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**PRELIMINARY DESIGN OF
THE CARRISA PLAINS
SOLAR CENTRAL RECEIVER POWER PLANT
VOLUME III, BOOK 1 — DESIGN DESCRIPTION**

*Prepared for the Department of Energy,
San Francisco Operations Office,
under Contract DE-FC03-82SF11674*

MASTER

Rockwell International
Energy Systems Group

ARCO Solar Industries

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This report, Preliminary Design of the Carrisa Plains Solar Central Receiver Power Plant, ESG-DOE-13404, consists of three volumes, one of which is further subdivided. These are:

Volume I. Executive Summary

Volume II. Plant Specifications

Volume III. Plant Design

Book 1. Design Description

Book 2. Design Drawings

Book 3. Appendices

Books 1, 2, and 3 in Volume III, Plant Design, are a single document, separated for reasons of format and readability. Book 1, Design Description, contains narrative material, tables, and figures suited to an 8½-in. by 11-in. format. Book 2, Design Drawings, is a 17-in. by 22-in. volume containing material whose readability is benefitted by a larger format. Graphic material cited in Book 1 is referenced as a figure if it appears in Book 1, or as a drawing if it appears in Book 2. Material appearing in Books 2 and 3 is assigned a number in accordance with the section of Book 1 in which it is referenced. Consequently, the numbering in Books 2 and 3 may appear to leave gaps.

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I. INTRODUCTION

I-1 DESIGN BASIS

The preliminary design of the 30-MWe Carrisa Plains Solar Central Receiver Power Plant was performed by a team drawn from Rockwell International's Energy Systems Group, the Pacific Gas and Electric Company (PGandE), and ARCO Solar Industries. The design was performed under a cost-sharing contract (DEFC03-82SF11674) with the U.S. Department of Energy (DOE). The team responsibilities were divided as follows:

- Collector System – ARCO
- Heat Transport System – Rockwell
- Electric Power Generating System – PGandE
- Master Control System – PGandE
- Balance of plant – PGandE.

An artist's concept of the Carrisa Plains Solar Power Plant is shown in Figure I-1. This 30-MWe solar power plant is a commercial demonstration plant, a measured step from the 10-MWe Solar One pilot plant toward larger solar plants based on central receiver technology. Successful completion of this project will lead to commercial power generation starting 1 July 1986.

The Carrisa Plains Solar Central Receiver Power Plant project was initiated in 1981 by Rockwell, PGandE, and ARCO as a privately funded design effort. The project had as its objective the development of a progressive step in central receiver technology which could be taken given the current economic, governmental, regulatory, and business climates. The plant was to be located within PGandE's service territory, which covers most of northern and central California.

Several critical design choices were made during the early planning cycle to give the project the best possible chance of success. Key project requirements were:

42600-95

Figure I-1. Artist's Concept of Carrisa Plains

- Ownership: The business climate and the federal energy tax credits combined to dictate that the project be privately, rather than utility, owned. Therefore, the total capital and equity investments had to be kept within an amount available through the venture capital community. Other investor requirements, including warranties, would have to be met. Electric power would be sold to PGandE under terms of a power sales agreement (PSA).
- Schedule: Since the federal energy tax credits are currently scheduled to expire at the end of 1985, the design and construction schedule must fit within that time period. Thus the plant must be relatively small — much less than 100 MWe. This schedule could be met only if no further proof-of-concept or development tests were required. This required that prototypes of all key solar components be available and tested.
- Economics: The plant must maximize the value of the energy produced to achieve acceptable investor economics. PGandE's standard PSA offers a capacity credit for reliable supply of the plant power during peak demand periods. The availability criterion (80%) could not be met without thermal energy storage, hence, a solar technology with efficient thermal storage would have to be selected, and the storage would have to be sized to earn the maximum capacity credits.
- Warranties: Private ownership would require that the plant be fully warranted by the suppliers. This was restrictive of technology choice. In particular, it required that the heat transport media be one fully developed at the applicable scale. Choices included water/steam and sodium.
- Technology Demonstration: To be of value to the suppliers the plant must demonstrate the technologies that the suppliers believe would lead to a follow-on market. For utility applications, the use of a water/steam receiver appeared to be precluded.
- Regulatory: The project must be kept below the 30-MWe Public Utilities Regulatory Policy Act (PURPA) limit for unregulated suppliers of electricity. It would then also fall within the 50-MWe California Energy Commission (CEC) threshold at which the State of California, rather than the county, becomes the lead environmental agency. This positively impacts the schedule constraint.

In summary, the constraint of the PURPA limit set the plant nameplate rating at 30 MWe, while the issues of warranties and technical demonstration value led to the selection of sodium as the heat transport medium. The energy value criterion led to maximum capacity credits at a thermal storage capacity of 99 MWt (1-1/6 full power hours) at the design point (noon vernal equinox).

To assure that all major performance goals are met, a design margin is provided even at a significant cost. This design margin precludes the possibility of a failure to meet a major performance goal and ensures the credibility of the solar industry.

Where plant design options have led to trade studies or optimization, the options have been evaluated in realistic project financial terms. Of prime importance is utilization of a realistic tradeoff between capital equipment and annual costs or revenue. Such considerations appear in such diverse areas as plant automation (i.e., capital equipment versus operating staff requirements) and power conversion systems equipment selection (i.e., capital cost versus heat rate or gross power output). The economics scenario described in Section VIII is used to derive an effective payback time for the comparison of capital and annual expenditures.) Because of the large tax credits available and the rapid depreciation, the required payback time for capital expenditures is large. The plant design naturally evolved toward a high efficiency, highly automated, capital-intensive plant.

The project structure has been clearly demarcated. Project roles acceptable to each participant have been identified. The project organization adopted takes into account that no company will participate in the project and accept the risks unless a role suited to its business objectives, skills, and normal mode of doing business is offered.

I-2 SITE CHARACTERISTICS

The selection of the Carrisa Plains site was the result of a survey by PGandE to identify the potential for solar power within its service territory. Requirements included availability of solar, water, and land resources. The survey identified several areas of high potential based largely on unpublished information. Of these areas, Carrisa Plains appeared to have the best water availability, and was therefore selected for a solar resource measurement program. Figure I-2 is a map of the general area. It also lists nearby population centers.

I-2.1 Site Location

A lease/option has been obtained for Section 34 near Simmler, California. This site is shown in Figure I-3; site photographs are shown in Figure I-4.

Access to the site from the east is along Highway 58 for about 64 km (40 miles) from Interstate 5 in the San Joaquin Valley. Access from the west is along Highway 58 for 80 km (50 miles) from State Highway 101 near San Luis Obispo. This is a two-lane highway, built to state standards. No limitations are imposed on the equipment sizes used for this project.

Access to the grid is available either through the 115-kV circuit from San Luis Obispo to Midway in the San Joaquin Valley or the two 230-kV circuits from the Morro Bay power plant to Midway. The economical connection is to the Midway-San Luis Obispo 115-kV circuit, which does not require reinforcement for a new 30-MWe installation. These circuits are about 1.6 km (1.0 miles) from the site area and are adjacent to the Carrisa Plains Substation.

Section 27, directly north of this project, is being developed by ARCO for a 16.5-MWe photovoltaic system.

I-2.2 Site Geography

Carrisa Plains is a sparsely populated, enclosed valley, about 65 km (40 miles) long and 13 km (8 miles) wide in southeastern San Luis Obispo County, 8 km (5 miles) from the Kern County line. The floor of the valley is about 600 m (2000 ft) above sea level. The site is flat and is currently used for farming. The land has a slope of about 0.5% to the southwest. The soil load-bearing capacity is suitable for supporting the heliostat pedestals, tower, and plant equipment.

The site is 10 km (6 miles) southwest of the San Andreas active fault zone. It is also 8 km (5 miles) northeast of the San Juan, Big Spring, and

CITY	DISTANCE km (mi)	POPULATION
ATASCADERO	80 (50)	10,000
BAKERSFIELD	97 (60)	75,000
SAN LUIS OBISPO	80 (50)	30,000
TAFT	64 (40)	5,000

Figure I-2. Location of Carrisa Plains Solar Power Plant

Figure I-3. Site for Carrisa Plains Solar Power Plant

NORTH

EAST

WEST

SOUTH

Figure I-4. Site Photographs

Chimeneas faults classed with Quaternary activity. Two short faults are mapped in the southwest portion of the area with pre-Quaternary activity. The site is 95 km (57 miles) south of the epicenter of the 2 May 1983, 6.5 magnitude earthquake at Coalinga, on a previously unmapped fault proximate to the San Andreas fault. ARCO's forty heliostat solar steam generator is about as close as Carrisa Plains to this earthquake epicenter. It operated during the earthquake without interruption.

I-2.3 Solar Resource

Solar resource and environmental assessments have been conducted by PGandE under PGandE funding and without DOE cost sharing. While the results are not part of the DOE-sponsored study, they are presented here for completeness.

A solar resource measurement program instituted by PGandE in early 1982 included horizontal insolation measurement. In late 1982, this program was augmented to include direct normal insolation measurements. Table I-1 shows the measured horizontal insolation for Fresno and Carrisa Plains in 1982/1983 and the measured direct normal insolation at Carrisa Plains for the 4 months available (December 1982 through March 1983). Santa Maria is no longer recording insolation, and Fresno records horizontal insolation only.

Table I-1 shows the long-term average for both Fresno and Santa Maria. Since California experienced a very rainy winter, the figures for Fresno are understandably much lower than its long-term average. Likewise, Carrisa Plains must also have been affected by the inclement weather. Horizontal insolation at Carrisa Plains consistently exceeds that of Fresno.

All performance analyses presented are based on the direct normal insolation at the site modeled as follows. The solar conditions at Carrisa Plains should be similar to Santa Maria during the months of October through March, and to Fresno from April to September. These are the nearest long-term insolation stations to Carrisa Plains, but have somewhat different climates.

TABLE I-1
ACTUAL MEASURED INSOLATION FOR 1982/1983

	1982												1983		
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
	Measured Horizontal Insolation														
Carrisa Plains	91	99	117	181	236	231	246	221	164	134	83	78	88	86	134
Fresno	46	73	98	167	213	214	233	NA	NA	121	57	49	42	67	109
	Long-Term Average														
Fresno	64	90	115	192	233	240	243	218	174	130	79	54			
Santa Maria	89	104	157	185	207	212	221	202	159	131	94	83			
	Measured Direct Insolation														
Carrisa Plains												106	125	77	109

Carrisa Plains is expected to have better insolation in the winter than Fresno, since its higher elevation reduces the incidence of Tule fog, and is expected to be as good as that of Santa Maria. In the summer, its insolation is close to that of Fresno, and is less affected by ocean fog than is Santa Maria. With no industry in the area, no pollutants or contaminants are expected in the air. Some fugitive dust from agricultural activities would be expected.

A second method to estimate the direct normal insolation is to use an average of the three closest stations — Fresno, Santa Maria, and China Lake — which form a triangle around Carrisa Plains. China Lake is about at the same latitude as Carrisa Plains and is located in about the same desert-type atmosphere. It is also the only station of the three to be at about the same elevation as Carrisa Plains. Table I-2 gives the results of the three-station average calculations and gives an annual total of 2552 kWh/m^2 . By comparison, a seasonal adjustment to Fresno and Santa Maria conditions is shown in to give an estimated $2524 \text{ kWh/m}^2 \text{ yr}$, within 1% of the three-station average. As a baseline, the estimated annual direct normal insolation will

TABLE I-2

ESTIMATED DIRECT NORMAL INSOLATION AT CARRISA PLAINS

Location	Latitude/ Longitude (deg)	Eleva- tion (ft)	Direct Normal Insolation (kWh/m ² month)												
			Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
Fresno	36.77/119.72	336	95	126	195	229	273	279	285	262	224	186	122	79	2356
Santa Maria	34.93/120.42	234	149	149	199	211	221	225	239	225	188	178	149	148	2281
China Lake	35.65/117.00	2440	182	181	249	272	297	297	285	272	248	218	190	179	2870
Carrisa Plains (three-station average)	35.30/120.00	2020	142	152	214	237	264	267	270	253	220	194	154	185	2552
Carrisa Plains (Seasonal correction)	35.30/120.00	2020	149	149	199	229	273	279	285	262	224	178	149	148	2524

Source (except for Carrisa Plains): P. Berdahl et al., California Solar Data Manual, March 1981
California Energy Commission (CEC) Publication

be taken at the lower value and the daily average as 6.9 kWh/m². Because of the cloudy weather this winter, the measured direct insolation (Table I-1) is less than the estimated values.

I-2.4 Ground Water

The Carrisa Basin ground water storage capacity, as listed by the California Department of Water Resources (DWR) in 1975, is 0.49 km³ (400,000 acre ft). Ground water wells in the Carrisa basin yield instantaneous average flows of 0.03 m³/s (500 gpm) with maximum flows of 0.05 m³/s (1000 gpm). The proposed solar power plant will require an average flow of only 0.01 m³/s (120 gpm, 185 acre ft/yr), which is less than typical agricultural use. Available ground water quality data for the eight state-numbered wells show the water quality to be acceptable.

I-3 FACILITY DESIGN DESCRIPTION SUMMARY

The 30-MWe Carrisa Plains plant design is depicted in Drawing I-1 of Book 2, the plant interface control drawing. This drawing shows the basic

plant design concept as well as the team member design responsibilities. In this plant, solar energy is redirected by a large field of mirrors to a receiver on top of a tall tower. In concept, it is similar to the 10-MWe Solar One plant being successfully operated at Barstow, California. It achieves higher efficiency and improved operability and thermal storage through the use of a single-phase heat transport fluid in the receiver and steam generator. The plant flow diagram is shown in Figure I-5. This figure shows the design point conditions for the major plant systems. Note that these conditions include a design margin and are not necessarily plant operating conditions.

A plant layout is shown in Figure I-6. The plant covers a 1.19 km^2 (295-acre) plot. The fan-shaped collector field is 1100 m (3600 ft) deep by 1400 m (4600 ft) at the widest point. The plant uses a north-facing vertical flat panel solar receiver of a tested design supported by a 107 m (352-ft) steel truss tower. The receiver intercepts the solar energy redirected from the 1877 third-generation ARCO heliostats. The receiver aperture is 12.2 m (40 ft) high by 52 ft wide. The solar energy heats liquid sodium flowing through the receiver tubes. As shown in Figure I-5, the cold (610°F) sodium is pumped to the receiver by conventional sodium pumps from a 40-ft-diameter by 50-ft-high atmospheric pressure storage tank at ground level. As the sodium passes through the receiver tubes it heats to 566°C (1050°F). The heated sodium then drains by gravity to a hot storage tank located at grade level. From the hot storage tank it is pumped through the steam generators, cools to 321°C (610°F), and returns to the cold storage tank. The three once-through-to-superheat steam generators are connected in parallel to deliver 34 kg/s (270,000 lb/h) of steam at 538°C (1000°F) and 10.1 MPa (1450 psig) to the turbine. The three parallel units provide redundancy to 90% of full power with one unit out of service. The state-of-the-art steam condition yields high efficiency with conventional turbine equipment.

The turbine-generator will deliver 32.7 MWe gross. The turbine operating schedule is set to meet the daily startup and shutdown cycle.

Figure I-5. Carrisa Plains Solar Plant Flow Diagram

Figure I-6. Carrisa Plains Solar Plant Layout

The plant design uses proved components and systems, thereby achieving high plant availability and low operating and maintenance costs. Redundancy has been provided at critical points to ensure that a single component failure will not compromise plant availability. The plant is designed to the appropriate engineering codes and standards throughout.

Incorporation of in-line thermal storage permits the solar portion of the plant (the collector and receiver) to start up and operate independently from the electric power generation portion of the plant (the steam and turbine generators) without sacrificing efficiency. This leads to a smaller operating staff since the startups can be carried out sequentially. In addition, the in-line thermal storage moderates cloud and other thermal transients, thus simplifying control functions. The plant is operated so that plant revenues are maximized. The basic plant control scheme matches power levels with flows and trims the flows to set final temperatures.

The basic plant parameters are summarized in Table I-3. The key performance characteristics are summarized in Table I-4.

TABLE I-3
KEY PLANT DIMENSIONS

Site area	1.20 km ² (295 acre)
Field area	1.064 km ² (11.46 x 10 ⁶ ft ²)
Total mirror area	0.1789 km ² (1.93 x 10 ⁶ ft ²)
Tower height	
Elevation above grade	110.3 m (352 ft)
Receiver aperture	
Width	16 m (52 ft)
Height	12 m (40 ft)
Receiver panels	8
Receiver panel	
Width	2 m (6.6 ft)
Height	15.2 m (50 ft)
Elevation above grade	125 m (410 ft)

TABLE I-4

TECHNICAL DATA SUMMARY

1. Site location and ownership: Carrisa Plains, California; Operating Company to be established for selling power to PGandE
2. Receiver:
 - Receiver fluid: Sodium
 - Configuration: External, north-facing billboard
 - Type: Once-through, forced circulation
 - Elements: Single-phase, liquid heater
 - Net power outlet at summer solstice: 107 MWt
 - Inlet and outlet fluid temperature: 610°F and 1050°F
 - Inlet and outlet fluid pressure: 35 psia and 15 psia
 - Peak and average flux on receiver panels: 1.2 MWt/m² and 0.61 MWt/m²
 - Tower type: Steel truss
 - Tower height (receiver centerline): 125 m (410 ft)
3. Heliostats:
 - Number: 1877
 - Individual heliostat reflective area: 95 m²
 - Cost: \$211/m² including foundations, wiring, controls and seated dollars
 - Type: ARCO third generation
 - Field configuration: North
 - Control approach: Distributed control
4. Storage:
 - Duration: 37.2 MWhe (gross)
 - Medium: Sodium
 - Containers: Two flat-bottom API cylindrical tanks (hot and cold)
 - Capacity: 99 MWht, 1420 m³ (375,000 gal - dynamic value)
5. Steam generator:
 - Capacity: 85 MWt (three units)
 - Heat transfer efficiency: 99.98%
6. Solar system performance efficiency calculation:
 - 236,790 MWht/456,541 MWht = 0.52. (The step diagram for the design point and the annual average are given in Section VII.)
7. Schedule:
 - Plant construction time: 2.5 yr
 - Operating lifetime: 30 yr
8.
 - a) Solar plant contribution at design point: 29.7 MWe (net)
 - b) Solar fraction (annual): 100%
 - c) Annual fossil energy saved: 163,035 (in barrels of crude oil equivalent at 5.800 x 10⁶ Btu/barrel)
 - d) Annual fuel displaced by type: Oil/gas
 - e) Annual energy:
 - Displaced: 278,200 MWht
 - Produced: 75,960 MWhe (236,790 MWht)
 - f) Solar energy cost (first year):* 90 mills/kWhe
 - g) Plant parasitic power requirements: 2.7 MWe
9. Site insolation (direct normal)
 - Design point: 950 W/m²
 - Annual average: 2524 kWh/m²
 - Source: California Solar Data Manual, March 1981, three-station average of Fresno, Santa Maria, and China Lake
 - Site measurements: Global Pyranometer since January 1982; direct normal insolation measurement program initiated December 1982
10. Estimated cost for solar facility construction (1983 \$) and plant annual operation and maintenance cost (1983 \$):
 - Construction: \$133.2M
 - Annual operation and maintenance cost: \$2.74M

*Based on project economic parameters described in Section VIII.

I-4 RATIONALE FOR DESIGN SELECTION

The emphasis of preliminary design has been largely on the development the necessary design detail, specifications, and drawings to ensure that the Carrisa Plains project is able to proceed expeditiously into final design and construction. The preliminary design has been developed from the privately-funded conceptual design with only minor change in design direction and key plant design features. During the conceptual design phase, by contrast, an emphasis was placed on the trade studies used to select the design direction and features. In view of the minor changes made in design concept during the preliminary design, the rationales for their selection developed during conceptual design remain applicable and salient.

Key features considered during conceptual design include the following:

- Receiver configuration--north facing versus cylindrical
- Steam cycle--reheat versus non-reheat
- Steam conditions--temperature and pressure
- Steam generation method--once-through to superheat versus evaporator plus superheater
- Steam generator surface area
- Thermal storage capacity.

These trade studies are described in the following sections.

I-4.1 Receiver Configuration

The configuration of the Carrisa Plains receiver was developed based on a study of alternatives for use with a sodium-cooled receiver. The receiver was assumed to be external, due to the compactness and inherent low thermal losses of a sodium-cooled receiver, and in light of the Rockwell experience in testing a prototype of such a receiver. Three alternatives were considered. The

first two utilized a north-facing receiver, the first a vertical billboard, the second with a billboard slanted downward at 20 degrees. The third option was a cylindrical receiver. The corresponding collector field layouts were developed using the Sandia-developed DELSOL computer code.

Table I-5 summarizes the results of this trade study. The three cases considered gave costs of energy within 2%, with the vertical billboard and cylindrical receivers within 1%. The apparent economic advantage of a slanted billboard (case 2) was considered highly uncertain due to potential mechanical complexities for such a design. Considering the uncertainties in the costs of energy at the stage at which this trade study was done, this difference was insufficient to determine the receiver configuration. Further consideration was therefore given to other design factors and advantages seen for the various options. Tables I-6 and I-7 summarize the advantages seen to the north-facing and cylindrical receivers, respectively.

The decision to use a north-facing receiver was based on its greater simplicity, similarity to the Rockwell test receiver, and trade studies developed by Sandia showing it to be preferred for small (<50 to 60 MWe) plants. The slanted billboard was rejected as being structurally complex and uncertain.

I-4.2 Steam Cycle

The selection of a reheat or non-reheat cycle was considered by examination of equipment available for use in the size range intended, as well as the economics. No utility turbine in the 30-MWe range was commercially available with reheat. While one could be developed, this was perceived as counter to the project requirement that tested components be utilized wherever possible. The same objection can be made with respect to the steam reheater, for which there is no applicable test experience. Further, preliminary economic studies indicated that for such a small plant, the increased capital costs for reheat could not be justified based on the higher efficiency. Consequently, a non-reheat steam cycle was adopted.

TABLE I-5
COMPARISON OF RECEIVER CONFIGURATION

Parameter	Case		
	1	2	3
Run type	Baseline	Optimized	Optimized
Receiver type	Vertical billboard	20° slanted billboard	Cylinder
Receiver power (MWt)	95	95	95
Number of panels	8	8	18
Tower focal height (m)	111	110	90
Receiver height (m)	12	15.4	8.1
Receiver width/diameter (m)	16	14	9.0
Receiver area (m ²)	192	216	229
Absorbed power efficiency			
Design point (%)	0.67	0.67	0.61
Annual (%)	0.58	0.59	0.55
Annual power (GWth)	221	225	228
Maximum flux (MW/m ²)	1.5*	1.3*	1.4
Cost (millions 1982 \$)	76.6	76.7	78.7
Cost/annual energy (mills/kWh)	347	341	345
Delta change (mills/kWh)	Base	-6	-2

*Flux should be reduced to ~1.1 MWt/m² with 9-point aiming

TABLE I-6
ADVANTAGES OF NORTH-FACING RECEIVER

1. Constant power distribution
2. Uniform outlet temperature each tube, orifice tube
3. Images can be homogenized on receiver
4. Single or few valves needed
5. Lower peak heat flux
6. Fewer stress problems
 - A. Lower peak heat flux
 - B. Lower peak tube temperature
 - C. Small thermal gradients across panel
7. Fewer manifolds, fewer tube-manifold welds
8. Lower thermal losses
9. Easier startup
10. Resemble CRTF test panel

TABLE I-7
ADVANTAGES OF CYLINDRICAL RECEIVER

1. No problem from right and left edges
2. No orifices required
3. Similar to receivers of 60 MWe and over
4. Less wind force
5. Shorter panels easier to handle
6. Similar to Barstow

I-4.3 Steam Conditions

With the cycle established, the steam conditions could be selected. It was perceived that modern steam conditions should be used if possible and economic. Consequently, a baseline condition of 1000°F/1550 psia was selected, and the costs for other options were developed with reference to this baseline.

The use of higher temperatures was rejected based on current U.S. practice for turbines being largely limited to 1000°F. A reduction in temperature from the baseline would lead to lower thermal efficiency and high power costs unless compensating cost reductions could be identified. Since none of sufficient magnitude could be identified, the steam temperature was fixed at 1000°F.

The pressure was next examined. Pressures in the range of 1650 to 2200 psig were examined. These entailed substantially higher turbine costs, and it was unclear that higher efficiencies would result due to the small turbine size. Even if higher efficiencies could be obtained, the higher turbine costs could not be justified based on the small saving in solar plant costs due to the higher plant efficiency.

It should be noted that further examination during preliminary design has corroborated the selection of the lower pressure cycle. The later evaluations show that a 1000°F/1450 psig cycle produces the highest thermal efficiency for a 30-MWe turbine. Consequently, the preliminary design utilizes this still lower pressure.

I-4.4 Steam Generation Method

Two alternative means of implementing a non-reheat cycle were considered — once-through to superheat and separate evaporator and superheater units. These alternative designs are summarized in Table I-8. It was found

TABLE I-8
COMPARISON OF ONCE-THROUGH TO SUPERHEAT AND SEPARATE
SUPERHEATER/EVAPORATOR DESIGNS

	Superheater/ Two Evaporators	Once-Through Parallel Units
Units required [number (area - ft ²)]	1 (1200)/2 (1650)	3 (1420)
Steam exit velocity (ft/s)	300	100
Sodium pressure drop (ft)	170	15
Reliability	Significant outage if unit fails	Redundancy
Water quality requirements	Moderate	High
MSG test exp.	No superheater	Essentially same conditions
Controls	More stable Easier startup	Demonstrated
Incremental costs	Piping (\$ 400,000) Pump power (850,000) Steam drum (100,000) <u>\$1,350,000</u>	Water treatment (\$500,000) <u>\$500,000</u>

that the once-through to superheat design offered a slightly lower capital cost.

The principal disadvantage of the once-through design was the requirement for stringent water quality control. Utility experts viewed this requirement as routinely demonstrated in the field. In addition to capital cost, this design has the advantage of a high degree of redundancy should one unit fail. Consequently, the once-through to superheat design was adopted.

I-4.5 Steam Generator Surface Area

Given the adoption of a once-through to superheat configuration for steam generation, the steam generator surface area could be selected. This parameter affects the sodium outlet temperature from the steam generators, as greater area provides a closer approach in temperature between steam and sodium sides of the steam generator. A larger steam generator area will by itself cost more, but will increase the difference in temperature between the inlet (hot) and outlet (cold) sodium. This in turn reduces the amount and cost of sodium required for thermal storage of a fixed quantity of energy.

