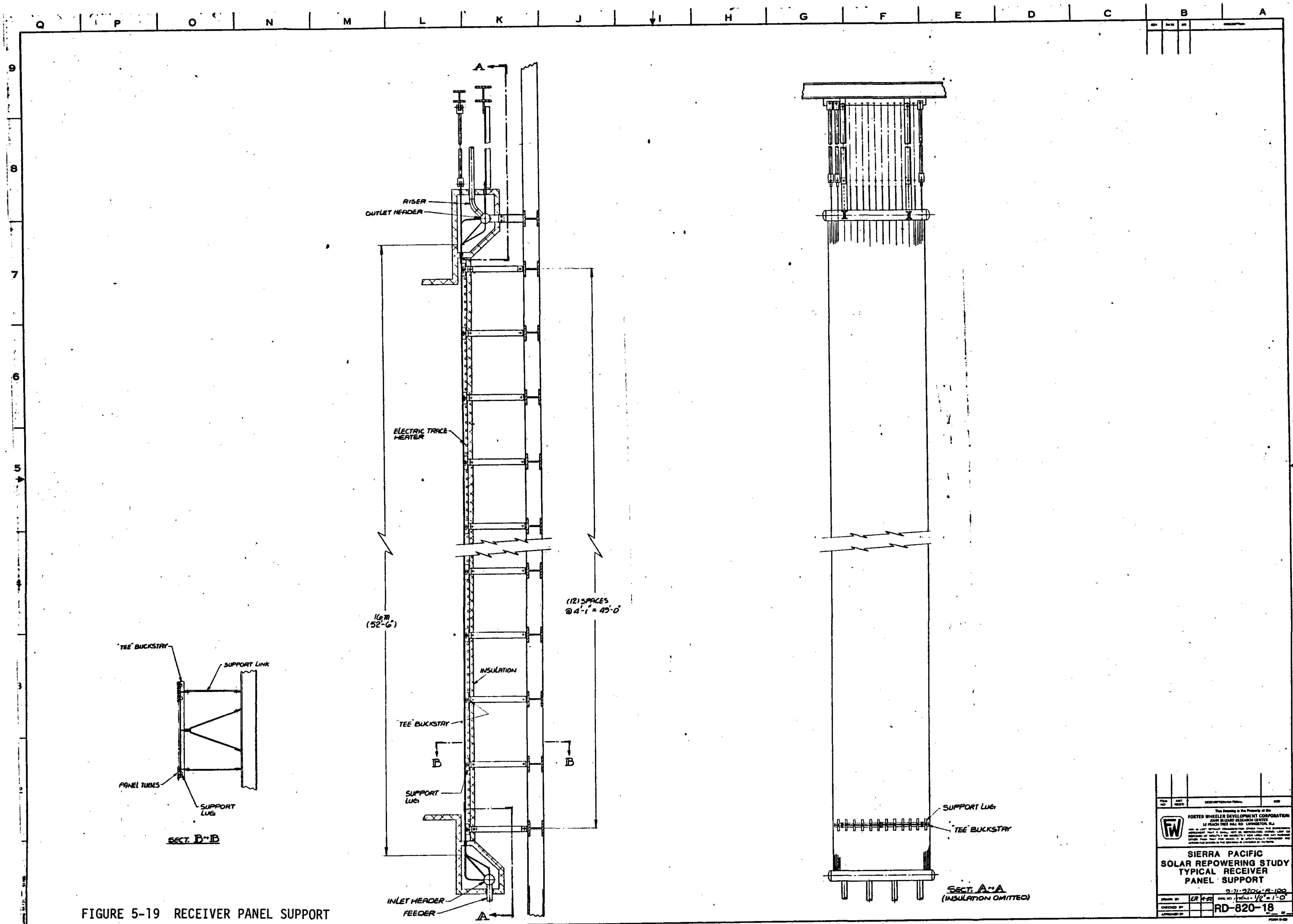


FIGURE 5-19 RECEIVER PANEL SUPPORT

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 5-19 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 depend on the panel fabrication method which requires further analysis and development.

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.

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

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

supplemented 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 the finite element program ANSYS. The model of the tube used in the analysis is shown in Figure 5-20. 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 National Laboratories (Livermore) has demonstrated that the 2-dimensional generalized plane strain model reflects the state of stress and strain accurately[e]. A cosine heat flux distribution is assumed in the heated side of the tube.

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.

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a. ASME Boiler and Pressure Vessel Code, Section VIII, Division 2 (Rules for Construction of Pressure Vessles - 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, CA., 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, Volume 101, February 1979.

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

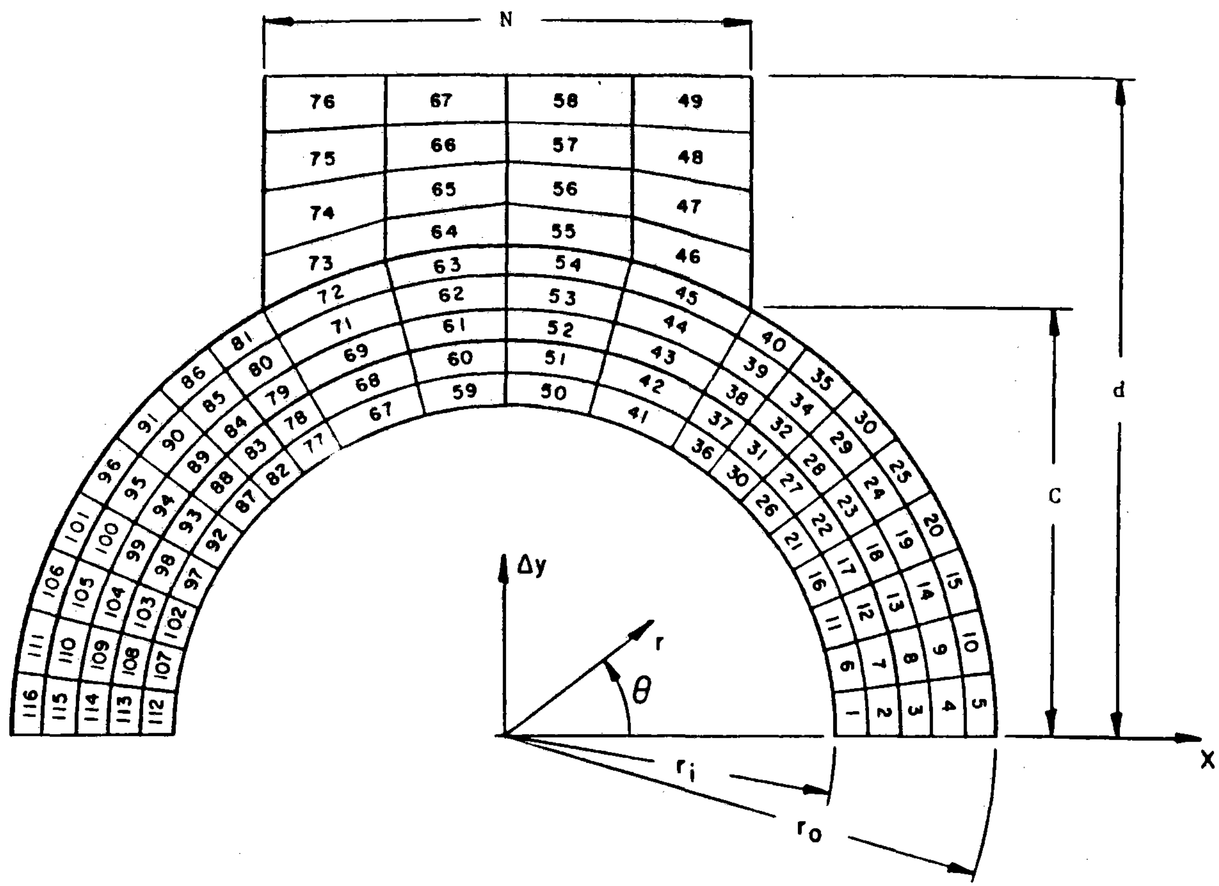

FIGURE 5-20 TUBE MODEL

This approach is consistent with that of References c and d (p 5-34). 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.*

Two critical locations in the receiver were analyzed for the design point (equinox noon) conditions. The points analyzed are points within each receiver pass with the highest front-to-back tube temperature differences. Results of the analysis are summarized in Table 5-2.

Table 5-2 indicates that the linearized axial stress for each of the points analyzed is less than two times the yield stress, sstisfying the aforementioned second criteria. Creep rupture lives were estimated by using Figure 1-14.6C of Code Case N-47. This estimation based on 1.25 S_y indicates that the creep life of Pass 4 is less than desirable. However, it should be noted that this evaluation is very conservative. If an inelastic analysis, accounting for creep and plasticity is done, it can be shown that creep relaxation would reduce the stresses and increase the creep rupture life.

The fatigue life was evaluated using Figure 1420-1C of Code Case N-47. The strain ranges were first calculated elastically. These strain ranges were increased by 10% to enter in Figure 1420-C. Many previous analyses by FWDC have shown that the inelastic strain ranges are only about 10% higher than the elastic strain ranges for solar receiver panels. The difference in elastic and inelastic strain ranges is minimal because of the fact that the stress state in the tube is very nearly uniaxial, the hoop and radial stresses being considerably lower than the axial stresses. For a uniaxial case, these two strain ranges are identical provided the loading is strain controlled.

From this study, it appears that creep fatigue will be satisfactory. In order to demonstrate this, an inelastic stress/strain analysis and creep fatigue evaluation should be done during detailed design phase.

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*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 5-2 RECEIVER TUBE ANALYSIS

Pass	2	5
q_{FP}, MW/m^2 (Btu/hr-ft^2)	0.647 (205,000)	0.596 (189,000)
t_{OD}, °C (°F)	504 (940)	613 (1136)
t_{OD}-t_{Salt}, °C (°F)	150 (270)	137 (246)
σ_z, MPa (ksi)	-280.5 (-40.68)	-256.4 (-37.19)
F, MPa, (ksi)	-97.8 (-14.18)	-89.9 (-13.04)
σ_{z1}, MPa (ksi)	182.7 (26.5)	166.5 (24.15)
σ_e, MPa (ksi)	261.4 (37.92)	233.8 (33.91)
$2S_y$, MPa (ksi)	223.4 (32.4)	213.7 (31.0)
Creep-rupture life based on 1.25 S_y, (hr)	>300,000	30,000
Fatigue ife, N_D (cycles)	85,000	55,000

Nomenclature

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

t_{OD} = Peak outside surface temperature

t_{salt} = Bulk salt temperature

σ_z = Axial stress

σ_{z1} = Linearized axial stress

σ_e = Effective stress

S_y = Yield stress

F = Peak stress

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.

Foster Wheeler is currently developing the joining and attaching techniques for thin wall tubes for Sandia National Laboratories, Livermore, under Sandia Contract 84-2292C, "Molten Salt Solar Receiver Subsystem Research Experiment." The objective of this development task is to establish the optimum methods for joining tubes-to-tubes and attaching support lugs to tube panels. Incoloy 800 tubes of 25.4 mm (1 in.) O.D. with 1.65 mm (0.065 in.) minimum wall, are used in this development work. Welding of a 0.94 m (3 ft) wide and 2.44 m (8 ft) long test panel has recently been completed. The tube welding method selected appears promising for fabricating large tube panels.

5.4.2 Tower

5.4.2.1 Description

The receiver tower will be constructed of structural steel. The baseline tower design is shown in Figure 5-21.

The baseline tower will consist of the steel structure, a structural steel top deck and a substantial concrete foundation. The top deck will be covered with standard 6.3 mm (1/4 in.) 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.

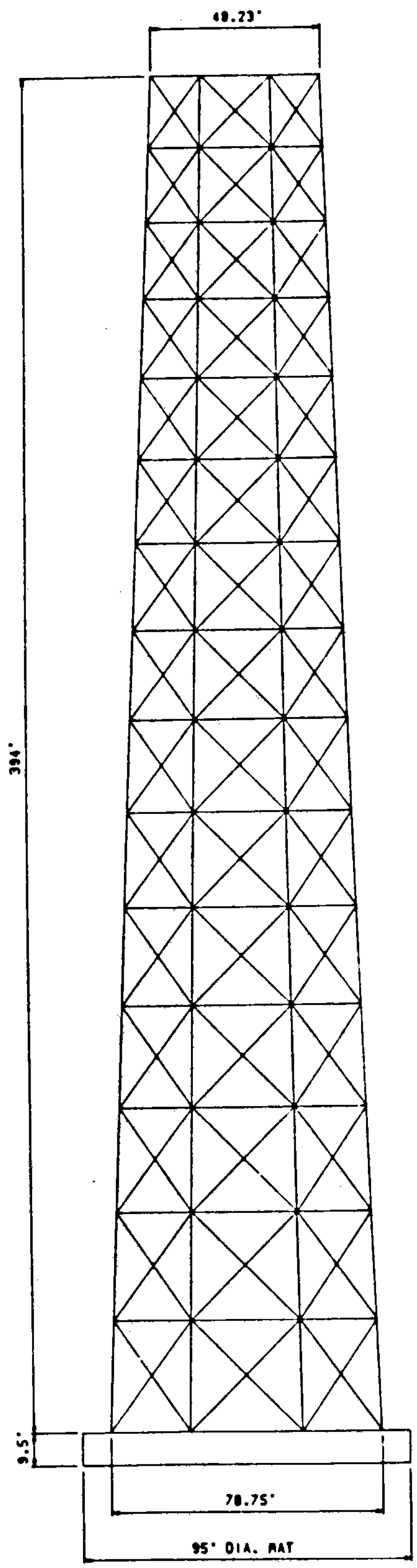

FIGURE 5-21 FT. CHURCHILL SOLAR REPOWERING (PHASE 2): STEEL TOWER DESIGN

5.4.2.2 Tower Performance

The effects of wind forces and seismic forces on the 120 m tower were evaluated by Stearns-Roger as a part of the tower trade study. The vibration performance of the steel tower was calculated and the results shown in Figure 5-22. The key characteristics are summarized on Table 5-3. These data indicate that the 120 m steel tower is significantly better than the 198 m concrete tower selected for the large single module field. The details of the complete tower trade study are presented in Appendix D.

5.4.2.3 Tower Structural Design

The detail structural design of the 120 m tower will be accomplished during the next phase of this program.

5.4.2.4 Tower Construction/Erection

The receiver tower foundation and structure 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 conjunction 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 Receiver Fluid Loop

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 5-4. 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.

Figure 5-22

FT. CHURCHILL SOLAR REPOWERING (PHASE 2): TRIAL STEEL TOWER DESIGN NO. 3

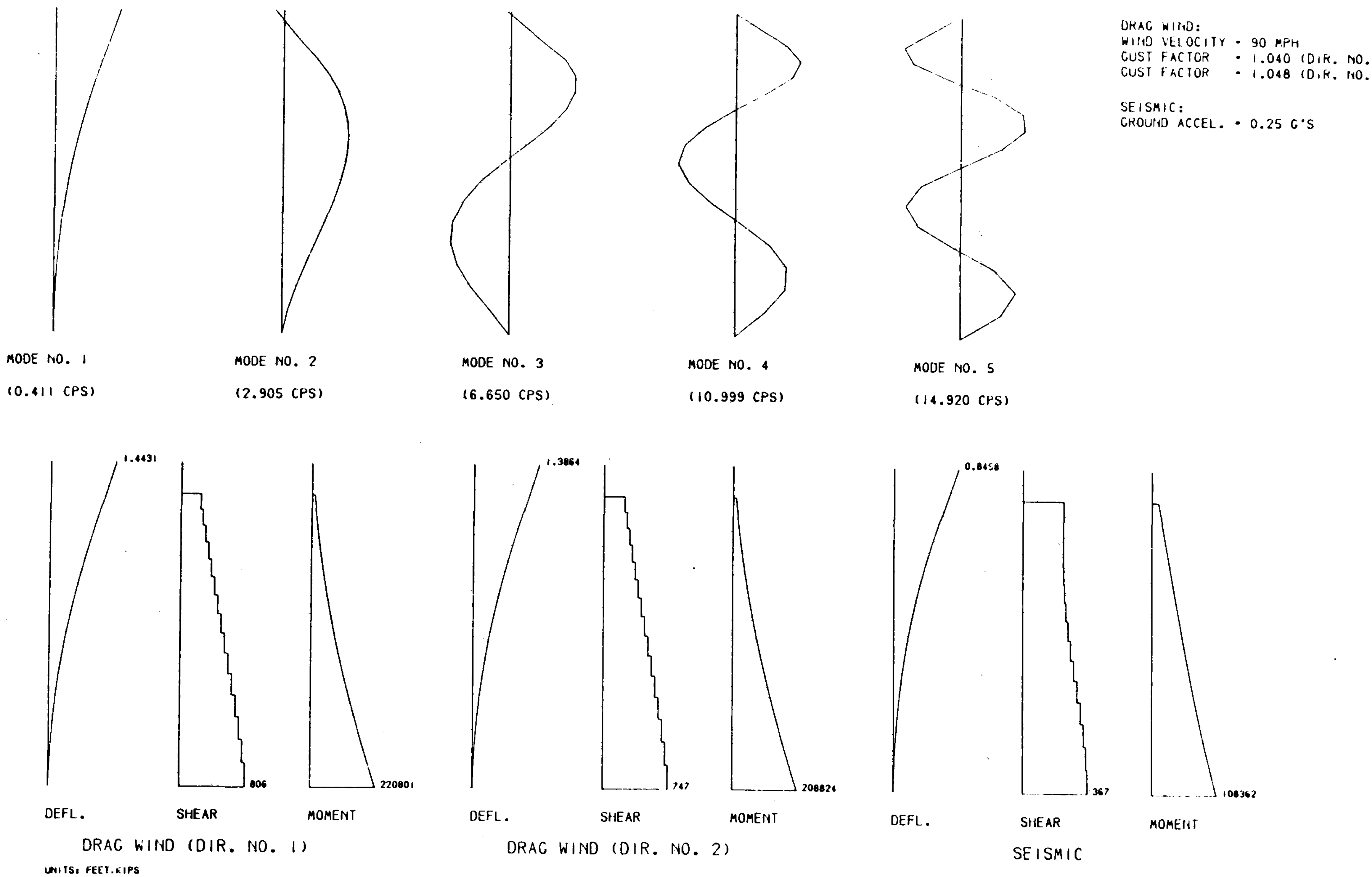

TABLE 5-3 TOWER CHARACTERISTICS

SUMMARY OF RESULTS

120 m (394 ft) TOWERS

Description	Structural Steel Tower
DEFLECTION, m (in.)	
a. 13.4 m/s (30 mph) Wind	
Top of Tower	0.041 (1.63)
Center Line Receiver	0.049 (1.92)
b. 40.2 m/s (90 mph) Wind	
Top of Tower	0.372 (14.65)
Center Line Receiver	0.440 (17.32)
c. 0.25 g Seismic	
Top of Tower	0.214 (8.41)
Center Line Receiver	0.258 (10.15)
MAXIMUM ACCELERATION, g's	
a. Top of Tower	0.32
b. Center Line Receiver	0.19
MAXIMUM WIND SHEAR, MN (10^3 lb)	
a. Bottom of Tower	3.59 (806)
b. Top of Tower	1.07 (240)
SEISMIC SHEAR, MN (10^3 lb)	
a. Bottom of Tower	1.63 (367)
b. Top of Tower	1.03 (231)

Table 5-4 RECEIVER FLUID PIPING CHARACTERISTICS

	HOT SALT Downcomer and Horizontal Piping	COLD SALT Riser and Horizontal Piping
Design Pressure	2.6 MPa (375 psig)	5.8 MPa (850 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	0.25m (10 in.) Nominal Sch. 403 9.27mm(0.365 in.) Nom. Wall	0.3m (12 in.) Nominal Sch 40 10.3mm (0.406 in.)Nom. Wall
Weight Per Meter (Ft.)	60 kg (40.5 lb.)	80 kg (53.5lb.)
Approximate Length	1561m (5120 ft.)	1408 m (4620 ft.)
Insulation Type	Calcium Silicate	Calcium Silicate
Insulation Thickness	0.20 m (8 in.)	0.13 m (5 in.)

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 .25 m (10 in.) pipe is approximately equal to 75% of the vertical head. The balance of the vertical head will be dissipated 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 566°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°C (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 .14 m^3/s (2100 GPM) at a pumping head of 228 m (750 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 347 kW (500 BHP) based on an overall pump efficiency of 75%.

The design conditions for the steam generator feed system was selected to handle the higher (50 MWe) solar standard conditions. These conditions give a flow of 0.17 m^3/s (2850 GPM) at a pumping head of 84 m (275 ft.). The specific gravity of the molten salt is 1.67 at 566°C (1C50°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 154 kW (207 BHP) based on an overall pump efficiency of 75%.

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

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., Bingham, 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.

Bingham has built many high volume, low head pumps for molten salt applications.

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.

5.4.4 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 shown on Table 5-5.

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 0.254 MW_{th} (0.87×10^6 Btu). 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 0.276 MW_{th} (0.94×10^6 Btu), with the aforementioned ambient conditions.

5.4.5 Control

Receiver control, while part of the receiver system, is discussed 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 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.

5.4.7 Development Items

Receiver system items requiring further detailed analysis include the following:

- Creep relaxation 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.

TABLE 5-5 TRACE HEATER REQUIREMENTS

Item	Number of Units	Length/Unit m (ft)	Power Watt/m	Power* Watt/ft	Power* Total Kw
Downcomers	18	132 (433)	191	58	25.2
Transfer Pipe	34	103 (338)	191	58	19.7
Feeders and Risers	160	21 (69)	74	23	1.55
Headers	224	15 (50)	495	151	7.42
Panels	305	213 (700)	839	256	178.7
					232.57

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

- Seal arrangement for gap between receiver panels provided for panel lateral expansion.
- Detailed transient analysis of receiver panels.
- Seal arrangement for door.

Receiver subsystem items which require development or qualification testing include:

- 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 Ft. Churchill No. 1 power plant solar retrofit provides control of the collector, receiver, thermal storage, and interfaces with the existing plant. The MCS for the one-third size module will consist of the same system as the full size unit. This arrangement will permit the installation of the second and third module without changing the MCS.

Design descriptions of the MCS for the Solar Repowering Retrofit System at SPPCo 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 4-2.

The MCS 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 5-23. 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.

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 the 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 5-24.

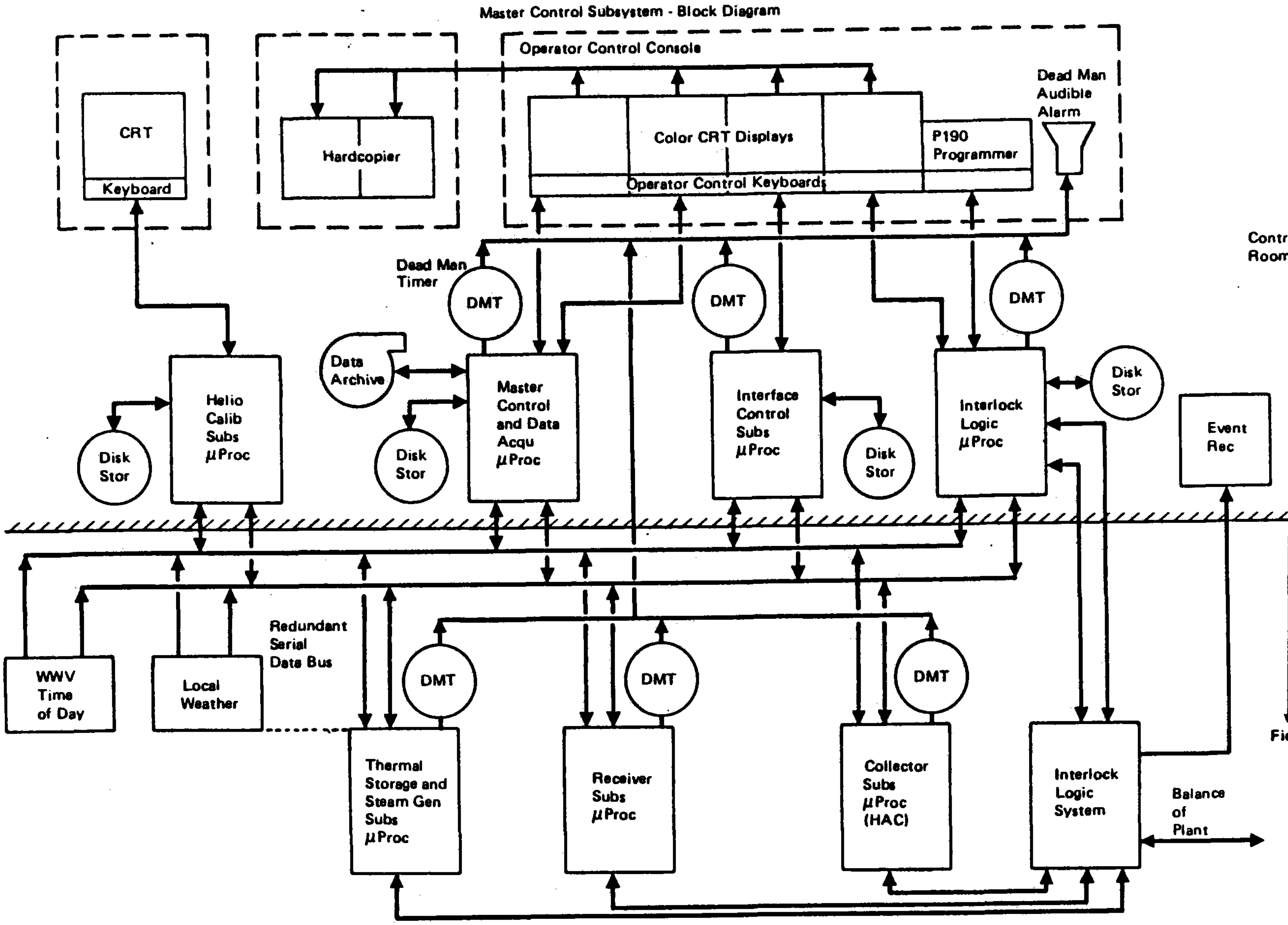


FIGURE 5-23 MCS DIAGRAM

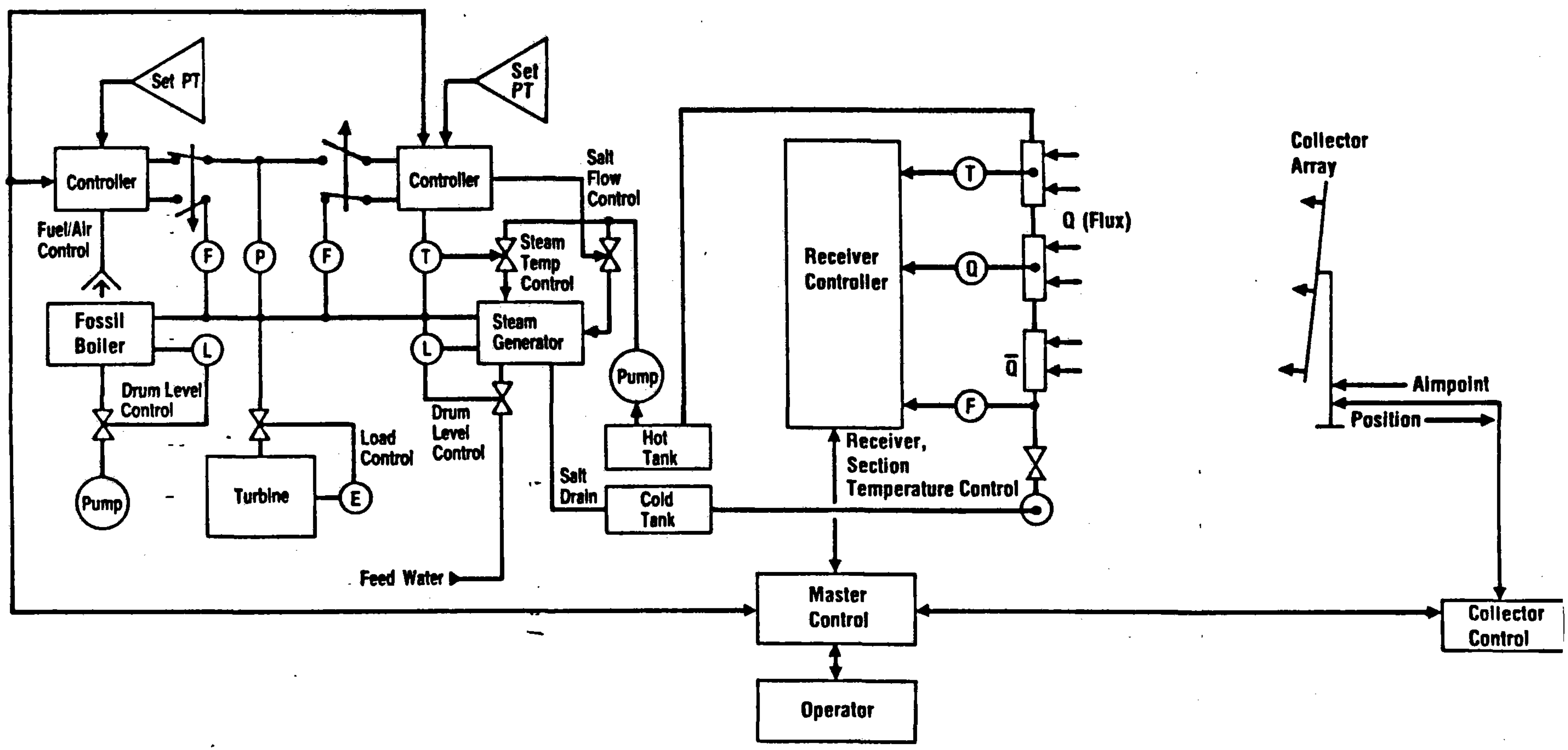


FIGURE 5-24 BLOCK DIAGRAM FOR PLANT OPERATION

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 microprocessor 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 functions 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 will be developed in the final design. 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 the 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 Controller (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.

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 5-25. 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.

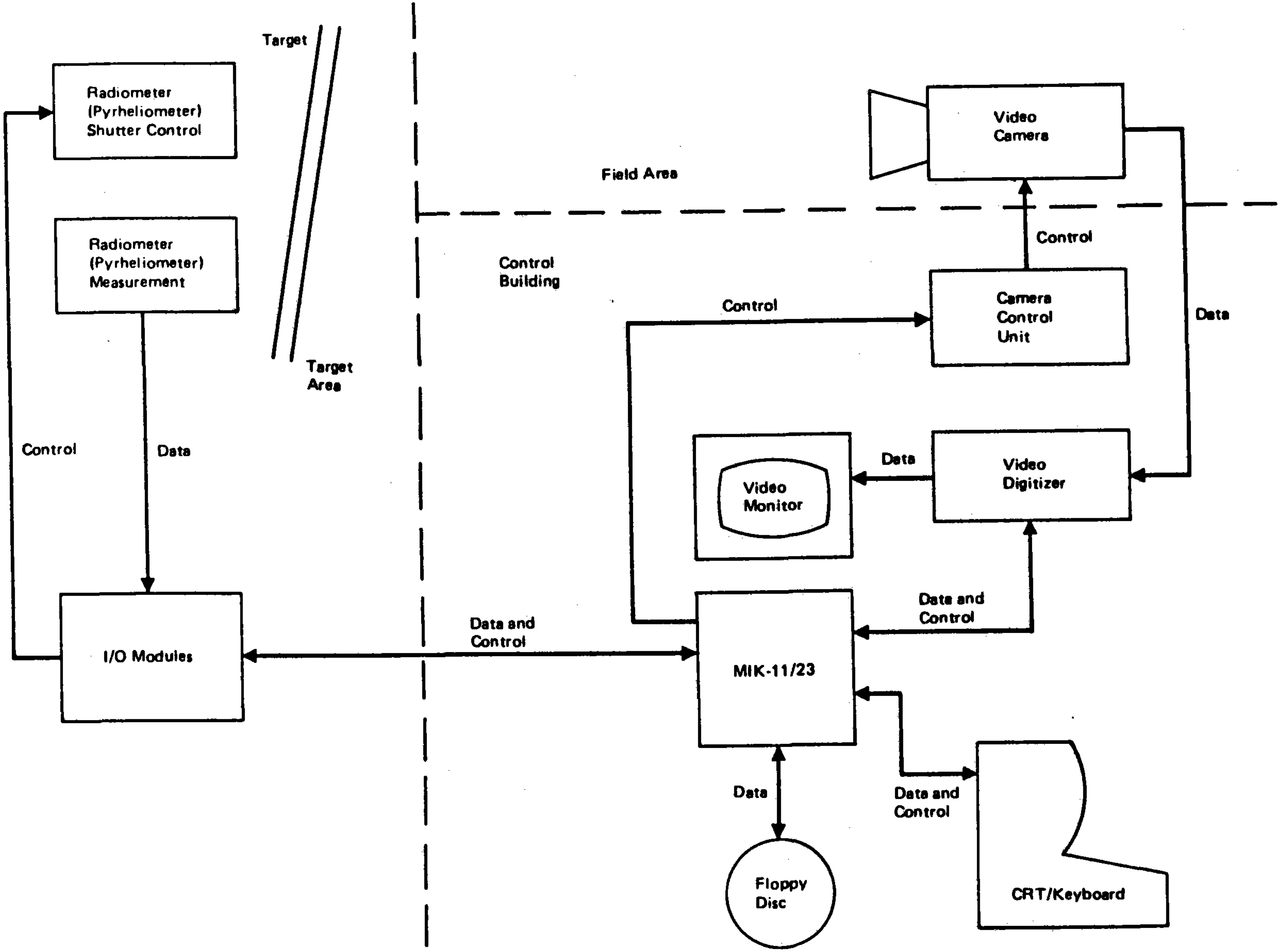


FIGURE 5-25 HELIOSTAT CALIBRATION SUBSYSTEM BLOCK DIAGRAM

- 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 Design

The central control console shown in Figure 5-26 is 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 connects three processor units (the Master Control, Interface Control and Interlock Logic Microprocessor) to the common digital data bus and the processor control terminals. A block diagram of this arrangement was presented in the master control system block diagram, Figure 5-24.

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

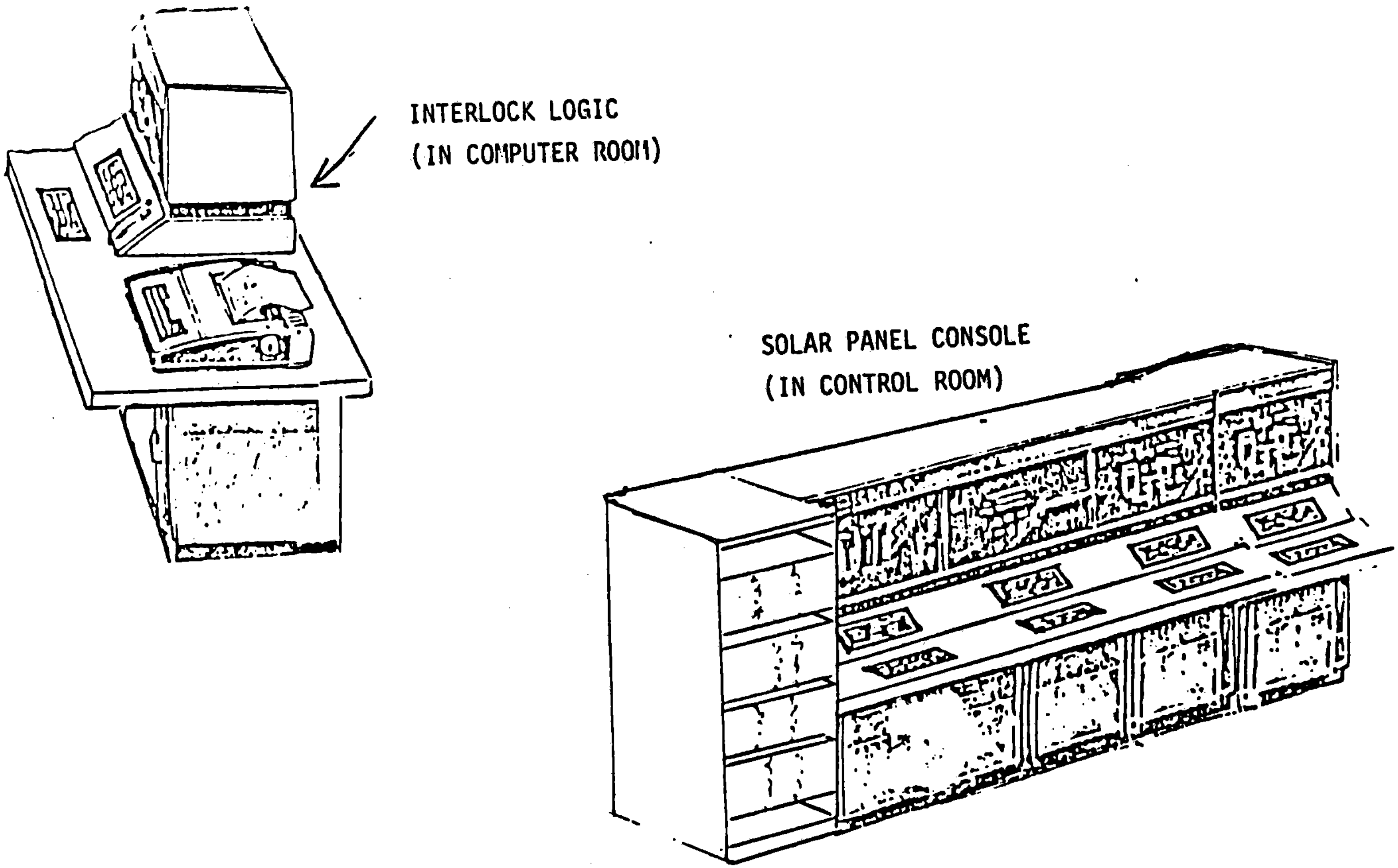


FIGURE 5-26 CONTROL CONSOLES

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 mid-1980s.

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
- Discrete Controllers (digital output)
- Discrete 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 5-27. The specific equipment making up these components and the communication paths between them are illustrated in Figure 5-28.

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

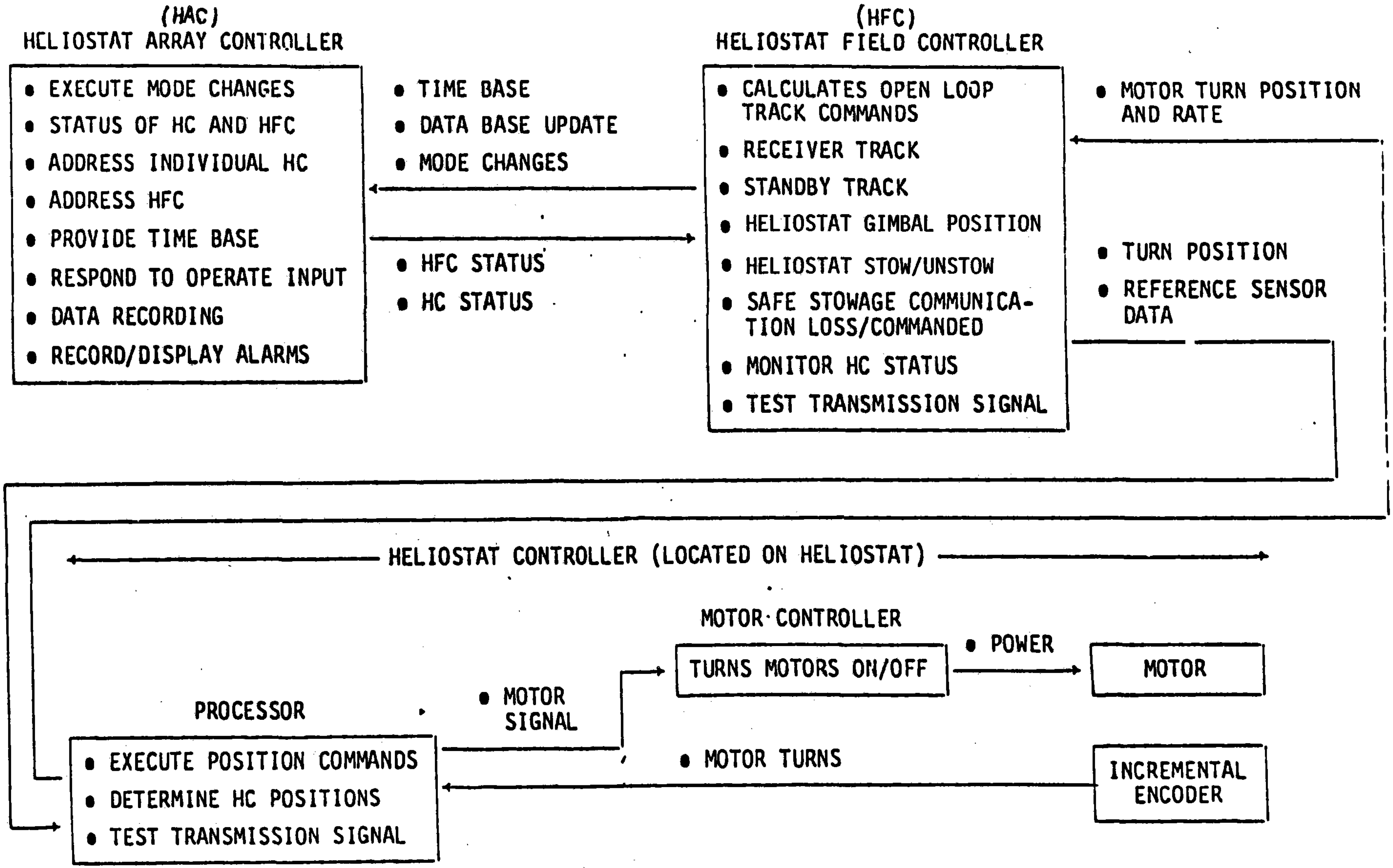


FIGURE 5-27 CONTROLS SUBSYSTEM

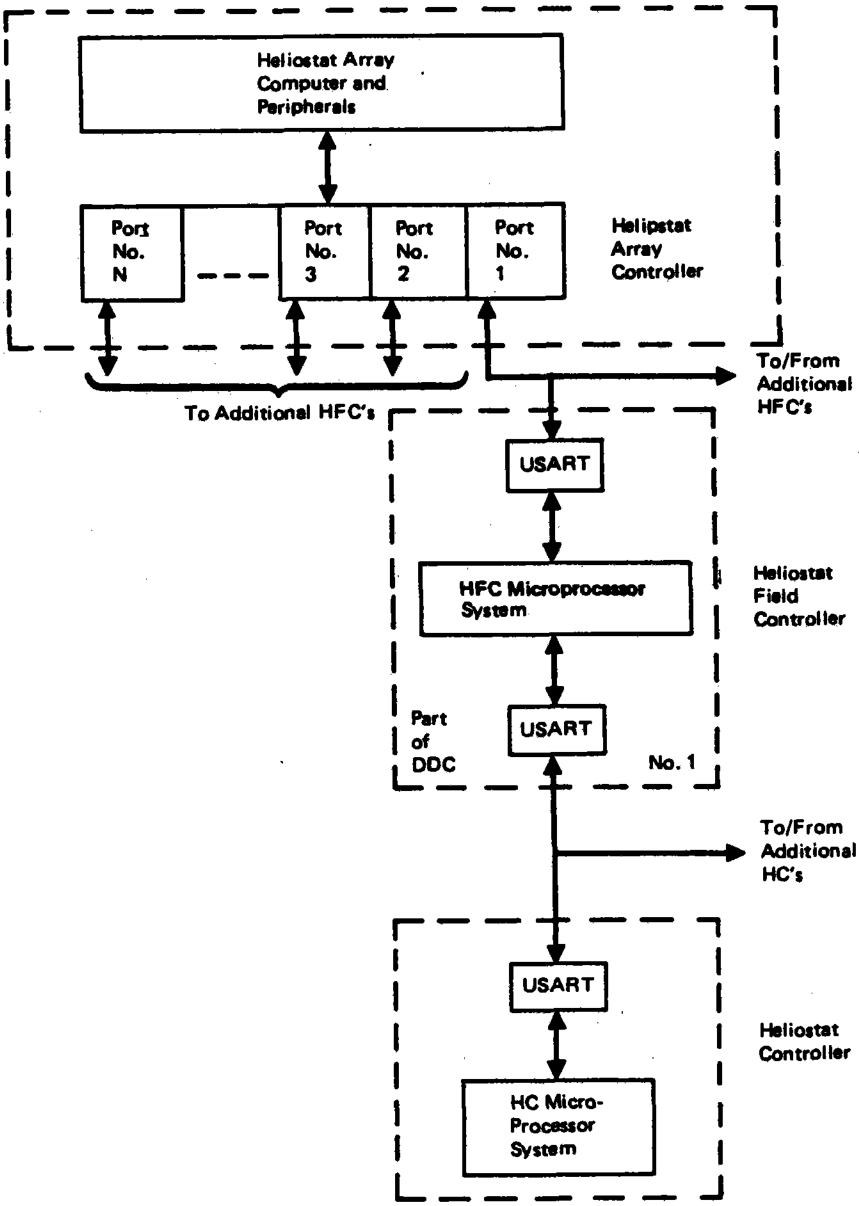


FIGURE 5-28 COLLECTOR FIELD CONTROLLER HARDWARE

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. Command 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 the 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 2K 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 clockwise/counterclockwise direction control signal to 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 receiver control strategy and details of the controller response was determined on an independent trade study. The details of this study and the results obtained are presented in Appendix E.

