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PHASE I OF THE FIRST SMALL POWER SYSTEM EXPERIMENT (ENGINEERING EXPERIMENT NO. 1)

Final Technical Report
Volume V - Supporting Analyses and Trade Studies

MCDONNELL DOUGLAS CORPORATION

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Final Technical Report
Volume V — Supporting Analyses and Trade Studies

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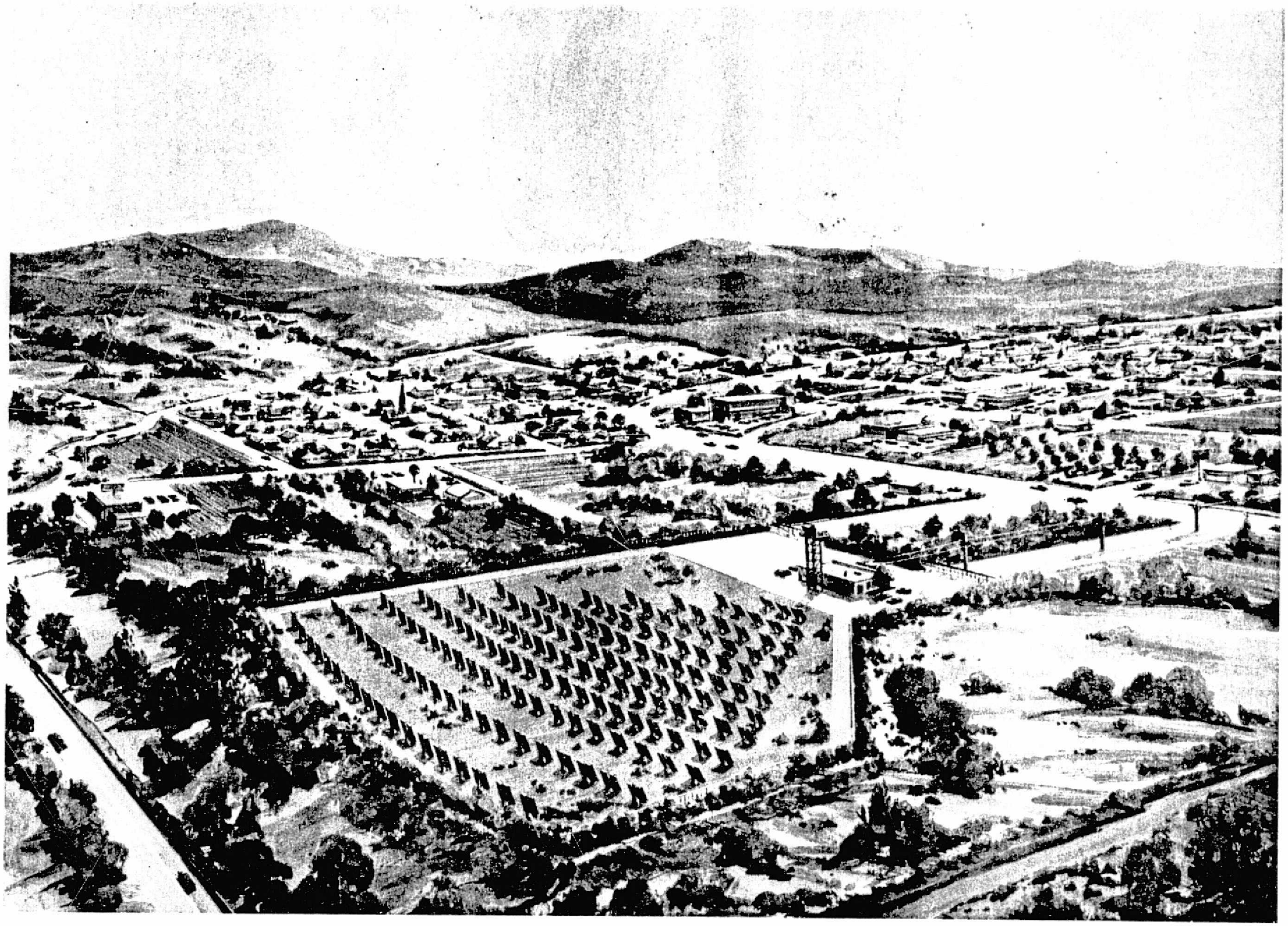

PREFACE

This document constitutes the McDonnell Douglas Astronautics Company (MDAC) final technical report for Phase I of the First Small Power System Experiment (Engineering Experiment No. 1). Phase I is an investigation of various system concepts that will allow the selection of the most appropriate system or systems for the first small solar power system application. This 10-month study is a part of the Small Power Systems Program that is being developed under the direction of the Department of Energy (DOE) and managed by the Jet Propulsion Laboratory (JPL). The final report is submitted to JPL under Contract No. 955117.

The final technical report consists of five volumes, as follows:

Volume I	Executive Summary
II	System Concept Selection
III	Experimental System Definitions (3.5, 4.5, and 6.5 Year Programs)
IV	Commercial System Definition
V	Supporting Analyses and Trade Studies

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CONTENTS

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Section 1
PHASE I PROGRAM INTRODUCTION

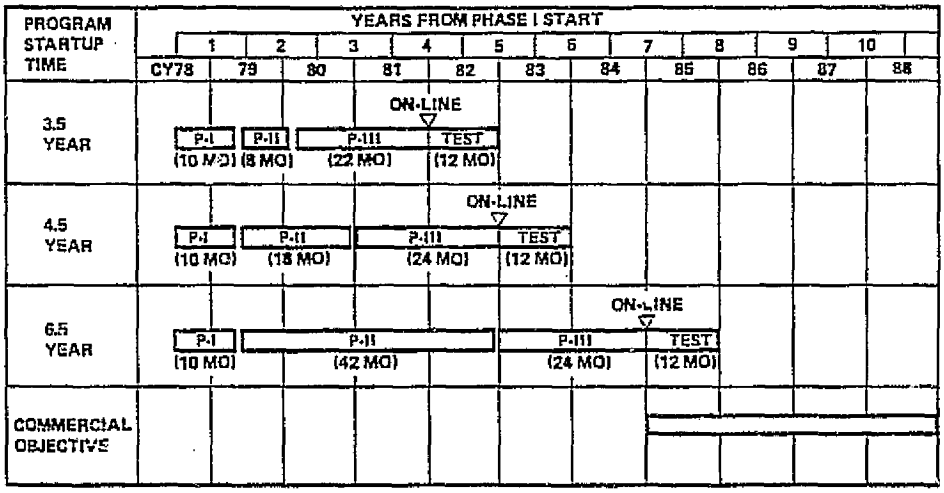
The Solar Thermal Power Systems Office of the Division of Solar Energy of DOE has initiated several application-oriented programs, one of which is the Small Power Systems Program. The overall objective of this program is to develop and foster the commercialization of modular solar thermal power systems for application in the 1 to 10 MWe range. Potential applications include power systems for remote utility applications, small communities, rural areas, and industrial users. Engineering Experiment No. 1 represents the first small power system to be developed under this program.

The primary goal of Engineering Experiment No. 1 (EE No. 1) is to identify suitable technological approaches for small power systems applications and to design, fabricate, field install, test and evaluate a solar power facility based on an optimum use of near-term technologies. Investigation of the performance, functional, operational and institutional interface aspects of such a facility in a field test environment are additional objectives.

Engineering Experiment No. 1 will be conducted in three phases: Phase I - Concept Defnition, Phase II - Design and Development Testing, and Phase III - Plant Construction and Testing. Three candidate programs for EE No. 1 are shown on Figure 1-1.

Phase I objectives were to investigate various system concepts and develop information which will allow selection of the most appropriate system for the first small power system application. System design and system optimization studies were conducted considering plant size, annual capacity factor, and startup time (the time from start of Phase I to the initiation of testing in Phase III) as variables. The primary output of Phase I was to be the definition of preferred system concepts for each startup time, design sensitivity and cost data for the systems studied, and Phase II Program Plans for each preferred system concept.

- THREE CANDIDATE PROGRAMS FOR EE NO. 1



- THREE PROJECT PHASES
  - I CONCEPT DEFINITION
  - II PRELIMINARY AND DETAILED DESIGN; COMPONENT/SUBSYSTEM DEVELOPMENT/TESTING
  - III FABRICATION, INSTALLATION, TEST AND EVALUATION
- CATEGORY A CANDIDATE SYSTEMS - GENERAL, EXCLUDING DISH CONCENTRATORS

Figure 1-1. Overall Program Scope

Phase II involves the preliminary and detailed design of the preferred system, and component and/or subsystem development testing that are needed before proceeding with plant construction in Phase III. Phase II may be from 8 to 42 months depending on the program selected by JPL as a result of Phase I.

Phase III will consist of subsystem fabrication, plant construction, installation, testing, and evaluation of the solar power facility (Engineering Experiment No. 1). A 3-year schedule is anticipated for this phase, with testing conducted during the third year.

Late in the Phase I study period, DOE concluded that a better balance of the overall solar thermal electric program could be achieved by limiting the JPL Small Power Applications activities to point-focus distributed systems. Consequently, DOE directed that JPL take the necessary steps to constrain the JPL-managed first Engineering Experiment (EE No. 1) to point-focusing distributed receiver technology for all phases beyond Phase I. Accordingly, on 3 April 1979, all MDAC efforts on Phase II program planning were terminated by JPL directive.

1.1 STUDY TASK APPROACH

Phase I study objectives were: (1) select preferred system concepts for each of the three program durations, (2) complete conceptual designs for each of three system concepts, (3) provide sensitivity data over range; plant rating: 0.5-10 MWe; annual capacity factor: 0 storage to 0.7, (4) prepare detailed Phase II plans and cost proposal (3 versions of EE No. 1), (5) prepare Phase III program and cost estimates (3 versions of EE No. 1), and (6) recommend preferred EE No. 1 program. Three major tasks were planned for the 10-month Phase I effort. They were Task 1 - Development of Preferred System Concepts, Task 2 - Sensitivity Analyses, and Task 3 - Phase II Program Plans. The Top-Level study flow is indicated in Figure 1-2.

In Task I, three preferred concepts were defined to the conceptual design level. The concepts were consistent with the three specified program startup

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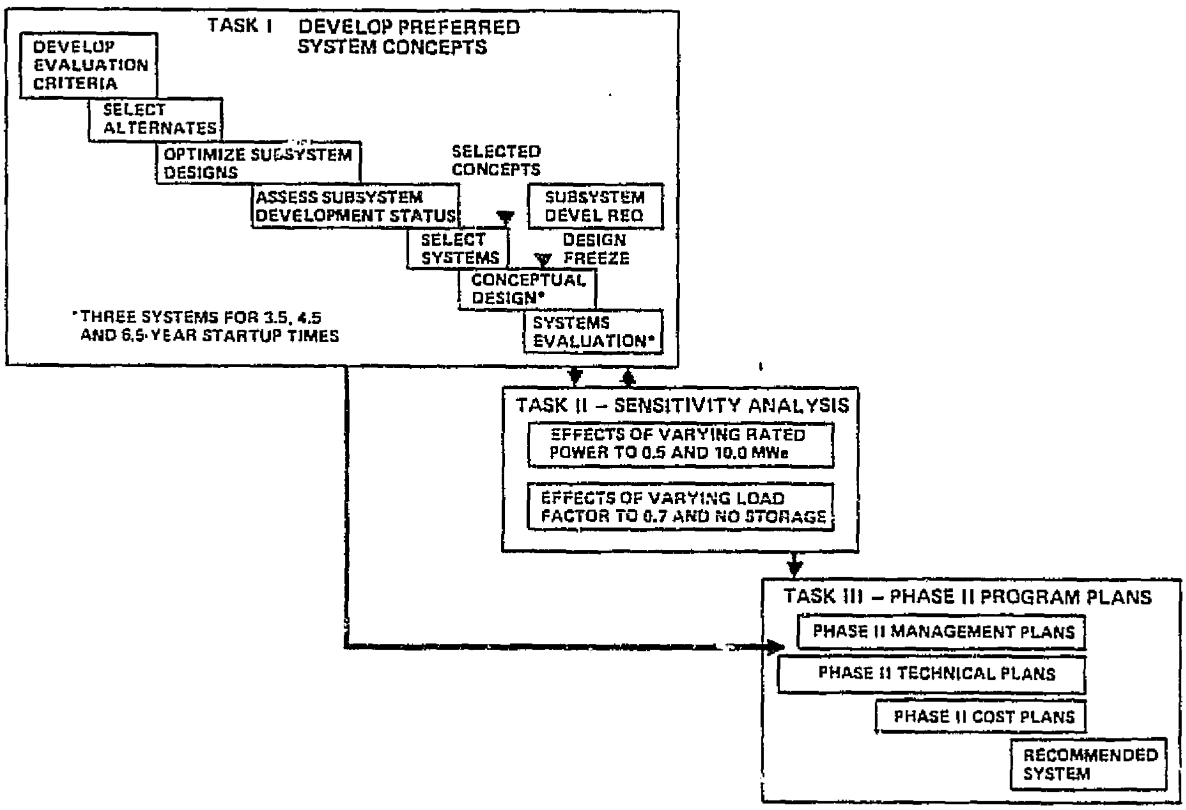


Figure 1-2. Top Level Study Flow

times of 3.5, 4.5, and 6.5 years. In Task I, power plants were considered for a nominal 1.0 MWe rated capacity and 0.4 capacity factor. Activities in Task I through the selection of the three preferred system concepts were primarily a systems engineering/evaluation conducted by MDAC. Subsystem characteristics, performance, and preliminary development requirements were supplied by the appropriate subcontractors. Following this concept selection, the conceptual design of subsystems was initiated in which descriptions, finalized development requirements, performance, reliability, and cost data for each of the three selected concepts were developed.

In Task II, the impact of varying rated power (0.5 and 10.0 MWe) and system capacity factor (zero storage case and 0.7) was investigated. Sensitivity analysis in Task II was performed by MDAC using subsystem data supplied by the subcontractors. This task featured system and subsystem reoptimization for each of the cases evaluated.

In Task III, the management, technical and cost plans for Phase II for each of the three selected concepts were to be prepared in accordance with JPL guidelines and MDAC system recommendations were to be provided. However, as reviewed above, during the latter period of the contract, JPL directed MDAC to terminate all Task III efforts. Accordingly, Task III efforts were discontinued and Phase II Program Plans are not reported.

1.2 ROLES AND RESPONSIBILITIES

A team of companies led by the McDonnell Douglas Astronautics Company (MDAC) was contracted to conduct the Phase I definition of Category A systems (general only excluding dish concentrators). The team includes MDAC, Rocketdyne, Stearns-Roger, the University of Houston Energy Laboratory, and Energy Technology, Incorporated (ETI). MDAC was the prime contractor for the effort and was responsible for overall contract compliance. The four major subcontractors and their prime areas of responsibility were: (1) Rocketdyne Division of Rockwell International (receiver, dual-media energy storage),

(2) Energy Technology, Inc. (radial turbine and gearbox), (3) Stearns-Roger (tower and plant layout/equipment), and (4) University of Houston Solar Energy Laboratory (collector field optimization).

1.3 SYSTEM SUMMARY

From the preliminary design analyses efforts to date, MDAC concludes that the proposed central receiver power system concept is a feasible, low-cost, and low-risk approach for a small solar power system experiment. It is particularly suitable for early deployment under the 3.5- and 4.5-year programs. The concentrator subsystem is currently under development and low-cost, high-production rate heliostats will be available for this program. The proposed receiver subsystem using Hitec is similar to existing fossil fired/Hitec heaters. The tower is a standard low-cost guyed steel tower. The energy transport system using Hitec is based on standard state-of-the art equipment and operating conditions. For the 3.5- and 4.5-year programs, a simple two-tank storage subsystem is proposed which requires no development. The power conversion system is based on existing axial steam turbines. All the balance of plant equipment involves state-of-the-art equipment and processes. The 6.5-year program contains development of a radial outflow turbine and qualification of a dual media thermocline storage subsystem. The technology employed in all programs is consistent with the development time available. Thus, the proposed MDAC concepts satisfy all of the important JPL selection criteria, namely, high operational reliability, minimum risk of failure, good commercialization potential, and low program costs.

1.4 SUPPORTING ANALYSES AND TRADE STUDIES

This volume contains all supporting analyses and trade studies conducted during Phase I on the preferred system concepts. Analyses and trades on the overall system are contained in Section 2. Subsystem analyses and trades are contained in Sections 3 through 9. The state of the art and applications of Hitec and heat transfer salt (HTS) are contained in Section 10. Preliminary cost estimates of the development programs for each of the three EE No. 1 concepts are contained in Appendix A of this volume. Cost information on the commercial system is given in Volume IV.

Section 2

OVERALL SYSTEM ANALYSES AND TRADE STUDIES

This section presents a description of system level analyses and trade studies. These discussions reflect the supporting studies identified in Volume III.

2.1 CONCENTRATOR FIELD OPTIMIZATION

The purpose of the concentrator field optimization analysis was to establish sizing requirements for the concentrator field, receiver, and tower which result in the lowest cost of thermal energy on an annual basis. In order to satisfy the annual thermal energy requirements for the alternate systems, the concentrator field was optimized for outputs ranging from 10,000 to 15,000 MWHt per year.

2.1.1 Field Optimization Methodology

The optimization analysis, which was carried out by the University of Houston, utilized well established computer codes which have been exercised extensively in support of other DOE contracts. The objective of the codes is to determine the most cost effective approach to the gathering and delivery of thermal energy to the base of the tower over a representative 1-year period. The resulting subsystem characteristics are, of course, dependent on the nature of the inputs assumed for the analysis. Table 2-1 presents a listing of the principal study inputs along with typical values for the current study.

Before initiating the optimization procedure, the collector field was divided into a number of computational cells. In this case 14 rows and 15 columns were used (rows run west to east and columns north to south). The cell size was $\sqrt{3/4}$ times the tower height. A performance data base was established for each cell containing annual cell performance information as a function of heliostat spacing. The performance information reflects cosine, shading, and blocking efficiencies. The data are used as input to the optimizer.

Table 2-1. Field Optimization Input Data

Heliostat Cost	$\$240/m^2$
Heliostat Wiring Costs	
Cable	$20.50/m
Trenching	$15.60/m
Receiver Cost	$\$250{,}000 \left(\frac{\text{Peak Power}}{4.8\ \text{MWt}}\right)^{0.5}$
Tower Cost	
38 m Optical Height	$84,000
42 m Optical Height	$90,000
Riser/Downcomer Cost	$\$23{,}000 \left(\frac{\text{Power}}{3.7\ \text{MWt}}\right)^{0.5}$
Pump Cost (28 HP at 5.6 MWt)	$350/HP
Land Cost	$5,000/acre
Heliostat Area	$49\ m^2$
Receiver Loss Model	0.037 (Incident Power)
	+ 0.430 MWt
Heliostat Error Budget	2.83 mr (1σ)

The optimizer requires as an input a figure of merit based on the expected total cost of the field, including the tower, receiver, etc., divided by the annual collected energy. From this, a cell matching parameter is formed based on the ratio of heliostat cost to input figure of merit times annual available energy. For each cell the optimizer locates all possible values of heliostat spacing which will satisfy the cell matching parameter. The optimizer also locates all values of heliostat spacings which will maximize the production of energy from each cell. The optimal heliostat spacings satisfy both of the conditions, thus minimizing cost and maximizing energy.

The optimizer compares the product of annual energy contributed by the cell and cell intercept fraction (see Section 2.1.2) to the cell matching parameter.

As long as the product is greater than the cell matching parameter, the cell is not degrading the figure of merit and stays in the field. If it is less, the cell is trimmed from the field. Thus, the field boundary is formed. Once the optimal heliostat spacings and field boundary are determined, the number of heliostats in each cell can be determined and a new output figure of merit is formed. The process can be repeated and convergence is quickly obtained. Use of the cell matching parameter in defining the heliostat separation and in determining the field boundary assures that each cell is contributing to the system performance in a cost optimal way. All of the various costs and losses are balanced throughout the field so the converged figure of merit defines the economic optimal system.

Implicit in the figure of merit are the influences of all cost and performance considerations which can be allocated to the individual heliostats. These factors include:

A. Shading and blocking of adjacent heliostats
B. Guidance error model
   1. Slope errors of reflectors
   2. Tracking errors
C. Aberration model for canted heliostats
D. Heliostat aim strategy
E. Cost model
   1. Heliostats (including guidance, etc.)
   2. Tower
   3. Receiver
   4. Plumbing in tower
   5. Land for heliostat
   6. Wiring for heliostat
   7. Receiver feed pump
F. Energy loss model
   1. Mirror reflection and receiver absorption
   2. Receiver absorptivity versus angle of incidence
   3. Reradiation and convection from receiver
   4. Atmospheric losses between heliostat and receiver
   5. Interception losses at receiver

The interception factor data (as defined in Section 2.1.2) between individual heliostats and the receiver were calculated off line and used as inputs to the optimization analysis. A description of the approach used to define the interception factors for each cell is presented in Section 2.1.2.

The information developed as a result of this optimization analysis includes a specification of the optimized cost of annual energy, the annual energy absorbed into the receiver working fluid, the peak power level, field shape, and heliostat spacing data for each of the computational cells selected for use. A simple change in tower height (expressed in terms of revised interception factors) and the corresponding cost scaling will result in a new set of collector subsystem performance and design data. This process was repeated until a sufficient parametric data base was established to cover the range of interest from 10,000 to 15,000 MWH of annual thermal energy.

2.1.2 Receiver Interception Factor

The average annual receiver interception factor (AIF), which is a primary input to the concentrator field optimization analysis, is defined as the ratio of the total annual energy collected within the aperture to the total annual energy redirected by the heliostat field.

An analysis was made, using the McDonnell Douglas optical analysis computer code (CONCEN), of the variation in annual interception factor with location in the field. A heliostat mirror size of 7.4 by 7.4 m was used. The height of the receiver aperture center above the heliostat mirror center was taken to be 38 and 42 m. The receiver was assumed to be tilted downward 30^{o} from due north, and the ambient temperature was $32^{o}C$ ($90^{o}F$). Figures 2-1 and 2-2 contain values of the AIF extrapolated from the above data for each of the cell locations in the collector field for a circular receiver aperture of 4.5 m diameter.

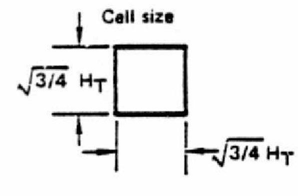
2.1.3 Field Optimization Results

The results of the concentrator field optimization analysis carried out by the University of Houston are shown in Figure 2-3 for different tower heights. The figure-of-merit parameter represents the capital cost divided by the annual

North

0.8830	0.875	0.860	0.8331			
0.925	0.915	0.900	0.870			
0.9597	0.950	0.940	0.9202	0.840		
0.980	0.970	0.960	0.9449	0.865	0.780	
0.9937	0.990	0.9826	0.965	0.9411	0.860	
1.0	0.995	0.990	0.9729	0.940	0.8927	
1.0	1.0	0.995	0.970	0.9384	0.830	
1.0	1.0	0.990	0.960	0.870	0.760	
1.0	1.0	0.975	0.9002			
T						

East



Aperture: 4.5 m dia
Heliostat: 7.4 x 7.4 m

Figure 2-1. Receiver Intercept Factor, 38-m Optical Height

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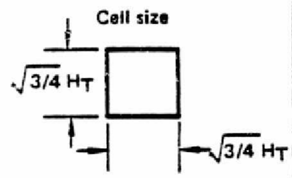
North

0.8408	0.835	0.810	0.7826			
0.895	0.885	0.860	0.825			
0.9356	0.925	0.910	0.8878	0.820		
0.970	0.955	0.945	0.9199	0.840	0.785	
0.9884	0.985	0.9714	0.950	0.9213	0.825	
0.998	0.995	0.980	0.9616	0.925	0.8676	
1.0	1.0	0.995	0.970	0.9217	0.810	
1.0	1.0	0.990	0.960	0.860	0.750	
1.0	1.0	0.975	0.9005			
T						

East



Aperture: 4.5 m dia.
Heliostat: 7.4 x 7.4 m

Figure 2-2. Receiver Intercept Factor, 42-m Optical Height

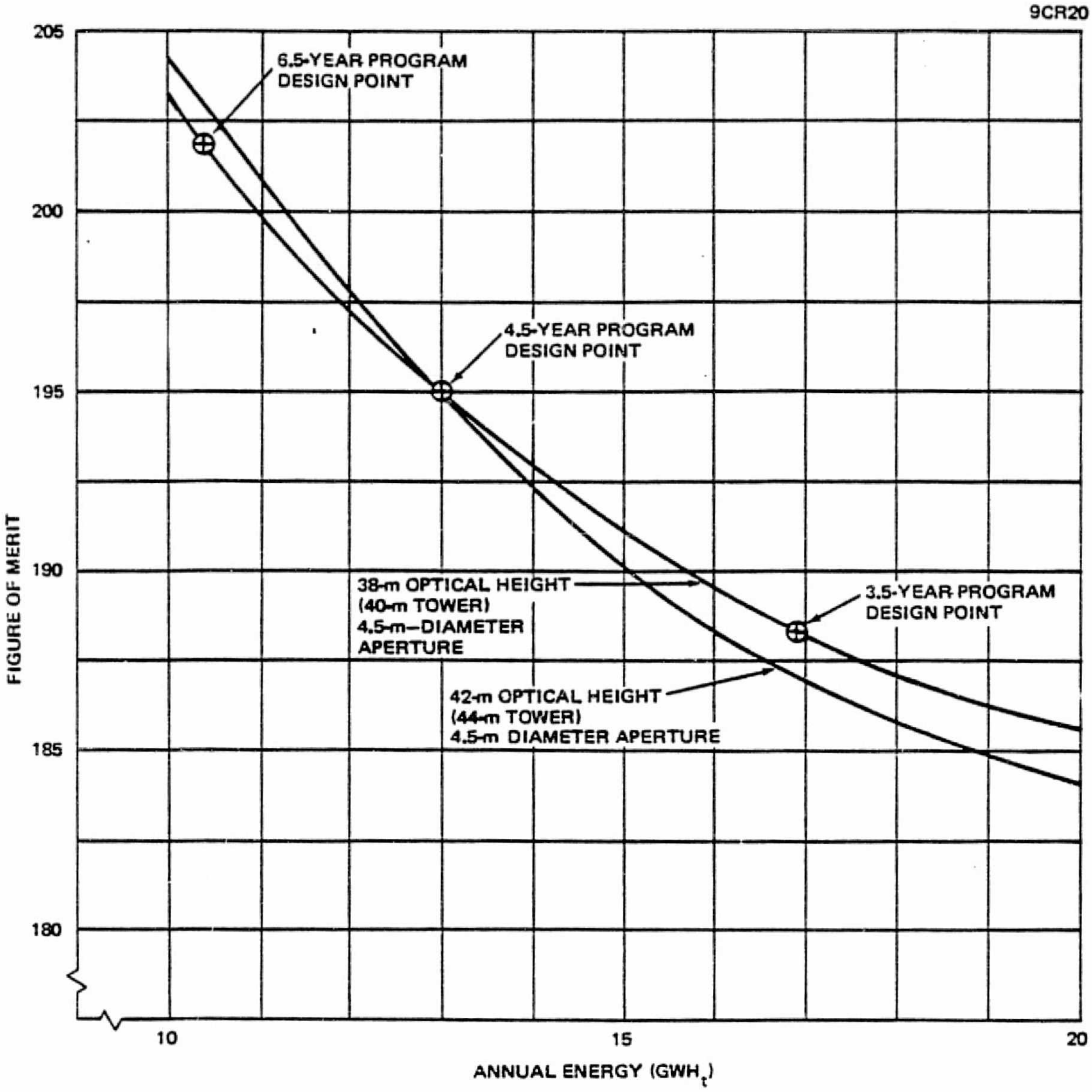


Figure 2-3. Experimental Field - Optimization Results

thermal energy delivered to the base of the tower through the energy transport subsystem expressed in $/MWHt per year. Cost factors considered include heliostats, land, wiring, tower, receiver, piping, pumps, and a fixed cost which is independent of the specific system under consideration. The indicated values of the figure of merit were based on an insolation model defined by the University of Houston.

In order to refine the predictions of annual energy production provided by the University of Houston's optimization analysis, a reference case was analyzed using the MDAC Program P5595 and comparing its results to those obtained by the University of Houston. The program P5595 uses insolation, ambient temperature, and wind velocity for the specific site (Barstow 1976) and evaluates the performance of the concentrator/receiver subsystem at 15-minute intervals. The performance is integrated for each day for an entire year and can be presented at 15-minute intervals or given as daily average efficiencies.

The design characteristics of the reference run are presented below.

Number of heliostats	154
Heliostat area	49 m^2
Receiver aperture	4.0 x 4.0 m
Receiver absorptivity	0.95
Receiver thermal Losses	430 kW_t
Optical height	38 m

Performance results for typical days near winter and summer solstice and spring equinox are given in Figure 2-4. Average daily performance is shown for each day in Table 2-2. The results of this analysis show the annual energy produced to be approximately 4.5% greater than that predicted by the University of Houston results which corresponds to a 4.5% reduction in figure of merit.

This study was made to determine the collector field characteristics for the experimental plant and to determine whether a 40 or 44 m tower is preferred. From the results presented it is seen that the figure of merit is nearly identical for the two tower heights; therefore, the more conservative 40 m tower (38 m optical height) was selected for the alternate systems. The closeness of the results also confirms that the tower heights analyzed span the optimum.

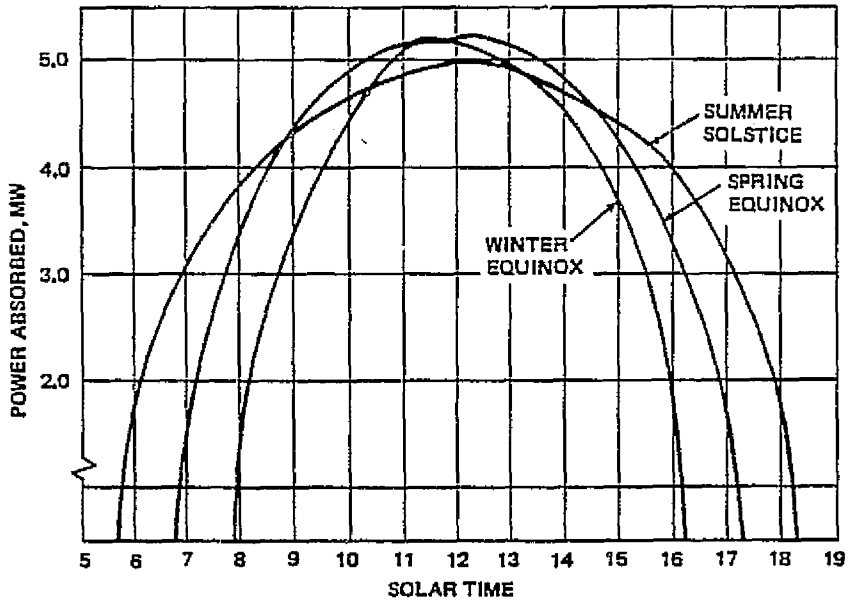


Figure 2-4. Typical Performance (Reference Run)

2.2 SYSTEM AVAILABILITY

The work sheets for the availability analysis of the three EE-1 concepts are presented in Tables 2-3 through 2-14. The overall results are shown in Tables 2-15 through 2-18.

The analysis considered each generic type of component for each subsystem. A failure rate was estimated for each of the applicable failure modes for each generic component. These failure rates were estimated using data from References 2-1 through 2-7.

The operating time for each type of component was established. The operating time for the collector, energy transport, and energy storage was set at 3,861 hr/yr which was derived from the average sun insolation of 11.7 hr/day for 330 cloudless days per year. The operating time for the power conversion subsystems was based on a 40% load factor and was calculated to be 3,504 hr/yr. The operating time for the plant control and components that contain fluids on a full-time basis used the actual clock time per year (8,760 hr).