Figure I-7 shows the relationship between steam generation plus thermal storage cost and the sodium outlet temperature. Marked on the curves is the number of Rockwell Modular Steam Generator (MSG) units required to obtain a given sodium outlet temperature. The use of two MSG units was rejected as an option since the temperature difference between boiler feedwater and outlet sodium exceeds 200°F, the maximum allowed for the MSG. Consequently, the system was optimized by the use of three MSG steam generators and a sodium outlet temperature of approximately 595°F.

I-4.6 Thermal Storage Capacity

The amount of thermal storage to be incorporated in the plant was evaluated based on energy production cost and energy value to the utility. Busbar

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Figure I-7. Steam Generator Area Selection

energy costs were evaluated as a function of the amount of thermal energy storage and were found relatively insensitive, varying over a $\pm 10\%$ range from no storage up to 6 h of storage.

The value of the energy produced, however, was found to vary more dramatically. In particular, in accordance with PGandE's standard offer for the sale of power by a privately owned power plant, a capacity credit would be paid for a reliable delivery of power during a peak demand period. The thermal storage level was therefore set at 70 full-power minutes of operation to obtain this capacity credit payment. Figure I-8 shows that this selection does allow the plant to provide power during the entire required operating period for capacity credit payments if the weather is clear. Even considering expected weather outage, the plant provides sufficient energy to earn these credits. The very substantial impact of capacity credits on plant revenue is shown in Figure I-9.

Reducing the amount of thermal storage would make the plant unable to obtain capacity credits, reducing plant revenues disproportionately to the capital cost savings. Increasing the amount of thermal storage would not significantly increase these credits, and therefore their impact would be reduced due to the greater capital cost of the plant. Consequently, 70 full-power minutes of thermal storage capacity was adopted to optimize the plant energy value.

Figure I-8. Plant Operating Hours and Capacity Credit Required During Operating Period

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(1) MINIMUM QUALIFICATION REQUIREMENT

Figure I-9. Impact of Capacity Credit on Plant Revenue

II. COLLECTOR SYSTEM

II-1 INTRODUCTION

ARCO Solar Industries has undertaken the design and specification of the collector field for the Carrisa Plain 30-MW facility. This work includes the performance specification of the collector system, the preliminary design of the beam characterization system (BCS), washing equipment, data acquisition systems, and all of the associated hardware required for the turnkey delivery of a collector field. The specification for the collector system is presented in Volume II, Section II, of this report. At the same time that this collector system work was being performed under the DOE contract, ARCO Solar Industries continued its active internal heliostat development program which has resulted in significant refinements to the existing third-generation heliostats.

ARCO intends to assume the responsibility for supplying the total collector system for the plant. This system includes the heliostats and their installation, the heliostat control system, and the BCS. ARCO's scope also includes all of the field preparation for the installation of the collector system, except the rough grading, and the installation of the field wiring. In addition, ARCO will supply all of the washing equipment, and a full complement of spare parts and maintenance equipment for the heliostat field.

II-2 FIELD DESIGN

The field layout for this facility was constrained by the design principles governing the plant, which is to make the facility as simple and modular as possible, and to make the maximum use of existing components. This approach has significantly reduced the cost of the facility and has greatly reduced the technical risk. The shape of the collector field was derived from the desire to use the proven Rockwell flat panel receiver geometry, and by the desire to reduce the tower height to minimize tower and pumping costs.

ARCO proprietary codes were used to lay out the collector field, and the results were confirmed with the Sandia-developed collector field code, DELSOL. A north field configuration was chosen early in the design process because of the receiver geometry and because of the superior performance of a north field for this application. The field optimization process centered around the selection of the field angular width, the tradeoff being between the improved geometric (cosine) factor of a narrower field, and the reduced slant range of a wider field. The trade between a number of field shapes produced a very broad optimum. The 150° width field was found to have performance within 1% of the 90° width field; the latter was chosen as the design solution. This design is shown in Figure II-1.

ARCO believes that it is important to begin the design process with an actual X-Y layout of a field, so that field design constraints can be incorporated early in the design process. After the trial layout is completed, shading and blocking analyses are run on the layout and design point, and annual energy estimates are run on the layout. This process is iterated until an optimum solution is found. An example of the design process is shown in the comparison between the baseline and refined designs given in Table II-1. For this plant, the broad optimum in collector field performance means that the preferred layout could be selected to ensure that the field is compatible with the receiver design with no performance penalty.

Once the field geometry is selected, the field wiring layout will be designed and optimized to minimize the cost of the trenching and cabling in the field. (The results of this study are contained in Drawings VI-31 and VI-32 of Book 2).

Flux maps have been produced for the receiver geometry. The design point flux pattern is given in Table II-2. The flux patterns are reflective by the long thin field, which produces a large image from the outer rows. As a result, multiple aim points from the inner rows are required to distribute properly the power across the receiver aperture. The flux is diffused somewhat by the large image size, but the need to control spillage requires careful aiming strategies.

Figure II-1. Carrisa Plains Solar Plant Collector Field Layout

TABLE II-1
COMPARISON OF BASELINE AND REFINED COLLECTOR
FIELD PERFORMANCE

Parameter	Baseline Design	Refined Design
Number of heliostat positions	1904	1883
Outer row radius (ft)	3330	3631
Inner row radius (ft)	395	366
Plot size (acres)	292	371
Winter noon cosine factor	0.961	0.958
Equinox noon cosine factor	0.921	0.918
Summer noon cosine factor	0.845	0.841
Winter noon blockage factor	0.923	0.966
Equinox noon blockage factor	0.957	0.991
Summer noon blockage factor	0.987	0.997
Atmospheric attenuation factor	0.936	0.935
Average annual geometric efficiency	0.755	0.789

II-3 COLLECTOR SYSTEM DESIGN

The ARCO approach to the development of the collector field system is to keep the system as simple as possible, consistent with the plant requirements. For example, at the Bakersfield thermal test facility, a 1-MW solar steam generator, there is no provision for emergency collector field stow. The receiver system, part of a natural circulation boiler, is designed to withstand a total loss of field power without damage. Currently the system operates unattended, with the control computer operating both the collector field and the heat transfer loop.

The Carrisa Plains plant requires a different approach because of the high flux density, which makes receiver protection more demanding. To accomplish this, the collector system provides for emergency stow powered by the plant UPS. Because the field is relatively long, the linear rates of heliostat focal point motion are high. This reduces the amount that the heliostat

TABLE II-2
RECEIVER FOCAL PLANE FLUX TABLE

Day No.: 80
Time: 12:00
Sun azimuth: 0.00
Sun elevation: 54.57

12 point aim strategy No. 3: Displacements for center point
Inner zones displaced 12 ft vertical and 18 ft horizontal
Central zones displaced 6 ft vertical and 9 ft horizontal
Outer zones displaced 6 ft vertical and 9 ft horizontal

Total Energy = 118349 kWt:

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Vertical Position (ft from c/l)	18	118	256	344	318	221	169	160	159	159	159	160	169	221	318	343	256	119
	15	275	616	846	754	511	385	370	359	354	359	370	386	512	752	843	615	276
	12	369	842	1174	1062	749	591	571	544	530	543	570	590	748	1057	1168	838	369
	9	315	696	992	1031	894	830	848	815	795	813	844	827	890	1026	987	694	316
	6	202	416	623	824	909	965	1028	994	970	990	1022	959	904	820	620	415	203
	3	138	267	430	709	903	1023	1118	1093	1070	1089	1112	1015	897	704	428	266	139
	0	127	237	389	679	890	1020	1129	1114	1096	1111	1125	1016	886	676	387	237	128
	-3	153	283	440	704	878	983	1083	1071	1058	1070	1082	984	878	703	438	283	155
	-6	223	417	599	796	873	913	980	964	950	965	983	918	875	793	593	413	223
	-9	318	614	838	925	851	794	815	795	782	796	819	799	851	915	821	602	316
	-12	356	697	928	909	717	587	587	543	532	544	569	590	714	893	904	681	352
	-15	279	538	704	676	513	402	381	368	362	368	383	404	511	665	688	527	277
	-18	139	261	334	326	246	191	173	169	167	169	174	192	246	323	329	258	139
		-24	-21	-18	-15	-12	-9	-8	-3	0	3	6	9	12	15	18	21	24
		Horizontal Position (ft from c/l)																

must travel to be off the target, and the power required for stow. The drift-off in the absence of an emergency stow procedure is shown in Figure II-2. For this facility, ARCO is also changing to a new and faster control computer which will allow greater flexibility in the ability of the field operators to adapt the control of the heliostats to the needs of the receiver.

The control system for this plant is based on the system that is being installed at the Carrisa Plains photovoltaic facility. It uses an HP 1000 computer, which is equipped with 8-channel multiplexers for heliostat communication. The computer communicates with the heliostats via an RS-232 serial interface. Each communications channel can handle up to 60 heliostats. The computer is redundant with the backup computer performing data acquisition and monitoring functions, and it is provided with an automatic fail-over capability.

The BCS for the Carrisa Plains plant is intended to be less expensive and simpler than the one being used at Barstow. ARCO is currently testing a video imaging system at its Bakersfield test facility, which will provide the capability to scan the target and provide information on the beam quality and flux levels at the target. The target for the BCS will be similar to that used at Barstow, in that it will be larger in size than the receiver, but it will incorporate folding or stowable panels to reduce the wind loads on the tower.

The emergency defocus procedures are determined by the need to have the heliostats leave the receiver as quickly as possible and in a manner which prevents the receiver flux and flux distribution limits from being exceeded. In particular, a "pile-up" of flux must be avoided as heliostat images overtake one another. Since a multiple aim strategy is used, the heliostats will be pulled either east or up, depending on which edge is closer to the heliostat aim point. The heliostats on the west edge of the receiver will be moved vertically to a point above the receiver, while the heliostats aimed at the east edge of the receiver will be moved horizontally to the east to a standby position. During emergency defocus, only one heliostat axis will be energized to reduce the power drain. The heliostats will be sequenced over a 4-min

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Figure II-2. Receiver Energy vs Time After Power Failure (12 Point Aim No. 3)

period starting at the inner edge of the field, since these heliostats have a slower rate of linear motion. The outer rows of heliostats have a large image size and relatively rapid linear motion, which makes them less of a problem. In this manner, the flux level at the receiver can be maintained at safe levels throughout the emergency stop.

The field maintenance requirements have been developed from the experience at Lugo and at Bakersfield. The same distributed control philosophy will be used at this plant, and the same field maintainable assemblies will be used to minimize downtime for the heliostats. Currently, washing concepts are being evaluated at Bakersfield and it is expected that washing equipment will be provided under the heliostat scope of supply.

II-4 SCOPE OF SUPPLY AND SPECIFICATION

A scope of supply was prepared to identify all of the hardware and services that the collector field supplier would provide for the project. ARCO, as the collector field supplier, should have the capability to provide all of the hardware and services that would be needed to provide a working collector system and have structured the scope of supply in that direction. The design basis of the heliostat field, including wind loads and operating requirements, have been developed based on the design requirements of the Barstow field. However, the design requirements have been altered to conform to the seismic requirements at Carrisa Plains. The specification for the collector system is presented in Volume II Section II of this report.

II-5 ARCO HELIOSTAT DEVELOPMENT

ARCO Solar Industries has a continuing commitment to the development of heliostat technology for this plant and for the future of solar thermal systems. ARCO has an ongoing research program for heliostat development, and much of the most important progress was made during this past year. ARCO's latest generation heliostat, shown in Figure II-3, has a number of significant refinements beyond the existing design used as a basis for this study. The

Figure II-3. ARCO Third-Generation Heliostat
(PV modules in background)

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unit has been installed at the Bakersfield facility for testing. The Bakersfield receiver and BCS target are shown in Figure II-4. Major features are summarized in Table II-3. The unit has a new mirror module design, more advanced electronics, and other refinements to reduce the cost and improve the performance. ARCO is currently installing 756 of these units equipped with photovoltaic modules in Carrisa Plains near the site proposed for this plant. The unit has been redesigned to accommodate the stricter seismic requirements of Carrisa Plains. This facility will have six times the output of the Lugo facility shown in Figure II-5. All of these improvements will significantly benefit the project and have been made at no cost to the government. During the final design effort, these design improvements will be incorporated into the specifications and in further refinements to the cost estimates. The performance of these new fourth generation units is currently being validated, and modifications to the field layout and control strategy will be made, if needed.

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Figure II-4. Bakersfield Receiver and BCS Target

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TABLE II-3
MAJOR FEATURES OF ARCO MODEL 3.4 HELIOSTAT

Configuration	= Dual axis tracking, pedestal drive mount
Area	= 95.2 sq m (1024 sq ft)
Height	= 9.93 m (32.58 ft)
Width	= 9.83 m (32.25 ft)
Stow positions	= Normal, vertical, 60 E of S High winds, horizontal face up
Mirror module	
Mirror	= 4 ft by 16 ft 1 mm by 3.2 mm glass laminate
Substrate	= 26-gauge steel hat section system
Bond	= RTV silicone
Mounting	= 3 point
Drive	= 18400:1 ratio azimuth-elevation gear system
Input stage	= 460:1 planetary
Output stage	= 40:1 worm
Electronics	= HC logic, power supply, motor revolution counter
Motor	= 1/4 hp dc motors
Control	= Single computer with I/O to HC logic
Structure	
Stationary	= 24-in.-diameter steel pipe pedestal
Tracking	= 2 double 29.5-in. truss racks

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Figure II-5. Lugo Facility

III. HEAT TRANSPORT SYSTEM

III-1 OVERVIEW

The Carrisa Plains Solar Power Plant generates electricity by converting solar insolation into sensible thermal energy in a form that can be used for immediate power generation or can be stored for delayed use. The heat transport system (HTS) provides the plant functions needed to convert the solar insolation redirected by the collector system to thermal form and to generate steam, either immediately or with a delay, which is utilized by the power conversion system to produce electricity. (The interfaces of the HTS with other plant areas are shown in Drawing III-1.1 of Book 2.)

The HTS process inputs are concentrated sunlight and boiler feedwater; its output is steam. The HTS is subdivided into (1) the receiver subsystem, which thermalizes the solar insolation, (2) thermal storage, which provides for delayed power production, (3) steam generation subsystem, which produces steam from the solar energy, (4) the heat transport loop, which implements material flow between portions of the HTS, and (5) electrical, instrumentation, and control, which provides power and controls to HTS operations and interface with plant controls.

The principal features of the HTS are shown in Figure III-1.1 and are summarized below:

- The receiver subsystem utilizes eight independent solar receiver panels which are mounted at the 125-m (410 ft) level of the receiver tower. These collect the concentrated solar insolation redirected by the collector field heliostats. The sodium coolant enters the receiver at 321°C (610°F) and is heated to 566°C (1050°F) with a peak power of 107 MWt delivered.
- Thermal storage provides independent hot and cold storage reservoirs for enough sodium [1400 m³ (370,000 gal)] to generate electricity for 1-1/6 h at full power.
- The heat transport loop includes receiver and steam generator pumps, valves, piping, and supporting auxiliary equipment. The

Figure III-1.1. Carrisa Plains Solar Plant Flow Diagram

loop supplies sodium to the receiver and steam generator at independently controlled rates. It also provides for sodium loading and cleanup, provides an inert atmosphere for all sodium components, and provides plant protection.

- The steam generator subsystem has three identical units in parallel, with a total power rating of 85 MWt. This subsystem is designed to supply steam at 10.1 MPa (1465 psia) and 538°C (1000°F) at the turbine inlet.
- The electrical, instrumentation, and control subsystems include electrical trace heating, control functions for the heat transport system operations including operator interface through master control, and independent data acquisition.

(The interfaces between the HTS subsystems and between the HTS and the remainder of the plant are shown in Drawings III-1.1 through III-1.3 in Book 2.)

A sodium facility for testing steam generators is operated for DOE by ESG through the Energy Technology Engineering Center (ETEC). This facility is a 70-MWt loop (Figure III-1.2) which is similar in all ways to this solar plant except for the solar receiver. The operation of this type of facility provides a sound basis for the design, fabrication, and operation of the heat transport components.

III-2 RECEIVER SUBSYSTEM

III-2.1 General Description

The receiver subsystem consists of the absorber panels, accumulator tank, surge tank, associated piping, tower, riser and downcomer, tower equipment, instrumentation and valves, cable spreading room, and support structure. Receiver subsystem design requirements are given in Design Specification N10048, with the structure requirements identified in Design Specification N10047. These specifications are included in Volume II of this report. Figure III-2.1 shows the major components of the receiver subsystem.

- OPERATIONAL SUMMARY
 - 70 MWt TEST SCHEDULED FOR CRBRP STEAM GENERATOR
 - 35 MWt — 16,000 h AT 593°C (1100°F)
 - 300 h AT 704°C (1300°F)
- SODIUM COMPONENT TESTING AND OPERATIONS
 - STEAM GENERATORS
 - FFTF DUMP HEAT EXCHANGER
 - CONTROL AND GATE VALVES
 - PUMPS
 - LOOP INSTRUMENTATION AND CONTROL

Figure III-1.2. SCTI Flow Diagrams

41028-86A

Figure III-2.1. Receiver Subsystem Layout
Ref: Drawings III-2.15 and III-2.16

ESG-DOE-13404

The north facing, flat receiver panel is exposed to the redirected solar energy from the collector field. This energy is absorbed by the sodium flowing in a single pass through the receiver. Figure III-1.1 is a simplified flow diagram of the heat transport system. Liquid sodium is pumped up the tower from the cold storage tank, enters the receiver at 321°C (610°F), and exits the panel at 565°C (1050°F). Hot sodium flows down the tower through the downcomer to the hot storage tank. (The detailed piping and instrumentation diagram for the receiver subsystem is given in Drawing III-2.1 of Book 2.)

III-2.2 Receiver Design

The receiver assembly consists of eight panels arranged in a flat array to form the absorber surface 12.2 m (40 ft) high by 15.8 m (51.8 ft) wide. Each panel is 2.0 m (6.5 ft) wide and 15.2 m (50 ft) in length from header-to-header. Figure III-2.2 shows the panel assembly. The upper and lower header regions are shielded from the incident radiation so that the aperture height for the absorber surface is 12.2 m (40 ft). A panel consists of 102 19-mm (3/4-in.)-diameter Type 316 stainless steel tubes with a 1.2-m (0.49-in.) wall connected to 152-mm (6-in.)-diameter Type 316 stainless steel inlet and outlet headers. The tubes are butt welded to the header nipples that are arranged in two rows, each 45° from the plane of the panel. This arrangement permits access to the tube-to-nipple weld joint and adequate web thickness in the header.

The receiver header length is designed to be less than the panel width so that the eight panels can be identical, arranged side by side as shown in Figure III-2.3. (Panel details are shown in Drawings III-2.2 through III-2.7 of Book 2.). Key receiver design parameters are given in Table III-2.1.

The tubes of each panel are held in position by mechanical constraints, Figure III-2.3, located on the backside of the panel and spaced every 4 ft along the panel length. These mechanical constraints are joined to hat-band sections that are supported as shown in Figure III-2.2 by swing arm assemblies

Figure III-2.2. Panel Assembly Drawing

Figure III-2.3. Tube Mechanical Constraint Detail

TABLE III-2.1
KEY RECEIVER DESIGN PARAMETERS

Aperture	
Height (ft)	40
Width (ft)	51.70
Area (ft ²)	2068
Number of panels	8
Panel	
Height (ft)	50
Width (ft)	6.46
Weight (lb)	
Dry	3568
Wet	4362
Tubes	
Number of panels	102
OD (in.)	0.75
Wall thickness (in.)	0.049
Material	316 SS
Header	
OD (in.)	6.625
Thickness (in.)	0.134 (Schedule 10)
Material	304 SS
Absorption coating	Solkote
Number of tube constraint (tang) sets per panel	11
Number of tongs per panel	2244
Performance	
Total power (MWt)	107
Temperature (°F)	
Outlet	1050
Inlet	610
Flow rate (gpm)	775
Pressure drop (psi)	9.0
Maximum flux (MWt/m ²)	1.2

(Drawing III-2.7 of Book 2) to a strong back structure. The strong back structure is also used for shipping, hoisting, and installation in the tower. Panel position and alignment are maintained by the swing arm assemblies.

Since the panel is supported at the lower header, the panel elongation at the upper header at operating temperature is about 5 in. The outlet piping for each panel includes a loop for flexibility to accommodate this growth as shown in Drawing III-2.16 of Book 2. The analysis of the outlet piping showing the flexibility to be acceptable according to the requirements of ANSI B31.1 for the life of the plant is contained in Appendix III-4.3, "Preliminary Piping Stress Report. (Carrisa Plains Unit 1 Solar Power Plant (079TI000008))."

The inlet piping to each panel contains a flow control valve and an electromagnetic flowmeter. The valve modulates the panel flow rate so the outlet temperature is maintained at the set point condition. Details of the panel control system are presented in Section III-5.

The Carrisa Plains receiver is constructed similarly to the three-panel prototype test receiver that was designed and built by Rockwell and successfully tested at the Sandia National Laboratory's Central Receiver Test Facility (CRTF). The peak solar flux on the prototype test receiver was 1.5 MWt/m^2 , which provides a 25% margin above the Carrisa Plains plant design flux. The test unit was operated at an outlet temperature of 1100°F compared to the 1050°F for the subject plant unit, thus providing a further design margin. Since all of the key features of the receiver design have been tested, and the scaleup of the units is basically in the length and number of panels used, the receiver is considered to be a state-of-the-art component.

The remainder of the receiver subsystem sodium components consists of the riser and downcomer piping and the surge and accumulator tank. The riser and downcomer piping are within the tower structure and use U-shaped bends every 27 m (90 ft) to allow for thermal expansion. Both pipes are insulated and electrically trace heated. The riser is 30.5 cm (12-in.)-diameter carbon

steel; the downcomer is 20.3 cm (8-in.)-diameter Type 304 stainless steel. The small diameter on the downcomer serves to dissipate some of the tower head and lessen the pressure/flow-rate demands on the low-pressure recovery valves located near the tower base.

An accumulator tank is connected to the riser. It is a protective device that supplies flow to the receiver in the event that coolant flow is lost. This 68 m³ (18,000 gal) tank is kept about half full of sodium under pressure. This supply would provide the necessary flow through the receiver for 1-1/2 min under full power conditions. This is adequate energy carrying capability for the reflected energy from the collector field to be removed from the receiver solely by retrogressive solar motion if the heliostats stop tracking the sun. In the event that pump power and collector field power are lost simultaneously, energy on the receiver can be removed by coolant flow long enough that a combination of retrogressive motion of the sun's image and the use of the uninterruptible power source (UPS) to move the heliostats off target can bring the receiver to a safe shutdown. Accumulator tank level is used as a control signal for the receiver pump valve modulation.

The surge tank, located at the high point of the sodium system, provides a free surface for gases entrained in the sodium to escape. In addition, this tank contains a sodium-level measurement which is the control signal for the valves at the base of the downcomer.

III-2.3 Receiver Structure

Details of the receiver subsystem structure are presented in Drawings III-2.8 through III-2.12 of Book 2. The interface control requirements are given by Drawing III-2.13 of Book 2. The interface between the receiver structure and the tower was defined at elevation 107.49 m (352 ft 8 in.). Above this level is a transition section between the square tower top and the trapezoidal cross section of the receiver structure. This transition section contains a temperature-controlled cable-spreading room with about 37 m² (400 ft²) of floor area, and the machine room and topmost stop for the tower

elevator. Five deck levels are provided within the receiver structure for equipment support and personnel access. Provision is made for a track-type service elevator on the south side of the receiver structure.

The tower top structure is covered with corrugated metal siding to provide weather protection for maintenance activities and equipment. Selected areas around the receiver panel aperture are covered with high-temperature insulation to protect the structure from solar energy spillage. These insulated areas and the type of insulation used are shown in Figure III-2.4.

The receiver panel front surface is serviced by a portable scaffold that is lowered from the top deck. Provision is also made for securing a hoist at this location to be used in lifting panels from the ground for installation and for replacing panels.

III-2.4 Tower

Figure III-2.5 is an artist's concept of the tower. The tower was designed by PGandE and is described in Section VI. (The interface requirements are given in Drawing III-2.13 of Book 2.)

III-2.5 Receiver Thermo-Hydraulic Studies

These studies were performed to develop the thermodynamic and hydraulic characteristics of the receiver panel and are reported in Appendix III-2.1. The temperature distributions developed are used in the structural studies described in Section III-2.6.

The reference (design point) flux distribution used for these analyses are given in Figures III-2.6 and III-2.7. The total energy for these distributions is 119.5 MWt. These distributions are typical of the flux patterns developed by ARCO during the collector field studies.

REGION	TOTAL AREA ₂ PLUS WASTE (ft ²)	MATERIAL *	THICKNESS (in.)
A	120	3000	1.5
B1	1100	2600 or AB	1.0
2			
3			
4			
C1	2200	HD	1.0
2			
3			
4			
5			
TOTAL	3420		

*FIBERFRAX DURABOARD OR EQUIVALENT

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Figure III-2.4. Receiver Surface Insulation

Figure III-2.5. 30-MWe Central Receiver Power Plant

83-011-0-55

Figure III-2.6. 30-MWe Receiver Vertical Flux Distribution Reference

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Figure III-2.7. 30-MWe Receiver Lateral Flux Distribution Reference

Both these flux distributions and nonstandard distributions were used to develop the temperature profiles used in the structural analysis. A typical axial temperature distribution is shown in Figure III-2.8.

Each tube of the edge panels is orificed in order to achieve a more uniform tube outlet temperature considering the substantial flux gradient across the panel as shown by Figure III-2.7. The orifice fixtures for these edge panels are shown in Drawing III-2.14 of Book 2. The outer one-half of the tubes in the edge panels use the double orifice fixture. In order to reduce the total number of orifice plates, groups of three tubes have an identical orifice size. Hence, the inboard 51 tubes use 17 different orifice plates and the outboard 51 tubes use combinations of orifice plates in the double orifice fixture. These edge panels are otherwise identical to the others. The pressure drop for the full flow panels is 62.3 kPa (9.03 psi) at design conditions. For the orificed panels the added pressure drop from the inboard tube to the outboard tube is 39.3 kPa (5.7 psi) in order to obtain a constant outlet temperature.