5.5.3.4 Thermal Storage Controller Design

The thermal storage and steam generation control subsystem is built around a MIL-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 subunits for better clarity, as shown in Figure 5-29. Controller #1 is the main salt supply control. It controls the outlet steam flow (or pressure) by supplying the proper flow of 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

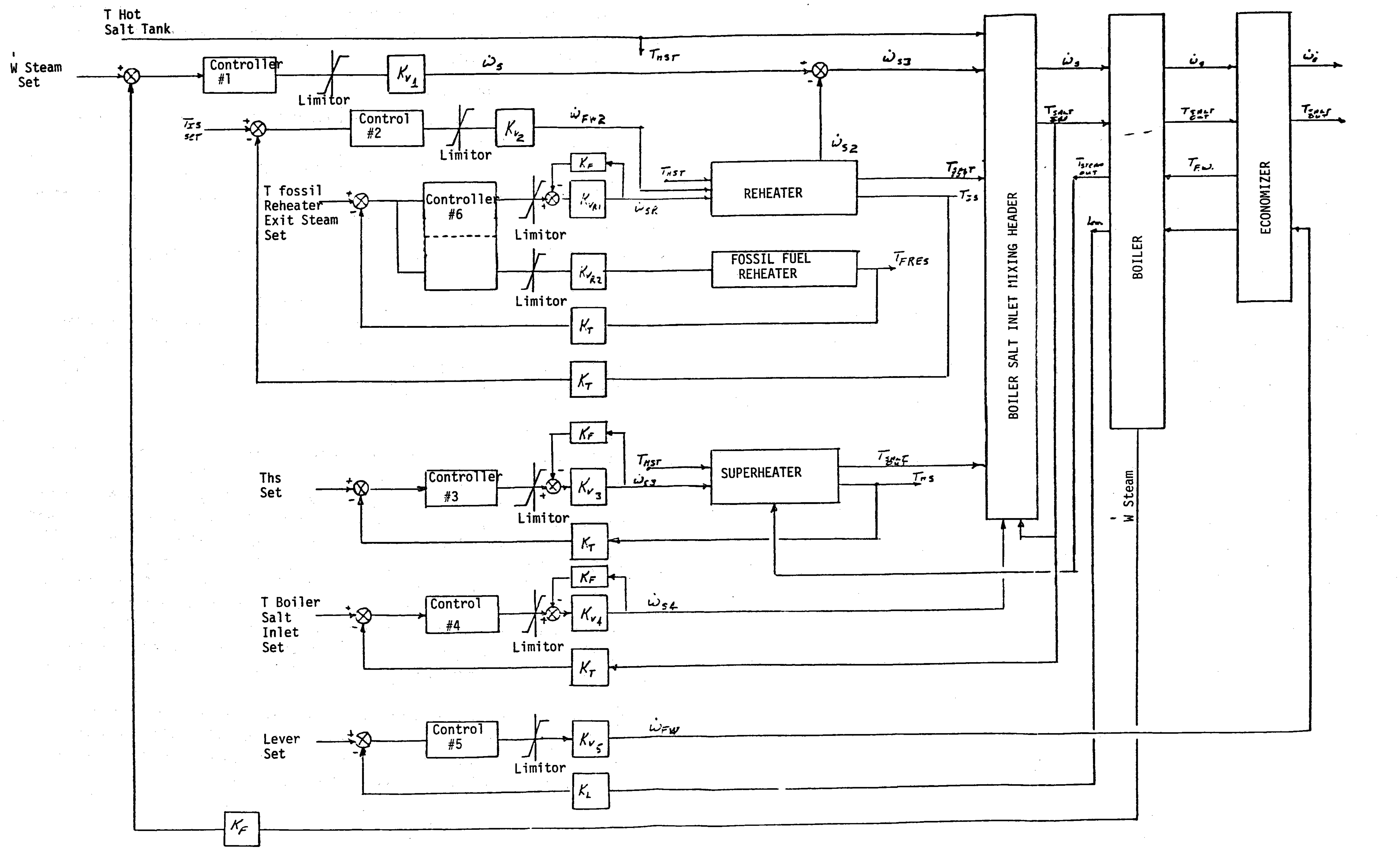


FIGURE 5-29 THERMAL STORAGE CONTROL BLOCK DIAGRAM

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:

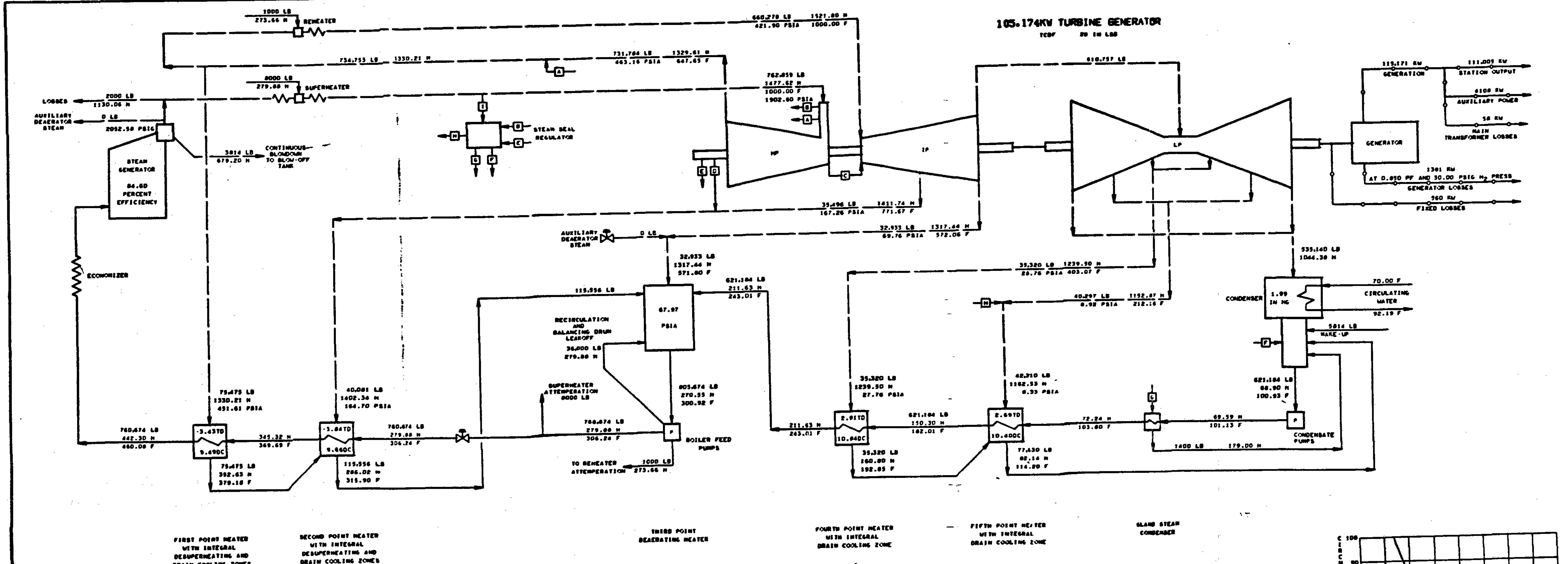
Manual	-	Subsystem Stand-Alone
Programmed-Auto	-	Semi-Automatic Operation with Operator Intervention required.
Automatic	-	Programmed Automatic Operation with Operator Monitoring

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/generator 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 5-30. 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:



TURBINE HEAT RATE = BOILER DUTY / GENERATION = 9.20938X10^+08 / 115,171 = 7996.24 BTU/KW-HR

STATION HEAT RATE = BOILER DUTY / (STATION OUTPUT X BOILER EFF.) = 9.20938X10^+08 / (111,005 X .8460) = 9807.06 BTU/KW-HR

LEAKAGES

	FLOW	ENTHALPY
A	2969	1477.62
B	819	1477.62
C	10,908	1457.59
D	4586	1329.64
E	3794	1329.61
F	1200	1355.[illegible]
G	1400	1355.08
H	2013	1355.08
I	0	0.

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

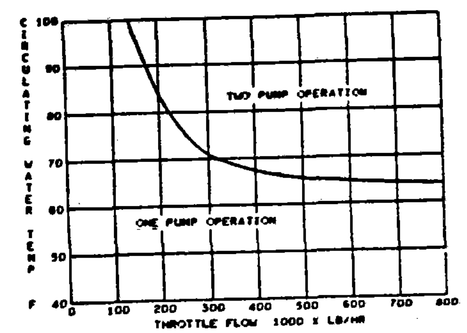
CONSTANT REQUIREMENTS EQUIPMENT	KILOWATTS
2 CIRCULATING WATER PUMPS	292
1 DEEP WELL PUMP	110
MISC MECH EQUIP	180
BUILDING SERVICE	23
MISC + LIGHTING	120
TOTAL CONSTANT REQUIREMENTS	725

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	9816.89

LEGEND

- STEAM (dashed line)
- WATER (solid line)
- POWER (line with circle)
- 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 SELECTION 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
		6/9/67

FIGURE 5-30 HEAT BALANCE DIAGRAM

	Unit No. 1	Unit No. 2
Reheater	772 m^2 (8313 ft^2)	976 m^2 (10503 ft^2)
Superheater	1744 m^2 (18772)	2484 m^2 (26736)
Superheater	298 m^2 (3208)	298 m^2 (3208)
Economizer	1496 m^2 (16105)	1050 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 (54 MWe gross) for approximately 2 hours.

Figure 5-31 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 startup, 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 4-2. The physical location of these components is shown on the site plot plan, Figure 4-6.

5.7.1.2 <u>Storage Tank Description</u>

Figures 5-32 and 5-33 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 347 stainless steel. The cold tank operating temperature (288°C [550°F]) permits the use of carbon steel.

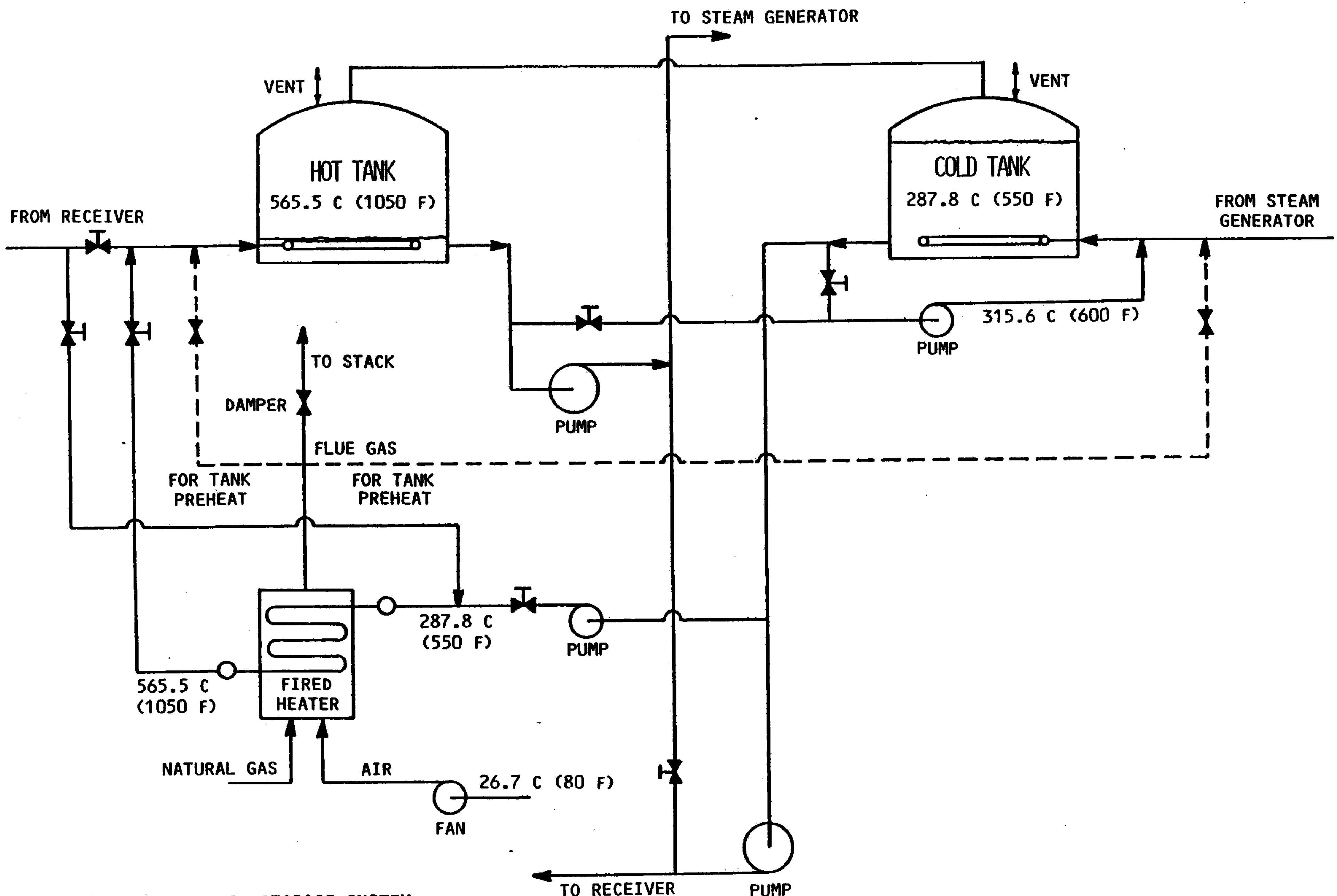


FIGURE 5-31 THERMAL STORAGE SYSTEM

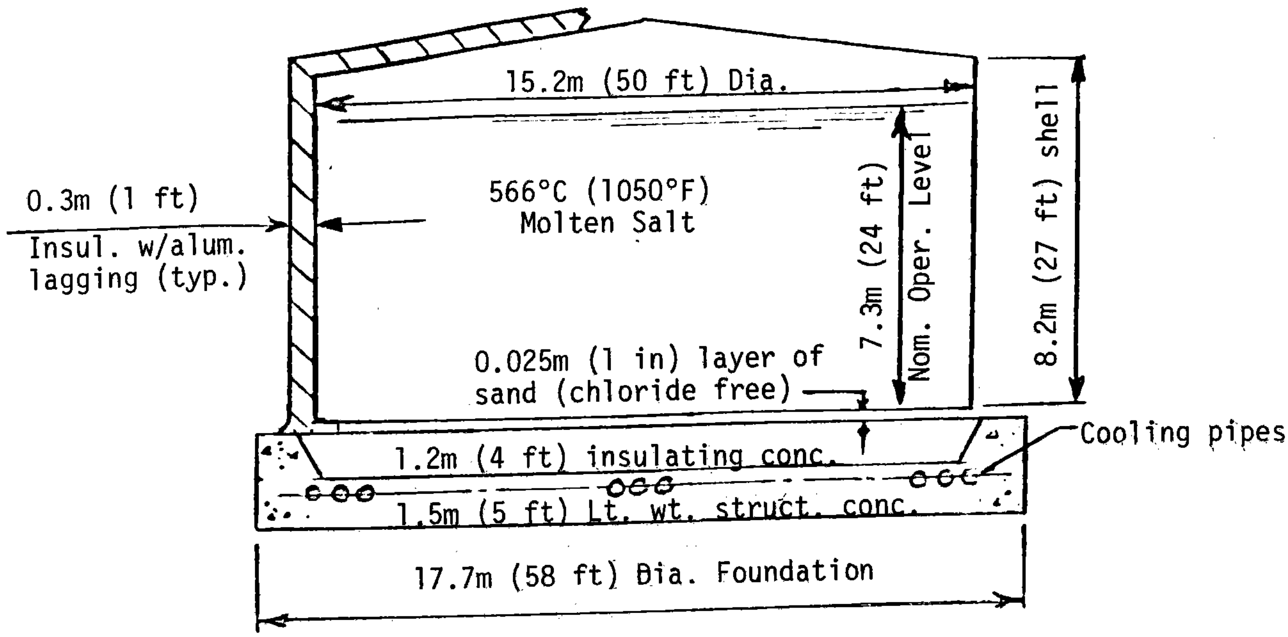


FIGURE 5-32 HOT SALT STORAGE TANK

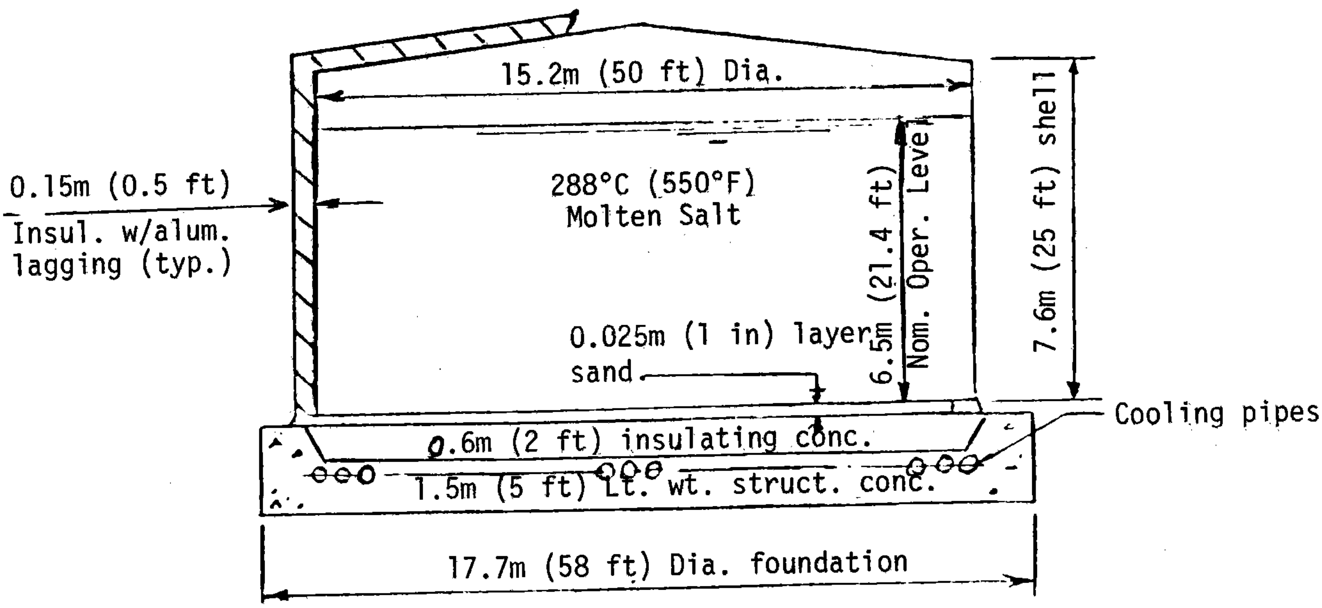


FIGURE 5-33 COLD SALT STORAGE TANK

5.7.1.4 Freeze Protection/Preheat

The recommended means for providing freeze protection during an extended plant shutdown is schematically illustrated in Figure 5-31. 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.

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 5-31, 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 obtainea 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.

5.7.1.6 Development Items

Items requiring further analysis in the detail design phase 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

The molten salt steam generator subsystem (SGS) briefly described below, is the 50 MWe hybrid SGS designed and evaluated by Foster Wheeler for Sandia National Laboratories, Livermore (SNLL) under Sandia Contract 20-9909B, "Molten Salt Steam Generator Subsystem Research Experiment - Phase 1." As a basis for design, the SPPCo Ft. Churchill Unit #1 was used to establish turbine-generator and environmental requirements. For details on the design, analyses, fabrication, and modes of operation of the SGS, refer to the final report for the aforementoined study.

5.7.2.1 Subsystem Description

The SGS is comprised of four heat exchangers (preheater, natural-circulation evaporator, superheater, and reheater) and a vertical steam drum mounted atop the evaporator designed to generate 48.1 kg/s (381.4 x 10^3 lb/h) of superheated steam at 541°C (1005°F), 13.48 MPa gage (1955 lb/in^2g), and 41.6 kg/s (330.1 x 10^3 lb/h) of reheat steam at 541°C (1005°F), 2.86 MPa gage (415 lb/in^2 g). The SGS is schematically illustrated in Figure 5-34.

Hot molten salt entering the system at 563°C (1045°F) flows in parallel through the superheater and reheater, combines, and then passes in series through the evaporator and preheater. Cold salt leaves the preheater at approximately 293°C (560°F). All heat exchangers are oriented vertically with all heated steam/water flowing upward. The preheater, superheater, and reheater are counterflow; the evaporator is parallel flow to improve natural circulation. A drum-water recirculation pump maintains the feedwater at a temperature abovr the salt freezing point (221°C [430°F]) during start-up and part-load operation. An optional gas-fired heater is located downstream of the drum-water recirculation

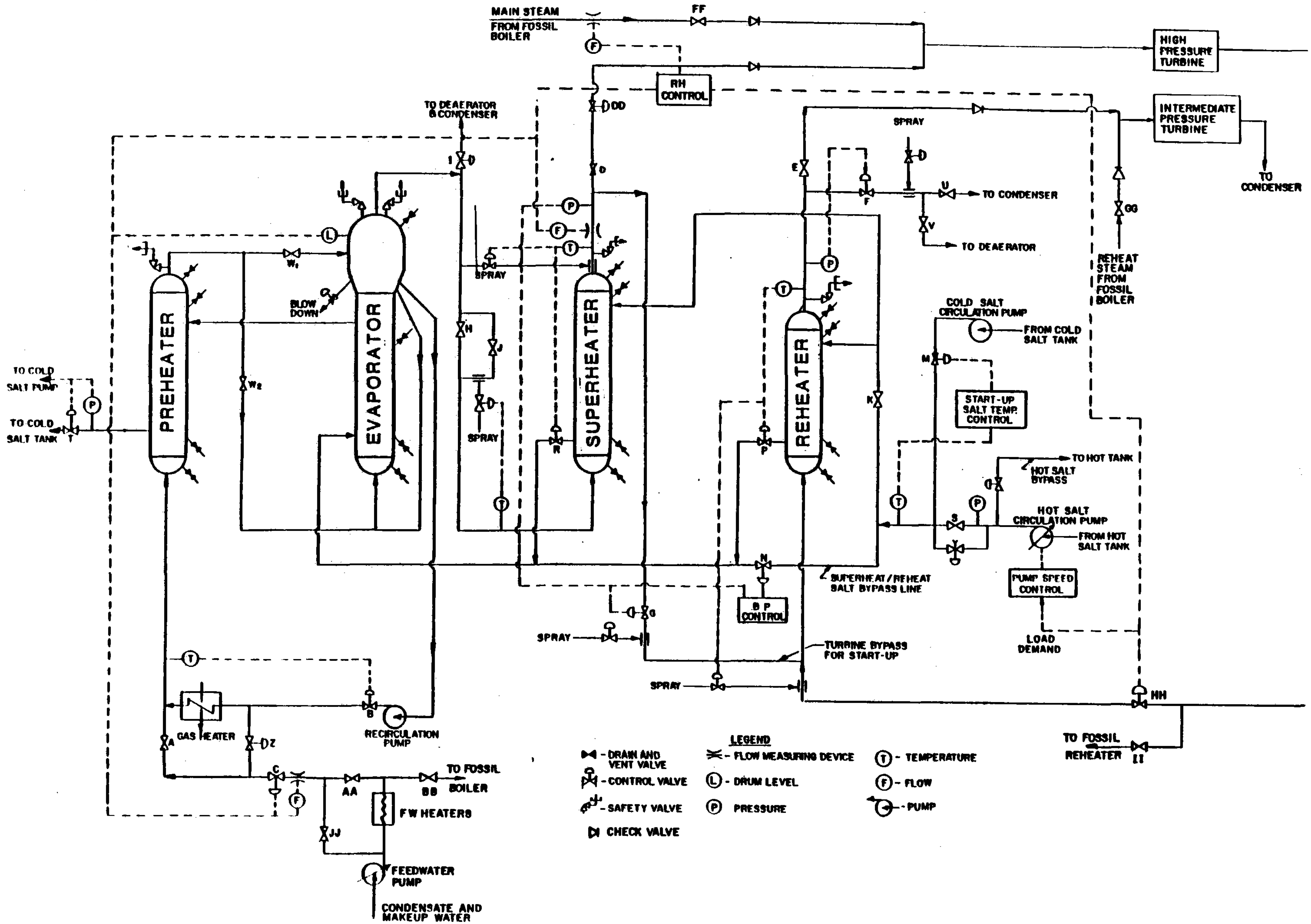


FIGURE 5-34 STEAM GENERATOR SUBSYSTEM SCHEMATIC

pump for cold start-up feedwater heating if hot water is not available from the fossil steam generator. A cold-salt recirculation pump controls the temperature of salt entering the subsystem during unit start-up and shutdown.

Final main steam temperature is controlled by a superheater outlet valve, which controls salt flow through the superheater. Saturated steam from the steam drum is directed to the superheater outlet for emergency control. Reheat steam temperature is controlled by a valve at the reheater outlet that controls salt flow through the reheater. A spray attemperator is located at the reheater steam inlet for emergency control. The quantity of steam generated is determined by the flow rate and temperature of the salt entering the evaporator. A salt line that bypasses hot salt around the superheater and reheater to the evaporator is used for this purpose. An evaporator/preheater salt bypasss line which is under pressure control is provided to minimize pressure surges during emergency shutdown conditions.

Electric trace heating is provided on all SGS components containing molten salt. The trace heaters are sized to preheat the unit initially and to compensate for ambient heat losses during warm standby. Insulation and lagging are provided on all SGS components that might be a danger to personnel and on all components that are potential sources for significant heat loss. Safety valves are provided on the preheater outlet, steam drum, superheater outlet, and reheater inlet and outlet as required by the Code. Rupture discs in the salt inlet and outlet of each heat exchanger prevent overpressuring of the exchanger shell in the event of a tube leak. All steam/water and salt components can be fully drained. Salt drains from the SGS to a sump, from which it is pumped back to the cold-salt sotrage tank.

5.7.2.2 Heat Exchanger Description

The heat exchangers are the straight-tube, single-pass shell and tube type, each with a floating lower steam/water inlet head and double segmental baffles.

An expansion bellows welded into the lower section of the shell permits differential expansion between the tube bundle and the shell. Figures 5-35 through 5-38 illustrate the preheater, evaporator, superheater, and reheater designs. The superheater and reheater are built using Type 304 stainless steel. The preheater is made of carbon steel and the evaporator of 1-1/4% Cr-1/2%Mo (T-11) material.

The designs of the preheater, superheater, and reheater are similar in that hot salt enters an upper nozzle located in a flared-out section of the exchanger shell that forms an annular space with a shroud surrounding the tube bundle in the flared area. The shroud acts as an impingement plate and is circumferentially slotted to distribute salt uniformly to the tube bundle. Sufficient space is provided between the nozzle and distributor slots to create a uniform flow pattern. After passing through the distributor slots, the salt flows downward through the tube bundle and out of the exchanger through a nozzle located in the shell. Tie-rods attached to the upper tubesheet support the double segmental baffles, which function as tube support plates to suppress vibration and buckling. Heat transfer tubes are welded to the face of the tubesheet using the fillet-type welding technique. The superheater and reheater are vertically hung from a support skirt welded to the shell near the upper tubesheet. The preheater is vertically hung from lugs welded to the exchanger shell.

The evaporator design is similar to the preheater, superheater, and reheater designs except for the following:

- Steam/water discharges into a vertical drum mounted atop the evaporator.
- Hot salt enters through a nozzle in the flared-out section of the shell at the bottom of the unit and leaves through the upper nozzle located in the shell.

The vertical steam drum, which is designed as an integral part of the evaporator, is equipped with spiral arm separators and box-type Chevron driers to provide dry, saturated steam. Feedwater enters the steam drum through a

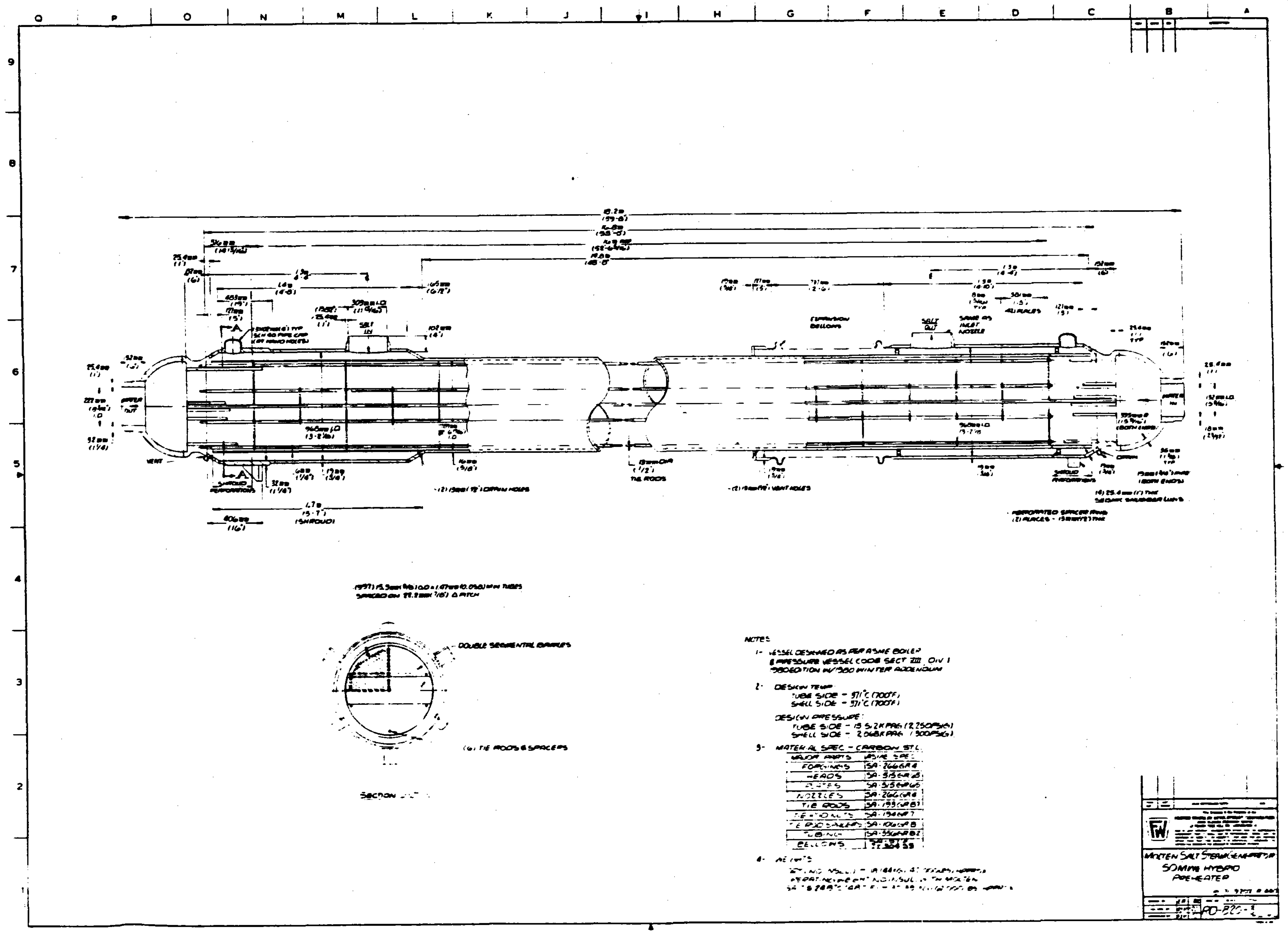


FIGURE 5-35 PREHEATER

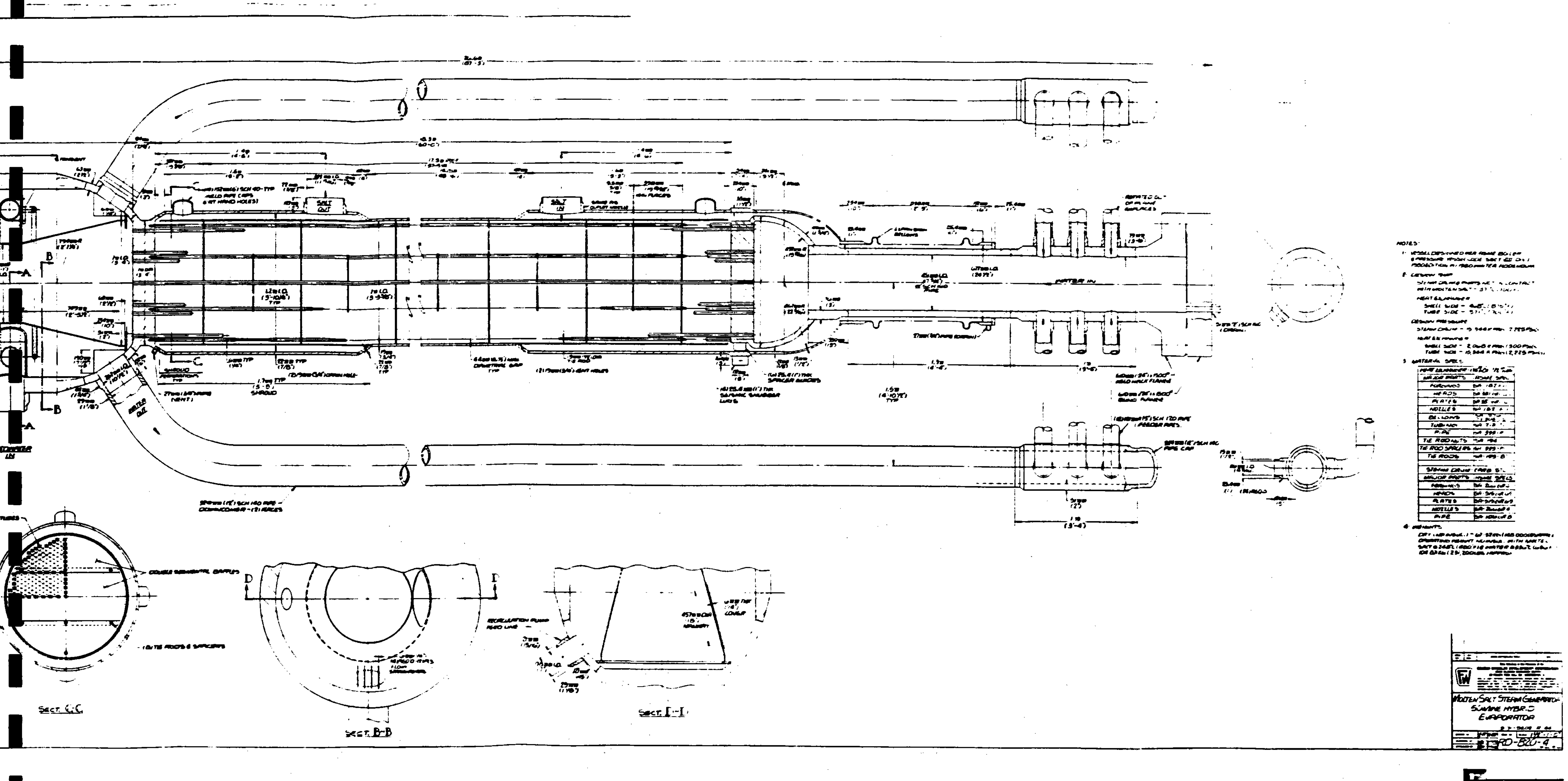


FIGURE 5-36 EVAPORATOR

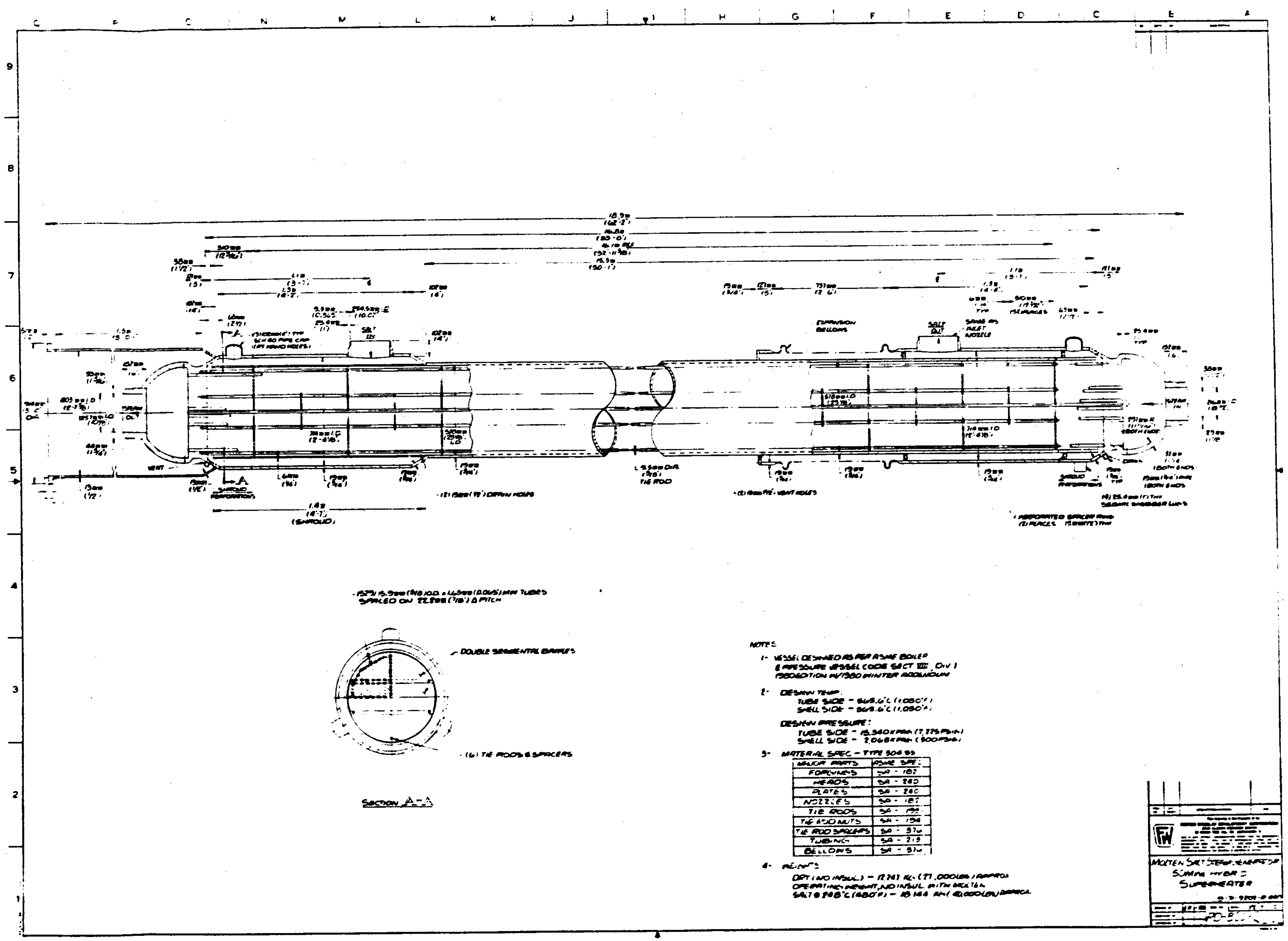


FIGURE 5-37 SUPERHEATER

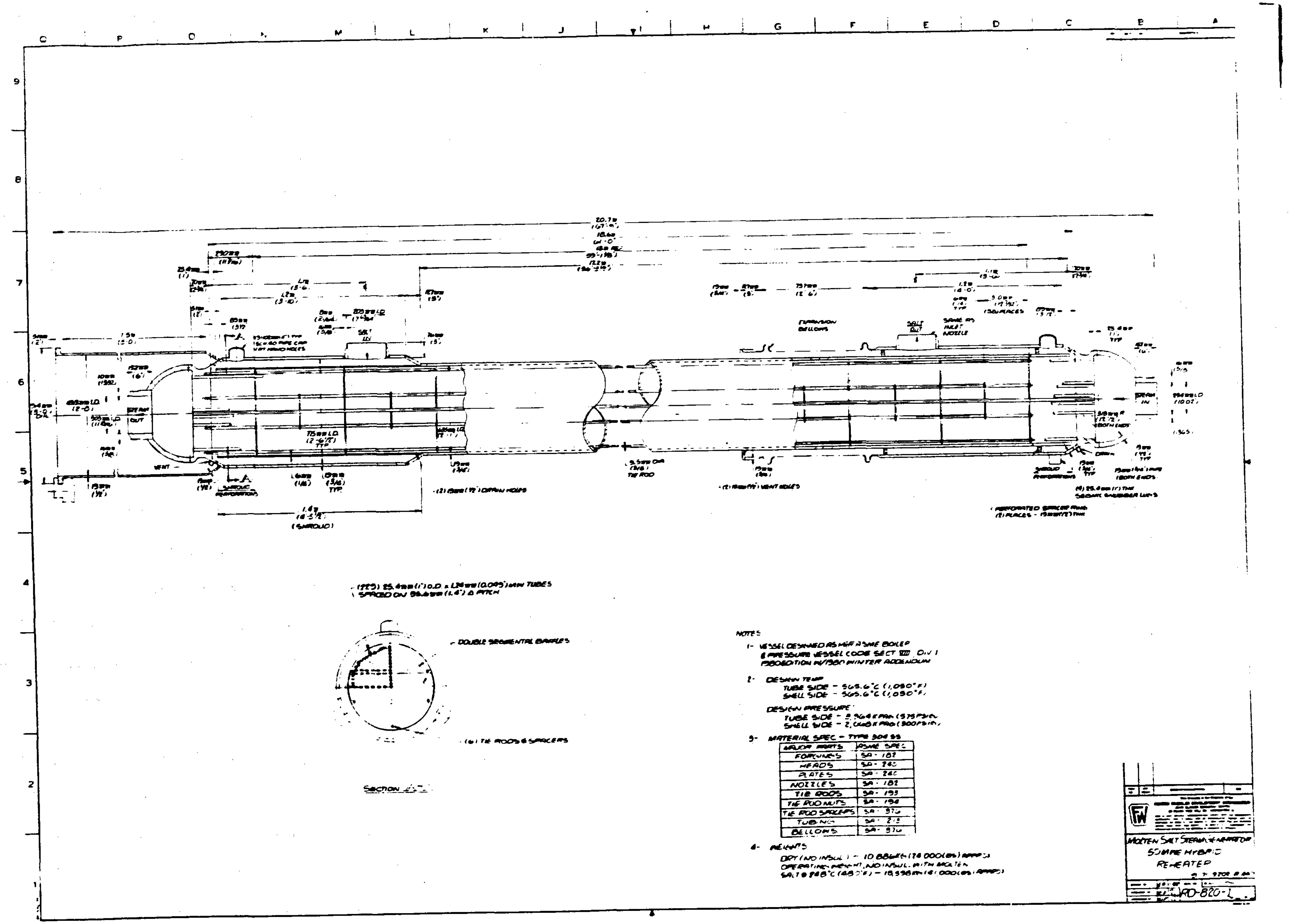


FIGURE 5-38 REHEATER

toroidal distribution pipe positioned below the drum-water level. Blowdown and chemical feed lines control the concentration levels of impurities in the evaporator water. The water line feeding the drum-water recirculation pump is attached directly to the steam drum. A manway is provided to gain access to the upper tubesheet for maintenance.

5.7.2.3 PERFORMANCE

Heat exchanger performance was estimated by using FW's computer code MSSG. The MSSG code is a one-dimensional thermal sizing computer code that determines the required heat-transfer tube length by breaking the tube lengthwise into a series of nodes. The equations governing energy and momentum for the series of nodes form a series of 1st-order ordinary differential equations, which are solved to determine the tube length that will meet the specified performance. Shell-side heat-transfer coefficients utilized by the MSSG program were first determined by the Heat Transfer Research, Inc. (HTRI) Computer Program ST-4 for shell-and-tube heat exchangers.

Appropriate surface margins were added to the heat transfer area determined by MSSG to accommodate the uncertainties associated with heat-transfer coefficients, thermal conductivity of the tubes, fouling factors, and tube plugging. The surface margin was determined statistically by the Root of Sum Square (RSS) method. The required heat-transfer surface area was then determined according to the desired design confidence level (90 percent).

In sizing the heat exchangers, configurations were selected that resulted in reasonable overall heat-transfer coefficients, shell-and tube-side pressure drops, length-to-diameter ratios, and an absence of tube vibration. Estimated SGS performance for anticipated hybrid and solar stand-alone operation of the repowered SPPC Fort Churchill Unit #1 is listed in Table 5-6. Of note are the following items:

TABLE 5-6 STEAM GENERATOR PERFORMANCE

OPERATION MODE	SOLAR ONLY	HYBRID
TEMPERATURES.C (F)		
Steam/Water:		
Feedwater	213.3 (416)	237.8 (460)
Superheater Inlet	336.1 (637)	334.4 (634)
Final Steam	540.6 (1005)	540.6 (1005)
Reheater Inlet	317.2 (603)	341.1 (646)
Reheater Outlet	538.9 (1002)	540.6 (1005)
Salt:		
Superheater Inlet	562.8 (1045)	562.8 (1045)
Superheater Outlet	423.9 (795)	400.6 (753)
Reheater Inlet	562.8 (1045)	562.8 (1045)
Reheater Outlet	456.7 (854)	449.4 (841)
Evaporator Inlet	443.9 (831)	435.6 (816)
Evaporator Outlet	340.6 (645)	337.8 (640)
Preheater Inlet	340.6 (645)	337.8 (640)
Preheater Outlet	287.2 (549)	287.8 (550)
FLOWS, kg/sec (10^3 lb m/h)		
Steam/Water:		
Feedwater	46.51 (369.1)	29.58 (234.8)
Blowdown	0.23 (1.8)	0.11 (0.9)
Main Steam	46.28 (367.3)	29.45 (233.7)
Reheater	38.20 (303.2)	24.80 (196.8)
Recirculation	9.51 (25.5)	0 (0)
Salt:		
Preheater	315.88 (2507)	188.62 (1497)
Evaporator	315.88 (2507)	188.62 (1497)
Superheater	170.35 (1352)	92.36 (733)
Reheater	113.40 (900)	64.26 (510)
Bypass	32.13 (255)	32.0 (254)
PRESSURES, kPag (psig)		
Steam/Water:		
Feedwater	14,045 (2037)	13,645 (1979)
Drum	13,852 (2009)	13,562 (1967)
Final Steam	13,659 (1981)	13,479 (1955)
Reheater Inlet	1,737 (252)	2,958 (429)
Reheater Outlet	1,482 (215)	2,889 (419)
PRESSURE DROP, SALT kPa (psi)		
Superheater	228 (33)	69 (10)
Reheater	179 (26)	62 (9)
Preheater	331 (48)	117 ([illegible])

- The design point for the heat exchangers is the 5-percent over-pressure condition with the turbine valves wide open.

- A 2.8 C (5°F) drop in steam temperature 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 541°C (1005°F).

- A 2.8°C (5°F) temperature drop in salt was assumed in the hot salt line feeding the SGS. Consequently, the temperature of molten salt entering the superheater and reheater is 564°C (1045°F).

- Molten salt properties specified by SNL in the RFO for the Molten Salt SGS SRE (Phase 1) were used, as listed in Appendix F.

- A blowdown rate of 0.5 percent was used.

- The design-point temperature of salt leaving the preheater was increased to 293°F (560°F) to obtain a pinch-point temperature difference of 7.2°C (13°F) at the evaporator salt outlet and the preheater salt inlet. Depending on load conditions the salt exit temperature will vary as noted in Table 5-6.

- Shell-and tube-side fouling resistances used are as follows:

Component	Fouling Resistance $m^2 \cdot °C/MW$ ($h \cdot ft^2 \cdot °F/Btu$)	
Preheater	90 (5×10^{-4})	26 (1.5×10^{-4})
Evaporator	90 (5×10^{-4})	54 (3×10^{-4})
Superheater	90 (5×10^{-4})	26 (1.5×10^{-4})
Reheater	90 (5×10^{-4})	26 (1.5×10^{-4})

The design point temperature profiles through the SGS for full load hybrid and solar stand-alone operation are illustrated in Figures 5-30 and 5-40, respectively.

5.7.2.4 DESCRIPTION OF OPERATION:

Modes of operation for the SGS include the following:

- Cold Shutdown
- Cold Start-Up
- Full-and Part-Load Operation
- Load Changes
- Shutdown to Warm Standby
- Warm Standby
- Start-Up From Warm Standby
- Shutdown to Cold Conditions

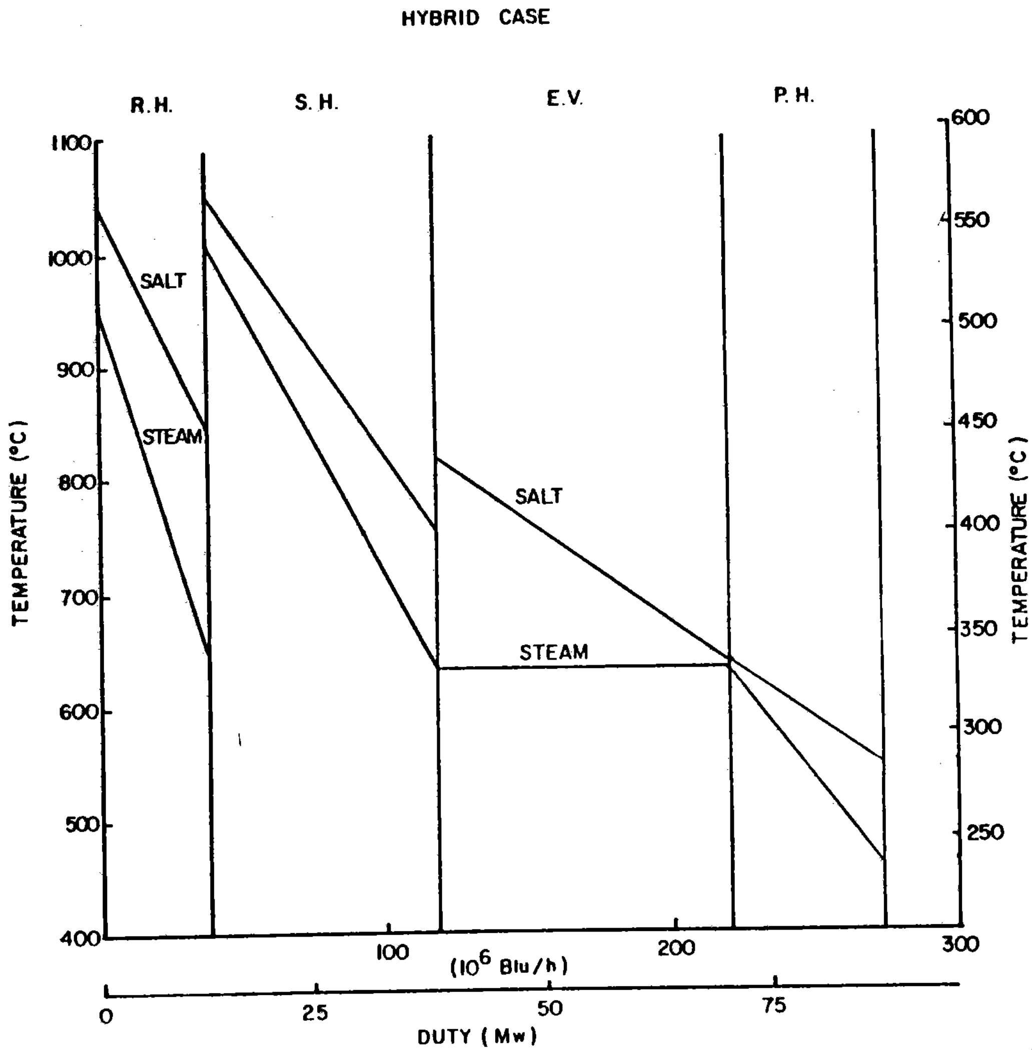


FIGURE 5-39 STEAM GENERATOR PERFORMANCE - HYBRID

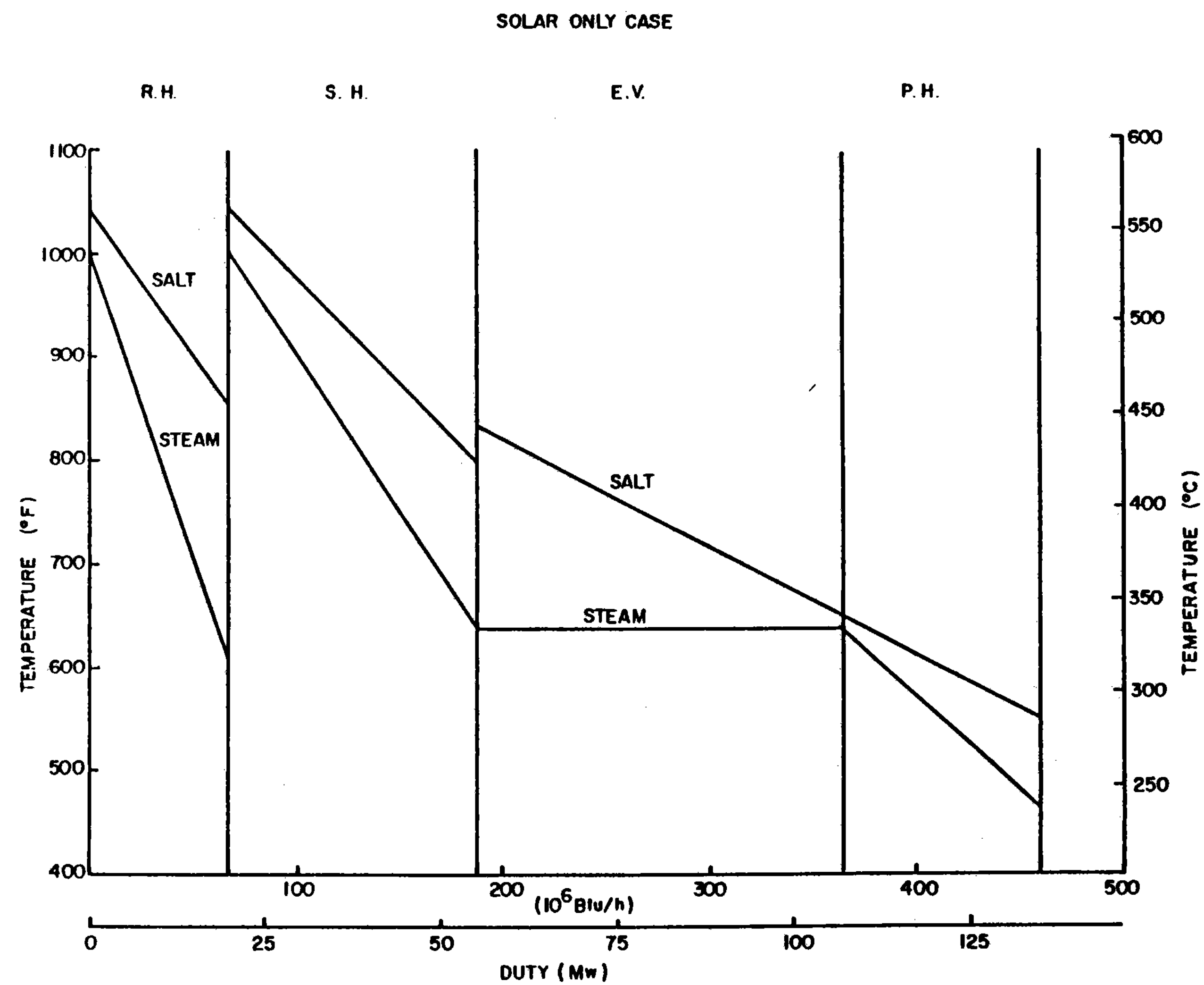


FIGURE 5-40 STEAM GENERATOR PERFORMANCE - SOLAR ONLY

- Dirunal Shutdown
- Diurnal Start-Up
- Emergency Shutdown

A typical operating cycle for the SGS is schematically illustrated in Figure 5-41. In describing the SGS operating cycle, the starting point is assumed to be the cold shutdown mode (State 7), where the whole SGS (including the connecting piping) is at ambient condition. It is also assumed that at least 1 hour of full load-operation hot salt is available in the hot-salt storage tank before a cold startup can begin.