Table 2-2. Average Daily Concentrator/Receiver Performance (Page 1 of 7)

Day	Date	Insol (kwh/m^2 - day)	Field eff.	Receiver eff.	Thermal engy (mw H_t)
1	1 1	6,7973	,701	,861	30,990
2	1 2	7,0248	,701	,864	32,121
3	1 3	5,4699	,718	,855	25,374
4	1 4	6,5844	,702	,844	29,469
5	1 5	5,6158	,702	,842	25,080
6	1 6	3,3967	,680	,706	12,308
7	1 7	5,7235	,712	,840	25,852
8	1 8	6,9185	,704	,868	31,947
9	1 9	6,1098	,709	,868	28,393
10	1 10	6,7371	,706	,851	30,567
11	1 11	7,0511	,706	,859	32,312
12	1 12	6,7288	,711	,849	30,685
13	1 13	6,8391	,706	,867	31,640
14	1 14	6,3644	,704	,849	28,711
15	1 15	7,1448	,707	,864	32,957
16	1 16	7,1048	,707	,857	32,483
17	1 17	6,2411	,706	,848	28,231
18	1 18	4,6912	,719	,821	20,943
19	1 19	6,8105	,708	,851	31,027
20	1 20	7,2321	,709	,866	33,503
21	1 21	7,0545	,718	,859	32,891
22	1 22	5,8926	,706	,838	26,350
23	1 23	7,0747	,709	,850	32,182
24	1 24	5,7437	,712	,806	24,871
25	1 25	6,6087	,711	,865	30,731
26	1 26	6,7366	,709	,850	30,654
27	1 27	7,0628	,717	,856	32,739
28	1 28	7,5344	,709	,865	34,922
29	1 29	7,4622	,711	,871	34,900
30	1 30	4,0577	,719	,800	17,630
31	1 31	7,7159	,714	,866	36,019
32	2 1	5,6665	,709	,834	25,335
33	2 2	7,8591	,713	,864	36,552
34	2 3	3,9850	,709	,776	16,557
35	2 4	5,1581	,724	,752	21,220
36	2 5	2,8929	,698	,710	10,822
37	2 6	3,8054	,749	,761	16,399
38	0 0	INSOLATION TOO LOW			
39	0 0	INSOLATION TOO LOW			
40	2 9	4,8385	,706	,782	20,160
41	2 10	3,3129	,725	,797	14,465
42	2 11	7,8866	,718	,862	36,904
43	2 12	7,7519	,718	,857	36,018
44	2 13	7,7712	,720	,853	36,065
45	2 14	7,4105	,726	,816	33,182
46	2 15	3,4493	,713	,768	14,268
47	2 16	4,4376	,719	,774	18,663
48	2 17	4,6465	,741	,796	20,717
49	2 18	7,8365	,733	,849	36,871
50	2 19	5,1214	,734	,722	20,514

Table 2-2. Average Daily Concentrator/Receiver Performance (Page 2 of 7)

Day	Date	Insol (kwh/m^2 - day)	Field eff.	Receiver eff.	Thermal engy (mw H_t)
51	2 20	8,1316	.734	.855	38,562
52	2 21	8,3159	.734	.860	39,643
53	2 22	5,8186	.743	.800	26,110
54	2 23	5,1637	.742	.789	22,842
55	2 24	7,9716	.731	.851	37,456
56	2 25	7,7984	.725	.858	36,609
57	2 26	6,3557	.755	.833	30,203
58	2 27	7,3886	.738	.839	34,587
59	2 28	7,3857	.735	.833	34,158
60	2 29	5,4308	.734	.764	23,001
61	3 1	3,3006	.729	.737	13,410
62	3 2	5,9582	.718	.771	24,927
63	3 3	3,7675	.704	.656	13,156
64	3 4	7,3763	.739	.845	34,799
65	3 5	7,2878	.739	.843	34,304
66	3 6	7,7425	.728	.851	36,264
67	3 7	8,6133	.727	.847	40,066
68	3 8	2,5058	.727	.680	9,358
69	3 9	3,4460	.710	.734	13,565
70	3 10	4,0219	.781	.777	18,444
71	3 11	7,3613	.742	.808	33,320
72	3 12	9,4696	.723	.861	44,516
73	3 13	8,7230	.724	.872	41,610
74	3 14	7,7804	.725	.835	35,618
75	3 15	8,8066	.726	.859	41,482
76	3 16	2,8393	.698	.702	10,503
77	3 17	4,3695	.712	.805	18,921
78	3 18	5,1309	.706	.734	20,099
79	3 19	5,3139	.726	.758	22,102
80	3 20	8,4598	.717	.868	39,779
81	3 21	9,2280	.718	.860	43,022
82	3 22	6,2454	.728	.827	28,410
83	3 23	8,5335	.724	.814	37,991
84	3 24	8,7936	.721	.830	39,745
85	3 25	5,4438	.730	.773	23,198
86	3 26	8,9600	.718	.857	41,677
87	3 27	8,4591	.720	.800	36,807
88	3 28	8,6357	.722	.816	38,419
89	3 29	9,1543	.715	.859	42,484
90	3 30	9,7686	.710	.856	44,802
91	3 31	8,3329	.720	.852	38,604
92	4 1	9,2392	.713	.835	41,558
93	4 2	8,9465	.714	.855	41,272
94	4 3	6,0164	.724	.787	25,871
95	4 4	4,3545	.742	.738	18,008
96	4 5	6,7055	.707	.774	27,701
97	4 6	9,0182	.711	.834	40,359

Table 2-2. Average Daily Concentrator/Receiver Performance (Page 3 of 7)

Day	Date		Insol (kwh/m^2 - day)	Field eff.	Receiver eff.	Thermal engy (mw H_t)
98	4	7	9,1746	.708	.865	42,474
99	4	8	6,1020	.682	.742	23,311
100	4	9	8,8684	.712	.857	40,869
101	4	10	6,6860	.721	.800	29,142
102	4	11	6,5846	.731	.807	29,337
103	4	12	3,6791	.719	.694	13,862
104	4	13	2,2362	.655	.543	6,002
105	4	14	4,9355	.682	.761	19,362
106	4	15	2,7710	.745	.640	9,987
107	4	16	6,4142	.700	.764	25,923
108	4	17	9,4741	.705	.839	42,312
109	4	18	9,3900	.701	.840	41,791
110	4	19	9,1884	.703	.856	41,754
111	4	20	9,4566	.702	.854	42,812
112	4	21	8,1846	.709	.827	36,239
113	4	22	7,8308	.723	.801	34,245
114	4	23	8,6153	.703	.843	38,555
115	4	24	8,2285	.700	.835	36,301
116	4	25	7,6156	.709	.772	31,468
117	4	26	9,7189	.700	.852	43,772
118	4	27	9,8876	.699	.856	44,660
119	4	28	8,5321	.695	.847	37,930
120	4	29	10,0621	.694	.854	45,020
121	4	30	10,1940	.692	.856	45,597
122	5	1	9,8601	.698	.846	43,969
123	5	2	8,8771	.694	.825	38,371
124	5	3	4,2682	.684	.706	15,560
125	5	4	8,6122	.689	.848	37,969
126	5	5	5,4127	.681	.700	19,490
127	5	6	6,0051	.687	.786	24,495
128	5	7	2,2896	.666	.608	7,002
129	5	8	9,9307	.687	.857	44,191
130	5	9	8,9267	.695	.834	39,086
131	5	10	9,0997	.690	.835	39,616
132	5	11	8,9760	.683	.836	38,733
133	5	12	9,5182	.685	.842	41,473
134	5	13	10,4815	.684	.859	46,553
135	5	14	9,8611	.684	.819	41,727
136	5	15	9,2331	.688	.835	40,066
137	5	16	9,1621	.685	.831	39,392
138	5	17	10,1977	.679	.839	43,875
139	5	18	8,9876	.693	.825	38,767
140	5	19	7,5611	.669	.786	30,027
141	5	20	3,7094	.684	.686	13,147
142	5	21	8,0761	.682	.797	33,183
143	5	22	9,3714	.680	.823	39,667
144	5	23	9,1580	.682	.813	38,371
145	5	24	9,5561	.682	.811	39,941
146	5	25	9,5670	.678	.830	40,692
147	5	26	9,9476	.676	.850	43,177
148	5	27	9,5115	.679	.836	40,792
149	5	28	8,6606	.675	.788	34,787

Table 2-2. Average Daily Concentrator/Receiver Performance (Page 4 of 7)

Day	Date	Insol (kwh/m^2 - day)	Field eff.	Receiver eff.	Thermal engy (mw H_t)
150	5 29	9,3013	,679	,801	38,220
151	5 30	9,6997	,675	,813	41,082
152	5 31	10,4037	,675	,822	43,589
153	6 1	10,2469	,673	,844	43,953
154	6 2	7,4449	,654	,779	28,621
155	6 3	10,3304	,675	,818	43,067
156	6 4	9,6830	,676	,813	40,204
157	6 5	9,9685	,676	,828	42,163
158	6 6	9,6302	,675	,812	39,898
159	6 7	9,5408	,677	,813	39,660
160	6 8	8,0849	,677	,813	39,660
161	6 9	7,8251	,684	,817	34,165
162	6 10	7,0863	,676	,787	31,431
163	6 11	10,4500	,654	,738	25,824
164	6 12	10,0293	,669	,835	44,096
165	6 13	9,9022	,668	,842	42,639
166	6 14	10,8781	,661	,824	40,710
167	6 15	11,2407	,665	,845	46,156
168	6 16	9,9196	,663	,870	48,991
169	6 17	9,6660	,671	,802	40,312
170	6 18	10,8363	,665	,820	39,809
171	6 19	10,4527	,665	,832	45,250
172	6 20	10,8800	,666	,841	44,219
173	6 21	10,7963	,665	,826	45,141
174	6 22	10,9537	,662	,830	44,838
175	6 23	11,1702	,664	,836	45,922
176	6 24	11,3631	,662	,847	47,329
177	6 25	10,1328	,662	,858	48,701
178	6 26	10,7693	,667	,830	42,410
179	6 27	10,4820	,668	,846	45,299
180	6 28	9,1903	,667	,847	44,779
181	6 29	9,5389	,677	,826	38,806
182	6 30	9,9084	,669	,816	39,322
183	7 1	10,9224	,666	,832	41,482
184	7 2	10,6461	,670	,833	46,067
185	7 3	10,2447	,669	,829	44,552
186	7 4	10,2014	,670	,847	43,934
187	7 5	10,5394	,669	,846	43,607
188	7 6	10,1475	,669	,839	44,706
189	7 7	9,5430	,670	,844	43,331
190	7 8	9,5469	,674	,837	40,662
191	7 9	9,6165	,674	,834	40,556
192	7 10	7,9894	,677	,820	40,316
193	7 11	8,7717	,669	,810	32,675
194	7 12	9,4203	,676	,824	36,955
195	7 13	9,5090	,678	,831	40,098
196	7 14	7,3423	,676	,840	40,773
197	7 15	4,2668	,687	,805	30,687
198	7 16	4,5075	,668	,711	15,309
199	7 17	8,9311	,685	,781	18,222
200	7 18	9,8842	,687	,829	38,414
201	7 19	10,2152	,678	,840	42,539
202	7 20	9,8130	,676	,852	44,458
203	7 21	9,6052	,677	,840	42,146
204	7 22	1,8738	,680	,845	41,664
205	0 0	INSOLATION TOO LOW	,654	,703	6,503

Table 2-2. Average Daily Concentrator/Receiver Performance (Page 5 of 7)

Day	Date		Insol (kwh/m^2 - day)	Field eff.	Receiver eff.	Thermal engy (mw H_t)
206	7	24	9,0295	.683	.830	38,656
207	7	25	4,2460	.686	.759	16,705
208	7	26	4,2755	.734	.785	19,610
209	7	27	5,1124	.697	.777	20,928
210	7	28	6,4022	.677	.800	26,165
211	7	29	5,3649	.696	.765	21,584
212	7	30	3,1530	.669	.744	11,855
213	7	31	9,2271	.684	.838	39,928
214	8	1	10,4821	.682	.856	46,255
215	8	2	10,2702	.685	.840	44,650
216	8	3	9,9105	.690	.828	42,742
217	8	4	10,3629	.685	.833	44,680
218	8	5	10,2390	.689	.846	45,081
219	8	6	10,3718	.689	.842	45,427
220	8	7	10,4122	.690	.843	45,793
221	8	8	9,9449	.691	.834	43,296
222	8	9	10,4157	.688	.861	46,650
223	8	10	10,4562	.692	.851	46,509
224	8	11	10,3909	.692	.856	46,481
225	8	12	10,1363	.697	.841	44,843
226	8	13	9,8082	.697	.820	42,306
227	8	14	3,5626	.701	.648	12,224
228	8	15	9,4712	.691	.795	39,317
229	8	16	9,9645	.697	.851	44,657
230	8	17	9,5800	.705	.837	42,737
231	8	18	8,5655	.702	.814	36,982
232	8	19	9,2230	.695	.847	41,004
233	8	20	9,8891	.698	.851	44,369
234	8	21	8,7912	.703	.844	39,403
235	8	22	9,7679	.700	.826	42,666
236	8	23	10,0325	.697	.863	45,593
237	8	24	9,5443	.703	.838	43,482
238	8	25	9,5145	.703	.845	42,702
239	8	26	9,5066	.704	.834	42,167
240	8	27	9,1049	.707	.857	41,656
241	8	28	8,6810	.708	.853	39,604
242	8	29	8,5366	.710	.852	39,003
243	8	30	8,2910	.713	.859	38,377
244	8	31	8,6058	.711	.851	39,295
245	9	1	9,0174	.706	.846	40,652
246	9	2	7,4392	.717	.813	32,739
247	9	3	2,4324	.701	.743	9,576
248	9	4	7,9461	.719	.832	35,876
249	9	5	6,0615	.702	.601	25,731
250	9	6	4,2244	.715	.612	18,516
251	9	7	8,0738	.715	.854	37,243
252	9	8	6,5541	.729	.628	29,904
253	0	0	INSOLATION TOO LOW			
254	0	0	INSOLATION TOO LOW			
255	0	0	INSOLATION TOO LOW			
256	9	12	7,6103	.716	.837	34,458
257	9	13	7,7527	.710	.846	35,174
258	9	14	5,4833	.747	.810	25,082
259	9	15	7,8792	.716	.824	35,105
260	9	16	7,8766	.724	.838	35,776

Table 2-2. Average Daily Concentrator/Receiver Performance (Page 6 of 7)

Day	Date	Insol (kwh/m^2 - dat)	Field eff.	Receiver eff.	Thermal engy ($mw H_t$)
261	9 17	8,6420	,720	,841	39,554
262	9 18	8,7647	,718	,861	40,918
263	9 19	6,6564	,739	,832	30,914
264	0 0	INSOLATION TOO LOW			
265	9 21	8,4372	,724	,864	39,853
266	9 22	4,9474	,731	,797	21,788
267	9 23	4,0698	,759	,793	18,511
268	9 24	2,7743	,759	,778	12,362
269	9 25	4,9445	,744	,806	22,392
270	9 26	7,3775	,729	,843	34,273
271	9 27	6,9551	,738	,839	32,523
272	9 28	2,9803	,726	,781	12,774
273	0 0	INSOLATION TOO LOW			
274	9 30	8,6133	,725	,845	39,871
275	10 1	7,0034	,735	,834	32,456
276	10 2	8,2611	,728	,817	37,156
277	10 3	8,1814	,726	,861	38,625
278	10 4	8,6478	,725	,865	40,989
279	10 5	8,7977	,724	,867	41,721
280	10 6	8,7510	,724	,864	41,344
281	10 7	8,1967	,735	,854	38,880
282	10 8	8,8726	,725	,867	42,178
283	10 9	8,8369	,725	,866	41,909
284	10 10	8,6379	,726	,884	41,913
285	10 11	8,2657	,730	,851	38,768
286	10 12	7,8012	,733	,852	36,769
287	10 13	8,3103	,728	,862	39,405
288	10 14	8,3558	,729	,852	39,171
289	10 15	8,1230	,732	,850	38,178
290	10 16	[illegible],0534	,745	,784	17,885
291	10 17	5,8634	,740	,823	26,976
292	10 18	6,7735	,747	,847	32,386
293	10 19	5,8998	,759	,841	28,466
294	10 20	1,6111	,794	,700	6,763
295	0 0	INSOLATION TOO LOW			
296	0 0	INSOLATION TOO LOW			
297	10 23	5,8765	,736	,826	26,996
298	10 24	6,7075	,733	,836	31,047
299	10 25	6,2465	,737	,835	29,021
300	10 26	6,4635	,737	,822	29,573
301	10 27	7,6380	,722	,854	35,572
302	10 28	8,0132	,720	,867	37,768
303	10 29	7,1604	,734	,861	34,184
304	10 30	7,2295	,721	,856	33,693
305	10 31	7,5600	,718	,863	35,376
306	11 1	7,7077	,716	,861	35,893
307	11 2	7,1490	,723	,857	33,450
308	11 3	7,6248	,714	,862	35,451
309	11 4	7,8980	,713	,869	36,966
310	11 5	7,8835	,712	,865	36,699
311	11 6	7,8205	,713	,868	36,541
312	11 7	7,5430	,713	,860	34,934
313	11 8	7,5566	,715	,863	35,197
314	11 9	4,9139	,706	,822	21,541
315	11 10	6,9622	,713	,844	31,631

Table 2-2. Average Daily Concentrator/Receiver Performance (Page 7 of 7)

Day	Date		Insol (kwh/m^2 - day)	Field eff.	Receiver eff.	Thermal engy (mw H_t)
316	11	11	1.7102	.722	.610	5,694
317	0	0	INSOLATION TOO LOW			
318	11	13	5.3939	.719	.837	24,543
319	11	14	4.6300	.708	.744	18,418
320	11	15	7.1480	.710	.852	32,673
321	11	16	7.1993	.708	.859	33,066
322	11	17	7.3339	.707	.868	34,019
323	11	18	7.1591	.708	.869	33,261
324	11	19	6.6818	.709	.863	30,878
325	11	20	6.7899	.710	.866	31,533
326	11	21	6.5116	.710	.851	29,700
327	11	22	6.6691	.708	.857	31,470
328	11	23	6.9126	.708	.867	32,073
329	11	24	6.9241	.708	.853	31,570
330	11	25	7.0602	.706	.844	31,804
331	11	26	5.6527	.719	.809	24,830
332	11	27	7.0698	.709	.837	31,682
333	11	28	6.7555	.710	.860	31,129
334	11	29	6.6472	.710	.865	30,828
335	11	30	6.6664	.709	.859	30,666
336	12	1	6.5443	.709	.862	30,211
337	12	2	7.0064	.705	.864	32,237
338	12	3	7.2622	.703	.858	33,074
339	12	4	6.3950	.705	.863	29,406
340	12	5	7.0803	.702	.841	31,588
341	12	6	6.8398	.707	.862	31,508
342	12	7	6.9576	.702	.859	31,678
343	12	8	6.9020	.701	.876	32,021
344	12	9	5.6538	.708	.826	24,984
345	12	10	6.8121	.700	.845	30,468
346	12	11	6.8004	.700	.862	30,989
347	12	12	6.7057	.699	.857	30,363
348	12	13	6.2193	.702	.874	28,793
349	12	14	5.5977	.694	.839	24,604
350	12	15	6.8612	.698	.865	31,281
351	12	16	6.8871	.697	.865	31,384
352	12	17	6.7738	.697	.855	30,527
353	12	18	4.8363	.700	.832	21,273
354	12	19	4.2409	.694	.797	17,701
355	12	20	6.3319	.698	.854	28,502
356	12	21	6.8012	.695	.872	31,115
357	12	22	6.1913	.705	.864	28,504
358	0	0	INSOLATION TOO LOW			
359	12	24	6.8555	.696	.839	30,271
360	12	25	6.9954	.696	.866	31,870
361	12	26	2.8082	.721	.784	11,984
362	12	27	6.5528	.696	.857	29,514
363	12	28	7.0682	.698	.872	32,477
364	12	29	1.2914	.697	.507	3,443
365	0	0	INSOLATION TOO LOW			
366	12	31	.6695	.694	.462	1,621

MCDONNELL DOUGLAS

Table 2-3. Availability Analysis (Page 1 of 5)

Subsystem: Collector, Assembly: Heliostat

System: All

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Power Cable	Open/Short	0.108	3,861	0.42	1.5	0.63	Yes	1	0.63	Field power must be turned off
Control cable	Open/Short	0.108	3,861	0.42	1.5	0.63	Yes	1	0.63	Field power must be turned off
Motors	F Top	2.0	3,861	7.72	1.9	14.7	No	2	0	
Harmonic Drive	F Top	1.65	3,861	6.37	4.0	25.5	No	1	0	
Linear Drive	F Top	2.94	3,861	11.4	2.2	25.2	No	1	0	
Azimuth Optical Encoder	F Top	1.35	3,861	5.21	2.7	14.1	No	2	0	

MCDONNELL DOUGLAS

Table 2-3. Availability Analysis (Page 2 of 5)

Subsystem: Collector, Assembly: Heliostat

System: All

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Elevation Optical Encoder	F Top	1.35	3,861	5.21	2.0	10.4	No	3	0	
Azimuth Limit Switches	F Top	1.87	3,861	7.22	2.0	14.4	No	2	0	
Elevation Limit Switches	F Top	1.87	3,861	7.22	1.1	7.9	No	4	0	
Pedestal	Structural Failure	0.1	8,760	0.876	1.0	0.876	No	1	0	
Structure	Structural Failure	0.5	8,760	4.38	1.5	6.57	No	1	0	

Table 2-3. Availability Analysis (Page 3 of 5)

Subsystem: Collector, Assembly: Heliostat

System: All

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Muroc Panel	Structural Failure	6.0	8,760	52.6	2.0	105	No	1	0	
Storage Motor	F Top	2.0	165	0.33	1.9	0.63	No	1	0	
Storage Actuator	F Top	2.94	165	0.5	2.2	1.07	No	1	0	
Helio Controller	F Top	5.79	3,861	22.36	2.2	49.2	No	31/32	0	Use for 4.5, 6.5 and commercial programs
Circuit Breaker	FTRC	1.0	3,861	3.86	1.6	6.18	Yes	1	6.18	
Field Power Cables	Open/Short	0.108	3,861	0.42	2.5	1.05	Yes	1	1.05	

Table 2-3. Availability Analysis (Page 4 of 5)

Subsystem: Collector, Assembly: Heliostat

System: All

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Field Control Cables	Open/Short	0.108	3,861	0.42	2.5	1.05	Yes	1	1.05	
Data Distri-bution Interface	F Top	9.74	3,861	37.6	2.2	82.7	Yes	1/32	2.58	Use for commercial programs
HAC/Field Control-ler Power Cables	Open/Short	0.108	3,861	0.42	2.5	1.05	Yes	1/32	0.04	
HAC/Field Control-ler Power Cables	Open/Short	0.108	3,861	0.42	2.5	1.05	Yes	1/32	0.04	
Helio Control-ler	F Top	26.22	3,861	101.2	2.2	223	No	31/32	0	Use for 3.5 year program

Table 2-3. Availability Analysis (Page 5 of 5)

Subsystem: Collector, Assembly: Heliostat

System: All

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Field Controller	F Top	43.25	3,861	167	2.2	367	Yes	1/32	11.5	Use for 3.5 year program

Table 2-4. Availability Analysis (Page 1 of 2)

Subsystem: Collector, Assembly: Receiver

System: All

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Absorber	Leak/ clogged	16.0	8,760	140.1	14	1962	Yes	1	1962	
Absorber Support Structure	Structural failure	1.0	8,760	8.76	10	87.6	Yes	1	87.6	
Absorber Door	Structural failure	1.0	8,760	8.76	8	70.1	Yes	1	70.1	
Piping	Leak/ clogged	1.0	8,760	8.76	12	105	Yes	1	105	
Vent Value	FTRC	5.23/d 1.72/hr	3,861	10.46	5.2	54.4	Yes	1	54.4	1 demand/week
Relief Valve	FTRC	10.0	3,861	38.6	4.5	173.8	Yes	1	173.8	
Trace Heaters	F Top	10.0	3,861	38.6	20	772	No	1	0	
Insulation	Structural failure	1.0	3,861	3.86	10	38.6	Yes	1	38.6	

Table 2-4. Availability Analysis (Page 2 of 2)

Subsystem: Collector, Assembly: Receiver

System: All

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Hand Valves	FTRC	0.1	3,861	0.386	4.5	1.74	Yes	2	3.47	
Sensors	F Top	1.0	3,861	3.86	4.0	15.44	No	20	0	
Door Motors	F Top	2.0	122	0.244	3.0	0.732	No	1	0	20 min/day

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Table 2-5. Availability Analysis

Subsystem: Energy Transport

System: 3.5, 4.5

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Control Valves	F Top	6.46	3,861	24.9	5.7	142	Yes	3	427	
Remote Valves	F Top	5.23/d 1.72/m	3,861	10.5	5.2	54.4	Yes	6	326	2 demands/day
Check Valves	FTRO	4	3,861	15.4	4.5	69.5	Yes	1	70	
Hand Valves	FTRO	0.3	3,861	1.16	4.5	5.2	YES	19	99	
Pumps	F Top	1000/d 30/m	3,861	467	9.7	4,530	Yes	2	9,060	1 demand/day
Sensor	F Top	1.0	3,861	3.86	3.0	11.6	No	5	0	
Heat Exchanger	Leak clogged	1.8	3,504	6.31	10	63.1	Yes	3	189	12.8 hr/yr planned outage
Heater	F Top	10	8,760	87.6	20	1752	No	1	0	

Table 2-6. Availability Analysis

Subsystem: Energy Transport

System: 6.5

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Control Valves	F Top	6.46	3,861	24.94	5.7	142	Yes	3	426	
Remote Valves	F Top	5.23/d 1.72/hr	3,861	10.46	5.2	54.4	Yes	7	381	2 demands/day
Check Valves	FTRO	4.0	3,861	15.44	4.5	69.5	Yes	1	70	
Hand Valves	FTRO	0.3	3,861	1.16	4.5	5.2	Yes	25	131	
Pumps	F Top	1.000/d 30/m	3,861	467	9.7	4,530	Yes	2	9,060	1 demand/day
Sensor	F Top	1.0	3,861	3.86	3.0	11.6	No	5	0	
Heat Exchangers	Leak, clogged	1.8	3,504	6.31	10	63.1	Yes	3	1.89	12.8 hr/yr planned outages
Mixer Tank	Leak	1.0	8,760	8.76	10	87.6	Yes	1	87.6	
Heaters	Leak	10	8,760	87.6	10	1752	No	1	0	

Table 2-7. Availability Analysis

Subsystem: Energy Storage

System: 3.5, 4.5

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Hand Valves	FTRO	0.3	3,861	1.16	4.5	5.2	Yes	5	26.1	
Check Valves	FTRO	4.0	3,861	15.4	4.5	69.5	Yes	2	139	
Regulator	F Top	18	3,861	69.5	5.7	396	Yes	2	792	
Sensors	F Top	1.0	3,861	3.9	3.0	11.6	No	20	0	
Relief Valves	FTRC	1.0	3,861	38.6	4.5	174	Yes	2	347	
Heater	F Top	0.4	100	0.04	10	0.4	No	20	0	
Tank	Leak	1.0	8,760	8.76	10	87.6	Yes	2	154	

Table 2-8. Availability Analysis

Subsystem: Energy Storage

System: 6.5

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Hand Valves	FTRO	0.3	3,861	1.16	4.5	5.21	Yes	4	20.8	
Check Valves	FTRO	4.0	3,861	15.4	4.5	69.5	Yes	1	69.5	
Regulator	F Top	18	3,861	69.5	5.7	39.6	Yes	1	39.6	
Sensor	F Top	1.0	3,861	3.9	3.0	11.6	No	10	0	
Relief Valves	FTRC	10	3,861	38.6	4.5	173.8	Yes	1	173.8	
Heater	F Top	0.4	100	0.04	10	0.4	No	10	0	
Tank	Leak	1.0	8,760	8.8	10	87.6	Yes	1	87.6	

Table 2-9. Availability Analysis (Page 1 of 2)

Subsystem: Power Conversion

System: 3.5, 4.5

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
										Planned Outage
Turbine	F Top	102	3,504	357	40	14,296	Yes	1	14,296	104 hr/yr
Generator	F Top	80	3,504	280	40	11,212	Yes	1	11,212	76 hr/yr
Condensor	Leak	1.0	3,504	3.5	10	35	Yes	1	35	12.8 hr/yr
Tank	Leak	1.0	3,504	3.5	10	35	Yes	1	35	
Diaerator	Leak	1.0	3,504	3.5	10	35	Yes	1	35	12.8 hr/yr
Pump	F Top	1000/d 30/hr	3,504	457	9.7	4,434	Yes	3	13,302	1 demand/day
Control Valves	F Top	6.46	3,504	22.6	4.7	106	Yes	8	848	
Hand Valves	FTRO	0.3	3,504	1.05	3.5	3.7	Yes	47	173	
Hand Valves	FTRC	0.1	3,504	0.35	3.5	1.2	Yes	7	8.6	
Pressure Sensor	F Top	1.0	3,504	3.5	2	7.0	No	8	0	

Table 2-9. Availability Analysis (Page 2 of 2)

Subsystem: Power Conversion

System: 3.5, 4.5

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Flow Sensor	F Top	12	3,504	42	3.5	147	No	2	0	
Level Sensors	F Top	1.0	3,504	3.5	2	7.0	No	13	0	

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Table 2-10. Availability Analysis (Page 1 of 2)

Subsystem: Power Conversion

System: 6.5

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Heat Exchanger	Leak Clogged	1.8	3,504	6.31	10	63.1	Yes	4	252	Planned outage 12.8 hr/yr
Deaerator	Leak	1.0	3,504	3.5	10	35	Yes	1	35	
Pumps	F Top	1000/d 30/hr	3,504	457	9.7	4,434	Yes	4	17,736	1 demand/day
Turbine	F Top	102	3,504	357	40	14,296	Yes	1	14,296	Planned outage 104 hr/yr
Generator	F Top	80	3,504	280	40	11,212	Yes	1	11,212	Planned outage 76 hr/yr
Condenser	Leak	1.0	3,504	3.5	10	35	Yes	1	35	
Control Valves	F Top	6.46	3,504	22.6	4.7	106.4	Yes	12	1,277	
Remote Valves	F Top	5.23/d 1.72/m	3,504	9.85	4.2	41.4	Yes	5	207	2 demands/day
Three-way Valves	F Top	5.23/d 1.72/m	3,504	9.85	4.7	46.3	Yes	12	555	2 demands/day

Table 2-10. Availability Analysis (Page 2 of 2)

Subsystem: Power Conversion

System: 6.5

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Check Valves	FTRO	4.0	3,504	14.0	3.5	49.1	Yes	11	540	
Relief Valves	FTRC	10	3,504	35.0	3.5	122.6	Yes	9	1,104	
Hand Valves	FTRO	0.3	3,504	1.05	3.5	3.68	Yes	88	324	
Hand Valves	FTRC	0.1	3,504	0.35	3.5	1.23	-	15	11.1	6 not critical 9 critical
Level Sensors	F Top	1.0	3,504	3.5	2	7.01	No	16	0	
Flow Meters	F Top	12	3,504	42	3.5	147	No	2	0	
Tempera-ture Sensors	F Top	1.0	3,504	3.5	2	7.01	No	4	0	
Pressure Sensors	F Top	1.0	3,504	3.5	2	7.01	No	7	0	

Table 2-11. Availability Analysis (Page 1 of 2)

Subsystem: Power Conversion, Assembly: Cooling Tower Feed

System: All

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Pump	F Top	1000/d 30/m	3,504	457	9.7	4434	Yes	2	8,868	1 demand/day
Heat Exchanger	Clogged	1.8	3,504	6.31	10	63.1	Yes	2	126	Planned outage 12.8 hr/yr
Remote Valves	F Top	5.23/d 1.72/hr	3,504	9.85	4.2	41.4	Yes	2	82.8	2 demands/day
Control Valves	F Top	6.46	3,504	22.64	4.7	106.4	Yes	3	319	
Hand Valves	FTRO	0.3	3,504	1.05	3.5	3.7	Yes	35	130	
Hand Valves	FTRC	0.1	3,504	0.35	3.5	1.23	Yes	11	13.5	
Relief Valves	FTRC	10	3,504	35.04	3.5	123	Yes	4	491	
Level Sensors	F Top	1.0	3,504	3.5	2.0	7.0	No	3	0	

Table 2-11. Availability Analysis (Page 2 of 2)

Subsystem: Power Conversion, Assembly: Cooling Tower Feed

System: All

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Pressure Sensors	F Top	1.0	3,504	3.5	2.0	7.0	No	12	0	
Check Valves	FTRO	4.0	3,504	14.02	3.5	49	Yes	4	196	
Tank	Leak	1.0	8,760	8.76	10	87.6	Yes	3	261	
Structure	Structural Failure	1.0	8,760	8.76	10	87.6	Yes	1	87.6	

Table 2-12. Availability Analysis

Subsystem: Power Conversion, Assembly, Boiler Chemical Feed

System: All

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Hand Valves	FTRO	0.3	3,504	1.05	3.5	3.68	No	20	0	
Hand Valves	FTRC	0.1	3,504	0.35	3.5	1.23	No	8	0	
Relief Valves	FTRC	10	3,504	35	3.5	123	No	5	0	
Tanks	Leak	1.0	3,504	3.5	10	35	No	3	0	

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Table 2-13. Availability Analysis

Subsystem: Power Conversion, Assembly: Demineralizer

System: All

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Remote Valve	F Top	5.23/d 1.72/m	3,504	9.85	4.2	41.4	No	24	0	2 demands/day
Hand Valve	FTRO	0.3	3,504	1.05	3.5	3.68	No	6	0	
Hand Valve	FTRC	0.1	3,504	0.35	3.5	1.23	No	3	0	
Flow Meter	F Top	12	3,504	42.05	3.5	147	No	2	0	
Level Meter	F Top	1.0	3,504	3.5	2	7.0	No	2	0	
Tanks	Leak	1.0	3,504	3.5	10	35	No	4	0	

Table 2-14. Availability Analysis (Page 1 of 2)

Subsystem: Plant Control

System: All

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year ($x10^{-3}$)	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Computer	F Top	20.4	8,760	179	4	715	Yes	1	715	
CRT/Key-board Pro-grammer	F Top	4.0	8,760	35.0	2	70.0	Yes	1	70.0	
Console with Controls	F Top	14.4	8,760	126.1	1	126	Yes	1	126	
Interface Units	F Top	5.2	8,760	45.6	1	45.6	Yes	18	821	5+2+7+4
Power Supply	F Top	9.9	8,760	86.7	1	86.7	Yes	1	86.7	
Timer/ Counter	F Top	0.198	8,760	1.73	1	1.73	Yes	1	1.7	Assume 3 chips

Table 2-14. Availability Analysis (Page 2 of 2)

Subsystem: Plant Control

System: All

Item	Failure Mode	Failure Rate (10^{-6}/hr)	Operating Time (hr)	Failures per year (x10^{-3})	MTTR (hr)	Downtime per year (10^{-3}hr)	Critical	Population	System Downtime per year (10^{-3}hr)	Comments
Modules	F Top	0.397	8,760	3.48	1	3.48	Yes	79	274.7	11+21+21+26 Assume 3 chips, 3 resistors, 3 capacitors, 2-20 pin connectors
Cables	Open/Short	0.108	8,760	0.95	1	0.95	Yes	43	40.7	
Modules	FYOp	0.397	8,760	3.48	1	3.48	Yes	15	52.2	Add for 4.5 yr
Modules	F Top	0.397	8,760	3.48	1	3.48	Yes	30	104.4	Add for 6.5 comm system