The circumferential temperature for a tube heated on one side were computed using a thermal analyzer program, TAP, computer model. Figure III-2.9 gives the distribution around a tube at the peak flux location. This distribution is used in the structural calculations to determine tube lifetime.

Backface panel temperatures were determined to estimate heat loss and the temperature of various structural members that support the panel. The backside of the receiver panel covers 10.2 cm (4 in.) of Cerafelt 600 insulation blanket, held in place by corrugated metal sheets. The surface temperature on these sheets is estimated to be 104°C (220°F) and 88°C (190°F) at the top and bottom ends, respectively, for a local ambient temperature of 66°F (150°F).

Hat-band temperatures at the outlet end are estimated to be 110°C (230°F) due to conduction through the mechanical constraints. Overall heat loss from the backside of the panel is calculated to be 0.6 kW/m^2 .

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Figure III-2.8. Axial Temperature Distribution
Full Flux Distribution

Figure III-2.9. Temperature Distribution Map

The heat loss from the front face of the panel is caused by reflection, radiation, and convection. These losses are presented in detail in Appendix III-2.1. A reflection loss of 5% ($\alpha = 95\%$) is obtained from the paint manufacturers of the black absorption coating, either Solkote or Pyromark.

The method used in Appendix III-2.1 to determine the radiation and convection losses is to determine an effective panel surface temperature ($\bar{T}$) by integrating over the panel to get:

$$\bar{T}_{\text{conv}} = \frac{\int T dA}{\int dA}$$

$$\bar{T}_{\text{rad}} = \left[\frac{\int T^4 dA}{\int dA} \right]^{1/4} .$$

The step-wise integration used also included the temperature variation on the curved surface of the tubes. The overall effective temperatures for radiation and convection loss are 936.7°F and 894.2°F, respectively. Heat loss resulting from radiation is calculated to be 3.4 MWt. Referenced to the incident power of 119.5 MWt, the loss is calculated to be 2.8%.

Convection heat loss from the receiver surface is due to the combined effect of natural and forced (wind) convection. The natural convection heat transfer coefficient is calculated to be 1.412 Btu/h-ft² °F. For forced convection effects, the receiver structure or top of the tower is considered to be a large cylinder. The Nusselt number for flow normal to a cylinder is obtained from the correlations by Achenback for a rough surface (900×100^{-5}). The mean wind condition at Carrisa Plains was considered to be 15 ft/s at the 410 ft elevation. Maximum operating wind was considered to be 64 ft/s. For these wind conditions, the forced convection and combined heat transfer coefficients (h) are:

<u>Velocity (ft/s)</u>	<u>Nusselt Number</u>	<u>h Forced (Btu/h-ft² °F)</u>	<u>h Combined (Btu/h-ft² °F)</u>
15	4,400	2.36	2.76
64	12,000	6.44	6.60

The natural and forced convection heat transfer coefficients are combined using

$$h_{\text{comb}} = \left(h_{\text{nat}}^n + h_{\text{forced}}^n \right)^{1/n} \text{ where } n = 2,$$

while higher values of n are suggested by the literature, such as 3.2 by Siebers, et al., in Ref. 1, the use of $n = 2$ gives somewhat conservative results. The convective loss for the two wind conditions are:

<u>Wind (ft/s)</u>	<u>Loss (MWt)</u>	<u>Ratio to Incident Power (%)</u>
15	1.4	1.2
64	3.3	2.8

The total power loss as the mean wind condition due to reflection, radiation, and convection losses is 9%.

III-2.6 Structural Studies

The receiver panels were analyzed for loading conditions from internal pressure, dead weight, seismic, wind, and temperature gradients. The following components were analyzed in detail during this phase:

¹D. L. Siebers, R. G. Schwind, and R. J. Moffat, Sand 83-8225, "Experimental Mixed Convection Heat Transfer from a Large Vertical Surface in a Horizontal Flow," July 1983

- 1) Panel tubes
- 2) Tube mechanical supports
- 3) Panel support hat bands
- 4) Panel swing arms (support rods)
- 5) Inlet and outlet headers
- 6) Main panel support box and truss
- 7) Header end caps
- 8) Header-to-tube joint
- 9) Header inlet or outlet nozzles.

The analyses of these components under the specified loading combinations and the evaluations performed in accordance with the appropriate structural criteria are summarized in Table III-2.2. These structural criteria use the ASME Boiler and Pressure Vessel Code Section VIII Division 1 as the basic public safety code for minimum requirements and code stamping. This Code has been supplemented by ANSI B31.1 requirements for occasional loads, such as wind gusts and seismic, and for thermal expansion. The use of Section VIII Division 1 is supplemented further with the use of a Code Case N-47 type criterion for creep-fatigue evaluation of total stresses including heat flux stresses. In using this type of criterion, the safety factor on life has been reduced from 20 to 4, reflecting the nonnuclear application. Credit is also taken for the less damaging compressive hold time stresses by use of a linear creep-fatigue damage interaction diagram. All of the design margins are positive. Some of the significant load conditions used are given in Table III-2.3. Figure III-2.10 gives the cyclic histogram for panel temperature.

ASME Section VIII Division 1 was selected to verify the structural integrity of the pressurized (100 psi design) sodium tubes and headers because of its acceptance as a valid engineering design criteria document for nonnuclear power plant component design. Section VIII does not give explicit consideration to thermal stresses. The only reference to them is Paragraph UG-22 where

"the effect of temperature gradients" is listed among the loadings to be considered. However, there is no indication of how this loading is to be evaluated and allowables set. On the other hand, the Piping Code (ANSI B31.1) does give allowable values for the thermal stresses which are produced by expansion of piping systems and also varies these allowable stresses with the number of cycles expected in the system.

For Carrisa Plains the nonpressure components of the receiver subsystem are being designed to the criteria of the AISC code. This code of construction was selected since it is an industry standard for civil-type structures.

TABLE III-2.2
SUMMARY OF RESULTS

Component	Type of Loading	Material	Criteria	Stress Values		Design Margin	Reference Page Appendix
				Calculated	Allowable		
Sodium tubes	Pressure	SS316	Section VIII	100 psi	2,000 psi	High	61
Sodium tubes (thermal window)	Thermal expansion	SS316	ANSI B31.1	17,320 psi	18,900 psi	0.09	95
Sodium tubes (thermal window)	Thermal expansion + sustained loads	SS316	ANSI B31.1	17,943 psi	33,400 psi	0.86	95
Sodium tubes (shaded area)	Thermal expansion	SS316	ANSI B31.1	11,790 psi	18,900 psi	0.60	96
Sodium tubes (shaded area)	Thermal expansion + sustained loads	SS316	ANSI B31.1	15,280 psi	33,400 psi	1.18	96
Tangs	DW + TE + seis + wind	SS304	AISC	0.66 ^a	1.00 ^a	0.51	107
Hatbands	DW + TE + seis + wind	ASTMA 366	AISC	0.39 ^a	1.00 ^a	1.56	116
Support rods	DW + TE + seis + wind	ASTMA 519	AISC	1,720 psi	11,900 psi	5.93	120
Inlet and outlet headers	DW + TE + seis + wind	SS316	ANSI B31.1	7,130 psi	18,900 psi	1.65	123
Support box section	DW + TE + seis + wind	SS304	AISC	0.74 ^a	1.00 ^a	0.35	129
Support truss	DW + TE + seis + wind	ASTM A36	AISC	0.29 ^a	1.00 ^a	2.45	134
Sodium tube	Creep fatigue	SS316	Modified ASME	0.488 ^b	0.90 ^b	0.84	
Sodium tube to header weld	Thermal expansion	SS316	Section VIII	11,760 psi	16,560 psi	0.41	
Header to inlet pipe	Thermal expansion	SS316	Section VIII	17,083 psi	27,600 psi	0.62	

^aStress ratio per AISC:

$$\frac{f_a}{F_a} + \frac{f_b}{F_b} \leq 1.0$$

^bDamage fraction:

$$\sum \frac{n}{N_d} + \sum \frac{t}{T_d} \leq D$$

TABLE III-2.3
LOADING CONDITIONS

Panel	Unit Load	Total (lb)
Wind load		
Operating	5 psf	10,340
Survival	54 psf	111,600
Seismic		
Horizontal	0.4 W	1,427
Vertical	0.27 W	963
Weight, panel		
Dry		3,568
Wet		4,362
Tower (resulting from receiver system)		
Wind, design (lb)		
N-S		340,000
E-W		224,000
Seismic (0.4 (dead load horizontal)) (lb)		272,000
Weight (lb)		678,000
Detailed load conditions given in Drawing III-2.13 of Book 2		

The use of the AISC code as a guide for receiver components at greater than room temperature applications is justified by commentary contained in Part 6 of the AISC code which pertains to high temperature conditions. The ASME Code for linear component supports (NF) uses approximately the same criteria for allowable stresses as the AISC code for greater than room temperature applications. In most cases that involve combined stresses, the design margins presented in the summary of results, Table III-2.2 are based on stress ratios rather than stresses.

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1.0 ,$$

Figure III-2.10. Carrisa Plains Solar Receiver Cyclic Histogram

where

f = actual stress (psi)

F = allowable stress (psi).

In the case of the local stresses in the tang-to-sodium tube interface detailed structural analysis will be performed during final design to ensure structural integrity of the design.

The use of AISC structural allowable stresses (a percentage of the yield strength) is justified for stainless steel since the ASME Code for linear-type supports (NF) uses approximately the same criteria.

One of the most significant items of Table III-2.1 is tube life time. The temperature distributions through a tube are used to determine the strain range for that section (peak flux). This value is then used to determine the number of allowable cycles using the criteria curves of Code Case N-47.

The creep fatigue damage fraction allowable for the sodium tubes is obtained from Figure T-1420-2 of Ref. 2, given here as Figure III-2.11. Preliminary inelastic analysis indicates that the following creep and fatigue damage fractions exist for the sodium tubes:

$$\text{Creep } \sim \sum \frac{t}{T_d} = 0.438 ,$$

$$\text{Fatigue } \sim \sum \frac{n}{N_d} = 0.050 .$$

Based on these damage fractions, the allowable total damage fraction, D , from Figure III-2.11 will be $D = 0.90$. The design margin will be:

²ASME Code Case N-47, "Class 1 Components in Elevated Temperature Service, Section III, Division 1."

Figure III-2.11. Creep-Fatigue Damage Envelope
(Code Case N-47, Figure T-1420-2)

$$DM = \frac{0.90}{0.488} - 1 = 0.84 .$$

From the ASME Criteria Document, "Criteria of the ASME B&PVC for Design by Analysis in Sections III and VIII, Division 2," the allowable design stress values for fatigue were obtained from the best fit fatigue curves by applying a factor of 2 on stress or a factor of 20 on cycles, whichever was more conservative at each point. It is felt that the conservative factor used for nuclear plants is not required. Therefore, the design values used for fatigue damage calculations are based on a factor of safety of 4 rather than 20. The creep damage computations are based on the same rationale — the computed allowable time is based on a factor of safety of 4.

Based on these criteria, the total creep-fatigue damage fraction for the tubes for a 30-year life is 0.488, which gives a design margin of 0.84, Table III-2.1.

III-2.7 Operation

The intended mode of operation for the plant requires daily startup and shutdown of the receiver. After of the receiver is shut down, sodium will be drained to about 0.3 m (1 ft) below the lower header [116 m (382-ft) level]. This level is controlled by a dip leg in the supply piping system. The exposed panel surface within the aperture will cool to the ambient air temperature. However, the upper and lower header regions will be electrically heated to maintain temperature in preparation for the startup in the morning. Sodium temperature will be maintained with electric heat in the riser and downcomer piping.

Prior to startup, the panel surface is heated to about 316°C (600°F) using the heliostats. The number of heliostats required for this preheat activity is a function of the time after sunrise and the time of year as shown in Figure III-2.12. For very early morning startup, field power increases rapidly with time (Figure III-2.13). Once the preheat temperature is

Figure III-2.12. Heliostats Required For Preheat

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Figure III-2.13. Power From Sunrise

attained, the panel fill operation must be promptly executed in preparation for the power buildup phase. Otherwise, heliostats must be removed from the target to avoid overtemperature.

The sodium fill volume as a function of elevation above the 116-m (380-ft) level is shown in Figure III-2-14. With a total fill volume of about 79.5 m^3 (21,000 gal), the fill time will be about 4 min at the design flow rate. Once the sodium fill is accomplished, the panel outlet temperature is increased to the set point and additional heliostats brought on target until the desired power level is achieved.

Receiver shutdown will normally occur at the end of the day or when there is a cloud cover. The automatic control system will reduce panel flow rate in proportion to the solar insolation available while maintaining panel outlet temperature at the set point. When the low-limit flow rate is reached, the shutdown sequence is initiated. The receiver pump is stopped, but flow through the panel continues from the accumulator tank to remove heat while the heliostats are removed from the panel. When the panel outlet temperature reaches 371°C (700°F), panel flow is stopped, the surge tank is drained through the downcomer, and the accumulator tank and panel are drained through the riser to the 116-m (382 ft) level. The electrical preheat system is activated to maintain pipe and component temperatures.

III-2.8 Collector Field and Receiver Performance and Interface

A critical design issue in the development of the collector system and solar receiver designs is their mutual performance and interaction. The collector system design presented in Section II was developed around a maximum permissible flux at the solar receiver, 1.2 MW/m^2 . Similarly, the receiver design and performance evaluation was based on the preliminary estimate of the flux profiles and is described in Figures III-2.6 and III-2.7. For the success of the project, however, it will become more important to codify the mutual design requirements for the collector system and receiver in the form

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Figure III-2.14. Receiver Fill Schedule

of a performance specification and verification. The following sections address the key interface issues as perceived from the standpoint of the solar receiver supplier.

III-2.8.1 Delivered Power

The collector system, at the design point (vernal equinox solar noon), will deliver 118 MWt to the receiver aperture. The receiver aperture is a vertical plane 40 ft high and 51.7 ft wide, with a midplane elevation of 410 ft, oriented true north, and unobstructed from view from the collector field at any angle between 0 and 45° measured downward from the lower receiver edge in a true north direction.

The receiver will be capable of absorbing the redirected solar insolation with aggregate thermal losses estimated to be 9.0% for design point conditions.

III-2.8.2 Annual Energy

The collector system annual energy delivered to the receiver aperture, described above will be as a minimum 243,500 MWt hr/yr under conditions in which the power plant is operational and the available solar power is sufficiently high to warrant its operation. For the purposes of specificity, it may be assumed that the receiver will warrant operations at all times at which the direct normal insolation at the site is in excess of 150 W/m² for a sustained period. The annual energy delivered shall take into account the availability of the collector system equipment. The collector system will permit the special flux variations at the receiver aperture to be controlled based on the power level at the aperture.

The receiver will be capable of start-up and operation under conditions in which the aggregate power delivered to the receiver aperture is at least 15% of the aggregate power under design point conditions.

III-2.8.3 Solar Flux Spacial Variation

The maximum solar flux density within the receiver aperture will be no greater than 1.2 MW/m^2 . The operation of the collector system will be arranged to control the vertically integrated flux density within the following ranges:

Vertically Integrated Flux (MW/m)
Allowed Variability (edge-to-edge)

Edge Panels: Factor of 3 within one panel

Interior Panels: Factor of 1.2 within any one panel aggregate
 Factor of 1.5 within the six interior panels)

No region in the vicinity of the receiver aperture will be exposed to a solar flux in excess of 0.2 MW/m^2 under normal operating conditions, including transitions between operating and standby conditions. All regions in the vicinity of the solar receiver will be insulated or otherwise protected to withstand this level.

III-2.8.4 Startup Capability

The collector system will be designed to provide for receiver startup using a number of heliostats or power level specified on a daily basis. The operational controls for the collector will provide reasonably uniform and controllable flux over the receiver aperture during startup.

Transition from startup (zero delivered power to the receiver coolant) to full power operations (118 MWt delivered to the receiver aperture; c. 107 MWt delivered to the sodium coolant) shall incorporate a progression from the uniform flux pattern specified for startup to the allowable variation in vertically integrated flux density specified above. The controls system will be capable of continuously utilizing information on receiver delivered power and power distribution available through the plant control system to perform this transition.

III-2.8.5 Emergency Defocus Capability

The collector system will be designed to provide emergency defocusing of the heliostats promptly on command of the plant control system. The defocus will be completed within 6 min, using only the plant UPS to provide sufficient power to maintain collector controls operations plus a maximum of 10 kW to the collector field operations.

The defocus action will be implemented in a manner that prevents the peak flux at any region within the receiver aperture from exceeding its vernal equinox solar noon design value by an instantaneous amount of more than 25%, or an amount averaged over any 1 min of more than 10%.

III-2.8.6 Performance Verification

The power delivered will be verifiable based on direct performance measurements and corrections to those measurements. These measurements and corrections may include coolant flow, receiver reflectivity and thermal losses, and solar insolation. In the event that a correction need to be applied for solar insolation during performance verification and other tests, a peak direct normal solar insolation of 950 W/m^2 will be assumed at vernal equinox solar noon.

The annual energy delivered will be verifiable based on direct performance measurements and corrections to those measurements. These measurements and corrections may include coolant flow and temperature, receiver reflectivity and thermal losses, solar insolation, and power plant insolation during performance verification. The annual direct normal solar insolation delivered to the Carrisa Plains site will be taken to be 2.524 MW/m^2 of flat surface, of which 98.8% may be taken to be under conditions in which the direct normal insolation is in excess of 150 W/m^2 . In the event that a correction needs to be applied to the power plant availability, the plant availability will be taken to be 93.0% of the available hours of plant operation, or 94.4% of the available solar energy for operation, exclusive of unavailability due to the collector system.

III-3 THERMAL STORAGE SUBSYSTEM

III-3.1 General Description

The thermal storage subsystem is used to store hot sodium for delayed steam generation. The design requirement for thermal storage is that it be able to provide sodium for generation of 1-1/6 full power hours (99 MWt) of steam delivered to the turbine. In doing so, thermal storage satisfies the following requirements:

- It increases the plant energy value by providing high-availability power generation during PGandE's peak demand period.
- It provides substantial buffering of the steam generators from the receiver and simplifies startup by allowing the steam generation and turbine startups to be delayed from the collector and receiver startup.
- It provides much of the energy needed for feedwater cleanup and turbine roll during startup, thereby reducing parasitic electric power consumption.

III-3.2 Thermal Storage Design

Based on the design requirements, thermal storage is provided by two vertical cylindrical tanks. Each tank is 12.2 m (40 ft) in diameter and 16.5 m (54 ft) high. This provides each tank with sufficient capacity to store the entire plant inventory of sodium, 1779 m³ (470,000 gal). The dynamic volume is 1400 m³ (370,000 gal).

The hot storage tank to which sodium from the receiver is sent and sodium for steam generation is drawn, operates at 566°C (1050°F). It is therefore constructed of Type 304 stainless steel. The cold tank operates at 321°C

(610°F) and is constructed of Type A-555 carbon steel. Each tank is equipped with internals to provide sodium flow distribution and to determine the sodium level. A minimum sodium level of 0.9 m (3 ft) is maintained in each tank and sufficient insulation is provided to prevent the hot tank from cooling more than 67°C (120°F) overnight with this minimal sodium level.

Each tank is set on a multilevel insulating foundation. The foundation is provided with a cooling system to prevent excessive ground heating. Structural keys and tiedowns are provided to prevent tank motion on the foundation in the event of a seismic activity.

Drawing III-3.1 (Book 2) is the interface control drawing for the hot and cold storage tank. Additional design drawings have been developed by the Pittsburgh-Des Moines Company without charge to this contract.

III-3.3 Alternative Tank Designs

Because of the unique requirements of thermal storage, alternatives to the vertical cylindrical storage tank described above have been examined. These have been pursued so far as to obtain a cost estimate and an assessment of technical readiness. Of these options, two have been identified as having potential for use in the Carrisa Plains plant.

The first, shown in Drawing III-3.2 of Book 2, is a vertical tank similar in configuration to the baseline design. However, as shown in that drawing, the tank base is supported on a series of concentric rings 1.9 m (6 ft) high. Thermal insulation provides a linear temperature gradient down the rings, with the top and bottom at tank and foundation temperatures, respectively. This temperature gradient reduces the stress levels, as thermal expansion of the rings largely compensates for tank expansion and foundation conditions. This avoids the lower joint stress problem endemic in vertical tanks. A manway through the rings also provides a means of locating and repairing a leak in the tank bottom. Such a ring support structure is used in nuclear reactor core vessel supports and has been used by Rockwell in its Sodium Reactor Experiment (SRE).

The second alternative, shown in Drawings III-2.3 and III-2.4 of Book 2, is to use a bank of five horizontal cylindrical tanks. As shown, the tanks are joined by a manifold and provide a step down between tanks to allow complete drainage.

III-4 HEAT TRANSPORT LOOP

III-4.1 Introduction

This section describes the design requirements and principal design features of the heat transport loop. The overall loop makeup, functions, arrangement, and interfaces are given first, followed by a detailed description of piping arrangements for the loop and, finally, a detailed description of the components.

The heat transport loop design requirements are given in detail in the MTS specification, Volume II, Section 3.0, of this report. The principal design requirements are summarized in Table III-4.1.

The heat transport loop provides three principal functions: provision of sodium coolant to the receiver, hot sodium to the steam generators for power generation, and control and support of process functions including inerting of components, safety and equipment protection, and material supply.

The associated instrumentation and controls are discussed in principal only in this section. The details of the instrumentation and controls are discussed in Section III-6. Appendix III-4.1 contains the plant safety plan for the sodium systems. The allowable materials of construction for the heat transport loop and the remainder of the HTS are defined in Appendix III-4.2.

III-4.2 Summary Description

For the purpose of this report, the heat transfer loop encompasses the main sodium loop and the functional elements that support it. These include

TABLE III-4.1

HEAT TRANSPORT LOOP KEY DESIGN REQUIREMENTS^a

Design Requirements	Operating	Design
Plant life (years)		30
Cycles		
Daily		10,000
Solar		50,000
Power (MWt)		
Receiver	107	
Steam generator	85	
Temperatures (°F)		
Cold sodium	580	610
Hot sodium	1050	1075
Pressure	Sufficient to take pump shutoff pressure	Sufficient to take pump shutoff pressure
Design margin (flow)		120% of operating
Redundancy (pumping)	70% with one component failed	
Oxygen level (ppm)	6	
Construction Materials		
800°F		Carbon steel
800°F		2-1/4 Cr/1 Mo or stainless steel
Availability, MTS (%)		
Annual		92
12:30-6:30 p.m., May through September		90

^aIn the event of a discrepancy between this table and the MTS specification (N10046) or other project released specifications, the specification shall be taken to be authoritative.

0115C/glb

the associated instrumentation and controls, the sodium receiving and purification equipment, the mixing tank, the argon cover gas equipment, safety equipment including the sodium-water reaction products (SWRPS) tank, and the pipe and tank heating installations.

The heat transport loop picks up the heat energy gained by the receiver in the form of hot sodium and delivers it to the thermal storage subsystem; from there, it is delivered by the loop to steam generation. The associated instrumentation and controls keep the loops operating within design limits. The sodium receiving installation provides a means of transferring sodium delivered to the plant and preliminarily cleans it. Final cleaning and purity maintenance are accomplished with the sodium purification equipment. The mixing tank supplies sodium over a range of temperatures which can be set to match the steam generator startup requirements. In addition, the mixing tank is used to transfer sodium from the receiving station to the storage tanks and provides a means of filling the steam generators, the riser pipe, and down-comer pipe. It also serves as a drain tank for components. The inert gas chosen for the loop is argon, which is used to exclude air from the tank ullages and to maintain hydraulic balance in the sodium loops. Electric heaters are used to preheat the piping tanks and components and to maintain selected parts of the loop at temperature during shutdown.

III-4.3 Detailed Description

The heat transfer loop may be considered as two flow loops, which may be operated independently of each other within the limits imposed by thermal storage. One, the receiver loop, starts with the cold storage tank and flows through the receiver to the hot storage tank; the other, the steam generator loop, starts with the hot storage tank and flows through the steam generators back to the cold storage tank.

III-4.3.1 Functional Description

The detailed discussion of the heat transport loop process follows the flow direction starting with the receiver loop. (Refer to Drawing III-4.1,

"Heat Transport System P&ID," [079000029] for process information and to Drawings III-4.2, III-4.3, and III-4.4 for plant arrangement information. Drawing III-4.5 is the loop piping isometric.) The receiver loop performance characteristics are given in Table III-4.2, and the steam generator loop performance characteristics are given in Table III-4.3.

TABLE III-4.2
RECEIVER LOOP

Temperature [°C (°F)]	321 (610)
Flow	
Operating condition	
2 pumps, m ³ /s (gpm)	0.39 (6200)
1 pump, m ³ /s (gpm)	0.29 (4560)
Percent redundancy one pump	73.5
Design condition	
2 pumps, gpm	7440
1 pump, gpm	4560
Percent redundancy	61
Material	
Mild steel, typical	SA 106/515
Life, years	30
Standards	ANSI B31.1
Code	ASME B&PV Section VIII Division 1
Seismic	
Horizontal	0.4 W
Vertical	0.27 W

Suction line 0001 starts at an inverted elbow located at the cold storage tank wall (tank T-1), then branches – first to supply cold sodium to the mixing tank (T-5) (line 0034), and again to supply the redundant pumps (lines 0077 and 0078). These lines are sized to avoid vortexing in the tank and to maintain adequate net positive suction head at the selected pump elevation. Valves 001A and B and the stop check valves V-002A and B permit

TABLE III-4.3
STEAM GENERATOR LOOP

Temperature [°C (°F)]	566 (1050)
Flow	
Operating condition	
2 pumps, m ³ /s (gpm)	0.33 (5300)
1 pump, m ³ /s (gpm)	0.28 (4388)
Percent redundancy	82
Design condition	
2 pumps, m ³ /s (gpm)	0.40 (6400)
1 pump, m ³ /s (gpm)	0.28 (4388)
Percent redundancy	70
Material	
Stainless steel, typical	SA 312/240
Life	30
Standards	ANSI B31.1
Code	ASME B&PV Section VIII
Seismic	
Horizontal	0.4 W
Vertical	0.27 W

pump removal and "on-line" pump maintenance. Pump drainage is accomplished by gravity head through line 0076. Fluid for prelubing the pump bearing feeds through line 0040 and discharges through line 0049 along with the pump internal seal leakage. Argon pressurization of the ullage by means of FCV-100A and B controls the pump fluid level at a preset value. The bypass line 0035 aids in matching the system and pump performance characteristics. In the unlikely event that tank T-1 develops a leak, its contents can be pumped directly to the T-2 tank through valves V-037A or 037B. Flow to the receiver subsystem interface is through the 30.5-cm (12 in.) riser pipe 0002. A check valve, V-004, prevents back flow through FCV-019 when the pumps are off. A shutoff valve, FCV-003, maintains sodium in the riser pipe during plant shutdown. A level transmitter monitors this level.