The normal SGS operating load range is from full to 25 percent load, with hybrid operation at about 65 percent of full load. Load changes are achieved by adjusting the feedwater and salt flows using the automatic control logic. All load changes are limited to 3 percent per minute. Below 25 percent load, the SGS is in a start-up or shutdown mode.

The hot standby mode consists of bottling the SGS on the steam/water and salt sides so that all flows into and out of the SGS stop. The SGS is allowed to remain under these conditions for 7.5 hours, after which Diurnal start-up begins. Diurnal start-up takes the SGS from the hot standby mode to the full-load mode. This daily operating cycle is continually repeated unless an extended shutdown or cold shutdown is necessary.

It may be necessary to bring the SGS to a warm standby mode (State 6) from the hot standby mode because of extended cloud cover. In the warm standby mode, the SGS continues to cool from the hot standby mode, losing heat to ambient. The SGS remains in this mode until either a fresh supply of hot salt becomes available (in which case, the SGS is brought to full-load) or the SGS is drained of salt and water and cooled down to the dry, ambient long-term cold shutdown

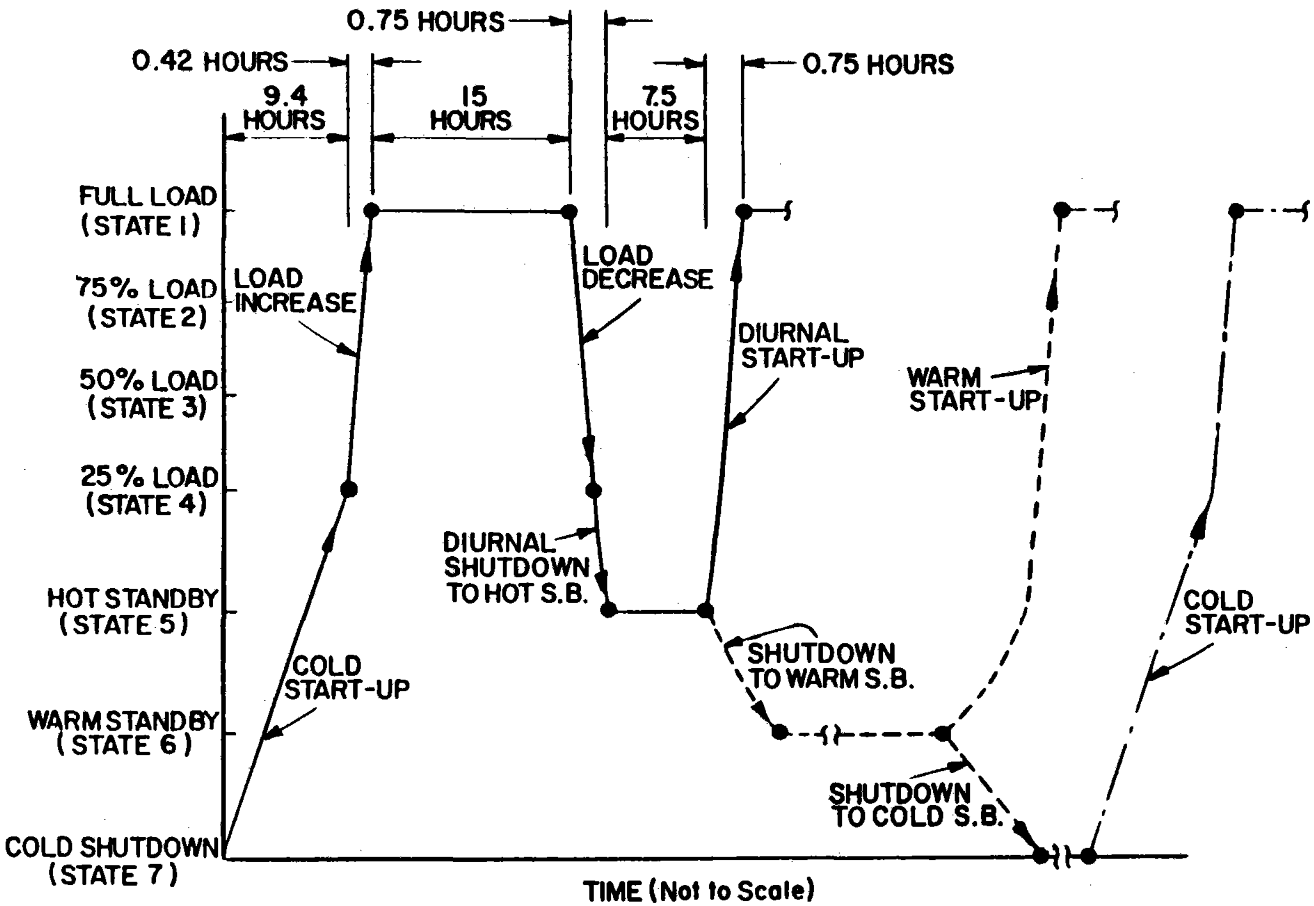


FIGURE 5-41 TYPICAL STEAM GENERATOR OPERATING MODE

mode (State 7) for maintenance or other reasons. From the cold shutdown mode, the SGS is brought to full-load as described earlier.

Proper procedures and safeguard mechanisms are also built into the control system for safe, orderly shutdown resulting from the following emergency events.

- Turbine trip
- Loss of feedwater flow
- Loss of salt flow
- Rupture of any water/steam/salt pipe
- Rupture of heat exchanger tube
- Loss of pneumatic pressure
- Failure of control systems
- Loss of all station power.

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_2$6 HE86W	34.4 (272,701)	15,793 (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^2(watt/ ft^2)**
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 (0.381×10^6 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 87 kQ (0.299×10^6 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 4-2. The actual routing of these lines are shown on Figures 5-42 and 5-43. The design characteristics of these four lines are shown in Table 5-7. 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]).

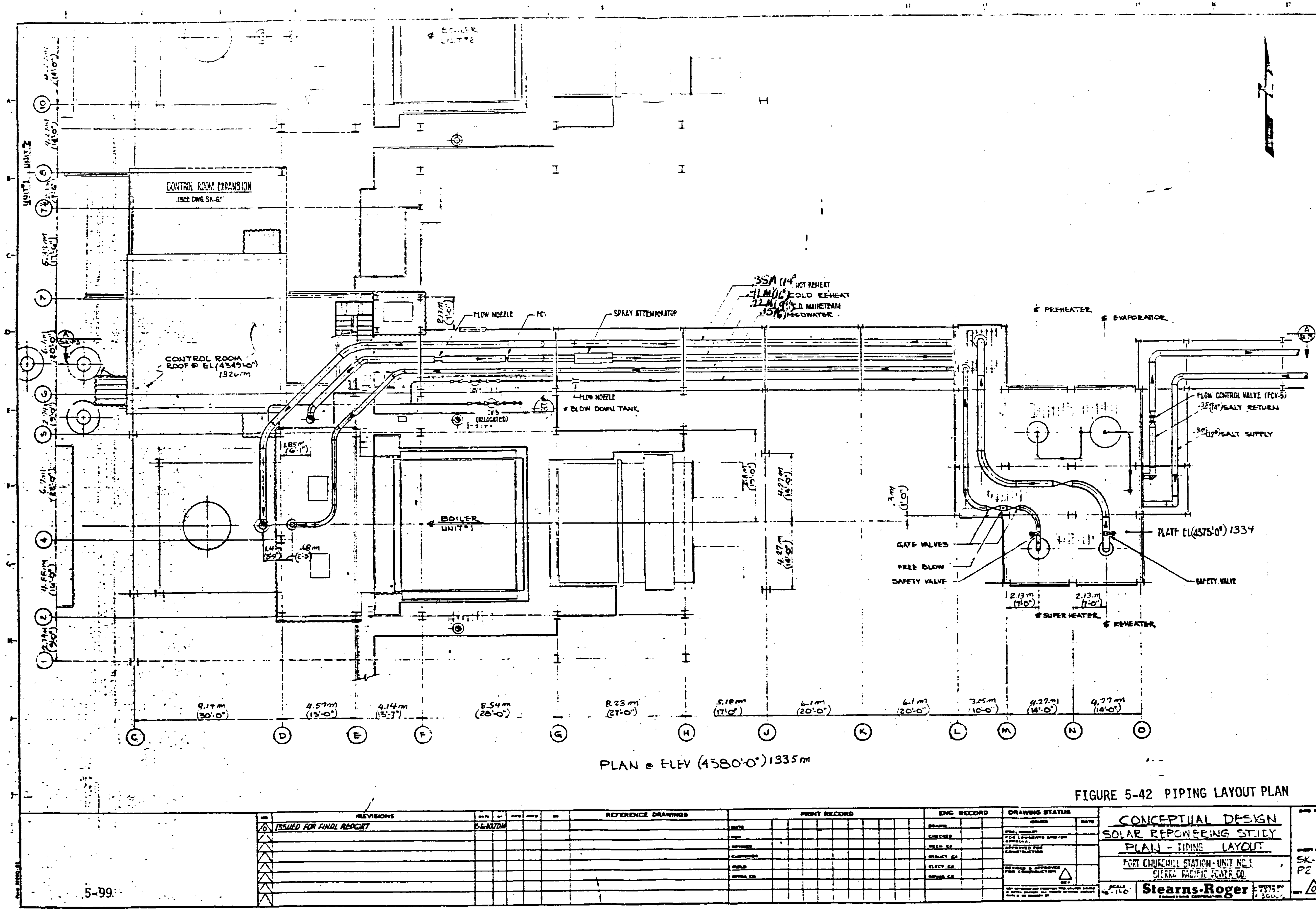


FIGURE 5-42 PIPING LAYOUT PLAN

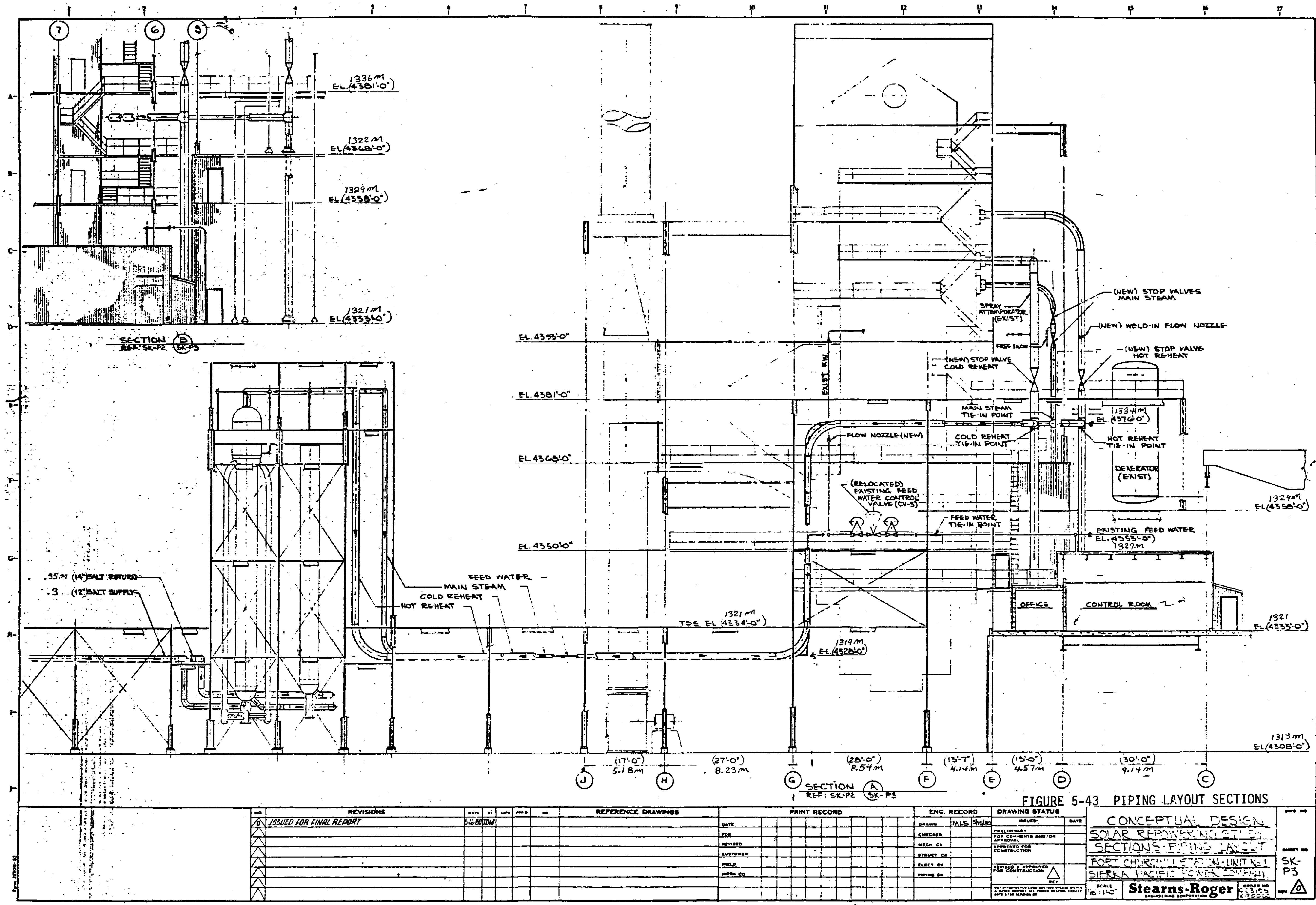


FIGURE 5-43 PIPING LAYOUT SECTIONS

TABLE 5-7

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	.17	.31	.41 Sch. 40	.13 Sch. 160
Mimimum Wall	mm	27.4	19	12.5	18
Nom. O.D.	m	.22	.35	.41	.15
Weight/m	Kg/ m	134.4	158	124	67.8
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 15.3 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)	13.7 (1985)	3.9 (500)	3.5 (500)	15.5 (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 4-2. 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 500 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:

<u>Electrical Equipment List</u>

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

17 Transformers, pad mount, 3 phase, 500 KVA, 4160-208 V/ 120 volt, for heliostat field.

Lot Lighting and Power Panels

1 Emergency engine generator, 500 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 has been greatly simplified by the fact that all fuel displacement will come against natural gas. The total cost with all allocations and factors is $\$158 \times 10^6$. This cost included heliostats at $\$198/m^2$ and conceptual estimates for other solar equipment. The fuel costs and economic analyses were made using economic data supplied by SPPCo. The economic and financial data are compared to the previous study in Table 6-1.

A capacity credit of $\$17 \times 10^6$ was assumed under all cases. This credit is based on the expected increase in the usable life of Unit #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 is needed to produce a more accurate capacity credit.

6.2 RESULTS AND CONCLUSIONS

6.2.1 Grid Dispatch Analysis Results

Sierra Pacific forecasts that the Ft. Churchill units will be run at 0.79 capacity factor throughout their remaining useful life. Hence, all fuel displacement is against natural gas. No additional grid dispatch analysis was required.

The total cost and project value are computed in Table 6-2. The project shows a net present value of - $109.9M, indicating a cost in excess of worth. The degree of subsidy required to make the cost equal to the value (net present value of zero) is about $58M or 58%. of the project cost.

The typical load and output characteristics for the baseline plant are shown in Figure 6-1. These characteristics are for week 22 of 1995 and with projected load and capacity available to SPPCo. The plant is operated at a minimum 40 MWe overnight to minimize cycling impact on the fossil equipment and turbine. Solar output is based on a typical week of insolation profiles in early summer.

TABLE 6-1

SIERRA PACIFIC COST AND FINANCIAL DATA

	FEBRUARY, 1982	JUNE, 1980 (1982 $)
FUEL TYPE	NATURAL GAS	RESIDUAL OIL
1982 COST	$4.64/GJ (4.4013 $/10^6 Btu)	$6.18/GJ (5.86/10^6 Btu)
ESCALATION RATE	10% /YEAR	12%/YEAR
LEVELIZED FIXED CHARGE RATE	20.4%*	15%/YEAR
CAPITAL ESCALATION RATE	10%, 1982 - 8% AFTER	7%, 1982 - 6% AFTER
O&M ESCALATION RATE	10%/YEAR	10%/YEAR
COST OF CAPITAL	17%/YEAR	11.6%
DISCOUNT RATE	17%/YEAR	11.6%
COAL COST	$2.20/GJ (2.0812 $/10^6 Btu)	$2.10/GJ (1.99/10^6 Btu)

*The June 1982 value is 19.3%.

TABLE 6-2

REPOWERED FT. CHURCHILL UNIT 1 COST/VALUE ANALYSIS

Annual Energy Delivered to Grid = 93.5 GWhe

Station Heat Rate = 9807 Btu/KWh

Annual Fuel Displaced = 923,800 x 10^6 Btu

Baseline Construction Cost, including owner's cost 1982 Dollars = $99.4M

Escalation to 1986 Dollars = $137.8

Plus Allowance for Funds during Construction = $158.4
(15% of Construction Cost)

Levelized Cost, 1986 Dollars = $32.3M
(Fixed charge rate times total cost)

Present Value of 30 Years Capital Cost, 1986 Dollars = $188.4M

Annual Fuel Displacement Value, 1982 Dollars = $4.04M

Annual Fuel Displacement Escalated to 1986 Dollars = $5.91M

Average Year Annual O&M Cost, 1982 Dollars = $534.1K

Annual O&M Cost Escalated to 1986 Dollars = $782.0K

Net Revenue, 1986 Dollars = $5.13M

Net Cash Flow in 1986, 1986 Dollars = <$27.2M>

Present Value of 30 Years O&M, 1986 Dollars = $9.57M

Present Value of 30 Years Fuel Displacement, 1986 Dollars = $71.1M

Capacity Value, 1986 Dollars = $17M

Net Present Value of Plant, 1986 Dollars = <$109.9M>

Present Value Cost/Benefit Ratio = 2.40

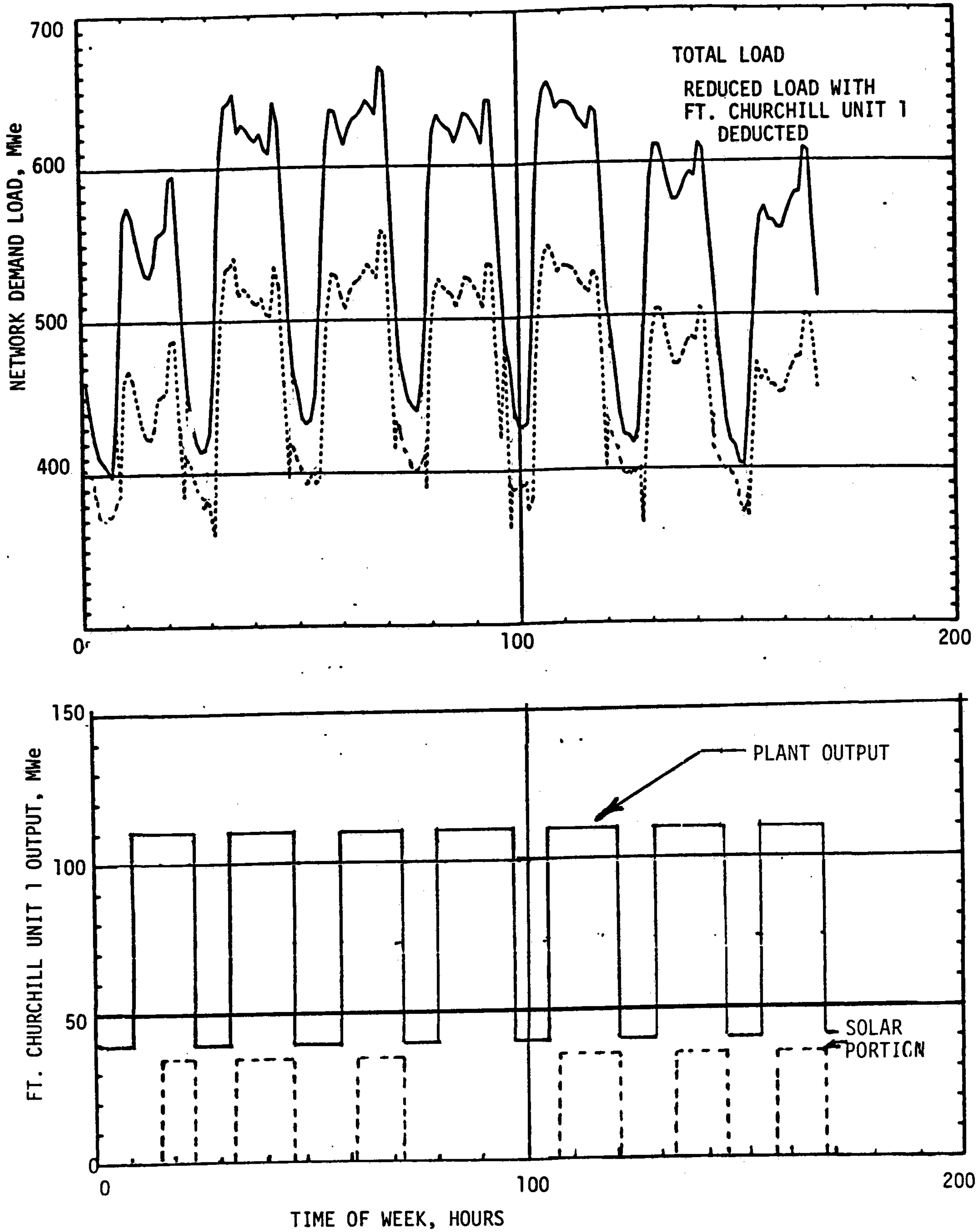


FIGURE 6-1 SOLAR AND FOSSIL OUTPUT PROFILES, WEEK 22

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. Hence, the fast response times indicated in Figure 6-1 may be practical and desirable.

6.2.2 Economic Findings and Conclusions

The economic findings of this study are heavily influenced by the cost and financial parameters of Table 6-1. These parameters primarily affect the present value of capital cost and the present value of fuel displaced.

In the previous study, repowering was found to be competitive with continued operation on oil at the Ft. Churchill plant. Several economic factors, as outlined in Table 6-1, have combined to reverse this picture at the present time. The principal changes are due to:

a. The availability and low cost of natural gas.
b. The high interest rates and fixed charge rates.
c. The high discount rates for the value of future fuel savings.

These factors combine in the computation of net present value of fuel save and capital cost. The net present value of the plant capital cost uses four principal parameters; total plant cost including fees, owner's cost, interest during construction, and all other indirect and distributables; levelized fixed charge rate including equity, debt service, taxes, 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:

$$PVF = \frac{1}{1 + i} \left[\frac{1 - x^n}{1 - x}\right] . \qquad (1)$$

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 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:

$$PWC = C \times FCR \times PVF \times R \qquad (2)$$

where C is the total capital cost

FCR is the fixed charge rate, and

R is a factor which provides for inflation.

$$R = \left(\frac{1 + r}{1 + i}\right)^m \qquad (3)$$

where r is now the inflation rate, and

m is the number of years to project completion

The nominal example for SPPCo would use:

$C = \$99.4 \times 10^6$
AFDUC Factor = 1.15
FCR = 0.204
PVF = 5.83
R = 0.726

The present worth of the capital cost of the repowered plant would then be

PW = \$98.7

This present worth cost would move up or down, depending on any of the above parameters.

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. The equation equivalent to equation (2) for the present value of fuel saved is:

$$PWF = AC \times PVF \times R, \qquad (4)$$

where AC is the annual cost of fuel saved in current year dollars.

The nominal example for SPPCo for all savings in natural gas is:

AC = \$4.04M

PVF = 12.04

R = 0.781

$PWF = \$38.0 \times 10^6$

The major impact of these changes is in the high ratio of discount rate to fuel escalation rate. This ratio appears in formulae for present value. When the discount rate is high and substantially larger than the fuel escalation rate, the present value of future fuel savings is very minimal.

In today's volatile economic climate, it is very difficult to forecast the trends of significant economic parameters. It is therefore, interesting to speculate on what might happen to make the project economically attractive.

Factors Reducing Cost - The project cost can be reduced by a significant amount in several ways:

- Direct subsidy by the Federal Government.
- R&D expensing by the utility and regulatory agency.
- Third party financing utilizing investment and energy tax credits.
- Consortium contributions anticipating direct benefit from the demonstration. demonstration

Of these ways, the only one currently in place is the tax credits resulting from third party financing. The effect of investment tax credits would be similar to a 25% to 36% reduction of capital cost, depending on whether the credits and depreciation are sold on a lease back arrangement or taken by the third party investor. However, the $4M annual revenue generated by the plant for steam sales would not approach the level necessary for an attractive third party financed project. A major investment from the federal government would be required to make the project viable under present economic conditions.

Factors Improving Value - The two factors which could improve the value of the project are an increased fuel cost and a decreased cost of money. Fuel costs are unlikely to increase by an amount which would make the project viable because of the constraining influence of coal prices. Repowering Ft. Churchill with coal will remain an alternative to use of oil/gas should prices escalate rapidly.

A decreased cost of money affects also the levelized fixed change rate and the discount rate. This is the most likely near-term change which may affect the viability of the project.

Comparative present values for the 110MWt design and the 330 MWt design of the previous study are shown in Table 6-3. The financial and economic data of Table 6-1 are used. From the data of Table 6-3, the impact of changing economic and financial parameters is clearly seen. The value of fuel saved is reduced because of lower cost fuel. But much more important is the value of fuel savings discounted to 1982 present value. The lower escalation rate (10% vs 12%) and higher discount rate (17% vs 11.6%) combine to make fuel savings near the end of the plant life have a very low present value (12% vs 113% in the previous study for the last year of operation).

TABLE 6-3 PRESENT VALUE COMPARISONS

COMPARISON	PREVIOUS STUDY AT 330 MW_t	PRESENT STUDY AT 110 MW_{th}	3 MODULE REPOWERING AT 330 MWe
CAPITAL COST (10^6 1982 $)	235.7	99.4	256.5
ESCALATION FACTOR TO 1986 $	1.27	1.39	1.39
AFDUC	1.15	1.15	1.15
FIXED CHARGE RATE	0.15	0.204	0.204
PRESENT VALUE FACTOR	8.30	5.83	5.83
DISCOUNT RATE TO 1982 $	0.645	0.534	0.534
PRESENT VALUE CAPITAL COST MULTIPLIER	1.176	1.011	1.011
PRESENT VALUE CAPITAL COST (10^6 1982 $)	277.2	100.5	259.4
ANNUAL FUEL SAVINGS (10^6 1982 $)	16.7	4.004	12.012
ESCALATION FACTOR TO 1986 $	1.574	1.464	1.464
PRESENT VALUE FACTOR	28.37	12.04	12.04
PRESENT VALUE FUEL MULTIPLIER	33.39	9.41	9.41
PRESENT VALUE OF FUEL SAVINGS (10^6 1982 $)	557.6	37.7	113.1

Section 7

DEVELOPMENT PLAN

7.1 DESIGN PHASE

General

The development plan for the repowering of Ft. Churchill No. 1 with a full-size solar field was generated on the Phase 1 study and reported in SAN 0609-1. The present Phase 2 effort includes the refinement of the original data and the incorporation of a modularized approach to this project. Two critical areas were identified on the development plan for the full-size repowered plant. They were the receiver development and fabrication and the production of 8,411 heliostats. The results of the Phase 2 effort show that both of the critical areas are improved with the modular approach. The design of the smaller receiver used on the one-third size modular field will result in a simplification in the receiver design and will permit the direct application of some of the design criteria generated on the DOE-sponsored receiver SRE. The smaller solar field (2,565 heliostats instead of 8,411 heliostats) will shorten the time needed to manufacture and install these units. These changes are incorporated into the new development plan. This new plan is based on time from ATP, instead of absolute dates, so that it can be utilized for the program with the least amount of updating.

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. System engineering activities will start with a contract go-ahead. 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) 39 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 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, 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 would be recommended. During this time, System Engineering could develop more definitive requirements and better system and subsystem specification. A more orderly approach toward interface requirements, plot plans, layouts, and operating and maintenance requirements would be developed.

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 2 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 4 months, and Interface Documents at 6 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 at 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 one (1) month 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.

The DOE-sponsored receiver SRE program being conducted by Foster Wheeler will provide data on the design of an "omega" partial cavity receiver and the tube welding required on this type of unit. These data will provide some of the preliminary design data required; however, this task is not completely eliminated. A functional design phase is still needed to apply the SRE data to the specific configuration needed for the one-third module size unit for Ft. Churchill No. 1.

Tests of the MMC receiver panel at the Central Receiver Test Facility (CRTF) have provided adequate and timely data for the receiver panel design. Therefore, no additional panel tests are envisioned.

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 design changes are anticipated at this time. Operational activities will begin upon receipt of approved contract.

7.1.6 Master Control Subsystem

The software design effort will begin one (1) month after ATP. Hardware design will begin 3 months after ATP. The concurrency of design will permit early hardware procurement and software development and procurement, so that subsequent laboratory preparations can be accomplished to support start of the integration program.

7.2 CONSTRUCTION PHASE

General

This phase is broken down into two sections: first, the procurement and fabrication of 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 completed in the first 10 months for earthwork, warehouse, and mechanical equipment. This activity will continue until the last construction bid package for painting is released during the 26th month after ATP.

Site construction activities (earthwork) are planned to start in the 11th month and to be completed by the 16th month. This will then permit construction activities associated with the heliostat and thermal storage tank foundations to start as planned during the 16th month, and the tower and warehouse foundations to start two months later. Installation activities on site will begin in the 17th month for collector field electrical, and will end with electrical, and controls and instrumentation in the 36th month.

7.2.2 Receiver Subsystem

The program of panel weld development will be completed on the receiver SRE before the start of this program. The panel tooling will start in the 3rd month and panel fabrication will start in the 12th month. 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 during the 26th month--the same date delivery of the last receiver panel is expected on site. Panel installations will be completed during the 31st month. 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 during the 4th month. The MDAC plan is to fabricate, assemble and test three major subsystems prior to site delivery. Controllers, which will start fabrication during the 12th month, will be solely built and tested at MDAC. First delivery to site will be during the 16th month. 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 an 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.

Installation of the first heliostat is scheduled during the 18th month, one month following the completion of first foundation. Final installations and start of stand-alone testing will occur the 31st month.

7.2.4 Master Control Subsystem

Upon the receipt of hardware, during the 16th month, 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 during the 30th month, 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 in the 27th month.

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 during the 13th month after ATP.

The second critical path involves the software development for the master control subsystem. The development of software specifications requires an accurate functional/operational simulation of plant dynamics and the control algorithms required to achieve control. The hardware/software integration and checkout in the System Integration Laboratory has proved to be invaluable in the successful startup of Solar One.

The receiver panel design, development and fabrication had been a critical path in the longer schedule of the 330 MW_{th} receiver. Design and development work on the receiver SRE has enabled this schedule to be shortened, such, that it is no longer critical. The one potentially critical path in the receiver schedule involves the loads and interface requirements on the tower through tower design and construction.

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.

REPOWERING - FORT CHURCHILL
MASTER PROGRAM PHASING SCHEDULE

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
A		[illegible]	[illegible]
B		[illegible]	[illegible]
C	Modularize Solar System	11 May 82	[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 / DASH NUMBERS OPPOSITE	PREPARED [illegible]			
	APPROVED [illegible]			
PART OR IDENT NO.	CHECKED	SIZE A	CODE IDENT NO. 18355	DRAWING NO. 1D22600
	DESIGN ACTIVITY APPROVAL			
FOR USAGE DATA SEE ENGINEERING RECORDS	CUSTOMER APPROVAL	SCALE		SHEET 1 OF

13 1A21 01 SEPT 71

SHEET REVISION RECORD

SHEET NO.	REVISION

MCDONNELL DOUGLAS ASTRONAUTICS CO.
HUNTINGTON BEACH, CALIF.

MCDONNELL DOUGLAS

SIZE	CODE IDENT NO.	DRAWING NO.
A	18355	

SCALE	REV	SHEET

60-0213-1A19 (01 DEC 71)

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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 repowering 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)

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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

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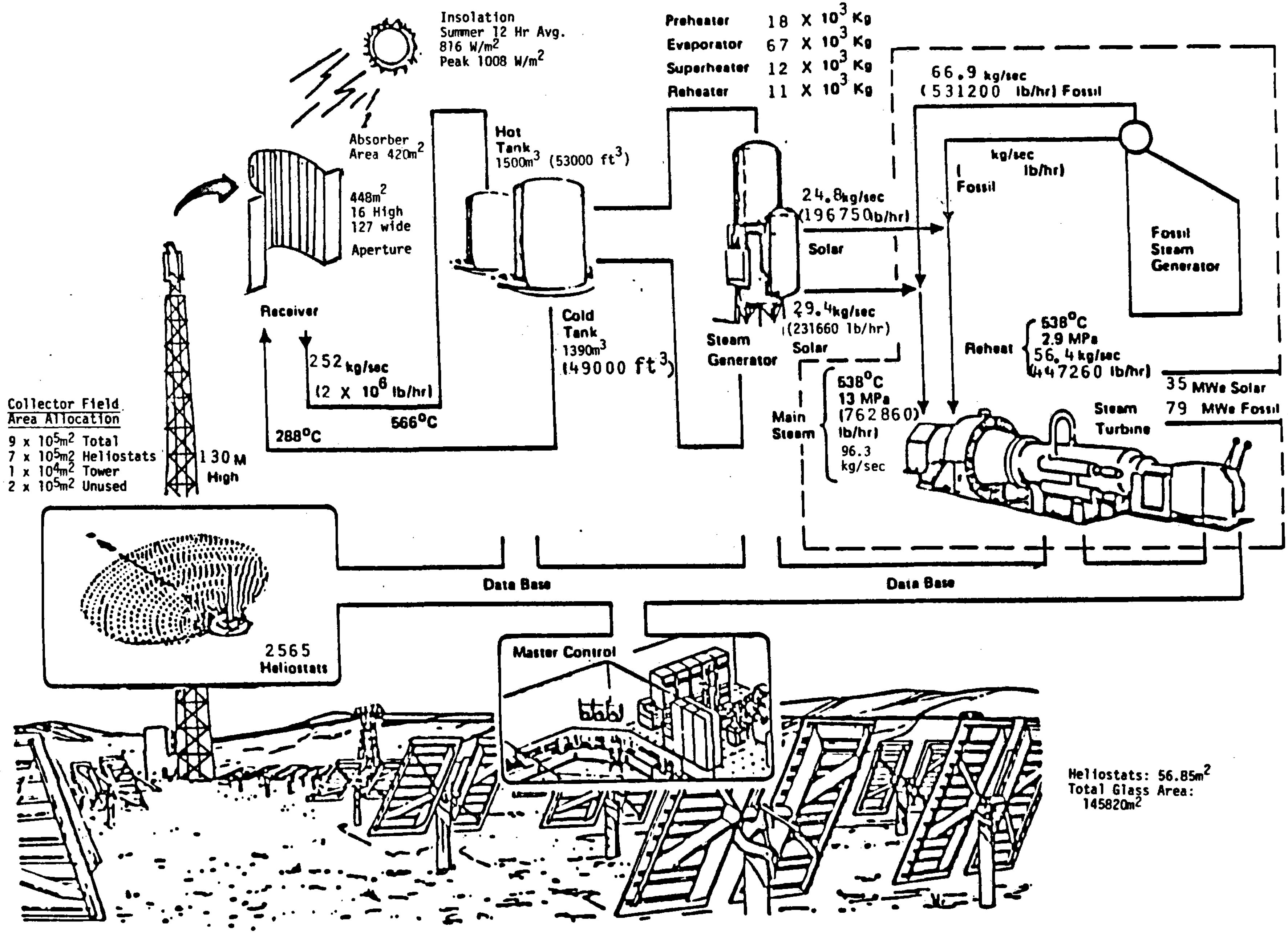

Figure 4-1 Sierra Pacific Power Co. Fort Churchill No. 1

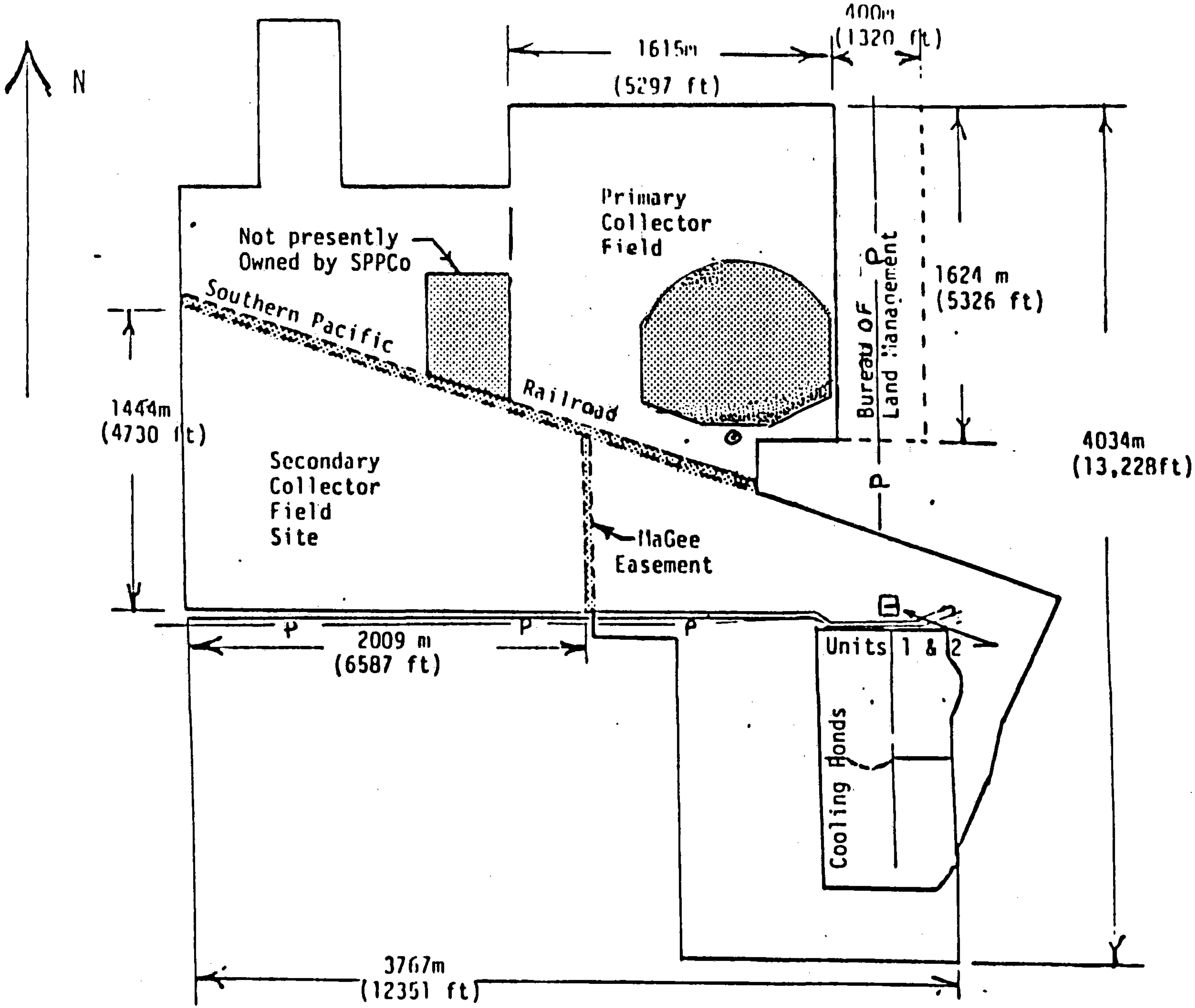

Figure 1.2 Fort Churchill Site Plot

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1.2.1 Site

The site is located 75 km 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 site 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 2,565 heliostats of 56.86 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 145,820 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 National Laboratory, Livermore. 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: 56.85 m^2 (612 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 2565 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 field layout is shown on Figure 1.3.

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 and (12) internal cavity panels. The aperture plane is vertical with the absorber panels stairstepping back at an angle of 25°. 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 110 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 14 absorber panels are arranged in two parallel passes of 7 panels each in series. This arrangement is as follows:

Pass	Panels	
1	L1	R1
2	L2	R2
3	L3	R3
4	L4	R4
5	L7	R7
6	L5	R5
7	L6	R6

1.2.4.1 Absorber Panel

The absorber panels will consist of panels which are 16 meters long and which will be of three different widths. The tubing used will be 28.6 mm (1 1/8") x 1.65 MM (.065") made from Incolloy 800. The panel width data will include the following:

10 panels - 1.86 meters wide with 60 tubes
2 panels - 1.67 meters wide with 54 tubes
2 panels - 2.06 meters wide with 66 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 under all 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

Molten nitrate salt, 60% sodium nitrate/40% potassium nitrate by weight.

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 .3M x 10.3 mm (12" x .406") carbon steel pipe. The downcomer will be a .25M x 9.3 mm (10" x .365") pipe made of 304 CRES. Expansion loops 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 a steel tower that is 120.1 m(394 ft) in height (ground level to tower top). The top of the tower will be 15.0 m (49.23 ft) in diameter with a base that is 24.0 m (78.75 ft) diameter. The tower will set on a mat which has a diameter of 24.0 m (95 ft) and a thickness of 2.90 m (9.5 ft).

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 .066 m^3/s (1050 GPM) when operating with a head of 212 M (700 ft). These pumps will be powered with electric motors of approximately 374 KW (500 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 .10 M^3/s (1600 GPM) at a head of 84.8 M (280 ft). The heat exchanger feed pumps will be of stainless steel construction. The two pumps will be powered with an electric motor of 154 KW (207 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 with integral steam drum

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 steam 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 controller 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 the 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 500 KW emergency diesel generator for emergency conditions. The 500 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 annual energy 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 power output provided by a conversion device divided by total input power at specified conditions.

Conversion Efficiency, Net - Actual net power 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 35,000 KW Solar/79,564 KW fossil
c. Solar only 54,849 KW (max)

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 gravel 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 110 MWth (absorbed) or 115 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 stairstepped at an angle of 25° from the horizontal. The front aperture opening for the receiver will be approximately 13.5 meters wide and 16 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° to 33°C (23°F to 92°F)
Azimuth Angles - at all angles (Note: Gimbal lock does not occur within the proposed field boundaries.)

b. Temperature - -5° to 33°C (23°F to 92°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 595 KVA (395 KW) for emergency stow with a duration of 20 seconds. The average power during normal operation is 225 KW.

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 total weight on the tower top shall not exceed 377,000 Kg ($.83 \times 10^6$ 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 spillage irradiance at a level of 10 kW/m^2, at any location, and for time intervals of 12 hours.

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	419 m^2	4,510 (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	110 MW_t	$.375 \times 10^9$ (Btu/hr)
e.	Receiver coolant fluid	Molten nitrate salt, 60% $NaNO_3$, 40% KNO_3 by weight	

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)	110	115	20
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 2.6 MPa (375 psi)
- Design Temperature 593°C (1100°F)
- Pipe Material ASTM A312 (304 SS)
- Code ANSI B31.1

Hot Fluid Horizontal Piping:
- Design Pressure 2.6 MPa (375 psi)
- Design Temperature 593°C (1100°F)
- Pipe Material ASTM A312 (304 SS)
- Code ANSI B31.1

Riser:
- Design Pressure 5.8 MPa (850 psig)
- Design Temperature 302°C (575°F)
- Pipe Material ASTM A106-GR.B
- Code ANSI B31.1

Cold Fluid Horizontal Piping:
- Design Pressure 5.8 MPa (850 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. Each pump shall meet the following requirements:

a. Capacity	.066 m^3/S (1050 GPM)
b. Head	212 m (700 ft)
c. Efficiency (minimum)	75%
d. Type Drive	Electric Motor
e. Motor Power	375 Kw (500 HP)
f. Motor Speed	1800 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. Each pump will have the following requirements:

a.	Capacity	.10 m^3/S (1600 GPM)
b.	Head	85 m
c.	Efficiency, Minimum	75%
d.	Type Drive	Electric Motor
e.	Motor Power	205 KW (275 HP)
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 410,000 KG (900 KIPS) at a height of 133 m (receiver center line to ground level).

The tower will survive wind loads resulting from a 40 m/s (90mph) wind at 10 m elevation from any direction and will survive an earthquake having a simultaneous .05g veritical 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 (gross)
2.	Hybrid	37 MWe to 115 MWe fossil, 20 MWe to 40 MWe Sol ar
3.	Solar only	20 MWe to 54 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 controller(s) - 5
10. Strip charts - 4

II Field Process Control Electronics.