Table 2-15. Availability Analysis Results - 3.5 Year System

	Collector	Energy Transport	Energy Storage	Power Conversion	Plant Control	Total System
Total Failures/yr	58.94	1.23	0.35	4.31	1.57	66.40
Critical Failures/yr	2.55	1.13	0.27	3.54	1.57	9.06
Forced Outages, hr/yr	7.08	10.17	1.46	50.52	2.14	71.37
Planned Outages, hr/yr	0	12.80	0	104.00	0	104.00
Total Outages, hr/yr	7.08	22.97	1.46	154.52	2.14	175.37
Forced Outage Rate, %	0.18	0.26	0.04	1.44	0.02	1.94
Planned Outage Rate, %	0	0.33	0	2.97	0	2.97
Total Outage Rate, %	0.18	0.59	0.04	4.41	0.02	4.91
Operating Availability, %	99.82	99.41	99.96	95.59	99.98	95.09
CMTBF, hr	1,608	3,417	14,300	990	5,580	460
CMTTR, hr	2.83	9.00	5.41	14.27	1.36	7.98
Corrective MMH/yr	463	41	4	149	0	657
Preventive MMH/yr	713	96	1	994	0	1,804
Total MMH/yr	1,176	137	5	1,143	0	2,461

Table 2-16. Availability Analysis Results - 4.5-Year System

	Collector	Energy Transport	Energy Storage	Power Conversion	Plant Control	Total System
Total Failures/yr	32.57	1.23	0.35	4.31	1.62	40.08
Central Failures/yr	1.17	1.13	0.27	3.54	1.62	7.73
Forced Outages, hr/yr	4.14	10.17	1.46	50.52	2.19	68.48
Planned Outages, hr/yr	0	12.80	0	104.00	0	104.00
Total Outage, hr/yr	4.14	22.97	1.46	154.52	2.19	172.48
Forced Outage Rate, %	0.11	0.26	0.04	1.44	0.03	1.88
Planned Outage Rate, %	0	0.33	0	2.97	0	2.97
Total Outage Rate, %	0.11	0.59	0.04	4.41	0.03	4.85
Operating Availability, %	99.88	99.41	99.96	95.59	99.97	95.15
CMTBR, hr	3,387	3,417	14,300	990	5,407	540
CMTTR, hr	3.59	9.00	5.41	14.27	1.35	8.88
Corrective MMH/yr	211	41	4	149	0	405
Preventive MMH/yr	566	96	1	994	0	1,657
Total MMH/yr	777	137	5	1,143	0	2,062

Table 2-17. Availability Analysis Results - 6.5-Year System

	Collector	Energy Transport	Energy Storage	Power Conversion	Plant Control	Total System
Total Failures/yr	26.54	1.26	0.18	5.58	1.72	35.28
Central Failures/yr	0.99	1.15	0.14	4.77	1.72	8.77
Forced Outages, hr/yr	3.83	10.35	0.39	58.16	2.29	75.02
Planned Outages, hr/yr	0	12.80	0	104.00	0	104.00
Total Outages, hr/yr	3.83	23.15	0.39	162.16	2.29	179.02
Forced Outage Rate, %	0.10	0.27	0.01	1.66	0.03	2.07
Planned Outage Rate, %	0	0.33	0	2.97	0	2.97
Total Outage Rate, %	0.10	0.60	0.01	4.63	0.03	5.04
Operating Availability, %	99.89	99.40	99.99	95.37	99.97	94.96
CMTBR, hr	3,900	3,357	27,579	735	5,093	466
CMTTR, hr	3.87	9.00	2.79	12.19	1.33	8.55
Corrective MMH/yr	174	41	2	169	0	386
Preventive MMH/yr	464	96	1	1,122	0	1,683
Total MMH/yr	638	137	3	1,291	0	2,069

Table 2-18. Availability Analysis Results - Commercial System

	Collector	Energy Transport	Energy Storage	Power Conversion	Plant Control	Total System
Total Failures/yr	25.56	1.26	0.18	5.58	3.44	36.02
Central Failures/yr	1.12	1.15	0.14	4.77	0	7.18
Forced Outages, hr/yr	4.12	10.35	0.39	58.16	0	73.02
Planned Outages, hr/yr	0	12.80	0	104.00	0	104.00
Total Outages, hr/yr	4.12	23.15	0.39	162.16	0	177.02
Forced Outage Rate, %	0.11	0.27	0.01	1.66	0	2.05
Planned Outage Rate, %	0	0.33	0	2.97	0	2.97
Total Outage Rate, %	0.11	0.60	0.01	4.63	0	5.02
Operating Availability, %	99.9	99.40	99.99	95.37	100.0	94.98
CMTBF, hr	3,713	3,357	27,579	735	--	509
CMTTR, hr	3.83	9.00	2.79	12.19	--	10.26
Corrective MMH/yr	166	41	2	169	0	378
Preventive MMH/yr	445	96	1	1,122	0	1,664
Total MMH/yr	611	137	3	1,291	0	2,042

Based on the failure rates and operating times, the failures per year were calculated for each of the specified components. This is multiplied by the mean time to recover (MTTR) to obtain the downtime per year for each component. The MTTR was obtained by detailed analysis of recovery times on similar programs and by actual time measurements on test heliostats in field operations at China Lake, California.

A determination was then made on the criticality of each component. If the failure of the component would cause a system shutdown, it is classified as critical. This is the case of most valves, pumps, etc. It was assumed that most sensors and some auxiliary systems (e.g., demineralizer) were not critical and the system could continue to run while corrective maintenance was performed. The majority of the heliostat components are non-critical, as discussed below, due to the fact that the loss of one or a few heliostats would not cause a system shutdown.

The next column (Population) of Tables 2-3 through 2-14 lists the number of components of the generic type within the subsystem. The product of this number and the component downtime per year for the critical component gives the system downtime per year.

The results of this analysis are displayed in Tables 2-15 through 2-18.

The results of the study indicate that the overall availability for this type of system should be about 0.95 with small variations due to design specifics. The 3.5-year program with an axial turbine subsystem, a dual tank energy storage subsystem and 217 heliostats has a projected availability of 95.09%. The 4.5-year system with the same power generation and energy storage but with only 171 heliostats has a projected availability of 95.15%. The 6.5-year and the commercial programs with radial turbine power generation subsystems, single tank energy storage subsystems and 139 and 133 heliostats have an availability of 94.96% and 94.98%, respectively.

The loss of a single heliostat, or a few heliostats, does not directly affect the system availability due to the fact that system outages of less than 2% are not counted as a forced outage (Reference 2-1). Losses greater than 2% are counted as either partial forced outages or total forced outages depending on the magnitude of the outage. In this study the concept of partial forced outages was not used due to very small probability of losing several heliostats at the same time and the fact that the remainder of the system is a single thread design which means that any critical failure causes a total shutdown. The probability of losing one heliostat in one operating day is 0.15 for the 3.5-year system (and even less for the 4.5- and 6.5-year programs) and 0.0225 for losing two heliostats in one day. The loss of 4 heliostats (probability of 0.00051) would still result in a loss of power of less than 2%.

However, some failures on the heliostat (failure of power or control cables) will cause a loss of 32 heliostats due to the fact that power must be removed from all heliostats on that circuit in order to effect the repair. In addition, failure of a field controller will cause loss of 32 heliostats. These failures are classified as critical and appear in the critical failure classifications in Table 2-3. The collector subsystem in Tables 2-3 and 2-4 include the heliostat field and the receiver.

The large difference between the total failures per year value for the collector subsystem (55.16 in Table 2-15) and the critical failures per year, failures which cause a system shutdown (2.4 in Table 2-15) reflect the fact that most failures in the heliostat field do not cause a system shutdown.

The reduction in collector system total failures, critical failure and forced outage hours from the 3.5-year program and the commercial program reflects the reduction in the number of heliostats from 217 to 133. The corrective maintenance values also reflect this reduction. Most of the preventive maintenance shown for the collector subsystem represents heliostat mirror washing. The details of the maintenance analysis are discussed in Volume III, Section 6.2.

The cumulative mean time between failure (CMTBF) and the cumulative mean time to recover (CMTTR) are calculated by dividing the operating time per year by the number of critical failures per year and the forced outage hours per year by the number of critical failures per year.

The differences in failure characteristics in the energy storage subsystems for the different programs reflect the change from a two-tank system to a single-tank dual-media system with the reduction of system components. The increase in the failure characteristics of the power conversion subsystem of the 6.5 year and commercial program over the 3.5 and 4.5 year system reflects the change to the radial turbine and the four feedwater heaters as opposed to the axial turbine with no feedwater heaters.

The lack of maintenance manhours for the plant control subsystem reflects the fact that all maintenance on this subsystem will be performed by the supplier and the cost is included in the initial acquisition cost. Also, the plant control subsystem for the commercial program will be redundant, therefore there are no critical failures in that subsystem.

The preventive maintenance (planned outage) downtime is shown for each subsystem. Specifically, this represents the downtime required to clean heat exchanger (steam generator and feedwater heaters) tubes and perform seasonal maintenance on the turbine and generator. However, it is assumed that all of this maintenance would be scheduled at the same time, therefore only the largest downtime (104 hours for the turbine) is charged overall system downtime.

The results of this analysis can be compared to the historical experience of conventional power generating plants as reported in Reference 2-2 and Figure 2-5. The figure shows the operating availability and outages (forced and planned) are strong functions of plant size. There is little information on power plants in the 1 MW range, but extrapolations of the data from larger power plants indicate that the forced outage for a 1 MW plant should be about 2.5%. This compares with the results of this study which range from 1.88 to 2.07%. The lower value from the study probably reflects the relatively simplified designs available at this stage of the program. It would be expected that as the design matures the design will contain more components. The historical data indicate that the planned outage should be about 5.5% as opposed to the study results of 2.97%. This is primarily due to the fact that the solar system operates only 40% of the time; therefore, preventive maintenance can be performed on a 24-hour basis but is only charged at a 0.6-hour basis. The charged planned outage may be somewhat high, based on this comparative analysis, indicating that the critical planned outage may be less.

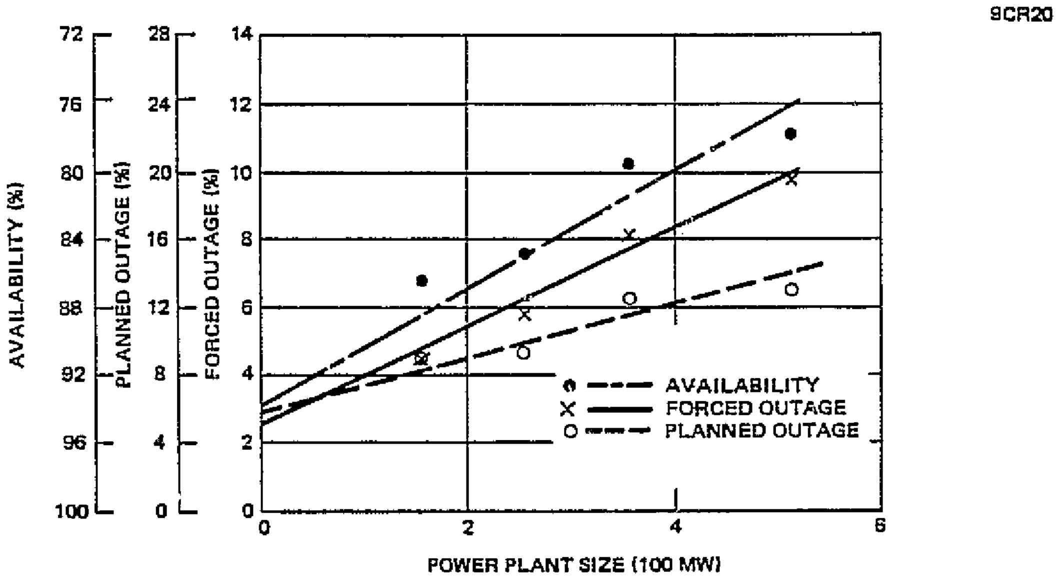


Figure 2-5. Power Plant Failure Characteristics

The extrapolated availability value is 94% as compared with analysis results of 94.96 to 95.09. This higher availability is primarily the result of the advantage of the charged versus actual planned outage time.

The mean time to recover (MTTR) values used in Tables 2-3 through 2-14 assume that maintenance personnel are on the site or within a short distance. This may not be true in all cases. For example, the maintenance for the plant control will be performed by the noted supplier. Also, maintenance personnel may be situated some distance from some plant locations when several locations utilize on the same maintenance crews.

The results of an analysis of the effect of this type of operation are shown in Figure 2-6. Figure 2-6 shows the drop in system availability as a function of the travel time (time it takes to get to the power plant site).

2.3 STAND-ALONE CAPABILITY

The experimental plant, as defined in Volume III, is designed to interface with an existing electrical transmission grid. The plant can be modified to operate as a stand-alone unit in a location not serviced by a grid by making a few alterations.

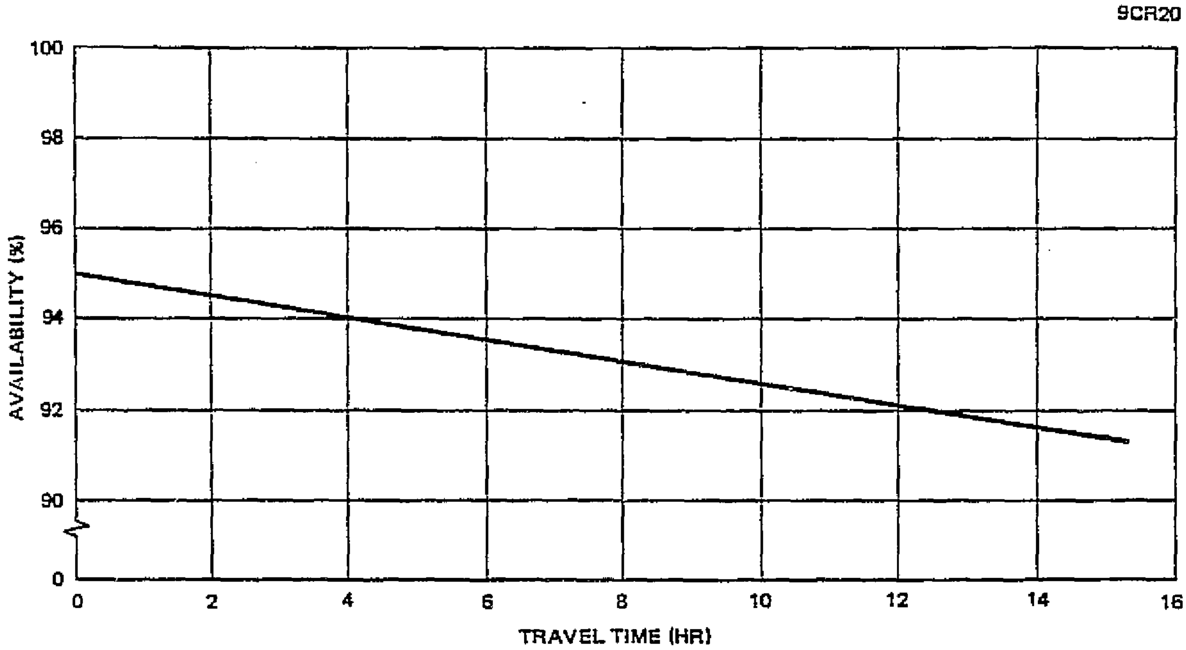


Figure 2-6. Effect of Maintenance Personnel Travel Time on System Availability

The most obvious constraint placed upon a plant operating in this mode is that it must be capable of supplying the electrical demand 24 hr/day throughout the year. This can be accomplished by either or both:

A. Adding a diesel generator capable of supplying the plant rated power.

B. Adding a fossil fuel fired Hitec heater capable of supplying the heat input necessary for operation.

The diesel generator would provide a reliable, quick-starting source of electrical energy to make up that portion of the electrical load the solar powered steam turbine could not provide. It would also provide a redundant power source for periods of no insolation or when the steam cycle is down for repair or maintenance. The capital cost of such a system would be low, but operating and maintenance costs would be relatively high.

The second approach consists of a fossil fired Hitec heater placed in parallel with the receiver. This heater would function in a capacity identical to that of the receiver, taking the Hitec/HTS from the energy storage at the "cold" temperature and returning it to storage at the "hot" temperature. This unit would not need to be sized for the same thermal output as that required by the steam generator since the steam generator (and power conversion subsystem) would not be operating at full capacity 24 hr/day. The heater could then operate 24 hr/day at a reduced output and still supply the necessary energy per day. The use of the plant as a stand-alone unit would require operating the steam cycle 24 hr/day. This would eliminate the penalties associated with daily shutdown and startup procedures such as thermal fatigue, water cleanup procedures, gaseous nitrogen blanketing, and make unsupervised operation less complicated. The capital cost of the fired Hitec heater is less than that of a diesel generator and the operating and maintenance costs are much less due to fewer moving parts and the ability to burn lower grades of fuel than required for a diesel generator.

Assuming that the application is one that can tolerate occasional losses of electrical power, the Hitec heater is the preferred approach due to lower costs and easier operation.

Additional equipment required in a stand-alone plant would be an electrical resistance bank to serve as a buffer for electrical load transients. This unit would be cooled using the cooling tower water.

2.4 AUXILIARY POWER REQUIREMENTS

A tabulation of the auxiliary power requirements of the experimental systems is made in Tables 2-19 through 2-21. These power requirements are based on the component efficiencies and power needs presented in Volume III for design conditions during periods of insolation, no insolation, night standby, and emergency shutdown conditions. Where appropriate, the power consumption of cycling units such as the instrument air dryer has been averaged over the cycle period. The results of these tabulations have been used to refine (1) the gross electrical power that the turbine should produce for 1 MWe net power, and (2) the gross electrical energy to be produced annually to meet the 0.4 capacity factor requirement.

Table 2-19. Plant Auxiliary Power Requirements (kW), 3.5-Year Axial Turbine Case

Component	Daylight operation (1.0 mW_e)	Evening operation (1.0 mW_e)	Night standby	Emergency power (AC)
Steam Generator Feed Pump	23.0	23.0	No	No
Condensate Pump	2.3	2.3	No	No
Condenser Exhauster Vacuum Pump	6.0	6.0	No	No
Condensate Transfer Pump	No	No	0.1	No
Plant Air Compressor	2.8*	2.8*	0.5**	No
Circulating Water Pump	13.8	13.8	No	No
Cooling Tower Fan	15	15	No	No
Turbine DC Oil Pump	No	No	No	No
Chemical Pumps	1.9	1.9	No	No
HVAC	5.0	5.0	3.0	5.0
Lighting	3.0	3.0	2.0	1.0
Uninterruptable Power Supply	7.5	7.5	7.5	8.3
Receiver Pump	40	No	No	No
Hot Storage Pump	6	6	No	No
Heliostats	6.0	No	No	24.9
Trace Heating	No	No	1.7****	1.7****
Powdex Recirculating Pump	No	No	Neg	Neg
Plant Air Dryer	0.7***	0.7***	0.7***	No
Misc Equipment				
Transformer and Transmission Loss	1	1	Neg	Neg
TOTAL	134.0	88.0	15.5	40.9

*Estimated average power requirement during operation-maximum requirement 11.9 kW

**Estimated average power requirement during standby-maximum requirement 11.9 kW

***Average requirement based on one regeneration per 4 hours — requirement is 1.8 kW for 1-1/2 hours

****Estimated average power requirement during 14-hour standby

Table 2-20. Plant Auxiliary Power Requirements (kW), 4.5-Year Axial Turbine Case

Component	Daylight operation (1.0 mW_e)	Evening operation (1.0 mW_e)	Night standby	Emergency power (AC)
Steam Generator Feed Pump	18.4	18.4	No	No
Condensate Pump	1.9	1.9	No	No
Condenser Exhauster Vacuum Pump	6.0	6.0	No	No
Condensate Transfer Pump	No	No	0.1	No
Plant Air C^mpressor	2.8*	2.8*	0.5**	No
Circulating Water Pump	11.4	11.4	No	No
Cooling Tower Fan (avg)	113.0	13.0	No	No
Turbine DC Oil Pump	No	No	No	No
Chemical Pumps	1.9	1.9	No	No
HVAC	5.0	5.0	2.0	5.0
Lighting	3.0	3.0	2.0	1.0
Uninterruptable Power Supply	2.0	2.0	2.0	2.8
Receiver Pump	3.0	No	No	No
Hot Storage Pump	5	5	No	No
Heliostats	5.4	No	No	22.4
Trace Heating	No	No	1.3****	1.3****
Powdex Recirculating Pump	No	No	Neg	Neg
Plant Air Dryer	0.7***	0.7***	0.7***	No
Misc Equipment				
Transformer and Transmission Loss	1	1	Neg	Neg
TOTAL	107.5	72.1	8.6	32.5

*Estimated average power requirement during operation-maximum requirement 11.9 kW

**Estimated average power requirement during standby-maximum requirement 11.9 kW

***Average requirement based on one regeneration per 4 hours — requirement is 1.8 kW for 1-1/2 hours

****Estimated average power requirement during 14-hour standby

Table 2-21. Plant Auxiliary Power Requirements (kW), 6.5-Year Radial Turbine Case

Component	Daylight operation (1.0 mW_e)	Evening operation (1.0 mW_e)	Night standby	Emergency power (AC)
Steam Generator Feed Pump	19.3	19.3	No	No
Condensate Pump	1.0	1.0	No	No
Condenser Exhauster Vacuum Pump	6.0	6.0	No	No
Condensate Transfer Pump	No	No	0.1	No
Plant Air Compressor	2.8*	2.8*	0.5**	No
Circulating Water Pump	8.4	8.4	No	No
Cooling Tower Fan (avg)	10	10	No	No
Turbine DC Oil Pump	No	No	No	No
Chemical Pumps	1.9	1.9	No	No
HVAC	5.0	5.0	2.0	5.0
Lighting	3.0	3.0	2.0	1.0
Uninterruptable Power Supply	2.0	2.0	2.0	2.8
Receiver Pump	14	No	No	No
Hot Storage Pump	3	3	No	No
Heliostats	4.0	No	No	16.6
Trace Heating	No	No	8.1****	8.1****
Powdex Recirculating Pump	No	No	Neg	Neg
Plant Air Dryer	0.7***	0.7***	0.7***	No
Misc Equipment				
Transformer and Transmission Loss	1	1	Neg	Neg
TOTAL	82.1	64.1	15.4	33.5

*Estimated average power requirement during operation-maximum requirement 11.9 kW

**Estimated average power requirement during standby-maximum requirement 11.9 kW

***Average requirement based on one regeneration per 4 hours — requirement is 1.8 kW for 1-1/2 hours

****Estimated average power requirement during 14-hour standby

Section 3
COLLECTOR SUBSYSTEM ANALYSIS - CONCENTRATOR ASSEMBLY

Four trade studies have been identified for adapting existing heliostat designs to small power systems. The trade studies stem from two requirements specific to small central receiver power systems. The first requirement is to generate a reflected image size at the receiver which is sufficiently small to achieve the desired concentration ratio. High concentration ratios are desired to maximize receiver efficiency and minimize receiver size and cost. The second requirement is to minimize the assembly, transportation, and installation costs of the heliostats and field electronics, consistent with the requirements of small power systems.

Most of the design analyses which are necessary to perform the preliminary trade studies have been performed under parallel contracts and prior company funded studies.

3.1 DESIGN MODIFICATIONS TO THE HELIOSTATS

Design modifications to the heliostats to achieve the short focal lengths of a small power system include curving the mirror modules and establishing cant angles for each mirror module.

3.1.1 Mirror Module Curvature

An individual mirror module is 1.22 by 3.15 m (48 by 124 in) for the Barstow heliostat. If this module were perfectly flat, perfectly aligned, and the sun's rays perfectly parallel, the image from the mirror module would be exactly its size. All of the reflected energy could be accepted into a 3.5-m-diameter aperture. However, the sun angle, alignment errors, and surface irregularities combine to cause a total cone angle spread of about 12 mrad.

At the maximum slant range of EE No. 1 (∿200 m), this spread adds an effective 2.4 m to the image size from a nominally flat mirror module. Thus, the apparent size of an individual mirror module grows to about 3.62 by 5.55 m.

The short dimension is still well within the allowable for 4.5-m receiver aperture of EE No. 1. However, the long dimension falls somewhat outside the aperture. Providing a single curvature in the long dimension to achieve perfect focus at about 200 m, as described in Volume III, Section 4.2, will give the minimum image size, and the image becomes 2.4 by 3.62 m. It is easily shown that holding the radius of curvature constant for all heliostats produces a net image size which is everywhere smaller than that of the most remote heliostat. For example, at 100 m, the growth due to sun and angular errors is 1.2 m. The apparent height is half of the 3.15 m actual height or 1.575 m. The image size is 2.775 by 2.42 m. This image is only about 77% as large as the image at 200 m.

Off-axis aberration will cause the image height to be either greater or less than that indicated above. However, the off-axis angles for the north field are sufficiently small that the effects of aberration are not dominating.

Detailed computer studies conducted on the DOE 10 MWe Pilot Plant program (Reference 3-1) verify the adequacy of this approach.

These analyses were used to establish that the mirror modules will be singly curved to a single radius of curvature equal to twice the maximum slant range (perfect focus at the maximum slant range).

3.1.2 Mirror Module Cant Angles

The reflective unit, comprised of 12 mirror modules plus support structure, would still produce an unacceptably large image at the receiver if all the mirror modules were parallel. Cant angles are introduced for each mirror module to cause the images of the individual mirror modules to be superimposed at the receiver. A spherical focus of the mirror modules is thereby achieved.

The larger dimensions of the reflective unit (7 by 7.4 m) will require that the reflective unit focal length (cant angles) be varied over the field. No substantial additional growth in image size can be permitted if the image size is to be bounded by the 4.5-m aperture. Hence, it appears that five discrete cant angle sets or reflective unit focal lengths will be required.

Two methods for providing variable cant angles for the heliostat were considered. In the first method, a kit of standard spacers would be made for each discrete focal length desired. The reflector panels would be assembled with a nominal cant angle for all panels. The heliostats would be mounted on the foundations and a crew would insert a kit of standard spacers between the support structure and the mirror modules to achieve the offset required from the nominal cant angles.

The second method employs an automatically adjusting assembly fixture for the reflector panel. The fixture is adjusted for each panel focal length and the changes in cant angles are taken up in the bondline thickness between the cups or stringers and the mirror module. For Small Power Commercial System requiring less than 200 heliostats, this method of obtaining cant angles can easily be accomplished in a high volume production line. By introducing an adjustable bonding fixture in a production loop parallel to the production line, the few heliostats having special cant angle requirements can be pulled from the production line and sent through the loop. The cost impact of adding the adjustable bonding fixture is small, especially for commercialization of the Small Power Systems.

3.2 SUBSYSTEM ASSEMBLY AND CHECKOUT

The 10 MWe Pilot Plant heliostats have been designed to utilize a site assembly facility. The facility receives details of the reflective unit plus assembled main beams and mirror modules. The reflective units are built up and integrated with the remainder of the heliostat. The heliostat is then moved as one piece to the foundation and emplaced. The validity of this production approach tends to vary with site size and production volume.

The alternative approach adopted for Small Power Systems is to divide the reflective unit into two halves. The drive unit includes the center section of the main beam and the mounting interfaces for the reflector panels. The drive unit is assembled in the factory and shipped to the site. It is in the factory and shipped to the site. The panels are installed on the drive unit, again using automated equipment.

Small Power Systems will not provide for the installation of enougı heliostats in one location to justify a site assembly facility. The allocated cost of moving a site assembly facility from one small power system site to another may exceed $10/m^2. Hence, the approach of assembly on the pedestal is preferred. A final determination will be made during the preliminary design phase (Phase II) on the installation equipment design.

3.3 COLLECTOR FIELD ELECTRONICS

The pilot plant and second generation heliostats employ intermediate distribution points in the field for both power and data communication networks. Field transformers are used to step high voltage ($\sim$ 2.4 kV) primary feeder power down to 208/240 V power for the heliostats. Each transformer services 200 to 300 heliostats. For the small power system, the field transformers will not be required. A decision has been made to distribute power directly from the power conversion subsystem to the heliostats along 7 (for the 3.5-year program) parallel, serial hookups of about 32 heliostats each.

The data network uses high baud rate serial connections to each of the field controllers. The field controllers control the heliostats by a secondary, low baud rate serial hookup. EE No. 1, using the pilot plant controls system, will employ such a serial connection. However, in the 4.5-, 6.5-year and in the commercial programs, the field controller function may be incorporated into the plant controller.

3.4 MIRROR MODULE THERMAL CHARACTERISTICS

The mirror modules of both heliostat designs use, in effect, glass backed by steel. As the mirror module temperature changes, the different thermal expansion coefficients of the glass and steel will cause a warping of the mirror, i.e., a tendency to change focal length. The total movement of the mirror module from $0^{o}C$ to $40^{o}C$ is about 10 mrad in the reflected beam. Hence, this effect is not negligible.

For the pilot plant mirror module, the thermal warping can be reduced by increasing the foam core thickness. Doubling the thickness cuts the warping in half and reduces spillage accordingly. The added cost would be about $\$4/m^2$.

Composite (glass fiber/plastic) stringers designed to match the expansion coefficient of the mirror glass may eventually prove economic for the second generation heliostat configuration. This approach would completely eliminate thermal warping.

The trade study to determine the most cost effective approach among the three alternatives (accept the losses, reduce the losses by increasing mirror module thickness, and reduce losses by use of composite structures) must be determined for the specific field layout. The results are expected to be that the curvature of the mirror modules is biased to minimize annual losses, and no design changes are made. Based on data previously reported in the first quarterly report, losses are expected to be not more than about one percent. If this result is verified, no corrective design action will be justified.

Section 4
COLLECTOR SUBSYSTEM ANALYSES - RECEIVER ASSEMBLY

4.1 ABSORBER CONFIGURATION SELECTOR

The investigation leading to a set of receiver design conditions appropriate to the 3.5-year program goals is described in this section. The objectives are: (1) a minimum absorber surface area, together with a power density distribution and fluid flow path such that the peak receiver temperature occurs near the apex of the cavity; (2) a peak heat flux less than 400 kW/m^2 (126,900 Btu/hr ft^2); and (3) maximum spillage of 3%.

The absorber surface configuration and the power density distribution over the absorber surface were varied systematically. The resulting configuration/power density combinations were analyzed to evaluate the receiver performance as limited by the system operating temperatures and by fluid heat transfer.

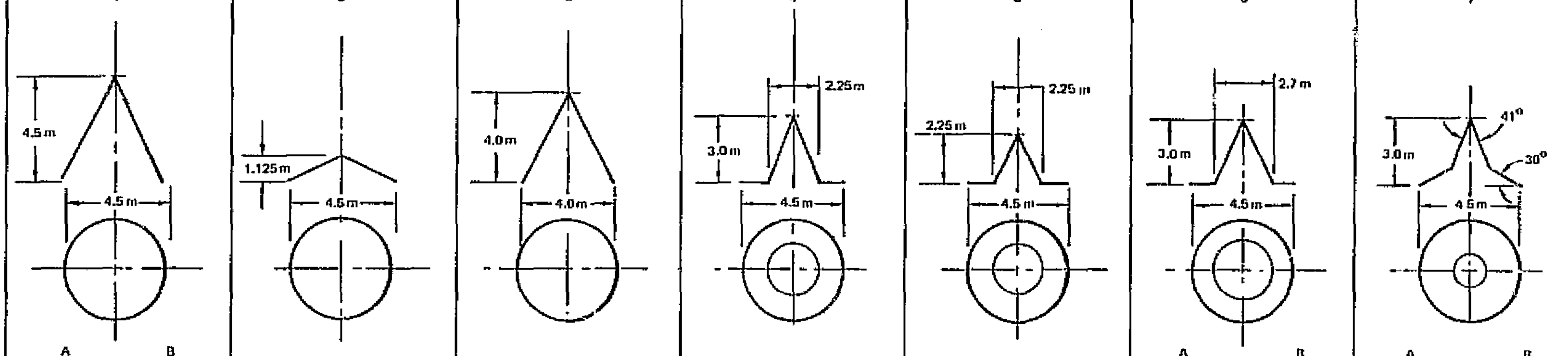
4.1.1 Candidate Configurations/Irradiation Patterns

Outline dimensions of the absorber surfaces which were investigated are shown in Figure 4-1. The design power for all receivers is 7.08 MWt absorbed, and is determined by the thermal efficiency of the power conversion system which has been selected for the 3.5-year program. The aperture diameter of 4.5 m is near the minimum consistent with a maximum spillage of 3% and an acceptable power density distribution at the absorber surface.