The process description for this section will stop at the receiver input interface and start again at the receiver output interface. The interfaces between the heat transfer loop and the receiver subsystem occurs at the piping branch point which supplies accumulator tank T-3 and the receiver header at the hydraulic input to the receiver and the piping branch point for the receiver header and surge tank T-4 effluent lines. In addition, there is an interface between the level control in the surge tank and control valve FCV-014 which controls the level in T-4. The process description for the receiver is given in Subsection III-2. At full flow, the 20.3-cm (8 in.) downcomer line dissipates most of the hydraulic head as a result of the receiver elevation. At reduced flow, this head is dissipated in FCV-014 as it controls the level in T-4. Valve V-015 maintains the sodium level in line 0024 during shutdown. Sodium is introduced into the bottom of the tank through a sparger. As the solar part of the plant is started up, the cold sodium from the receiver may be diverted to cold tank T-1 via lines 0042 and 0043. Line 0042 may also be used to fill line 0024 from line 0002 or used as a recirculation line during the checkout period. Line 0404 maintains an ullage balance between tanks T-1 and T-2.

The steam generator loop performance characteristics are given in Table III-4.2. The suction line (0025) in this loop starts at an inverted elbow at the hot tank wall. It then branches to supply hot sodium through line 0039 to the mixing tank T-5. The line branches again to supply each of the redundant steam generator pumps via lines 0081 and 0082. The arrangement of the pumps, piping, and valves is similar to that described for the receiver pump arrangement. Two differences are: (1) each of the two pumps can draw suction from the mixing tank, T-5, through the mixing T in each pump suction line during startup of the steam generators; and (2) the prelube line 0044 is supplemented by lines 0047 and 0072 for the two pumps. The emergency drain for the hot storage tank, T-2, is through line 0101. Sodium to the steam generators is supplied through 0026 and exits through line 0033 on a first-in, last-out basis. Sodium flow is monitored by means of an EM flowmeter, and it is controlled by FCV-018 during power operation. During startup, the sodium flow is controlled by FCV-040 and is monitored by a small EM flowmeter in line.

The supply and discharge headers are vented in accord with note 2 on the P&ID drawing. The steam generators are supplied with flow-monitored running vents. The steam generators are filled and drained through line 0055. The discharge line from the steam generator terminates at a sparger located near the bottom of the hot storage tank, T-1. This completes the description of the sodium heat transport loop thermal hydraulic process.

Drawing III-4.6 (Book 2) is the pipeline list for the heat transport system. This list describes the size and material of each pipeline. Drawing III-4.7 is the comparison valve list. Appendix III-4.3 presents the complete stress analysis of all piping in the heat transport system.

III-4.3.2 Supporting Functional Elements

1. Sodium Receiving Station

The sodium receiving station is of conventional design. A diagram of it is shown in Figure III-4.1. Sodium is trucked to the site in leased tank trailers and parked at the sodium receiving station. A leased oil heater is used to melt the sodium, which is then transferred to the mixing tank through 10- m, pore-sized stainless steel filters at a temperature of 149°C (300°F). This process limits the initial oxygen transferred to the system to less than 3 ppm by weight. Approximately 3 months are allowed to fill the system with sodium, which is not considered to be a problem in view of the number of sodium trailers available. Plant startup is possible within 2-1/2 weeks if storage requirements are waived. A more detailed description of this equipment is given in Appendix III-4.4.

2. Sodium Purification Installation

The sodium purification equipment arrangement is shown in Drawing III-4.8 (Book 2). The receiver pump delivers sodium to the cold traps and the plugging temperature in parallel, through line 0061, at a temperature nominally 610°F. During equilibrium operation, an economizer, which is integral with

Figure III-4.1. Na Receiving and Transfer System

the cold trap, will lower the sodium temperature to about 300°F as it enters the trapping volume. The sodium is then reduced to 250°F in the trapping volume. This trapping temperature will set the oxygen concentration of the effluent sodium at approximately 1.0 ppm by weight. As the sodium leaves the cold trap it is reheated by the economizer to approximately 310°C (590°F) and returned to the hot storage tank through line 0062.

The flow capacity of the cold trap is 1.3 l/s (20 gpm) with a 70% trapping efficiency. It will take about 3 weeks on a two-shift basis to reduce the oxygen to less than the required minimum plugging temperature of 400°F.

A plugging temperature meter is used to monitor the oxygen concentration level in the system. The cold traps and the plugging meter indicator use forced convection air cooling. The expected life of the two initial cold traps is in excess of 15 years.

3. Argon Service Installation

The argon gas service installation is shown in Drawing III-4.9 (Book 2). It functions as a closed system. Argon cover gas vented from sodium components flows into a vacuum tank; the gas is filtered and compressed into the surge tank for reuse. A 30-day argon supply, consisting of 60 compressed argon gas cylinders, is provided for makeup. The cylinder gas pressure is 16.7 MPa (2400 psig). Pressure regulators are installed in the supply main to reduce pressure to 5.3 MPa (750 psig) and in branch lines to that required for the sodium components. The argon vacuum vessel pressure is held between 53 and 81 kPa (7.7 and 11.7 psia) by a redundant set of argon compressors which compresses the gas through a filter into a surge tank and is stored for reuse. The surge tank pressure is 1.14 MPa (150 psig). The standby argon is a dedicated supply and is provided as an independent source to protect the cold and hot storage tanks and the sodium pumps from loss of argon pressure from the normal sources. The standby argon consists of a 6-pack of argon cylinders. It will be permanently connected to the 30.5-cm (12 in.) pressure equalization line of the tanks and argon feed lines to the pumps. Argon will

be automatically released to the tanks if their pressures become negative compared with the ambient, and to the pump if the sodium level rises above their high alarm limits.

Argon is supplied to the storage tanks to control cover gas pressure. During the charge mode operation, cover gas volume in the tanks will be reduced as a result of temperature changes. An argon feed of $0.046 \text{ Nm}^3/\text{s}$ (98 scfm) is required to maintain a constant pressure. During the discharge mode operation, temperature changes will cause the cover gas volume in the tanks to increase. Argon will be bled out of the tank at the rate of $0.037 \text{ Nm}^3/\text{s}$ (78 scfm) to maintain a constant pressure. Argon pressure is used to control a constant sodium level in the accumulator tank and constant pressure in the surge tank.

Argon is supplied to the free surface pumps to control their sodium level. In the sodium reaction product tank, it provides an inert atmosphere. The argon storage inventory in the system can provide a continuous purge of $0.024 \text{ Nm}^3/\text{s}$ (50 scfm) for at least 3 h. Argon pressure is provided to the mixing tank (T-5) and the sodium receiving station for transfer of sodium. It is provided to the steam generators and the cold traps to facilitate sodium fill and drain operations. The pressure supply is obtained from the high-pressure header.

The argon vacuum tank is provided to receive argon vented from the sodium components. The tank pressure is maintained between 53 and 81 kPa (7.7 and 11.7 psia) by the argon compressor in order to effect argon flow from the storage tank at near atmospheric pressure. The tank is a welded pressure vessel constructed of carbon steel, 4.6-m (15 ft) long by 3.0 m (10 ft) in diameter. Thus, it has an accumulating volume for 5.7 Nm^3 (200 scf) of argon. The capacity of each of the compressors is $0.024 \text{ Nm}^3/\text{s}$ (50 scfm) flow rating at 62-kPa (9 psia) suction pressure. It is equipped with a low lube oil pressure switch and a high lube oil temperature switch that will shut down the compressor if either parameter exceeds the operating pressure range.

Normally, one compressor is operating and the other is on standby. Both compressors will operate when the upper pressure limit is exceeded. The argon surge vessel is a welded pressure vessel constructed of carbon steel, is approximately 2.4 m (8 ft) in diameter by 3.7 m (12 ft) long, and is mounted horizontally. It is used to accumulate argon up to 1.14 MPa (150 psig), which is resupplied to the sodium components.

4. Electrical Trace Heaters

Except for the large storage tanks, MgO-insulated stainless steel clad resistance heaters, banded directly to the piping and components, are used to preheat and maintain temperature. The heaters are derated by about 50%. The heater electrical circuits have ground fault interrupters. The electrical system is discussed in Section III-6.

5. Heat Transport Loop Control Loops

The heat transport loop shares controls with the receiver subsystem and the steam generator subsystem. In the receiver area, the argon ullage pressure in the accumulator tank is set to oppose the net receiver pump pressure and maintain 50% tank inventory of sodium in Tank T-3. A fixed inventory of sodium is maintained by measuring level and adjusting tank ullage pressure. The surge tank, T-4, ullage pressure is maintained at near atmospheric pressure by a feed and bleed argon control loop. Independently, the tank level is maintained at the halfway mark by modulating the FCV-014 with a level sensor signal originating within the tank.

The pump speed control sets the FCV-040 operating range at startup and provides "bumpless" transfer of control from FCV-404 to FCV-018.

III-4.3.3 Heat Transport Loop Components

1. Mixing Tank (T-5)

The mixing tank is used to adjust the sodium supply temperature to the steam generator startup requirements. To match the temperature requirements, sodium from the hot tank is mixed with sodium from the cold trap in the mixing tank. It is then pumped from the mixing tank by the steam generator pump to the steam generators. The mixing tank temperature can be increased by decreasing the cold tank flow and/or increasing the hot tank flow until operating temperature is reached. (The tank design is shown in Drawing III-4.10, Book 2.)

2. Sodium Water Reaction Products (SWRPS) Receiving Tank (T-7)

The vertically mounted tank is 9 ft in diameter and 22.5 ft high. It has a tangential inlet nozzle and a vertical exhaust stack. Under normal operating conditions, the tank is held at ambient temperature with an argon atmosphere at a slight positive pressure. In the event of a generator leak, the steam generator rupture relief disc will burst in the affected generator and the shell side contents will enter the tank through the inlet nozzle. The tangential nozzle and relief tank configuration provide efficient cyclone-type separation, allowing hydrogen to be flared safely without emission of sodium oxides to the atmosphere.

The volume of the tank is 40 m^3 (10,500 gal). It is sized to contain the sodium inventory of all three steam generators and still have space for liquid disengagement since the two remaining generators will drain through the failed relief line of the generator.

3. Sodium Pumps

The sodium pumps selected for this application are Hallam¹ type, centrifugal pumps (Figure III-4.2). For more detailed discussion of this pump,

Figure III-4.2. Receiver and Steam Generator
Pump Configuration

see Refs. 3 and 4. Drawing III-4.11 (Book 2) is the interface control drawing for these pumps. Table III-4.4 summarizes the pump sizes and performance characteristics. The pump is a vertical shaft sump-type pump. The impeller is welded to the end of the vertical pump shaft and is surrounded by a diffuser ring assembly. The diffuser discharges directly to the high-pressure plenum which supplies the discharge nozzle. A suction flow guide passes through the high-pressure plenum connecting the eye of the impeller to the inlet nozzle by means of a labyrinth seal. The hydrostatic bearing is located just above the impeller. The bearing surfaces are faced with Colmonoy hard-facing material. The bearing may be supplied directly from the high-pressure plenum or, as shown in the reference design, it may be supplied from an external pressure source. The labyrinth case seal separates the high-pressure plenum from the free surface chamber. This seal permits the rotating parts of the pump to be removed for maintenance. The leakage through it flows back to the storage tank along with the bearing leak-off sodium. The key dimensions and operating characteristics estimated for these pumps are given in Figures III-4.3 and III-4.4. The flow percentages given are for the design point, which is 20% over the operating point. The flow design margins are evident from the figure. As installed, the pumps have 14 m (46 ft) of net positive suction including fluid acceleration requirements while changing from two pump to one pump operation. The flow head curves have adequate negative slope to ensure stable operation.

Sodium pumps are covered by Specifications N30500 and N30501, Volume II, Sections 3.3.1 and 3.3.2, of this report.

³S. McLain and J. H. Martens Eds., Reactor Handbook, 2nd Ed., Vol IV, p. 678 (Wiley, New York, 1964)

⁴C. E. Fair (Borg-Warner Corp.), "History of Liquid-Metal Reactor Coolant Pumps in the United States," Proc. ASME Winter Annual Meeting, San Francisco (1978).

Figure III-4.3. Receiver Pumps — Carrisa Plains Unit One Design

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Figure III-4.4 Steam Generator Pumps — Carrisa Plains Unit One Design

TABLE III-4.4
PUMP SIZES AND PERFORMANCE CHARACTERISTICS

Item	Receiver Pump		Steam Generator Pump	
Length, m (ft)	3.14	(10.3)	2.96	(9.7)
Barrel diameter, m (ft)	1.19	(3.9)	0.88	(0.88)
Impeller diameter, m (ft)	8.2	(27)	5.2	(17)
Temperature, °C (°F)	321	(610)	566	(1050)
Flow, m ³ /s (gpm), operating pt.	0.24	(3800)	0.20	(3200)
TDH, m (ft), operating pt.	198	(650)	76	(250)
NPSH required, m (ft)	12	(40)	12	(40)
Speed, rpm	1780		1335 to 1780	
Motor rating, hp	1000		250	
Volts	480		4160	

4. Valves

The sodium valves are of standard commercial patterns with standard hard-facing trim. Valves 5 to 10 cm (2 to 4 in.) in diameter use bellows sealed stems. Valves 15 cm (6 in.) in diameter and larger used for control and shut-off service utilize standard commercial globe valves with a modified extended bonnet which is free-convectively air cooled. The air cooling freezes the sodium in the annulus formed by the valve stem and bonnet. This frozen sodium is sheared as the valve is operated. For control operations that do not require tight shutoff, butterfly valves are used. These use a rotating stem seal. Swing check valves are totally enclosed. The actuator for stop-check valves operates through a freeze seal gland. All valves are furnished with butt welding ends.

Sodium globe valves are covered by ANSI B16.34 and Specification N30499, Volume II, Section 3.3.3, of this report.

III-5 STEAM GENERATION SUBSYSTEM

III-5.1 General Description

The steam generation subsystem satisfies the HTS functional requirement for production of steam from the boiler feedwater supplied by the power conversion system. Heat for this is obtained from hot sodium generated in the solar receiver and pumped from the hot thermal storage tank. This sodium is returned to the cold thermal storage tank.

The project constraint of using tested and proven components required the selection of the Rockwell modular steam generator (MSG) as the hardware basis of the steam generation subsystem. The MSG was designed and fabricated by Rockwell and tested at DOE's Energy Technology Engineering Center (ETEC). ETEC is operated for DOE by Rockwell. Testing included over 9000 h at operating temperatures, with more than 4000 h of steaming conditions. Power levels exceeded 33 MWt for the single MSG. By comparison, 85 MWt is to be provided by the steam generation subsystem. Thus, three MSG units would provide ample capacity.

The three MSG units could be arranged in several ways, the preferred configuration being parallel, once-through-to-superheat steam generators. While use of once-through steam generation demands extremely high quality water, this is not viewed as a technical problem, particularly in view of the success with once-through steam generation at Solar One. Much of the MSG test experience was also in the once-through mode. Three parallel units also provide the highest level of redundancy. The leading alternative, in which two evaporators and one superheater are used in series, would produce a relatively high steam velocity compared to test experience.

Principal design criteria for the steam generation subsystem are included in the HTS specification, N10046. This specification is presented in Volume II, Section 3.0 of this report, Section 3.0. Table III-5.1 summarizes these design requirements.

TABLE III-5.1

STEAM GENERATION SUBSYSTEM DESIGN REQUIREMENTS^a

<u>Key Design Parameters</u>	
Number of Units	3
Size	
Diameter	0.45 m (18 in.)
Length	21.1 m (69.3 ft)
Number of tubes per unit	158
Tube dimension	
OD	1.59 cm (0.625 in.)
Wall	0.277 cm (0.109 in.)
Heat transfer area per unit	139 m ² (1,500 ft ²)
<u>Performance Parameters</u>	
Design power per unit	28.3 MWt
Steam conditions	
Pressure	10.45 MPa (1515 psia)
Temperature	538°C (1000°F)
Feedwater temperature	224°C (436°F)
Sodium conditions	
Inlet temperature	566°C (1050°F)
Outlet temperature	308°C (587°F)
Inlet pressure	0.69 MPa (100 psia)
Flow rate per unit	
Steam	11.35 kg/s (89,910 lb/h)
Sodium	63.36 kg/s (684,200 lb/h)
Pressure drop	
Steam side	0.42 MPa (61 psia)
Sodium side	0.07 MPa (10 psia)
Pump characteristics	
Flow	0.33 m ³ /s (5,300 gpm)
Head	58 m (190 ft)

^aIn the event of a discrepancy between this table and the HTS specification (N10046) or other project-released specifications, the specification shall be taken to be authoritative.

III-5.2 Subsystem Design

The steam generator subsystem is comprised of three once-through steam generators, power relief and vent valves, and a steam attemperator as shown in P&ID Drawing III-4.1, Book 2. The MSG steam generator module configuration is shown in Figure III-5.1. This subsystem has been designed to produce superheated steam to match turbine requirements. The steam generator design requirements are summarized in Table III-5.1. The steam generator specifications are listed in Table III-5.2, and include the top level design, manufacturing process, and material procurement specifications. As noted in this table, all of these specifications are given in Volume II of this report. Materials specified for pipe, tubing, forgings, and forged fittings are standard procurement items covered by the requirements of ASME B&PV Code Section VIII Division 1. A design layout drawing comprising eleven sheets was completed during preliminary engineering and served as a basis for performing stress and thermal analyses and for development of a manufacturing plan. These comprise Drawings III-5.1 through III-5.11, Book 2. Sheet 2 of the steam generator assembly drawing is presented in Drawing III-5.2, Book 2, which provides an overview and top-level assembly drawing of the steam generator. The content of the complete steam generator assembly drawing (079R000004) is given in Table III-5.3 where a summary of each sheet is listed.

III-5.3 Manufacturing Plan

The manufacturing plan for the steam generators is presented in Appendix II-5.1. The plan defines the procurement, shop fabrication, tooling, procedures, support devices, and quality control activities necessary to fabricate, test, code stamp, and deliver three units. The master schedule for fabrication of the steam generators is presented in Figure III-5.2. Material procurement was initiated in September 1983. Fabrication of unit one will begin in July 1984, followed by units two and three in September and November 1984. The completion of all steam generator units is expected by the end of August 1985 when unit three has been readied for shipment.

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Figure III-5.1. Steam Generator Unit Configuration and Physical Interfaces

TABLE III-5.2
STEAM GENERATOR SPECIFICATIONS

Volume II Section	Rockwell Specification Number	Specification Title
3.4.1	N10049	"Steam Generator Module, Solar Central Receiver Power Plant, Carrizo Plains, Unit No. 1"
3.4.1.1	N40107	"Welding, Tube-to-Tubesheet Joints, Steam Generator, Solar Central Receiver Power Plant (SCRPP)"
3.4.1.2	N30448	"Pipe, Alloy Steel 2.25 Cr - 1.0 Mo, Seamless"
3.4.1.3	N30449	"Forged Fittings, Alloy Steel, 2.25 Cr - 1.0 Mo"
3.4.1.4	N30450	"Tubing, Alloy Steel 2.25 Cr - Mo, Seamless"
3.4.1.5	N30486	"Forgings, Alloy Steel, 2.25 Cr - Mo"
3.4.1.6	N40114	Postweld Heat Treatment, SCRPP, Steam Generator Modules"
3.4.1.7	N40113	"Cleanness, Steam Generator, Solar Central Receiver Power Plant"

III-5.4 Steam Generator Module Design Analysis

Performance, stress, and thermal analyses have been completed to verify that the steam generator design complies with the design requirements given in the HTS specification (Volume II, Section 3.0) and steam generator module specification (Volume II, Section 3.4.1).

The thermal performance of the steam generator units has been tested using the proprietary Rockwell MODULE code. The thermal performance analysis is presented in Volume III, Book 3, of this report, Appendix III-5.2. The operational capability has been verified for part-load conditions ranging from startup to full load. The analysis demonstrated that a single unit is assured of delivering 28.3 MWt, including an adverse condition where five tubes are plugged and the remaining heat transfer surface is in a fouled condition.

TABLE III-5.3
DRAWING LOCATION FOR STEAM GENERATOR PARTS AND SUBASSEMBLIES
(Drawing 079R000004)

Drawing	Items
III-5.1	General Notes and Applications
III-5.2	Overall Assembly
III-5.3	Interface dimensions and section views of lower flow distribution and tube spacer locations. Also, orifice fitting dimensions.
III-5.4	Details: Steam head, upper and lower reduces Na outlet header, support ring, Na inlet header, and the cross.
III-5.5	Upper and lower tubesheets, and disk and ring details.
III-5.6	Tubespace details and the component support assembly.
III-5.7	Upper flow distributor assembly
III-5.8	Lower flow distributor assembly
III-5.9	Tube spacer assembly
III-5.10	Steam tube dimensional data, upper and lower wastage liner assemblies.
III-5.11	Vibration suppressor assembly and elbow thermal liner assembly.

Sodium and water temperature profiles for the 100% (28.3 MWt) power condition are presented in Figure III-5.3. These results are for a steam generator with five plugged tubes and a water-side fouling coefficient of $18.7 \text{ kW/m}^2\text{K}$ ($3300 \text{ Btu/hr-ft}^2 \text{ }^\circ\text{F}$). Temperature profiles were generated for power levels corresponding to startup or part-load operations at reduced power, full load and on up to 150% of nominal conditions. The flow rates for sodium and water, along with sodium outlet temperature, are given in Figure III-5.4 for operation above 100%. The excellent capability of the steam generator subsystem design is demonstrated by the fact that two steam generators operating in parallel are capable of delivering 90% (76.5 MWt) of full plant power. This operation point can be achieved when each of the two parallel modules are operating at the parameters shown in Figure III-5.4 for 135% power ($1.35 \times 28.3 \text{ MWt} = 38.2 \text{ MWt}$). This condition corresponds to the maximum sodium flow that can be developed by the steam generator pumps. This 76.5-MWt operating

CONDITIONS:

28.3 MW_t (100% POWER)

OUTLET STEAM PRESSURE = 1515 psia

5 PLUGGED TUBES

WATER SIDE FOULING COEFFICIENT = 3300 Btu/h · ft² · °F

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Figure III-5.3. Steam Generator Temperature Profiles

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Figure III-5.4. Steam Generator Performance at Power Levels Above Design Conditions

condition would occur with outlet steam at the design condition of 538°C (1000°F) and 10.45 MPa (1515 psia). However, at some small efficiency penalty, high power levels can be achieved by lowering the steam temperature and pressure.

Departure from nucleate boiling (DNB) was evaluated and it was determined that no problem exists either in part or full-load operation. The analysis is presented in Volume II, Book 3, of this report, Appendix III-5.2. The difference in sodium and water temperatures at DNB in the Carrisa Plains operation is 89°C (160°F) and 103°C (186°F) at 10.1 MPa (1450 psig) and 8.7 MPa (1250 psig), respectively. Since the greatest sodium-to-water temperature difference is less than the 117°C (210°F) difference at design point in the CRBRP steam generator, it was concluded that there is a significant margin against fatigue failure.

A detailed thermal model of the lower tubesheet and component has been developed and exercised to provide input to the stress analysis of this critical area. This analysis is presented in Volume III, Book 3, of this report, Appendix III-5.3.

The results of this analysis are summarized in Volume III, Book 3, of this report, Appendix III-5.4. The results of the structural analysis demonstrate that the steam generator module complies with the structural design requirements of Section VIII Division 1 of the ASME Boiler and Pressure Vessel Code. The steam generator pressure boundary is 2-1/4 Cr 1 Mo steel. The analysis considered the complete design and verified that:

- All wall thicknesses have positive design margins for design pressure and temperature
- All nozzles are adequately reinforced
- All components have acceptable stress levels resulting from combined pressure and mechanical loads to ensure a 30-year lifetime.

The steam generator pressure boundaries were defined as follows:
(1) sodium/air for all portions of the external shell between the inside faces of the tubesheets, (2) sodium/steam pressure boundary includes the tubesheets and steam tubes, and (3) steam/air pressure boundary for the steamheads and nozzles. For analysis purposes, the steam generator pressure boundaries and component support were divided into selected design zones as shown in Figure III-5.5. The minimum design margin calculated for each steam generator design zone is presented in Table III-5.4. All design zones have positive design margins for the specified design conditions. The supporting calculations for the structural analysis may be found in Ref. 5.

III-5.5 Steam Generation Controls and Operations

The detailed electrical, instrumentation, and controls diagram for the steam generator is given in Drawing III-5.2, Book 2. This drawing describes the instrumentation and controls provided for the steam generator, and the means by which its operation is coordinated with the turbine-generator through master control. Controls provide for protection of the steam generator from temperature transients, particularly important in view of the 28°C (50°F) spread in design temperature between the sodium and steam sides of the generator. The steam generator is operated in a turbine-following mode. A more detailed description of the instrumentation and control is found in Section III-6.

Startup procedures have been integrated with turbine requirements. These are described in Section IV.