A. Receiver Subsystem (Reference only, part of Receiver)

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 (Reference only, part of Collector)

1. Heliostat control processors - 2
2. Heliostat controllers - 2565
3. Incremental encoder circuit assemblies - 2565
4. Mother board circuit assemblies (for HFC) - 80
5. Heliostat field controllers - 80
6. Cabling harnesses - 2565
7. Data bus interface controller - 2
8. Power supply - 2
9. Termination panel - 2

C. Thermal Storage and Steam Generation Subsystem

1. PID controller processors - 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. (Reference only, part of Collector)

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

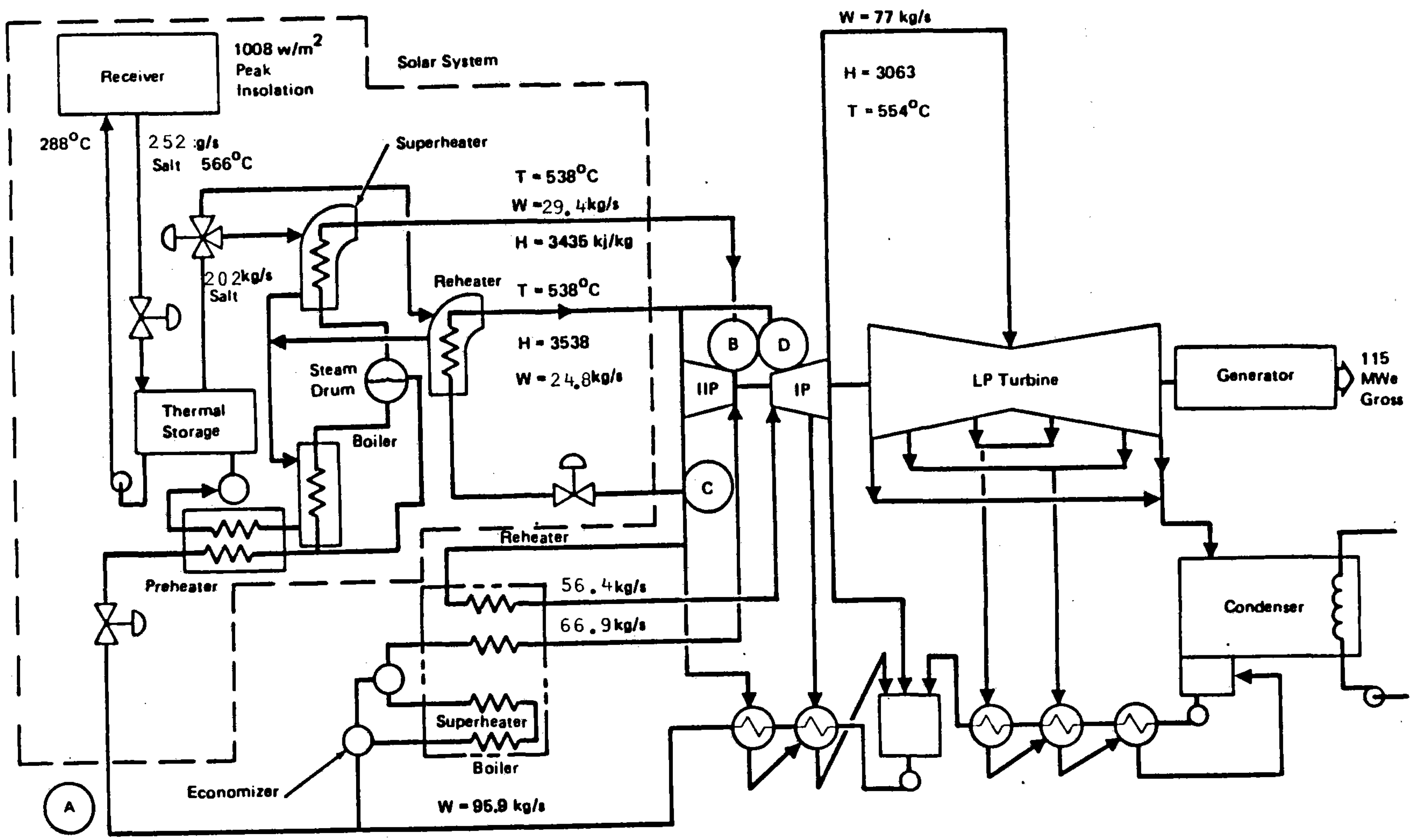


Figure 3 1. Interfaces

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	278 MWH_{th}
b.	Type	Two tank - hot and cold
c.	Receiver fluid	Molten nitrate salt
d.	Fluid Quantity	2.27×10^6 Kg (5×10^6 lb)
e.	Hot fluid temperature	566°C (1050°F)
f.	Cold fluid temperature	288°C (550°F)
g.	Pressure	690 ± 690 Pa (.1 ± .1 psig)
h.	Charging Rate - Max.	110 MW_{th}/ hr
i.	Discharging Rate - Max.	170 MW_{th}/ hr
j.	Thermal Leakage Rate	1% per day
k.	Trace heating rate-max	0.13 MW (4.6×10^5 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.	830 m^2	(9000 ft^2)
3.	Weight - max. (wet) - max. (dry)	30400 kg 18140 kg	(67000 lbs) (40000 lbs)
4.	Heat Exchanged (rated)	30.88 MW	(105.2×10^6 Btu/hr.)
		Shell Side	Tube Side
5.	Fluids	Molten Nitrate Salt	Water
6.	Temperature - inlet	340.6°C (645.1°F)	237.8°C (460°F)
7.	Pressure	2068 kPag (300 psig)	15512 kPag (2250 psig)
8.	Temperature - outlet	287.8°C (550°F)	335.8°C (635.8°F)
9.	Flow rate - max.	375 kg/s	46 kg/s

	(2.976 x 10^6 lbs/Hr	(369,126 lbs/hr)
10. Flow rate - min.	93.6 kg/s (744,000 lbs/hr)	10.75 kg/s (85,355 lbs hr)
11. Thermal efficiency - min	99.9%	

b. Evaporator

1. Type	Parallel flow Tube and Shell	
2. Heat exchanger area-min.	920 m^2	(9900 ft^2)
3. Thermal efficiency-min	99.9%	
4. Weight-max (wet) -max (dry)	104871 Kgs 67152 Kgs	(231,200 lbs) (148,000 lbs)
5. Heat Exchanger	33.8 MW	(115 x 10^6 Btu/hr)
	Shell Side	Tube Side
6. Fluids	Molten salt	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.	375 kg/s (2.976 x 10^6 lbs/hr	46.0 kg/s (369,126 lbs/hr)
11. Flow Rate - min.	93.6 kg/s (744,000 lbs/hr)	10.75 kg/s (85,355 lbs/hr)

c. Superheater

1. Type	Parallel Flow	Tube and Shell
2. Heat Exchanger area-min.	440 m^2	(4800 ft^2)
3. Thermal efficiency-min.	99.9%	
4. Weight - max. (wet) (dry)	18144 kg 12247	(40000 lbs) (27000 lbs)
5. Heat Exchanger (rated)	21.0 MW	(71.8 x 10^6) (Btu/hr)
	Shell Side	Tube Side
6. Fluids	Molten salt	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/s (2.267×10^6 lb/hr)	4.6 kg/s (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.	340 m^2 (3700 Ft^2)	
3.	Thermal efficiency-min.	99.9%	
4.	Weight-max (wet)	18598 kg (41000 lbs)	
	(dry)	10886 kg (24000 lbs)	
5.	Heat Exchanged (rated)	11.18 MW (38.1×10^6 BTU/HR)	
		Shell Side	Tube Side
6.	Fluids	Molten salt	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	123.3 kg/s (9.7×10^5 (lbs/hr)	38.2 kg/s (303,182 lbs/hr
11.	Flow Rate - min	21.68 kg/s (172,000 lbs/hr)	9.54 kg/s (75,745 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

2 Transformers, pad mount, 3 phase, 500 KVA, 4160-208 V/120 volt, for heat tracing

15 Transformers, pad mount, 3 phase, 500 KVA, 4160-208 V/120 volt, for heliostat field.

Lot Lighting and Power Panels

1 Emergency Engine Generator, 500 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, 20 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 demineralized water on the mirror panels. The two trucks shall be capable of washing 2565 heliostats in a normal working month. Note: Washing has been assumed to be subcontracted.

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 58^6 KW (2 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^{o}C (16 to 122^{o}F). Performance requirements shall be met throughout an ambient air temperature range of 0 to 50 ^{o}C (32 to 122^{o}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 7×10^5 m^2 area which contains 2565 heliostats. The collector control system will include:

- 2565 Heliostat Controls (HC)
- 80 Heliostat Field Controllers (HFC)
- 2 Heliostat Array Controllers (HAC) (One redundant)
- 2 Power Supplies
- 2565 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 132° north field layout shown in Figure 5.2. The collector field was optimized in a radial staggered layout.

5.1.1.2 Aim Strategy

The aim strategy consists of a single zone, four-point system. The four points are high/low, right and left.

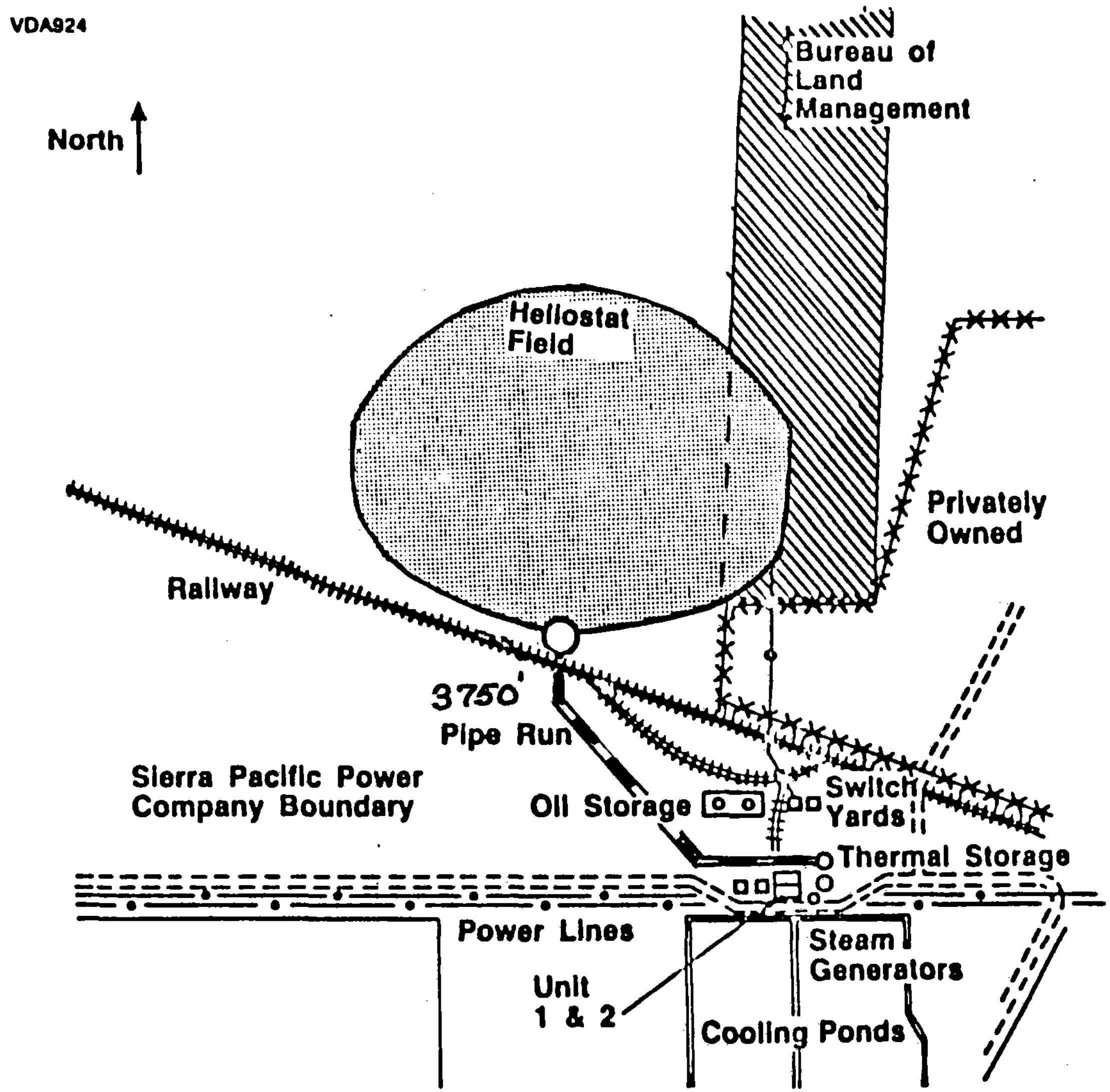
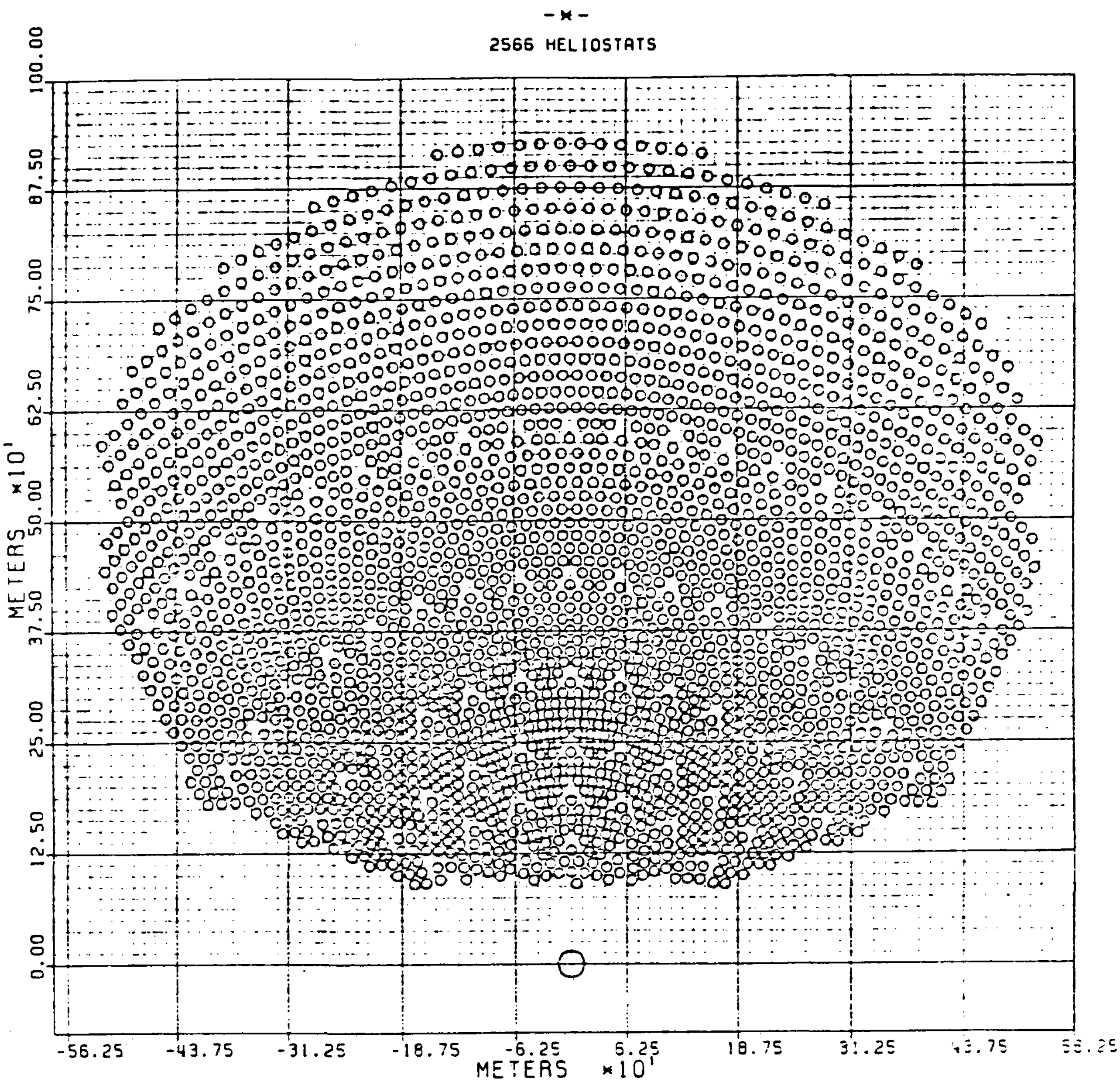
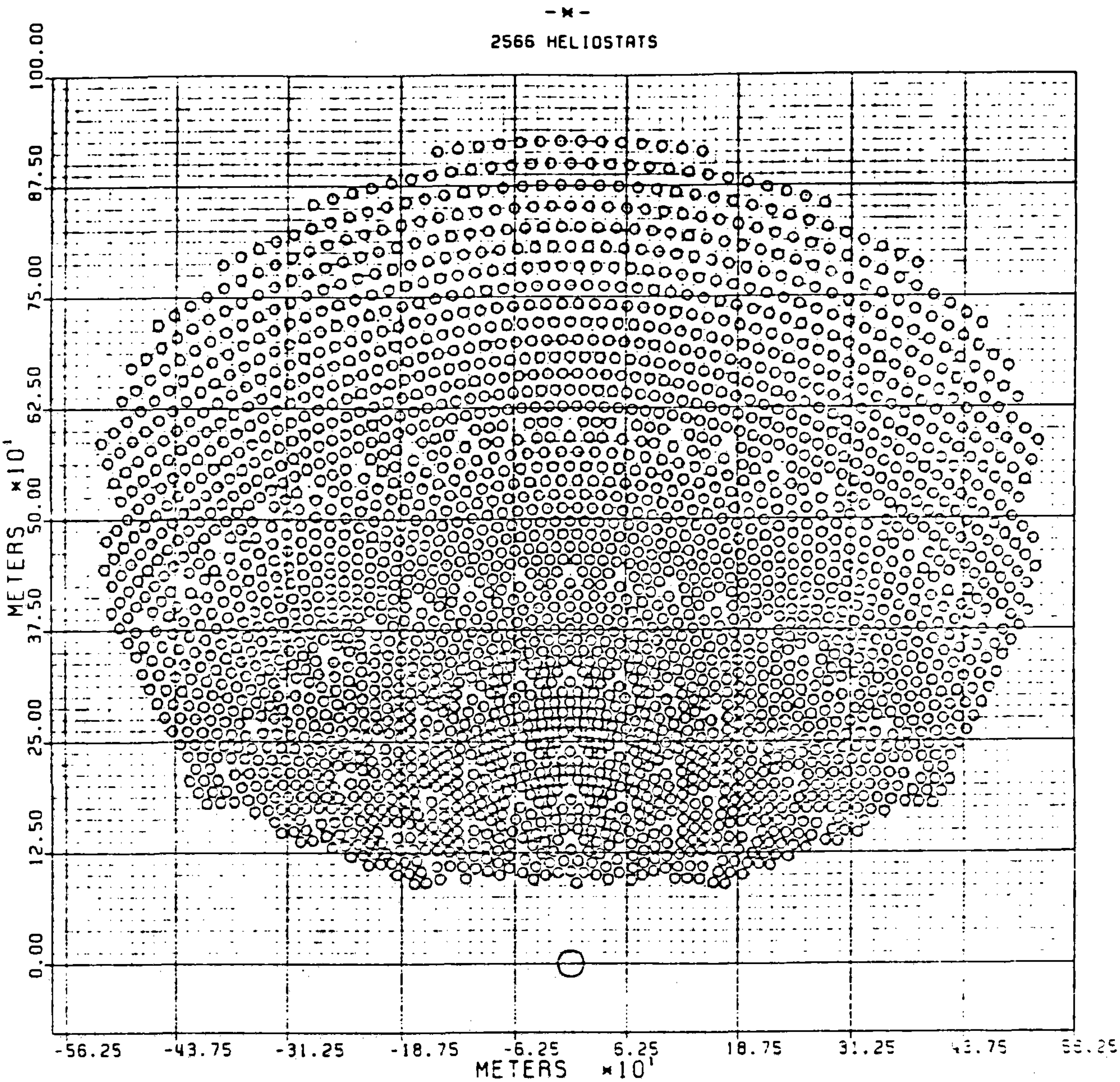


Figure 5.1 Plot Layout



5.2 Collector Field Layout



5.2 Collector Field Layout

5.1.1.3 Heliostats

The heliostat selected for this application is based on the MDAC Second Generation Design. Each heliostat contains 56.85 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	Kilovoltamps
a) Tracking Mode				
Motors	2 watts	3VA		
Electronics	51.3 watts	52 VA		
Total	53.3 watts	55 VA	224 kW	264 kVA
b) Slew Mode (Emergency Defocus)-Sequential Program				
Motors	453.7 watts	709 VA		
Electronics	51.3 watts	52 VA		
Total	505.0 watts	761 VA	416 kW	595 kVA
c) Stow Mode, Normal				
Motors	624 watts	864VA		
Electronics	51.3 watts	52VA		
Total	675 watts	916VA	131 kW	186 kVA
d) Stow Mode, Emergency, High Wind				
Motors	422 watts	659 VA		
Electronics	51.3 watts	52 VA		
Total	473.3 watts	711 VA	445 kW	613 kVA

The heliostats will be mounted on tapered concrete pedestals. The details of this heliostat design (shown on Figure 5.3) 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 Hat 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
Drive Units	192
Pedestal	218
Total	2389

5.1.1.4 Collector Field Performance

The estimated collector field performance is shown on Figures 5.4 - 5.7.

5.1.2 Receiver Data

5.1.2.1 Description

The receiver shall be an omega-shaped, partial cavity design consisting of two (2) external wing panels, and twelve (12) internal panels. The

REFLECTOR SHAPE	RECTANGULAR (8.66 M x 6.87 M)
MIRROR AREA	65.85 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	12°/MIN ELEVATION, 15°/MIN AZIMUTH
DRIVE	AZIMUTH: HARMONIC DRIVE ELEVATION: LINEAR ACTUATORS
CONTROL SIGNAL DISTRIBUTION	HARD WIRE

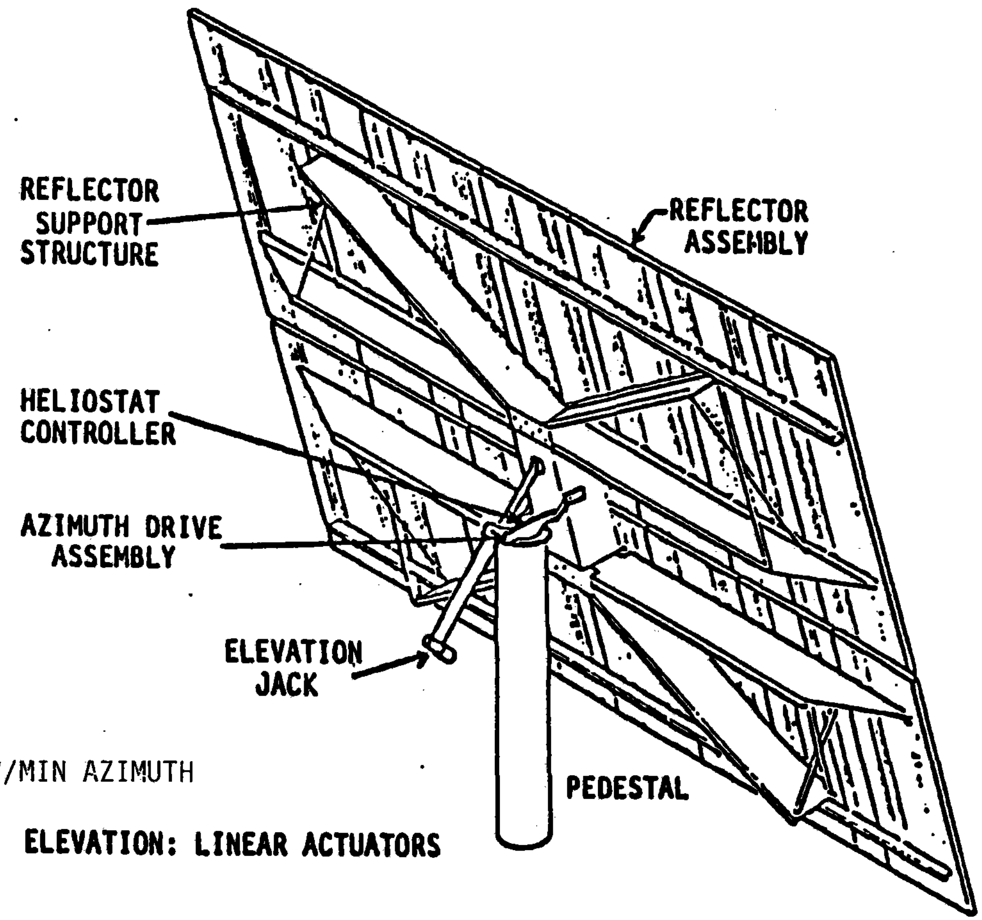


Figure 5.3 MDAC Second Generation Heliostat

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15 May 1982

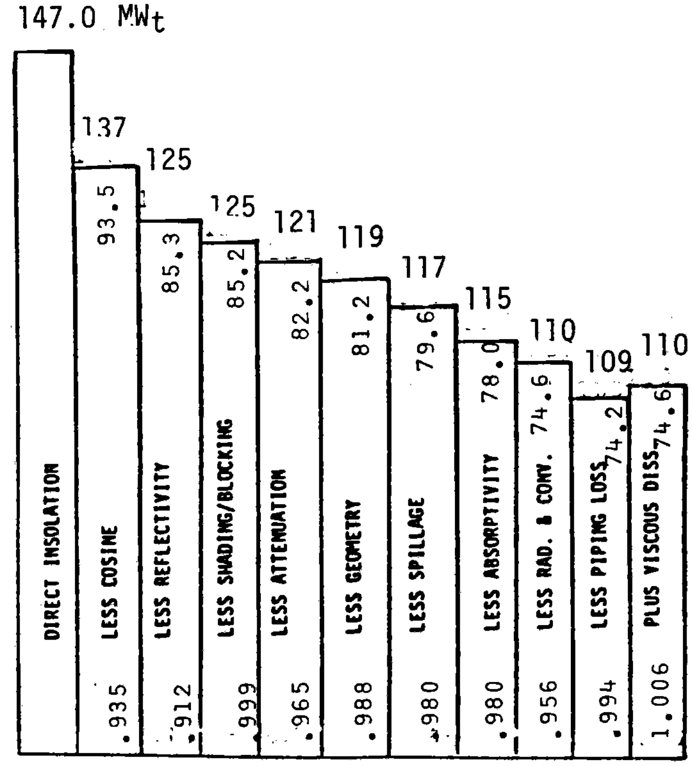


Fig. 5.4 Design Point--Spring Equinox

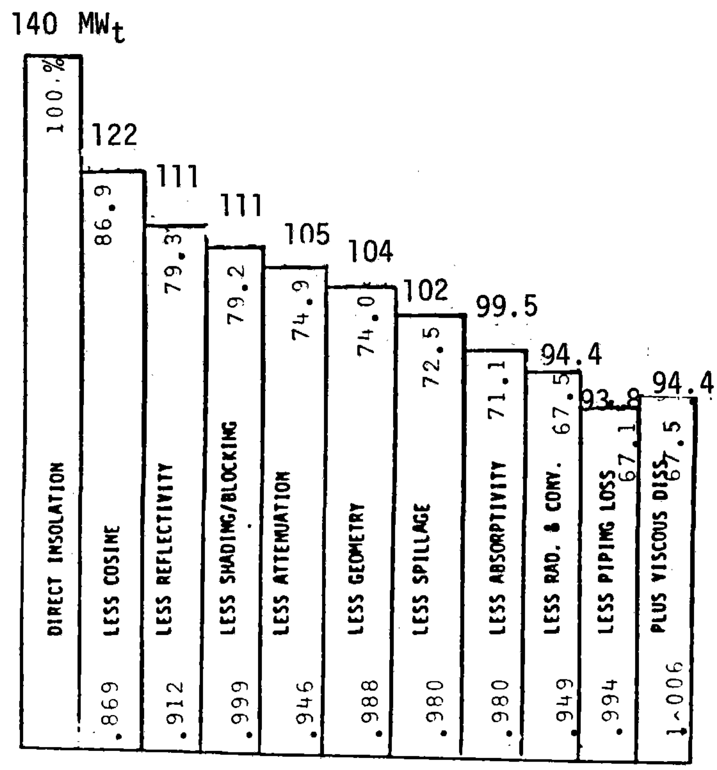


Fig. 5.5 Summer Solstice Noon Performance

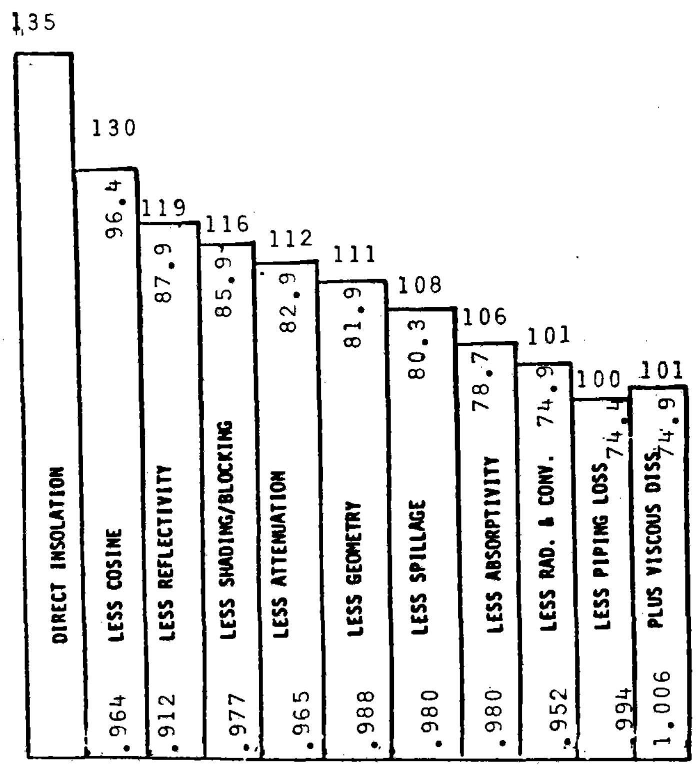


Fig. 5.6 Winter Solstice Noon Performance

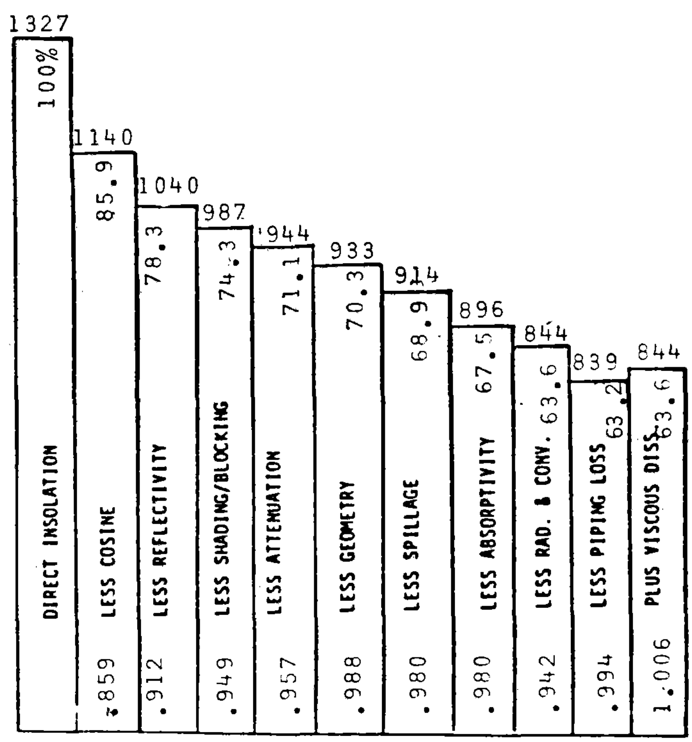


Fig. 5.7 Clear Day Annual Average

aperture plane shall be vertical. The receiver panels are mounted on a 25° incline, with the higher level on the south side of the receiver. 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 110 MW_{th}.

The absorber portion of a receiver panel consists of 28.6 mm (1-1/8 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 31.7 mm (1-1/4 in.) centers. The heated length of each panel is 16 m (52.8 ft.). Panel widths vary from 1.67 m (5.51 ft.) to 2.06 m (6.79 ft.). The heated face of each panel is coated with a high temperature absorptive paint (Pyromark).

Panel	Width	No. of Tubes
L1, R1	1.86 m	60
L2, L5, L6, L7	1.86 m	60
R2, R5, R6, R7	1.86 m	60
L3, R3	1.67 m	54
L4, R4	2.06 m	66

Panels are grouped in a two (2) pass arrangement. Low temperature inlet passes L1 and R1 are positioned toward the front of the receiver, while high temperature passes L5 and R5 are positioned toward the rear of the receiver to minimize ambient heat losses. The other 10 passes are arranged around the sides and back of the receiver.

The arrangement of the receiver circuitry is schematically illustrated in Figure 5.8. 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.

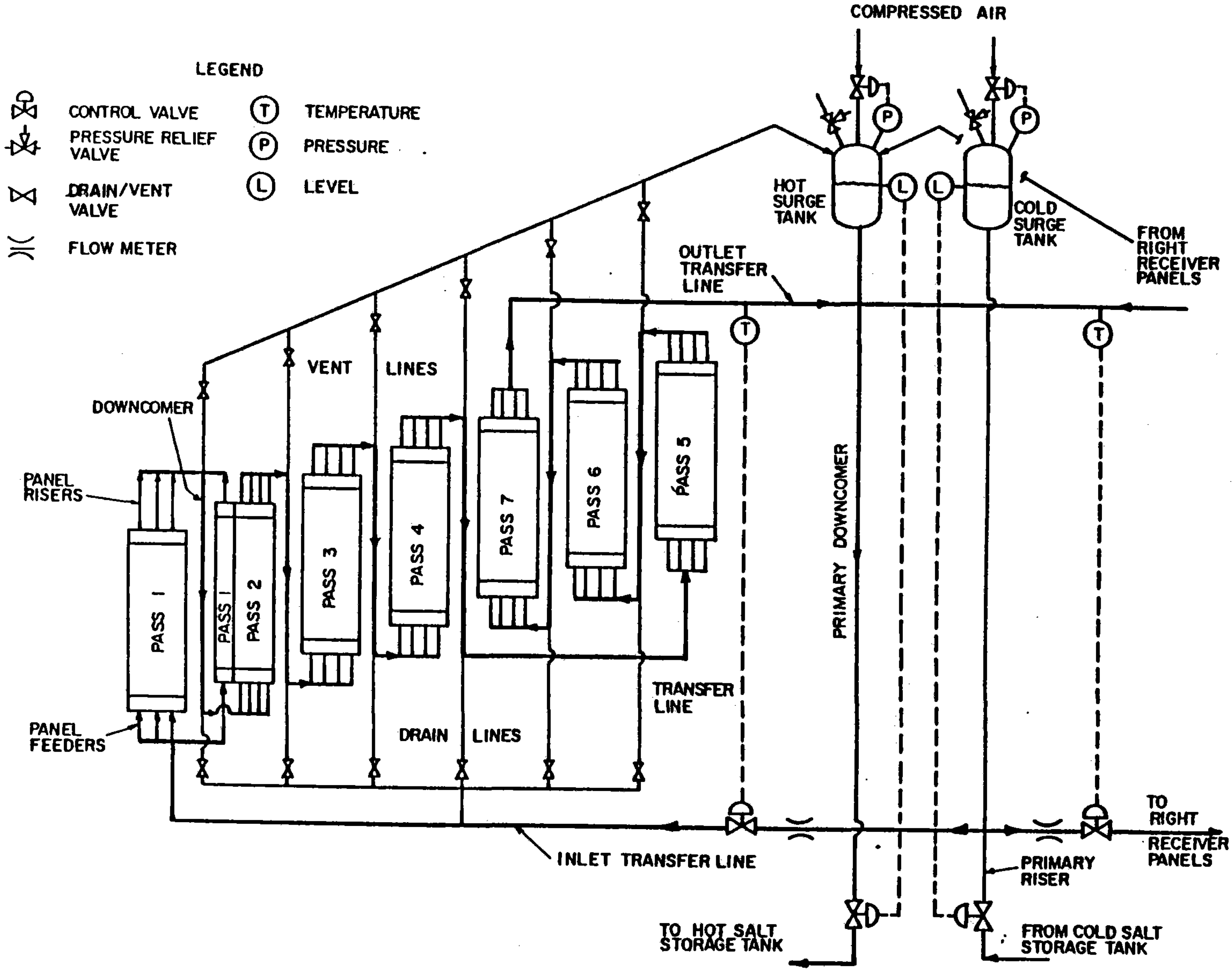


Figure 5.8 Receiver Circuitry Arrangement

All headers, feeders, and risers are 0.20 m (8 in.), 0.10 m (4 in.) and 0.10 m (4 in.) schedule 20 and 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 5.9. The piping layout was arranged to 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 5.8 and Figure 5.9. 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:

- The receiver design point is equinox noon with 110 MW_{th} absorbed, heating 255 kg/sec (2 x 10^6 lb/hr) 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 5.10 for equinox (noon and 4:00 p.m.) and from Figure 5-11 for winter solstice 9:00 a.m.).

The predicted receiver flux map is shown in Figure 5.12 for the design point condition. The desired receiver efficiency values are shown on Figure 5.13. 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 4.5 x 10^5 Kg, 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.	--	120 m (130 m optical)
6. Type of construction.	--	Steel
7. Tower dimensions	--	14.9 m top, 23.9 m bottom
8. Tower foundation dimensions.	--	28.8 m dia. x 2.88 m thick
9. Weights.	--	Receiver system 4.5 x 10^5 kg

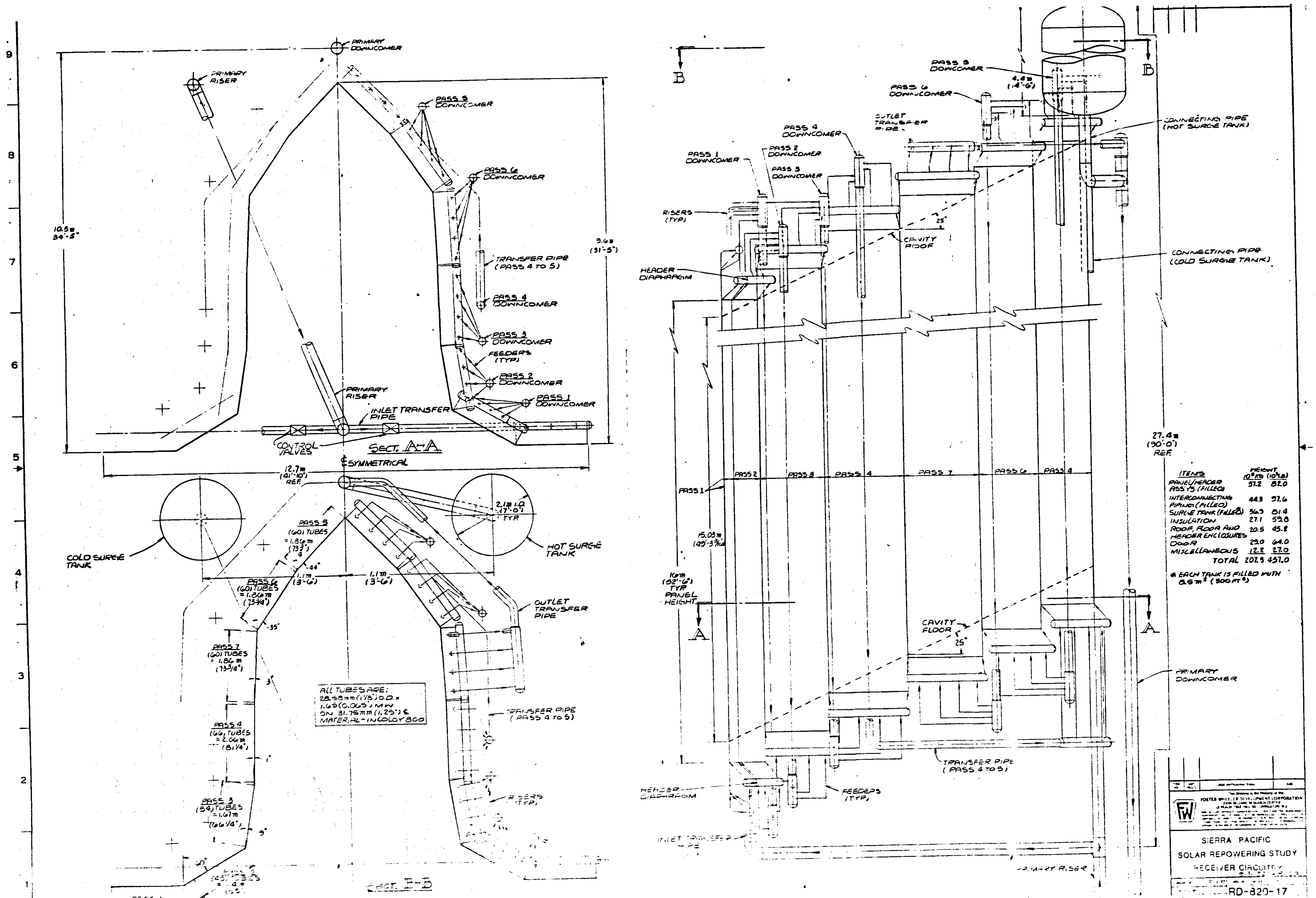
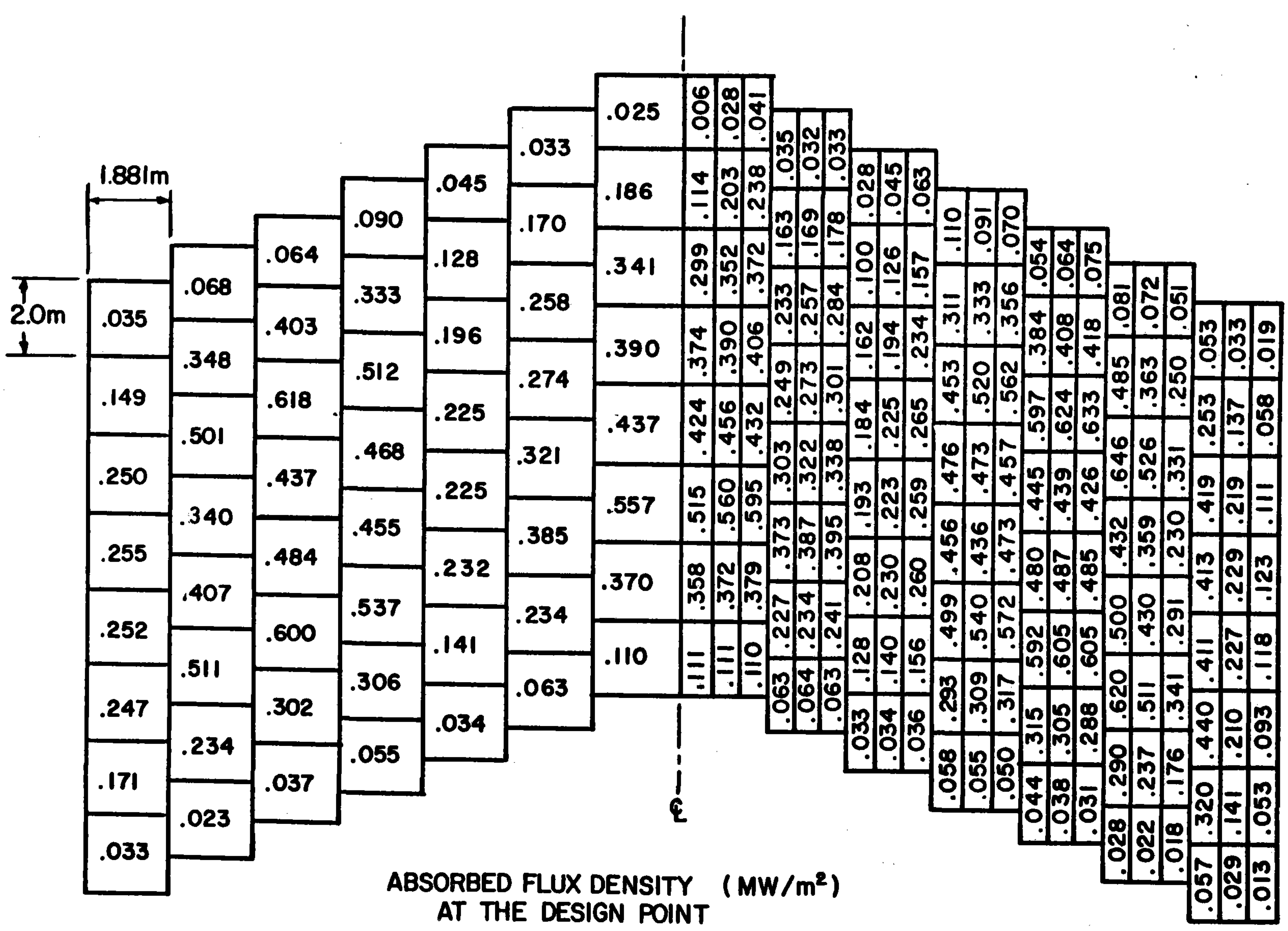


Fig. 5.9. Receiver Design



ABSORBED FLUX DENSITY (MW/m²)
AT THE DESIGN POINT

Figure 5.10. Receiver Flux - Equinox

Fig. 5.11 Receiver Flux - Winter

Flux Density (MW/m^2) at Winter, Noon

.011	.048	.086	.111	.116	.105	.064	.018
.026	.126	.192	.210	.213	.204	.126	.031
.051	.284	.397	.375	.379	.384	.231	.050
.017	.158	.319	.294	.249	.326	.240	.053
.020	.210	.450	.389	.329	.467	.329	.066
.026	.258	.550	.456	.395	.577	.390	.075
.028	.259	.545	.447	.394	.572	.380	.069
.035	.277	.554	.454	.410	.572	.374	.063
.041	.290	.549	.451	.419	.553	.354	.059
.047	.294	.533	.445	.428	.523	.329	.062
.052	.289	.506	.438	.439	.484	.305	.077
.055	.275	.469	.426	.438	.436	.282	.090
.033	.146	.245	.238	.243	.218	.141	.051
.033	.132	.217	.208	.207	.182	.113	.036
.031	.120	.196	.181	.172	.152	.091	.023
.060	.227	.372	.320	.286	.268	.163	.029
.061	.220	.361	.304	.260	.241	.153	.028
.060	.213	.347	.286	.238	.218	.145	.028
.105	.356	.556	.458	.386	.348	.213	.035
.106	.350	.524	.433	.372	.328	.182	.024
.106	.337	.485	.405	.355	.304	.148	.014
.106	.337	.485	.405	.355	.304	.148	.014
.106	.350	.524	.433	.372	.328	.182	.024
.105	.356	.556	.458	.386	.348	.213	.035
.060	.213	.347	.286	.238	.218	.145	.028
.061	.228	.361	.304	.260	.241	.153	.028
.060	.227	.372	.320	.286	.267	.162	.029
.031	.120	.196	.181	.172	.151	.091	.023
.033	.132	.217	.208	.207	.182	.113	.036
.033	.146	.245	.238	.243	.218	.141	.051
.055	.275	.469	.426	.438	.436	.282	.090
.052	.289	.506	.438	.439	.484	.305	.077
.047	.294	.533	.445	.428	.523	.329	.062
.041	.290	.549	.451	.419	.553	.354	.059
.035	.277	.554	.454	.410	.572	.374	.063
.028	.259	.545	.447	.394	.572	.380	.069
.026	.258	.550	.456	.395	.557	.390	.075
.020	.210	.450	.389	.329	.467	.329	.066
.017	.158	.319	.294	.249	.326	.240	.052
.051	.284	.397	.375	.379	.384	.187	.050
.026	.126	.192	.210	.213	.204	.126	.031
.011	.048	.086	.111	.116	.105	.064	.018

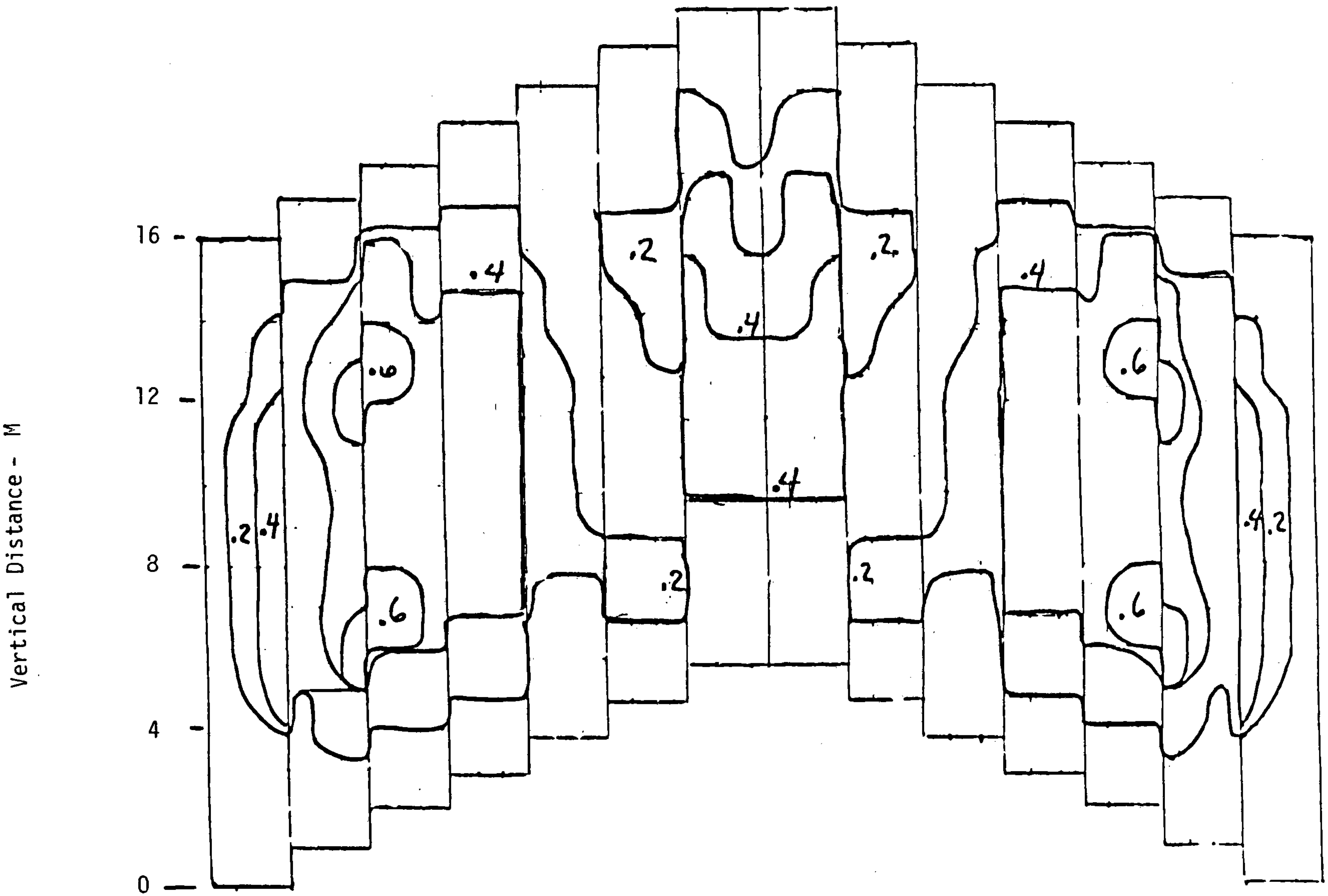


Figure 5.12 Receiver Flux Map Equinox Noon

Figure 5. 13

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. 0.05 m, Centerline w/40.2 m/s wind
2. Tower acceleration	--	0.32 g's top, 0.19 g's centerline of receiver

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 (each)	Steam Generator (each)
Quantity	2	2
Capacity, each	.067 m^3/S (1050 gpm)	.09 m^3/S (1425 gpm)
Head, each	228 m	84 m
Pumping temperature	288°C	566°C
Spec. gravity	1.87	1.67
Pump efficiency	.80	.80
Pump Power	347 KW	154 KW
Motor rating, hp	500	206
Motor speed, rpm	1750	1750 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	2.6 MPa (375 psig)	5.8 MPa (850 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	0.25m (10 in) Nominal Sch. 40 S	0.3m (12 in) Nominal Sch 40
	9.27mm (.365 in) Nom. Wall	10.3mm (0.406 in.) Nom. Wall
Wt. Per Meter (Ft)	60 kg (40.5 lb)	80 kg (53.5 lb)
Approx. Length	1561 m (5120 ft.)	1408 m (4620 ft)
Insulation Type	Calcium Silicate	Calcium Silicate
Ins. Thickness	0.20 m (8 in)	0.13 m (5 in.)