Irradiation patterns were obtained by means of the CONCEN computer program. The CONCEN program determines the irradiation pattern at the receiver by summing the circular solar images from elementary areas of the heliostat mirror surfaces. The mirror surface is modeled as 480 identical plane elements, each approximately 0.1 m^2 (1 ft^2). Focusing is provided by applying appropriate slope deviations to each mirror element. For computation, a single heliostat is randomly selected. Then a mirror element on that heliostat is randomly selected. The image location and its size, for that element, are computed

8CR20

Receiver No.	1		2	3	4	5	6		7	
	A	B					A	B	A	B
Aiming pattern	1-Point	5-Point 1 x 1 m	5-Point, 1 x 1 m	5-Point, 1 x 1 m	5-Point, 1 x 1 m	5-Point, 1 x 1 m	5-Point 1 x 1 m	5-Point 1.5 x 1.5 m	1-Point	5-Point 1 x 1 m
Spillage, %	0.33	0.90	0.90	2.2	0.90	0.90	0.90	1.75	0.33	0.90
q_{peak}, MW/m²	0.67	0.81	2.10	0.80	0.94	1.44	1.03	0.41	1.27	1.55
$q_{peak}/q_{average}$	3.39	4.06	5.28	3.16	3.09	4.23	3.60	1.39	3.92	4.77
Surface area, m²	35.6	35.6	17.8	28.1	23.3	20.8	24.1	24.1	21.8	21.8



Receiver No.	8	9		10	11	12				
						A	B	C		
Aiming pattern	5-Point, 1 x 1 m	4-Point 1.5 x 1.5 m	8-Point Circle 2.1 m Diam	4-Point, 1.5 x 1.5 m	4-Point, 1.75 x 1.75 m	8-Point	8-Point	9-Point 1.6 m Circle & Cont.		
Spillage, %	0.90	2.1	1.0	2.1	4.4	4.3	3.3	0.2		
q_{peak}, MW/m²	1.77	0.36	0.32	0.30	0.24	0.39	0.37	.60		
$q_{peak}/q_{average}$	4.95	1.62	1.46	1.65	1.33	1.58	1.49	2.04		
Surface area, m²	19.8	32.4	32.4	30.1	38.0	28.9	28.9	28.9		

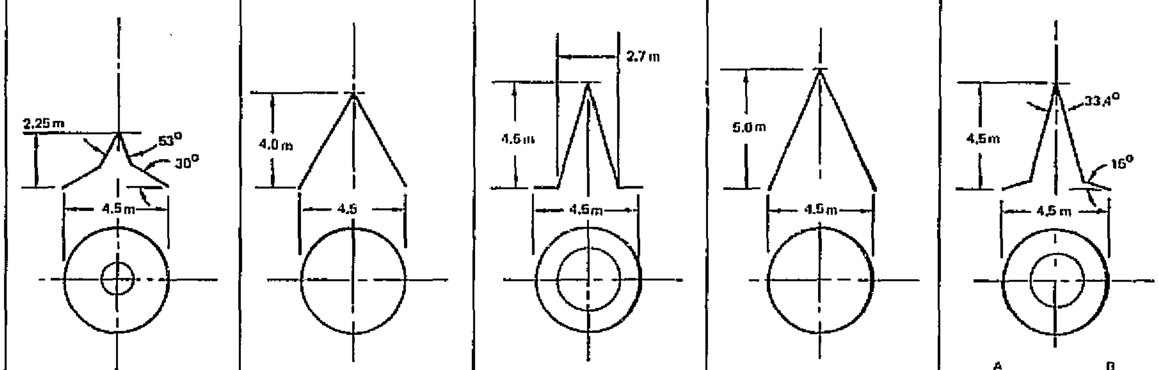


Figure 4-1. Absorber Surfaces Investigated

at a plane normal to the reflected beam at the receiver. Points on a grid on a plane receiver absorber surface are projected back, in the direction of the reflected beam, onto the normal plane and their positions are related to that of the element image. By repeating the random selection of elements over the heliostat field 10,000 to 15,000 times, the irradiation pattern over the grid on the absorber surface is built up. By computing the fraction of each element image that is included within the receiver aperture, the absorbed power and the spillage are determined.

4.1.2 Heat Transfer/Fluid Flow Analysis

The absorber surface is a coil of small diameter steel tubing, spiral wound, and arranged to form one or more parallel fluid flow paths through the receiver. Given the total absorbed power, the power density distribution, the design fluid temperatures and the fluid flow path, the analysis proceeds as follows:

- Compute the power density and fluid bulk temperature profiles, from receiver inlet to outlet.
- Determine the location, along the flow path, of the maximum inside tube surface temperature (maximum film temperature) and the corresponding required heat transfer coefficient.
- Determine the number of parallel flow paths, fluid pressure drop and pumping power as functions of tubing diameter and wall thickness.
- Determine the maximum tube metal temperature.

4.1.3 Collector Field Model/Heliostat Aiming/Aperture Power Distribution

The power density distribution at the receiver aperture is determined by the design of the individual heliostat (i.e., mirror size, number of mirror elements per heliostat, element curvature and canting), the layout of the collector/receiver complex (i.e., the total number of heliostats and their locations relative to the receiver), and the aiming pattern. The field conditions are given in Table 4-1.

Table 4-1. Operating Conditions for Power Density Distributions

217 heliostats, in radial - concentric array
7.4 x 7.4 m heliostat mirrors
Reflectance - 0.88
Mirror surface waviness - 1.1 mrad, 1σ
Tower height = 40 m
Date = March 21
Time = 1000 hr
Atmospheric attenuation coefficient = 0.092 km^{-1}
Latitude = 35° N
Receiver cavity tilt = 30°, 20°, and 15° toward N
Cant angle adjusted for each heliostat location
Panel curvature = 0.0025 m^{-1}
Ambient temperature = 90°F
Pointing error = 2 mrad, each coordinate axis

The following aiming patterns, with variations, were investigated and are shown in Figure 4-2.

One-point: All heliostats are aimed to project an image which is centered on the receiver aperture.

Four-point, Five-point, Eight-point-circle: Equal numbers of heliostats, uniformly distributed in the collector field, are assigned to each aim point.

Eight-point: Heliostats at distances greater than 100 m are aimed in the 1.4 by 1.4 m square pattern. Those at less than 100 m are aimed in the 2.1 by 2.1 m square pattern.

Nine-point: Heliostats at distances greater than 150 m are aimed at the center of the receiver. Those between 150 and 100 m are aimed in the 1.4 by 1.4 m square pattern and those less than 100 m distance are aimed in the 2.1 by 2.1 m square pattern.

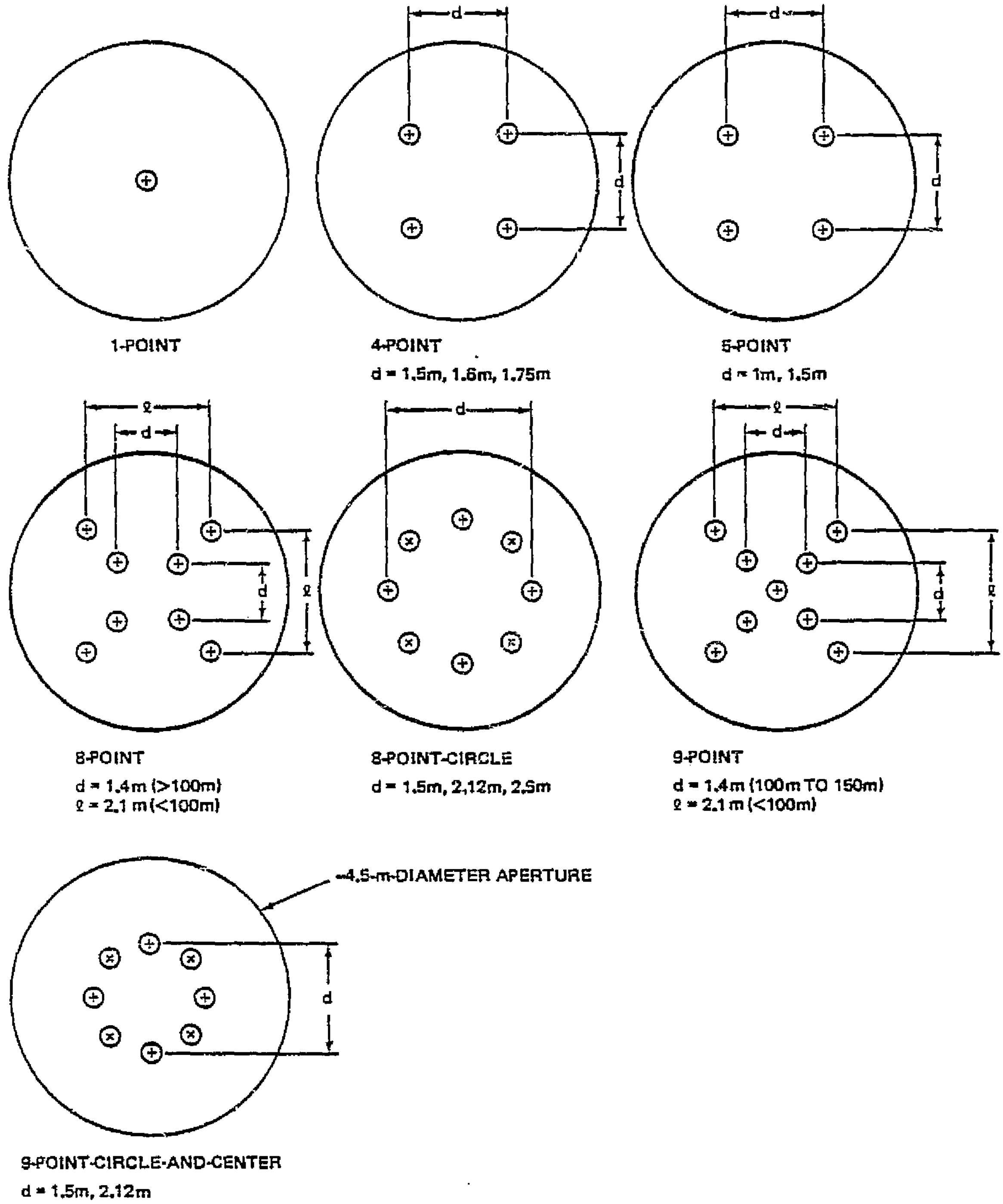


Figure 4-2. Heliostat Aim Patterns

Nine-point-circle-and-center: Heliostats at distances greater than 150 m are aimed at the center of the receiver. All others are uniformly distributed among the eight points on a 1.5 m diameter circle.

Figure 4-3 shows the power density distributions, along a horizontal center line in the aperture plane, for 7.08 MWt into a 4.5 m diameter aperture, for the aiming patterns of Figure 4-2. As would be expected, the peak power density decreases with spreading of the aim points; actually from about 2.8 MW/m^2 for the one-point aim to 0.5 MW/m^2 for the four-point (1.75 by 1.75 m) aim point.

Peak power density, peak/average ratio, and percent spillage are tabulated, for the various aiming patterns, in Table 4-2. The 8-point, 8-point- circle (2.6 m) and the 4-point (1.75 by 1.75 m) aiming patterns are rejected because of excessive spillage.

Table 4-2. Power Density at Aperture Plane and Spillage vs Aiming Pattern*

Aiming Pattern	Peak MWt/m^2	Peak MWt/m^2 / Average MWt/m^2	Spillage, %
1-Point	2.6	6.2	0.3
5-Point, 1 x 1 m	1.8	4.0	0.90
5-Point, 1.5 x 1.5 m	1.0	2.3	1.75
4-Point, 1.5 x 1.5 m	0.77	1.6	2.1
4-Point, 1.6 x 1.6 m	0.58	1.4	2.6
4-Point, 1.75 x 1.75 m	0.50	1.2	4.4
9-Point Squares and Center	0.90	1.9	3.3
9-Point Circle and Center	1.5	3.7	0.2
8-Point Squares	0.57	1.4	4.3
8-Point Circle 1.5 m	1.4	2.9	.7
8-Point Circle 2.12 m	0.80	1.8	1.9
8-Point Circle 2.6 m	0.61	1.4	5.3

*7.08 MWt
4.5-m-diameter aperture

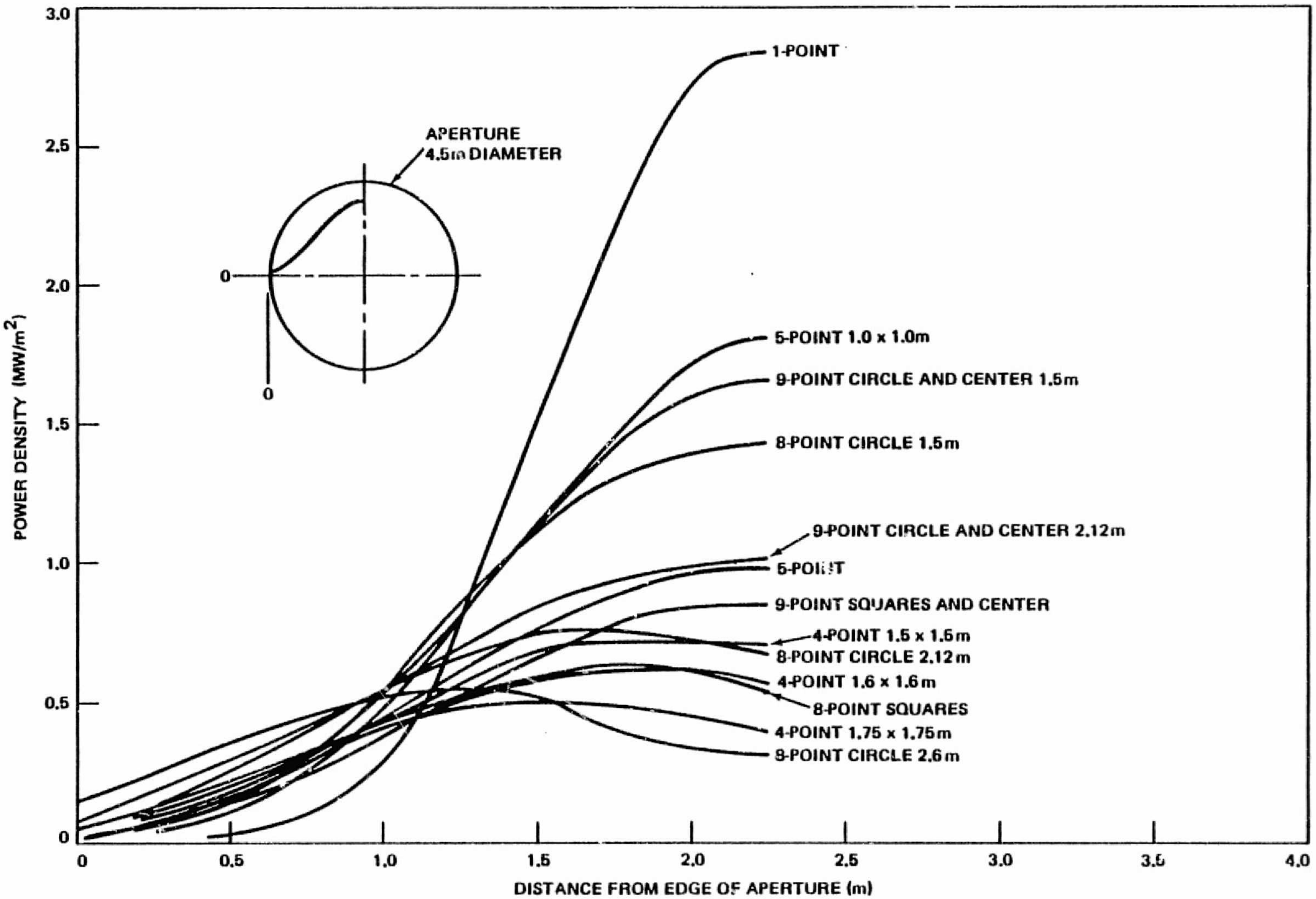


Figure 4-3. Power Density Profiles At Horizontal Centerline of Aperture (7.08MW$_t$)

4.1.4 Absorber Configuration Screening Analysis

As a starting point for optimizing the absorber configuration, CONCEN power density profiles were generated for configurations 1 through 8 of Figure 4-1 using the five-point 1 by 1 m aiming pattern, and for configurations 1 and 7 using the one-point aim. These configurations are variations of the receiver types which were identified as being the most favorable in initial screening (Volume II). Figures 4-4 through 4-13 show the power density profiles at the absorber surface, along a line from the aperture edge of the horizontal center line to the apex of the cone. The peak power densities are all greater than 0.4 MW/m^2. For all of these configurations, the five-point aim appears to be too narrow; and, for the partial-cavity configurations, the depth of the conical section should be increased.

Power density profiles for configurations 6B, 9A, 10, and 12B are shown in Figures 4-14 through 4-17. All of these meet the design objectives for spillage and peak power density. However, configurations 6B and 9A are deficient in that the peak power density occurs at locations deep inside the cavity. In order to maintain the design temperatures and reasonable flow velocities with these configurations, the low temperature fluid must enter the receiver at the apex of the cone, and the heated fluid exit at the edge of the aperture. In order to achieve minimum radiation and convection losses, this temperature profile should be reversed, i.e., minimum temperature should occur at the edge of the aperture, and maximum temperature at the apex of the cone.

Configurations 10 and 12B can be operated with "edge-to-center" fluid flow, to give the desired temperature profile. Configuration 12 has slightly smaller surface area.

4.1.5 Absorber Configuration Optimization

A receiver tilt of 30^{o} downward, and several aperture-centered aiming patterns (Figure 4-2) were used for the preceding horizontal centerline profiles, which show the power density along the line of intersection of the absorber surface with the plane containing both the horizontal diameter of the aperture and the apex of the cone. The horizontal profile may or may not be representative of the entire absorber surface, depending upon the aiming

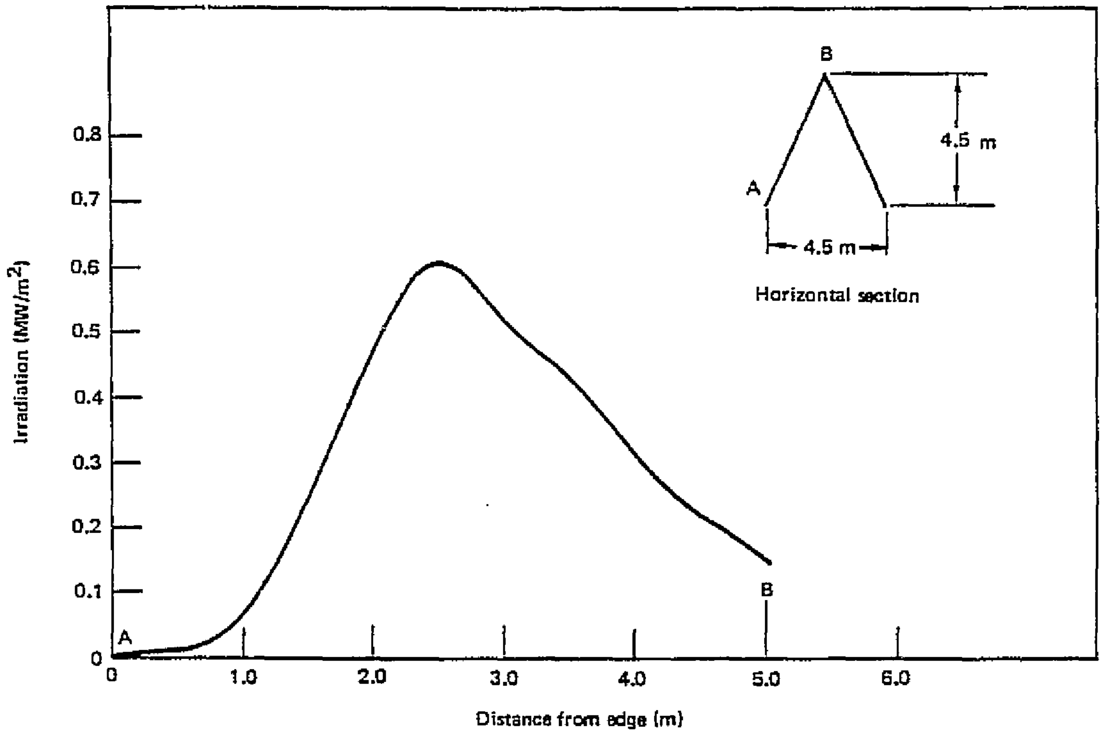


Figure 4-4. Cavity Receiver Irradiation - Configuration 1A, 1-Point Aim

9CR20

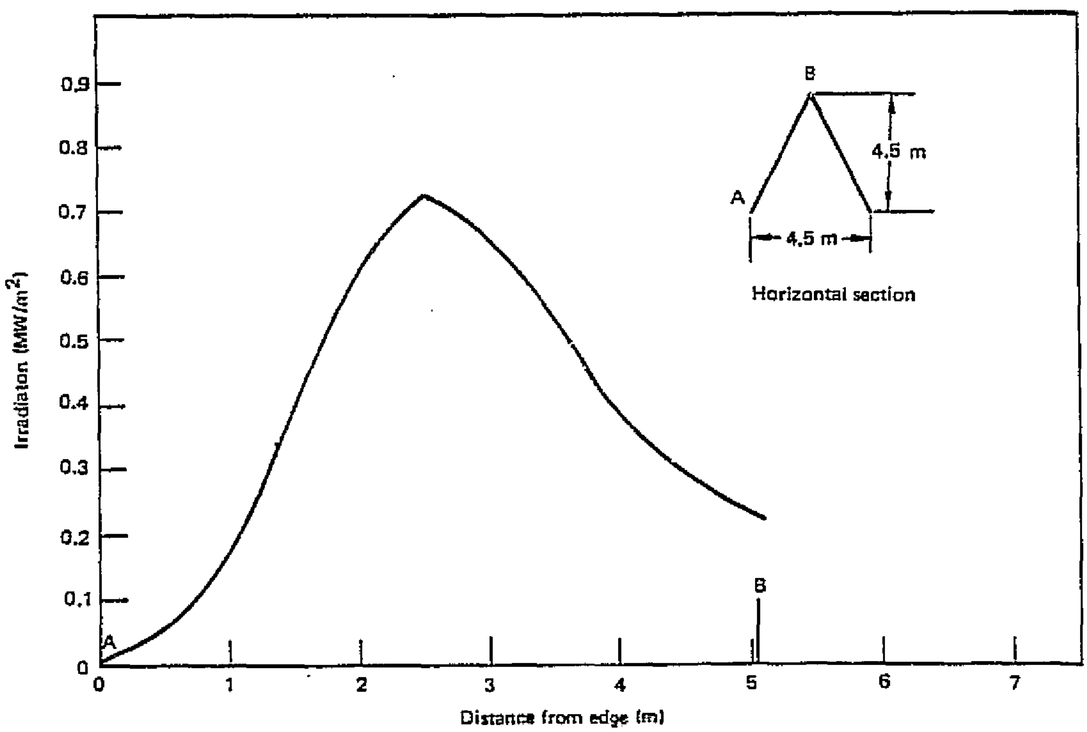


Figure 4-5. Cavity Receiver Irradiation - Configuration 1B, 5-Point Aim - 1.0 x 1.0 m

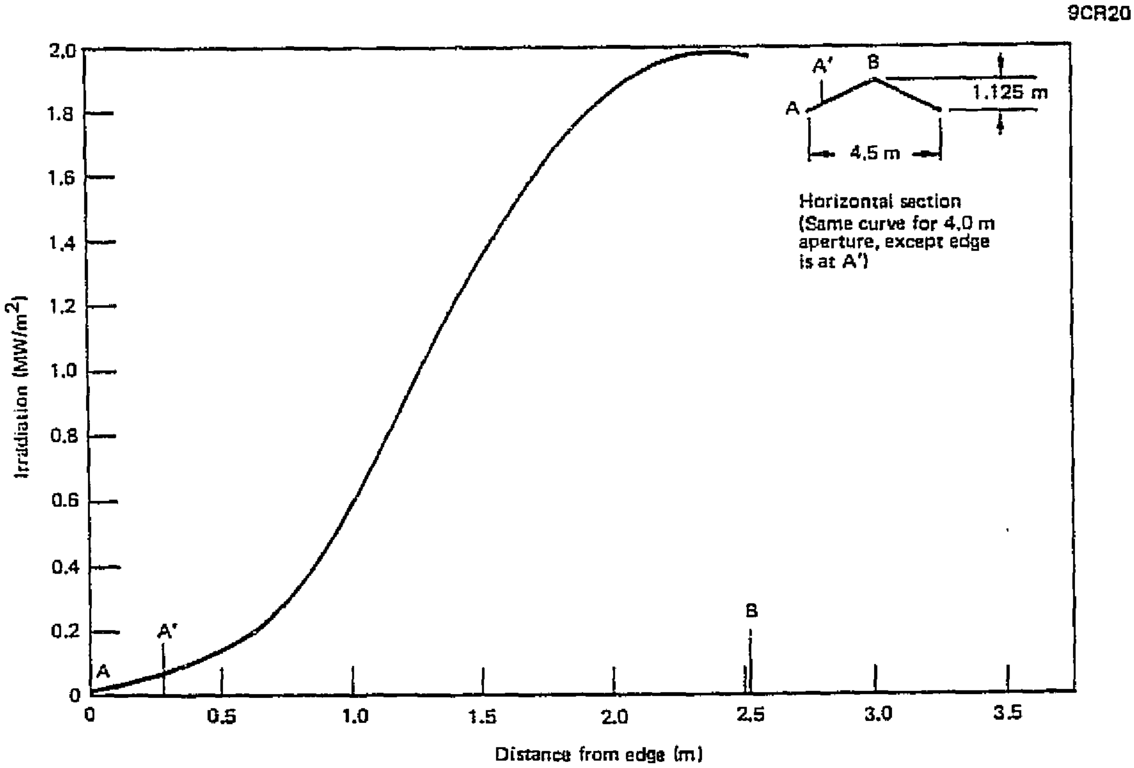


Figure 4-6. Cavity Receiver Irradiation — Configuration 2, 5-Point Aim - 1.0 x 1.0 m

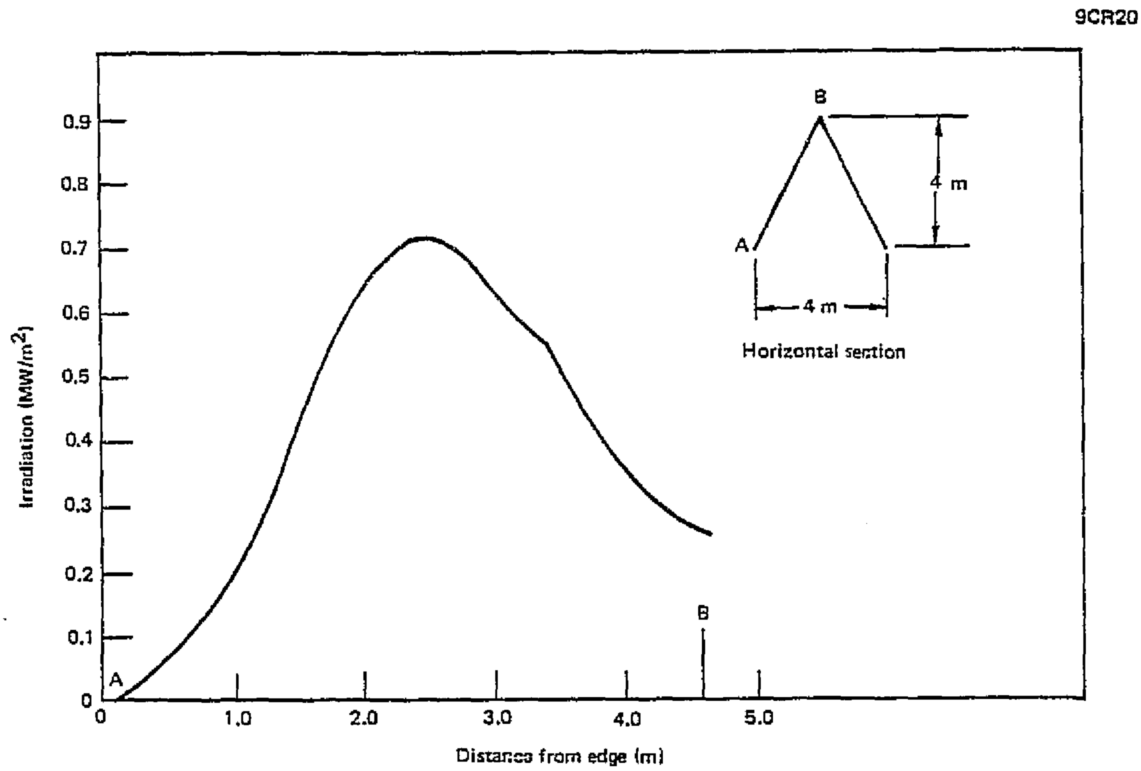


Figure 4-7. Cavity Receiver Irradiation — Configuration 3, 5-Point Aim - 1.0 x 1.0 m

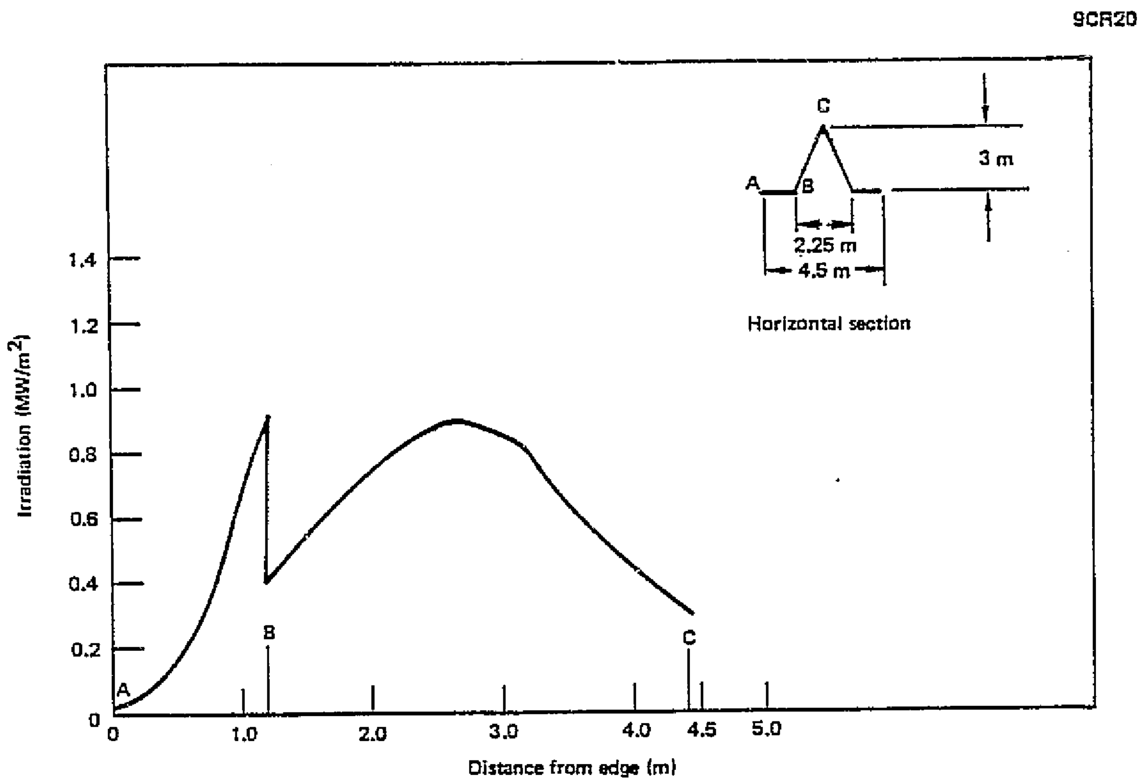


Figure 4-8. Cavity Receiver Irradiation — Configuration 4, 5-Point Aim - 1.0 x 1.0 m

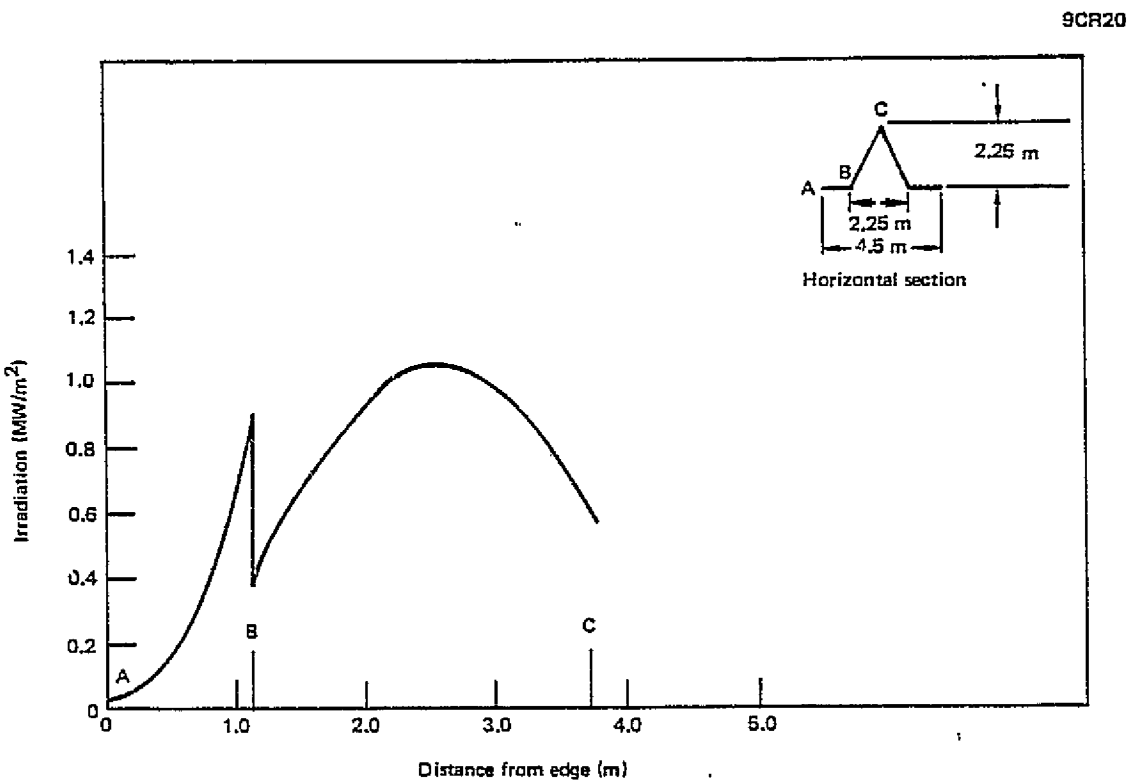


Figure 4-9. Cavity Receiver Irradiation — Configuration 5, 5-Point Aim - 1.0 x 1.0 m