III-5.6 Steam Generation Interfaces

The steam generation area interfaces with other plant areas in several aspects: physical interfaces with main steam and boiler feedwater piping and

⁵K. Kim, "Thermal/Hydraulic Analysis for the Carrisa Solar Power Plant, Steam Generator," 079TI000006, April 4, 1983

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Figure III-5.5. Steam Generator Design Zones

TABLE III-5.4
STEAM GENERATOR MODULE STRUCTURAL DESIGN MARGIN SUMMARY

Design Zone	Element ^a and Node Number	Minimum Design Margin
Inlet Steamhead		
Nozzle flange	E56N6	0.20
Nozzle	E5N6	1.63
Shell	E5N5	1.84
Lower tubesheet		
Rim	E4N4	12.2
Plate	NA	1.73
Outlet Header		
Lower reducer	E3N3	3.67
Lower run	E6N3, 7	16.1
Inspection port nozzle	NA	9.16
Inspection port junction	E6N (NA)	4.94
Outlet nozzle	E7N7, 8	3.81
Outlet nozzle junction	E6, 7, 8N7	1.64
Upper run	E8N9	9.44
Upper reducer	E9N10	3.05
Main shell	E12N12, 13	1.42
Inlet header		
Lower reducer	E14N14	0.50
Lower run	E15N15	2.71
Inlet nozzle	E16N16, 17	1.36
Inlet nozzle junction	E15, 16, 17N16	0.19
Upper run	E17N16	6.25
Upper ring section	E17N18	2.72
Elbow	E18N18, 19	2.85
Cross		
Run Section	E19N19,20	3.88
Inspection port nozzles	NA	3.73
Inspection port junction	E19N (NA)	1.25
Cross reducer	E20N20	1.42
Upper tubesheet		
Rim	E21N21	5.29
Plate	NA	0.88
Outlet steamhead		
Nozzle	E22N23	0.28
Shell	E22N22	0.31
Component support		
Building interface	E1N1	5.42
Bolted joint	E2N2	2.65
Bifurcation joint	E2N3	2.07
Steam tube	NA	0.10

^aEXXNYY denotes Element XX and Node YY as defined in Figure III-3.4

support structures, and operational interfaces with the turbine generator mediated through the master control system.

The main steam piping is of particular concern, since it represents a potentially large load applied to the hot end of the steam generator through the steam nozzle. The applied loads are also readily transmitted between it and the hot sodium nozzle and piping. The main steam piping serves to interconnects the three steam generators; hence it must be able to operate even when one unit has been removed from service. This piping must be carefully routed. The stress analysis of it and the steam generator is presented in Appendix III-4.3. (The fact that the steam generator is only moderately stiffer than the piping to which it is attached accounts for the relatively large degree of coupling between hot sodium and steam nozzles.)

The support interfaces for the steam generator are shown in Drawing III-5.3. This drawing describes nozzle sizes and locations and maximum loads exerted by the generator on the foundation and support structure. The principal component support is a skirt located near the lower tubesheet. (Appendix III-5.3 describes the thermal analysis of this critical region.) A seismic restraint is provided below the upper sodium nozzle.

Operational interfacing is shown in Drawing III-5.2. The master control sends a command for power level, which is utilized by HTS controls to generate internal control element set points. Appropriate feedback is provided to achieve these set points. A detailed discussion is found in Section III-6.

III-6 ELECTRICAL, INSTRUMENTATION, AND CONTROL

III-6.1 General Description

The electrical, instrumentation, and control functions for the HTS have been developed in conjunction with project work on balance of plant and master control. The electrical design has been prepared based on an interface in which the balance-of-plant electrical distribution, described in Section VI,

feeds to a series of motor control centers located in the power complex and tower. The HTS electrical picks up at that point and provides distribution throughout the HTS.

The HTS controls package, in a similar way, picks up from a data buss provided by master control at remote instrumentation rooms located on the power complex deck and in the tower below the receiver level. The environmentally controlled rooms are provided under balance of plant.

The HTS controls package, while a single entity, reflects the split in HTS operations; the receiver area must be integrated with the collector system, while the steam generation area is integrated with the turbine. The HTS controls package is to provide all necessary protective actions for the HTS, while master control and the plant operator set all functional conditions for the HTS. Specifications for the HTS controls area are described in the HTS specification, given in Volume II, Section 3.0, of this report.

Electrical, instrumentation, and control design for the Carrisa Plains plant was based on the experience developed in the design, construction, and operation of the functionally similar Sodium Components Test Installation (SCTI) located at the Energy Technology Engineering Center (ETEC). This facility is operated by Rockwell for DOE.

III-6.1.1 Electrical Design Summary

Electrical power for the heat transport system is supplied by a dual load center located at the concentration of the load. Noncritical electrical loads are equally divided between two 480-V main motor control centers, each fed from its own 4160-V/480-V transformer through a nonsegregated metal enclosed busway. Critical loads are connected to a separate motor control center which may be supplied from either of the main motor control centers via an automatic transfer switch to minimize service interruption upon loss of a transformer.

The 4160-V receiver pump motors are supplied through a separate 5-kV motor control center.

III-6.1.2 Controls Design Summary

Control of the HTS is provided by digital computer/microcomputer-based controllers which perform sequential, logic, and analog control functions. The interfacing master control system provides the operator interface, data acquisition and display, monitoring, and supervisory functions for the HTS control system. Redundant controllers, power supplies, and interfaces to the data highways are provided. Critical alarm signals are hardwired to the plant annunciator system. Similarly, signals required for equipment protection are hardwired to the protective system and are independent of, or isolated from, other controls.

III-6.2 Electrical Design

III-6.2.1 Load Requirement

The electrical load requirements for the heat transport system are detailed in the electrical load list, Drawing III-6.1, Book 2, which lists the connected loads and gives the demand kVA, load factor, and average kVA for both day and night conditions.

III-6.2.2 Distribution

Single line diagram Drawing III-6.2 shows the power distribution scheme for the heat transport system. A dual load center consisting of two oil-filled, outdoor-type transformers rated at 1000/1333 kVA, 4160/480 V, 3Ø, 60 Hz, and three motor control centers (MCCs) are used distribution of 480-V power.

The transformers are located as close as possible to the motor control centers, in order to reduce the lengths of the 2000 A, nonsegregated busways. Each of the two normal load motor control centers (MCC-2, MCC-3) consists of a 1200-A main breaker, 1600-A horizontal bus, 300-A vertical bus, and 22,000-A bus bracing. The critical load motor control center (MCC-4) consists of a

400-A auto transfer switch, 600-A horizontal bus, 300-A vertical bus, and 22,000-A bus bracing.

In addition to the process loads such as motors and electric heaters, the motor control centers provide power for the facility lighting, power, heating, and instrumentation equipment. The instrumentation power is provided by a 10-kVA, 480/120/208-V miniload center.

The 750-hp receiver pump motors are supplied from a separate 5-kV motor control center (MCC-1) which consists of a 600-A fused load break isolating switch feeding two limit-amp motor controllers. The controllers are a one-high line up of NEMA 12 enclosures with 3-phase, 1000 A ac power bus with provisions for terminating incoming cables. The controllers are nonreversing, for induction motors rated 750 hp, fused-type employing current-limiting power fuses that give controllers an interrupting capacity of 200,000 kVA, 3-phase, symmetrical at 4000 V, 50/60 Hz. The controllers employ magnetic air-break line contactors rated 400 A, 5000 V, with an interrupting capacity of 50,000 kVA, three-phase, symmetrical. The controllers have solid-state relay protection, including ground-fault interrupters, overload, open-phase, and phase unbalance protection. Start-stop pushbuttons are mounted on the door, but the circuits are wired through terminals to accommodate remote start-stop signals from the control system.

Electrical grounding is provided for the building steel, system neutral, electrical enclosures, and electrical motors. In addition, a separate ground station is provided for the isolated instrumentation ground system. The instrumentation and power grounds are tied together at the ground well only.

III-6.2.3 Preheat

Electrical heating is provided for the sodium heat transfer piping, components and the storage tanks. The heating system is fed from the motor control centers at appropriate voltages and includes the necessary switching, sensors, and controllers. Typically, 400-A, 3Ø, 4 W, 277/480-V panels,

fed from the motor control centers are used to distribute power to the individual heaters. Three-phase solid state SCR power controllers are used to control power to the heaters. Tubular resistance heaters rated at 480 V are used. The heaters are operated at 277 V. The heaters are nominally 1/2 in. in diameter and are formed to fit the system piping and/or components, banded to the pipe or component with stainless steel bands and covered with a stainless sheeting. The heater installation is covered with the required thermal insulation.

III-6.2.4 Lighting

Indoor and outdoor lighting is provided in compliance with OSHA requirements and accepted engineering practice. Wherever practicable, high intensity discharge lighting fixtures and lamps, such as sodium vapor, are used to take advantage of their high energy efficiency. Incandescent lighting is kept to a minimum. Emergency lighting is provided by battery powered units as required.

Convenience receptacles for 120-V appliances and tools, and for 480-V welding equipment, are located throughout the facility.

III-6.3 Instrumentation and Control Design

The basic instrumentation and control requirements for the heat transport system are shown on the P&ID Drawing III-4.1. Additional detail on the instrumentation loops is given in the loop diagrams referenced later. For simplicity, the P&ID and loop diagrams depict controllers and computing devices using conventional analog device symbology to illustrate control functions. Many of these functions will be implemented digitally, and the final configuration of the control system depends on the selection of the controls supplier.

The controls are partitioned into three areas: The receiver, steam production, and auxiliaries. By necessity, the thermal storage subsystem and heat transport loop control functions are incorporated, as appropriate, with the solar receiver and steam production.

III-6.3.1 Receiver Instrumentation and Control

Receiver instrumentation and control covers the receiver itself and associated sodium coolant supply functions. Instrumentation for a typical receiver panel is shown in Drawing III-2.1. The primary function of the receiver panel controls is to maintain sodium temperature at the outlet of the panel at the set point determined by the master control system. This function is accomplished by manipulating the sodium flow rate through the panel primarily in response to the flux received by the panel, and, to a lesser degree, in response to the measured outlet temperature.

The solar flux is measured at five locations on the panel by flux sensors (JE). The median of these measurements is selected and used in a feed-forward configuration as the primary index for sodium flow rate. Outlet temperature is measured and used as a trim on the sodium flow rate to maintain the temperature at the set point. The output of the temperature controller (TIC) is multiplied by the solar flux signal and the resulting product used as the set point for the sodium flow rate controller (FIC). The flow rate controller positions the flow control valve at the panel inlet as needed to provide the required flow. A flow control valve is provided in the common supply line to the eight panels. This valve is positioned by the operator as needed to keep the panel control valves within a satisfactory control range.

The following alarms related to receiver outlet temperature controls are provided:

- Sodium flow rate deviation exceeding 5% of set point
- High flux
- High outlet temperature
- High outlet temperature rate of change
- Panel flow control valve 80% open
- Tube temperature deviation of $\pm 75^{\circ}\text{F}$ from panel average (indicates flow maldistribution).

The sodium inventory in the accumulator tank (T-3) is controlled at the half-full level to provide continued flow on loss of pump pressure. The sodium level is controlled by regulation of the cover gas (argon) pressure using a bleed and feed control valve arrangement. The bleed and feed valves are positioned by a single level controller (LIC). If the sodium level increases significantly above the set point, the feed valve admits argon to the tank to raise the pressure and force sodium from the tank. On a level decrease, the bleed valve opens to reduce pressure and additional sodium flows into the tank.

Pressure in the surge tank (T-4) is controlled by a feed-and-bleed arrangement similar to the level control described above for the accumulator tank. Sodium level in the surge tank is controlled by positioning the control valve in the downcomer to the hot tank (T-2). High/low alarms are provided for both surge tank pressure and level.

Sodium supply to the receiver is provided by the cold tank (T-1) and receiver pumps (P-1A and P-1B). Instrumentation for those is shown on Drawing III-6.4.

An inductive level probe and transmitter are used to provide continuous indication of sodium level in the cold tank. Point level probes are used to provide alarms on high, low, and low-low sodium levels. Redundant thermocouples provide a representative measurement of sodium temperature.

As with other sodium tanks, pressure in the cold tank is maintained by controlling the feed and bleed rates of the inert cover gas in the tank (PIC 1160). The cold tank and hot tank share common pressure controls on the pressure equalization line connecting the cover gas spaces of the two tanks.

Instrumentation for the receiver pumps is provided to monitor and control sodium level in the pumps by control of the argon cover gas pressure. Sodium flow to the pump bearings is measured using a magnetic flowmeter; it is controlled by a pneumatically operated valve in the bearing supply line. The

pump controls are interlocked with the bearing flow controls so that the pump cannot be started or run with insufficient sodium flow to the bearings.

Each receiver pump has the following alarms:

- Suction low pressure
- Discharge pressure high/low
- Sodium level high/low
- Bearing flow high/low

III-6.3.2 Steam Production Instrumentation and Control

The steam production instrumentation and control includes the steam generator, hot tank, mix tank, and steam generator pumps. The instrumentation and control for each of these components is described below.

III-6.3.2.1 Steam Generator

Instrumentation for the steam generators is shown in drawing III-5.2. Only one steam generator (X-1) is shown in the drawing since the instrumentation is typical for all three units. The primary function of the steam generator controls is to match system temperatures and flow rates to the power demand. The master control system provides plant power demand and steam temperature demand signals to the HTS controls which maintain the appropriate balance between sodium and steam side variables.

The sodium flow rate set point for power range operation is determined by dividing the power demand signal by the difference between the measured inlet and outlet sodium temperatures. The flow rate is set by steam generator pump speed. Speed trim is provided to maintain the desired steam temperature of the steam generator outlet.

The feedwater flow rate set point is determined from its functional relationship to power demand, steam temperature set point and feedwater temperature. The flow rate is sensed by an orifice plate flow transmitter and is controlled by a valve in the feedwater line to the steam generator. A speed trim signal based on feedwater valve position is provided to the feed pump controls to keep the feedwater valve in a 20 to 80% regulating range.

For operation at low flow rates, i.e., startup, the sodium and feedwater flow rates are set by a low-range sodium valve and a low-range feedwater valve ratioed to a common power demand. For startup, the steam generator pumps and boiler feed pumps are on manual speed control and the power range isolation valves for sodium and feedwater are closed. When the flowrates have increased to values within the control limits of the power range instruments, control is transferred and the low-range feedwater controls are isolated.

Final control of steam temperature at delivery to the EPGS is accomplished by controlling the rate of feedwater flow to attemperator A1.

Response to a sodium-water reaction is initiated automatically upon detection of sodium between the two diaphragms in a rupture disk assembly. The feedwater flow, steam generator sodium flow, and the flowing vent are all automatically shut off. Also, the power relief is actuated and steam is blown down to a safe pressure. High argon pressure in the rupture disk and high hydrogen concentration in the sodium are alarmed and serve as precursors to rupture disk failure.

The following alarms are provided for each steam generator:

- Feedwater block (maintenance) valve closed
- Feedwater flow high/low (power range)
- Feedwater flow high/low (low range)
- Steam temperature high
- Hydrogen concentration in sodium high
- Argon pressure in rupture disk high

In addition, the following alarms common to all three steam generators are provided:

- Feedwater temperature low
- Main steam temperature high/low
- Sodium flow high/low (power range)
- Hydrogen concentration in vent flow high
- Sodium flow high/low (low range)

III-6.3.2.2 Hot Tank and Steam Generator Pumps

Instrumentation for the hot tank (T2) is shown in Drawing III-6.3.

Pressure within the hot tank is maintained by the cold tank pressure controls (see Subsection III-6.3.2.4) via the pressure equalization line between the two tanks.

Sodium level in the hot tank is measured using an inductive probe and transmitter for continuous level indication and for determination of the collector power demand. Point level probes are used to provide alarms on high, low, and low-low sodium. Redundant thermocouples are used to provide a representative measurement of sodium temperature.

Instrumentation for the steam generator pumps (P2A and P2B) is also shown in Drawing III-6.3. The pumps are operated at variable speed with the speed setting (P-2 speed master in Drawing III-5.2) determined primarily by the steam generator sodium flow controller and trimmed based on steam temperatures at the steam generator outlets (See Subsection III-6.3.2.1).

Sodium level in the pumps is maintained by controlling the pressure of the argon cover gas using a bleed and feed arrangement similar to that used for the accumulator tank (T-3) as described above.

Sodium flow to the pump bearings is measured using a magnetic flowmeter and is controlled by a pneumatically operated valve in the bearing supply line. The pump controls are interlocked with the bearing flow controls so that the pump cannot be started or run with insufficient sodium flow to the bearings.

The following alarms are provided for each steam generator pump:

- Suction pressure low
- Discharge pressure high/low
- Sodium level high/low
- Bearing flow high/low.

III-6.3.2.3 Mixing Tank

Drawing III-6.3 shows the instrumentation and controls for the mixing tank (T-5). The mixing tank is used to mix hot and cold sodium to match the steam generator inlet temperature during startup. This temperature is matched by suitably proportioning the flows of hot and cold sodium into the tank. Sodium level in the mixing tank is measured and used to generate an index for hot and cold sodium flow rates to the tank. The flow rate of cold sodium is set by this index via flow controller (FIC1531). To establish the required flow rate of hot sodium, the temperature of the sodium in the tank is measured and used as process feedback to temperature controller (TIC531). The set point for the temperature controller is derived from steam generator inlet sodium temperature. The output of the temperature controller is multiplied by the index based on level and the product is used to set (via FIC1500) the hot sodium flow rate into the tank.

Pressure in the mixing tank is maintained by controlling the feed and bleed of cover gas to and from the tank.

Alarms for monitoring mixing tank operation are listed below:

- Sodium level high/low
- Sodium temperature deviation
- Pressure high/low.

III-6.3.3 Auxiliary Systems Instrumentation and Control

III-6.3.3.1 Sodium Purification

Drawing III-4.8 shows the instrumentation for the sodium purification system. The primary functions of this instrumentation are to provide a relative measure of sodium purity by determining the plugging temperature and to control and monitor the cold trapping process.

A plugging temperature indicator (PTI) is used to measure the temperature at which a well-defined flow restriction becomes plugged by precipitation of impurities. As shown in Drawing III-4.8, a magnetic flowmeter and one pen on a recorder are used for indication of sodium flow to the PTI. Sodium temperature near the flow restriction is sensed by a thermocouple and displayed using a second pen on the same recorder. As the sodium flow decreases indicating plugging of the restriction, the plugging temperature is indicated by the second pen on the recorder. A flow switch (FSHL) also senses the low flow plugged condition and activates the plugging device to clear the restriction. The flow to the PTI increases until the high set point of the flow switch is reached and the plugging cycle is repeated. Air flow to the cooler is adjusted by a manually operated damper.

Sodium flow to each cold trap is sensed by a magnetic flowmeter and is recorded. Temperature is measured, recorded, and automatically controlled by positioning a damper on the cooling air blower. Temperature switches (TSH and TSL) provide for high and low temperature alarms and for shutting off the blower on low temperature.

III-6.3.3.2 Argon System

Argon system instrumentation is shown in Drawing III-4.8. Descriptions of the level and pressure controls for the sodium tanks and pumps have been given previously and will not be repeated here. The primary function of the remaining argon instrumentation is to supply argon and vent argon at appropriate pressures for sodium components.

Pressure transmitters are provided to monitor the argon supply pressure and the standby argon supply and a low pressure alarm is provided for each supply. Pressure reducing regulators are installed in the main supply line to provide a nominal pressure of 1.14 MPa (150 psig) and in branch lines to provide the pressures required by the sodium components. Pressure-reducing regulators are also installed in the standby argon supply line to provide a backup source of cover gas to the hot and cold storage tanks and the sodium pumps. Standby argon is automatically supplied to the tanks if their pressure becomes less than ambient and to the pumps if the sodium level rises above the high limit.

Argon vented from sodium components is received by the argon vacuum tank. Pressure within the vacuum tank is maintained between 53 and 81 kPa (7.7 and 11.7 psia) by automatically selecting the number of operating compressors as a function of the measured pressure. At less than 53 kPa (7.7-psia) both compressors are off. Normally, one compressor is operating and the other is on standby. If the pressure exceeds 81 kPa (11.7 psia), both compressors operate until the pressure returns to the normal range.

Each argon compressor is provided with a lube oil pressure (low) switch and a lube oil temperature (high) switch that will shutdown the compressor if either parameter exceeds the safe operating range.

Differential pressure instruments are installed across each compressor inlet filter to indicate incipient plugging of the filter.

The following alarms are provided for the argon system:

- Argon supply pressure low
- Standby argon supply pressure low
- Argon supply (T-1, T-2, P1, and P2) pressure low
- Argon vacuum tank pressure high/low

III-6.3.4 Control System Architecture

The master control system is a computer/microcomputer-based distributed control system and is described in Section V of this report. The heat transport system controls comprise two distributed blocks of the master control system; i.e., the receiver controls located on the tower and the heat transport controls located in the steam generator area. The detailed architecture of the controls is dependent on the "to be determined" control system supplier, but the general configuration will be similar to that shown in Figure III-6.1.

The receiver controls include an input/output (I/O) cabinet, controller module (CM), and local control panel. The I/O cabinet accepts input signals from field sensors, multiplexes the inputs, and makes them available on the data link. The controller module accepts control input signals from field instruments, implements the control algorithms, and provides outputs to control actuators. The receiver controller module performs both analog and digital control functions. The local panel provides backup manual control where required for critical loops.

The heat transport controls also include an I/O cabinet, controller module, and local panel. In addition, a programmable logic controller (PLC) is provided to handle the larger digital control function.

Communications between the receiver and transport controls and to the master control system are by a redundant data link. Additional I/O is provided in both areas as part of the master control system to accommodate non-control data for display and alarming.

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Figure III-6.1. HTS Control System

III-6.3.4.1 Overall Heat Transport System Control

Drawing III-6.5 shows the control functions needed to bring the various parts of the heat transport system into an integrated control system. Also shown is a schematic of the signal interface with the master control system (MCS).

Three master demand signals are provided by the MCS which set the required sodium temperature at the receiver outlet, steam temperature, and plant power for power range operation. An additional startup master signal is required for startup and low-power operation. Other indices required for heat transport control are derived from these signals by the HTS controls using the logic indicated in Drawing III-6.5.

The logic for generating the collector demand signal and boiler feed pump speed trim signal is also given in Drawing III-6.5. The signals are supplied to the heliostat array controller and EPGS controls via the MCS.

III-6.3.4.2 Interface with Master Control System

In addition to the supervisory control signal interface with the MCS as described above, extensive functional and physical interfaces exist between the MCS and HTS controls. The interface between the two systems is generally as described below. The HTS control system provides the hardware and software needed to implement HTS control functions, including sensors, final drives, controllers/computers, I/O equipment for control data, and interfacing devices for connection to the MCS data links. For noncontrol data, HTS sensors are terminated at MCS I/O equipment. The MCS includes the hardware and software necessary to provide the following for HTS use:

- CRT-based operator interface
- Display of HTS operating data
- Graphic displays of HTS subsystems/components
- Alarming of analog and contact inputs

- Trending and logging of data
- Hardcopy printout of logs, trends, sequence of events, and alarms
- Addressable indicators and recorders
- Redundant communication links.

A common supplier will furnish both MCS and HTS control system hardware.

III-6.3.5 Control Equipment

With the exception of sensors and control devices for sodium service, suppliers' standard equipment suitable for continuous duty in an industrial environment is used. For sodium service, the types of instruments used are:

- Electromagnetic flow meters for sodium flow measurements (Correction for magnet temperature will be provided as required.)
- NaK-filled transmitters for pressure and differential pressure measurements
- Induction probes for level measurements
- Inconel-sheathed Type E thermocouples for temperature measurements
- Bellows seal control valves.

A complete list of HTS instrumentation is given in Appendix III-6.1, "Carrisa Plains Solar Power Plant Instrument Index" (079000052).

IV. POWER CONVERSION SYSTEM

The Power Conversion System (PCS) is a heat engine working between liquid-sodium-heated steam generators and moist air as a heat sink. It is a steam Rankine cycle without reheat, using five stages of feedwater heating and cooled by a forced-draft evaporative cooling tower. The PCS is organized into the following subsystems:

Main Steam and Turbine	Generator and Auxiliaries
Condensate and Feedwater	Condensate Polishing
Extractions and Drains	Circulating Water
Service Cooling Water	Auxiliary Steam
Lube Oil Storage	Boiler Water Make-up

The foregoing paragraph is taken from the Design Criteria (Vol. II). Reference should be made to those documents for a statement of the design basis and as a companion to this design description, since what is there will seldom be repeated here.

The design of this steam cycle is similar to that of the usual utility thermal power plant which has evolved over the past 50 years. The job is distinguished, however, by these features:

- the plant is small;
- the overnight shutdown requirement makes it harder to protect equipment from cyclic thermal stresses and to meet the feedwater requirements of a once-through boiler;
- the design is affected by the presence of tax credits in the financing structure which reduces the effective cost of capital and reduces the importance of plant cost in relation to operating revenue and expense.

Design criteria are the starting point for the design of the power conversion system and subsystems. They set forth the design basis, functional requirements and design standards. The Design Criteria for this system and its subsystems can be found in Volume II of this report. Design work was carried through, in this design phase, to the point of piping schematic drawings. The schematics show the first element of instrument sequences. Lines were not finally sized, although sizes of control valves were estimated. Equipment was located and main-steam piping laid out. The resulting drawings are listed in Table IV.1.

Determination of the basic cycle configuration began with the fact that the steam generators were not available for reheat operation, since their long operating history has been in boiler service. An examination of the heat-rate and turbine-cost variation with inlet steam pressure for non-reheat cycles showed that pressures above 1500 psi led to excessive equipment costs. We thus set the main steam conditions at 1465 psia, 1000°F. The selection of the number of feedwater heaters was made from past design experience; limiting the number of heaters restrains plant cost, while increasing the number brings the cycle nearer its maximum thermodynamic effectiveness.

OVERNIGHT MANAGEMENT AND START-UP. Between operating periods and at the subsequent start-up, the plant must be handled in a way that accounts for:

- protection against corrosion and excessive thermal stress,
- the cost of whatever auxiliary steam is used, and
- heating the feedwater and deaerating any feedwater exposed to air, in preparation for the next operating period.

We have decided to shut the plant down, break condenser vacuum, and backfill condenser and turbine with air overnight. At start-up, feedwater will be demineralized, heated and deaerated. Feed water purity should be established with 15 minutes demineralization and deaeration.

The following options for the shutdown periods were considered and rejected:

- operating the plant overnight at reduced power from a fired boiler,
- maintaining condenser vacuum overnight by maintaining steam seals and operating the condenser air ejectors, and
- backfilling the turbine and condenser with nitrogen during shutdowns.

The costs of heat or nitrogen for these options are unattractive. The option chosen may require some additional drain lines or corrosion-resistant materials.

Procedures and the system alignment for shutdown and start-up steps are detailed in Appendix IV.1.

EQUIPMENT LIST. Purchased equipment for the PCS is listed in Drawings IV.22, IV.23 and IV.24.

CONTROL SYSTEM. The PCS is designed for manual or attended automatic operation from a central control room. Control logic is provided as part of a distributed digital system which includes the Master Control System as well. Provision is made for automatic sequencing of functions, coordinated if necessary with other plant systems, and for computations within control loops. Further delineation of the control features to be provided and standard practices to be followed are contained in Design Criteria D23-2, located in Volume II. Considerable effort was spent detailing the control functions to be provided for the PCS subsystems. These descriptions constitute the Instrumentation and Controls Design Criteria, D23-16I through D23-25I.