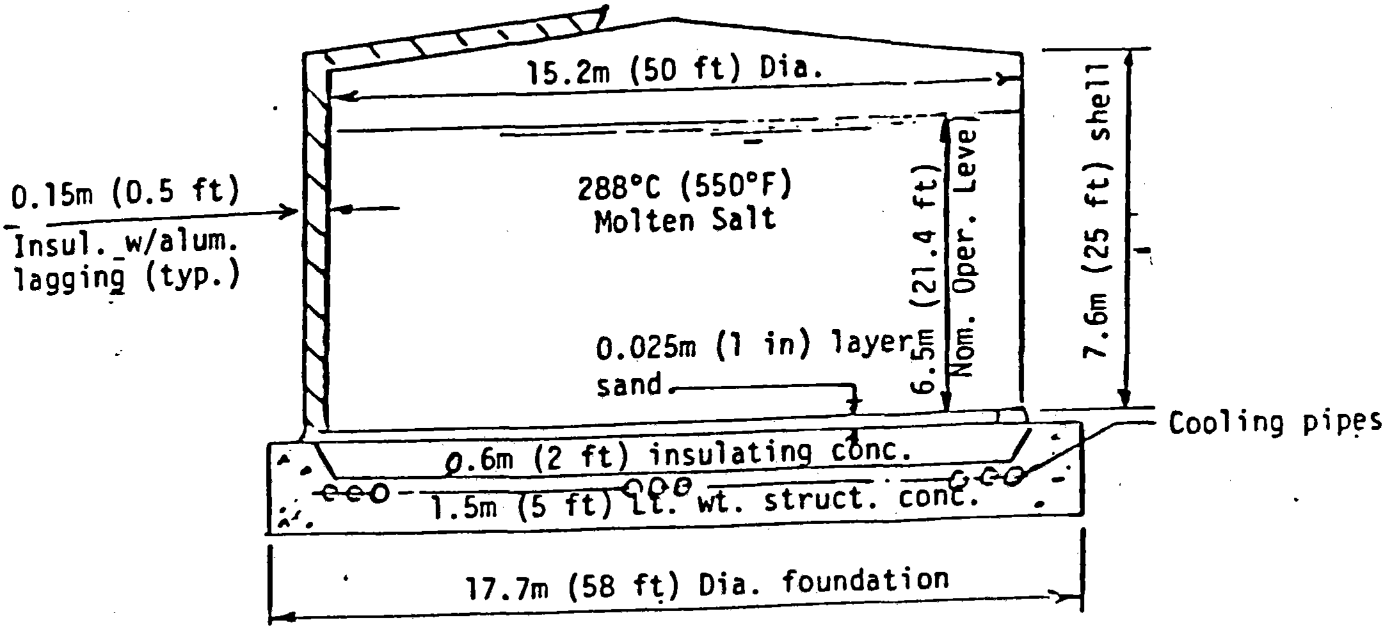


Fig. 5.14 Cold salt storage tank

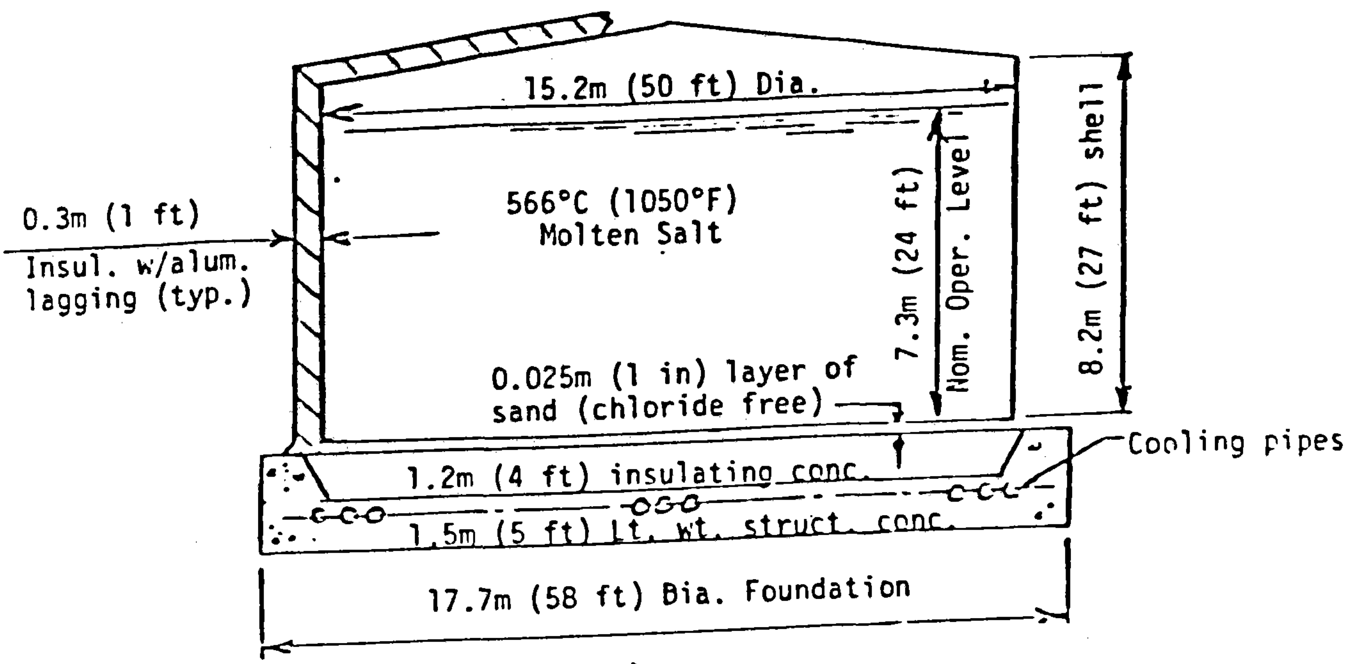


Fig. 5.15 Hot salt storage tank

2. Tankage

   a. The cold tank configuration is shown on Figure 5.14.

   b. The hot tank configuration is shown on Figure 5.15.

1. Extractable energy capacity and duration of output.

   278 MW Hr_{th} for 3 hours.

2. Rates

	Charge	Discharge
Maximum	110 MW_{th}/hr	130 MW_{th}/hr
Minimum	33 MW_{th}/hr	30 MW_{th}/hr
Design	110 MW_{th}/hr	87 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 5.16. The design selected is the unit being developed on the DOE/SRE. The details of this unit will be available at the completion of the SRE. The design configuration for the counterflow preheater, superheater and reheater are shown on Figure 5.17-5.19. The parallel flow evaporator is shown on 5.20.

b. Operating Characteristics

The operating characteristics will be determined on the DOE/SRE program.

5.1.5.3 Steam Drum

The steam drum is an integral part of the evaporator assembly and is covered in Section 5.1.5.2.

5.1.6 <u>Piping Data, Miscellaneous</u>

a. Piping Data

The data for the new piping required in the EPGS system is presented in Table 5.3.

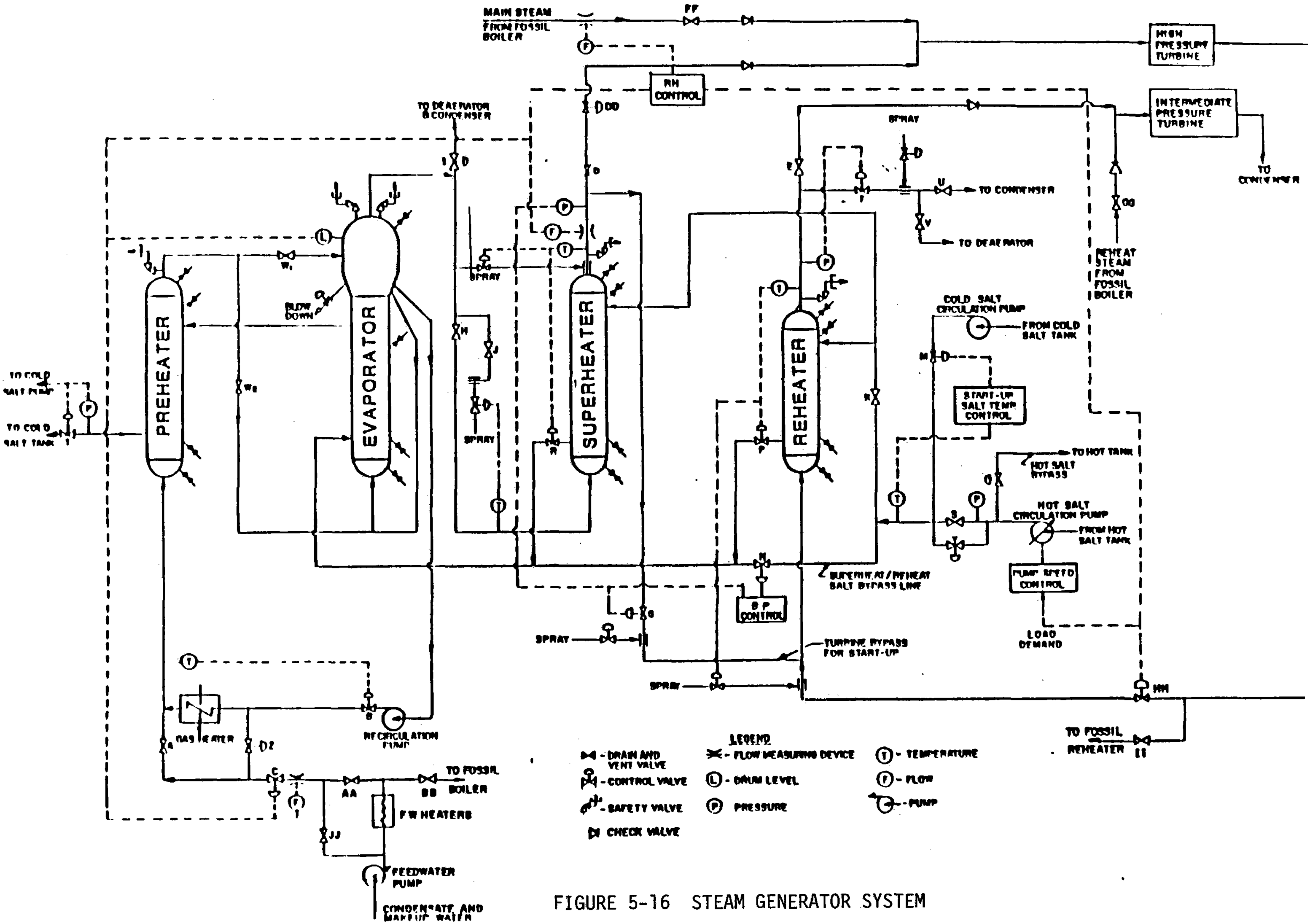


FIGURE 5-16 STEAM GENERATOR SYSTEM

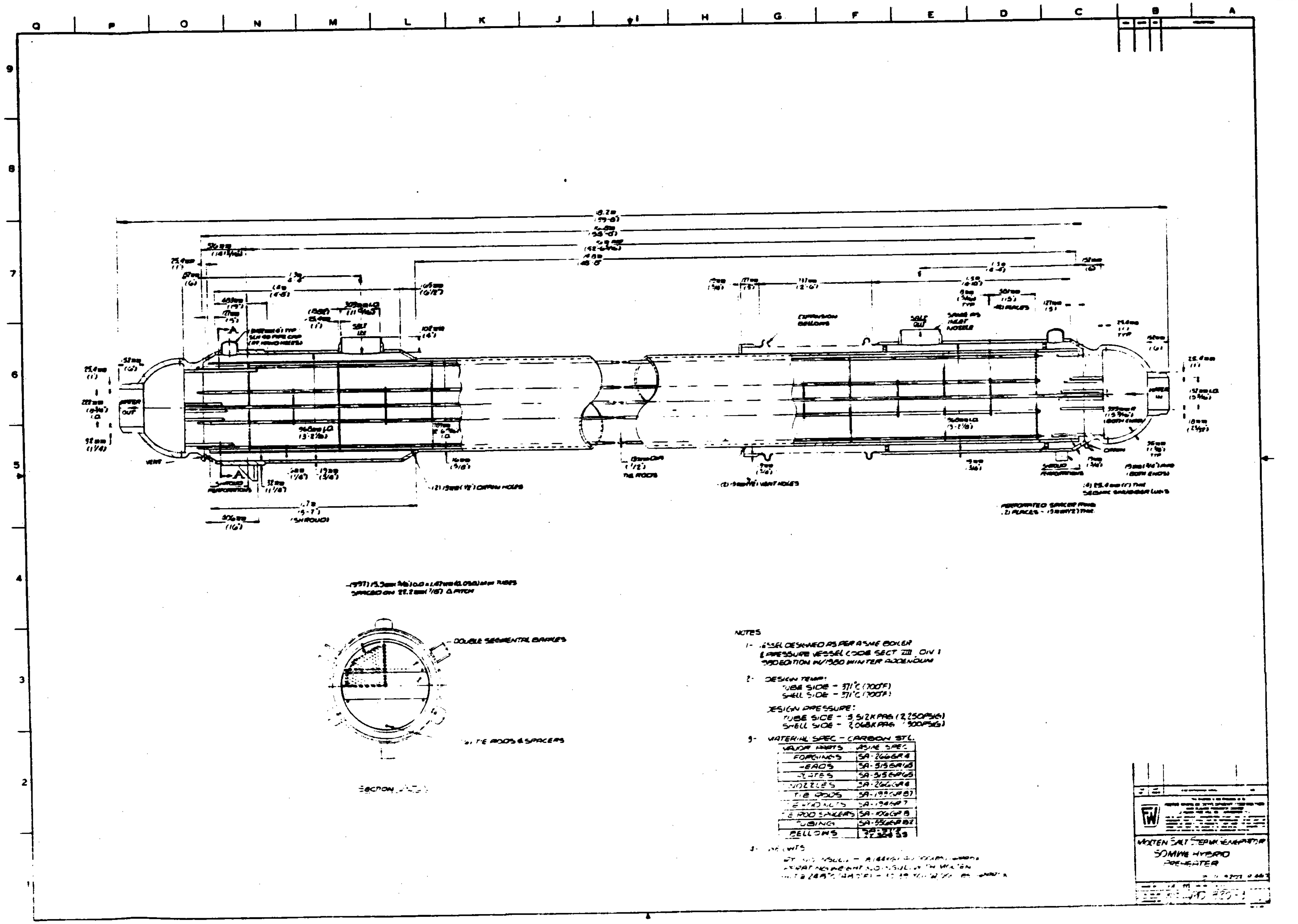


Fig. 5.17 - Heat Exchanger Design - Preheater

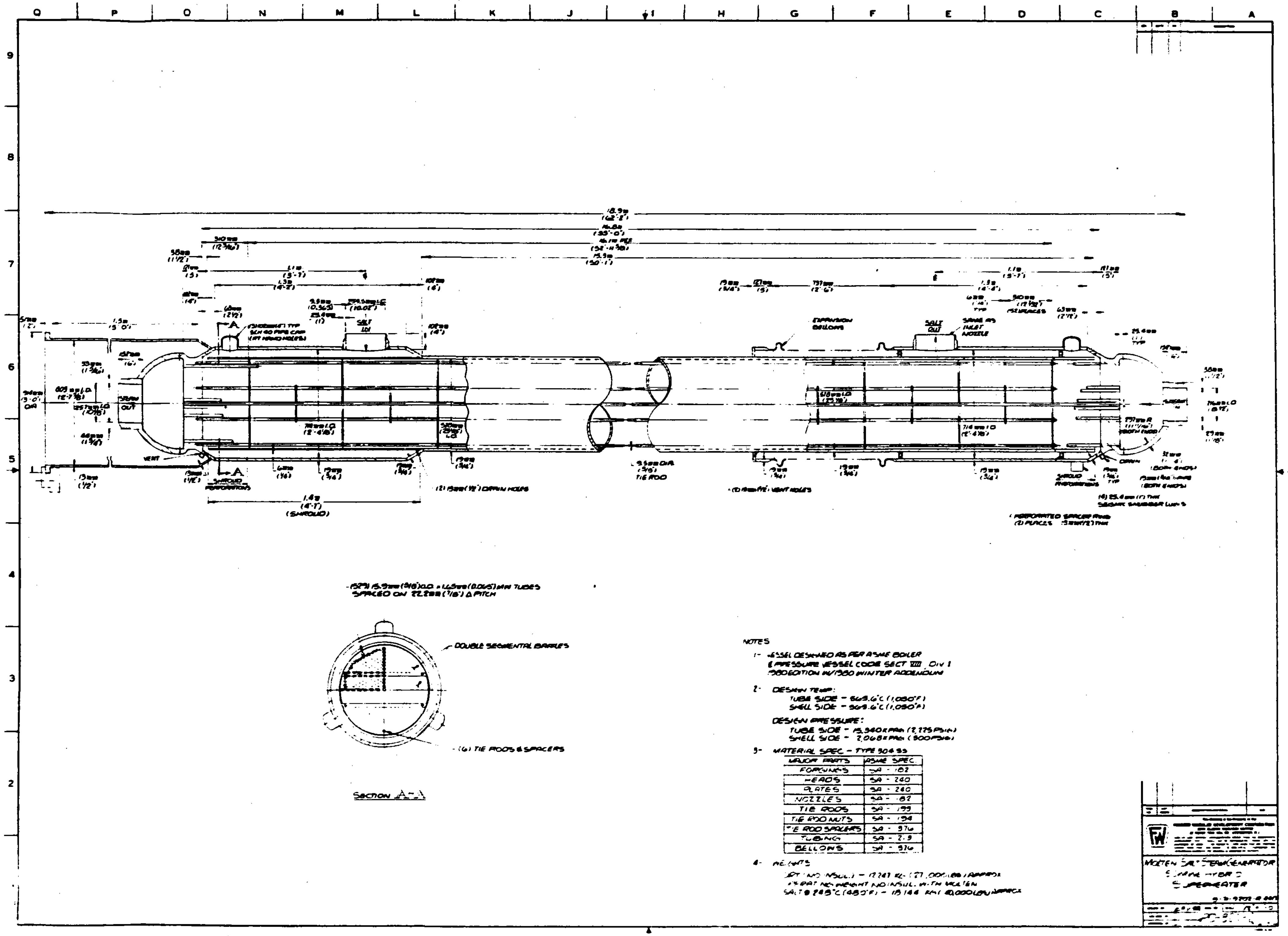


Fig. 5.18 - Heat Exchanger Design - Superheater

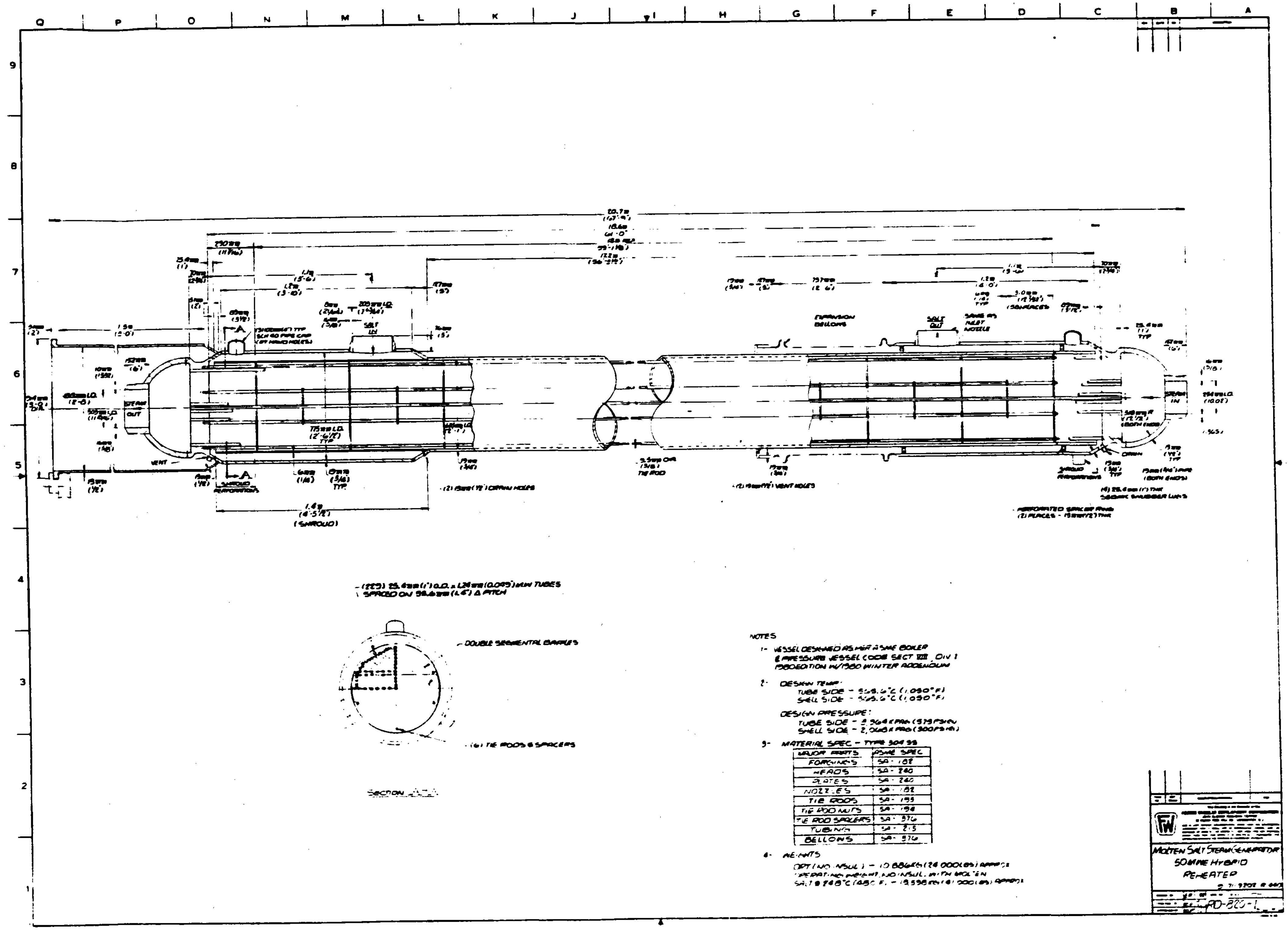


Fig. 5.19 - Heat Exchanger Design - Reheater

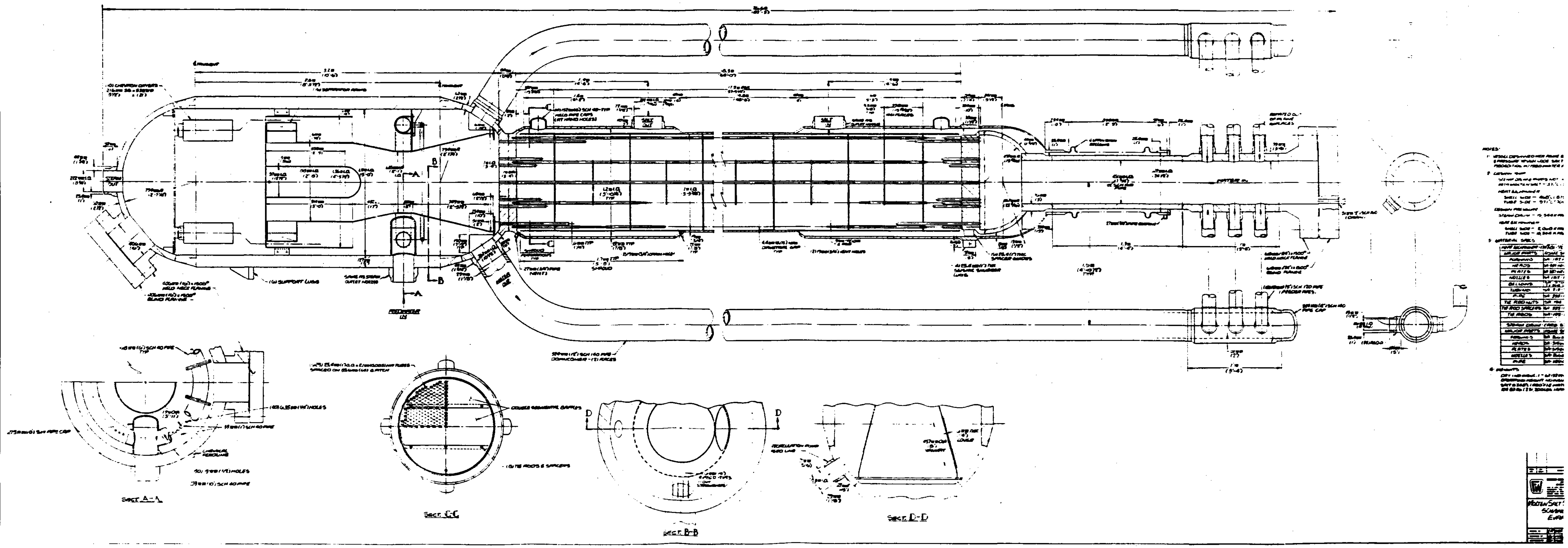


Fig. 5.20 - Heat Exchanger Design - Evaporator

TABLE 5-2 STEAM GENERATOR PERFORMANCE

OPERATION MODE	SOLAR ONLY	HYBRID
TEMPERATURES, C (F)		
Steam/Water:		
Feedwater	213.3 (416)	237.8 (460)
Superheater Inlet	336.1 (637)	334.4 (634)
Final Steam	540.6 (1005)	540.6 (1005)
Reheater Inlet	317.2 (603)	341.1 (646)
Reheater Outlet	538.9 (1002)	540.6 (1005)
Salt:		
Superheater Inlet	562.8 (1045)	562.8 (1045)
Superheater Outlet	423.9 (795)	400.6 (753)
Reheater Inlet	562.8 (1045)	562.8 (1045)
Reheater Outlet	456.7 (854)	449.4 (841)
Evaporator Inlet	443.9 (831)	435.6 (816)
Evaporator Outlet	340.6 (645)	337.8 (640)
Preheater Inlet	340.6 (645)	337.8 (640)
Preheater Outlet	287.2 (549)	287.8 (550)
FLOWS, kg/sec (M lbm/h)		
Steam/Water:		
Feedwater	46.51 (369.1)	29.58 (234.8)
Blowdown	0.23 (1.8)	0.11 (0.9)
Main Steam	46.28 (367.3)	29.45 (233.7)
Reheater	38.20 (303.2)	24.80 (196.8)
Recirculation	9.51 (25.5)	0 (0)
Salt:		
Preheater	315.88 (2507)	188.62 (1497)
Evaporator	315.88 (2507)	188.62 (1497)
Superheater	170.35 (1352)	92.36 (733)
Reheater	113.40 (900)	64.26 (510)
Bypass	32.13 (255)	32.0 (254)
PRESSURES, kPag (psig)		
Steam/Water:		
Feedwater	14,045 (2037)	13,645 (1979)
Drum	13,852 (2009)	13,562 (1967)
Final Steam	13,659 (1981)	13,479 (1955)
Reheater Inlet	1,737 (252)	2,958 (429)
Reheater Outlet	1,482 (215)	2,889 (419)
PRESSURE DROP, SALT kPa (psi)		
Superheater	228 (33)	69 (10)
Reheater	179 (26)	62 (9)
Preheater	331 (48)	117 (17)

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	.17	.31 (Sch. 80)	.41 (Sch. 40)	.13 (Sch. 160)
Mimimum Wall	mm	27.4	19	12.5	18
Nom. O.D.	m	.22	.35	.41	.15
Weight/M	Kg/m	134.4	158	124	67.8
Insulation	-	Calcium Silicate	Calcium Silicate	Calcium Silicate	Calcium Silicate
Ins. Thickness	m	.15	.15	.128	.076

5.2 EXISTING PLANT DESCRIPTION

The performance level of the existing power plant is shown on the Heat Balance Diagram, Figure 5.21 . 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. Turbine performance is shown in Table 5-4.

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.

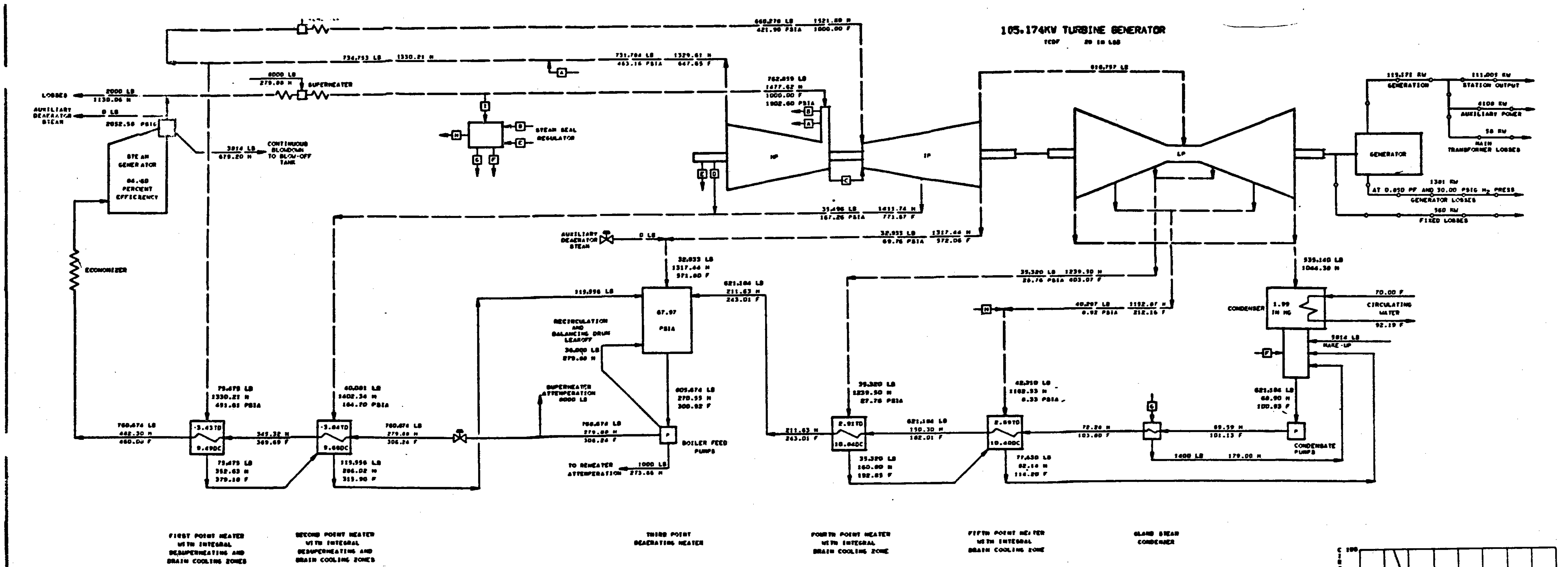
d. Condenser - The 4420m^2 (47,500 sq. ft.) two pass steam surface condenser equipped with 7.9 m (26 ft) long, 22.2 mm (7/8 in.) OD tubes.

TABLE 5-4 TURBINE PERFORMANCE SUMMARY FORT CHURCHILL-UNIT NO. 1

Operating Mode	Season	Gross Generation Fossil	Solar	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 35)	Equinox	79564	35000	114,564	13.1(1903)	538(1000)	538(1000)	6.4 (1.90)	238(460)	8470 (8028)
Solar Only (Case 36)	Summer	0	54849	54849	13.1(1903)	538(1000)	538(1000)	6.7 (2.00)	219(427)	8886 (8423)

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)



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 109 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.

$$\text{TURBINE HEAT RATE} = \frac{\text{BOILER DUTY}}{\text{GENERATION}} = \frac{9.20938\times10^{+08}}{115.171} = 7996.24\ \text{BTU/KW-HR}$$

$$\text{STATION HEAT RATE} = \frac{\text{BOILER DUTY}}{\text{STATION OUTPUT} \times \text{BOILER EFF.}} = \frac{9.20938\times10^{+08}}{111.005 \times .8460} = 9807.06\ \text{BTU/KW-HR}$$

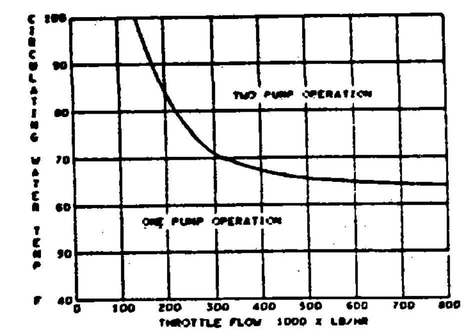
CIRCULATING WATER TEMPERATURE F	CONDENSER PRESSURE IN HG	BOILER EFFICIENCY PERCENT	LAST EXTRACTION FLOW LB/HR	TURBINE EXHAUST FLOW LB/HR	EXPANSION LINE END POINT BTU/LB	EXHAUST ENTHALPY BTU/LB	GENERATION KW	STATION OUTPUT KW	TURBINE HEAT RATE BTU/KWHR	STATION HEAT RATE BTU/KWHR
90.00	3.46	84.85	31.754	545.177	1051.82	1056.93	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	530.640	1013.51	1043.04	115.225	111.059	7992.51	9816.89

LEAKAGES

	FLOW	ENTHALPY
A	2969	1477.62
B	819	1477.62
C	10,000	1457.59
D	4586	1329.61
E	3794	1329.61
F	1200	1355.88
G	1400	1355.88
H	2015	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
JP	[illegible]	6/9/67

Figure 5.21 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 switchyard 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 voltage regulator.

5.3 PLANT COST DATA

5.3.1 <u>Design Cost Estimate</u> - Includes system design and design integration only.

5.3.2 <u>Owner's Cost Estimate</u>

The following costs are considered owner's costs for this conceptual design study.

a. Permits
   - Environmental
   - Listing of other permits required including franchises and consents required
b. Land and Land rights and cost of Right of Ways
c. Water rights and water allocations
d. Landscaping and Recreational areas required (creating or modifying)
e. Consulting services for site studies (e.g., soils, aerial surveys)
f. Archeological search for artifacts, if required
g. Environmental studies required for permits

h. Dealing with public agencies, long-range community relations, and general public relation activities (both local and regional)

i. Owners home office services directly associated with project
   - Managerial
   - Engineering
   - Financing
   - Accounting
   - Procurement activities
   - Labor relation activities
   - General services
   - Estimating
   - Planning and Scheduling
   - Coordination
   - Construction management
   - Other home office services directly associated with project

j. Plant initial consumable supplies and owner's startup costs

k. Property and other taxes on the land and plant during construction

l. Insurance costs on land and plant during construction

m. Cost of money, AFDC (Allowance for Funds During Construction)

n. Furnishings

o. Initial Spare Parts

5.3.3 Construction Cost Estimate

a. Breakdown of construction cost estimate is in accordance with:
   1. Code of accounts shown in 5.3.4
   2. Sub account codes shown in 5.3.5

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, 1982.

d. Material priced to job location, 1982.

e. All unique equipment, not built at the construction site, was costed at the site of manufacture.

5.3.4 Code of Accounts

5311	Site Improvements
5312	Buildings and Structures
5320	Steam Generating System
5321	Collector System
5322	Receiver System
5323	Heat Transfer System - Horizontal Piping
5324	Plant Control System
5325	Heat Transfer Media
5326	Energy Storage System
5327	Heat Exchange System
5330	Engines and Engine-Driven Generators
5340	Turbogenerators and Related Equipment
5350	Accessory Electrical Equipment
5360	Miscellaneous Power Plant Equipment
5370	Substation Equipment
5380	Process
5390	Miscellaneous Modifications

5.3.5 Sub Account Codes

Direct Field Costs

A - Excavation and Civil

B - Concrete

C - Structural Steel

D - Buildings - Prefabrication or on a based SF cost

E - Machinery and Equipment

F - Piping - Incl. Trenching, hangars, SPTS, pipeways (trenching and pipeways should be shown separately

G - Electrical

H - Instrumentation incl. wire and tubing

I - Painting

J - Insulation

Indirect Field Costs

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 sites maintenance.

M - Construction Services, Supplies, and Expense

Services: Includes cleanup, nonproductive time, medical examinations, doctors' fees, move on and off, and construction equipment maintenance and servicing.

Supplies: Includes welding rod, oxygen, acetylene, rags, and other consumables. Include small tools when required.

Field Office Supplies: Includes office machines, telephone, telegraph, postage, computer rental, stationery, furniture.

N - Field Staff, Subsistence and Expense

Field Staff: Includes salaries for superintendents, field engineers, cost engineers, field administration, warehouseman, purchaser, nurse, safety engineer, timekeeper, accountant, clerks, Q/A control, watchman, and security service.

Field Staff Subsistence: Includes travel, subsistence, transportation, and relocation for field staff.

Field Staff Burden: Includes vacation, sick leave, and holiday allowance.

P - Contractors risk insurance, bonds (NO LABOR RELATED INSURANCE):
Includes: builder's risk, performance bonds, and marine insurance.

O - Equipment Usage: Construction Equipment Purchase/Rental
Special Equipment Purchase/Rental
Fuel Consumption and Normal Maintenance where required

Office Costs

R - Engineering During Construction (do not include original plant design)

* Design and Engineering
* Home Office Costs
* R&D: for anticipated research and development required to design and produce special equipment which is not currently manufactured.

S - Construction Management and Home Office Support

Contingency and Prime Contractors' Fee

V - Contingency

* Bidding Contingency
* Change in Scope Contingency
* 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 - Prime Contractors Fee (exclude design contingency)

* Material Markup
* Fee on Labor and Indirects
* Fee on Subcontract Work

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Capital Cost Summary

(1982 dollars in thousands)

5100	Design Cost	23,942
5300	Construction Cost	70,592
5400	Startup and Testing Cost	1,600
	Total	96,134

SPPCo Advanced Repowering Study

5100 Total Design Cost

(1982 dollars in thousands)

5101	Site improvements	0
5102	System design (A&E)	8639
5103	Subsystem design *	
	Receiver	1371
	Tower	387
	Master control	3635
	Steam generator	1271
5104	Design integration (SFDI)	8639
	Total	23,942

*Other subsystem design costs are in fixed price procurement contracts.

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CONSTRUCTION COST ESTIMATE

CLIENT ______

DESCRIPTION 5300 Total Construction Cost

LOCATION ______

CONT. NO. ______

PROJECT SPPCo Advanced Repowering Study

MADE BY ______

APPROVED ______

(1982 Dollars in Thousands)

A/C NO.	ITEM & DESCRIPTION	MAN HOURS	ESTIMATED COST			
			LABOR	SUBCONTRACTS	MATERIALS	TOTALS
A	Excavation & Civil		17	1,186		1,203
B	Concrete		190	461	186	837
C	Structural Steel		580	5,105	383	6,068
D	Buildings			275		275
E	Machinery & Equipment		1,743	32,607	2,124	36,474
F	Piping		1,311	1,857	3,415	6,583
G	Electrical		147	202	1,149	1,498
H	Instruments			936		936
I	Painting		17	6		23
J	Insulation			1,120	1,120	2,240
	DIRECT FIELD COSTS		4,005	43,755	8,377	56,137
L	Temporary Construction Facilities					
M	Construction Services, Supplies & Expense					
N	Field Staff, Subsistence & Expense					
P	Contractors' Risk Insurance					
Q	Equipment Usage					
	INDIRECT FIELD COSTS					1,534
	TOTAL FIELD COSTS					57,671
R	Engineering During Construction					-
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Construction Management					4,319
	TOTAL OFFICE COSTS					4,319
	TOTAL FIELD & OFFICE COSTS					61,990
U	Escalation					-
V	Contingency					5,768
W	Prime Contractors' Fee					2,834
	TOTAL CONSTRUCTION COST					70,592

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CONSTRUCTION COST ESTIMATE

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CLIENT ______

LOCATION ______

PROJECT SPPCo Advanced Repowering Study

DESCRIPTION 5311 Site Improvements

CONT. NO. ______
MADE BY ______
APPROVED ______

(1982 dollars in thousands)

A/C NO.	ITEM & DESCRIPTION	MAN HOURS	ESTIMATED COST LABOR	SUBCONTRACTS	MATERIALS	TOTALS
A	Excavation & Civil			1,186		1,186
B	Concrete					
C	Structural Steel					
D	Buildings					
E	Machinery & Equipment					
F	Piping					
G	Electrical					
H	Instruments					
I	Painting					
J	Insulation					
	DIRECT FIELD COSTS			1,186		1,186
L	Temporary Construction Facilities					
M	Construction Services, Supplies & Expense					
N	Field Staff, Subsistence & Expense					
P	Contractors' Risk Insurance					
Q	Equipment Usage					
	INDIRECT FIELD COSTS					-
	TOTAL FIELD COSTS					1,186
R	Engineering During Construction					-
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Construction Management					89
	TOTAL OFFICE COSTS					89
	TOTAL FIELD & OFFICE COSTS					1,275
U	Escalation					-
V	Contingency					119
W	Prime Contractors' Fee					42
	TOTAL CONSTRUCTION COST					1,436

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JOB NO. ______ PROJECT SPPCo Advanced Repowering Study (1982 dollars in thousands) LOCATION ______ CLIENT ______

DATE ______ TAKE-OFF ______ PRICED ______ CALC. CHKD ______ APPROVED ______ SHEET ______ OF ______

	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5311 Site Improvements									
A	Excavation & Civil									
A1	Site Clearing and Grading								661	661
A2	Roads and Parking								172	172
A3	Fencing								254	254
A4	Railroad Spur								77	77
A5	Drainage and Sewers								22	22
	Total A									1186
S	Construction Management									89
V	Contingency									119
W	Fee									42
CODE	Total									1436

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CONSTRUCTION COST ESTIMATE

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CLIENT

DESCRIPTION 5312 Buildings & Structures

LOCATION

CONT. NO.

MADE BY

PROJECT SPPCo Advanced Repowering Study

APPROVED

(1982 Dollars in Thousands)

A/C NO.	ITEM & DESCRIPTION	MAN HOURS	ESTIMATED COST			
			LABOR	SUBCONTRACTS	MATERIALS	TOTALS
A	Excavation & Civil					
B	Concrete					
C	Structural Steel					
D	Buildings			275		275
E	Machinery & Equipment					
F	Piping					
G	Electrical					
H	Instruments					
I	Painting					
J	Insulation					
	DIRECT FIELD COSTS			275		275
L	Temporary Construction Facilities					
M	Construction Services, Supplies & Expense					
N	Field Staff, Subsistence & Expense					
P	Contractors' Risk Insurance					
Q	Equipment Usage					
	INDIRECT FIELD COSTS					-
	TOTAL FIELD COSTS					275
R	Engineering During Construction					-
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Construction Management					21
	TOTAL OFFICE COSTS					21
	TOTAL FIELD & OFFICE COSTS					296
U	Escalation					-
V	Contingency					28
W	Prime Contractors' Fee					10
	TOTAL CONSTRUCTION COST					334

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JOB NO. ______ PROJECT SPPCo Advanced Repowering Study LOCATION ______ CLIENT ______

(1982 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
	5312 Buildings & Structures									
D	Buildings									
D1	Warehouse								107	107
D2	Garage								168	168
	Total D									275
S	Construction Management									21
V	Contingency									28
W	Fee									10
CODE	Total									334

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CONSTRUCTION COST ESTIMATE

CLIENT ______

LOCATION ______

PROJECT SPPCo Advanced Repowering Study

DESCRIPTION 5321 Collector System

(1982 dollars for thousands)

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			28,872		28,872
F	Piping					
G	Electrical					
H	Instruments					
I	Painting					
J	Insulation					
	DIRECT FIELD COSTS			28,872		28,872
L	Temporary Construction Facilities					
M	Construction Services, Supplies & Expense					
N	Field Staff, Subsistence & Expense					
P	Contractors' Risk Insurance					
Q	Equipment Usage					
	INDIRECT FIELD COSTS		(not separable)			-
	TOTAL FIELD COSTS					28,872
R	Engineering During Construction					-
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Construction Management					2,162
	TOTAL OFFICE COSTS					2,162
	TOTAL FIELD & OFFICE COSTS					31,034
U	Escalation					-
V	Contingency					2,887
W	Prime Contractors' Fee					1,010
	TOTAL CONSTRUCTION COST					34,931

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JOB NO. ______ PROJECT SPPCo Advanced Repowering Study LOCATION ______ CLIENT ______

(1982 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
	5321 Collector System									
E	Machinery & Equipment									
	Total including delivered hardware and all field effort								28872	28872
S	Construction Management									2162
V	Contingency									2887
W	Fee									1010
CODE	Total									34931

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CONSTRUCTION COST ESTIMATE

1D22600
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15 May 1982

CLIENT ______________________

DESCRIPTION 5322 Receiver System

LOCATION ______________________

CONT. NO. ______________

MADE BY ______________

PROJECT SPPCo Advanced Repowering Study

APPROVED ______________

(1982 Dollars in Thousands)

A/C NO.	ITEM & DESCRIPTION	MAN HOURS	ESTIMATED COST LABOR	SUBCONTRACTS	MATERIALS	TOTALS
A	Excavation & Civil		17			17
B	Concrete		190		186	376
C	Structural Steel		580	4,224	383	5,187
D	Buildings					
E	Machinery & Equipment			245		245
F	Piping		86	882	221	1,189
G	Electrical			202		202
H	Instruments			143		143
I	Painting		17	6		23
J	Insulation			155		155
	DIRECT FIELD COSTS		890	5,857	790	7,537
L	Temporary Construction Facilities					
M	Construction Services, Supplies & Expense					
N	Field Staff, Subsistence & Expense					
P	Contractors' Risk Insurance					
Q	Equipment Usage					
	INDIRECT FIELD COSTS					482
	TOTAL FIELD COSTS					8,019
R	Engineering During Construction					-
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Construction Management					600
	TOTAL OFFICE COSTS					600
	TOTAL FIELD & OFFICE COSTS					8,619
U	Escalation					-
V	Contingency					802
W	Prime Contractors' Fee					504
	TOTAL CONSTRUCTION COST					9,925

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	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5322.1 Tower									
A	Excavation & Civil (Earthwork)							17		17
B	Concrete (Foundation)						186	190		376
C	Structural Steel						383	224		607
E	Machinery & Equip. (Elevator)								245	245
G	Electrical (lighting)								117	117
I	Painting						6	17		23
L-Q	Indirect									422
S	Construction Management									135
V	Contingency									181
W	Fee									244
CODE	Total									2367

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	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5322.2 Receiver									
C	Structural Steel									
C1	Panels & Headers								2700	2700
C2	Doors & Shielding								642	642
C3	Surge Tanks								161	161
C4	Support Structure								454	454
C5	Misc. Structure								267	267
C6	Field Erection							356		356
	Total C									4580
F	Piping (incl. valves)								882	882
G	Electrical (trace heaters)								85	85
H	Instrumentation								143	143
J	Insulation								97	97
S	Construction Management									433
V	Contingency									579
W	Fee									203
CODE	Total									7002

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CODE	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5322.3 Riser/Downcomer									
F	Piping									
F1	Riser Piping						30	42		72
F2	Downcomer Piping						191	44		235
	Total F									307
J	Insulation									
J1	Riser Insulation								25	25
J2	Downcomer Insulation								33	33
	Total J									58
L-O	Indirect									60
S	Construction Management									32
V	Contingency									42
W	Fee									57
	Total									556

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CONSTRUCTION COST ESTIMATE

CLIENT ______

DESCRIPTION 5323 Heat Transfer Sys. — Horizontal Piping

LOCATION ______

CONT. NO. ______

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(1982 Dollars in Thousands)

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		892		2,373	3,265
G	Electrical					
H	Instruments					
I	Painting					
J	Insulation			603		603
	DIRECT FIELD COSTS		892	603	2,373	3,868
L	Temporary Construction Facilities					
M	Construction Services, Supplies & Expense					
N	Field Staff, Subsistence & Expense					
P	Contractors' Risk Insurance					
Q	Equipment Usage					
	INDIRECT FIELD COSTS					624
	TOTAL FIELD COSTS					4,492
R	Engineering During Construction					-
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Construction Management					336
	TOTAL OFFICE COSTS					336
	TOTAL FIELD & OFFICE COSTS					4,828
U	Escalation					-
V	Contingency					449
W	Prime Contractors' Fee					606
	TOTAL CONSTRUCTION COST					5,883

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CODE	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5323 Heat Transfer Sys.-Horiz. Piping									
F	Piping									
F1	Cold Piping						29.0		41.2	70.2
F2	Hot Piping						208.3		48.0	256.3
	Total F									326.5
J	Insulation									
J1	Cold Insulation								24.4	24.4
J2	Hot Insulation								35.9	35.9
	Total J									60.3
L-Q	Indirect									62.4
S	Construction Management									33.6
V	Contingency									44.9
W	Fee									60.6
	Total									588.3

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CONSTRUCTION COST ESTIMATE

CLIENT ______

DESCRIPTION 5324 Plant Control System

LOCATION ______

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(1982 Dollars in Thousands)

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		75		1,276	1,351
F	Piping					
G	Electrical		49		13	62
H	Instruments					
I	Painting					
J	Insulation					
	DIRECT FIELD COSTS		124		1,289	1,413
L	Temporary Construction Facilities					
M	Construction Services, Supplies & Expense					
N	Field Staff, Subsistence & Expense					
P	Contractors' Risk Insurance					
Q	Equipment Usage					
	INDIRECT FIELD COSTS					86
	TOTAL FIELD COSTS					1,499
R	Engineering During Construction					-
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Construction Management					112
	TOTAL OFFICE COSTS					112
	TOTAL FIELD & OFFICE COSTS					1,611
U	Escalation					-
V	Contingency					150
W	Prime Contractors' Fee					52
	TOTAL CONSTRUCTION COST					1,813

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Code	Item and Description	Quantity	Unit	Mat'l	Labor	Sub-Cont	Material	Labor	Sub-Contract	Total
	5324 Plant Control System									
E	Machinery & Equipment									
E1	Computers & Peripherals						494			494
E2	Sys. Control Elements						49			49
E3	S/Sys. Oper. Control Elements						492			492
E4	Consoles						228			228
E5	Control Lines/Cables						13			13
E6	Field Installation							75		75
	Total E									1351
G	Electrical (Field Wiring)						13	49		62
L-Q	Indirect									86
S	Construction Management									112
V	Contingency									150
W	Fee									52
CODE	Total									1813

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CONSTRUCTION COST ESTIMATE

CLIENT

DESCRIPTION 5325 Heat Transfer Media

LOCATION

CONT. NO.