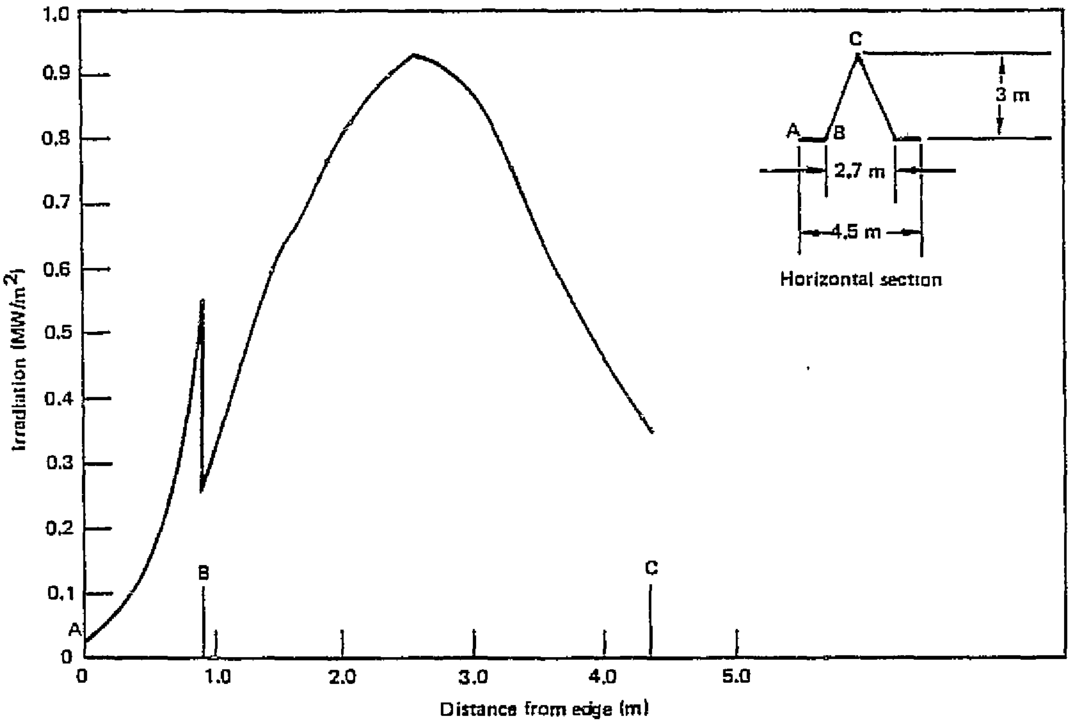


Figure 4-10. Cavity Receiver Irradiation – Configuration 6A, 5-Point Aim - 1.0 x 1.0 m

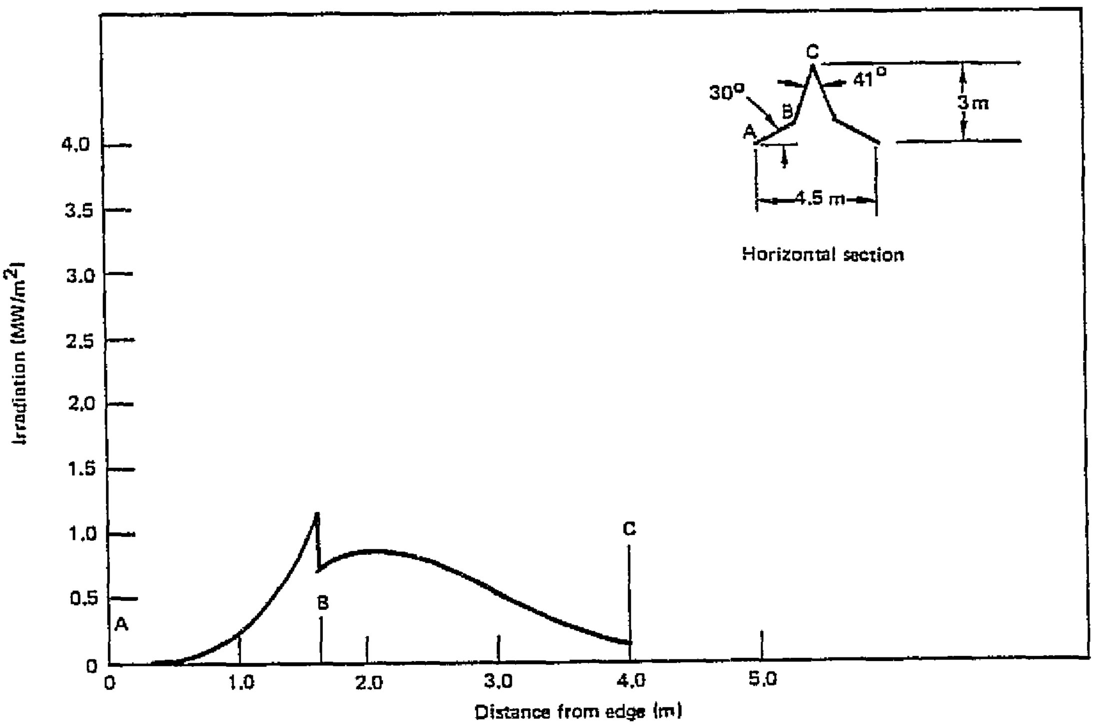


Figure 4-11. Cavity Receiver Irradiation – Configuration 7A, 1-Point Aim

9CR20

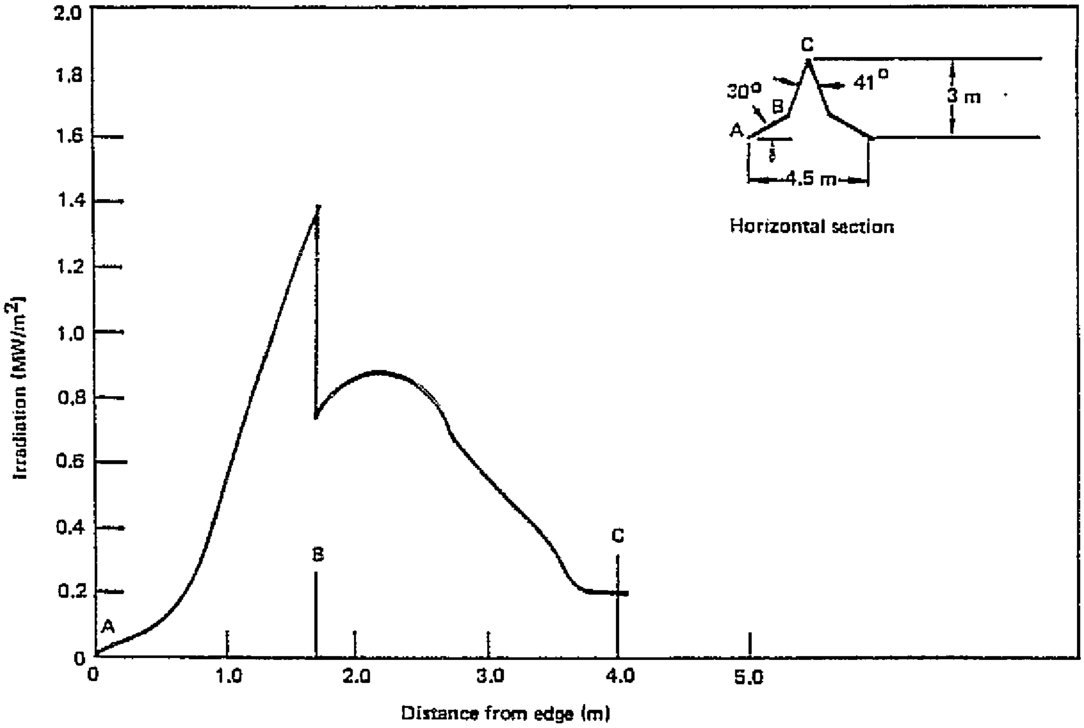


Figure 4-12. Cavity Receiver Irradiation — Configuration 7B, 5-Point Aim - 1.0 x 1.0 m

9CR20

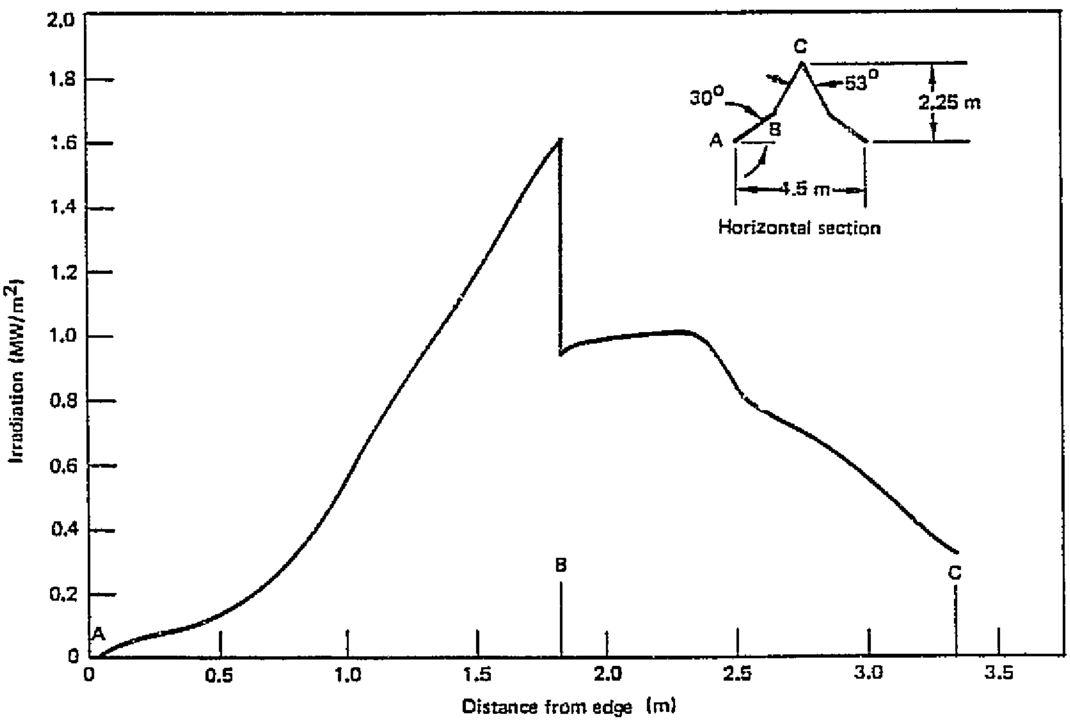


Figure 4-13. Cavity Receiver Irradiation — Configuration 8, 5-Point Aim - 1.0 x 1.0 m

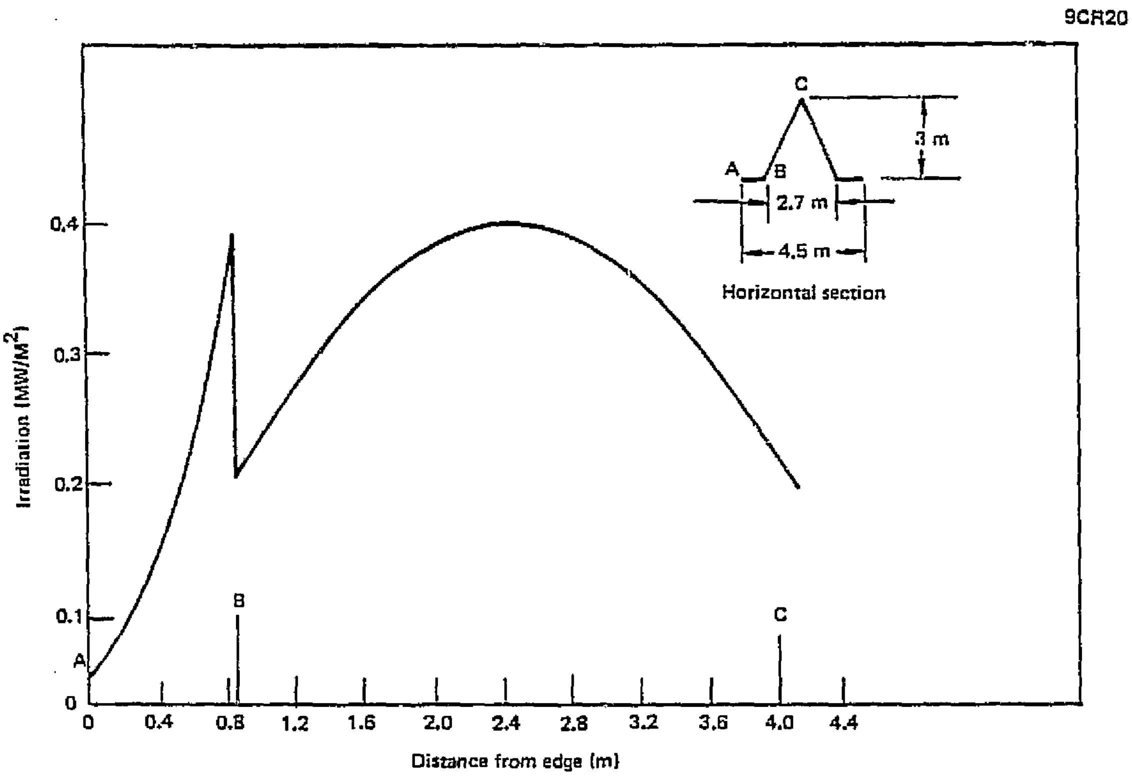


Figure 4-14. Cavity Receiver Irradiation — Configuration 6B, 5-Point Aim - 1.5 x 1.5 m

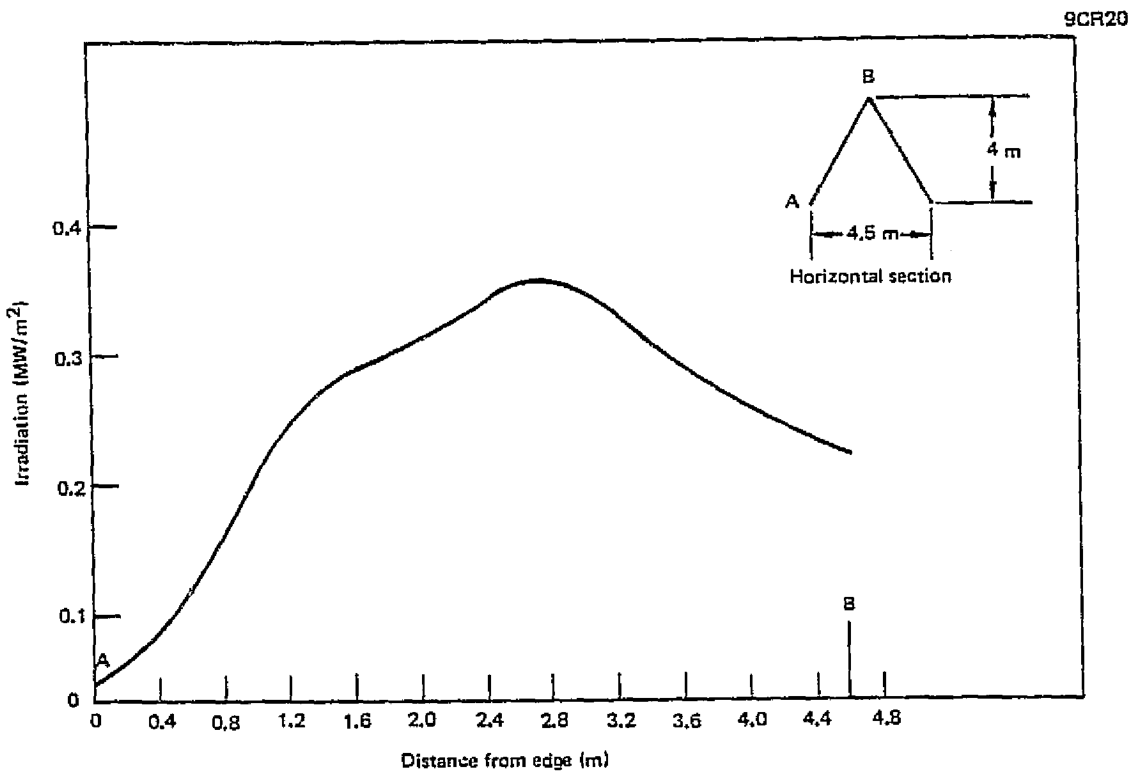


Figure 4-15. Cavity Receiver Irradiation — Configuration 9A, 4-Point Aim - 1.5 x 1.5 m

9CR20

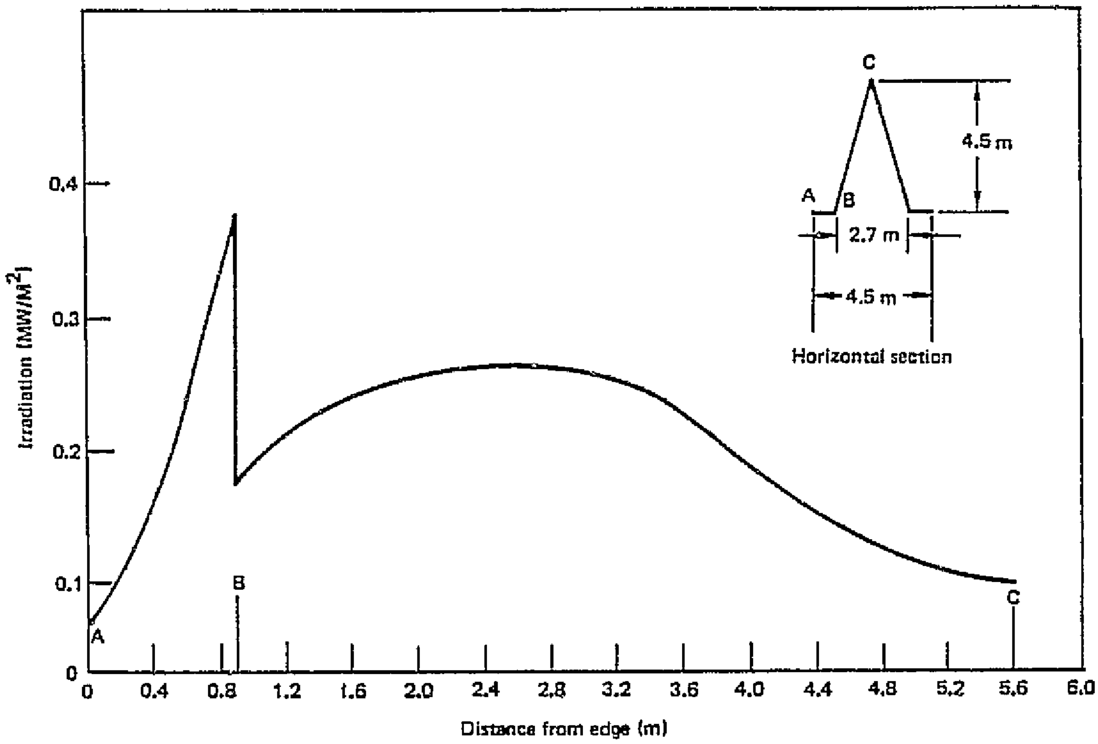


Figure 4-16. Cavity Receiver Irradiation – Configuration 10, 4-Point Aim - 1.5 x 1.5 m

9CR20

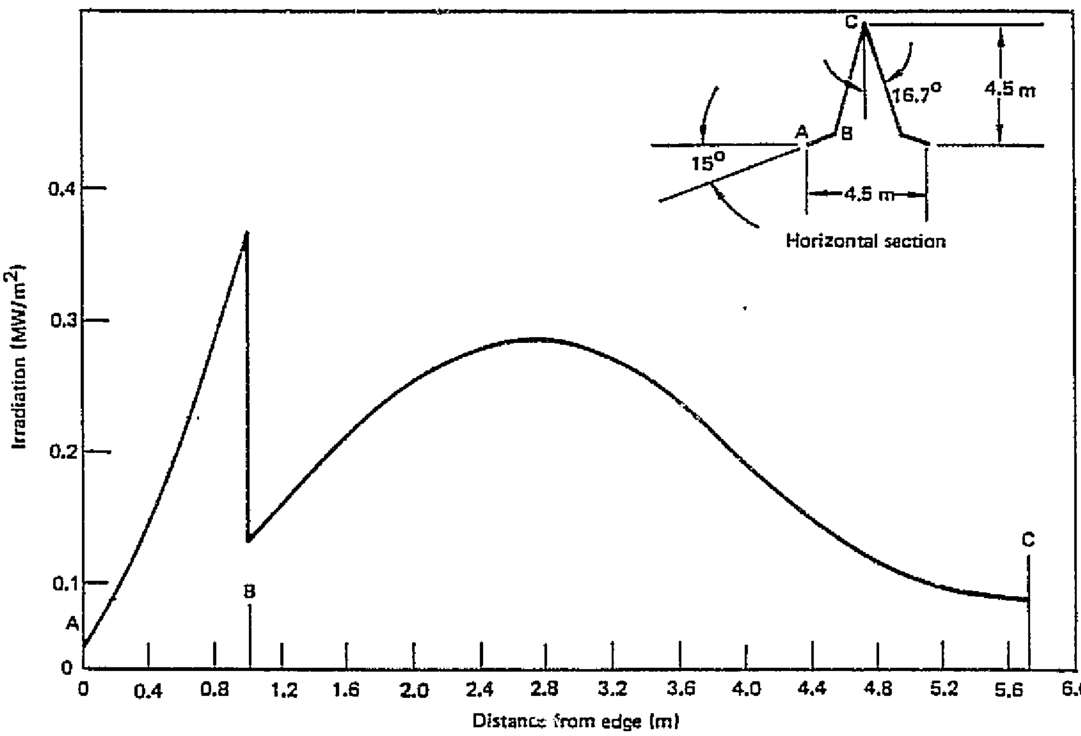


Figure 4-17. Cavity Receiver Irradiation – Configuration 12B, 9-Point Aim

pattern and the tilt of the receiver axis with respect to the heliostat field. Figures 4-18 and 4-19 show the effect of receiver tilt, for configuration 6A. Three power density profiles (horizontal, 45° and vertical) are shown in each figure. For the 30° tilt angle, Figure 4-18, the peak power density occurs in the vertical cross-section on the lower half of the absorber surface and it is evident that more than half of the total power is absorbed in the lower half of the receiver. For the 15° tilt angle, the peak occurs in the vertical cross-section on the upper half of the absorber surface, and more than half of the power is absorbed in the upper half of the receiver.

The situation is similar for receiver configuration 12B as shown in Figures 4-20 and 4-21. Also, it is apparent that for this receiver shape, the design goal of 0.4 MW/m^2 peak cannot be met with the 9-point-squares-and-center aim, which tends to concentrate the irradiation at the 45° cross-section.

Figure 4-22 shows power density profiles for configuration 12C. The tilt is 20° and a circular aiming pattern is used to improve the circumferential symmetry of the power distribution. The flux peak at the junction of the inner and outer cones has been reduced by substituting a 16.5 cm radius for the sharp corner.

Figure 4-23 shows heat flux and fluid bulk temperature profiles along the spiral flow path for configuration 12C.

4.2 ABSORBER THERMAL PERFORMANCE

A wide spectrum of receiver absorber concepts was studied, and the most promising of these were selected for more detailed analyses of thermal performance, hydraulic characteristics, and fatigue life. A summary of the analyses and design work accomplished by Rocketdyne is given in this Section.