TABLE IV.1
POWER CONVERSION SYSTEM

Volume III Number	PGandE Number	Title	Rev.	Issue Date
IV.1	107308	Legend	03	07-08-83
IV.2	107309	Main Steam System	04	07-08-83
IV.3	107310	Auxiliary Steam System	03	07-08-83
IV.4	107311	Extraction & Drains System	04	07-08-83
IV.5	107312	Condensate and Feedwater System	04	07-08-83
IV.6	107313	Compressed Air System	03	07-08-83
IV.7	107314	Lube Oil Transfer and Storage	03	07-08-83
IV.8	107315	Fire Protection System	04	07-08-83
IV.9	107316	Raw Water System	04	07-08-83
IV.10	107317	Condensate Polishing System	02	07-08-83
IV.11	107318	Circulating Water System	04	07-08-83
IV.12	107319	Service Cooling Water System	03	07-08-83
IV.13	107323	Boiler Make-up Water System	03	07-08-83
IV.14	223782	Heat Balance Diagram	01	03-17-83
IV.15	511706	Equipment Location, Turbine Gen. Building, Elevation 1,000 ft.	05	12-17-82
IV.16	511707	Equipment Location, Turbine Gen. Building, Elevation 1,020 ft.	04	12-17-82
IV.17	511708	Equipment Location Turbine Gen. Building, Section B	03	12-17-82
IV.18	511709	Equipment Location Turbine Gen. Building, Sections C and D	03	12-21-82
IV.19	511710	Equipment Location Turbine Gen. Building, Section A	03	12-17-82
IV.20	511712	Equipment Location Steam Gen. Building, Plan 1,020 ft.	02	Undated
IV.21	511713	Equipment Location Steam Gen. Building, Sections	02	Undated

The Heat Balance diagram, Drawing IV.14, shows the primary flows and states in the PCS at the design point. The energy balance in that figure shows:

PCS heat input	85 000 kW
Gross electrical output	32 740 kW
System auxiliary power	1 457 kW
Net electrical Output	31 283 kW

A Second Law balance is also given in the figure.

The design description continues with descriptions of the individual sub-systems.

MAIN STEAM. The steam generators supply main steam to the turbine at the design conditions of 1465 psia and 1000^oF through an attemperator, which adds feedwater from the boiler feed pump to moderate main steam enthalpy when necessary. Steam is supplied to the auxiliary steam and gland-seal steam systems from the main steam header. Main steam can also be bypassed to the condenser, if necessary after a turbine trip.

We were not able to choose between fixed and variable pressure operation of the main steam and feedwater systems. Variable pressure operation can result in lower pumping power at part load if variable speed drive is provided for the boiler feed pump. Except during start-up, shutdown, and curtailments, however, the plant is not expected to operate at part load. Nevertheless, variable main steam pressure is of interest because it may provide an operability benefit to the turbine. Since full information about this benefit will only come with the turbine suppliers' proposals in the next design phase, the choice is left open.

TURBINE AND GENERATOR. The turbine will be a single-shell 3600-rpm machine. It is sized for steam flow of 270,000 lb/hr and an exhaust pressure of 2.4 in. mercury (absolute). If the boiler operates at constant pressure, it will have sequentially-opening throttle valves and a control stage (a heavier first rotor disc and blading to withstand the admission of steam over part of the stage circumference, or arc, at part load). If the boiler operates at variable pressure, the turbine may have a single throttle valve, full arc admission, and no control stage. The generator will operate from the single shaft (3600-rpm, two-pole) and will be cooled, not hydrogen, since air is sufficient for this generator size. Each machine, as supplied, will include control and auxiliary systems, such as lubrication, cooling and exciter. A fuller description is given in the Data Sheets in Appendix IV.2

CONDENSATE AND FEEDWATER SYSTEM. The function of the condensate/feedwater system is to pump the condensate from the condenser hotwell through the low-pressure feedwater heaters, the deaerating heater, raise the pressure with the boiler feedwater pumps, then through the high-pressure feedwater heaters to the inlet connections of the sodium heated steam generators. The system is also used for recirculation during startup to clean and heat the feedwater.

The design condition at the condenser hotwell is 2.4 inches Hg. absolute, 107.3°F at full-load conditions.

The pressure at the steam generator inlet is:

1,465 psia At turbine inlet

50 psi Main steam line pressure drop

65 psi Steam generator pressure drop

_____ (Including elevation difference)

1,580 psia Pressure at steam generator inlet

The feedwater heaters will heat the feedwater/condensate with extraction steam from the main turbine. The deaerating heater will remove the dissolved oxygen in the feedwater as well as heat it to its saturation temperature.

Installed spare condensate and boiler feed pumps are provided for reliability.

Stainless steel was selected for feedwater heater (and condenser) tubes in order to avoid alloys containing copper, which would migrate to the steam generators.

A flash tank, an economizing heat exchanger and certain piping are provided to meet the start-up requirements. (Appendix IV.1)

CONDENSATE POLISHING SYSTEM. Since the steam generators operate in the once-through mode (there is no steam drum), they require feedwater purity in the parts-per-billion range to protect them and the turbine from scaling and corrosion. The feedwater specification is given in Table IV.2. The purity requirement will be met by full-flow demineralization ("polishing"). The condensate polishing unit will be dual full-flow mixed-bed demineralizers. One bed will be in operation, with the other bed on standby. It is estimated that the condensate will be contaminated to the extent of about 100 ppb iron after an overnight shutdown. In that case, the capability of each bed would be five daily cycles of plant operation. The exhausted bed will be regenerated in place during an overnight shutdown. Mixed beds were selected over other options because they can handle high flow rates, act as very effective filters, provide the highest purity product, contain substantial capacity, and cost less to operate.

EXTRACTIONS AND DRAINS. This system handles steam withdrawn at intermediate points of the turbine for feedwater heating. Steam is withdrawn from the steam turbine and routed to feedwater heaters in order to transfer the thermal energy (both sensible and latent heat) from this steam to the boiler feedwater. For constant main steam flow, this raises the feedwater inlet

temperature to the steam generators while decreasing heat input and generator output. This is the regenerative feature of the cycle. The average temperature difference across which heat is transferred in the cycle is reduced which improves the heat rate of the cycle.

TABLE VI.2 - FEEDWATER CHEMISTRY

	Expected Purity Level During Preheat/Startup Operation	Maximum Impurity Level During Steady State Operation	Best Purity Level Expected During Steady State Operation
Total Dissolved Solids	150 ppb	100 ppb Max	50 ppb
Silice, SiO ₂	20 ppb	20 ppb Max	10 ppb
Iron	100 ppb	10 ppb Max	10 ppb
Copper	5 ppb	2 ppb Max	2 ppb
Dissolved Oxygen	10 ppb	7 ppb Max	5 ppb
Free Caustic	-	Zero	Zero
pH	8.5 - 9.2	8.5 - 9.2	8.5 - 9.2
Percent of Operating Period Expected	Less than 1.0 percent	10 percent	89 percent

The steam bled off the turbine is the extraction. After all of the steam's latent heat and as much of its sensible heat as is economically practical has been transferred to the feedwater, the condensed extraction is drained to the next lower pressure feedwater heater or the condenser in order to add the balance of its available sensible heat to the feedwater. This condensed extraction is the drains.

The cycle fluid contains noncondensable gases. These gases are present either because they were dissolved in the feedwater make-up or because of in-leakage to the system. The feedwater heaters contain vents which are present to remove and transport these noncondensable gases from the feedwater back to the condenser or the deaerator where the gas is removed from the cycle.

Normal, full-load operating conditions at the heater shell inlet are as follows:

<u>Heater No.</u>	<u>Flow Rate</u>	<u>Temperature</u>	<u>Pressure</u>
1	20154 pph	690°F	373 psia
2	16784 pph	531°F	166 psia
3	15117 pph	762°F	59 psia
4	11004 pph	215°F	15.6 psia
5	11027 pph	166°F	5.4 psia

Valving is provided so that feedwater heater shell-sides can be bottled-up hot (steam-blanketed).

CIRCULATING WATER SYSTEM. This system, which includes the main condenser and cooling tower, constitutes the plant cooling system. The circulating water system is a closed-loop system. Water is circulated from the cooling tower through the main turbine condenser and the plant service cooling water system.

The circulating water flows from the cooling tower basin to the pump pits. Fixed screens at the pump pit inlet will protect the condenser from debris. A pump pit bypass line is provided for system filling.

Makeup from the raw water storage to the tower basin will compensate for all the water losses in the system. Blowdown to control the total solids in the circulating water is removed from the system after the condenser and prior to return to the cooling tower.

The exact raw water conditions are not known. For design purposes, we will use the analysis shown on Table 1 of Design Criteria D23-18 which is from a well near to the proposed site. This analysis did not measure silica, so an estimate was made based on analysis from wells somewhat more distant. By controlling alkalinity with acid injection and with a side stream lime soda softener, it should be able to operate the system at high cycles of concentration of the raw water. Blowdown will be estimated on this basis. The softener will not be shutdown overnight. Low alkalinity and a pH of six to seven will mean care must be taken in the selection of materials to avoid corrosion.

The cooling tower is a full-capacity wood mechanical draft design with fiberglass reinforced piping. It will be provided with a tower bypass to the basin for startup and shutdown. Biologic control will be by periodic injection of chlorine. The amount and frequency are dependent upon the conditions which may exist at the time of operation. The baseline system will employ sodium hypochlorite. Blowdown will be disposed of in an evaporation pond. The evaporation rate in the area is estimated to be 70 inches per year with a standard deviation of 4-5 inches. Of this, 70 percent occurs during May through October. Mechanical vacuum pumps will be used (no steam ejectors). Condenser vacuum will be broken during overnight shutdowns. Hogging and holding will be with mechanical vacuum pumps. Circulating water-side of the main condenser shall have automatic venting at each waterbox.

An optimization was done to select cooling tower approach-to-wet-bulb, condenser surface area and water velocity, turbine exhaust blading, and exhaust pressure. For the annual distribution of wet-bulb temperatures, data from a nearby location (Paso Robles) were taken as an assumption. Preliminary discussions with turbine suppliers identified a recommended range of turbine exhaust area (last-stage blade length), at increasing turbine cost. We chose two blade lengths and based the optimization on the corresponding exhaust-pressure-correction curves. The remainder of the analysis is described in Appendix IV.3.

The optimization resulted in the following set of cooling system parameters:

- Cooling water flow of 11,130,000 lb/hr at 16.6°F rise and 12°F approach to the design wet bulb of 72°F;
- the longer turbine blading (we did not consider still-longer blades for reasons of technical confidence);
- 2.4" Hg(abs) turbine exhaust pressure;
- condenser area of 30,000 sq. ft.

We provided two half-size circulating water pumps. In the event of outage of one pump, the remaining pump will provide about 65% of design water flow, and at most times of the year -- whenever the wet-bulb temperature is below about 65°F -- will give design power output. The condenser tubing material, AL29-4C, was chosen as the most cost-effective stainless steel suited for this circulating water.

SERVICE COOLING WATER SYSTEM. This system is a closed loop of clean water which cools such equipment as air compressors, vacuum pumps, lube oil, etc., and is cooled by circulating water from the cooling tower basin. Duplicate full-size circulating water and service cooling water pumps are provided for system reliability.

AUXILIARY STEAM SYSTEM. The function of the auxiliary steam system will be to supply steam to the plant auxiliary equipment that require steam (see Drawing IV.3):

- Feedwater heating during start-up
- Deaerator pegging steam
- Hotwell deaeration
- Building heating
- Main turbine shaft sealing

Steam is supplied either attemperated from the main steam header or from either of two electrically-heated auxiliary boilers. For the heat duty required, the high energy cost from electrode boilers is not sufficient to justify fired boilers and the attendant fuel storage. Start-up needs are discussed in Appendix IV.1.

The auxiliary steam system, during plant start-up, must be capable of heating the feedwater to the steam generators to a minimum of 450°F. The auxiliary steam system operating pressure will, therefore, be 455 psig saturated (460°F). The design pressure shall be 500 psig and temperature 500°F. Valves and flanges shall be ANSI Class 300.

The electric boiler is preliminary sized at 1,000 kW which is 3.413×10^6 Btu/hr and will generate 3,298 lbs/hr of 455 psig steam from 212°F feedwater. The preliminary flow requirement of the main steam supply to the auxiliary steam system is 12,000 lbs/hr.

LUBE OIL STORAGE SYSTEM. The system cleans, cools, transfers, and stores the oil which lubricates pumps and the turbine.

BOILER WATER MAKE-UP SYSTEM. The distilled water make-up requirement is supplied by dual vapor-compression evaporator package units. This choice followed comparison of the initial and operating costs of reverse osmosis/demineralization and multi-effect evaporators.

V. MASTER CONTROL SYSTEM

The master control system provides digital plant control and data logging in a single distributed system. Digital control has become the standard for PGandE's designs for new, large construction because it provides reliable and sophisticated control capability, is cost-effective in large plants, and gives the flexibility to add and reconfigure control functions when plant control sequences evolve. Functions essential to equipment protection are provided hard-wired, independent of the distributed system. Remote switching of plant electric power is hard-wired and located on a separate board in the control room.

Functional requirements and overall standards for design are given in the Design Criteria located in Volume II, Plant Specifications. System hardware is listed in Table V.1.

The arrangements are indicated in two figures. The MCS architecture is shown in Figure V.1 and is described herein. The physical arrangement of the control console is shown in Figure V.2.

Automatic control loop functions are provided by distributed processors. One processor provides control functions for the Power Conversion System (PCS) with automatic switchover on failure to a second processor. The Heat Transport System and the Collector System are controlled by separate processors. The HTS and CS control processors are provided by the suppliers of those systems, but function as part of the master control system. A programmed logic controller (PLC) provides overall sequencing for plant autostarts and equipment standby starts. Each of the distributed processors has the I/O for its respective part of the plant. A central computer in the control room does plant data collection, plant-level computations and off-site communications.

In the control room is an operators' console comprising three independent CRT displays and several hardware indicators, recorders, and loggers. An engineer's console contains a CRT display, keyboard, and printer. The control room console is shown in figure 999. Dual (redundant) high-speed data links connect the control processors, PLC, and the operator interface equipment. Another data link feeds data to a remote data analysis site.

Provision of added control processors for control room redundancy and for design use were considered, but were deleted for the sake of economy.

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Figure V-1. Master Control System Conceptual Layout

Figure V-2. Control Console Conceptual Layout

TABLE V.I
30 MW SOLAR PROJECT
DATA SHEET
MASTER CONTROL SYSTEM

1. One main control computer
 - a. Typical capability: 16 bit word, 1 megabyte memory, processor cycle time under 1 micro sec.
 - b. Plant data, display, optimization calculations, and high-level computations to be in main memory or static bulk storage.
 - c. Moving head disc for historical data storage, off-line operations only.
2. Dual (redundant) programmed-logic controllers
 - a. Performs plant digital logic functions (sequential start).
 - b. Automatic switchover on failure.
3. Three color CRT's (microprocessor-based)
 - a. For data display, alarming, and control.
 - b. All three are interchangeable.
4. Two medium speed typers/loggers (redundant)
 - a. Microprocessor-based.
5. Four 3-pen CRT addressable recorders
(Any variable in the MCS can be recorded.)
6. Four 3-pen hardwired recorders
7. Six 2-pen CRT-addressable indicators
8. Six 2-pen Hard-Wired Indicators
9. One operator's console housing items 2-7 plus ARCO interface and several hardwired control switches for control of critical equipment independent of the MCS.
10. One engineer's station (for programming, etc.)
 - a. One color CRT and keyboard

- b. One (1) medium speed typer
- 11. Two high-speed redundant communications link to the HTS control computer, for sequence of events (SOE) data.
- 12. Slow to medium speed RS-232 (communications standard) links to remote site for plant data analysis (no control).
- 13. Three remote, distributed, I/O control stations, microprocessor-based
 - a. Stations will handle all control loops and alarming.
 - b. Stations will communicate with computers and other devices via a multiplexed, redundant, communication link.
 - c. Stations will have separate field termination and electronics cabinet.
 - d. I/O will be as follows (estimated):
 - Station 1 - Receiver tower (nonredundant)
 - 1075 type K thermocouples
 - 210 4-20 mA analog inputs
 - 165 digital inputs (30 sequence of events)
 - Station 2 - Steam generators (nonredundant)
 - 110 4-20 mA analog inputs
 - 70 digital inputs
 - Station 3 - PCS (redundant)
 - 115 4-20 mA analog inputs
 - 42 thermocouples
 - 42 100 ohm platinum RTD's
 - 480 digital inputs
(145 digital control loops/100 sequence of events)
 - 260 digital outputs
 - 5 pulse inputs
 - e. All digital outputs will have interposing relays rated 15 amps @ 120 VAC.
 - f. All analog I/O to have 30 V power supplies.
- 14. All cards and exposed electronic equipment will be coated with a protective sealant.

15. Software provided by supplier will include:

- display builders
- text editor
- compiler
- linkers
- loaders
- I/O handlers (including I/O to HTS computer)
- trending and logging programs

VI. BALANCE OF PLANT

Balance of plant facilities are shown in drawings which are listed in Table VI.1. The specification documents D23-2 and D23-8 through D23-12 contain the design requirements.

COLLECTOR FIELD. The collector field extends 3650 ft. north from the plant reference at the receiver tower center. Its east-west extent is 4712 ft. The field is enclosed by a 7 ft. chain-link fence. Roadways, as indicated, are graded and minimally drained *. The land parcels under consideration have topography similar to the design basis parcel shown in the drawing. No grading is planned in the collector field except as may be required, local to individual heliostat column sites, for free travel by highway vehicles. No surface treatment of the collector field is planned. After the plant enters commercial operation, control of vegetation will be improvised if it is required.

PLANT AREA. Facilities south of the receiver tower are shown in Drawing VI.1. The evaporation pond is sized for disposal of 20 acre-feet per year. The cooling tower is located in the southwest sector because wind from this direction has the lowest annual frequency. The need to remove steam generators is not expected to arise. Removal is possible, however, through a lane provided to the west of their location. Roads and parking areas will be unpaved * except for 40,000 ft² of gravel surface at the entrance roadway, parking lot, and turbine building

* Certain civil features of the design as documented in drawings were altered at a later design stage in a cost reduction effort. The cost estimate is based on the altered design. In this text, which describes the altered design, features differing from drawings will be indicated by *.

TABLE VI.1
DRAWING LIST
BALANCE OF PLANT

Volume III Number	PGandE Number	Title	Rev.	Issue
<u>CIVIL</u>				
VI.1	515242	Plot Plan	03	02-09-83
VI.2	515246	Turbine-Generator Bldg. Plan & Details @ El. 1020'-0" (Structural Steel)	02	02-09-83
VI.3	515247	Steam Generator & Deaerator Support Framing Plan & Sections (Structural Steel)	02	02-09-83
VI.4	515249	Steam/Turbine Generator Bldg. Misc. Struct. & FDN Plan & Sections (Structural Steel)	02	02-09-83
VI.5	515250	Steam/Turbine Generator Bldg. Column Schedule & Details (Structural Steel)	02	02-09-83
VI.6	515251	Steam/Turbine Generator Bldg. Plan & Sections at El. 1000'-0" (Reinforced Concrete)	02	02-09-83
VI.7	515252	Turbine Generator Bldg. Plan & Section at El. 1020'-0" (Reinforced Concrete)	02	02-09-83
VI.8	515253	Turbine Generator Pedestal Plan & Sections (Reinforced Concrete)	02	03-07-83
VI.9	515257	Requirements - Raw Water and Distilled Water Tanks	01	03-16-83
VI.10	515261	Receiver Tower Plan & Elevation	01	03-11-83
VI.11	515262	Receiver Tower Foundations & Details	01	03-11-83

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TABLE VI.1 (cont.)

Volume III Number	PGandE Number	Title	Rev.	Issue
VI.12	515265	Cooling Tower Basin Plan, Sections, & Details (Reinforced Concrete)	02	02-17-83
VI.13	515269	Arrangement & Sets of Foundation Switchyard (Reinforced Concrete)	02	03-08-83
VI.14	515275	Misc. Underground Pipings Plan (Piping)	02	03-08-83
VI.15	515279	Requirements for Gantry Crane	02	02-28-83
<u>ARCHITECTURAL</u>				
VI.16	502579	Sanitary System	01	03-17-83
VI.17	502580	Warehouse/Shop	01	03-18-83
VI.18	502581	Admin. Control Building	01	03-15-83
VI.19	502582	Admin. Control Building	01	03-15-83
VI.20	502583	Domestic Water System	01	03-17-83
VI.21	514721	Admin. Control Building	01	03-15-83
VI.22	514722	Admin. Control Building	01	03-15-83
VI.23	514723	Warehouse/Shop	01	03-15-83
VI.24	514724	Fire Pump, Paint Stor., and Aux. Boiler/Water Bldgs.	01	03-15-83
VI.25	514725	Receiver Tower	01	03-09-83
VI.26	515240	Grading, Drainage, Paving, & Fencing Plan (Site Work)	02	02-09-83

TABLE VI.1 (cont.)

Volume III Number	PGandE Number	Title	Rev.	Issue
<u>ELECTRICAL</u>				
VI.27	220837	Schematic Single Line Diagram	02	02-03-83
VI.28	470302	Schematic Single Line Meter and Relay Diagram	01	03-21-83
VI.29	470303	Schematic Single Line Diagram	01	03-21-83
VI.30	470304	Schematic Single Line Diagram	01	03-21-83
VI.31	470306	Arrangement Helio-stat Area (East)	02	04-11-83
VI.32	470308	Arrangement Helio-stat Area (East)	02	04-11-83
VI.33	513948	Arrangement Site Work Ground Grid	02	04-11-83
VI.34	513950	Arrangement Turbine- Generator Building	02	04-11-83
VI.35	513952	Arrangement Turbine- Generator Building, Embedded Conduits and Grounds	02	04-11-83
VI.36	513953	Arrangement Steam-Generator Building, Embedded Conduits and Grounds	02	04-11-83
VI.37	513956	Schematic Single Line Diagram	01	03-21-83
VI.38	513957	Arrangement Switchyard	02	04-11-83
VI.39	513958	Arrangement Switchyard Embedded Conduits and Grounds	02	04-11-83
VI.40	513959	Arrangement Outdoors Embedded Conduits	02	04-11-83

EQUIPMENT LOCATION. The heat-transport system pumps and steam generators and the power conversion system equipment are in the "Turbine Building," located immediately south of the receiver tower. Proceeding from north to south in this building, one finds sodium pumps, steam generators, main steam piping, turbine-generator and electrical equipment room. The condenser is beneath the turbine, straddled by the turbine pedestal which supports the turbine at the 15 ft. operating level *. Feedwater heaters and the remaining PCS equipment are located wherever is convenient within and adjacent to the Turbine Building. The deaerating heater is at 67 feet above grade to provide the NPSH required by the boiler feed pump. The switchyard, and the electrical switchgear within the Turbine Building, are located on the east side -- the direction of the transmission line tap.

STRUCTURES. The Turbine Building is a semi-open steel frame with concrete deck at grade and at the 15 ft. operating level. Certain areas are enclosed: electrical switchgear, station battery and shop. In addition, siding will be added in the event there is a freezing hazard to piping. No crane is installed *. T-G maintenance, when it is required, will be accomplished with mobile equipment. The design basis interval is five years. At the south end of the turbine building are the shop and electrical switchgear, which will be enclosed by a single-level prefabricated steel building *. The control building will have two levels *. The upper level, located at the the elevation of the operating deck, houses the control room and computer room. The control room has been located at a distance from the electrical switchgear to reduce any effect of electromagnetic interference on electrical instruments. Administrative office and lab space will be provided in mobile buildings *.

* See the footnote on page VI.1

TOWER. Our selection for the receiver tower structure is a steel truss. Except for the heavier weight of its members, it resembles a transmission tower. The tower corner foundations are supported by piling. The ground level cross-section is a 100-ft square. It is equipped with passenger elevator and stairway. A concrete tower in this soil and this seismic setting we estimate to be more expensive.

The design basis seismic loading in this design phase follows the model of the Uniform Building Code, with values for Zone 4. For the tower, we further specify a minimum base shear of 0.25 W. In the next design phase, a site-specific geotechnical study should be made to evaluate further the potential ground motion.

Electrical Systems. The main generator, which generates at 12 KV, is connected through transformers to a transmission line at 115 KV and to a station service bus at 4.16 KV. Station loads above 208/120 V are served at 4160 V and at 480 V. The 480 V loads on motor control center no. 1 can be supplied by a diesel engine-generator. Control systems and some preferred loads can be supplied from a 125 VDC 1200 A-h station battery, either directly or through an inverter. Refer to drawing VI.37.

The heliostats are 120 V single phase loads fed by 208 V/120 V three phase leads through ten distribution panels in the field. A ground grid underlays the plant area and collector field for personnel safety. It provides no appreciable lightning protection to each heliostat's control circuiting.

Electrical loads are listed in Appendix VI.1.

Water Management. The water balance is guided by these constraints:

- the evaporative cooling consumption of about 150 acre-feet a year;
- practical limits on dissolved solids (against scale formation) in circulating water of about 2500 ppm (and more-specific limits on individual species);

- mineral analysis of the ground water available;
- boiler make-up requirement of about 7 gpm (annual average);
- cost of lined evaporation pond for disposal of blowdown.

The plant water balance is shown in Figures VI.1 and VI.2. The network consists primarily of the circulating water (main cooling) loop, the steam-condensate-feedwater loop and the service cooling loop. Evaporation and blowdown in the circulating water system are made up with raw water. Side stream cold lime-soda softening is provided on this loop. Purified water is made in vapor-compression evaporators and stored for boiler-feed makeup and for demineralizer regeneration.

The circulating water system operates at a constant composition determined as the highest impurity concentration possible without danger of scaling in condenser or cooling tower. Salts entering the network in raw water leave only when they go to the evaporation pond. There are two routes: directly in blowdown or indirectly via the lime-soda softener. The blowdown rate can be traded off with softener flow. The amount of blowdown can be used to control the total dissolved solids concentration and the side-stream softener to control calcium-magnesium hardness and silica. We have chosen to operate the tower at nine or ten cycles of concentration of raw water. In this case, the blowdown would amount to about 18 acre-feet year, requiring 6 or 7 acres of evaporation pond. The alternative exists of operating at three cycles of concentration, dispensing with softening and blowing down 50 acre-feet a year. This would triple the size and cost of the pond and is therefore not attractive.