MADE BY

PROJECT SPPCo Advanced Repowering Study

APPROVED

(1982 Dollars in Thousands)

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					
G	Electrical					
H	Instruments					
I	Painting					
J	Insulation				1120	1120
	DIRECT FIELD COSTS				1120	1120
L	Temporary Construction Facilities					
M	Construction Services, Supplies & Expense					
N	Field Staff, Subsistence & Expense					
P	Contractors' Risk Insurance					
Q	Equipment Usage					
	INDIRECT FIELD COSTS					--
	TOTAL FIELD COSTS					1120
R	Engineering During Construction					--
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Construction Management					84
	TOTAL OFFICE COSTS					84
	TOTAL FIELD & OFFICE COSTS					1204
U	Escalation					--
V	Contingency					112
W	Prime Contractors' Fee					39
	TOTAL CONSTRUCTION COST					1355

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(1982 Dollars in Thousands)

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	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5325 Heat Transfer Media									
J	Insulation									
	Total for all Systems						1120			1120
S	Construction Management									84
V	Contingency									112
W	Fee									39
CODE	Total									1355

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CONSTRUCTION COST ESTIMATE

CLIENT

DESCRIPTION 5326 Energy Storage System

LOCATION

CONT. NO.

MADE BY

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APPROVED

(1982 Dollars in Thousands)

A/C NO.	ITEM & DESCRIPTION	MAN HOURS	ESTIMATED COST LABOR	SUBCONTRACTS	MATERIALS	TOTALS
A	Excavation & Civil					
B	Concrete			271		271
C	Structural Steel			542		542
D	Buildings					
E	Machinery & Equipment				529	529
F	Piping			975		975
G	Electrical					
H	Instruments					
I	Painting					
J	Insulation			310		310
	DIRECT FIELD COSTS			2098	529	2627
L	Temporary Construction Facilities					
M	Construction Services, Supplies & Expense					
N	Field Staff, Subsistence & Expense					
P	Contractors' Risk Insurance					
Q	Equipment Usage					
	INDIRECT FIELD COSTS		(not separate)			--
	TOTAL FIELD COSTS					2627
R	Engineering During Construction					--
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Construction Management					197
	TOTAL OFFICE COSTS					197
	TOTAL FIELD & OFFICE COSTS					2824
U	Escalation					--
V	Contingency					263
W	Prime Contractors' Fee					92
	TOTAL CONSTRUCTION COST					3179

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	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5326 Energy Storage System									
B	Concrete									
B1	Hot Tank Foundation								152	152
B2	Cold Tank Foundation								119	119
	Total B									271
C	Structural Steel									
C1	Hot Tank								430	430
C2	Cold Tank								112	112
	Total C									542
E	Machinery & Equipment									
E1	Receiver Feed Pumps						375			375
E2	Steam Gen. Feed Pumps						154			154
	Total E									529
F	Piping (Interconnect)								975	975
J	Insulation									
J1	Hot Tank Insulation								149	149
J2	Cold Tank Insulation								77	77
J3	Interconnect Pipe Insulation								84	84
	Total J									310
S	Construction Management									197
V	Contingency									263
W	Fee									92
CODE	Total									3179

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CONSTRUCTION COST ESTIMATE

CLIENT ____________

DESCRIPTION 5327 Heat Exchanger System

LOCATION ____________

CONT. NO. ____________

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PROJECT SPPCo Advanced Repowering Study

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(1982 Dollars in Thousands)

A/C NO.	ITEM & DESCRIPTION	MAN HOURS	ESTIMATED COST LABOR	SUBCONTRACTS	MATERIALS	TOTALS
A	Excavation & Civil					
B	Concrete			190		190
C	Structural Steel			339		339
D	Buildings					
E	Machinery & Equipment		1668	3490		5158
F	Piping		333		821	1154
G	Electrical					
H	Instruments			793		793
I	Painting					
J	Insulation			52		52
	DIRECT FIELD COSTS		2001	4864	821	7686
L	Temporary Construction Facilities					
M	Construction Services, Supplies & Expense					
N	Field Staff, Subsistence & Expense					
P	Contractors' Risk Insurance					
Q	Equipment Usage					
	INDIRECT FIELD COSTS					233
	TOTAL FIELD COSTS					7919
R	Engineering During Construction					--
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Construction Management					593
	TOTAL OFFICE COSTS					593
	TOTAL FIELD & OFFICE COSTS					8512
U	Escalation					--
V	Contingency					792
W	Prime Contractors' Fee					421
	TOTAL CONSTRUCTION COST					9725

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	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5327 Heat Exchanger System									
B	Concrete (Foundation)								190	190
C	Structural Steel (Support)								339	339
E	Machinery & Equipment									
	Heat Exchangers								2103	2103
	Aux. Systems & Equipment								1387	1387
	Field Erection							1668		1668
	Total E									5158
F	Piping (Steam & Reheat)						821	333		1154
H	Instrumentation								793	793
J	Insulation (Steam & Reheat)								52	52
L-Q	Indirect									233
S	Construction Management									593
V	Contingency									792
W	Fee									421
CODE	Total									9725

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CONSTRUCTION COST ESTIMATE

CLIENT ______

DESCRIPTION 5350 Access. Electrical Equip.

LOCATION ______

CONT. NO. ______

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(1982 Dollars in Thousands)

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					
G	Electrical		98		1136	1234
H	Instruments					
I	Painting					
J	Insulation					
	DIRECT FIELD COSTS		98		1136	1234
L	Temporary Construction Facilities					
M	Construction Services, Supplies & Expense					
N	Field Staff, Subsistence & Expense					
P	Contractors' Risk Insurance					
Q	Equipment Usage					
	INDIRECT FIELD COSTS					109
	TOTAL FIELD COSTS					1343
R	Engineering During Construction					--
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Construction Management					101
	TOTAL OFFICE COSTS					101
	TOTAL FIELD & OFFICE COSTS					1444
U	Escalation					--
V	Contingency					134
W	Prime Contractors' Fee					47
	TOTAL CONSTRUCTION COST					1625

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	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5350 Access. Electrical Equip.									
G	Electrical									
	Transformers, MCC, Wiring						1136	98		1234
L-Q	Indirect									109
S	Construction Management									101
V	Contingency									134
W	Fee									47
CODE	Total									1625

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CONSTRUCTION COST ESTIMATE

CLIENT

DESCRIPTION 5360 Misc. Power Plant Equip.

LOCATION

CONT. NO.

MADE BY

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APPROVED

(1982 Dollars in Thousands)

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				319	319
F	Piping					
G	Electrical					
H	Instruments					
I	Painting					
J	Insulation					
	DIRECT FIELD COSTS				319	319
L	Temporary Construction Facilities					
M	Construction Services, Supplies & Expense					
N	Field Staff, Subsistence & Expense					
P	Contractors' Risk Insurance					
Q	Equipment Usage					
	INDIRECT FIELD COSTS					--
	TOTAL FIELD COSTS					319
R	Engineering During Construction					
	Design & Engineering					
	Home Office Costs					
	R & D					
S	Construction Management					24
	TOTAL OFFICE COSTS					24
	TOTAL FIELD & OFFICE COSTS					343
U	Escalation					--
V	Contingency					32
W	Prime Contractors' Fee					11
	TOTAL CONSTRUCTION COST					386

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	ITEM AND DESCRIPTION	QUANTITY	UNIT	MAT'L	LABOR	SUB-CONT.	MATERIAL	LABOR	SUB-CONTRACT	TOTAL
	5360 Misc. Power Plant Equip.									
E	Machinery & Equipment									
E1	Service Links						19			19
E2	Slings						29			29
E3	Washing Vehicles						94			94
E4	Repair Equipment						58			58
E5	Other Equipment						119			119
	Total E									319
S	Construction Management									24
V	Contingency									32
W	Fee									11
CODE	Total									386

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SPPCo Advanced Repowering Study

5400 Total Startup and Testing Cost

(1982 dollars in thousands)

5400	Total Effort	1600

5200 SIERRA PACIFIC OWNER'S COST DURING CONSTRUCTION

	COST ELEMENT	Private Land	Private and Public Land
a.	Land and land rights and right of ways		$ 933,000*
b.	Consulting services for site studies.		
c.	Archeological search for artifacts.		
d.	Other environmental studies.	$ 17,000	71,000
e.	Licenses, permits and statements		
f.	Public relations, etc.		
g.	Owner's Home Office Services.	519,000	519,000
h.	Plant consumable supplies and startup costs.	85,000	85,000
i.	Property taxes and insurance costs during construction.	2.52%**	2.52%**
		0.75%***	0.75%***
j.	Cost of money, AFDC (Allowance for Funds during Construction).	17% , 10%	17% , 10%
k.	Initial spares	126,000	126,000
	Total (Excluding "i" and "j")- - - - - - - - - - - - - -	$747,000	$1,734,000

(Items b. through f. are bracketed together against the $ 17,000 and 71,000 values.)

* Value of land already owned by Sierra Pacific.

** Property taxes on Assessed Value (35% Project Total Cost) = $847,608

*** Project Insurance applied on Project Total Cost = $720,800

Total owner's cost taken as $3.3M.

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:	17%	
e.	Stock fraction:	Preferred stock	0.1
		Common equity	0.4
f.	Return on stock:	Preferred stock	17%
		Common equity	17%
g.	Cost of capital:	17%	
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:	20.4%
m.	Rate of general inflation:	None used
n.	Capital escalation rate:	1982 - 10% 1983 and after - 8%
o.	O&M escalation rate:	10%
p.	Referfence year:	1981

5.4.2 Site Owners Alternate Fuel Cost Estimates

The study related to the use of alternate fueld for the Ft. Churchill plants has been completed and estimates of the cost of coal conversion have been determined. The estimates are as follows:

Direct Coal Conversion of Units 1 and 2

Capital Costs:	$630/net KWe (1977$)
O&M Cost:	$3.2/MWh (1977$)
Fuel Cost:	2.0812 $/$10^6$ Btu
Fuel Escalation:	10%
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

5.4.2.2 Cost Factors

The factors used in this estimation include:

a. Residual Fuel Oil: (#6)	Not estimated
Escalation Rate:	Greater than natural gas
b. Coal cost	$2.08/10^6$ Btu
Escalation rate	10%
c. Natural gas cost:	$4.40/10^6$ Btu
Escalation rate	10%

5.5 SIMULATION MODELS

5.5.1 Insolation

The solar insolation model for determining the plant performance consisted 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 were 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 used Typical Week Per Season insolation models. Those models had the following characteristics:

a. All four seasons were represented.

b. Seven actual days of historic data were chosen for each season.

c. For each season, the days were selected such that:

1. Average daily total energy equalled the best projections for the Ft. Churchill site,

2. The frequency distribution of isolation level closely matched that projected for Ft. Churchill, and

3. The frequency distribution of total daily energy closely matched that projected for Ft. Churchill.

Actual days for the Typial Week Per Season models were selected from sites close to Ft. Churchill, and having weather, humidity, turbidity and elevation characteristics which matched Ft. Churchill as closely as possible.

5.5.2 Plant Performance

The plant performance/heat balances were determined using the codes developed by Stearns Roger.

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 then determined the following conditions:

a. Hybrid	37 MWe Solar (gross)	77.5 MWe Fossil
b. Solar Standalone	54 MWe (gross)	

5.5.3 Plant Economic Model

Utility economic models were based on hybrid operation at 35 MW_e gross from solar. All fuel displacement will come against natural gas. Hence, there was no need to do utility grid interaction analysis.

APPENDIX B

OPTIMUM UNIT SIZE

Sierra Pacific Power Company
Repowering Advanced Conceptual Design
Trade Study Report - Optimum Unit Size

This trade study was proposed to examine the effect of constraints on the optimum size for a modular repowering unit for Sierra Pacific's Ft. Churchill Unit 1.

Constraints arise from the DOE published requirements and indicated objectives for repowering. Additional constraints arise from the unit itself, and the SPPCo operating plans.

The objective of this trade study is to identify sizes for the collector/receiver and the steam generator which will be consistent with these constraints. The constraints are quantified the following pages. The analysis reveals that no size is consistent with all constraints. The best compromise appears to be a 110 MW_{th} collector/receiver and a 50 MW_e steam generator. These sizes are selected for the study.

Constraints on the Optimum Repowering Unit Size

Seven considerations suggesting either a maximum or minimum size for the solar repowering project were considered. These constraints are discussed below, together with the consensus minimum or maximum recommended.

Plant Capital Cost - The DOE had indicated a limit of $150M for the government's cost share of any single repowering project. SPPCo will not be able to share construction costs to any significant degree until the value of the repowering project is demonstrated. These two limitations can both be met by repowering in modules. The first module can be sized to be designed and constructed within the $150M limitation. When the economic worth of the repowered system is determined, SPPCo may elect to add modules to bring their contribution to the project up to the established value.

The cost of the first module of a two or three module collector field is indicated in Figure 1. The costs include engineering, construction and startup costs. The costs are escalated to the year in which the expenditure is expected to be incurred. The top level makeup of costs is shown in Table 1, together with the basis for the costs, for a 110 MW_{th} module.

A module size as large as 140 MW_{th} appears to be feasible to construct for $150M.

Scaleup Technical Risk

A technical risk is associated with scaling a system over a large range. The prudent range of scaling varies with the type of technology, its relative maturity, and absolute system size, and the degree of change in approach to the hardware design. By definition, scaleup technical risk is not predicated on known, identifiable risk. It is, rather, an experience factor which derives from the unanticipated difficulties one encounters as a result of scaling a plant.

The solar plants would qualify as being relatively small; hence the scaling limitation normally applied to big plants (in the 500 - 1000 MW_e range) would not apply. The technology is not at all new, but is being extended to temperatures, flow rates, pressures, and total quantities of material which are beyond the area of extensive experience. Moreover, the solar application will introduce new variables of cyclic operation and limited control of the heat source (insolation). Hence, it is felt to be prudent to limit scaling ratios to those associated with new technology, i.e., 3-4:1. Figure 2 shows some system sizes relevant to establishing the appropriate repowering demonstration unit system size. The Molten Salt Receiver SRE program has baselined 320 MW_{th} as a receiver size representative of the commercial utility market. One limitation on the repowering demonstration size should be that the receiver be at least within a reasonable scaleup of the commercial utility receiver size, i.e., above the 80 - 120 MW_{th} range.

The largest central receiver project built to date is Solar I, at about 45 MW_{th}. A 120 MW_{th} system size would represent a scaling ratio midpoint between Solar I and a commercial utility system size.

Design and Construction Schedule

The construction schedule for the 330 MW_t collector/receiver was laid out in the primary to complete acceptance testing by the end of August 1985. A project ATP of 1 June 1981 was assumed. It now appears that preliminary design cannot begin until the fall of 1982. Moreover, there will be a delay between the conclusion of preliminary design and the start of detail design and construction. However, plant operation in early 1986 is still desired. The executive summary of the previous development schedule is shown in Figure 3. The key milestone in the construction schedule was the award of a contract to the heliostat supplier. From the award date to the completion of collector checkout required 43 months. The award was assumed to come two months after ATP. The start of collector hardware procurement must be delayed until final design (about 15 months).

The procurement lead time shown is for acquisition of materials, equipment, and tooling by both MDC and component suppliers. This lead time allowance cannot be shortened to any significant degree. Unless the fabrication time is shortened, the plant could not be operational until the end of 1986.

A higher rate factory could be used, instead of the intermediate rate factory envisioned for the schedule of Figure 3. However, the design and construction of such a factory requires at least 24 months. With an additional 15 month fabrication and installation time, no significant improvement in schedule results.

The remaining option is to shorten the production schedule by reducing the number of heliostats produced. Our best estimate is that a 50% reduction of heliostats produced (8411 down to 4200) would allow adequate time for plant startup and acceptance test by early 1986.

The combination of preliminary design and the Receiver and Steam Generator SRE programs will allow these systems to be fabricated and installed within the minimum heliostat schedule. The plant control system will also require the full allotted time to acquire.

Sierra Pacific Investment Strategy

SPPCo has been considering coal repowering of the Ft. Churchill units. If they were to repower the current boiler units, the firing rate and steam flow would have to be significantly reduced. The steam flow reduction results from the greater radiant heat transfer associated with coal combustion.

The estimate for the coal repowered boiler capacity is 75 MW_e, down from 110 MW_e equivalent. Hence, there is a 35 MW_e equivalent steam supply which could be replaced by solar steam to bring the total steam flow up to rated conditions.

SPPCo does not currently intend to repower with coal because the fuel cost savings do not appear to warrant the capital expenditure. However, gas price escalation, incentives, or regulatory actions could alter their plans in the next few years. A repowering system size consistent with coal repowering would be prudent.

SPPCo may also want to consider the Tracy plant for repowering. The BLM land available north of the Tracy plant is adequate for a full repowering, but the north/south depth of the land will not permit a single collector field to be constructed. Three reduced scale fields appear to be feasible to fit into the available land.

Demonstration Value to DOE and Other Utilities

Demonstration value should be evaluated according to criteria.

- Fossil fuel displacement of at least 20% annual average. This criterion will require the displacement of 109,000 to 257,000 bbl oil, depending on the capacity factor of the unit in 1986. SPPCo's forecast is for a 0.79 capacity factor, requiring displacement of 257,000 bbl oil. Hence, the plant thermal power level is set between 73 and 173 MW_{th}, with SPPCo's forecast of capacity factor leading to a minimum size of 173 MW_{th}.

- Technical feasibility must be demonstrated. This criterion relates to scaleup technical risk, primarily. The technology, general configuration and design approach to the system will all be representative of the full scale commercial system.

- Operational suitability of the system must be demonstrated. Key operational characteristics of controllability, thermal conditioning and energy output can be demonstrated over a wide range of system sizes. This criterion is not expected to impact the system size selection.

- Construction and O&M costs should be verified. These criteria are again related to scaling risk. The ability to estimate costs for commercial units will degrade slightly with scaleup. However, scaling of cost should be valid over a wider range than is prudent for technical risk.

- Solar electric output should be at least 2% of system load to understand the impact of solar operation on the system. The SPPCo peak load forecast in 1985 is almost 800 MW_e. This load occurs during December. Two percent of this peak load is 16 MW_e, substantially less than the minimum size considered.

- Availability must be demonstrated. This criterion also relates to scaleup technical risk.

Fuel Displacement

The DOE guideline of 20% minimum fuel displacement was discussed above. Beyond this level of fuel displacement, it is desirable to displace as much oil as possible, within other limitations. A detailed analysis is required to show penetration of fuel displacement into purchased power contracts and coal baseload. However, the conceptual design study showed penetration into other than oil/gas to be limited to purchased power from PG&E in 1985. Since the purchased power contract with PG&E is expected to end in 1984, all displacement will be oil/gas in 1986. The forecast for continued high capacity factor for Ft. Churchill will help the fuel displacement dominated by oil/gas for the foreseeable future.

Ft. Churchill Plant Operating Strategy

The solar repowering portion of the plant must be such as to be able to operate the turbine on solar steam, only. The normal minimum operating point is about 40 MW_e on fossil fuel, because of the inability of the boiler to maintain reheat temperature at a lower firing rate. Operation down to 30 MW_e on solar only is feasible from an SPPCo perspective. However, Stearns-Roger recommends a 52 MW_e minimum to maintain turbine efficiency close to the rated value. Figure 4 shows the heat rate of the Ft. Churchill turbine with its boiler characteristics and the effect of holding 1000°F turbine inlet temperature. Stearns-Roger recommends the two-valve open operating point at 52 MW_e.

Conclusions

Figure 5 shows the ranges of size resulting from the various constraints. The collector/receiver and the steam generator are shown separately.

For the collector/receiver, one minimum is established by the need to be able to operate on solar steam at 35 MW_e through the peak load. A 100 MW_{th} collector is required to carry the four-hour peak in the winter. The 20% fuel displacement minimum is quite high at 173 MW_{th}. This minimum is beyond all of the maxima. Hence, there is no size which can be chosen to meet all criteria. The downsizing is to be such as to allow modular construction of the full size plant. In this interest, 20% fuel displacement will be set aside. The lowest maximum is 120 MW_e, established by $\sim$ 3:1 scaleup to commercial system size. Hence, a one-third scale module of 110 MW_{th} rated power is selected as the most appropriate size. This size provides about 13% fuel displacement at .79 capacity factor.

For the steam generator, the minimum size is 52 MW_e, established by suitable solar only efficiency. The maximum is 36 MW_e, established by scaleup technical risk. Again, no size meets all criteria. A 50 MW_e size was selected because the design is available from the steam generator SRE and will operate in hybrid at a reasonable turndown ratio of 0.7.

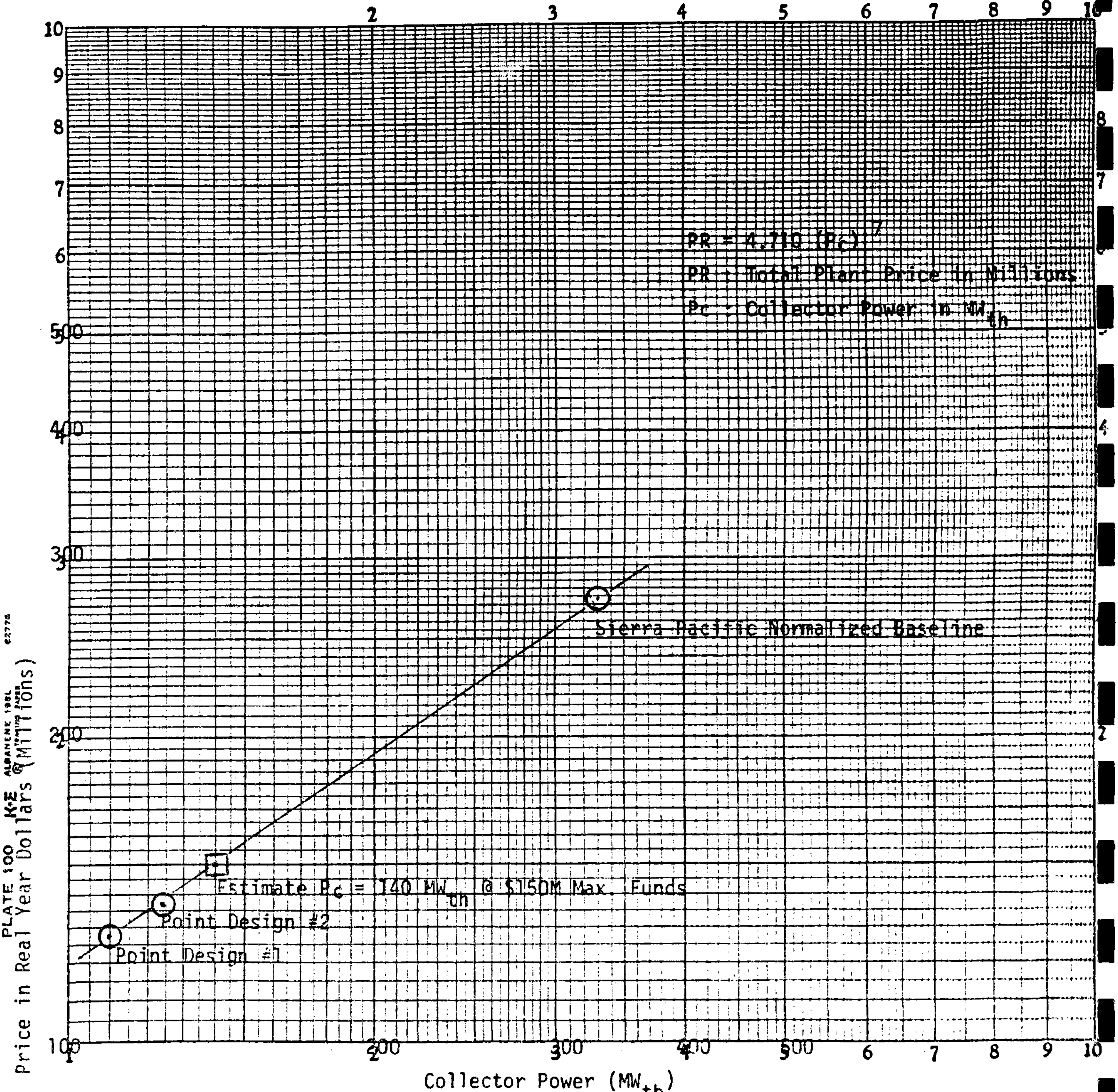


Figure 1 Sierra Pacific Solar Thermal Repowering Plant Sizing to Meet Funding Constraint

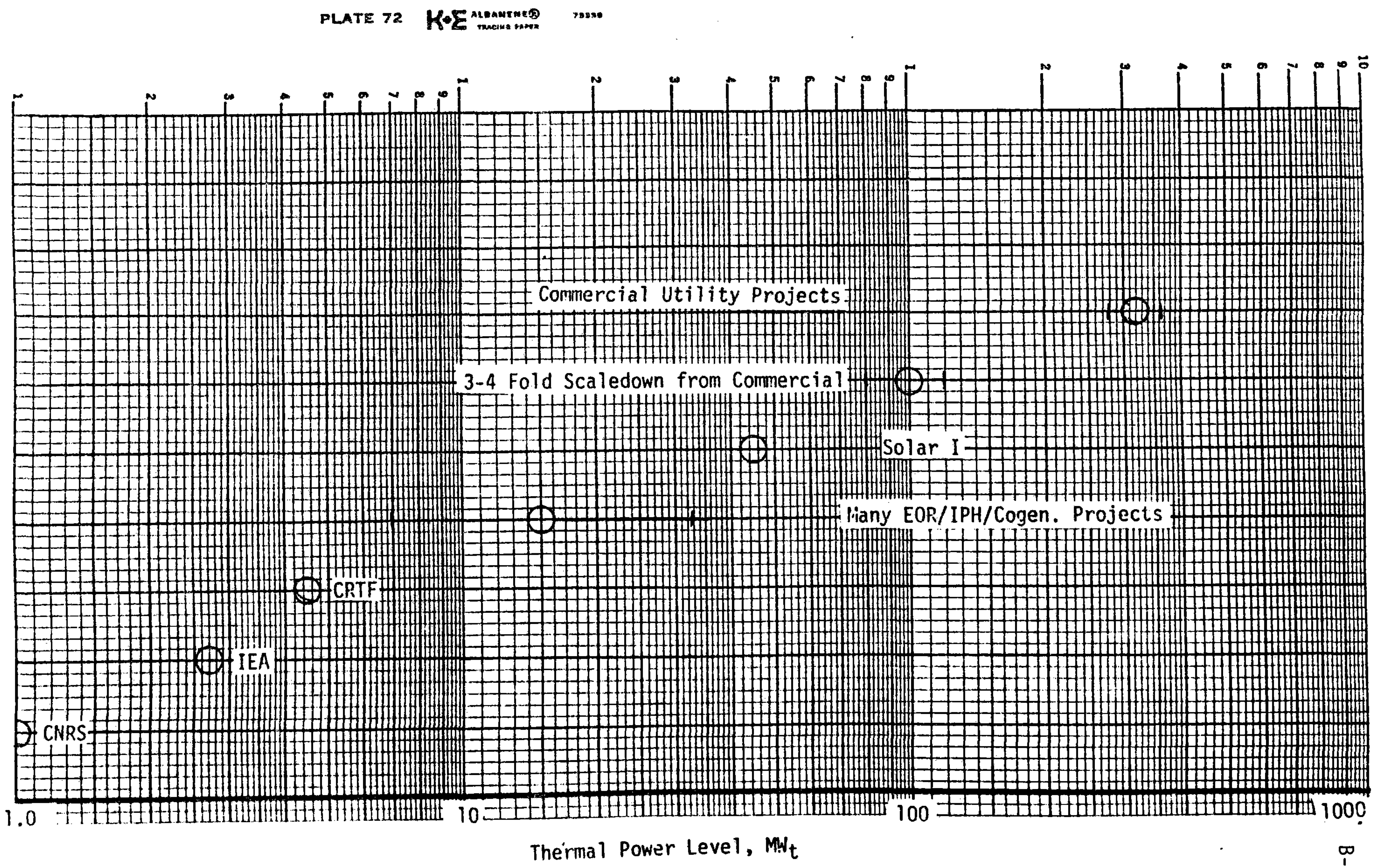


Figure 2. System Sizes for Current and Projected Central Receiver Systems

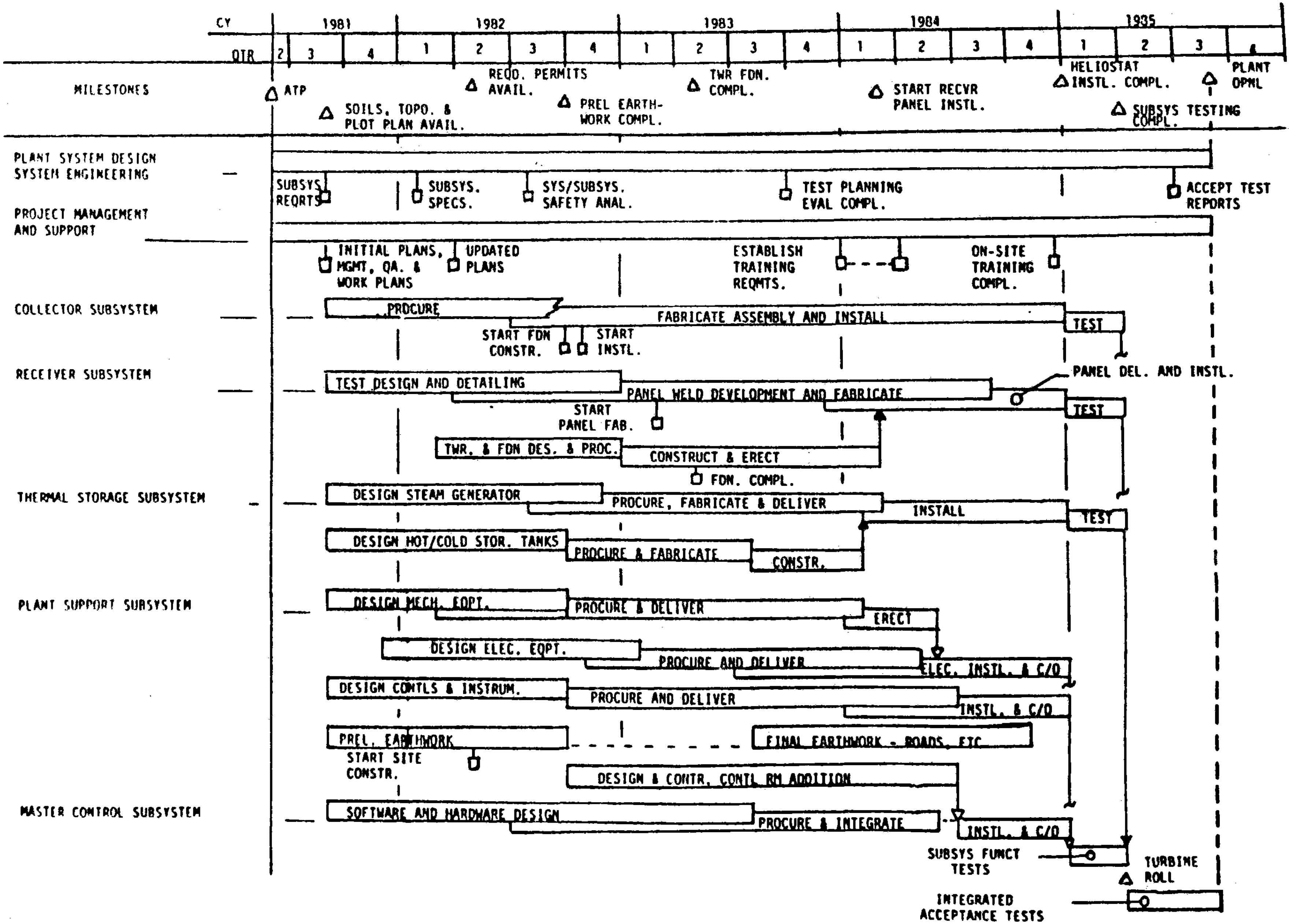


Figure 3. Development Plan Executive Summary From Previous Study

Stearns-Roger

PAGE 1 OF 1

JOB NO C-25953 DATE 12-23-81 BY AWM CH'K.

CUSTOMER MOAC PROJECT FT. CHURCHILL #1 REPOWERING

SUBJECT ESTIMATED GROSS TURBINE HEAT RATE VS. LOAD

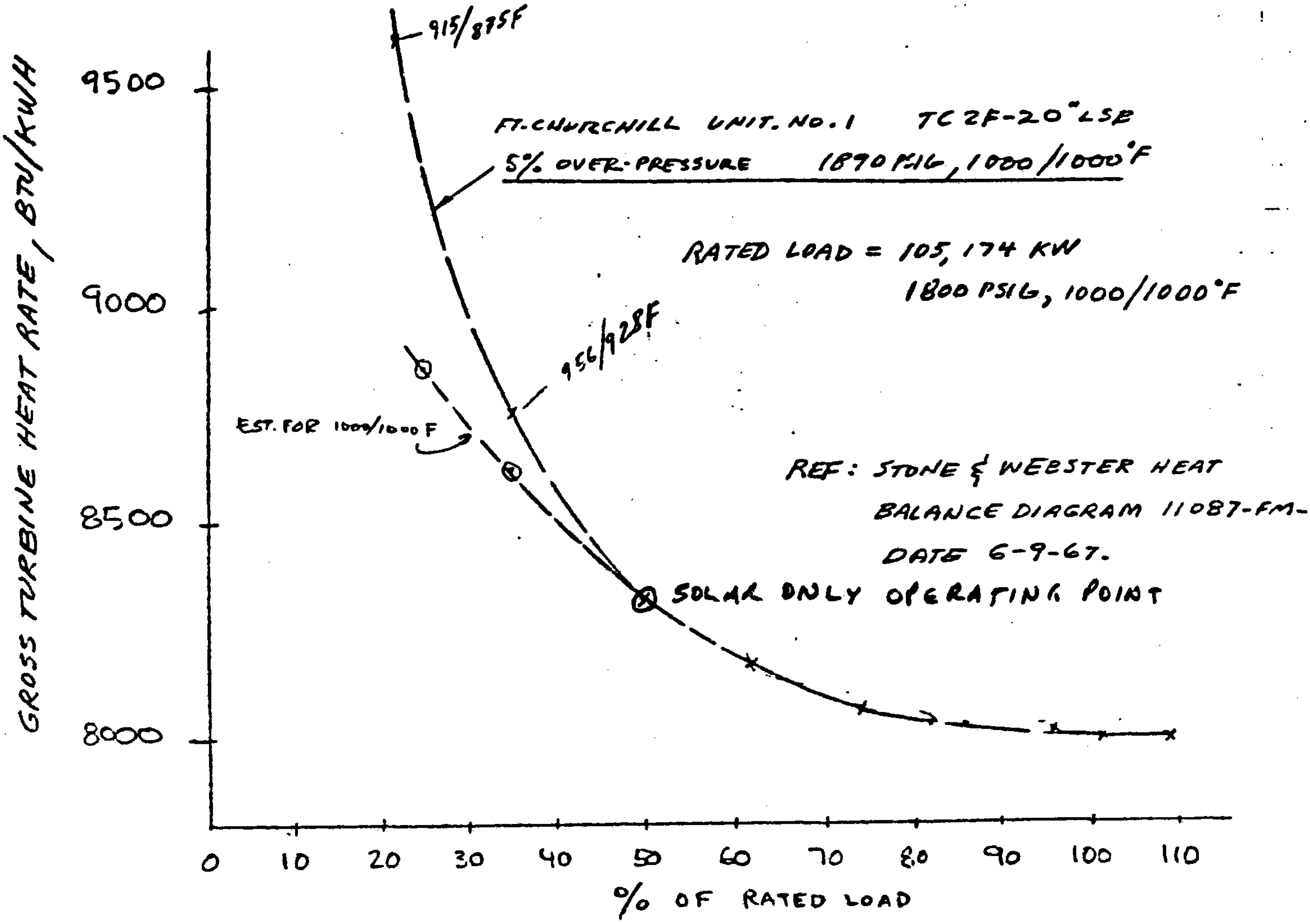


FIGURE 4

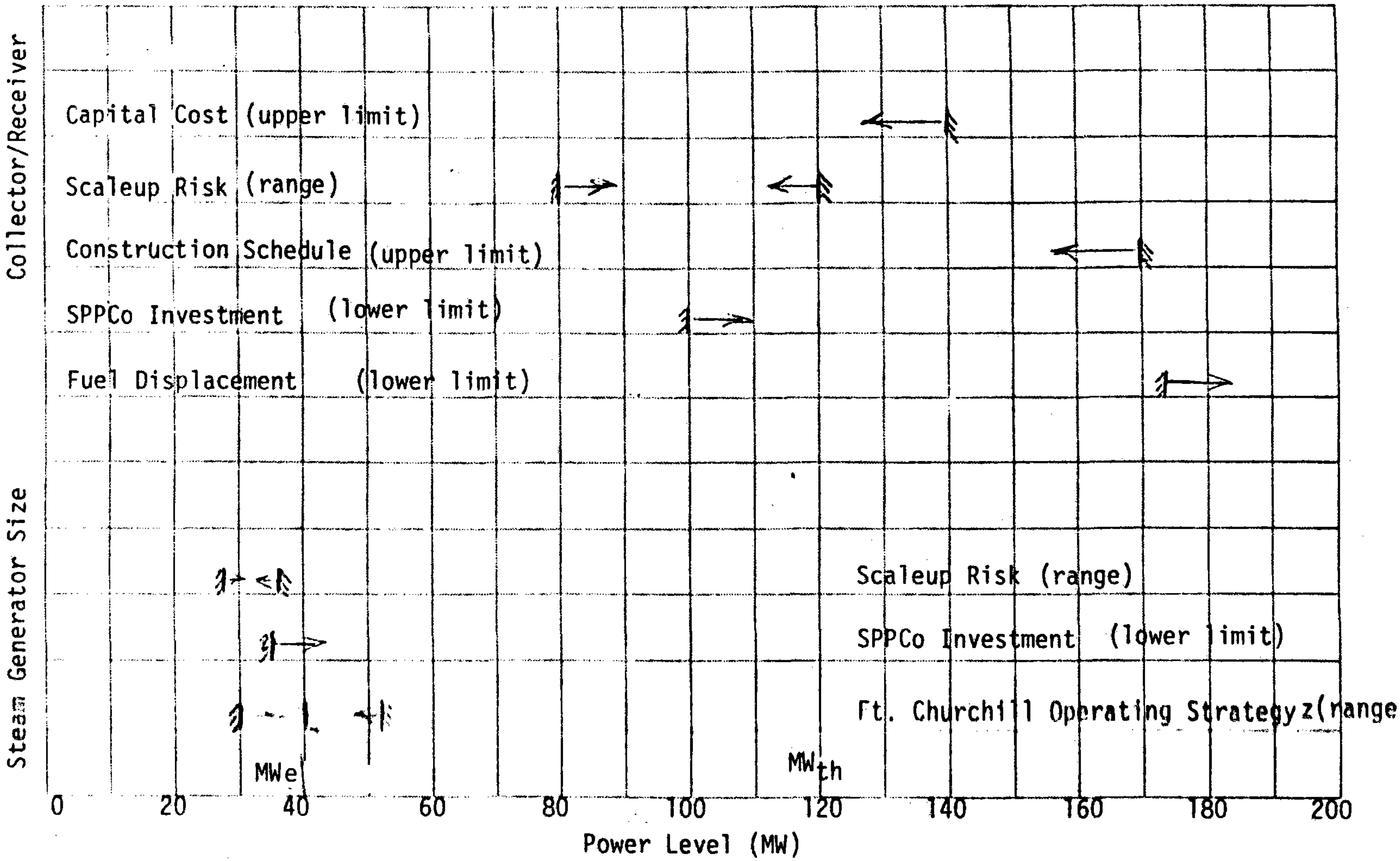


Figure 5. Constraints on Collector/Receiver and Steam Generator Power Level

APPENDIX C

SIERRA PACIFIC TILTED VS VERTICAL RECEIVER COMPARISON

A comparison of field size and performance was made for two different receiver configurations. One receiver was a tilted (25° down from vertical) omega configuration scaled down from the original Sierra Pacific receiver, and the other a vertical aperture receiver with upward sloping floor and ceiling. Both receivers were assumed to have 2-meter wide by 16-meter long preheat panel "wings" on either side of an 8-meter wide, 16-meter high aperture. The "wings" on the tilted receiver are in the plane of the aperture, while the wings of the vertical receiver are swept back at 45° to the aperture.

The field sizing and performance estimates were made by the University of Houston (under subcontract to MDC) using their R-CELL computer program. Prior to making these estimates, it was necessary for Houston to modify their codes in order to model the swept wings of the vertical receiver as a three-plane (aperture plus two wings) aperture.

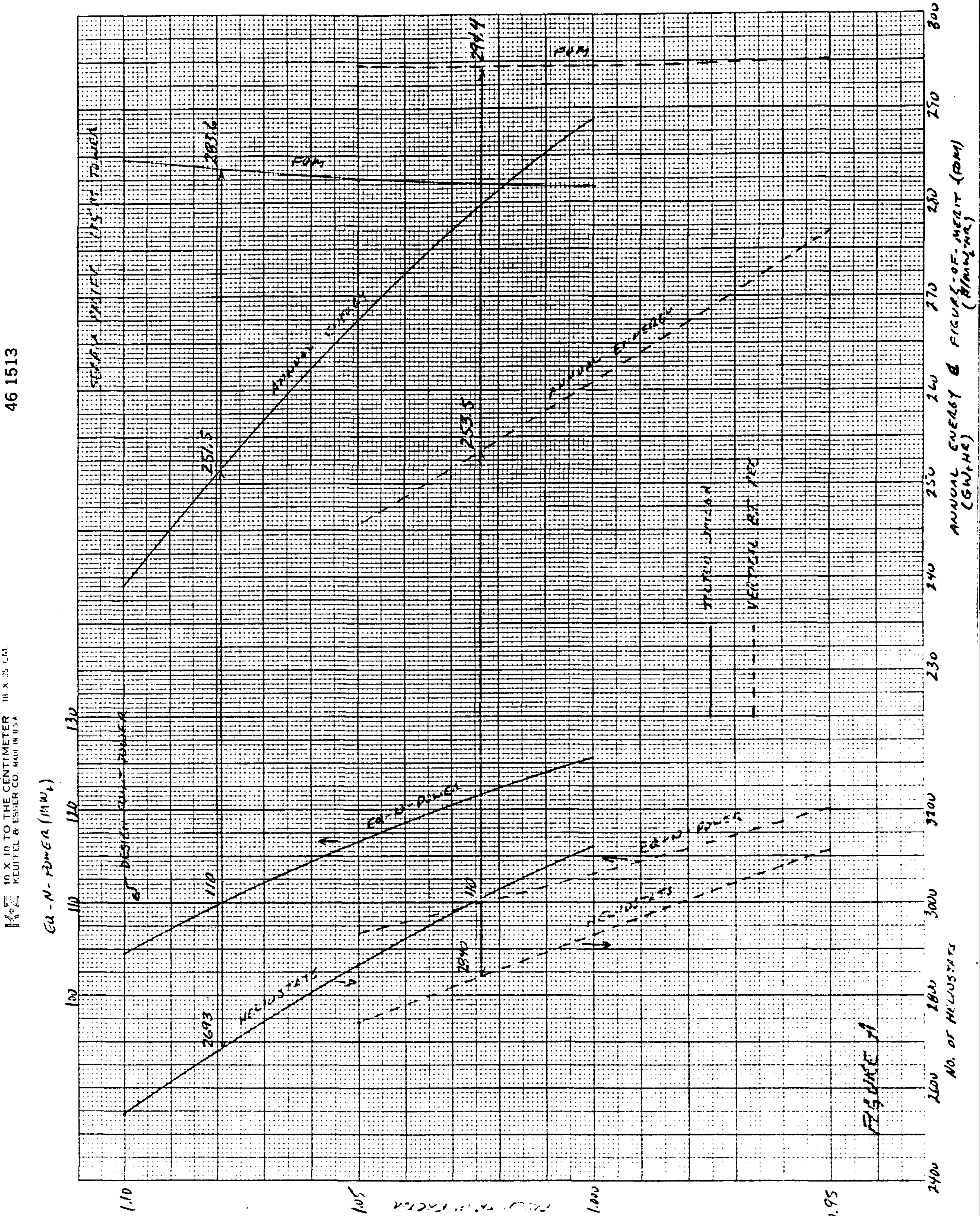
It was assumed, for purposes of this analysis, that there were no cost differences between the tilted and vertical receivers. Heliostat costs were assumed at $260/m^2 installed (excluding field wiring). The costs assumed for the tower were based on a steel tower design.

Initial runs were made at a tower optical height of 115 meters. The results of these runs are shown in Figure A. Parameters of interest (namely, number of heliostats, equinox noon (design point) power, annual energy, and figure of merit) are shown plotted against field trim factor. The trim value at which the design point power of 110 MW_t for each receiver is established and allows the determination of the other parameters at that power level. The appropriate values at the intercept of the design point power trim are shown on the figure. As can be seen, the tilted receiver requires some 147 fewer heliostats than the vertical receiver at the 110 MW_t design point. The tilted receiver produces slightly less annual energy, but provides a 4% better (lower) figure of merit.