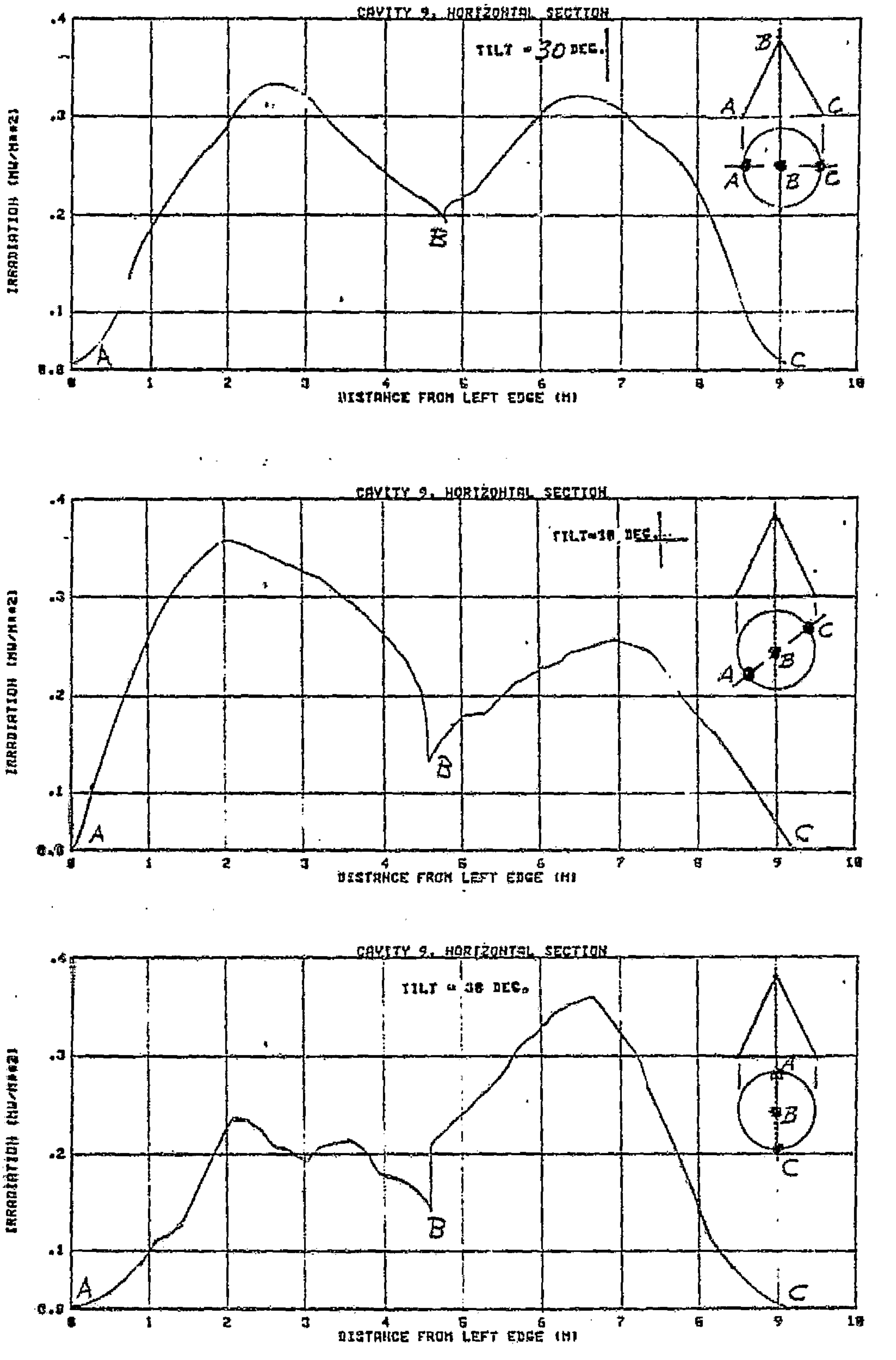


Figure 4-18. Irradiation Profiles, 30° Tilt

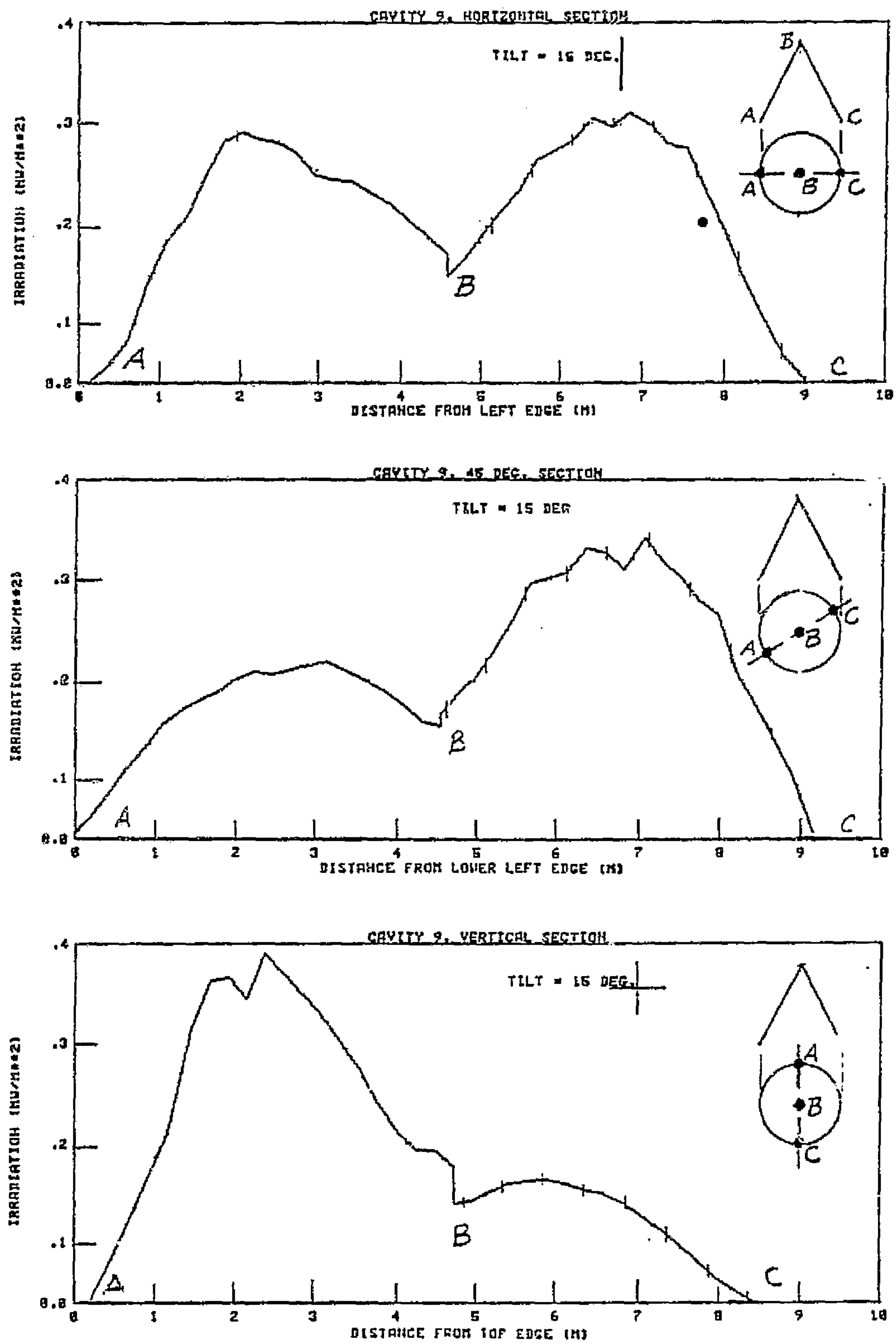


Figure 4-19. Irradiation Profiles, 15^{0} Tilt

9CR20

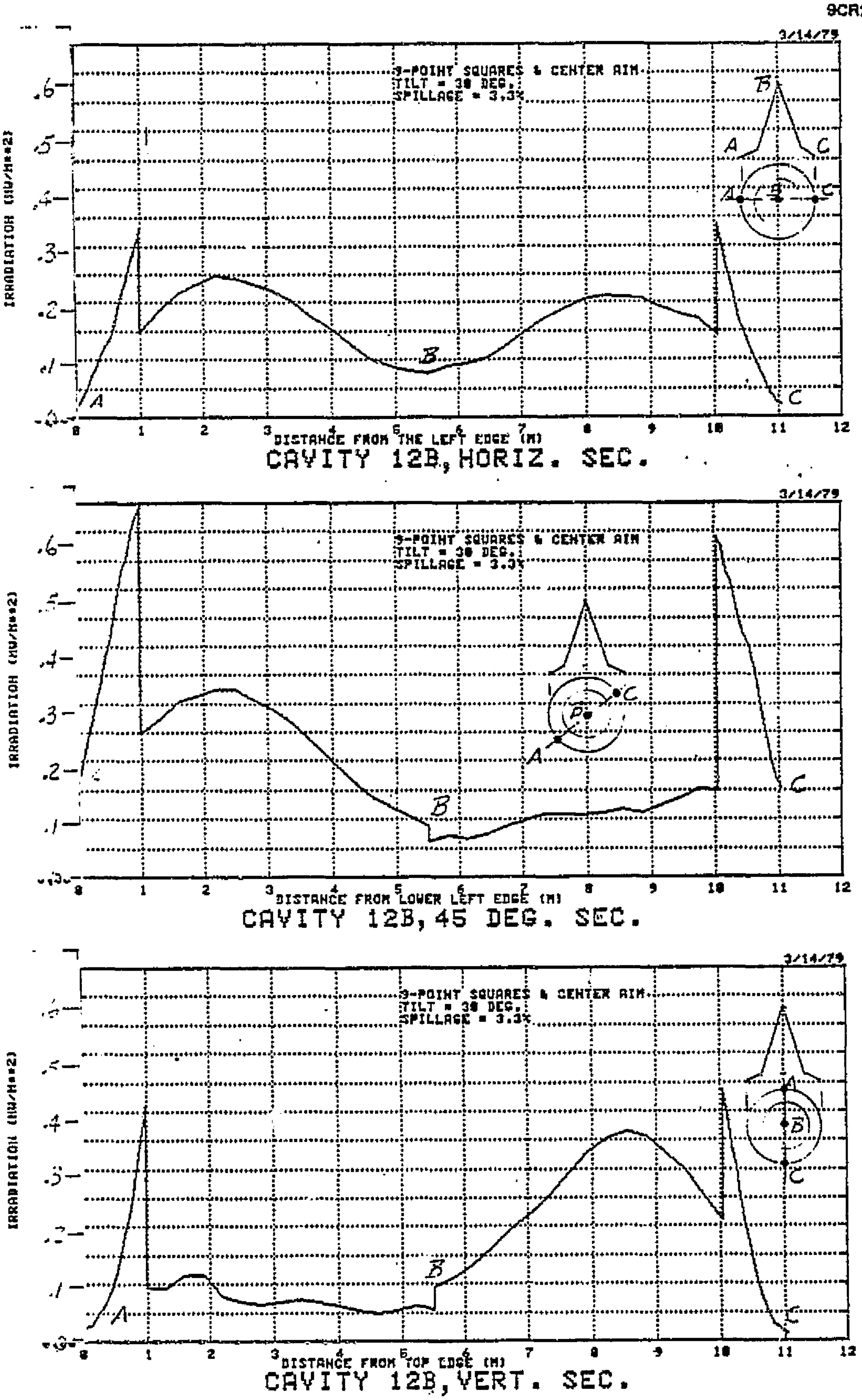


Figure 4-20. Irradiation Profiles, 30° Tilt

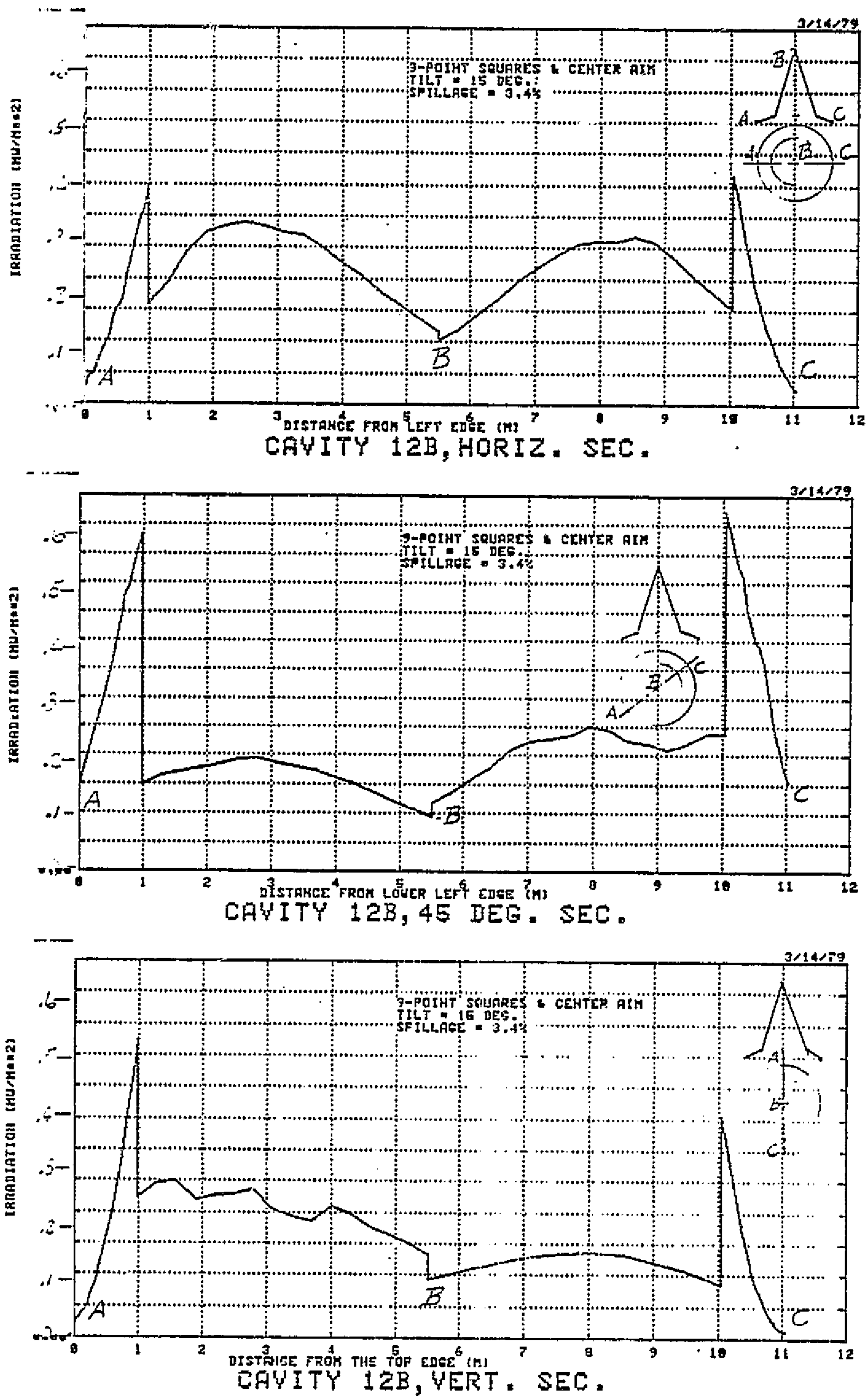


Figure 4-21. Irradiation Profiles, 15° Tilt

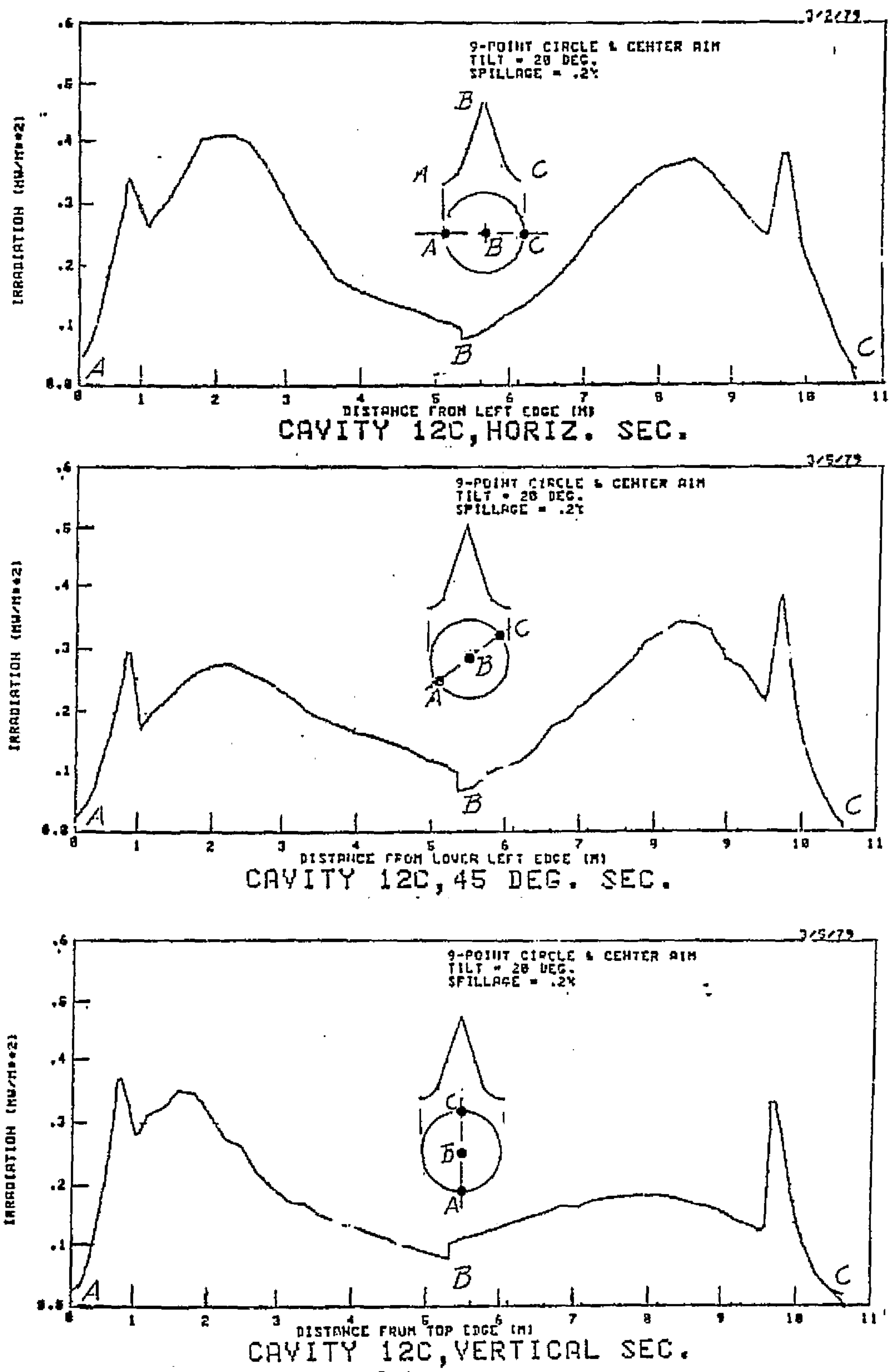


Figure 4-22. Irradiation Profiles, 20° Tilt

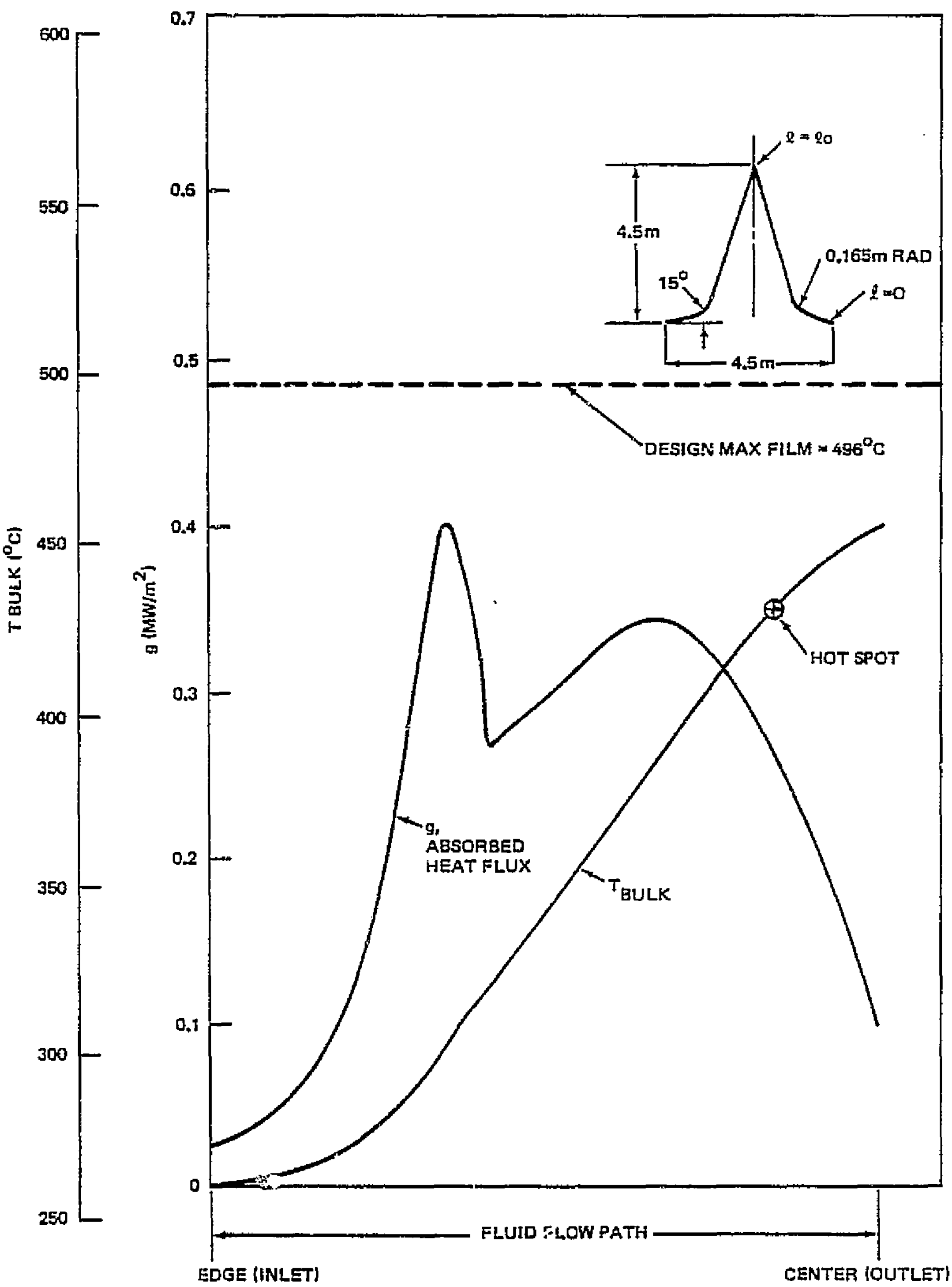


Figure 4-23. Fluid Temperature and Heat Flux Profiles, Receiver Configuration 12C, 7.08 MWT

4.2.1 Computer Model

A computer model was developed for performing a numerical integration of heat input and pressure drop along one or more tubes wound in a spiral with the contour of its wall defined by radius and depth coordinates. Heat flux is input either as the aperture field in radial and angular coordinates or as a table of flux versus position along the length of the tubes. With inputs of flow-rate, tube diameter and thickness, required coolant inlet pressure and inlet temperature, the program computes number of tubes in parallel, and at each nodal point on the tube, it computes the wall angles, coolant heat transfer coefficient, tube wall coolant surface and hot surface temperature, coolant temperature, pressure drop, Reynolds number, velocity and coolant properties. A subroutine for computing tube cross section temperatures provides data for accurate computation of fatigue life at the maximum heat flux location. To optimize the design, several parameters were varied with the program such as wall contour, routing of the flow circuit, and tube size. The computer program has the capability for thermal-hydraulic analysis of variations and combinations of the spiral disk and cone configurations. A printout of a typical run is shown in Figure 4-24. About 175 of these runs were performed during the Phase I program.

4.2.2 Preliminary Study Results

Thermal, hydraulic, and fatigue life analyses were performed for the spiral-flow-path conical cavity. The results are summarized in Tables 4-3, 4-4, and 4-5. The parameter Rw, the ratio of the tube OD to wall thickness, should not be greater than about 17 to ensure that the tube can be bent without undue flatening; i.e., this is a fabricability parameter.

The results show that, to attain an acceptable fatigue life and a reasonable fluid pressure drop across the absorber, a combination of heat flux less than about 600 kW/m^2 and coolant velocity less than about 3 mps is required. In addition, a tube material having a high thermal conductivity combined with an inherently high resistance to fatigue damage is advantageous. Note that the design finally derived permits a safety factor, since the heat flux is kept closer to 400 kW/m^2 than to 600 kW/m^2.

MAXIMUM HEAT FLUX = 114396. DO = 1.750 DI = 1.532 THICKNESS = 0.109 NO. TUBES = 1

INLET TEMP = 500. INLET PRESSURE = 200. FLOW/TUBE = 12.710 CRES 304

AXIAL DISTANCE (INCH)	FLUID TEMP (F)	FLUID PRESS (PSIA)	COLD WALL (F)	HOT WALL (F)	TOTAL HEAT (BTU/SEC)	OD HEAT FLUX (B/H-FT2)	REYNOLDS NUMBER	HF HITEC (B/H-FT2-F)	DENSITY HITEC (LB/FT3)	VISCOSITY HITEC (LB/FT-S)	VELOCITY HITEC (FT/SEC)	ANGLE PHI (DEG)	FRICTION FACTOR
0.	500.0	200.0	500.0	500.0	0.0	0.0	42879.1	0.0	119.0	0.002957	8.41	0.0	0.021796
400.	503.3	193.4	525.1	542.2	14.3	15940.8	41332.1	317.0	117.9	0.002925	8.42	302.0	0.021750
800.	509.0	187.7	541.5	566.9	12.6	24097.0	44140.4	645.5	117.8	0.002872	8.41	288.7	0.021579
1200.	517.0	182.0	559.7	593.2	17.0	32050.1	45126.1	757.4	117.6	0.002797	8.44	208.9	0.021555
1600.	530.3	176.3	616.0	682.2	33.9	55817.4	47419.0	877.3	117.2	0.002672	8.47	305.2	0.021159
2000.	554.7	170.7	687.8	788.6	55.4	105095.5	51903.0	914.2	116.6	0.002442	8.51	11.3	0.020979
2400.	589.6	165.2	731.6	843.1	67.0	120329.9	59952.8	967.4	115.8	0.002114	8.58	125.5	0.020382
2800.	618.2	159.8	722.6	809.7	49.6	92421.5	66274.0	1010.5	115.0	0.001918	8.63	292.7	0.019990
3200.	645.5	154.4	754.8	846.5	53.6	99848.9	71569.6	1051.6	114.4	0.001771	8.68	156.4	0.019673
3600.	675.1	149.5	787.1	884.8	34.7	107477.2	78615.2	1096.3	113.6	0.001612	8.74	68.7	0.019307
4000.	706.7	144.6	820.2	921.7	36.7	111524.7	87060.2	1142.3	112.8	0.001456	8.80	46.6	0.018917
4200.	723.3	142.0	836.9	939.2	31.2	115527.8	90519.3	1162.0	112.4	0.001408	8.83	187.8	0.018769
4400.	739.7	139.4	850.4	951.1	30.9	114460.3	94242.4	1181.6	112.0	0.001345	8.87	286.8	0.018620
4600.	755.7	136.8	860.6	957.3	29.9	113263.2	98179.2	1200.8	111.6	0.001291	8.90	348.2	0.018468
4800.	771.1	134.2	869.6	961.5	28.5	105177.7	102261.9	1210.4	111.2	0.001240	8.93	193.6	0.018318
5000.	785.7	131.9	878.1	965.3	16.3	100092.1	106488.7	1217.2	110.8	0.001190	8.96	61.5	0.018170
5200.	799.5	129.5	884.4	965.5	15.2	93196.8	110008.7	1254.0	110.4	0.001144	8.99	356.1	0.018025
5400.	812.2	127.2	889.8	963.0	13.8	85144.6	113402.5	1266.5	110.1	0.001118	9.02	33.0	0.017943
5500.	818.3	125.0	891.0	961.5	11.0	81039.0	115650.8	1272.4	109.9	0.001105	9.03	134.2	0.017904
5600.	821.9	124.6	892.7	959.7	10.4	77012.0	116010.4	1277.9	109.8	0.001094	9.04	280.0	0.017867
5700.	824.2	121.4	894.2	957.7	9.9	72085.0	116990.5	1283.1	109.7	0.001083	9.05	119.6	0.017831
5800.	834.2	122.2	893.8	952.3	5.5	67209.9	118080.7	1288.0	109.5	0.001073	9.06	2.3	0.017798
5900.	838.8	121.8	892.9	946.3	5.0	61234.4	119111.7	1292.5	109.4	0.001064	9.07	382.5	0.017758
6000.	842.9	119.8	891.6	939.9	4.5	55258.9	120055.8	1296.6	109.3	0.001056	9.08	345.7	0.017740
6050.	844.9	119.2	890.8	936.5	3.5	52711.4	120504.0	1298.5	109.3	0.001052	9.09	98.5	0.017726
6100.	846.7	118.6	889.9	933.0	3.3	49221.6	120922.4	1300.3	109.2	0.001048	9.09	248.9	0.017714
6150.	848.4	118.0	889.0	929.5	3.1	46235.8	121318.9	1302.0	109.2	0.001045	9.09	84.9	0.017702
6200.	850.0	117.4	887.8	925.7	1.8	43248.1	121671.1	1303.5	109.2	0.001042	9.10	331.6	0.017692
6250.	851.5	116.8	886.6	922.0	1.6	40260.3	122023.7	1304.9	109.1	0.001039	9.10	274.9	0.017682
6300.	852.9	116.2	885.4	918.1	1.5	37272.5	122352.9	1306.3	109.1	0.001036	9.10	319.0	0.017672
6325.	853.5	115.9	884.7	916.2	1.2	35748.8	122511.8	1307.0	109.1	0.001035	9.10	62.6	0.017668
6342.	854.0	115.7	884.2	914.8	0.3	34674.2	122613.4	1307.5	109.1	0.001034	9.10	78.9	0.017664

NUMBER OF ITERATIONS = 54
DIFFERENCE BETWEEN HEAT IN AND OUT = 0.00977%

CROWN HEAT FLUX = 0.2554B/IN2-S OR 132379.0/FT2-HR

```
801
            788
766
         755       750
748
       738      723
729
     720     709
                        692
        694       674
               665
           655
              605  600  611  619
              604  608  611  616
              604  607  610  614
           583
                 583
        580           583
                             583
     580   580
500
     580      580
580
        580       580
580
           580
580
```

Figure 4-24. Typical Computer Printout of Absorbent Thermal Analysis Code (3.5-Year Program Design)

Table 4-3. Summary of Preliminary Thermal Analysis Study of a 4.5 m Aperture Partial Cavity Absorber (3.5-Year Program)

Number of Parallel Tubes	Tubing Size ID cm (in.)	Tubing Size OD cm (in.)	Tubing Size Wall cm (in.)	Rw	Tm °C (°F)	Tf °C (°F)	Th °C (°F)	ΔP Bars (psi)	V m/sec (ft/sec)
4	3.891 (1.532)	4.445 (1.750)	0.277 (0.109)	16	427 (801)	387 (729)	519 (966)	5.8 (84)	2.77 (9.10)
5	3.338 (1.334)	3.81 (1.50)	0.211 (0.083)	18	409 (769)	379 (714)	504 (939)	7.0 (102)	2.93 (9.61)
5	3.327 (1.310)	3.810 (1.50)	0.241 (0.095)	16	414 (778)	378 (713)	509 (948)	7.7 (112)	3.04 (9.96)
6	3.256 (1.282)	3.810 (1.50)	0.277 (0.109)	14	429 (805)	388 (731)	521 (970)	5.2 (75)	2.64 (8.67)

NOTES:

Rw: Ratio of tube OD to wall thickness
Tm: Hotest outside tube wall temperature at point of maximum heat flux (flux = 416 kW/m^2)
Tf: Film temperature at the same point as Tm
Th: Hotest point on hotest tube in entire absorber
Heat Load: 7.08 MW(t)
Fluid: Molten HITEC at flowrate of 84,000 kg/hr
Fluid Inlet/Outlet Temperature: 260 (500)/454 (850) °C/(°F)
Material: CRES 304
V: Fluid velocity at absorber apex (outlet)

Table 4-4. Summary of Preliminary Thermal Analysis Study of a 4.28 m Aperture Partial Cavity Absorber (4.5- Year Program)

Number of Parallel Tubes	Tubing Size								
	ID cm (in.)	OD cm (in.)	Wall cm (in.)	Rw	Tm °C (°F)	Tf °C (°F)	Th °C (°F)	ΔP Bars (psi)	V m/sec (ft/sec)
3	4.023 (1.584)	4.45 (1.75)	0.211 (0.083)	21	440 (825)	412 (774)	551 (1023)	5.86 (85)	2.67 (8.78)
3	3.962 (1.56)	4.45 (1.75)	0.241 (0.095)	18	444 (831)	441 (771)	554 (1030)	6.4 (93)	2.76 (9.05)
3	3.891 (1.532)	4.45 (1.75)	0.277 (0.109)	16	447 (837)	409 (769)	558 (1037)	7.0 (101)	2.86 (9.39)
4	3.891 (1.532)	4.45 (1.75)	0.277 (0.109)	17	462 (863)	425 (797)	569 (1056)	3.0 (44)	2.15 (7.04)
4	3.388 (1.334)	3.81 (1.50)	0.211 (0.083)	18	436 (816)	407 (764)	549 (1020)	7.0 (101)	2.82 (9.28)
4	3.327 (1.310)	3.81 (1.50)	0.241 (0.095)	16	437 (819)	404 (760)	552 (1026)	7.7 (112)	2.94 (9.63)
5	3.256 (1.282)	3.81 (1.50)	0.277 (0.109)	14	452 (846)	414 (778)	563 (1046)	4.6 (66)	2.45 (8.04)

NOTES:

Rw: Ratio of tube OD to wall thickness
Tm: Hotest outside tube wall temperature at point of maximum heat flux (flux = 400 kW/m^2)
Tf: Film temperature at the same point as Tm
Th: Hotest point on hotest tube in entire absorber
Heat Load: 6.05 MW(t)
Fluid: Molten HITEC at flowrate of 62,800 kg/hr
Fluid Inlet/Outlet Temperature: 288 (550)/510 (950) °C/(°F)
Material: CRES 304
V: Fluid velocity at absorber apex (outlet)

Table 4-5. Summary of Preliminary Thermal Analysis Study of a 4 m Aperture Partial Cavity Absorber (6.5-Year Program)

Number of Parallel Tubes	Tubing Size			Rw	Tm	Tf	Th	ΔP	V
	ID cm (in.)	OD cm (in.)	Wall cm (in.)		°C (°F)	°C (°F)	°C (°F)	Bars (psi)	m/sec (ft/sec)
3	3.388 (1.334)	3.81 (1.50)	0.211 (0.083)	18	436 (816)	409 (768)	569 (1056)	7.4 (107)	2.47 (8.96)
3	3.327 (1.310)	3.81 (1.50)	0.241 (0.095)	16	437 (819)	407 (764)	572 (1061)	8.1 (118)	2.83 (9.29)
4	3.327 (1.310)	3.81 (1.50)	0.241 (0.095)	16	467 (873)	434 (814)	603 (1117)	3.6 (52)	2.15 (7.06)
4	3.256 (1.282)	3.81 (1.50)	0.277 (0.109)	14	456 (852)	421 (790)	582 (1080)	4.0 (59)	2.22 (7.27)
5	2.845 (1.120)	3.175 (1.25)	0.165 (0.065)	19	433 (812)	413 (775)	566 (1051)	4.9 (71)	2.32 (7.62)
5	2.753 (1.084)	3.175 (1.25)	0.211 (0.083)	15	434 (814)	408 (767)	571 (1059)	518 (84)	2.48 (8.14)
5	2.672 (1.052)	3.175 (1.25)	0.251 (0.099)	13	437 (819)	406 (763)	575 (1067)	6.7 (97)	2.63 (8.64)

NOTES:

Rw: Ratio of tube OD to wall thickness
Tm: Hotest outside tube wall temperature at point of maximum heat flux (flux = 400 kW/m^2)
Tf: Film temperature at the same point as Tm
Th: Hotest point on hotest tube in entire absorber
Heat Load: 4.72 MW(t)
Fluid: Molten HTS at flowrate of 44,900 kg/hr
Fluid Inlet/Outlet Temperature: 288 (550)/566 (1050) °C/(°F)
Material: INCO-800
V: Fluid velocity at absorber apex (outlet)

Using this analysis and the results shown in Section 4.1, the partial cavity configuration was selected. The regulating power density and tube wall temperature profiles are shown in Figure 4-25 for the 3.5-year program design.

4.3 STRUCTURAL DESIGN ANALYSIS

The primary purpose of the stress analysis is to ensure that the design is consistent with the applicable codes and that the predicted life of the absorber is adequate for the specified life of 30 years and 11,000 temperature cycles. Stress analyses are directly related to the thermal analysis results discussed above which define tube wall temperatures and temperature gradients. The two principal failure modes are discussed below: creep and low-cycle fatigue.

4.3.1 Creep Rupture Analysis

Any material operating at high temperature suffers creep damage and fails with a limited life under lower stress conditions than its short-term measured strength. The receiver tubes are subjected to a small internal pressure simultaneous with high temperature. The creep rupture life of the tube is determined by the tube hoop stress. For both Incoloy 800 and 316 stainless steel, the creep rupture life is substantially higher than the specified 30-year life time under the temperature and tube hoop stress calculated for the present absorber design. Hence, the effect of creep damage in this case is negligible.

4.3.2 Low Cycle Fatigue Analysis

Since only part of the tube surface is exposed to the insolation, temperature gradients exist along the tube circumference and across the tube wall under high heat flux conditions. This usually induces plastic strain in the tube and could possibly lead to low cycle fatigue failure if large strain variation occurs with the temperature cycling. The number of allowable cycles for a given material is a function of the design cycle strain range and the metal temperature. It decreases with increase in strain range and metal temperature.

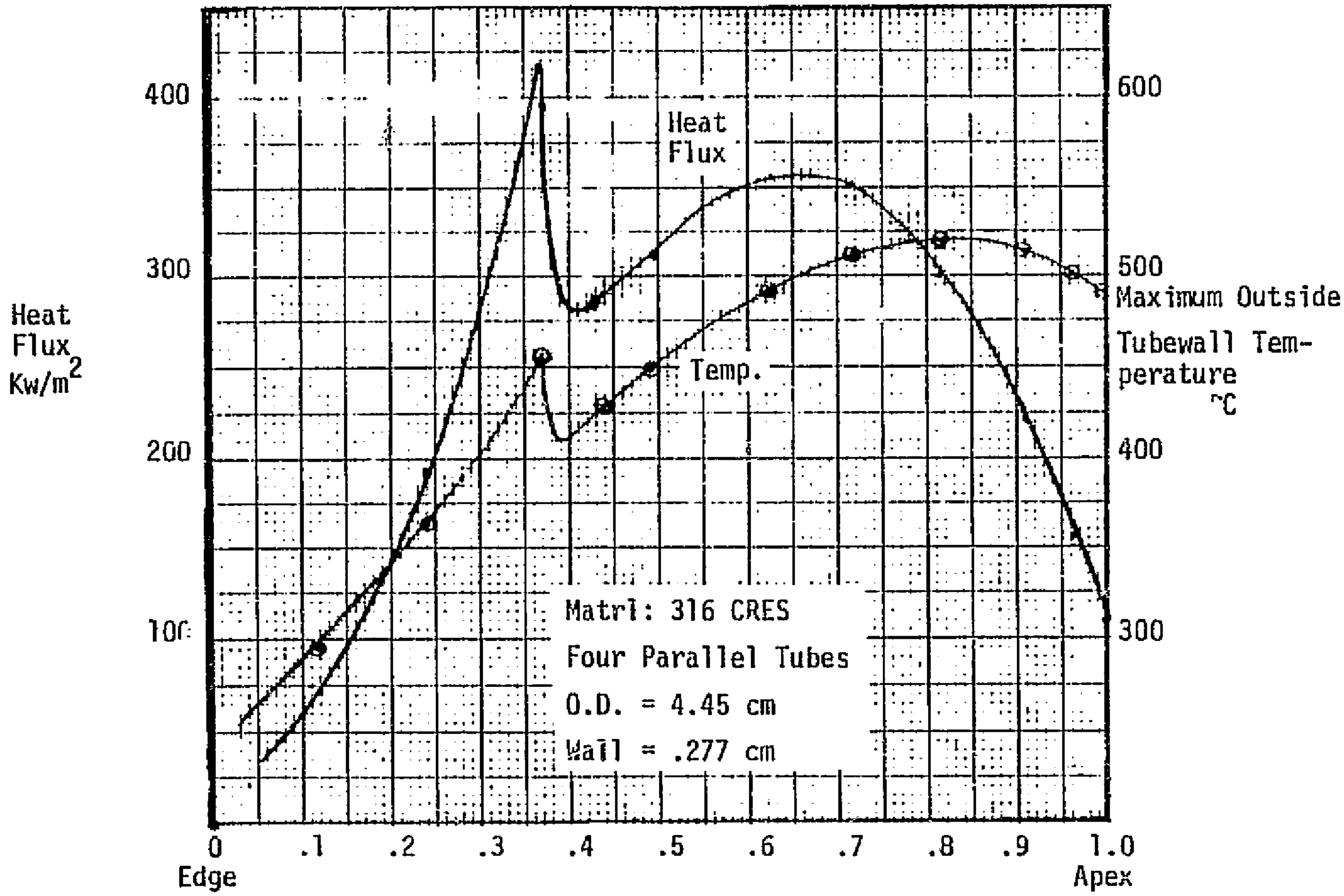


Figure 4-25. Tube Wall Temperature and Heat Flux Profiles (3.5-Year Design)

In this case, low cycle fatigue is considered to be the most critical factor affecting the receiver panel design life because of the large number of daily temperature excursions which the absorber will be subjected to during the 30-year life duration.

If the loading condition and the strain range are variable, then the accumulated creep and fatigue damage sustained during the various loading conditions are elevated. The total creep fatigue damage is a linear function of the creep component and the fatigue component is given in the ASME Code Case of N-47 (1592-10), and in the criteria for Design of Elevated Temperature Class 1 Components in Section III, Div. I, of the ASME Boiler and Pressure Vessel Code (Section 7.7.4). High cycle fatigue is considered to be negligible since there is no known excitation source to initiate vibration.

4.3.3 Analytical Techniques

To predict low cycle fatigue life, elastic and plastic strains induced by the thermal gradients in the tubes must be determined. A Finite Element Axisymmetric and Planar Structural Analysis Computer Program (APSA) has been used for stress and strain analysis. It is a two-dimensional program, used to determine the displacements, stresses, and strains in axisymmetric and planar solids. The program allows for orthotropic, temperature-dependent material properties under thermal and mechanical loads. The mechanical loads can be surface pressures, surface shears, and nodel point forces. The continuous solid is replaced by a system of ring or planar elements with quadrilateral cross section. Accordingly, the method is valid for solids that are composed of many different materials, and which have complex geometry. The APSA program analyzes elastic or elastic-plastic problems with a single set of loads.

A typical APSA model for analyzing stress and strain of a tube for an existing absorber design is shown in Figure 4-26. The figure shows the division of the tube cross section into nodal elements. Figure 4-27 shows the temperature distribution obtained from heat transfer analysis and used as input for computing stress and strain. Figures 4-28 and 4-29 give the maps of the effective stress and strain values obtained from the computer output. These are used in subsequent fatigue analyses.