Figure VI-1. Water Balance — Design

Figure VI-2. Water Balance — Average

VII. PERFORMANCE

The performance and operation of each major plant system is described in the preceding sections. In developing an overall assessment of plant performance, the following section summarizes the thermal losses and electric power consumption throughout the plant and overall considerations of plant availability and reliability.

The modeling of performance of the Carrisa Plains plant takes into account all operating modes and conditions. The plant hotel loads and parasitic power consumption have been estimated from detailed operating experience with equipment identical or similar to all portions of the plant.

VII-1 THERMAL LOSSES AND AUXILIARY POWER REQUIREMENTS

The principal thermal losses occur within the heat transport system (HTS), while auxiliary power is required throughout the plant. The HTS thermal losses under operating conditions, used to compute design point and annual energy efficiencies, are shown in Table VII-1.1. These losses are based on preliminary insulation sizing for a surface temperature not exceeding the OSHA limit of 54.4°C (130°F). The possibility of the cost-effective reduction of these losses remains a final engineering task.

TABLE VII-1.1
HEAT TRANSPORT SYSTEM OPERATING THERMAL LOSSES

Component	Loss (kWt)
Hot leg piping (including downcomer)	67.1
Hot tank	69.6
Pumps	10.0
Steam generators	15.0
Cold leg piping (including riser)	41.3
Cold tank	38.6
Miscellaneous	<u>38.4</u>
Total	280.0

The average thermal loss during nighttime and other nonoperating periods is estimated to be 204.1 kWt. The hot and cold pipes (especially the smaller size pipes) and some small miscellaneous equipment will require electrical heating to prevent excessive overnight temperature drops. Generally, HTS piping and equipment will be allowed to cool to 177°C (350°F) with the exception of critical pipes such as the inlet to the steam generators. The cold and hot tanks will not require overnight heating since their temperature drops are acceptably small and within the tank specifications.

The solar plant auxiliary power requirements are summarized in Table VII-1.2 for peak and annual average receiver operation.

TABLE VII-1.2
AUXILIARY POWER REQUIREMENTS

System	Peak (MWe)	Annual Average (MWe)
Collector	0.091	0.091
Heat Transport	1.217	0.923
Power Conversion	1.407	1.407
Master Control	0.050	0.050
Total	2.765	2.471

The HTS electric load is primarily composed of the receiver pump drive power requirements. It is noted that the receiver pumps are required to operate only a small fraction of the total annual power production hours at peak receiver power operating conditions. A further reduction in the receiver pump power requirements can be achieved by operating with only one receiver pump when the required receiver flow (power) is less than 72% of the peak value. A single pump operates more efficiently than two pumps for these conditions, resulting in some reduction in annual average power consumption by the power conversion system.

The overnight HTS power requirement is 0.210 MWe. The startup energy for the turbine and steam generators is estimated to be equivalent to 2 full power minutes used mainly in the thermal form.

VII-2. DESIGN POINT EFFICIENCY

The design point efficiency diagram Figure VII-2.1 is based on an insolation of 950 W/m^2 occurring at the design point, equinox noon. Plant operations are assumed to commence when the direct solar insolation exceeds 150 W/m^2 .

9479-24

Figure VII-2.1 Design Point Efficiency Diagram (equinox noon)

The thermal loss factors given in Figure VII-2.1 for collector system geometric losses and spillage are based on the collector system design shown in Section II. At the receiver aperture, 108.9 MWt is delivered. The values for received reflectivity, radiation and convection, thermal losses, and viscous dissipation represent the current HTS preliminary design status and the thermal analysis given in Appendix III-2.1. The steam-to-electric conversion efficiency is derived from the PCS heat balance, Section IV. The total thermal power delivered to storage is 105.7 MWt. Based on the 85-MWt steam generator design, the net electrical power is 29.7 MWe with a solar multiple of 1.24.

VII-3. ANNUAL ENERGY EFFICIENCY

The plant annual energy production performance is shown in Figure VII-3.1. The annual energy efficiency diagram is based on the estimated direct normal insolation at Carrisa Plains (see Section I) and 243.5-GW-h/yr energy delivered to the receiver aperture. The collector system factors also include low-power cutoff corresponding to direct insolation in excess of 150 W/m^2 . The plant energy availability is 93.3%. The energy efficiency is based on solar energy which is realistically usable, and thus excludes low power conditions and plant unavailability. The net electrical energy produced is 76.0 GWe-h/yr. The energy production on a monthly basis is presented in Figure VII-3.2. Note that the 20 days of scheduled outage is taken in December, which is estimated to be the lowest insolation period in the year. This has the positive effect of slightly increasing the "energy availability" (availability weighted by daily insolation) with respect to the "time availability" (unweighted availability). Collectively, operating and standby loads amount to 10.9% of the gross electric power production.

Figure VII-3.1 Annual Energy Efficiency Diagram

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9479-1

Figure VII-3.2. Monthly Energy Diagram
Carrisa Plains Solar Plant

VII-4 PLANT AVAILABILITY

The plant availability is summarized in Table VII-4.1. The power production hours lost as a result of forced outages and the corresponding availability are listed for each system and the plant. Also shown is the scheduled outage for maintenance and repairs. The power conversion scheduled outage requirements set the plant requirement and provide additional time for other systems. Note that the 20-day scheduled outage in December results in only 78 full-power hours lost. Plant availability for all systems and for outage for any reason is 93.3%.

Details of the heat transport system availability assessment is given in Table VII-4.2. The application of the component failure data given in Table VII-4.2 resulted in availability due to forced outages of 99.2%. This is a slight improvement over that estimated during conceptual design, and is a result of the change to redundant receiver and steam generator pumps. The pumps provide 100% redundancy up to 72% of peak power operating conditions. A loss of a single receiver pump could result in loss of up to one-third of the daily energy production, but would not necessarily result in plant shutdown. It is also noted only one-shift plant operation was assumed for repairs which result from forced outage.

The estimated plant availability, 93.3%, appears to be a reasonable goal for this size plant, as indicated by the data of Figure VII-4.1. This figure summarizes experience on plant availability as related to plant size. In addition to the 20 days in December scheduled for maintenance, nighttime, low sun angle, and weather outage periods are available for maintenance without interrupting power production. These additional maintenance periods are shown in Figure VII-4.2. A well-motivated plant crew may be able to make many of the repairs that normally necessitate calling an outage without affecting plant power production. Conventional power plants do not have these additional periods available for maintenance. This should be taken into consideration when considering the solar plant availability goal with respect to conventional power plant availability data.

TABLE VII-4.1
PLANT AVAILABILITY SUMMARY

System	Outage (Power Production h/yr)				Avail- ability (Forced Outage Only) (%)	Plant Avail- ability (%)
	Forced	Scheduled (Required)	Scheduled	Total		
Collector	29.3	-	78	-	99.1	
Heat transport	28.8	40 (10) ^a	78	-	99.2	
Power conversion	89.6	78 (20)	78	-	97.4	
Master control	2.0	3.6 (1)	78	-	99.9	
Plant	149.7	-	78 (20)	227.7	95.6	93.3
Plant availability = $\left(\frac{3400 - 227.7}{3400}\right) 100 = 93.3\%$						

^aEquivalent calendar days in December

TABLE VII-4.2
HEAT TRANSFER SYSTEM FORCED OUTAGE AVAILABILITY ASSESSMENT

Component	Operating (h/yr)	Failure Rate		MTTR ^d (h)	Unavail- ability (h/yr)
		Per Hour	Per Year		
<u>Receiver Subsystem</u>					
Receiver	3172	49 x 10 ⁻⁶	0.156	20	3.1
Receiver valves (9)	3172	81 x 10 ⁻⁶	0.257	10	2.57
Surge tank	3172	Nil			
Accumulator tank	3172	Nil			
Drag valves ^a (2)	3172	250 x 10 ⁻⁶	0.794	20	14.88
Pump - P1 ^{a,c} (2)	3172	3 x 10 ⁻⁶	0.010	100	1.0
Large valve (3)	3172	18 x 10 ⁻⁶	0.057	20	1.14
<u>Storage Subsystem</u>					
Tanks	8760	Nil			
<u>Heat Transport Loop Subsystem</u>					
Pumps, valves		See receiver and SG subsystems			
Piping		Nil			
<u>Steam Generator Subsystem</u>					
Steam generator (3)	3172	5 x 10 ⁻⁶	0.016	200	3.2
Pump - P2 ^{a,c} (2)	3172	9 x 10 ⁻⁶	0.029	100	2.9

Heat transfer system forced outage availability $\frac{3400^b - 28.8}{3400} = 99.2\%$

MTTR - mean time to restore

^aHeat transport loop subsystem component

^bMaximum available operable hours per year

^cRedundant for power operation less than 72%

^dOne shift operation assumed

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Figure VII-4.1. Forced Outage Rate as Function of Unit Size

9479-2

Figure VII-4.2. Solar Plants Allow for Maintenance Without Interrupting Power

VIII. FACILITY COST ESTIMATE AND ECONOMIC ANALYSIS

VIII-1 INTRODUCTION

The following sections discuss the capital cost, financing, and economics for the Carrisa Plains Solar Power Plant. The financing plan is being made on the basis of no government support in the construction and operation phases. Economic viability was determined on the basis of an acceptable rate of return (ROR) to the equity investor. Additional important criteria include the size of the investment, the state of development, the time period involved, and the assurances provided on net revenue. The advanced state of readiness proposed for the system has enabled the team members to be able to offer the entire plant at a fixed price and with a warranty. This considerably reduces the risks and makes the project more attractive to a private investor. The 30-MWe scale of the plant also favors third party ownership, since the amount of capital required is kept manageable and the construction period short. The schedule for the project, and the financials derived from it, assumed an expiration of the federal tax credits on 31 December 1985. The project would benefit from an extension of the tax credits and therefore the removal of this time constraint.

The conditions under which a private venture could be put together have been examined in depth with the investment community using company funds (outside the scope of this study). The conditions necessary or favorable for development of a third party venture have been used as project guidelines from the inception of the design. These conditions include ROR, financial assurances required by lenders, and supplier technology backing (2-year performance warranties).

The recent decreases in the cost of oil and gas and the lower projected rate of increase in cost of fuels have decreased the near-term attractiveness of solar energy sources. The effect is to require a decrease in the capital cost of the plant at a time when volume production of such components as

heliostats, which is the future hope for reduced capital costs, is not available. Tax credits are essential to enhance the economic attractiveness of this plant.

VIII-2 CONSTRUCTION COST

The plant construction cost estimate developed during the preliminary design phase is summarized in Table VIII-1. This estimate has been developed from three major sources:

- Manufacturing cost estimates
- Vendor component cost estimates
- Cost estimating services.

The first source, manufacturing cost estimates, has been used for major components that will be fabricated by the solar equipment suppliers, Rockwell and ARCO. This represents the most detailed means of obtaining a cost estimate for specialized components. The second source, vendor cost estimates, has been utilized for major equipment available from established vendor product lines. These include turbine-generators, pumps, and valves. These quotations have been obtained based on preliminary component specifications. Some modifications have been recommended by vendors, so that the status of these specifications and quotations must be reviewed during final design. Third many small items, bulk materials, and construction costs have been estimated using a computerized cost estimating service and an in-house cost estimating department.

The cost estimates of Table VIII-1 are based on a detailed evaluation of the preliminary design work by each of the team members working in their area of responsibility. The cost estimate breakdown has been developed in accordance with the following considerations:

Land and site permits: Purchase land and obtain all permits required to construct the plant in San Luis Obispo county.

TABLE VIII-1
CARRISA PLAINS COST ESTIMATE (\$M)

Land and Site Permits		0.5
Collector System		37.6
Heat Transport System		33.9
Receiver	8.0	
Thermal storage	6.1	
Heat transport loop	6.9	
Steam generation	9.7	
Auxiliaries	1.3	
Electrical, instrumentation, and control	1.0	
Spares and miscellaneous	0.6	
Electrical Power Generating System		15.1
Mechanical systems	12.3	
Plant electrical	1.1	
Switchyard equipment	1.3	
Spares	0.4	
Master Control System		1.9
Balance of Plant		4.6
Site improvements, foundations, and structures	3.9	
Water supplies, disposal, and fire protection	0.3	
Telecommunications	0.2	
Permanent tools	0.2	
Field Construction - Power Complex		24.1
Construction Management		<u>2.8</u>
		120.5

Collector system: Heliostats, controls, beam characterization system exclusive of the target, and repair and maintenance of equipment.

Heat transport system:

Receiver: Receiver panels, tanks, valves, instrumentation and support equipment located above elevation 380 ft in the receiver tower.

Thermal storage: Thermal storage tanks, sodium.

Heat transport loop: All sodium pumps, valves, piping, and tanks used in support of the heat transport system.

Steam generation: Steam generators, rupture assemblies, steam relief and power vent valves, and attenuator.

Auxiliaries: Inerting, purification, fill, and safety equipment.

Electrical, instrumentation, and control: Trace heating, instruments, and controls equipment for the heat transport system.

Spares: Replacement equipment for the heat transport system.

Electrical power generating system:

Mechanical systems: Turbine-generator, feedwater, auxiliary steam, and other mechanical equipment.

Plant electrical: Electrical power distribution materials and equipment within the plant.

Switchyard equipment: Transformers, transmission towers and lines, and other equipment for interconnect to the grid.

Spares: Replacement equipment for the electric power generating system.

Master control system: Computers, display consoles, control equipment, data acquisition equipment, and meteorological equipment used for operator interface and plant control and monitoring.

Balance of plant:

Site improvements, foundations, and structures: Site grading and roads, buildings, power complex foundation, and other site buildings.

Water supplies, disposal, and fire protection: Wells, evaporation ponds, and fire water system.

Telecommunications: Telephones, interconnect to central dispatch.

Permanent tools: Shop equipment and other tools for plant operation and maintenance.

Field construction - power complex: Erection of structural supports and receiver tower, and installation of heat transport system and electric power generating system equipment.

Construction management: A&E management services for the construction phase.

The estimates provided are the result of the preliminary design efforts and do not represent a commitment, certification of accuracy, or offer on the part of any of the participants.

The estimate for the collector field and for the sodium heat transport system is similar to the conceptual design cost estimates for these systems. The estimate for the Balance-of-Plant (BOP) systems has increased due to the many small systems that were missed in the earlier estimate and the more conservative final design costs. An A&E is expected to join the team for the final design effort to take over the responsibilities that PGandE had for this phase.

Additional costs due to construction interest, placement fee, and construction reserve brings the total plant estimated cost to \$147.4M in escalated dollars, Table VIII-2. Shown in Table VIII-3 is the cost breakdown by year, which is based on a construction schedule developed during this phase. Crucial to meeting a 1 July 1986 startup date is release of funds for final design in July 1983 and for long-lead procurement items in August/September 1983. The construction plan to meet the startup date is developed in Section IX.

TABLE VIII-2
COST BREAKDOWN BY SUBSYSTEM
(escalated dollars)

Subsystem	Capital Cost ^a (M\$)	Indirect Cost (M\$)	Total (M\$)
Heat transport system	33.9		33.9
Collector system	37.6		37.6
EPGS and BOP	21.6		21.6
Construction	27.4		27.4
Construction interest		8.6	8.6
Placement fee		7.3	7.3
Reserve		<u>11.0</u>	<u>11.0</u>
Total	<u>120.5</u>	26.9	147.4

^aFixed price by suppliers

TABLE VIII-3
COST BREAKDOWN BY CALENDAR YEAR

	1983	1984	1985	1986	Total
Capital cost	3.8	41.9	72.0	2.8	120.5
Indirect cost	<u>-</u>	<u>12.0</u>	<u>11.7</u>	<u>3.2</u>	<u>26.9</u>
Total	3.8	53.9	83.7	6.0	147.4

The tax credits available amount to 10% general, 15% energy (federal), and 15% energy (state, for California residents only). That portion of the plant investment available for tax credits is shown in Table VIII-4. The total tax credits taken for the financial analysis is \$26.6M. That portion of the plant cost depreciated by year, is shown in Table VIII-5. The Economic Recovery Act of 1982 limited the extent of the depreciation basis by one half the tax credits taken and revised the Accelerated Capital Recovery Schedule (ACRS) to a 150% double declining depreciation schedule. However, the shorter life basis of 5 years for nonutility equipment enacted in the Economic Recovery Tax Act of 1981 was retained. Because this is a qualifying facility not subject to utility regulation, legal advice has indicated that the project qualifies for the more generous 5-year depreciation schedule as indicated in IRS letter rulings 8238071 and 8234039.

TABLE VIII-4
QUALIFIED PROJECT COST FOR TAX CREDITS

Description	Tax Credit Qualification (%)			Expenditures by Year (M\$)					Cost Reduction (M\$)	Total Tax Credits (M\$)
	Federal State ^a									
	ITC	ETC	ETC	1983	1984	1985	1986	Total		
Land and permits	0	0	0	0.5				0.5		0
Real estate	0	15	25	0.4	6.6	2.9	0.0	9.9		1.5
Personal property	10	15	25	0.0	0.8	0.3	0.0	1.1		0.3
Equipment										
Collector & HTS	10	15	25	2.9	34.5	67.9	2.8	108.1	23.0	21.6
EPGS	10	15	25							
Spares	10	15	25			0.9		0.9		0.2
Equipment warranty	10	15	25		3.0	5.0		8.0		2.0
Financial warranty	0	0	0			3.0		3.0		0.0
AFDC	---prorated---				1.7	3.7	3.2	8.6		1.0
Equity placement	---expensed---				5.4			5.4		0.0
Debt placement	---expensed---				1.9			1.9		0.0
Total				3.8	53.9	83.7	6.0	147.4		26.6

^aMust be a California resident. Financial analysis based on federal tax credits only.
Will require a tax ruling to be certain of qualification.

TABLE VIII-5
QUALIFIED PROJECT COST FOR DEPRECIATION

Description	Depreciation Class		Qualifying Expenditures (M\$)					Reductions ^a	Net Depreciation Basis
	Federal	State	1983	1984	1985	1986	Total		
Land and permits	None	None	0.5				0.5		
Real estate	15 yr/ACRS	15 yr/SL	0.4	6.6	2.9	0.0	9.9	0.8	9.1
Personal property	5 yr/ACRS	5 yr/SL	0.0	0.8	0.3	0.0	1.1	0.2	1.0
Equipment	5 yr/ACRS	10 yr/SL	2.9	34.5	67.9	2.8	108.1	33.8	74.8
Spares	None	None			0.9		0.9		
Equipment warranty	5 yr/ACRS	10 yr/SL		3.0	5.0	0	8.0	1.0	7.0
Financial warranty	None	None			3.0		3.0		
AFDC	-----prorated-----			1.7	3.7	3.2	8.6	0.5	8.1
Equity placement	None	None		5.4			5.4		
Debt placement	-----expensed-----			1.9			1.9		
Total			3.8	53.9	83.7	6.0	147.4	36.3	100.0

^aReductions to depreciation basis due to tax credits (one-half) and possible PGandE and DOE contributions

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VIII-7

VIII-3. OPERATIONS AND REVENUE STREAM

The plant life has been designed for a 30-year life, which also forms the basis for the financial analysis. The long-term debt is based on a 15-year amortization.

The operations, maintenance, and materials cost of the proposed plant were evaluated by PGandE. New staff requirements are projected to be available in the Carrisa Plains area. Training will be available from PGandE, Rockwell, and ARCO. O&M manpower requirements were determined based primarily on PGandE experience. Table VIII-6 summarizes the estimated first year O&M costs. Annual costs are based on normal PGandE labor rates. Annual costs identified for maintenance in addition to payroll costs include contract labor, materials, and amortized major overhaul. O&M costs are expected to escalate at the same rate as general inflation. PGandE may contribute a significant portion of the manpower requirements in exchange for R&D technology information transfer. This arrangement would be subject to PUC approval, with a maximum of \$2 million per year.

Expenses incurred other than O&M are property taxes, insurance, partnership expenses, warranty/oversight expenses, taxes, and debt service. Property taxes in the state of California are normally 1% of assessed value at the time of sale and escalated at 2% a year thereafter. However, California has a property tax exemption for solar projects. Arrangements would be made with San Luis Obispo County to develop an equitable arrangement to reimburse the county for any additional burdens placed on the county due to the plant's presence. For planning purposes, \$300,000 per year escalating at 2% is used in the current financial analysis subject to negotiation. Insurance is based on 0.25% of the equipment and facility value and covers the normal type of insurance risks (i.e., vandalism, fire, earthquake). An optional one-time premium insurance covering performance shortfalls is included. Partnership expenses include accountant and legal fees to the limited partners and are budgeted at \$50,000 a year. Taxes paid are actually a tax benefit in the early years due to tax credits and ACRS depreciation. This tax benefit is passed through to the owners.

TABLE VIII-6
FIRST YEAR ESTIMATED OPERATION AND MAINTENANCE EXPENSES
(1986 dollars, full-year basis)

Payroll Distribution		
Supervisory and technical (6)	\$333,000	
Operation (10)	382,500	
Maintenance (14)	514,500	
Clerical (2)	74,000	
Total, Payroll		\$1,304,000
Payroll Burden at 47%		\$ 616,000
Maintenance Cost		
Major overhaul, amortized	\$400,000	
Repairs	600,000	
Contract labor	270,000	
Total, Maintenance Expense		\$1,270,000
Operating Expense		
Chemical supplies	\$ 40,000	
Safety supplies	30,000	
Miscellaneous supplies	50,000	
Total, Operating Expense		<u>\$ 120,000</u>
Total		\$3,310,000
The cumulative O&M cost for the life of the plant (30 years) is \$99M.		

The revenue stream is based on energy production of 75,600 MWh per year. Table VIII-7 is a breakdown of the revenue stream by on-, mid-, and off-peak summer and winter energy payments. A representative power sales agreement may include the following: a fixed rate of 9¢/kWh for the first 5 years. The fixed rate represents an estimated 5-year time-averaged discounted cash flow based on PGandE projected fuel-avoided costs. In the subsequent 5 years (1991 to 1996), the energy price will be the higher of a price floor of 10¢/kWh or 100% of fuel avoided costs. In the years 1996 to 2000, the energy price will be the higher of 10.5¢/kWh or a sliding scale of 98% to 90% of fuel-avoided costs. From year 2000 on, the price paid is 90% of fuel-avoided costs. The total revenue stream for year 1986 (a half year) is expected to be \$4.3M, of which \$3.5M is fuel-avoided cost and \$0.8M is as-delivered energy capacity credit. The total revenue stream for year 1987, the first full year of operation, is \$10.3M, of which \$6.8M is fuel-avoided cost and \$3.5M is firm capacity credit.

TABLE VIII-7
FIRST YEAR FUEL REVENUE STREAM
(based on a full operating year)

	Period A (May-Sept)	Period B (Oct-Apr)	Total
Energy Production (MWh/yr)			
On-peak	16,284	2,330	18,614
Partial peak	17,449	26,845	44,029
Off-peak	<u>6,352</u>	<u>6,372</u>	<u>12,409</u>
Total	40,085	35,547	75,632
Fuel Avoided Cost Schedule (£/kWh)			
On-peak, projected	7.97	8.61	-
Partial peak, projected	7.48	8.31	7.754
Off-peak, projected	6.70	7.36	-
Transmission loss (%)	0.989	0.989	0.989
Five-year fixed price	9.00	9.00	9.00
Energy Revenue Stream (\$000)			
On-peak, projected	1,283	199	1,482
Partial peak, projected	1,290	2,206	3,496
Off-peak, projected	<u>421</u>	<u>464</u>	<u>885</u>
Total	2,994	2,869	5,863
Five-year fixed price	3,608	3,199	6,807
Capacity Credit, As Delivered (\$000)			
On-peak	1,414	41	1,455
Partial peak	249	71	320
Off-peak	<u>0</u>	<u>0</u>	<u>0</u>
Total	1,663	112	1,775
Capacity Credit, Firm ^a (\$000)			
On-peak	3,024	442	3,466
Partial-peak			
Off-peak	<u>0</u>	<u>0</u>	<u>0</u>
Total	3,024	442	3,466
Escalation			
Energy (1983-1985) (%)			10.6
(1986-1990, projected)			9.5
(1986-1990, fixed price)			0.0
(1991-2002)			8.2
(2003-2016)			9.0
Capacity credit, as delivered			6.5
Capacity credit, firm			0.0

^aBased on a 29-year contract starting in 1987 with a capacity rating of 29.4 MWe and a base of \$159/kWe.

Table VIII-8 is the estimated first and second year revenue stream. Because the plant begins operation on 1 July 1986, the first year operation is for only a half-year revenue stream. Year 1987 is the first full year of operation and more typical of the net revenue stream. In 1987, the gross revenue stream is \$10.3M and total operating expenses are \$2.0M. This leaves a net revenue stream of \$8.2M to meet interest payments of \$5.5M.

TABLE VIII-8
FIRST AND SECOND YEAR NET REVENUE (\$M)

	1986 (July-Dec)	1987 (Jan-Dec)
Revenue		
Energy	3.40	6.81
Capacity credit	<u>0.79^a</u>	<u>3.47</u>
Total	4.19	10.28
Expenses Excluding Debt Service		
O&M	0.65 ^b	1.40 ^b
Property taxes	0.30	0.30
Insurance	0.28	0.28
Partnership administration	<u>0.05</u>	<u>0.05</u>
Total	1.28	2.03
Net Revenue to Cover Debt Service	2.91	8.24
Net Revenue/Plant Cost (%)	2.0 (full year)	5.6

^aReduced to 70% plant availability for July-September assumed for startup problems.

Preliminary estimate. Final number must be negotiated with the San Luis Obispo County.

^bReimbursed portion only

VIII-4 OWNERSHIP AND FINANCIAL STRUCTURE

An entire new range of opportunities for the ownership of electric power-producing facilities was created by the Public Utilities Regulatory Policy Act (PURPA). Under the terms of PURPA, these new forms of ownership can make it economically attractive for nonutility investors to own a power plant, connect

to a utility grid, and sell the power generated to that or another utility. This category of ownership is referred to as the Independent Power Producer (IPP). If the plant is small, 30 MWe being the applicable cutoff for a solar repowering plant under Section 16, USCA 796 et seq. of PURPA, the IPP will not be regulated as a utility. The IPP, therefore is, freed from regulatory controls on investments and allowable returns, and is able to fully utilize of existing solar investment tax credits, which are denied to utilities. Direct ownership by PGandE was rejected as an early consideration since the busbar energy cost for this early plant are high without the tax credits.