Both fields optimize at power levels above the design power level (the fields are considered optimum at a trim factor of 1.00.) Because of this, additional runs were made at reduced tower heights for both receivers. Since the tilted receiver was farther from "optimum" (design point trim - 1.00 comparison), its tower height was reduced the most, to 105 meters. The vertical receiver's tower was reduced to 110 meters. The tilted receiver was analyzed at two different input figures of merit in these subsequent runs.

The results of these later runs are shown, in the same format, in Figure B. There was a slight improvement in the vertical receiver system, with a reduction in both number of heliostats and figure of merit when compared to the previous data. This was not the case with the tilted receiver, which implies that the optimum tower height is probably somewhere between 105 meters and 115 meters. However, the changes were not significant enough to warrant further analysis.

In conclusion, even though the data show a slight advantage to the tilted receiver, without having analyzed the cost differences between the receiver, a clear-cut selection cannot be made at this time. Given a choice, had the performance been equal, the vertical receiver should be specified as it appears intuitively to be a simpler design with more straightforward assembly and potential maintenance procedures. There is, however, about a 1.5 to 2.0 million heliostat cost advantage in favor of the tilted receiver based on these data. Further runs will be made with a vertical receiver with the preheat panels unswept; that is, in the plane of the aperture, and with larger swept preheat panels such that the projected frontal area equals the tilted receiver.


10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1513
EQ-N-POWER (MWt)
100
110
120
130
DESIGN POINT POWER
2693
110
251.5
283.6
FOM
2840
110
253.5
294.4
1.10
1.05
1.000
0.95
2400
2600
2800
3000
3200
230
240
250
260
270
280
290
300
NO. OF HELIOSTATS
ANNUAL ENERGY & FIGURE-OF-MERIT (FOM)
(GWt HR)

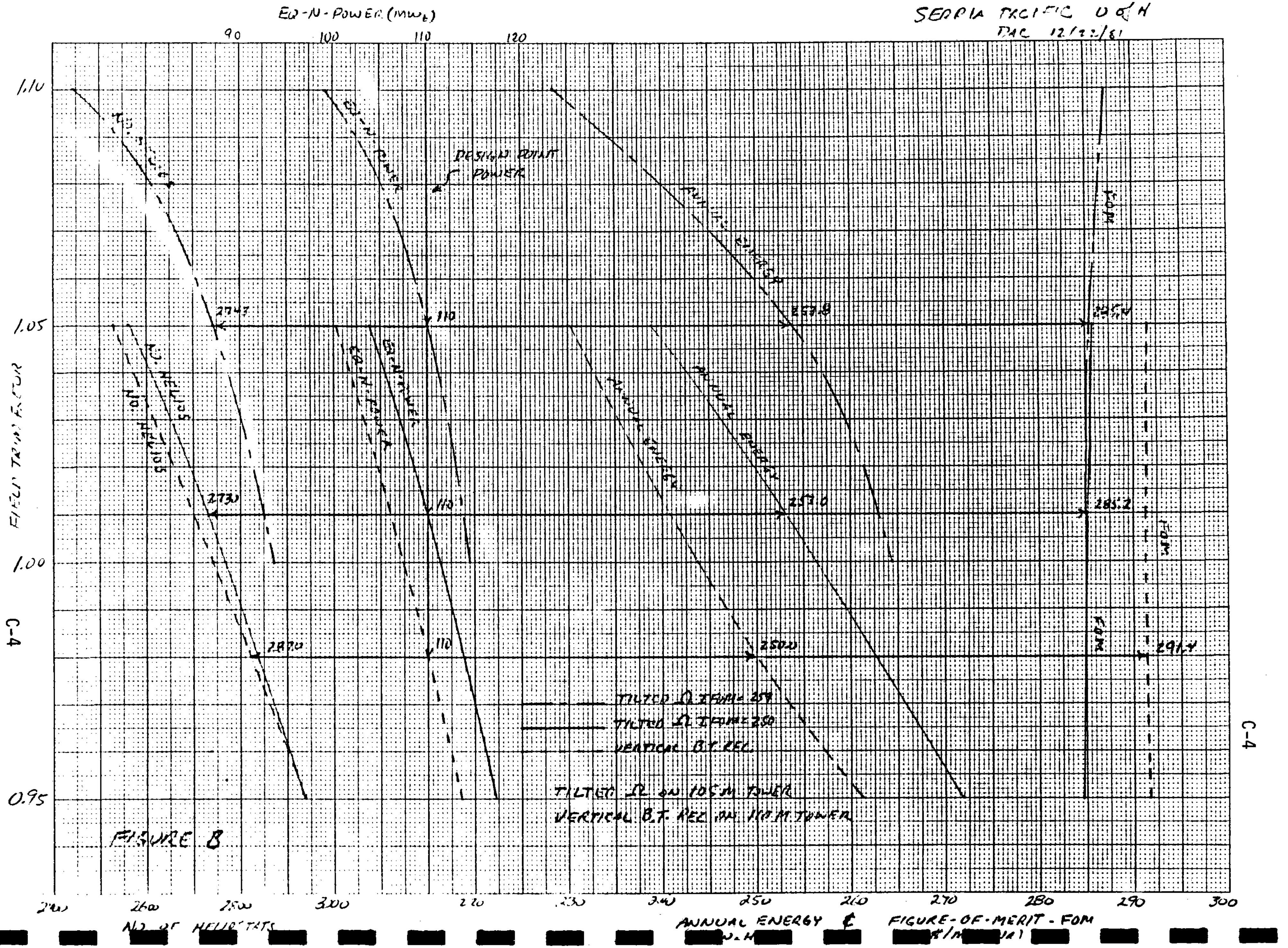

EQ-N-POWER (MWt)
90
100
110
120
1.10
1.05
1.00
0.95
DESIGN POINT POWER
2743
2730
2870
110
257.8
257.0
250.0
285.2
291.4
FOM
TILTED Ω IFOM=259
TILTED Ω IFOM=250
VERTICAL B.T. REC.
TILTED Ω ON 105 M TOWER
VERTICAL B.T. REC. ON 110 M TOWER
200
210
220
230
240
250
260
270
280
290
300
NO. OF HELIOSTATS
ANNUAL ENERGY & FIGURE-OF-MERIT - FOM

FIGURE 8

APPENDIX D

SIERRA PACIFIC UTILITY SOLAR REPOWERING
TASK 1C TRADE STUDY REPORT
120 METER RECEIVER TOWER SELECTION

1. OBJECTIVE AND SCOPE

The objective of this trade study was to select the receiver tower configuration which resulted in the most cost effective design meeting the design criteria while utilizing accepted construction practice. Two tower configurations were compared:

- Reinforced Concrete
- Structural Steel Truss

This study included the structural dynamic analysis and costing for the receiver towers and foundations only; tower design, engineering, accessories, and appurtenances were not included.

The receiver tower design criteria is shown in Table 1.

2. ANALYTIC PROCEDURE

Both towers were analyzed as multimass cantilever beam structures. The tower masses consisted of the tributary mass from the tower structure itself plus supported equipment. The rotational inertia of the tower masses was neglected in the dynamic analysis. The concrete tower was divided into fifteen segments of equal length, with the mass of each segment lumped at the segment centroid. For the steel truss tower, the masses were lumped at the level of each horizontal brace. The tower truss structure was represented by equivalent beam elements.

The receiver was modeled by rigid beam elements; the receiver mass was lumped at the receiver centroid.

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. The tower responses to both horizontal (one component) and vertical earthquake loading were computed (and plotted) using the response spectrum method. The ground response spectra was obtained using US NRC Regulatory Guide 1.60, scaled to a 0.25 g maximum ground acceleration. Model damping ratios for the towers were also obtained from the NRC Guide; the structural response to each earthquake component was computed from the appropriate modal responses. To compute member forces for design purposes, these component responses were then combined to obtain the complete earthquake response.

Drag wind loads were computed in accordance with "American National Standard Building Code Requirements for Minimum Design Loads in Buildings and Other Structures (ANSI A58.1-1972)." Design wind pressures were calculated based on

TABLE 1

RECEIVER TOWER DESIGN CRITERIA

SITE	Ft. Churchill Power Station Yerington, Nevada
ENVIRONMENTAL DESIGN DATA	
o Wind	40 m/s (90 mph) @ 10 m (30 ft)
o Seismic	0.25 g peak ground acceleration (UBC Zone 3)
o Allowable Soil Bearing	239 kPa (5000 psf)
TOWER HEIGHT	120 m (394 ft)
RECEIVER WEIGHT	544,300 kg (1.2 x 10^6 lb)

the specified basic wind velocity of 40 m/s (90 mph) at a height of 10 m (30 ft). In the case of the cylindrical concrete tower, the effects of Von Karman vortex shedding were also analyzed.

Various combinations of dead loads, and dead loads and wind loads, seismic loads, and, in the case of the concrete tower, vortex shedding loads, were examined as required by the design codes referenced in the following sections. Load factors were applied as allowed for and required by the design codes.

3. DESIGN PROCEDURE

For the reinforced concrete tower, minimum shell wall thickness and minimum circumferential reinforcement were determined in accordance with "Specification for the Design and Construction of Reinforced Concrete Chimneys." 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)." The steel tower members were sized in accordance with allowable stresses given in the AISC "Manual of Steel Construction," 7th Edition. Piping was assumed to add a dead load of 745 kg per meter (500 lb/ft) of tower height.

The foundation mats were designed to wind and seismic loads using the more cri-critical of two criteria: 1) the net soil pressure be less than or equal to the specified allowable soil static bearing pressure increased by 1/3, and 2) that in case of uplift, positive pressure must be maintained over at least 80% of the mat contact area. A load factor of unity was used in calculating soil bearing pressures.

4. 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 was 544,300 kg (1,200,000 lbs); the location of the center of gravity of the receiver was assumed to be on the tower center line extended and 13 m (42.65 ft) above the top of the tower.

5. TOWER DESCRIPTIONS

Drawings of the concrete and steel truss receiver towers are shown in Figures 2 and 3, respectively.

As indicated on Figure 2, the reinforced concrete tower has a height of 120 m (394 ft) above the top of the 36.6 m (120 ft) diameter mat which corresponds to grade elevation. The diameters of the top and base of the tower are 15.2 m (50 ft) and 19.5 m (64 ft), respectively. The tower taper is 1° and the wall thickness varies from 0.27 m (0.885 ft) at the top to 0.31 m (1.03 ft) at the base. The mat thickness is 3.65 m (12 ft).

Figure 3 shows the 120 m (394 ft) conventional structural steel truss tower constructed of standard structural steel shapes in an eight-legged structure of octagonal cross section. The dimensions across the flats are 15.0 m (49.23 ft) at the top and 24.0 m (78.75 ft) at the base. The mat dimensions are 29.5 m (95 ft) diameter by 2.9 m (9.5 ft) thick.

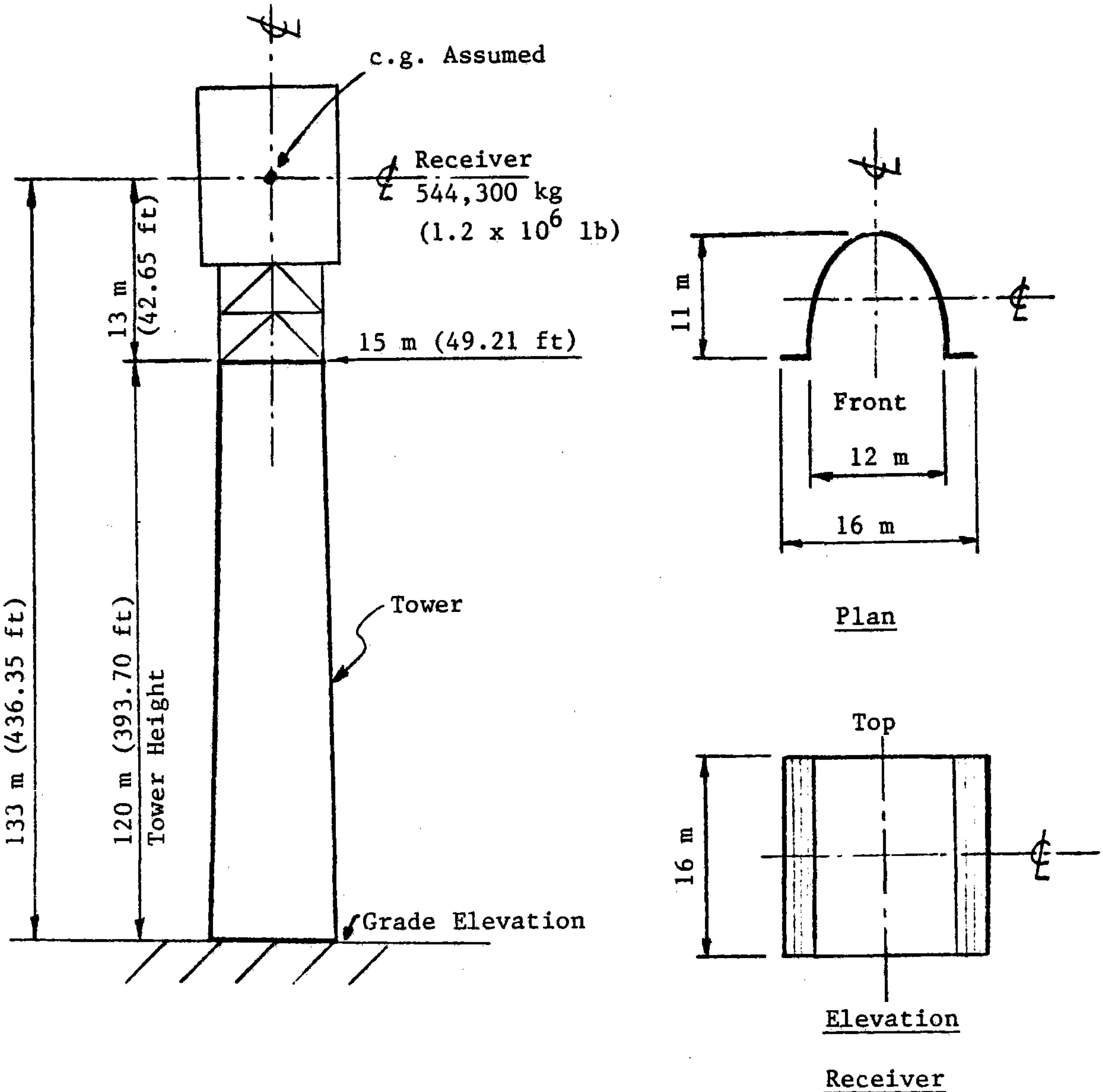


FIGURE 1

PRELIMINARY RECEIVER/TOWER CONFIGURATION

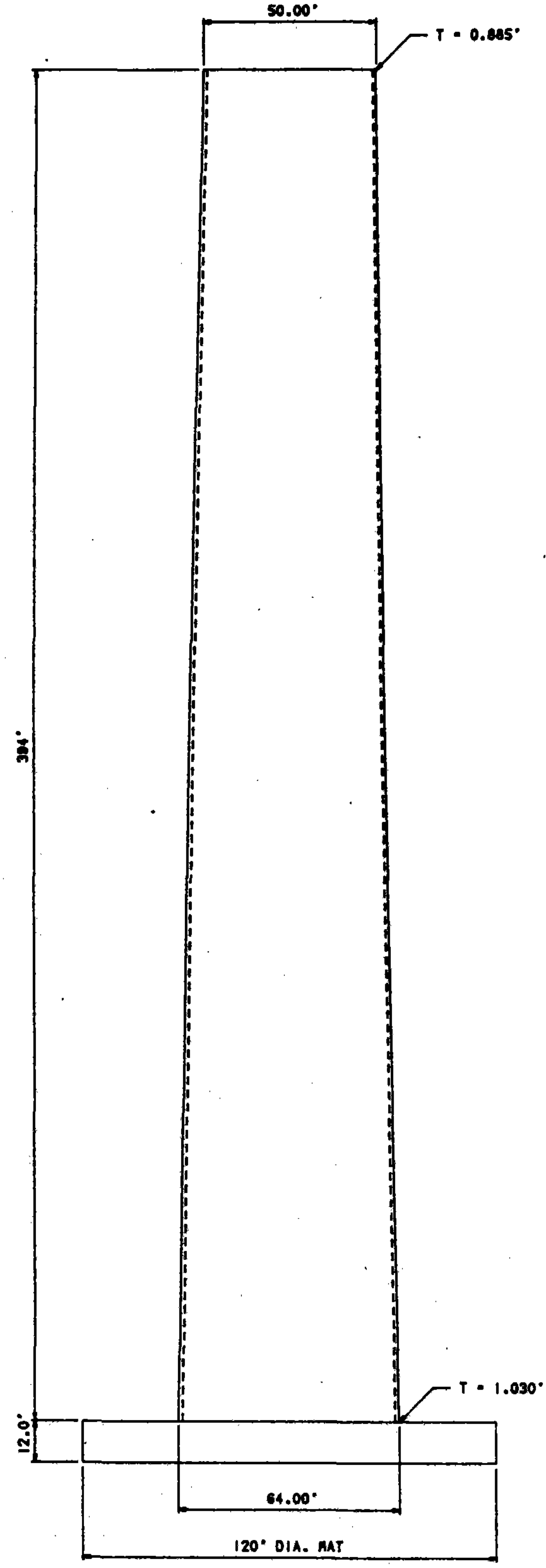


FIGURE 2

FT. CHURCHILL SOLAR REPOWERING (PHASE 2): CONCRETE TOWER DESIGN.

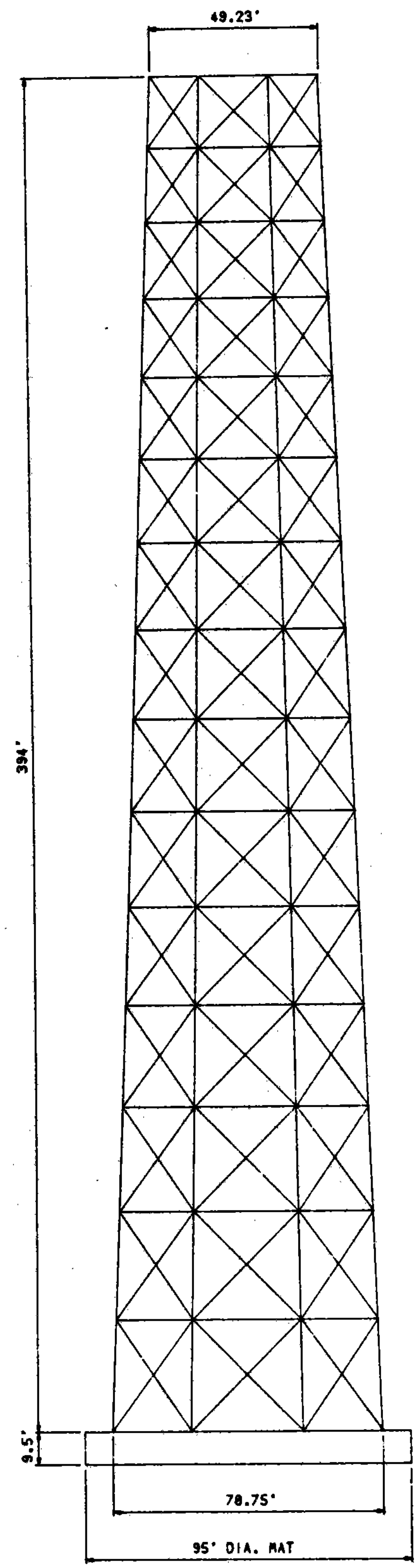


FIGURE 3

FT. CHURCHILL SOLAR REPOWERING (PHASE 2): STEEL TOWER DESIGN.

6. SUMMARY OF RESULTS

Table 2 shows a comparison of deflections, accelerations, and shear forces for both wind and seismic design conditions for each tower configuration. As shown, the laterial displacement for the operation wind of 13.4 m/s (30 mph) is very low for both towers. As expected, wind loads govern the steel tower design and seismic loads the concrete tower. The results show that the seismic induced accelerations at the tops of the towers and the receiver center lines are substantially lower for the steel tower than the concrete. Plots of the tower frequencies, drag wind deflections, shears and moments for the concrete and structural steel truss towers are shown in Figures 4 and 5, respectively.

7. COST ANALYSIS

The cost analysis for the towers was prepared by Stearns-Roger's Cost Estimating Department using current material prices and labor rates for Reno, Nevada. The material quantities used in the cost estimates for the two tower configurations are shown in Table 3. The comparison of tower costs is presented in Table 4. Indirect field costs include overhead (payroll taxes and insurance, field staff salaries, equipment rental, contractor's office overhead, and miscellaneous), sales tax (3-percent of material cost), and 10-percent profit.

8. RECOMMENDATION

A structural steel truss receiver tower is recommended for the advanced conceptual design. This recommendation is made for the following reasons:

1. The structural steel truss tower offers a capital cost advantage over the concrete tower at this particular tower height.

2. The lower seismic-induced accelerations of the steel tower offer the possibility of synergistic reductions in receiver and tower mass and consequent cost savings.

TABLE 2

SUMMARY OF RESULTS

120 m (394 ft) TOWERS

Description	Reinforced Concrete Tower	Structural Steel Tower
DEFLECTION, m (in.)		
a. 13.4 m/s (30 mph) Wind		
Top of Tower	0.0074 (0.29)	0.041 (1.63)
Center Line Receiver	0.0086 (0.34)	0.049 (1.92)
b. 40.2 m/s (90 mph) Wind		
Top of Tower	0.066 (2.61)	0.372 (14.65)
Center Line Receiver	0.077 (3.05)	0.440 (17.32)
c. 0.25 g Seismic		
Top of Tower	0.174 (6.85)	0.214 (8.41)
Center Line Receiver	0.203 (7.98)	0.258 (10.15)
MAXIMUM ACCELERATION, g's		
a. Top of Tower	0.39	0.32
b. Center Line Receiver	0.64	0.19
MAXIMUM WIND SHEAR, MN (10^3 lb)		
a. Bottom of Tower	2.97 (668)	3.59 (806)
b. Top of Tower	0.956 (215)	1.07 (240)
SEISMIC SHEAR, MN (10^3 lb)		
a. Bottom of Tower	10.31 (2317)	1.63 (367)
b. Top of Tower	3.44 (773)	1.03 (231)

FIGURE 4

FT. CHURCHILL SOLAR REPOWERING (PHASE 2): TRIAL CONCRETE TOWER DESIGN NO. 1

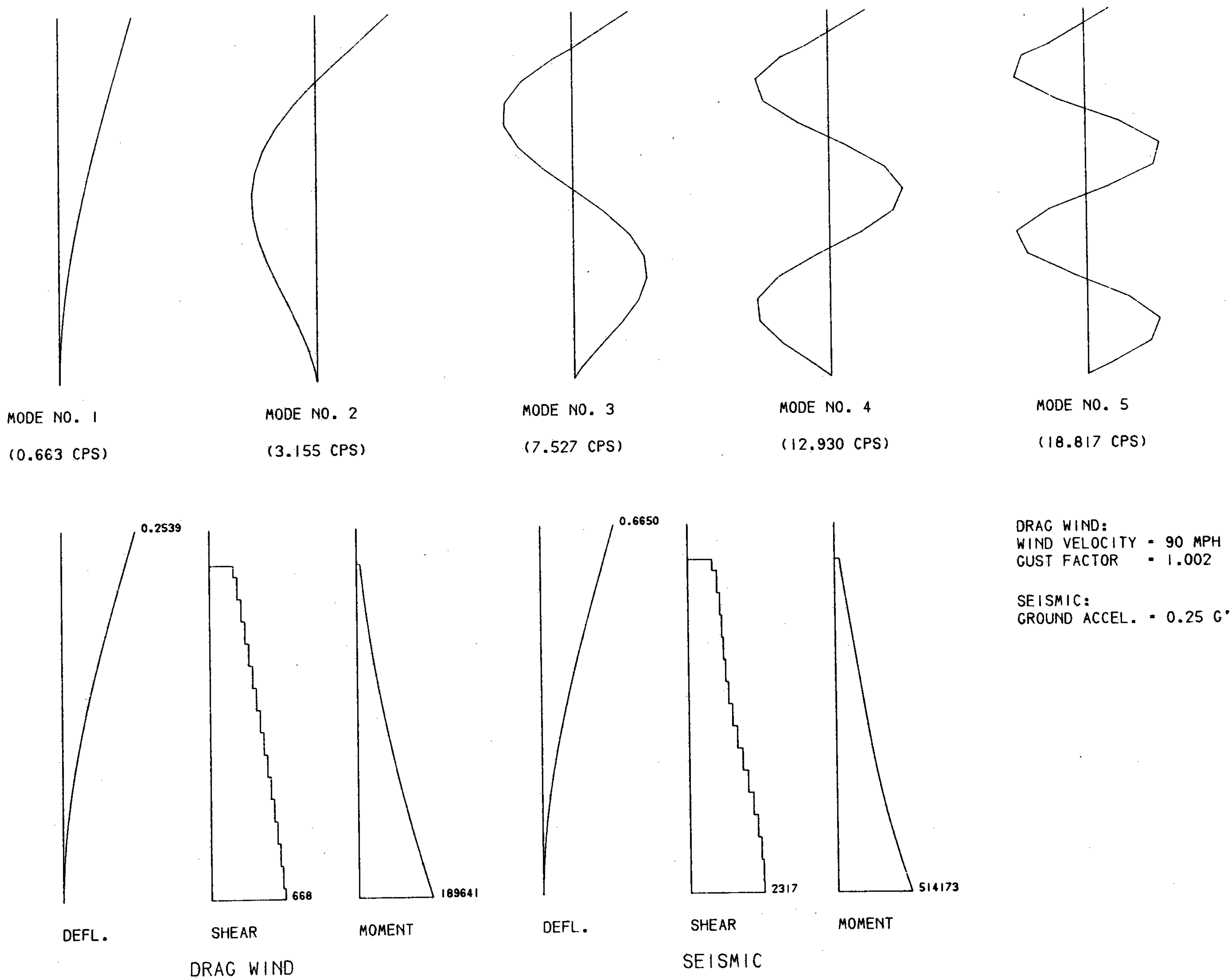
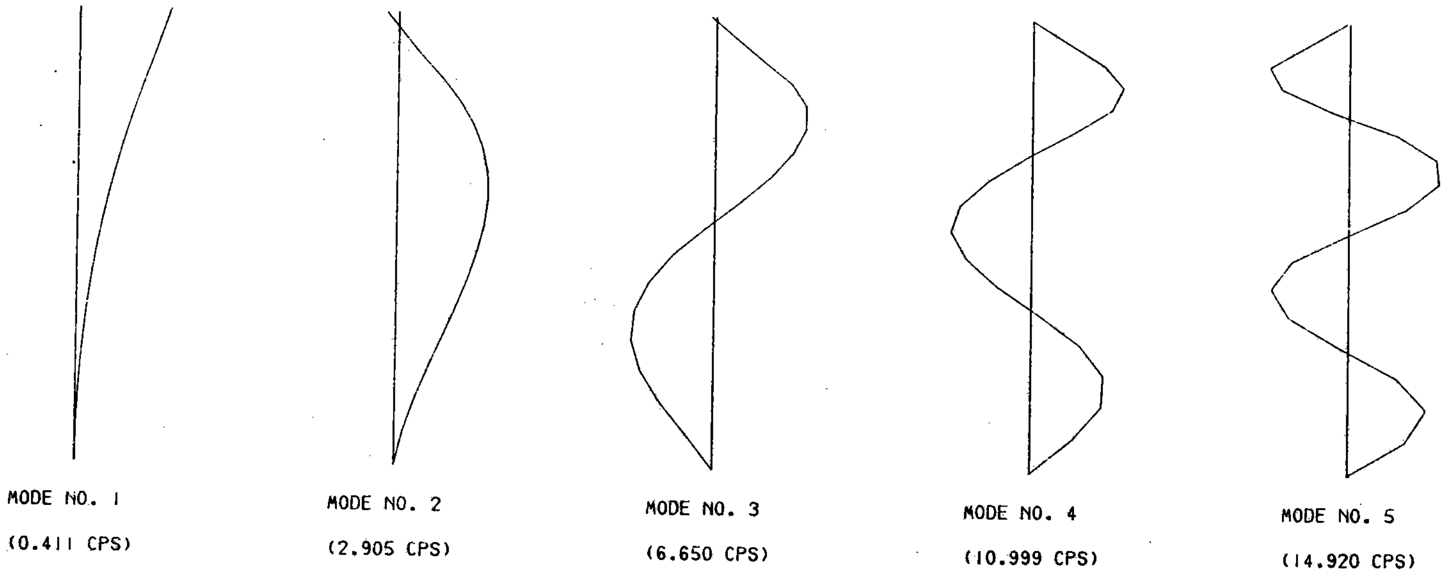


FIGURE 5

FT. CHURCHILL SOLAR REPOWERING (PHASE 2): TRIAL STEEL TOWER DESIGN NO. 3



DRAG WIND:
WIND VELOCITY = 90 MPH
GUST FACTOR = 1.040 (DIR. NO. 1)
GUST FACTOR = 1.048 (DIR. NO. 2)

SEISMIC:
GROUND ACCEL. = 0.25 G'S

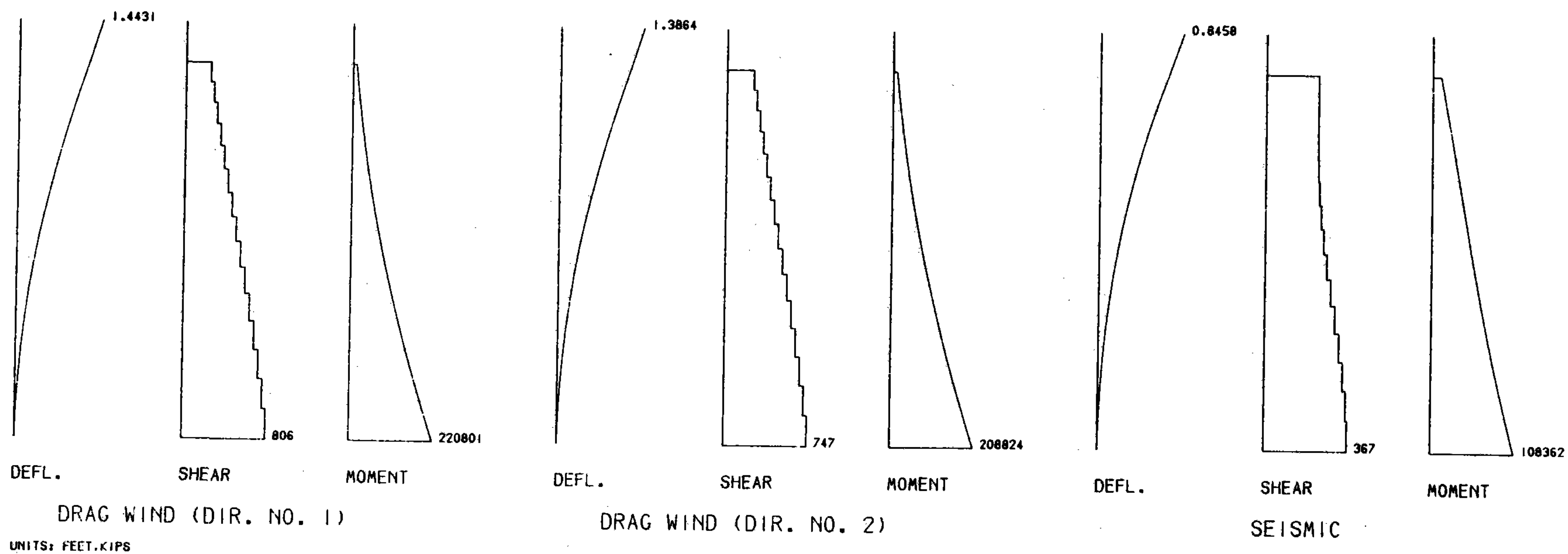


TABLE 3

MATERIAL QUANTITIES

120 m (394 ft) TOWERS

Description	Units	Reinforced Concrete	Structural Steel Truss
TOWER			
a. Concrete (4000 psi)	m^3 (yd^3)	1885 (2466)	N/A
b. Rebar (60,000 psi)	kg (ton)	168,740 (186)	N/A
c. Columns (A440 Steel)	kg (ton)	N/A	159,670 (176)
d. Bracing & Connections (A36 Steel)	kg (ton)	N/A	232,240 (256)
FOUNDATION MAT			
a. Concrete (3000 psi)	m^3 (yd^3)	3,842 (5,027)	1,907 (2,494)
b. Rebar (60,000 psi)	kg (ton)	171,460 (189)	84,845 (94)
SOIL EXCAVATION	m^3 (yd^3)	5,392 (7,055)	2,675 (3,499)

TABLE 4

TOWER COST COMPARISON

120 m (394 ft) TOWERS

(1982 DOLLARS)

	Reinforced Concrete	Structural Steel Truss
Direct Field Cost	1,310,900	1,007,000
Indirect Field Cost	504,100	583,000
TOTAL FIELD COST	1,815,000	1,590,000
% Over Base	+14	Base

Notes

1. Cost estimate is for tower and foundation only. Tower design, engineering, accessories and appurtenances are not included.

2. Labor rates for Reno, Nevada, first quarter 1982.

Stearns-Roger
ESTIMATE

ACCOUNT	TYPE EST.	BY	DATE	PAGE
		A.L.	3/82	SUMMARY

JOB NO.	CLIENT	PROJECT	LOCATION
C25953		FT. CHURCHILL RECEIVER TOWER	YERINGTON, NEV

ACCT. NO.	ACCOUNT DESCRIPTION	U/M	QUAN.	LABOR UNIT	LABOR MH	LABOR $/MH	LABOR AMOUNT	MATERIAL UNIT	MATERIAL AMOUNT	OTHER UNIT	OTHER AMOUNT	TOTAL
	STRUCT STEEL RECEIVER TOWER											
	SUMMARY											
	DIRECT FIELD COST						448951		558054			1007005
	OVER HEADS						171400		20000		229700	421100
	SUB-TOTAL						620351		578054		229700	1428105
	SALES TAX 3% OF M								17342			17342
	SUB TOTAL											1445447
	PROFIT 10%											144544
	TOTAL ▷											1589991
	USED ▷											1,590,000

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Stearns-Roger
ESTIMATE

ACCOUNT	TYPE EST.	BY	DATE	PAGE
		A.L.	3/82	

JOB NO.	CLIENT	PROJECT	LOCATION
C-25953		FT. CHURCHILL RECEIVER TOWER	YERINGTON, NEV

ACCT. NO.	ACCOUNT DESCRIPTION	U/M	QUAN.	LABOR UNIT	LABOR MH	LABOR $/MH	LABOR AMOUNT	MATERIAL UNIT	MATERIAL AMOUNT	OTHER UNIT	OTHER AMOUNT	TOTAL
	STRUCTURAL STEEL											
	RECEIVER TOWER											
	EARTHWORK:											
	EXCAVATION	CY	3500	.18	630	20.54	12940		-			12940
	BACKFILL	CY	1000	.22	220	20.54	4519		-			4519
	FOUND. CONCRETE											
	CONCRETE	CY	2494	2	4988	21.33	106394	50	124700			231094
	REBAR	T	94	20	1880	25.96	48804	525	49350			98154
	FORMS	SF	3600	.5	1800	17.33	31194	1.20	4320			35514
	EMBEDS	LB	2000	.1	200	20.18	4036	1.25	2500			6536
	STRUCTURAL STEEL											
	COLUMNS	T	176	20	3520	25.96	91379	856	150656			242035
	BRACING & CONNECTIONS	T	256	20	5120	25.96	132915	863	220928			353843
	PAINTING											
	STRUCT. STEEL	T	432	2.	864	19.41	16770		5600			22370
	SUB-TOTAL				19222	23.91	448951		558054			1007005

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FORM 43 135 REV 11/80

ACCOUNT				Stearns-Roger ESTIMATE	TYPE EST.	BY	DATE	PAGE
JOB NO. C-25953	CLIENT			PROJECT FT. CHURCHILL RECEIVER TOWER			LOCATION YERINGTON NEV.	

ACCT. NO.	ACCOUNT DESCRIPTION	U/M	QUAN.	LABOR UNIT	LABOR MH	LABOR $/MH	LABOR AMOUNT	MATERIAL UNIT	MATERIAL AMOUNT	OTHER UNIT	OTHER AMOUNT	TOTAL
	STRUCT. STEEL RECEIVER TOWER											
	INDIRECT COSTS											
	PAYROLL TAXES & INSUR. 20% OF LABOR. $448951						90000					90000
	FIELD STAFF: SUPT.	MO					22800					22800
	FIELD ENG	MO					19800					19800
	TYPIST/CLERK	MO					7500					7500
	SMALL TOOLS								10000			10000
	TRAILERS 4 EA	EA	4/6 MO							800	4800	4800
	TEMP. POWER & WATER	LS					13000		6000			19000
	SAFETY, FIRST AID	LS					6500		3000			9500
	TELEPHONE	MO	6								4000	4000
	CLEAN UP						11800		1000		1600	14400
	CONTRACTORS OFFICE OVERHEAD										58,600	58600
	CONSTRUCTION EQUIPT										160700	160700
							171400		20000		229700	421100

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Stearns-Roger
ESTIMATE

ACCOUNT	TYPE EST.	BY	DATE	PAGE
		A.L.		

JOB NO.	CLIENT	PROJECT	LOCATION
C25953		FT. CHURCHILL RECEIVER TOWER	YERINGTON NEV.

ACCT. NO.	ACCOUNT DESCRIPTION	U/M	QUAN.	LABOR UNIT	LABOR MH	LABOR $/MH	LABOR AMOUNT	MATERIAL UNIT	MATERIAL AMOUNT	OTHER UNIT	OTHER AMOUNT	TOTAL
	STRUCT. STEEL RECEIVER TOWER.											
	CONSTRUCTION EQUIPT.											
	225 TON CAP. CRANE	MO	4							20000	80000	80000
	MOVE IN MOVE OUT									20000	20000	20000
	25 TON TRUCK CRANE	MO	2							5000	10000	10000
	4CU.YD. F.E. LOADER	MO	2							4500	9000	9000
	CONCRETE PUMP.	DA	10							650	6500	6500
	WELDING MACHINES	EA	2/4M							1000	4000	4000
	CONCRETE FINISH. & VIBRATOR EQUIPT	LS	1							1200	1200	1200
	MISC. EQUIPT.										18000	18000
	FUEL & MAINT.	LS	1								12000	12000
	TOTAL ▷										160700	160700

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FORM 62-114
REV. 4-75

Stearns-Roger

PAGE ______

JOB NO. 625953 DATE 3/82 BY A.L CH'K. ______

CUSTOMER ______ PROJECT ______

SUBJECT COMPOSITE CREW RATE

CARPENTRY FORMING & STRIPPING CREW

1 FORE	- 21.52	=	21.52
6 CARPS	- 19.56	=	117.36
6 LABRS.	- 13.65	=	81.90
1 O.E.	- 23.45.	=	23.45
1 TMSTR.	- 15.70	=	15.70
			259.93 = $17.33 PER HR.

EMBED CREW

1 FORE	22.00	=	22.00
4 CARPS	19.56		78.24
4 I.W.	23.62		94.48
2 LABRS	13.65		27.30
			222.02 = $20.18 PER HR.

Stearns-Roger
ESTIMATE

ACCOUNT

TYPE EST. CONCEPT'L | BY A.L. | DATE 3/82 | PAGE SUMMARY

JOB NO. C25953 | CLIENT | PROJECT FT. CHURCHILL RECEIVER TOWER | LOCATION YERINGTON NEV

ACCT. NO.	ACCOUNT DESCRIPTION	U/M	QUAN.	LABOR UNIT	LABOR MH	LABOR $/MH	LABOR AMOUNT	MATERIAL UNIT	MATERIAL AMOUNT	OTHER UNIT	OTHER AMOUNT	TOTAL
	CONCRETE TOWER											
	DIRECT FIELD COST						639069		671867			1310936
	OVERHEAD						201400		17000		99500	317900
	SUB-TOTAL						840969		688167		99500	1629336
	SALES TAX 3% OF M								20645			20645
	SUB TOTAL											1649981
	PROFIT 10%											164998
	TOTAL											1814979
	USE											1,815,000

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Stearns-Roger
ESTIMATE

ACCOUNT	TYPE EST.	BY	DATE	PAGE
		A.L.	3/82	

JOB NO.	CLIENT	PROJECT	LOCATION
C25953		FT. CHURCHILL RECIEVER TOWER	YERINGTON NEV.

ACCT. NO.	ACCOUNT DESCRIPTION	U/M	QUAN.	LABOR UNIT	LABOR MH	LABOR $/MH	LABOR AMOUNT	MATERIAL UNIT	MATERIAL AMOUNT	OTHER UNIT	OTHER AMOUNT	TOTAL
	CONCRETE RECEIVER TOWER											
	EARTHWORK											
	EXCAVATION	CY	7055	.18	1270	20.54	26085		-			26085
	BACKFILL	CY	2000	.22	440	20.54	9037		-			9037
	CONCRETE TOWER	CY	2466	4.5	11097	21.13	234480	127	313182			547662
	FOUNDATION MAT											
	CONCRETE	CY	5027	2	10054	21.33	214451	50	251350			465801
	REBAR	T	189	20	3780	25.96	98128	525	99225			197353
	FORMS	SF	5277	.6	3166	17.33	54870	1.30	6860			61730
	EMBEDS	#	1000	.1	100	20.18	2018	1.25	1250			3268
	SUB-TOTAL ▷				29907	21.37	639069		671867			1310936

Stearns-Roger
ESTIMATE

ACCOUNT:

TYPE EST.: CONCEPTL | BY: A.L. | DATE: | PAGE:

JOB NO.: C25953 | CLIENT: | PROJECT: FT. CHURCHILL RECEIVER TOWER | LOCATION: YERINGTON, NEV.

ACCT. NO.	ACCOUNT DESCRIPTION	U/M	QUAN.	LABOR UNIT	LABOR MH	LABOR $/MH	LABOR AMOUNT	MATERIAL UNIT	MATERIAL AMOUNT	OTHER UNIT	OTHER AMOUNT	TOTAL
	CONCRETE RECEIVER TOWER											
	OVERHEADS											
	PAYROLL TAXES & INSUR.						127800					127800
	20% OF LABOR $639069											
	FIELD STAFF - SUPT	MO	6				22800					22800
	FIELD ENGR	MO	6				19800					19800
	TYPIST/CLERK	MO	6				7500					7500
	SMALL TOOLS	LS	1						6000			6000
	TRAILERS 4ea	MO	6							800	4800	4800
	TEMP. POWER, WATER	MO	6				17000		8000			25000
	SAFETY, FIRST AID	MO	6				6500		3000			9500
	TELEPHONE	MO	6								4000	4000
	CLEANUP											
	CONTRACTORS OFFICE OVERHEAD										50,000	50000
	CONSTRUCTION EQUIPT.										40700	40700
							201400		17000		99500	317900

FORM 43 135 REV. 11/86

Stearns-Roger
ESTIMATE

ACCOUNT	TYPE EST.	BY	DATE	PAGE
		A.L	3/82	

JOB NO.	CLIENT	PROJECT	LOCATION
625953		FT. CHURCHILL RECEIVER TOWER	YERINGTON NEV.

ACCT. NO.	ACCOUNT DESCRIPTION	U/M	QUAN.	LABOR				MATERIAL		OTHER		TOTAL
				UNIT	MH	$/MH	AMOUNT	UNIT	AMOUNT	UNIT	AMOUNT	
	CONCRETE TOWER											
	CONSTRUCTION EQUIPT											
	25 TON TRUCK CRANE	MO	2							5000	10000	10000
	4 CY F.E. LOADER	MO	2							4500	9000	9000
	CONCRETE PUMP	D	10							650	6500	6500
	CONCRETE FINISH & VIBRATOR EQUIPT	LS	1							1200	1200	1200
	MISC. EQUIPT	LS	1							8000	8000	8000
	FUEL & MAINT									6000	6000	6000
	TOTAL ▷										40700	40700

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COMPOSITE LABOR RATES

Excludes Fringe Benefits

PROJECT FT. CHURCHILL RECEIVER TOWER. BY A.L C-25953

LOCATION YERINGTON, NEV. RENO RATES, R.S. MEANS 1982 1ST QUARTER DATE 3/82

STRUCTURAL EARTHWORK (Hand & Machine)

LA	.65 x $ 13.65	= $ 8.87		
OE	.30 x $ 23.45	= $ 7.04		17.54
TM	.05 x $ 15.70	= $ .79		
	Composite Rate	= $ 16.70	+5% SUPVSN	

GENERAL EARTHWORK (Hand & Machine)

LA	.20 x $ 13.65	= $ 2.73		
OE	.55 x $ 23.45	= $ 12.90		20.54
TM	.25 x $ 15.70	= $ 3.93		
	Composite Rate	= $ 19.56	+5% SUPVSN	

CONCRETE

CA	.30 x $ 19.56	= $ 5.87		
CM	.10 x $ 18.60	= $ 1.86		
IW	.25 x $ 23.62	= $ 5.90		21.33
LA	.25 x $ 13.65	= $ 3.41		
OE	.10 x $ 23.45	= $ 2.35		
	Composite Rate	= $ 19.39	+ 10% SUPVSN.	

STRUCTURAL STEEL

IW	.85 x $ 23.62	= $ 20.08		25.96
OE	.15 x $ 23.45	= $ 3.52		
	Composite Rate	= $ 23.60	+ 10% SUPVSN	

BUILDING & STRUCTURES

CA	.30 x $	= $
CM	.01 x $	= $
IW	.39 x $	= $
LA	.15 x $	= $
OE	.15 x $	= $
	Composite Rate	= $

MASONRY

BL	.40 x $	= $
LA	.40 x $	= $
OE	.15 x $	= $
CA	.05 x $	= $
	Composite Rate	= $

EQUIPMENT

IW	.25 x $	= $
MW	.30 x $	= $
PF	.15 x $	= $
OE	.15 x $	= $
EL	.05 x $	= $
CA	.05 x $	= $
BM	.05 x $	= $
	Composite Rate	= $

"M" START-UP

PF	.45 x $	= $
EL	.45 x $	= $
MW	.10 x $	= $
	Composite Rate	= $

"D" BOILER ERECTION

BM	.60 x $	= $
IW	.15 x $	= $
PF	.05 x $	= $
OE	.15 x $	= $
MW	.05 x $	= $
	Composite Rate	= $

PIPING & PNEUMATIC INSTRUMENTATION

PF	.88 x $	= $
CA	.04 x $	= $
LA	.02 x $	= $
OE	.06 x $	= $
	Composite Rate	= $

PAINTING

PA	.95 x $ 18.75	= $ 17.81		19.41
LA	.05 x $ 13.65	= $ .68		
	Composite Rate	= $ 18.49	+5% SUPVSN	

INSULATION

AW	.60 x $	= $
SB	.30 x $	= $
CA	.05 x $	= $
LA	.05 x $	= $
	Composite Rate	= $

ROOFING

RF	.85 x $	= $
OE	.15 x $	= $
	Composite Rate	= $

INSULATION PANELS

IW	.40 x $	= $
CA	.25 x $	= $
LA	.30 x $	= $
OE	.05 x $	= $
	Composite Rate	= $

SPRINKLERS

SP	.89 x $	= $
CA	.04 x $	= $
LA	.03 x $	= $
OE	.04 x $	= $
	Composite Rate	= $

ELECTRICAL

Performed 100% by Electricians

$ 23.70 + 12.5% SUPV 26.66

"D" PRECIPITATORS (Not Including Electr.

BM	.45 x $	= $
IW	.30 x $	= $
OE	.15 x $	= $
MW	.10 x $	= $
	Composite Rate	= $

"D" TURBINE GENERATOR

MW	.40 x $	= $
PF	.35 x $	= $
IW	.10 x $	= $
EL	.05 x $	= $
CA	.05 x $	= $
OE	.05 x $	= $
	Composite Rate	= $

FORM 62-114
REV. 4-75

Stearns-Roger

PAGE ______

JOB NO. ______ DATE ______ BY ______ CH'K. ______

CUSTOMER ______ PROJECT ______

SUBJECT ______

* CONCRETE CREW FOR CONCRETE TOWER

CARPENTRY - 30%	5.87
IRON WORKER 27%	6.38
LABORERS 29%	3.96
CEMENT MASON - 6%	1.12
OPER. ENGR. 8%	1.88

4.5MH/C.Y.

$19.21

+ 10% SUPVSN. = $21.13

REBAR & CONCRETE COST

MATERIAL ~~REBAR.~~ - E.N.R - FEB-11th 1982
CONCRETE "
LOS ANGELES CA.; UNIT PRICES.

* CONCRETE STACK.

*. UNIT RATES FROM CONTRACTS AT BUEHLA, N.D. ANTELOPE BASIN ELECTRIC. 6/80 & ESCALATED TO 1ST QUARTER 1982

APPENDIX E

RECEIVER CONTROL DYNAMICS TRADE STUDY

THE OVERALL MODEL

The system model consists of a receiver, warm salt riser, riser surge tank/accumulator, hot salt downcomer, downcomer surge tank/accumulator, associated valves, air supply systems, and interconnecting piping. The receiver model consists of a partial cavity with 14 panels interconnected by headers to provide the best suited flow paths. There are two receiver salt flow control valves, one to control each half of the receiver independently. Since the use of long piping runs in the riser, downcomer, receiver and the salt surge tank/accumulators, the salt mass momentum was also taken into account. The salt surge tank/accumulators serve two purposes, one to provide a supply of salt to cool the receiver in case of pump failure and second to help remove large pressure transients (induced by the receiver flow control valves reacting to clouds).