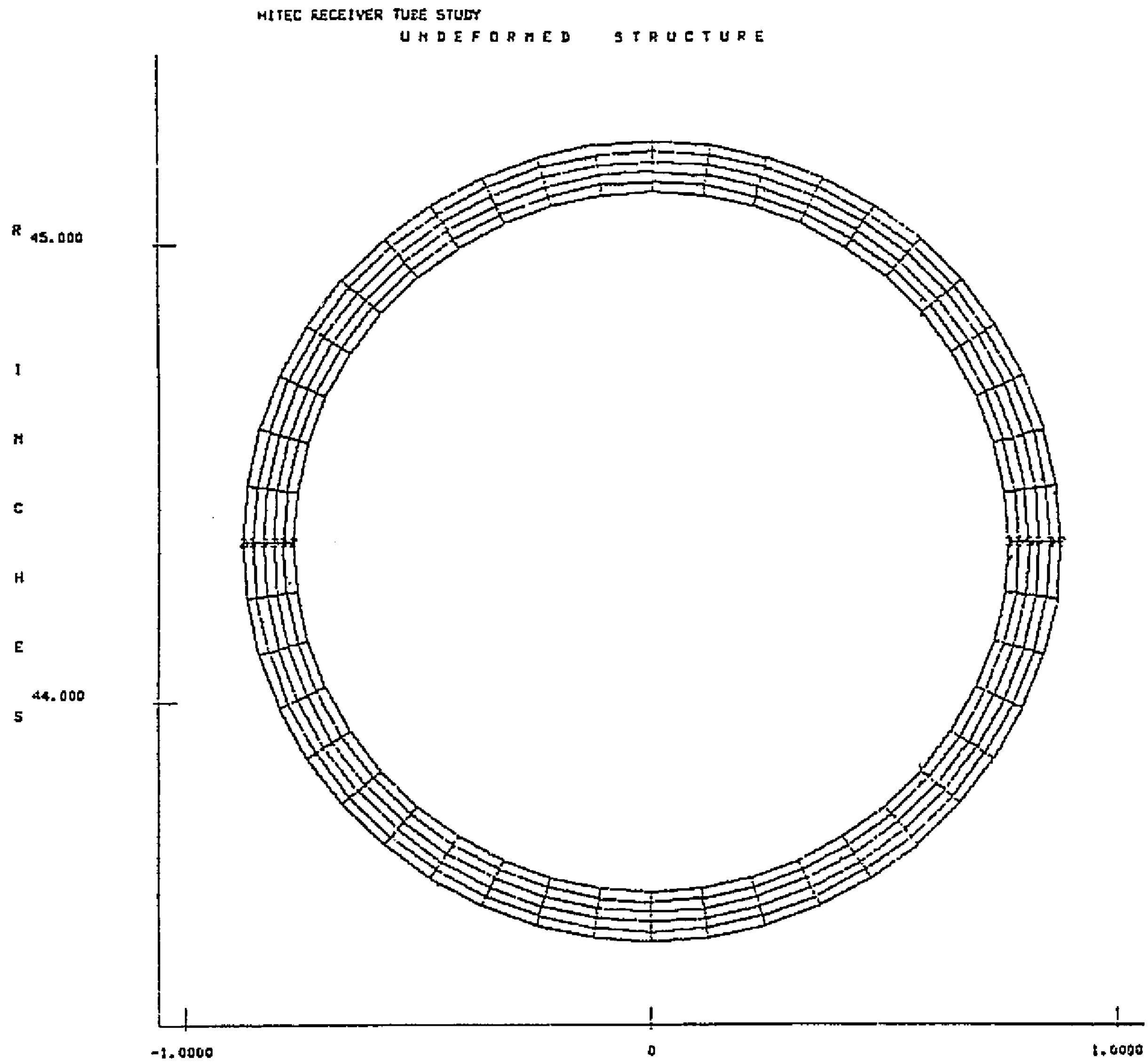


Figure 4-26. Division of the Tube Cross Section into Nodal Elements

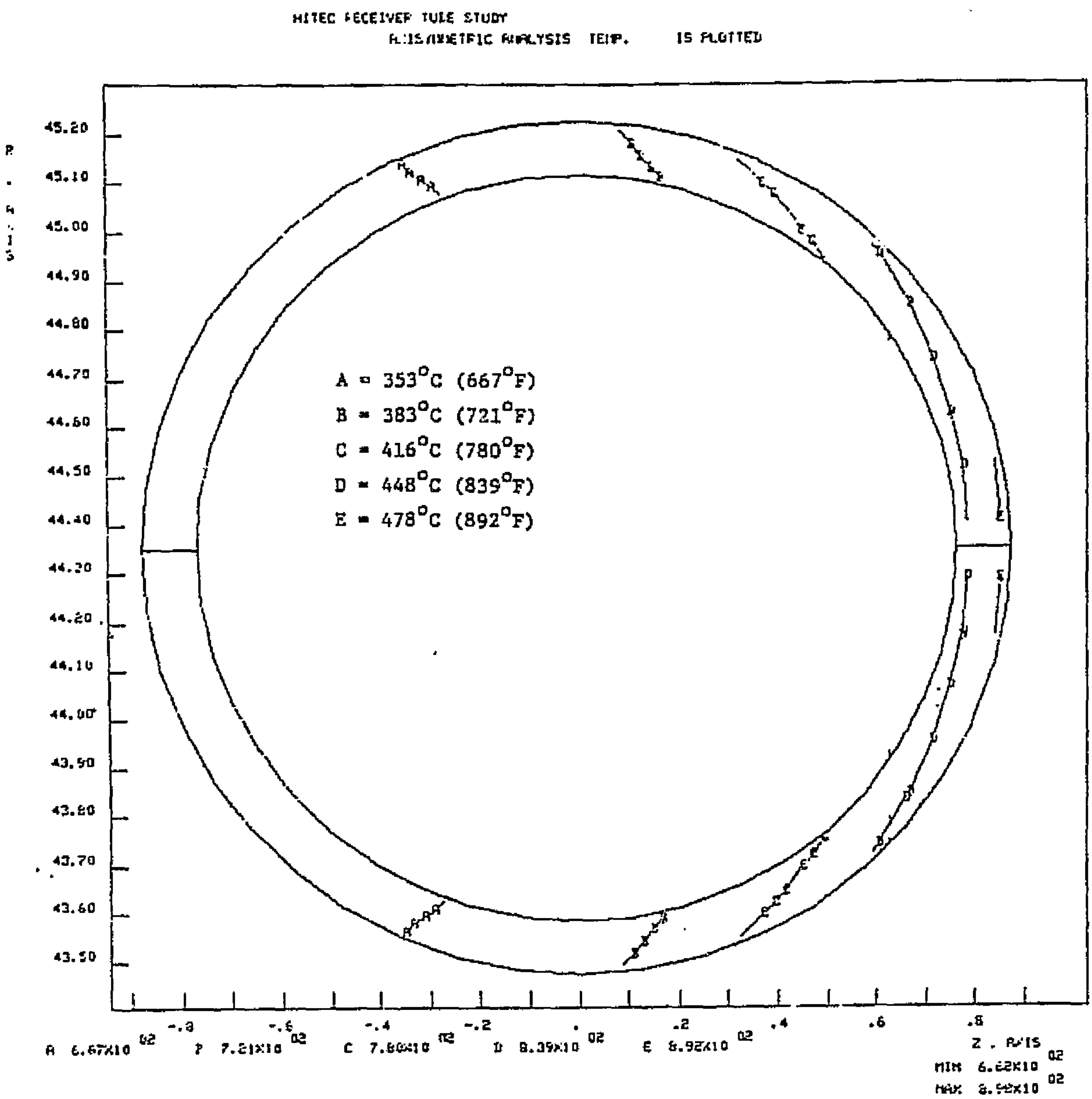
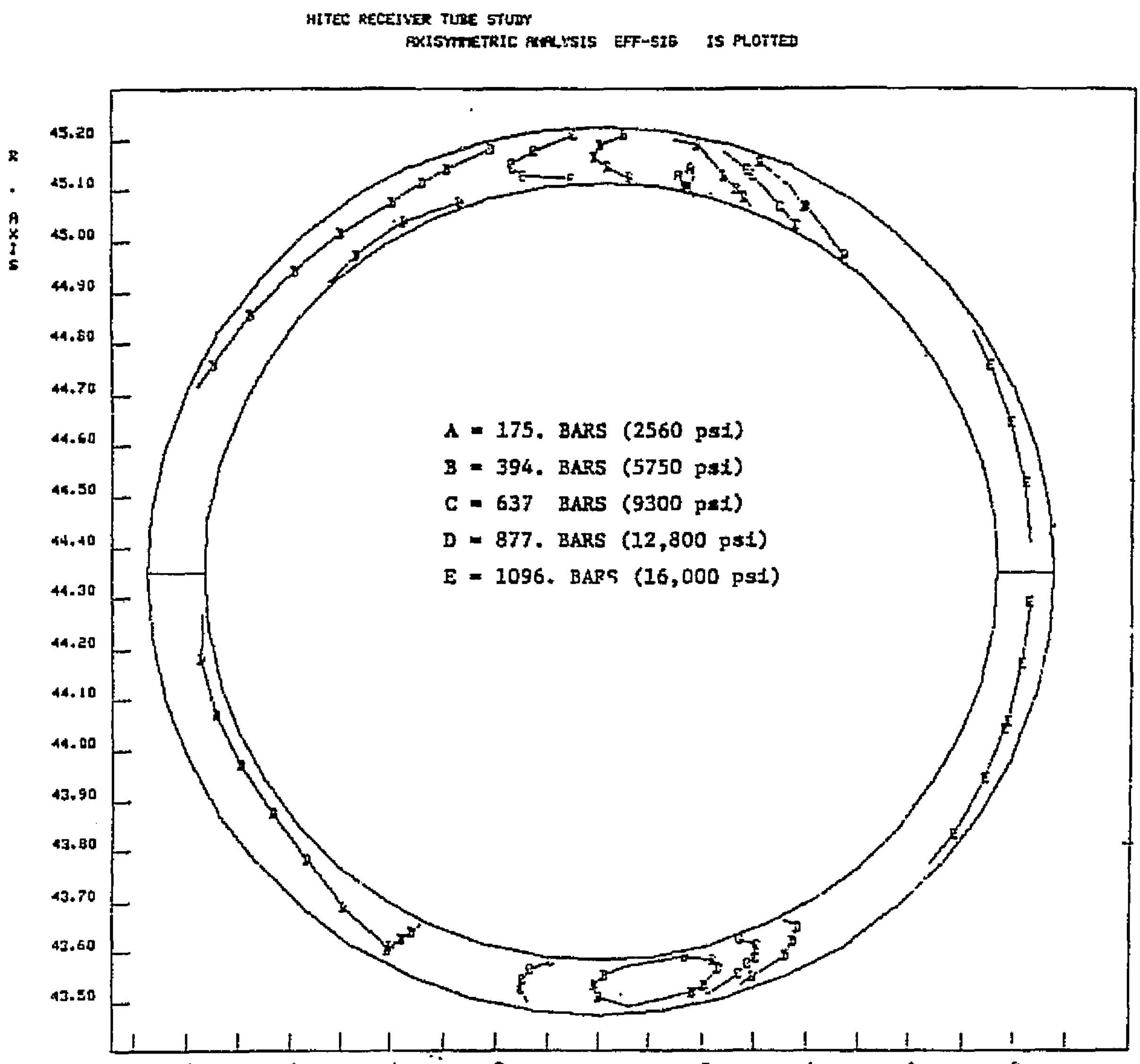


Figure 4-27. Temperature Distribution



A 2.56X10 03 B 5.75X10 03 C 9.30X10 03 D 1.28X10 04 E 1.60X10 04

MIN 2.20X10 03

MAX 1.63X10 04

Figure 4-28. Map of the Effective Stress

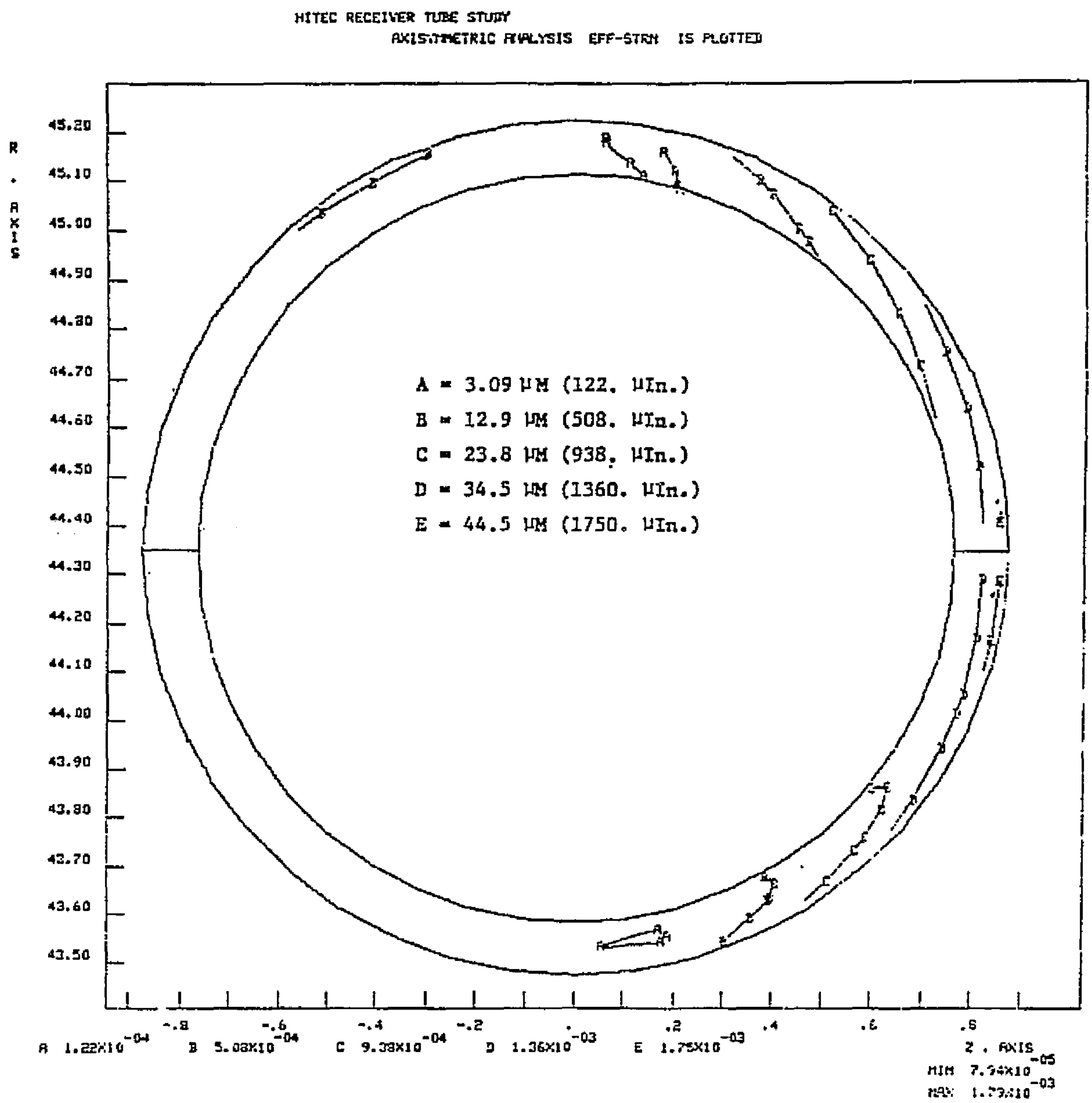


Figure 4-29. Map of the Effective Strain

Low cycle fatigue life studies were made on typical tube sizes. Both Incoloy 800 and 316L stainless steel tubes showed cycle life greater than 30 years (11,000 temperature cycles).

4.4 RECEIVER EFFICIENCY

The receiver efficiency is defined as the ratio: (Power Absorbed by the Receiver)/(Power Incident on the Receiver Aperture) Fluid. The power absorbed is a fixed design requirement. The losses (reflection and radiation from the asborbed surface, convective heat loss from the absorber surface to the atmosphere, and thermal conduction via the absorber insulation blanket and supports) are determined by the receiver geometry, the operating temperatures and thermal properties of the materials.

Receiver losses and efficiencies for four partial-cavity receivers and one external receiver are shown in Table 4-7. The data show that the partial cavity receiver achieves 91% efficiency over the entire range of fluid outlet temperatures, i.e., from 454^{o}C for the 3.5-year program to 566^{o}C for the commercial unit. Data for an "external" (flat disk) receiver having the same heat transfer area and fluid temperature profile as the 7.08 MWt partial cavity (last column of the table) is included in the table to show that advantage of the partial cavity configuration.

Table 4-7. Receiver Efficiency

	Partial Cavity				External (Disk)
	3.5 Yr	4.5 Yr	6.5 Yr	Comm	
Aperture Diameter, m	4.5	4.28	4.00	3.5	6.07
Absorbed Power, MWt	7.08	6.05	4.87	4.72	7.08
Reflection Loss, MWt*	0.195	0.167	0.134	0.125	0.337
Radiation Loss, MWt*	0.205	0.211	0.198	0.167	0.434
Convection Loss, MWt**	0.189	0.182	0.164	0.132	0.344
Conduction Loss, MWt	0.012	0.009	0.008	0.006	0.012
Efficiency, %	92.2	91.4	90.6	91.6	85.0

*$\alpha = \epsilon = 0.95$
**$h = 28.4\ W/m^2\ °C$

Section 5

TOWER SUBSYSTEM ANALYSES

The tower subsystem analyses consisted of: (1) a trade study to determine the most cost effective type of tower in the height and receiver weight range of interest, and (2) a preliminary design of the tower for Engineering Experiment No. 1.

The trade study was conducted comparing three different types of towers: (1) free-standing steel, (2) guyed steel, and (3) reinforced concrete. Reinforced concrete towers were given a precursor evaluation and eliminated from further consideration because of:

A. Traditionally higher costs associated with concrete structures of this size in comparison to steel structures due to extensive on-site construction activities and substantial foundation requirements. (Steel towers can be partially prefabricated and site assembled in sections.)

B. Structural stiffness which produces high receiver accelerations during seismic events which requires additional receiver structure. (Flexible steel towers absorb some of the ground motion, delivering less severe acceleration loads to the receiver.)

C. Greater difficulty in attaching pipe supports, work platforms, and providing extensive access for maintenance.

5.1 TOWER REQUIREMENTS

The requirements, upon which the preliminary design and costing activities were based, can be divided into design and environmental factors. From a design standpoint, it was desirable to develop data over a sufficient range of tower height and receiver weight to permit these results to be applicable to any of the candidate systems. As a result, three discrete combinations of tower height and receiver weight were specified for each tower type.

	Tower Height m (ft)	Receiver Weight kg (lb)
Case 1	48 (158)	7,273 (16,000)
Case 2	48 (158)	34,090 (75,000)
Case 3	42 (138)	7,273 (16,000)

In addition, the heavier receiver, with a face dimension of 12.2 by 12.2 m (40 by 40 ft), was assumed to have its center of gravity located 4.6 m (15 ft) above the top of the tower and located along the vertical centerline of the tower. The receiver attachment points were assumed to be the corners of a square pattern 4.9 m (16 ft) on a side. The lighter receiver, with a face dimension of 5.2 by 5.2 m (17 by 17 ft), was assumed to have its center of gravity located 2.3 m (8.5 ft) above the top of the tower and displaced by 1.6 m (5.3 ft) from the tower centerline. The receiver attachment points were assumed to be the corners of a square pattern 2.45 m (8 ft) on a side.

From an environmental standpoint, the following requirements were to be met:

Operating wind speed at 10 m elevation	16.1 m/sec	(36 mph)
Operating deflection	0.15 m	(6 in)
Survival wind speed	40.2 m/sec	(90 mph)
Seismic load	0.25 g	(horizontal ground acceleration)
Soil bearing strength	7,322 kg/m^2	(1500 lb/ft^2)

5.2 GUYED STEEL TOWER CONCEPTS

The guyed steel tower (Figure 5-1), in the configuration, required to support the heavier receiver load, is of a constant cross section with four guy cables strung at a 45° angle. In carrying out the analysis, it was found that the overturning moment associated with the survival wind load was a factor of 2 larger than the seismic-induced moment. As a result, the towers were designed on the basis of wind load requirements.

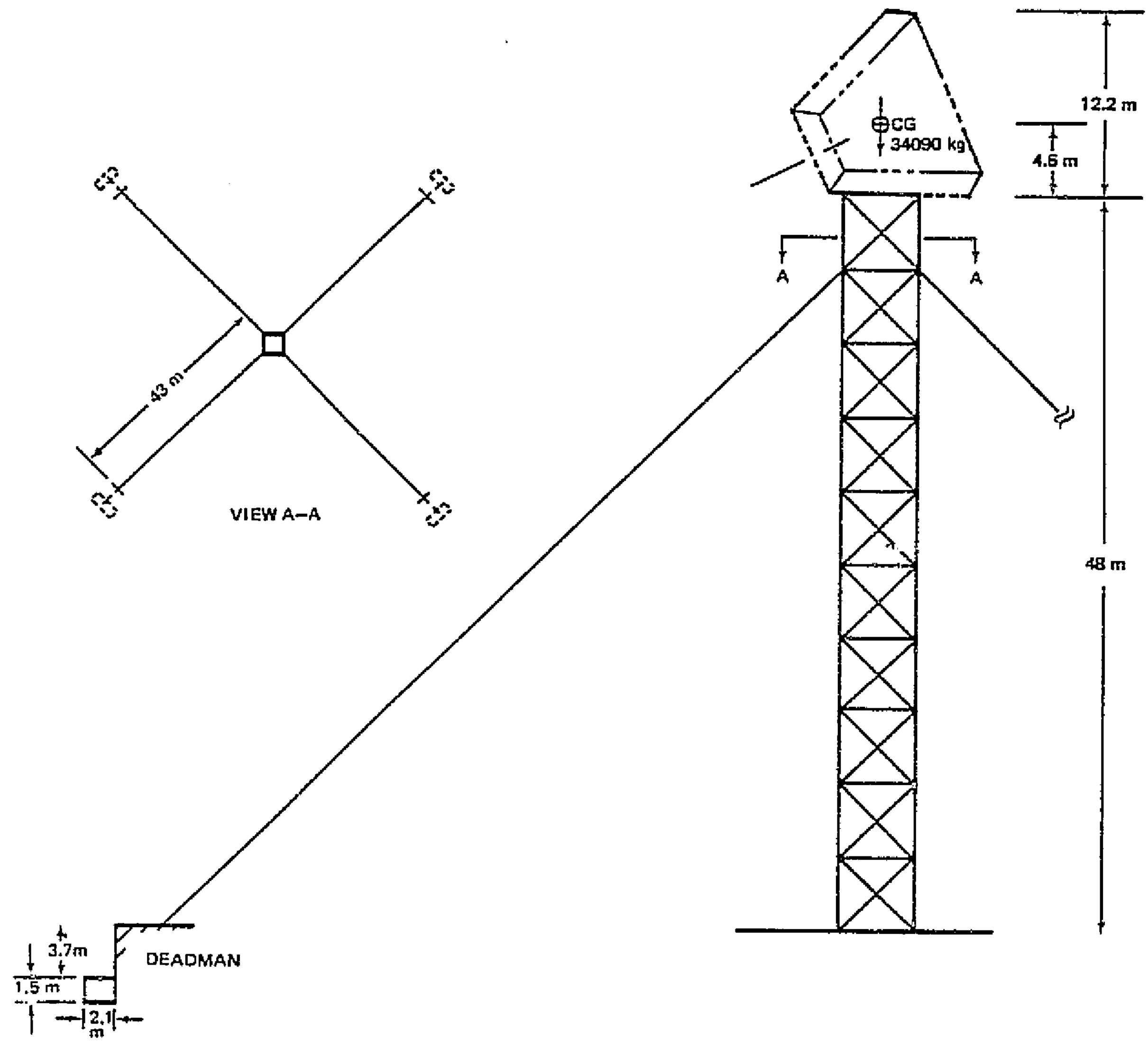


Figure 5-1. Guyed Tower Design (34,090 kg Receiver)

The principal design characteristics for each of the guyed towers are summarized in Table 5-1. The structural steel which forms the vertical structure and drag bracing is made up of commercial steel angles with the angle depth and thickness being selected to accommodate local load conditions. Cabling is assumed to be of commercial galvanized bridge cable type with the diameter being determined on the basis of loads associated with the maximum overturning moment condition.

TABLE 5-1. Characteristics of Guyed Steel Towers

Tower height m	(ft)	Receiver weight kg	(lb)	Structural steel kg	(lb)	Cable diameter cm	(in)	Cable length m	(ft)	Concrete m^3	(yd^3)
48	(158)	7,273	(16,000)	17,341	(38,150)	2.06	(13/16)	305	(1,000)	23	(30)
48	(158)	34,090	(75,000)	24,091	(53,000)	4.45	(1-3/4)	305	(1,000)	64	(84)
42	(138)	7,273	(16,000)	14,841	(32,650)	1.91	(3/4)	262	(860)	23	(30)

The tower foundation consists of a mat design of sufficient area to distribute the compressive load at a rate less than the soil bearing strength limit of 7,322 kg/m^2 (1,500 lb/ft^2). The mat is assumed to be 0.61 m (2 ft) thick which is a sufficient depth, based on Barstow soils data, to encounter reasonably stable soil. The deadmen consist of buried concrete piers which are sized to accommodate the maximum cable loads.

5.3 FREE-STANDING TOWER CONCEPT

The free-standing steel tower of the type shown in Figure 5-2 is a tapered design with the base dimension approximately one-fifth the tower height. As in the case of the guyed tower, the structural and foundation designs are based on the overturning moments created by the maximum wind loads.

The principal design characteristics for the free-standing towers are shown in Table 5-2. The structural steel contained in the vertical members and drag braces is assumed to be commercial angle steel. The foundations for each of the four legs are designed to withstand the overturning moments while

Table 5-2. Characteristics of Free-Standing Towers

Tower height		Receiver Weight		Structural steel		Concrete		Dimensions (square) Top		Base	
m	(ft)	kg	(lb)	kg	(lb)	m^3	(yd^3)	m	(ft)	m	(ft)
48	(158)	7,273	(16,000)	28,545	(62,800)	142	(186)	2.4	(8)	7.3	(24)
48	(158)	34,090	(75,000)	45,113	(99,250)	153	(200)	4.9	(16)	9.7	(31.8)
42	(138)	7,273	(16,000)	24,364	(53,600)	126	(165)	2.4	(8)	7.3	(24)

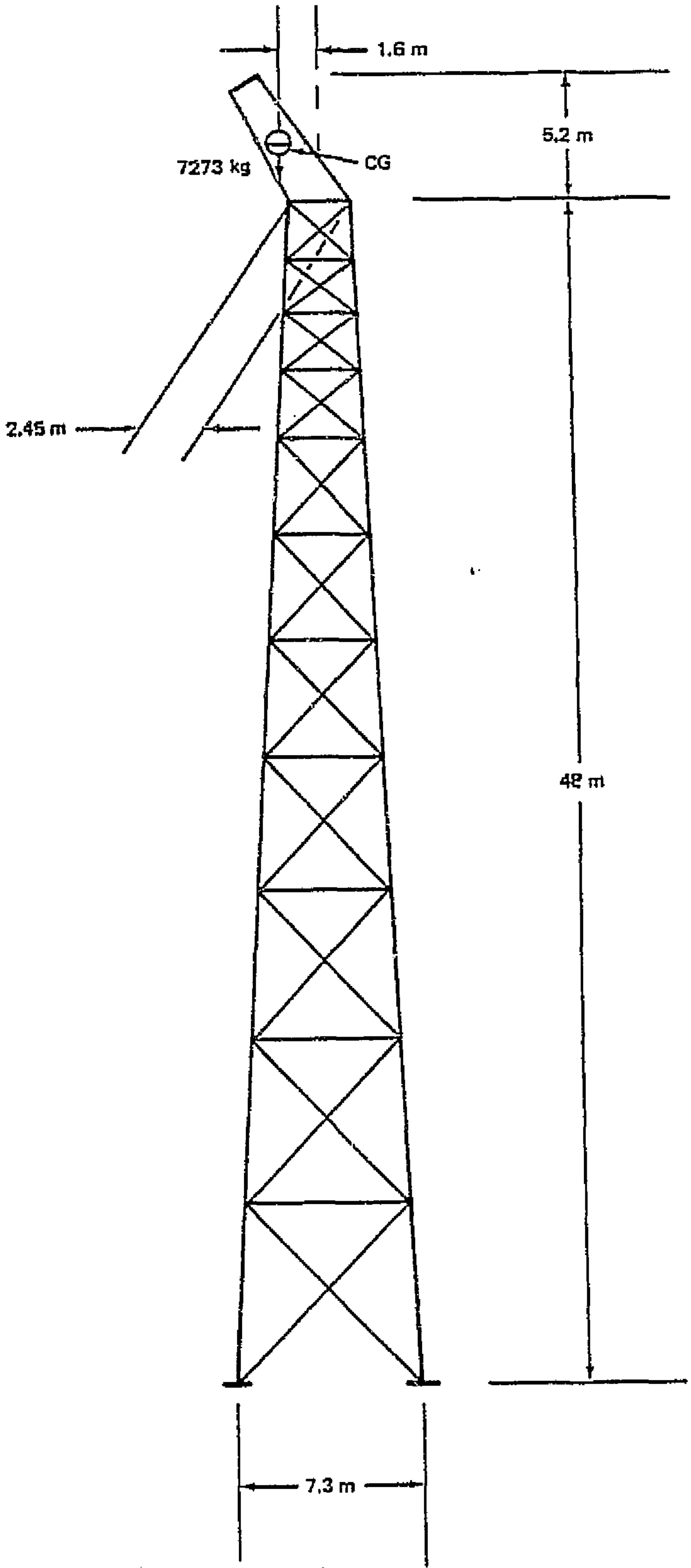


Figure 5-2. Free Standing Tower Design (7273 kg Reciever)

providing a sufficient base for the distribution of the compressive loads consistent with soil loading limitations.

5.4 TOWER CONCEPT EVALUATION

Figure 5-3 presents tower cost data as a function of tower height and receiver weight. The results indicate the consistent superiority of the guyed tower over the height and weight ranges of interest in this study. From a comparison of cost breakdowns for the two towers, it is seen that each of the cost increments for the free-standing tower exceeds the corresponding value shown for the guyed tower (except the electrical value) with the biggest discrepancy occurring for the concrete required for foundations and supports. The indirect entries include construction equipment and supplies, temporary facilities, labor benefits, and other field expenses. The miscellaneous category includes engineering, contingency, and fees.

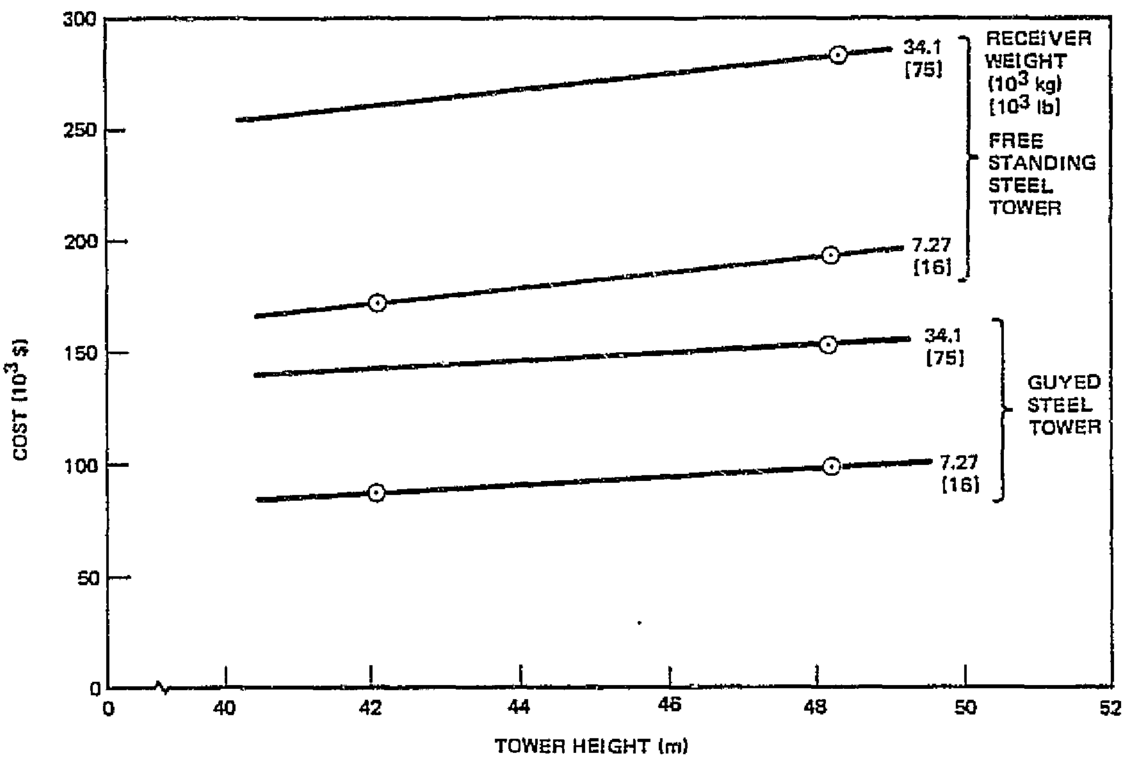


Figure 5-3. Cost Comparison Between Free Standing and Guyed Steel Towers

Based on these cost data, the guyed tower is a superior choice for the present application and will be retained as the baseline tower configuration. In addition, the high cost increment associated with concrete for the free-standing steel tower also supports the earlier decision to eliminate the free-standing concrete tower from further consideration.

5.5 GUYED TOWER DESIGN

A summary of the analysis and design work accomplished by Stearns-Roger is provided in the following pages. Table 5-3 presents the load requirements as applied to the structure. Figure 5-4 shows the design of the guy wires and Figure 5-5 the design of the foundation. Table 5-4 illustrates the method used to calculate the maximum allowable member loads. These values are then compared to the maximum design loads in Table 5-5. The resultant tower is a rather stiff structure with a deflection of only 1.7 cm at maximum load.