The following discussion presents a typical third-party venture arrangement (Figure VIII-1) with the three team members as major subcontractors to an IPP and also contributing through the partnership. While the arrangement described has been examined extensively by the team members, it is presented herein as a typical arrangement since there is no formal commitment on the part of the team members at this time.

VIII-4.1 Independent Power Producer (IPP)

The IPP will purchase the land and contract for the site preparation, construction management, equipment purchase, financing, and operation of the plant. The three team members may each become partners of the IPP in exchange for contributions of \$2.5M (\$2.83M with accrued interest). The Investment Partnership supplied a bulk of the equity. Day-to-day management of the plant will be the responsibility of PGandE pursuant to a long-term O&M contract with the IPP. The IPP will purchase the heat transfer system equipment from Rockwell; the installed collector field from ARCO; and the EPGS, master control system, and BOP from the A&E. The A&E will also serve as the project director. The construction contracts will, in the aggregate, provide for construction of the entire plant at a fixed price.

The IPP will enter into a power purchase contract with PGandE whereby PGandE agrees to purchase all electricity produced by the plant.

Figure VIII-1. Project Organization

VIII-4.2 Capital Cost Funding

Table VIII-9 is a summary of the application and source of all funds utilized in completion of the project.

The Investment Company will raise equity funds from qualified investors, up to a maximum of \$74.4M. It is expected that the financing fees will be 8% of all equity funds raised. Hence, the net equity available to the IPP is \$67.1M.

The IPP will obtain construction financing of \$49.9M at an interest rate not to exceed 12.5%. The construction loan will require advances of approximately 60% of approved monthly project expenses. The remaining 40% will be provided by equity funds from the Investment Company, and the three team members. After completion of the project, the construction financing will be converted to a long-term 15-year debt at an interest rate not to exceed 12.5%. When the construction debt of \$49.9M is refinanced, the IPP will use its

TABLE VIII-9
APPLICATION AND SOURCE OF ALL PROJECT FINANCING

	(\$M)
Application of Funds	
Plant construction cost	\$131.5
Construction interest at 10%	8.6
Financing fees	7.3
Loan repayment	8.5
Total	\$155.9
Source of Funds	
Equity	74.50
Long-term debt	49.9
ARCO equity	2.83
Rockwell equity	2.83
A&E equity	2.84
PGandE R&D contribution	17.00
DOE	6.00
Total	\$155.9

equity of \$8.5M to reduce the debt to \$41.4M; however, when the 6 months of interest-free operation (\$2.6M) are capitalized, the long-term debt will be \$44M. The 15-year long-term debt has a 5-year interest-only payment of \$5.5M followed by 10-year amortized interest-plus-principal payments of \$7.83M. The permanent financing will be secured by a first mortgage lien and security interest on the plant. Debt financing is assumed to be available immediately at the point equity commitments have been received.

PGandE is assumed to contribute \$17M in R&D funding upon PUC approval. Monies have already been included in the rate case application before the PUC. In return for the \$17M contribution, PGandE will be updated on all aspects of the technology as base technology transfer.

To make this a viable project, \$6M assumed to be available DOE for the final design effort. It is particularly needed early in the project to minimize risk exposure until finalization of all capitalization.

VIII-5. PRESENT WORTH AND ECONOMIC EVALUATION

Project cash flows for numerous scenarios have been examined. Of particular concern was the debt-to-equity ratio. The ultimate limit on debt of 43% was due to at-risk provisions of the tax laws. Several assumptions were made on operating cash flows that will be dependent on subsequent approvals by the PUC, by San Luis Obispo County, and by the team members. Table VIII-10 is the baseline partnership cash flows analysis. The expected rate of return to the limited partners of the Investment Company is 17.8% with an after-tax payback of 3.5 years from operational start date. Table VIII-11 is a tabulation of the project present worth using the investors' required 18% after-tax discount rate. To achieve the minimum 18% rate of return, the partners who contribute \$8.5M have to take a reduced rate of return. The partners' rate of return is slightly in excess of 10% and will be realized in 2003 through 2016 as their percentage ownership increases from 3% to 30%. This represents an indirect contribution by the general as this return is less than their normal minimum investment criterion.

The estimated cumulative savings in fossil fuel is k4.9M bbl over the 30-year life of the plant.

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TABLE VIII-10
CASE II - CARRISA PLAINS PROJECT SOLAR ENERGY PLANT PARTNERSHIP ANALYSIS
(\$000)

Equity \$ 67,128.61 Loan Proceeds 49,912.34 Cash Flow 0.00 Contribution to Eq. 0.00 Other 0.00 Total Funded \$117,040.95					Equipment \$108,460.00 Land 0.00 Interest 8,580.95 Other 0.00 Other 0.00 Total Use \$117,040.95						
Before Tax Yield 50.00% Tax 35.627183% per year After Tax Yield MISF 17.813591% per year Equity/Total Funded 57.354805% Loan Interest Rate 12.500000% per year Sinking Fund Rate 0.000000% per year					Inherent Profit \$238,600.67 203.8609% of Total Use Sinking Fund Earnings 0.00 0.0000% Residual Value 0.00 0.0000% Claimed ITC 26,621.65 22.7456% Recaptured ITC 0.00 0.0000% Fees 7,300.00 6.2371% Equity and Fees 74,428.61 63.5919%						
Period Ends	Total Income	Depre- ciation	Interest on Loan	Amort. + Other Expense	Taxable Income	Taxes Paid	Debt Service	B.T. Cash	A.T. Cash	Invest. + Fee	Net Cash Balance
12/1983	0	0	0	0	0	-69	0	0	69	0	69
12/1984	0	0	0	29	-29	-8,417	0	0	8,417	12,855	-4,369
12/1985	0	0	0	48	-48	-16,076	0	0	16,076	15,392	-3,685
12/1986	4,260	14,008	2,588	1,333	-13,669	-8,932	8,500	2,978	11,910	14,960	-6,734
12/1987	10,420	20,726	5,500	2,094	-17,900	-8,950	5,500	2,877	11,827	15,611	-10,518
12/1988	10,420	19,829	5,500	2,201	-17,110	-8,555	5,500	2,770	11,325	15,611	-14,804
12/1989	10,420	19,829	5,500	2,315	-17,224	-8,612	5,500	2,656	11,268	0	-3,535
12/1990	10,420	19,829	5,500	2,436	-17,345	-8,672	5,500	2,535	11,208	0	7,672
12/1991	11,158	994	5,500	2,563	2,101	1,050	5,500	3,146	2,095	0	9,768
12/1992	11,900	994	5,427	2,699	2,780	1,390	7,829	1,423	33	0	9,801
12/1993	12,411	994	5,118	2,843	3,457	1,728	7,829	1,790	62	0	9,863
12/1994	13,341	994	4,768	2,995	4,584	2,292	7,829	2,568	276	0	10,139
12/1995	14,437	994	4,374	3,157	5,913	2,956	7,829	3,502	546	0	10,685
12/1996	15,875	838	3,928	3,328	7,780	3,890	7,829	4,769	879	0	11,564
12/1997	16,893	682	3,426	3,510	9,275	4,637	7,829	5,605	967	0	12,532
12/1998	17,958	682	2,858	3,703	10,715	5,357	7,829	6,477	1,120	0	13,651
12/1999	18,678	682	2,217	3,890	11,889	5,944	7,829	6,992	1,048	0	14,699
12/2000	18,970	682	1,494	4,101	12,693	6,347	7,829	7,067	720	0	15,419
12/2001	19,600	284	677	4,331	14,307	7,154	7,829	7,466	313	0	15,732
12/2002	20,692	0	0	4,576	16,116	8,058	0	16,142	8,084	0	23,816
12/2003	22,747	0	0	4,836	17,911	8,955	0	17,937	8,982	0	32,797
12/2004	24,479	0	0	5,112	19,367	9,693	0	19,393	9,710	0	42,507
12/2005	26,367	0	0	5,405	20,962	10,481	0	20,988	10,507	0	53,014
12/2006	28,425	0	0	5,716	22,709	11,354	0	22,735	11,391	0	64,395
12/2007	30,668	0	0	6,047	24,622	12,311	0	24,648	12,337	0	76,732
12/2008	33,114	0	0	6,398	26,716	13,358	0	26,742	13,384	0	90,116
12/2009	35,779	0	0	6,770	29,009	14,504	0	29,035	14,530	0	104,646
12/2010	38,684	0	0	7,166	31,518	15,755	0	31,544	15,785	0	120,431
12/2011	41,851	0	0	7,587	34,264	17,132	0	34,290	17,158	0	137,589
12/2012	45,302	0	0	8,034	37,268	18,634	0	37,294	18,660	0	156,245
12/2013	49,064	0	0	8,509	40,556	20,278	0	40,582	20,304	0	176,553
12/2014	53,165	0	0	9,003	44,162	22,081	0	44,178	22,097	0	198,650
12/2015	57,635	0	0	9,527	48,108	24,054	0	48,112	24,058	0	222,708
12/2016	30,168	0	0	11,113	19,505	9,752	0	25,645	15,892	0	238,601
Total	755,751	103,041	64,376	153,276	434,959	190,858	114,288	503,887	313,029	74,429	

TABLE VIII-11
PROJECT AFTER-TAX PRESENT WORTH

Project Outlay	Discount Rate = 18%		Discount Rate = 10%
	Limited Partners (\$000)	General Partners (\$000)	General Partners (\$000)
Equity	-75,463	-8,500	-8,500
Energy tax credit (federal only)	19,920	616	561
Investment tax credit	11,944	369	337
Depreciation	34,069	1,054	1,223
Revenue	36,722	2,689	9,847
Operating expenses	-8,155	-559	-1,971
Long-term debt	<u>-19,366</u>	<u>-599</u>	<u>-990</u>
Total	-329	-4,930	+507

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IX. DEVELOPMENT PLAN

IX-1. PLANNING BASIS

The development plan for the Carrisa Plains Solar Power Plant has been organized around the scheduled expiration of the federal energy tax credits in December 1985. This requires that plant construction be completed by 31 December 1985. Commercial service is to begin by 1 July 1986, following the plant startup and acceptance testing. This schedule maximizes the potential for construction of the plant without further direct government participation and without new tax incentives or the extension of the Federal Energy Tax Credits. It also maintains a tight control over construction interest costs, allowance for funds used during construction (AFUDC), which could otherwise be a substantial contributor to overall project costs. However, the project would benefit by an extension of the tax credits and the removal of this schedule constraint. The overall structure of the development plan would not be expected to change appreciably should the schedule be delayed.

The development plan is considered in the following sections in four phases: final design, specifications and procurements, construction, and the startup and acceptance testing. The plan, developed to satisfy the schedule constraints imposed, embodies several key factors vital to the success of the project.

- Maximum utilization of the preliminary design outputs to reduce design time and cost
- Tight coordination between team participants to ensure that the design is complete and coherent
- Use of a program management system to track cost and performance and to identify corrective actions needed
- Assembly of a dedicated, knowledgeable, and experienced team able to bring the plant through construction and on line.

The following sections describe the overall development plan for final design, specifications, construction, and operation.

IX-2. PROJECT DEVELOPMENT PLAN

IX-2.1 Overview

The development schedule for the Carrisa Plains project provides an overall roadmap integrating the final design phase, procurement, fabrication, installation, checkout, acceptance testing, and commercial operation. This plan will be refined during the final design phase.

Figure IX-2.1 presents a summary schedule for plant construction, covering all major plant areas, procurement items, and site activities. A more detailed schedule is shown in Drawing IX-2.1. As can be seen, this schedule is consistent with the project plant completion date of 31 December 1985, and the acceptance date of 30 June 1986. Included in the schedule is the bid and award schedule for long-lead procurements as well as for other major procurement items. The final design work plan developed is consistent with the scheduled dates for release of long-lead and critical path procurement packages and component specifications.

The development plan is divided into a final design phase, lasting 12 months; an overlapping construction phase, lasting 25 months; and a check-out and acceptance phase, lasting 6 months. Operator training is performed in the 3 months preceding to the start of plant checkout. This schedule has been carefully considered by the preliminary design team companies, and is viewed as tight but feasible. Numerous larger projects have been built in comparable time periods without the cost penalties associated with "crash" programs. It is not uncommon in the petrochemical industry to find billion-dollar-class plants being designed and constructed in less than three years.

The overall schedule has been developed in reflection of the delivery schedule information provided in vendor quotations. Several major procurement items present a tight schedule, including steam generators and the turbine generator. The project critical path includes site preparation, turbine generator structure construction, and steam generator fabrication and

Figure IX-2.1. Development Plan Schedule Summary

checkout. However, several items could be placed on the critical path with schedule delays of only 2 to 3 months. Thus, the project will require continuous attention to schedule and prompt development of corrective actions if the overall project schedule is not to slip.

The following sections describe the individual elements of project development.

IX-2.2 Final Design Phase

The final design phase is scheduled to last 12 months, but will be heavily front loaded. This will reduce the extent and impact of overlap between the design and construction activities. The detailed design of long-lead and critical path items, including the receiver panels, steam generators, turbine-generator, and major pumps, will be completed early in the final design phase, with procurement documents for these items available within four months of initiation of the final design. The final design activities will use the vendor contacts made during the preliminary design phase to facilitate these procurement-related activities.

After completion of the work on these critical path items, the final design efforts will be directed toward the remainder of the plant. Principal outputs will be drawings and specifications from which subcontractors bid, and awards are made, for site preparation, foundations, structural, electrical, mechanical, process piping, insulation and weatherization, and painting.

The schedule for performance of the final design program is shown in Figure IX-2.2. The period covers 12 months. However, production of drawings and specifications is planned for the first seven months of the program in order to support the schedule for procurement, fabrication, and construction of the plant. Milestones are shown on the schedule chart.

The final design work plan has been scheduled around the need to provide bid packages for procurement in a timely manner and in a form consistent with the construction plan.

Figure IX-2.2. Final Design Program Schedule

A detailed accounting of end items has been prepared, and is presented in Table IX-2.1. This list includes bid packages and the end items from which they will be prepared. The bid packages reflect a difference in method of procurement between the solar and nonsolar portions of the plant. The solar portions of the plant are to be designed by the equipment fabricators, Rockwell and ARCO. The nonsolar portions of the plant rely more heavily on the purchase of materials and components in more general use. In addition, construction bid packages will be prepared which integrate inputs from both solar and nonsolar plant areas in the power complex. Figure IX-2.3 shows the schedule for release of principal bid packages or fabrication specifications within each plant area, and the way in which these are integrated by the construction manager into a series of construction bid packages.

TABLE IX-2.1
FINAL DESIGN END ITEMS

Task 1A, Collector System	
	Detailed collector field layout drawing
	Power and signal cable layout drawing
	BCS detail drawing
	Control logic and schematics
	Fabrication and installation schedule
Task 1B, Heat Transport System	
PRELIMINARY DESIGN DRAWINGS TO BE UPDATED	
079R000001	Panel Assembly - Solar Receiver, 30 MW Power Station
079R000002	Manifold, Solar Receiver Panel
079000003	Support Assembly - Solar Receiver Panel
079000004	Steam Generator Assembly - 30 MW Solar Central Receiver Plant
079R000005	Solar Receiver Assembly, 30 ME Power Station
079000006	Carrisa Plains Unit 1 - HTS Pipe Line List
079000007	Carrisa Plains Unit 1 - Valve List
079000011	Carrisa Plains Power Plant Piping Layout, Plan View
079000014	Carrisa Plains Power Plant Steam Generator Interface Control Drawing
079000015	Carrisa Plains Power Plant Hot and Cold Tanks Interface Control Drawing
079000016	Carrisa Plains Power Plant Receiver and Steam Generator Pump Interface Control Drawing

TABLE IX-2.1
FINAL DESIGN END ITEMS
(continued)

PRELIMINARY DESIGN DRAWINGS TO BE UPDATED (continued)	
079000017	Carrisa Plains Power Plant Mixing Tank Interface Control Drawing
079000018	Carrisa Plains Power Plant Tower: Elevation Layout Drawing
079000020	Carrisa Plains Power Plant Receiver Subsystem Layout Drawing
079R000021	Solar Receiver Panel Assembly, Handling, and Shipping
079000022	EIC Loop Diagram. Overall HTS Control
079000023	EIC Loop Diagram. Receiver
079000024	EIC Loop Diagram. Steam Generator
079R000025	Coolant Flow Orifice Assembly - Solar Receiver Panel
079R000026	Electrical Load List
079RD000027	Single Line Diagram
079000028	Tie Bar Assembly, Panel Support
079000029	Carrisa Plains Power Plant Main Heat Transport System P&ID
079000032	Carrisa Plains Power Plant Piping Isometric
079000034	Carrisa Plains Unit 1 Argon System P&ID
079R000035	EIC Loop Diagram. Sodium Purification System
079R000036	EIC Loop Diagram. Hot Tank, mixing tank, and Steam Generator Pump
079R000037	EIC Loop Diagram. Cold Tank and Receiver Pump
079R000039	Carrisa Plains Power Plant Piping Layout. Sections
079R000040	Carrisa Plains Power Plant Piping Layout. Elevation
079000047	Carrisa Plains Power Plant Tower - Receiver Interface Control Drawing
079R000048	Sodium Mixing Tank, T-5, Carrisa Plains Power Plant
079000051	Sodium Purification System P&ID
079000052	Carrisa Plains Power Plant Instrument Index
PRELIMINARY DESIGN HEAT TRANSPORT SYSTEM SPECIFICATIONS TO BE UPDATED	
N10046	Carrisa Plains 30 MWe Solar Power Plant Heat Transport System Specification
N10047	Structural Steel Tower, Carrisa Plains Solar Power Plant
N10048	Receiver Subsystem, Solar Central Power Plant, Carrisa Plains Unit 1
N10049	Steam Generator Module, Solar Central Receiver Power Plant, Carrisa Plains Unit 1
N10052	Auxiliary Systems, Carrisa Plains Unit 1
N30448	Pipe, Alloy Steel 2.25 Cr - 1.00 Mo, Seamless
N30449	Forged Fittings, Alloy Steel, 2.25 Cr - 1.00 Mo
N30450	Tubing, Alloy Steel, 2.25 Cr - 1.00 Mo, seamless
N30486	Forgings, Alloy Steel, 2.25 Cr - 1.00 Mo

TABLE IX-2.1
FINAL DESIGN END ITEMS
(continued)

PRELIMINARY DESIGN HEAT TRANSPORT SYSTEM SPECIFICATIONS TO BE UPDATED
(continued)

N30499	Valves, Globe, ANSI B16.34 Standard Class, Sodium Service
N30500	Carrisa Plains Unit 1 Receiver Pump
N30501	Carrisa Plains Unit 1 Steam Generator Pump
N40107	Welding, Tube-to-Tubesheet Joints, Steam Generator Solar Central Receiver Power Plant
N40113	Cleanness, Steam Generator, Solar Central Receiver Power Plant
N40114	Post Weld Heat Treatment, SCRPP, Steam Generator Modules

PRELIMINARY DESIGN SUPPORTING DESIGN DOCUMENTATION TO BE UPDATED

079TI000001	Structural Analysis - Carrisa Plains Solar Receiver Subsystem
079TI000002	Thermal Analysis of Central Receiver
079TI000003	Steam Generator Module Stress Report. Carrisa Plains Solar Thermal Power Plant
079TI000006	Thermal/Hydraulic Analysis for the Carrisa Plains Solar Power Plant Steam Generator
079TI000007	Sodium Safety Plan
079TI000008	Piping Stress Report. Carrisa Plains Solar Power Plant

ADDITIONAL DRAWINGS AND DOCUMENTS

Receiver Hoist Fixture Layout
Receiver Instrument Layout
Receiver Insulation and Heater Oven Layout
Solar Receiver Panel-to-Hoist Fixture Assembly
Solar Panel Assembly
Receiver Hoist Fixture Assembly
Receiver Absorption Coating Test Report
Receiver Support Stud Test Report
Receiver Tube-Manifold Joint Test Report
Receiver Fitting - Manifold-to-Tube, Hat Section, Heaters
Receiver Support Steel
Receiver Pipe Support
Surge and Accumulator Tank Interface Control Drawings
Steam Generator Top Assembly
Steam Generator Steam Head, Reducer, Cross, Headers, Support Rings Assembly Drawings
Steam Generator Tube Sheet, Ring, Disc, and Baffle Plate Assembly Drawings
Steam Generator Lower Flow Distributor Assembly
Steam Generator Tube Spacer and Tie Rods Assembly

TABLE IX-2.1
FINAL DESIGN END ITEMS
(continued)

ADDITIONAL DRAWINGS AND DOCUMENTS

Steam Generator Upper and Lower Wastage Baffle Assemblies
 Steam Generator Steam Tubes
 Steam Generator Elbow Thermal Liner Vibration Suppressor
 Steam Generator Heaters and Insulation
 Steam Generator Instrumentation Assembly
 Heat Transport Loop Pipe Supports and Restraints
 Heat Transport Loop Auxiliary Steel
 Heat Transport Loop Pipe Construction Specifications
 System Electrical Schematic
 Grounding Plan
 Electrical Equipment Room Plan
 Conduit/Raceway Plan
 Conduit Details
 Electrical Equipment Installation
 Wire List
 Local Board Assemblies
 Local Board Piping and Wiring
 Electrical Equipment Specification
 Electrical Preheat System Specification
 Electrical Heaters Sizing Specifications
 Instrument Air Supply P&ID
 Instrument Air Distribution
 Field-Mounted Instrument Installation
 Specification Flysheets
 Control System Procurement Specification
 Software and Logic Requirements Report
 Sodium Receiving, Fill, and Drain Layouts
 Sodium-Water Reaction Products P&ID
 Auxiliary Piping and Supports
 Safety Equipment Specifications

Task 1C, Electric Power Generating System

EPGS System Specifications
 EPGS Subsystem Specifications
 EPGS Equipment Specifications
 Heat Balance
 Equipment Location Drawings
 Civil System and Equipment Drawings
 Electrical System and Equipment Drawings
 Mechanical System and Equipment Drawings
 Instrumentation System and Equipment Drawings
 Cooling Tower and Evaporation Pond Drawings - Equipment

TABLE IX-2.1
FINAL DESIGN END ITEMS
(continued)

ADDITIONAL DRAWINGS AND DOCUMENTS

Task 1D, Master Control System

- Master Control System Procurement Specification
- Input/Output Lists
- Logic Diagrams
- System Flow Chart
- System Description

Task 1E, Balance-of-Plant

- Geotechnic Site Survey
- Site Preparation Requirements
- Site Preparation Drawings - Civil
- Site Preparation Drawings - Electrical
- Site Preparation Drawings - Mechanical
- Site Preparation Drawings - Facilities
- Turbine Generator and Steam Generator Structure Drawings - Civil
- Turbine Generator and Steam Generator Structure Drawings - Mechanical
- Turbine Generator and Steam Generator Structure Drawings - Electrical
- Turbine Generator and Steam Generator Structure Drawings - Foundations
- Turbine Decking Drawings - Civil
- Turbine Decking Drawings - Mechanical
- Turbine Decking Drawings - Electrical
- Cooling Tower and Evaporation Pond Drawings - Foundations
- Cooling Tower and Evaporation Pond Drawings - Civil
- Cooling Tower and Evaporation Pond Drawings - Mechanical
- Receiver Tower Design - Structural
- Receiver Tower Design - Transition Piece
- Receiver Tower Design - Foundations
- Receiver Tower Design - Civil
- Receiver Tower Design - Electrical
- Receiver Tower Design - Lighting
- Receiver Tower Design - Aircraft Safety Equipment
- Receiver Tower Design - BCS Target
- Receiver Tower Design - Controls and Cable Spreading Room
- Receiver Tower Design - Safety Equipment
- Receiver Tower Design - Personnel Access
- Control Building Design - Structural
- Control Building Design - Architectural
- Control Building Design - Civil
- Control Building Design - Mechanical
- Control Building Design - Electrical
- Office Building Design - Structural
- Office Building Design - Architectural

TABLE IX-2.1
FINAL DESIGN END ITEMS
(continued)

ADDITIONAL DRAWINGS AND DOCUMENTS

Office Building Design - Civil
Office Building Design - Mechanical
Office Building Design - Electrical
Warehouse Design - Structural
Warehouse Design - Architectural
Warehouse Design - Civil
Warehouse Design - Mechanical
Warehouse Design - Electrical
Domestic Water System - Mechanical
Domestic Water System - Civil and Architectural
Domestic Water System - Architectural
Domestic Water System - Mechanical
Domestic Water System - Instrumentation and Control
Makeup Water System - Mechanical
Makeup Water System - Civil and Architectural
Makeup Water System - Architectural
Makeup Water System - Mechanical
Makeup Water System - Instrumentation and Control
Instrument Air - Mechanical
Instrument Air - Civil and Architectural
Instrument Air - Architectural
Instrument Air - Mechanical
Instrument Air - Instrumentation and Control
Sanitary Systems - Mechanical
Sanitary Systems - Civil and Architectural
Sanitary Systems - Architectural
Sanitary Systems - Mechanical
Sanitary Systems - Instrumentation and Control
Maintenance Facilities - Mechanical
Maintenance Facilities - Civil and Architectural
Maintenance Facilities - Architectural
Maintenance Facilities - Mechanical
Maintenance Facilities - Instrumentation and Control
Electrical and Power Distribution - Installation Specifications
Electrical and Power Distribution - Civil and Architectural
Electrical and Power Distribution - Electrical
Electrical and Power Distribution - Mechanical
Electrical and Power Distribution - Instrumentation and Control
Electrical and Power Distribution - Erection Lists

Task 2, Solar Facility Performance

Power Production Report
Reliability Analysis
Failure Modes and Effects Analysis

TABLE IX-2.1
FINAL DESIGN END ITEMS
(continued)

ADDITIONAL DRAWINGS AND DOCUMENTS	
Task 3, Preparation of Bid Packages	
Bid Packages for Site Preparation and Construction	
Task 4, Facility Cost Estimate and Economic Analysis	
Construction Cost Estimate	
Operating Plan	
Maintenance Plan	
Facility Financial Plan	
Task 5, Project Construction Plan	
Construction Schedule	
Work Breakdown Structure	
Long-Lead Procurement Schedule	
Acceptance Test and Startup Plan	
Environmental Impact and Permit Plan

Figure IX-2.3. Schedule for Preparation of Fabrication Specifications and Bid Packages