THE RECEIVER MODEL

The receiver model is made up of 14 flat panels arranged in a cavity configuration, with panels 1-7 on the west half and 8-14 on the east half, as shown schematically in Figure 1. The panels are interconnected by 16 headers to complete the two flow paths of the receiver, as illustrated in Figure 2. The headers also provide for the time lag caused by the flow rate and each header's ;emgtj/ There are two salt flow control valves (one for each half) that control the receiver salt outlet temperatures. The valves are actually on the inlets to the flow paths. A math model was used to perform the heat transfer equations and transport delays that simulate the receiver dynamically. The number listed on each panel or by each header is assocaited with a matrix in the math mode.

Each panel is further subdivided into 8 equal length segements (nodes) as shown in Figure 3. The standard heat transfer equations for each panel tube node is shown in Figure 4. Not shown are the equations used to find the fluid heat transfer coefficient $h_{m \to s}$. These are found by using the Dittus & Boelter equation for fluids heating in smooth tubes having fully developed turbulent flow. As can be noted each panel node has its own unique solar flux heating the tubes. This flux matrix can be manipulated by a cloud subroutine to provide system disturbances.

RECEIVER CONFIGURATION

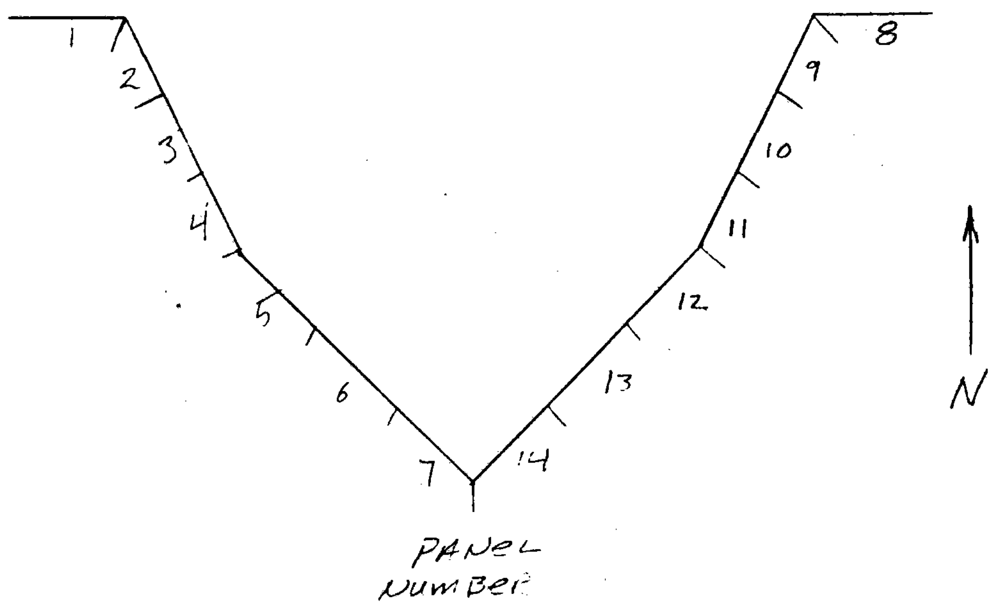


FIGURE 1

CONTROL DIAGRAM

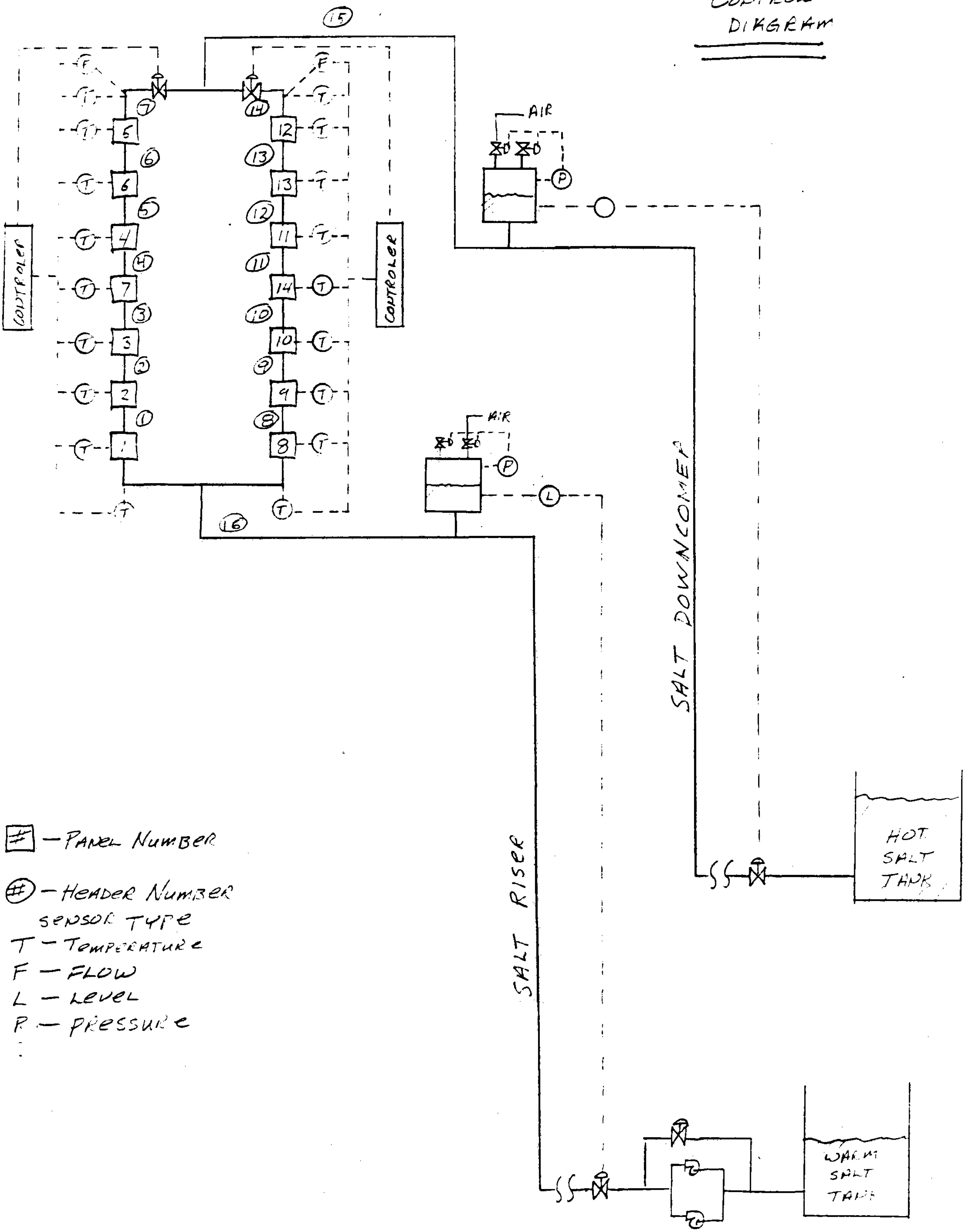


FIGURE 2

PANEL CONFIGURATION

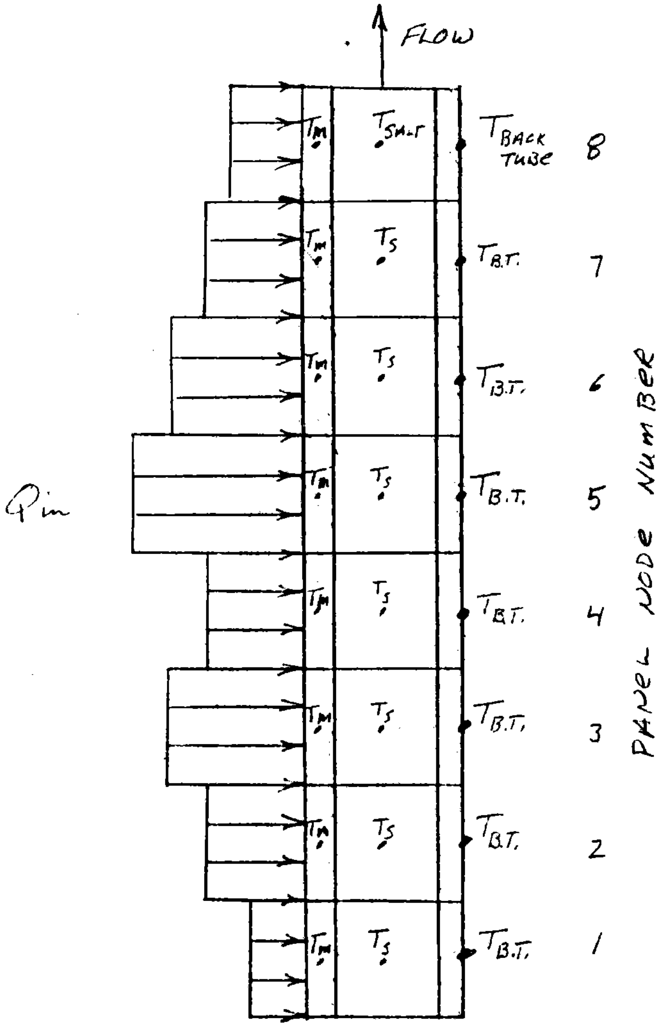
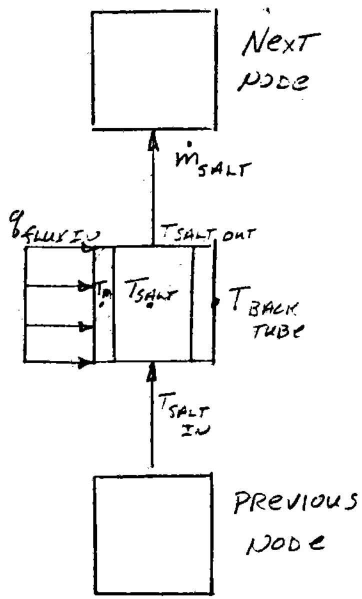


FIGURE 3

HEAT TRANSFER EQU



TUBE WALL:

$$M_{ASS_{TUBE}}\, C_{METAL} \frac{dT_m}{d\tau} = q_{FLUX}\, f_{RAD}\, A_{REA_{TUBE\ O.D.}} - \bar{h}_{m\to s}\, A_{REA_{TUBE\ I.D.}} (T_m - T_s)$$

$$\frac{dT_m}{d\tau} = \frac{q_f\, f_R\, A_{O.D.} - \bar{h}_{m\to s}\, A_{ID}\,(T_m - T_s)}{M_m\, C_m}$$

$$T_m = T_{m_{I.C.}} + \int_0^t \frac{dT_m}{d\tau}\, d\tau$$

SALT:

$$M_{ASS_{SALT}}\, C_{P_{SALT}} \frac{dT_s}{d\tau} = \bar{h}_{M\to S}\, A_{ID}\,(T_m - T_s) + \dot{m}_{SALT}\, C_{P_S}(T_{IN} - T_{OUT})$$

$$\frac{dT_s}{d\tau} = \frac{h_{m\to s}\, A_{ID}\,(T_m - T_s) + \dot{m}_s C_{P_s}\,(T_{IN} - T_{OUT})}{M_s\, C_{P_s}}$$

$$T_s = T_{s_{I.C.}} + \int_0^t \frac{dT_s}{d\tau}\, d\tau$$

BACK TUBE TEMPERATURE SENSORS:

$$T_{BACK\ TUBE} = T_s \left(\frac{1}{s + t} \right)$$

WHERE t = DELAY BETWEEN SALT TEMP. & BACK OF TUBE PLUS THE THERMOCOUPLE DELAY

FIGURE 4

RECEIVER CONTROL

The two receiver controllers, one for each receiver salt flow control valve, are identical and independent of each other. The basic control strategy uses an outer loop for outlet salt temperature control. The receiver back tube temperature heat and mass balance equations are used in an inner flow control loop as shown in Figure 5. This is a common cascade controller arrangement with the exception of the heat and mass balance equations. The addition of the back tube temperature equations was deemed necessary in that the fluid transport lag in the receiver is between 1 to 2 minutes at maximum flow and longer as the flow is reduced from maximum.

The general form for the back tube mass heat balance equation is:

$$q_{RAD} = \sum_{i=1}^{N} M_i C_{P_i} \left(\frac{T_i - T_i'}{\Delta t} \right)$$

Where: M - Mass of the receiver node.

Cp - Specific heat of the receiver node.

T - Back tube temperature at the node.

T′- Back tube temperature at the node at the last sample time.

Δt - Sample time.

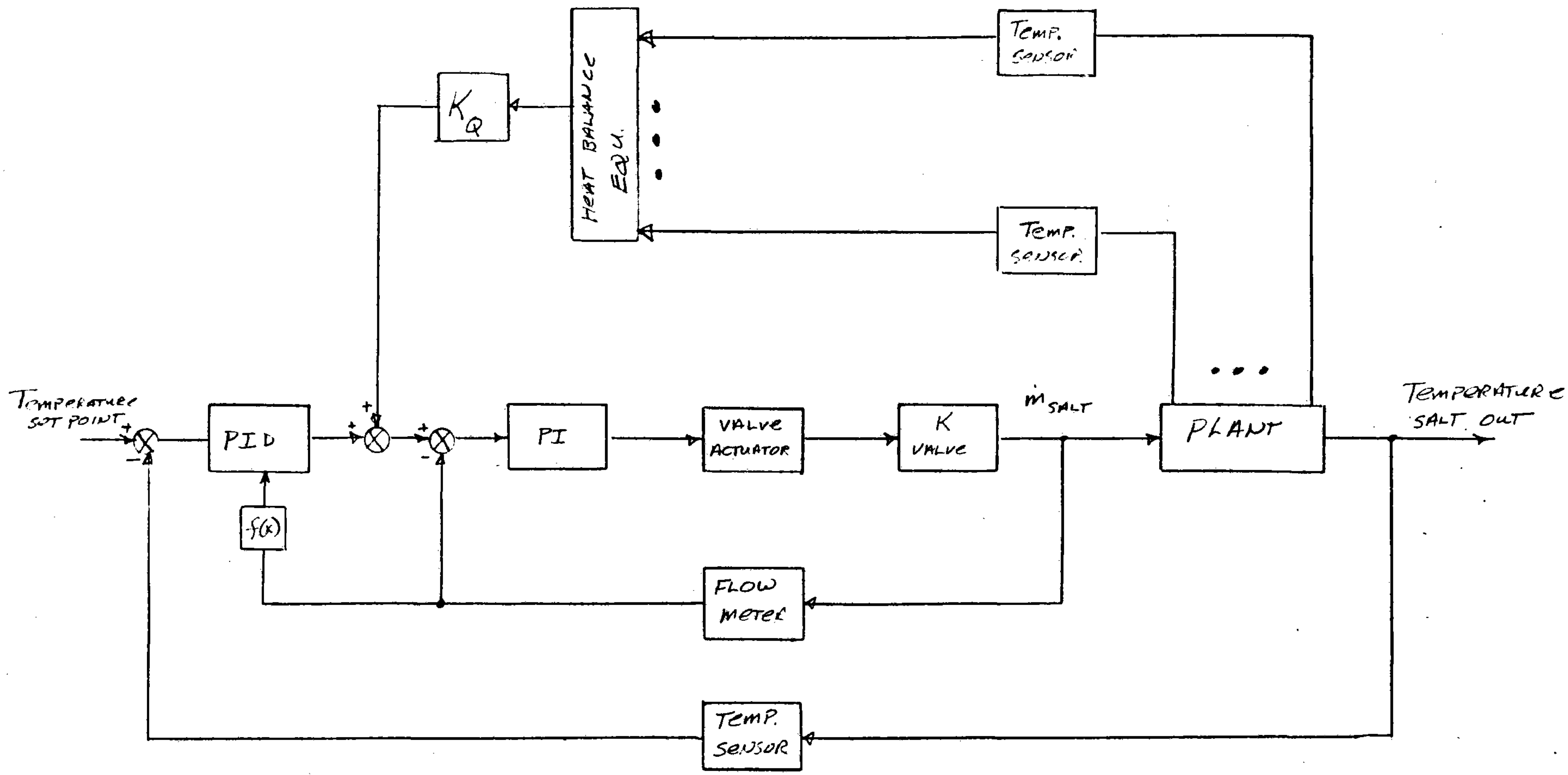
N - Number of receiver nodes

The reaction time of this calculation is rapid (2-4 sec), compared to that of the fluid transport lag, and will provide control of the receiver during cloud induced transients.

Since each receiver half is hydraulically coupled to the other, the outer flow loop serves two purposes. One is to help decouple each half of the receiver from the other and the second is to compensate for long term flow characteristic changes of the system.

THE DOWNCOMER AND RISER

The receiver salt riser and downcomer lengths are so great (over 1 mile each) that the mass momentum of the salt flowing in them must be taken into account. This done by using standard fluid flow calculations and momentum equations



PANEL SALT VALVE CONTROL

FIGURE 5

for incompressible flows. The sonic velocity of the salt is unknown, but is expected to be sufficiently high that the incompressible ($C \rightarrow \infty$) approximation is adequate.

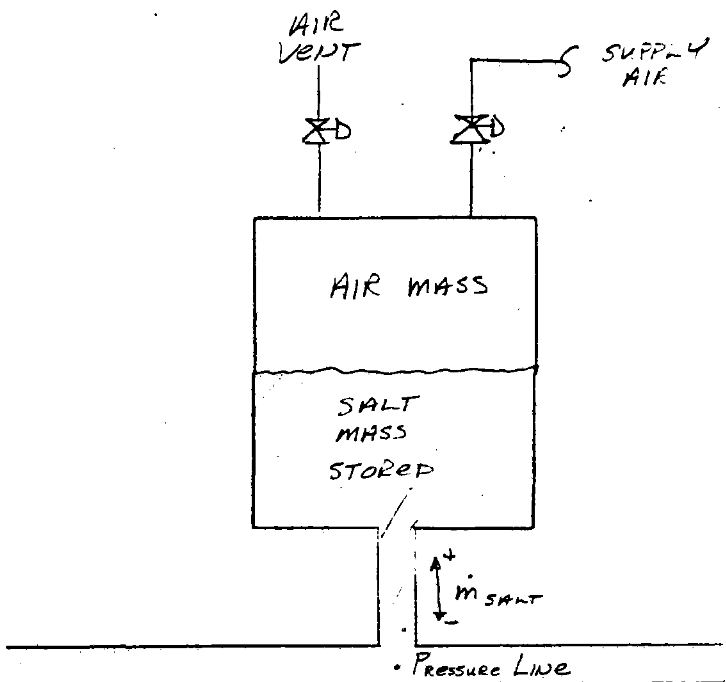
THE SALT SURGE TANK/ACCUMULATORS

Each surge tank/accumulator consists of a tank with air vent and supply valves. Approximately 50% of the tank is full of molten salt and the rest is compressed air. The surge tank model illustrated in Figure 6 takes into account the compressibility of the air and the mass momentum of the salt. Two methods were used to control the surge tank/accumulators. First, the salt level in the riser accumulator is controlled by a valve at the pump end of the salt riser. The downcomer surge tank level is controlled by a pressure reducing valve at the bottom of the downcomer. The pressure reducing valve serves two functions; one to control salt level in the surge tank and second to dissipate the static head pressure the salt develops in the downcomer (the static head pressure would cause cavitation in the downcomer because the hot salt storage tank is held at ambient pressure). Each tank has an air vent and air supply valve that provide for a positive pressure in the tanks and overpressurization protection. The control of these air valves is such that neither is open at the same time.

SYSTEM RESPONSE

All of the above mathematical models were interconnected to provide a dynamic simulation of the receiver system. The insolation and flux levels were set at equinox noon values. The total model was allowed to come within ±3°F of the set point of 1050°F. At 500 sec, the model was subjected to a cloud that reduced the insolation by 5%. The cloud was travelling from west-to-east at 43 ft/sec. The cloud size was set at half the field size so that it would obscure 1/2 of the heliostat field in succession. Thus, one half of the receiver was losing power while the other half was under full power. Then the east side gains back full power while the west side was losing power. The time history of the first half of the receiver is shown in Figure 7. The temperature excursions demonstrated show that the receiver system can be controlled with the control strategy used, but that more time and further study is necessary to optimize controller gains, rates and resets.

Accumulator/Surge Tank Model



$$M_{AIR_2} = M_{AIR_1} + \int_0^t \frac{\dot{m}_{AIR\ in}}{dt}\,dt - \int_0^t \frac{\dot{m}_{AIR\ out}}{dt}\,dt$$

$$M_{SALT_2} = M_{SALT_1} + \int_0^t \frac{\dot{m}_{SALT}}{dt}\,dt$$

$$V_{SALT_2} = M_{SALT_2} \Big/ \rho_{SALT}$$

$$V_{AIR_2} = V_{TANK} - V_{SALT_2}$$

$$P_{AIR_2} = P_{AIR_1} \left(\frac{V_{AIR_1}}{V_{AIR_2}} \right)^{k_{AIR}}$$

$$T_{AIR_2} = T_{AIR_1} \left(\frac{P_{AIR_2}}{P_{AIR_1}} \right)^{\left(\frac{k_{AIR}-1}{k_{AIR}} \right)}$$

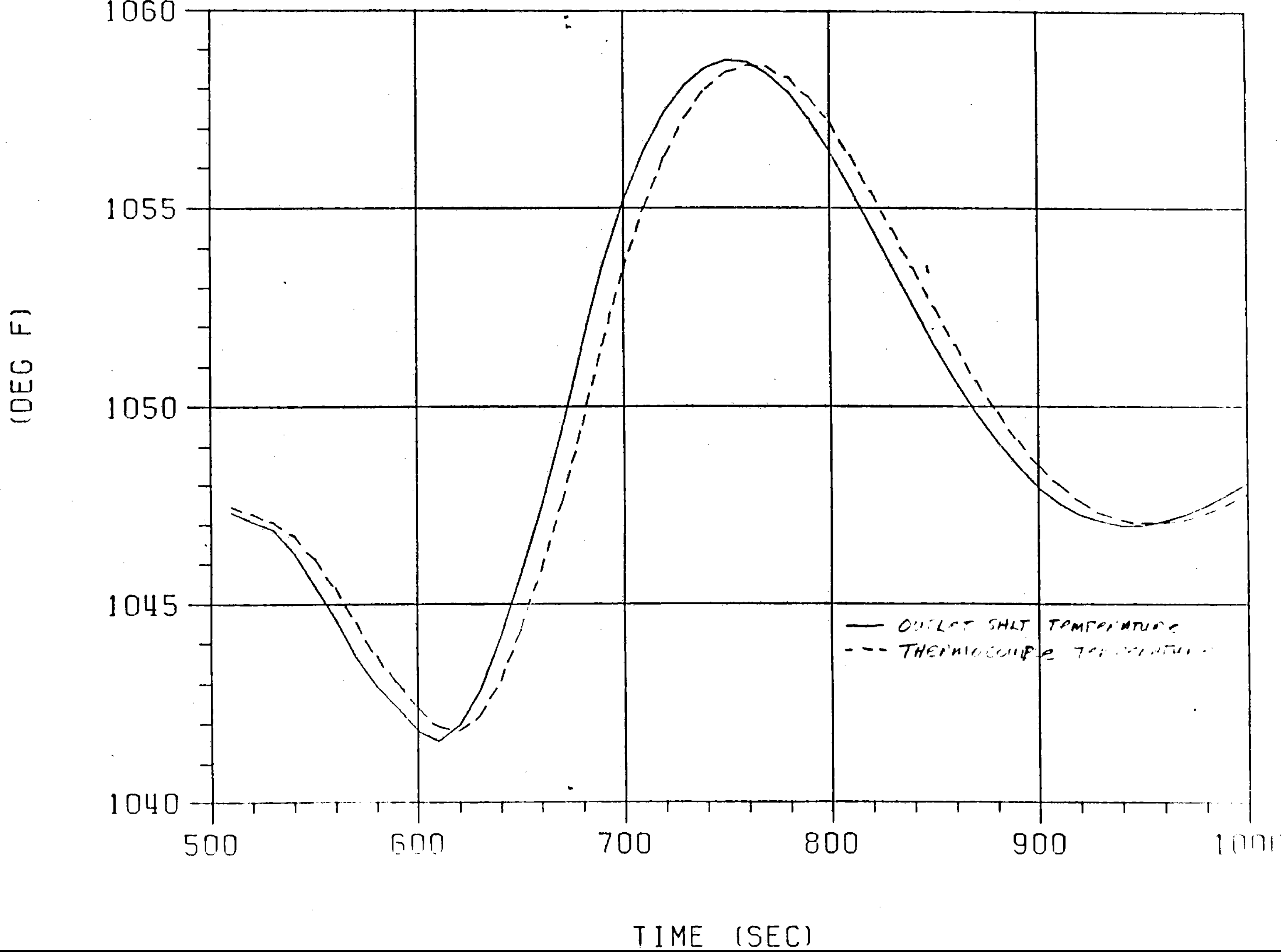
$$\dot{m}_{SALT} = Cv_{LINE} \sqrt{(P_{AIR_2} - P_{LINE})\, \rho_{SALT}}$$

Figure 6

FIGURE 7 SERRIA PACIFIC

95% TRANSPARENT CLOUD AT 500 SEC

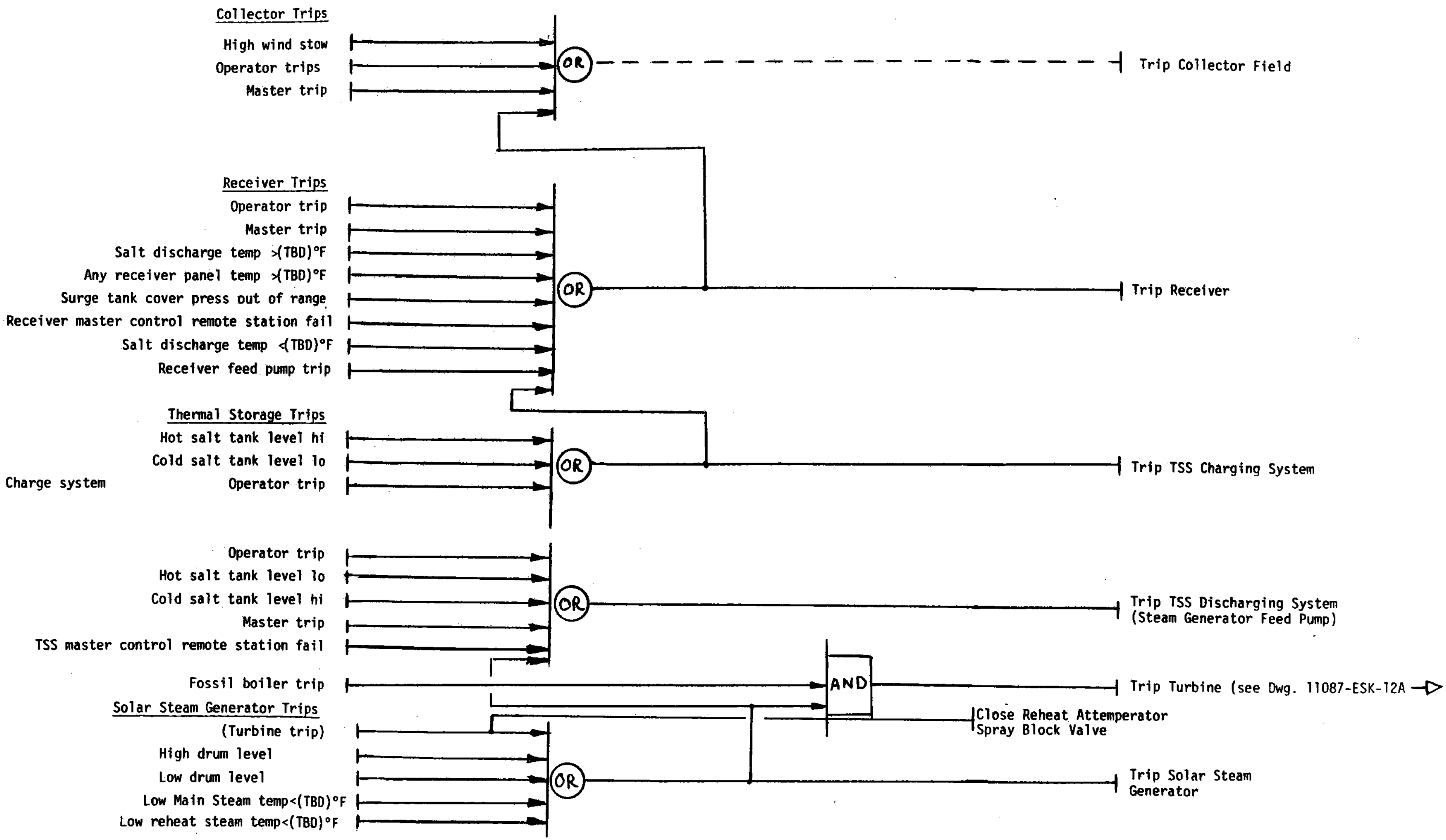
RECEIVER SALT OUTLET TEMPERATURE



PLANT TRIP CONTROL

The integration of the total power plant system (both fossil and solar) control complexity is best represented by the trip logic diagram, Figure 8. As can be seen, the overall control of the system is both highly interconnected but relatively straightforward. A trip of either the solar or fossil steam supply will not give a turbine trip, thus making it possible to still generate electricity with either system alone.

Solar Plant Trip Logic
(Ft. Churchill - Unit 1)



APPENDIX F

REVISED PHYSICAL PROPERTY VALUES FOR MOLTEN NITRATE SALTS

When molten nitrate salt mixtures were first chosen as a promising candidate for solar thermal heat transfer and storage applications, it was recognized that there was little or no good data on the physical properties of these salt mixtures above about 400-450°C. We obtained preliminary values for physical properties in the 450-600°C range by extrapolating existing lower-temperature data (primarily from Janz et al, Reference 1). This data has been supplied to contractors working on molten salt receiver, steam generator, and storage subsystems, with the understanding that it be used to provide a common data base for sizing and analyzing these designs.

Simultaneously, Sandia initiated a number of in-house and external studies to provide additional physical property data, with particular emphasis on measuring these properties in the 450-600°C range to replace current values obtained by extrapolation. Most of these studies have now been completed, and the results can be used to generate more representative expressions for the temperature-dependence of molten salt physical properties. Where available, these expressions have been plotted in the accompanying figures, and revised values for various temperatures calculated. The new plots and tabular calculated values are compared with the "old" values and expressions specified in various RFQ's for molten salt subsystem studies. In some cases, experimental data used to generate the new expressions is also shown.

Revised values of density and absolute viscosity are from Nissen (References 2 and 3). His measurements were made for a 50/50 mole percent mixture of $NaNO_3/KNO_3$ (46/54 wt pct), rather than the 60/40 wt pct mixture selected for most current solar applications. However, Nissen also points out that surface tension, viscosity, and density vary less than 1 percent over a fairly broad range of $NaNO_3/KNO_3$ mixtures (Ref. 4), so his measured values for 50/50 mole pct mixtures should be considered valid for the 60/40 wt pct mixture as well, within the limits of experimental accuracy. Revised values of heat capacity for a 60/40 wt pct mixture of $NaNO_3/KNO_3$ have been reported by Carling (Ref. 5). Sandia has funded Oye at the Norwegian Institute of Technology (NIT) to provide thermal conductivity measurements for several different $NaNO_3/KNO_3$ salt mixtures. That contract is not scheduled to be completed until June, 1982, and we have received no results to date. Interestingly, Nissen reports that we may be able to "back out" some heat capacity values from the NIT thermal conductivity study.

Old (RFQ) and revised values of density, viscosity, and heat capacity are compared in Figures 1-3. Table I also compares RFQ and new values of these properties at various temperatures. Wherever possible, these revised values of physical properties should be used to replace the data we have been using up to this point. Best-fit expressions for the temperature-dependence of the new data have been developed, and are presented below as well as plotted in Figure 1-3.

Density - Best-fit expressions and values from these expressions at various temperatures are plotted in Figure 1. Values based on Nissen's new data (References 2 and 3) are from 0.8 percent to 1.1 percent higher than values we have been using. The new best-fit expression* gives excellent agreement with the experimental data. The following expressions may be used instead of tabular values:

$$\rho(\text{g/cm}^3) = 2.090 - 6.36 \times 10^{-4}T\ (°C)$$

$$\rho(\text{lb/ft}^3) = 131.2 - 2.221 \times 10^{-2}T\ (°F)$$

Viscosity - Old and new values of viscosity for 50/50 mole pct mixtures of $NaNO_3/KNO_3$ are plotted in Figure 2, and compared with Nissen's experimental data (References 2 and 3). The values used to date were based on extrapolation of data from Janz et al (Ref. 1) above 450°C, assuming a single value of activation energy. Nissen's data (References 2 and 3) shows that a change in activation energy occurs at about 385°C, with the result that extrapolated viscosity values are about 10 percent lower than measured values in the 500-600°C region. Nissen provides a cubic best-fix expression which is within about ± 3 percent of his experimental data points. If it is desired to use tabular values of viscosity rather than the expression below, then we recommend values based on Nissen's experimental data (Table I) rather than values calculated from the expression:

$$\eta(\text{mPa}\cdot\text{s}) = 22.714 - 0.120T + 2.281 \times 10^{-4}T^2 - 1.474 \times 10^{-7}T^3 \quad (T \text{ in } °C)$$

(comparable expressions in other units would require curve-fitting a new equation)

Specific Heat - A substantial change in Sandia-specified values for specific heat of 60/40 wt pct $NaNO_3/KNO_3$ is proposed on the basis of Carling's data (from Ref. 5). As shown in Figure 3, the direction

*Nissen offers slightly different expressions for the temperature-dependence of density in Reference 2 (SAND80-8040) and Reference 3 (J. of Chem. and Eng. Data). The expression from Ref. 3, shown here, is preferred.

of temperature dependence is changed, with the result that new values are 10.5 percent lower than existing specified values at 300°C, but 5.7 percent higher at 600°C. The temperature-invariant value of 0.366 cal/g-°C recommended by Martin Marietta, Ref. 6 (based on data generated by Janz), is a reasonably good approximation of the newest values from Carling. The values attributed to Carling in Figure 3 were calculated from a linear fit of experimental data:

$$C_p \text{ (cal/g-°C)} = 0.345 + 4.11 \times 10^{-5} T \text{ (°C)}$$

$$C_p \text{ (BTU/lb-°F)} = 0.345 + 2.28 \times 10^{-5} T \text{ (°F)}$$

Thermal Conductivity - No change in currently-recommended values of thermal conductivity is proposed, pending completion of the studies at NIT.

Sandia will request that the revised values of physical properties shown herein be used for all future in-house and outside contracted studies. For contracts and studies currently in progress, changes in design or performance calculations occasioned by these new properties may be made at the option of the contractor, but we will not insist upon it. However, we should expect:

a) some assessment of what (if any) impact these changes in properties would have, and

b) inclusion of the new physical properties in reports issued by contractors, in a manner which clearly indicates that they (and not the RFQ values) should be used in all future work.

References

1. G. J. Janz, U. Krebs, H. E. Siegenthaler, and R. P. T. Tompkins, J. Phys. Chem. Ref. Data, 1972, vol. 1, p. 587.

2. D. A. Nissen, "Thermophysical Properties of the Equimolar Mixture $NaNO_3$-KNO_3 from 300-600°C," SAND80-8040, November 1980.

3. D. A. Nissen, same title, J. of Chem. and Eng. Data, in press.

4. D. A. Nissen, memorandum to D. B. Dawson, SNLL, March 22, 1982.

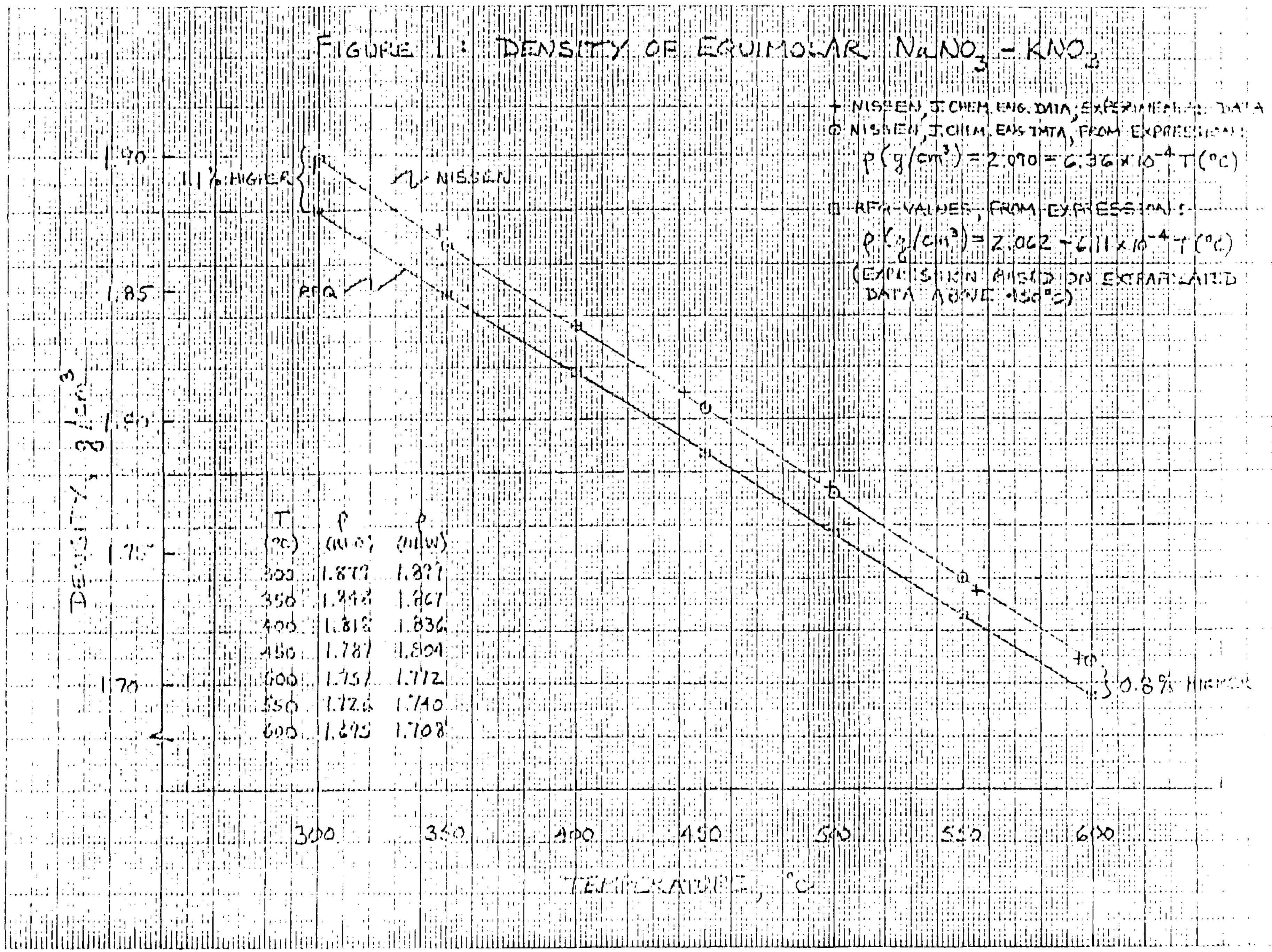
5. R. W. Mar, et al, "Progress Report: Molten Nitrate Salt Technology Development," SAND82-8220, April 1982.

6. Martin Marietta Corp., "Alternate Central Receiver Power System, Phase II," Vol. I, Final Report on Contract Sandia - 18-6879C, May 1981.

TABLE I: Comparison of Old* and Revised Values of Physical Properties for Molten Nitrate Salts (60 wt pct $NaNO_3$/40 wt pct KNO_3)

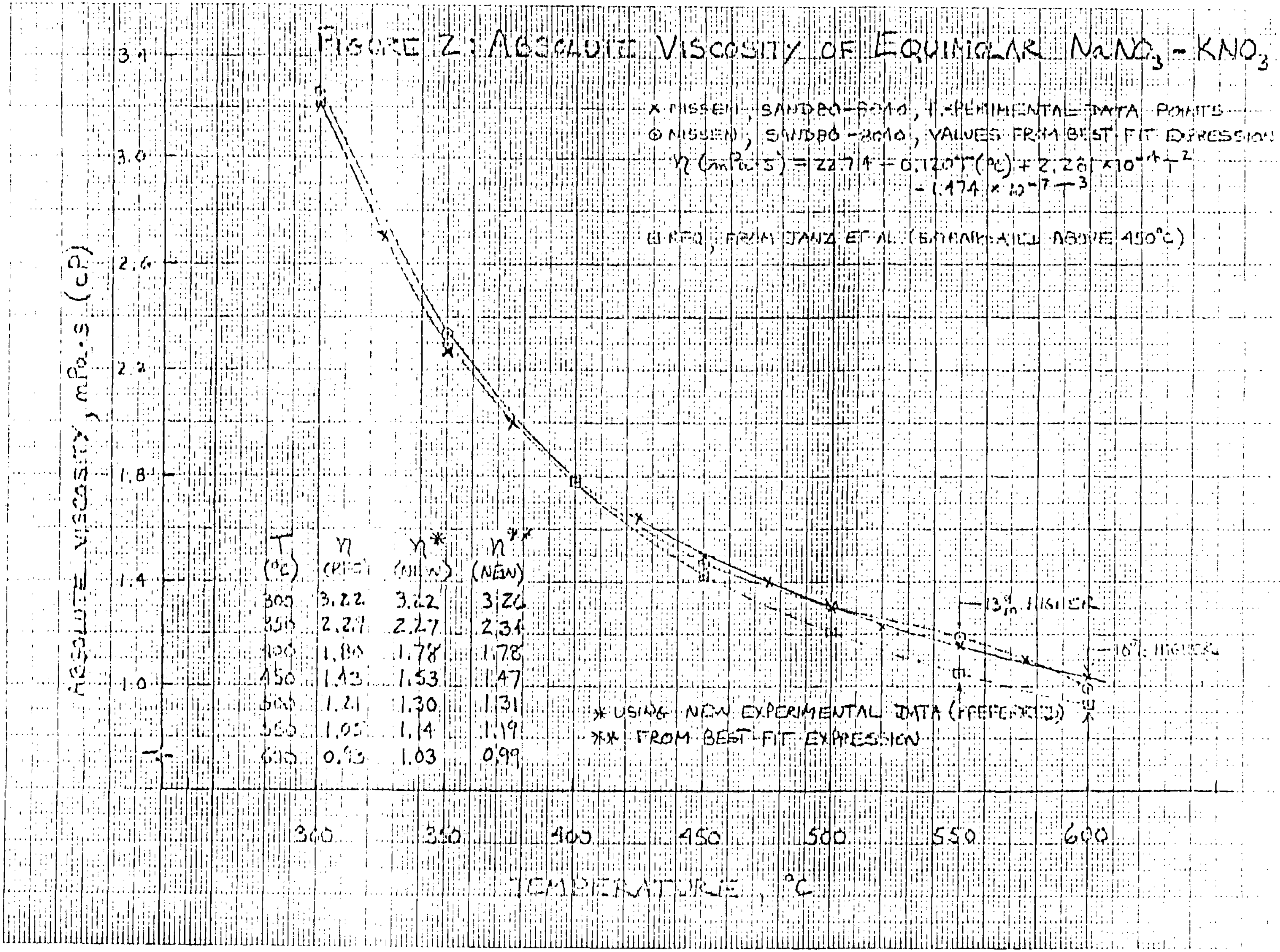
	Density (g/cm^3)		Viscosity ($mPa \cdot s$)		Heat Capacity (cal/g-°C)	
Temperature, °C	RFQ	New	RFQ	New	RFQ	New
300	1.879	1.899	3.22	3.22	0.399	0.357
350	1.848	1.867	2.29	2.27	0.389	0.359
400	1.818	1.836	1.80	1.78	0.381	0.361
450	1.787	1.804	1.43	1.53	0.374	0.363
500	1.757	1.772	1.21	1.30	0.366	0.366
550	1.726	1.740	1.05	1.14	0.358	0.368
600	1.695	1.708	0.93	1.03	0.350	0.370

*RFQ values supplied by SNLL for use in SRE contracts to date.



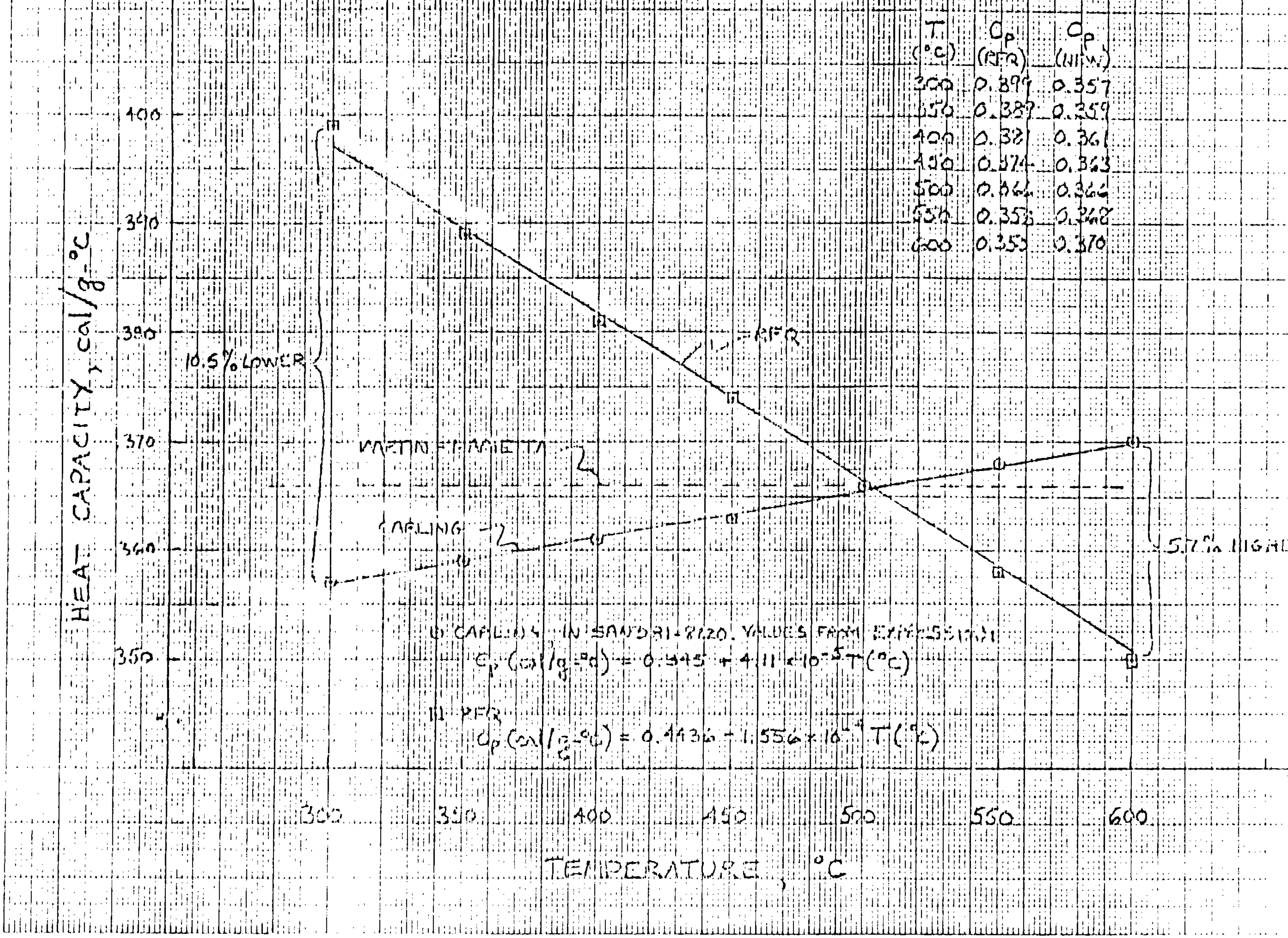
T (°C)	ρ [illegible]	ρ [illegible]
300	1.879	1.899
350	1.848	1.867
400	1.818	1.836
450	1.787	1.804
500	1.757	1.772
550	1.726	1.740
600	1.695	1.708

FIGURE 2: ABSOLUTE VISCOSITY OF EQUIMOLAR $NaNO_3 - KNO_3$



T (°C)	η (REF)	η* (NEW)	η** (NEW)
300	3.22	3.22	3.26
350	2.27	2.27	2.34
400	1.80	1.78	1.78
450	1.43	1.53	1.47
500	1.21	1.30	1.31
550	1.05	1.14	1.19
600	0.93	1.03	0.99

FIGURE 3. HEAT CAPACITY OF 60 WT. PCT. $NaNO_3$ / 40 WT. PCT. KNO_3



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