Table 5-3. Tower Loads

- Wind Loads

Wind loads were determined per the provisions of ANSI A58.1 - 1972.

Maximum wind velocity = 40 m/sec (at 9 m) [90 mph (at 30 ft)]

Exposure type C (flat open country)

Gust factor = 1.15 (from Appendix A6.3.4.1)

Net pressure coefficients:

Steel tower: Values of C_f from Section 6.9

Receiver: Normal wind, $C_f = 1.3$

Diagonal wind, $C_f = 1.0$

Projected area of receiver:

Normal wind, A = 28 m^2 (300 ft^2)

Diagonal wind, A = 39 m^2 (420 ft^2)

An additional area of 0.3 m^2/m (3 ft^2/ft) of height was added to account for wind on the ladder, elevator, piping, etc.

- Seismic

0.25 g maximum ground acceleration in both the horizontal (one component) and vertical directions.

Ground response spectra obtained from NRC Reg. Guide 1.60. Damping ratio assumed to be 7%.

SRSS method used for summing components and modes.

Load Factors for Member Design

1) 0.75 (D + G + W)
2) 0.75 (D + G + E)

D = Dead loads (tower and receiver)

G = Guy preloads

W = Wind load

E = Seismic load

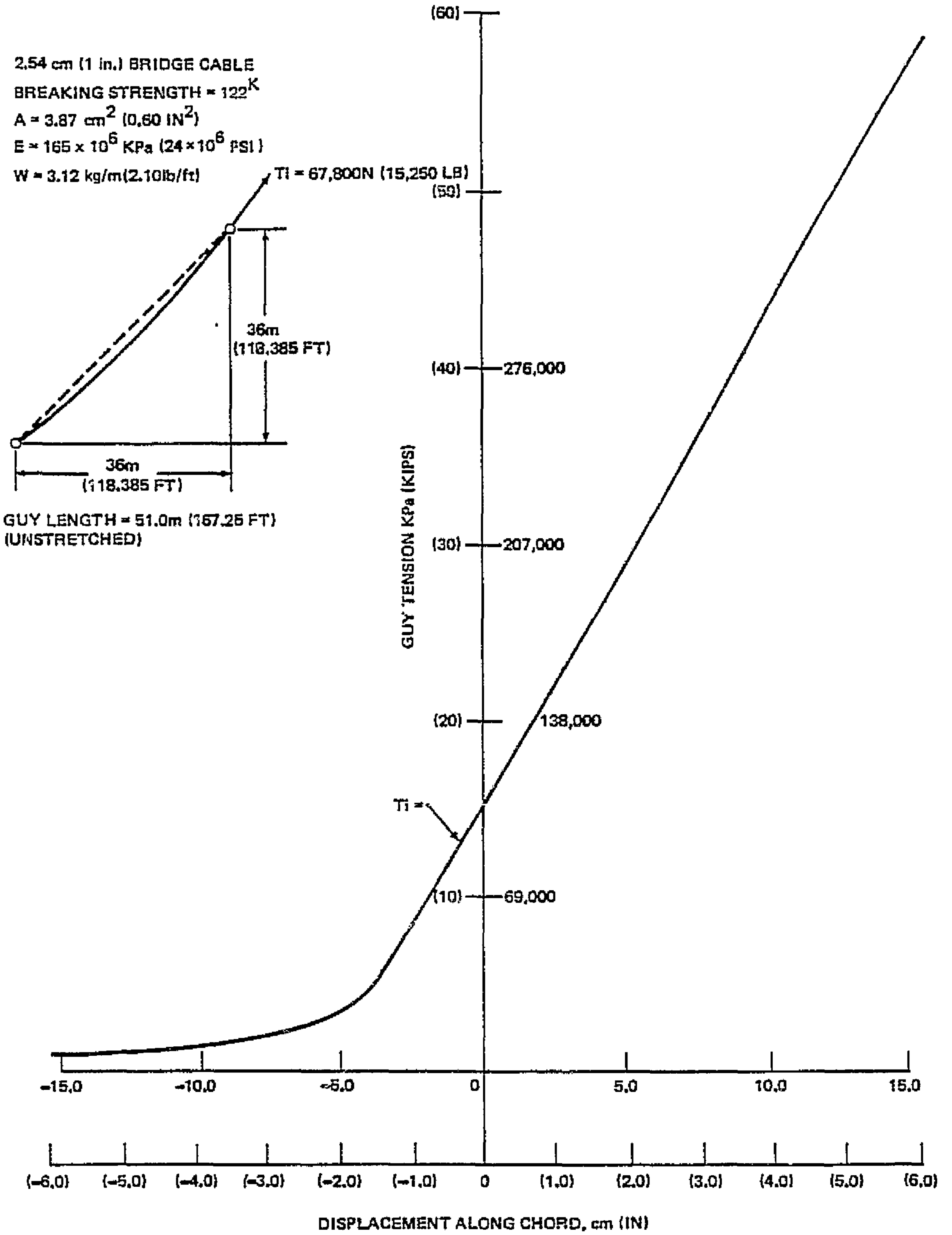
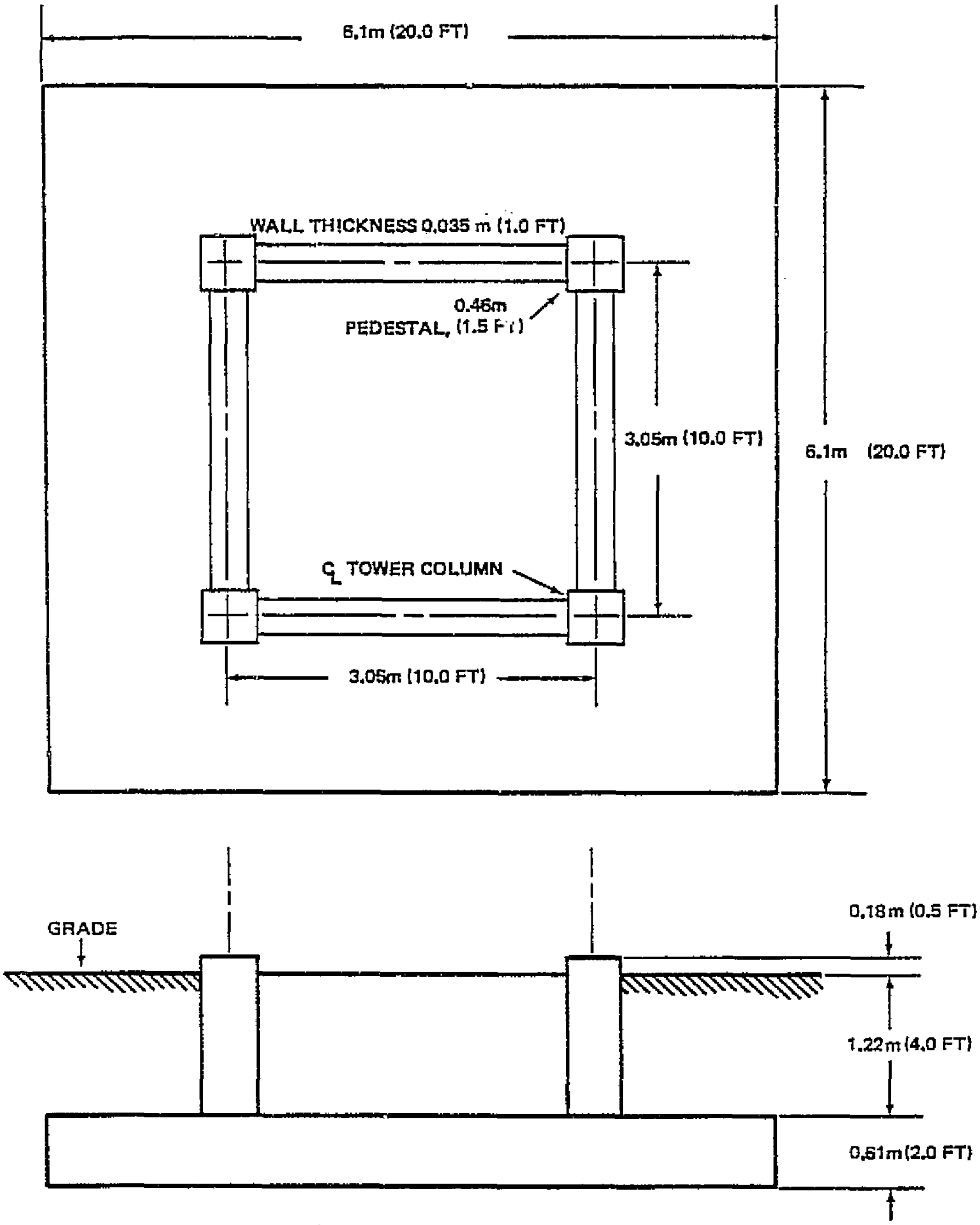


Figure 5-4. Guy Tension Design



CONCRETE VOLUME = 27.7m^3 (976.5 CU FT)

REBAR = 1230 kg (2712 LB)

Figure 5-5. Mat Design

Table 5-4. Allowable Member Loads

Allowable Member Forces $F_y = 248$ mPa (36 KSI)

Verticals L 15.2 x 15.2 x 1.9 cm (L6 x 6 x 3/4)

$\ell = 3.007$ m (118.385 in)

$\frac{\ell}{r_z} = \frac{118.385}{1.17} = 101.18$ $F_a = 88.5$ mPa (12.83 KSI)

$P_a = 12.83 \times 8.44 = 108.29^k$

Diagonal Braces L 7.6 x 7.6 x 0.63 cm (L3 x 3 x 1/4)

$\ell = 4.282$ m (168.568 in)

$\frac{0.75\ell}{r} = \frac{0.75 \times 168.568}{0.930} = 135.94$

$\frac{0.5\ell}{r_z} = \frac{0.5 \times 168.568}{0.592} = 142.37$ $F_a = 50.8$ mPa (7.37 KSI)

$P_a = 7.37 \times 1.44 = 10.61^k$

Horizontals L 7.6 x 7.6 x .48 cm (L3 x 3 x 3/16)

$\ell = 3.048$ m (120 in)

$\frac{\ell}{r_z} = \frac{120}{0.596} = 201.34$ $F_a = 25.4$ mPa (3.68 KSI)

$P_a = 3.68 \times 1.09 = 4.01^k$

Table 5-5. Computed Member Forces

Member Type	Maximum Member Force Load Case No.* 1	2	3	4	Allowable Force $N \times 10^3$ ($LB \times 10^3$)
Vertical, Compr.	92.38 (20.77)	497.0 (111.73)	303.7 (68.28)	161.2 (36.25)	481.7 (108.29)
Diagonal, Compr.	6.89 (1.55)	48.48 (10.90)	40.61 (9.13)	13.57 (3.05)	47.19 (10.61)
Horizontal, Compr.	-	10.45 (2.35)	12.19 (2.74)	-	17.84 (4.01)
Horizontal, Tens.	21.13 (4.75)	25.53 (5.74)	26.64 (5.99)	22.11 (4.97)	104.7 (23.54)

Deflection of receiver under operating wind (load case 4) = 1.74 cm (0.686 in.)

*Load case 1 = Tower and receiver dead loads + guy forces

Load case 2 = 0.75 x (Load case 1 + design wind along diagonal)

Load case 3 = 0.75 x (Load case 1 + design wind along flats)

Load case 4 = Load case 1 + operating wind along diagonal

Seismic load did not govern the design of any member.

Section 6
ENERGY STORAGE ANALYSES AND TRADE STUDIES

Trade studies for the energy storage subsystem are described in this section.

6.1 STORAGE TANK DESIGN

The storage tank volumes were determined based on the following considerations:

A. Minimum extractable energy requirements

B. Buffer requirement

C. Heat losses to the environment

D. Unavailable energy

E. Space requirements for internal components such as pumps, manifolds, or baffles

F. Ullage space

The tank configurations will depend on:

A. Storage technique (two tank or dual media)

B. Pump configurations

C. Transportation constraints

D. Tensile and thermal stresses

6.1.1 Minimum Volume Required

The determination of the energy storage requirement including extractable energy, system losses, and buffer allowance was described in Volume III, Section A.3.5. The minimum volume required to store this energy can be calculated by

$$V_m = Q_m/C_p \Delta T \rho)$$

Q_m = Total energy requirement including buffer and heat losses

C_p = Heat capacity of the storage media

ΔT = Temperature difference

ρ = Density of the storage media

Values used for the calculation of minimum volume requirements are shown in Table 6-1.

6.1.2 Heat Losses

The heat which is lost to the environment from the lines and the storage tanks represents energy which is collected but is unavailable for power generation. To compensate for this, the storage capacity must include energy which is equivalent to the heat lost in a 24-hour period. The duty cycle assumed for these calculations is as follows:

A. The hot tank is full for 12 hours and empty for 12 hours

B. The cold tank is full for 24 hours

Table 6-1. Storage Tank Minimum Volumes

Program/Tank	Q_m (MWHt)	(°C)	ρ (kg/m^3)	Cp (cal/g °C)	Minimum Volume (m^3)
3.5 Year	17.1	194		0.373	
Hot Tank			1,746		116
Cold Tank			1,889		107
4.5 Year	14.9	222		0.373	
Hot Tank			1,706		91
Cold Tank			1,870		83
6.5 Year	12.5	250	HTS 1,818	0.373	50
			Iron ore 5,247	0.2	

The steady state heat loss is given by

$$\dot{q}_s = (T_w - T_a) / \frac{X}{k_i A_{ave}} + \frac{1}{h_o A_o}$$

$\dot{q}_s$ = Steady state heat loss

T_w = Tank or pipe wall temperature

T_a = Ambient temperature

X = Insulation thickness

k_i = Thermal conductivity of the insulation

A_{ave} = Log mean area

A_o = Outside area of the insulation

h_o = Outside heat transfer coefficient

The transient heat loss which occurs when the tank is empty is given by

$$q_t = (mc)\, T_{w_i} - T_{w_f}$$

q_t = Transient heat loss

mc = Tank capacitance

T_{w_i} = Initial wall temperature

T_{w_f} = Final wall temperature

The ambient temperature was assumed to be 15.5°C and the outside heat transfer coefficient was taken to be 22.7 $W/m^2 - °C$. Based on tank dimensions given in Volume III, Section 4.5.1, heat losses have been calculated for the various program durations and are shown on Table 6-2 along with critical parameters. The thermal conductivity of tank insulation is shown in Figure 6-1 as a function of temperature. The capacitance of the insulation was conservatively ignored in these calculations. Cooldown transients for the hot tank in an empty condition are shown in Figure 6-2.

Table 6-2. Storage Tank Heat Losses

	X (cm)	T_{w_i} (°C)	q_s (MWH)	q_t (MWH)	Total Heat Loss (MWH)	% of Extractable
3.5 Year						
Hot Tank	27.9	454	0.208	0.176		
Cold Tank	20.3	260	0.220	-	0.604	3.7
4.5 Year						
Hot Tank	30.5	510	0.175	0.159		
Cold Tank	22.9	288	0.176	-	0.501	3.5
6.5 Year	30.5	538/ 288	Top 0.030	-		
			Side 0.144		0.272	2.3
			Bottom 0.098			

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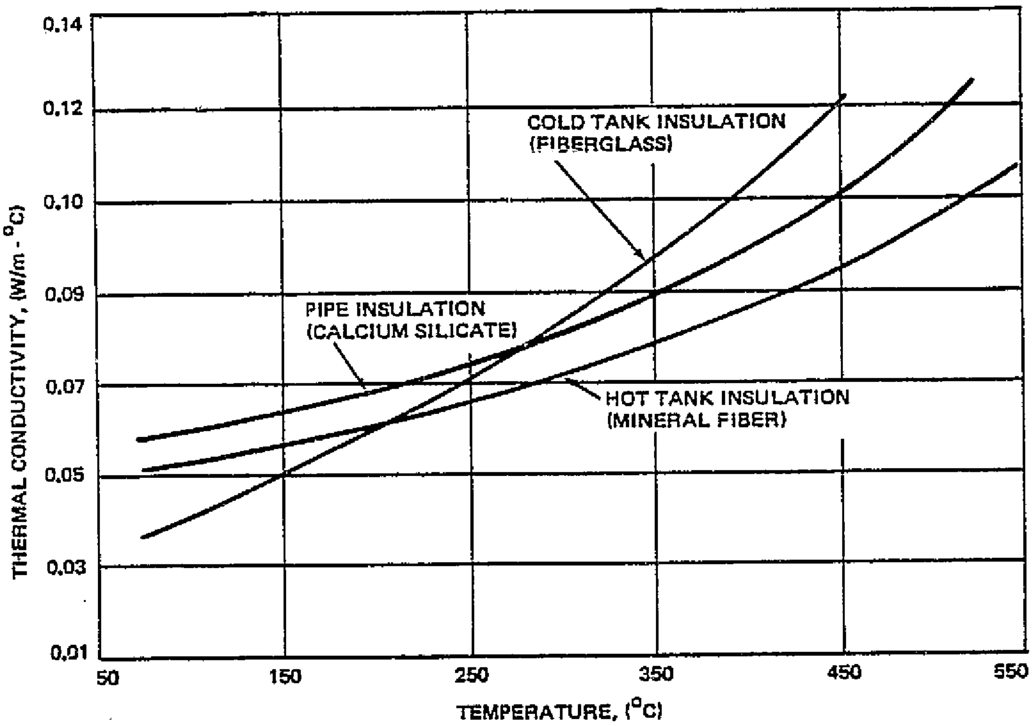

Figure 6-1. Thermal Conductivity of Different Insulation

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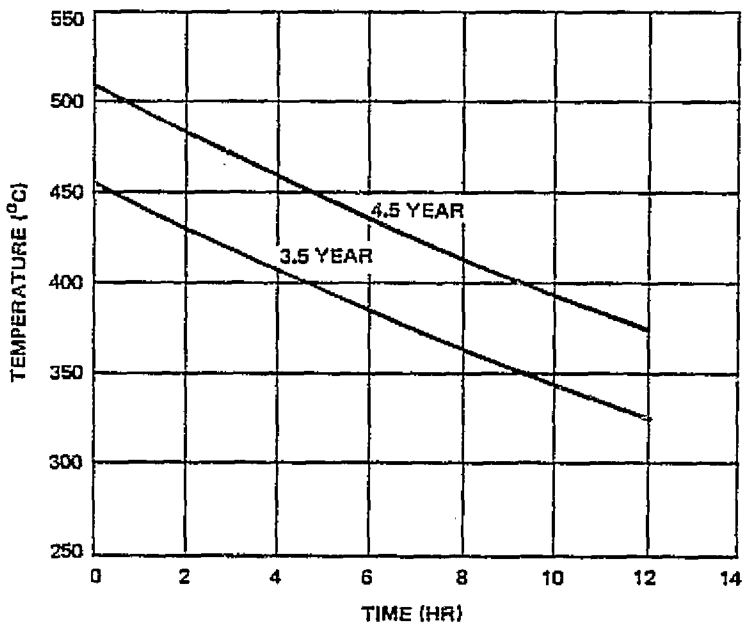

Figure 6-2. Hot Tank Cooldown Transients

6.1.3 Unavailable Energy

In the two-tank concept, all the sensible heat stored (excluding daily losses and the tank sump) is available for extraction. In the dual media thermocline technique, a portion of the stored energy cannot be extracted due to the thermocline thickness. This is typically on the order of 10%. The mass of storage media and tank volume was increased by 10% to account for this in the 6.5-year program. (See Section 6.4.)

6.1.4 Additional Space Requirements

In the two tank configuration, an excess of 2% was allowed for space occupied by the pump shaft, immersion heater, and ullage. A total of 9% excess is allowed for two manifolds and ullage space in the dual media thermocline tank.

6.1.5 Tank Configuration

Because submerged bearing pumps were selected over vertical cantilever designs, there was no constraint on tank diameters. In order to be transportable, the diameters were limited to 3.6 m. Horizontal tanks were chosen for the two tank configuration so that they could be easily installed below ground level to facilitate draining salt from the system back to the tanks. A vertical tank is, of course, required in the 6.5-year program for thermocline operation. In this case, a length/diameter ratio greater than 1.5 was assumed adequate.

6.1.6 Tank Gage

Using standard equations established by the ASME boiler code, the thermal storage tank gages were determined based on the following assumptions:

	Cold Tank	Hot Tank
Differential Pressure	3 Bars	3 Bars
Diameter	3.6 m	3.6 m
Allowable Stress	880 kgF/cm^2	1056 kgF/cm^2
Corrosion Allowance	2.5 mm	0.9 mm

The calculated wall thickness was increased to the next closest 1.58 mm (1/16 in) as a safety measure and the gage was specified as 11.1 mm (7/16 in) for the carbon steel cold tanks and 8.1 mm (5/16 in) for the stainless 316 hot tank.

6.2 INSULATION THICKNESS

As the insulation thickness increases, the cost of the insulation increases accordingly. Since heat losses are reduced, the storage requirements and related costs are decreased. The required heat input to the system is also less and this is related directly to the required number and cost of heliostats. An optimum thickness will therefore exist. As illustrated in Figure 6-3 for the hot tank (4.5-year program), the optimum insulation thickness can be chosen for the cold tank and the hot tank at the minimum total system cost. Data assumed in the optimization analysis are given in Table 6-3. Because the effective thermal conductivity of installed insulation is always greater than

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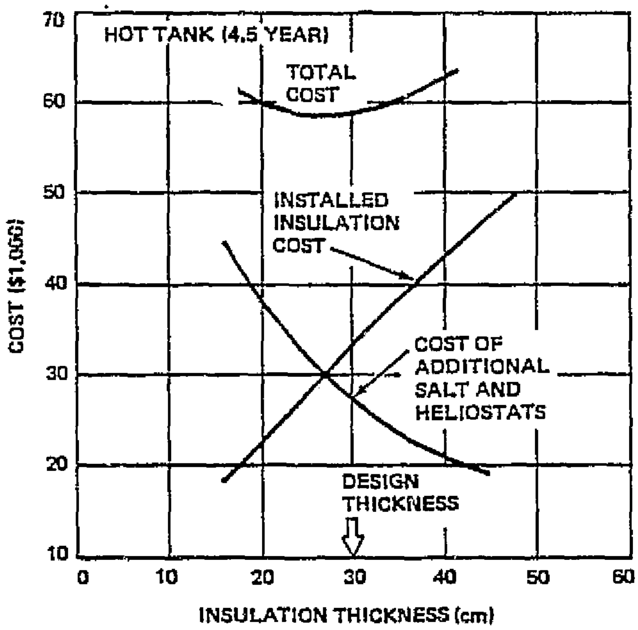

Figure 6-3. Hot Tank Insulation Optimization

Table 6-3. Tank Insulation Optimization

	3.5 Year Hot Tank	3.5 Year Cold Tank	4.5 Year Hot Tank	4.5 Year Cold Tank	6.5 Year
Insulation Cost (Installed), $\$/m^3$	777	600	777	600	847
Cost of Salt, $/kWh capacity	9	9	8	8	3
Cost of Collector $/kWh/day	69	69	71	71	73
Design Thickness					
in	11	8	12	9	12
cm	27.9	20.3	30.5	22.9	30.5

that specified by a manufacturer, the design thickness was increased to the next standard interval (inch). It should be noted that the installed cost of insulation is a function of the material and thickness as well as the tank configuration (horizontal, vertical). The collector cost is based on the figure of merit.

6.3 IMMERSION HEATER DESIGN

Immersion heaters must be selected which are capable of:

A. Melting the entire salt inventory in a reasonable period of time (less than 2 weeks)

B. Maintaining the salt above the melting point or minimum operating temperature if required.

The total heat required to bring solid heat transfer salt to operating conditions is given by

$$Q = M_s C_{p_s} (T_m - T_a) + M_s \Delta H_f + M_s C_{p_\ell} (T_o - T_m) + M_t C_t (T_o - T_a) + Q_L$$

where

M_s = Mass of salt

M_t = Mass of tank

C_{p_s} = Heat capacity of solid salt

C_{p_ℓ} = Heat capacity of liquid salt

C_t = Heat capacity of steel tank

T_m = Salt melting temperature

T_a = Ambient temperature

T_o = Minimum salt operating temperature

ΔH_f = Salt heat of fusion

Q_L = Heat loss to the environment

With a selected 100 kW heater, the total time required to raise the temperature of salt to the minimum operating temperature is given below. This size heater is more than sufficient to maintain salt at the operating temperature. The maximum loss is from the hot tank in the 3.5-year program and amounts to 17.4 kW.

	3.5 Year	4.5 Year
T_0(°C)	260	288
Q(MWh)		
Salt Heatup	19.9	17.0
Salt Melting	4.6	3.5
Tank Heatup	0.4	0.3
Losses	0.8	0.7
t(hr)	256	216

6.4 THERMOCLINE DEGRADATION

This section provides the rationale for sizing the dual-media thermal storage unit above the value required if an ideal thermocline could be assumed. The means whereby increased storage capacity can be obtained by careful operating techniques and the increased turndown ratio required to achieve this goal are also discussed.

If the thermocline is caused to move up and down in the middle of the thermal storage unit several times, it has a tendency to be smeared or degraded. Thus the change from the high temperature in the top of the tank to the lower temperature in the bottom of the tank, as one proceeds across the thermocline, is no longer as abrupt. When this region reaches the top of the tank, typically near the end of the discharge period, the exiting fluid temperature going to the steam generator will necessarily decrease below the design value. The amount of temperature drop that the steam generator can tolerate is usually limited to an 8°C to 16°C range. The heat remaining in the thermal storage unit is thus not available for use to generate power. Similarly, after the thermal storage unit has been almost fully charged, the thermocline reaches the bottom of the tank, and the temperature of the exiting fluid begins to rise above the level of the design value. For this case, the control system must necessarily increase the flowrate to assure that the exiting temperature from the receiver does not climb above the design value. This process can continue until the control valve is fully opened and the flow is at its maximum. At this point some heliostats must be repositioned to decrease the energy to the receiver.

It can be seen that the material in the thermocline band contains heat that is not available to the system. The thermal storage unit must thus be constructed somewhat larger, usually by from 10 to 15%. This factor can be reduced somewhat by ensuring that the thermocline is run off the bottom of the tank and off the top of the tank (if possible) whenever the opportunity presents itself. Each time this occurs, it tends to upgrade the thermocline, resulting in a slightly increased thermal capacity for the thermal storage tank. Should a condition arise where no sunlight reaches the system for a number of days or possibly weeks, the thermocline will tend to degrade and create a condition as previously described. This thermocline degradation can, however, be eliminated by carefully bringing the system on stream when heat is again first being received from the receiver. This can be accomplished with the aid of instrumentation which measures the available energy in the thermal storage unit and the degree of degradation of the thermocline. This instrumentation consists of a series of thermocouples placed in the bed in a vertical row spaced approximately 15 to 30 cm apart. The thermocline profile can be displayed on a cathode ray tube in the control room to show the degradation of the thermocline to the operator. In addition, if desired, the computer can determine the amount of available energy in the thermal storage unit.

A convenient time to reestablish a steep thermocline is in the early morning when only a small amount of energy is absorbed by the receiver. The temperature of the fluid entering the receiver can then be allowed to rise above the normal operating range and still not require excessive flowrates to maintain the proper outlet temperature from the receiver. The thermal storage unit is thus charged slowly to reestablish an efficient thermocline field. Since the opposite action of discharging at a slow rate to the steam generator is probably not possible (since the turndown ratio of the steam generator will be limited), it is best to run the thermocline out of the bottom of the tank, utilizing small amounts of energy coming to the receiver, rather than trying to improve the thermocline by running it out of the top of the tank upon discharge. The above condition is rare since the degradation of the thermocline to the point where such measures must be taken, will require many many days and possibly many weeks. Therefore, the condition referred to above and the action taken will seldom occur.

Section 7
ENERGY TRANSPORT SUBSYSTEM ANALYSES

Analyses and trade studies for the energy transport subsystem are described in this section.

7.1 FEEDPUMP SELECTION AND DESIGN

Because molten salt is utilized as the heat transport medium, certain precautions must be taken in pump selection. The following types were considered for use:

A. Vertical centilever — With a pump of this type, all bearings are above the mounting plate. Long shafts on the order of 2 m (6 ft) are extremely expensive or totally impractical. Extension pipes can be attached to the pump inlet at a nominal depth of 1 m (3 ft). However, an auxiliary pressurization system or suction device is required to ensure that liquid is above the impeller during pump startup.

B. Sleeve bearing design — Normally used for low-head, low-speed applications, this design would allow the pump shaft to be as long as necessary so that tank diameters would only be limited by transportation constraints. Because of problems encountered with auxiliary systems used for pump startup with cantilever designs, the submerged bearing type was recommended by pump manufacturers. They are also less expensive and were found to be used quite extensively in industrial molten salt applications with minimum maintenance.

7.1.1 Receiver Feedpump Requirements

The total head requirements were based on the system configurations shown in Figure 7-1. The requirement includes the frictional pressure drop from the

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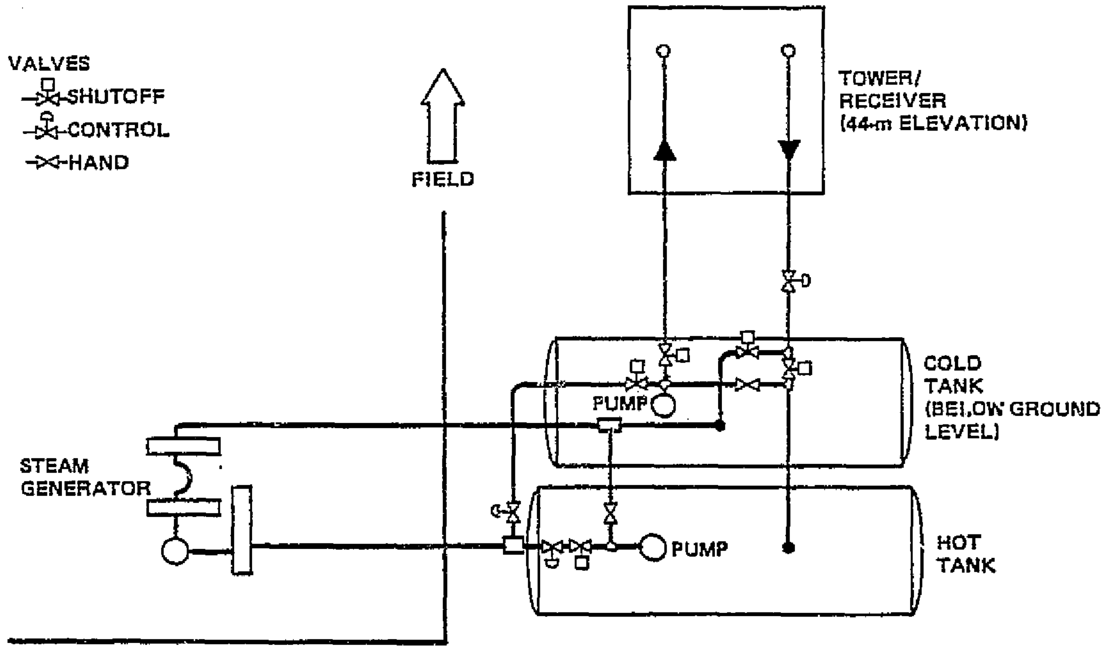
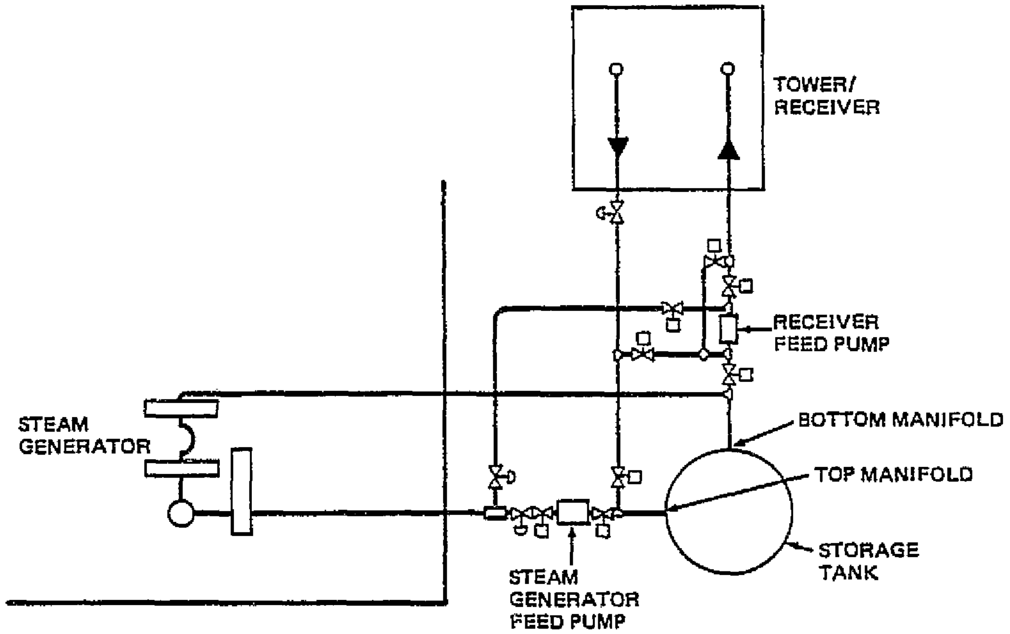


3.5/4.5 YEAR SYSTEM



6.5-YEAR SYSTEM

Figure 7-1. System Layout

pump inlet to the receiver outlet, in addition to the static head. Frictional losses include contributions from elbows, tees, valves, and entrance/exit effects, in addition to line losses. Data used in standard pressure drop calculations are shown in Table 7-1.

7.1.2 Steam Generator

The total head was determined from frictional losses through the lines and the steam generator and the static head requirements. Losses in valves, tees, and elbows were accounted for although losses in the steam generator were conservatively estimated. Results are shown in Table 7-1.

7.2 HEAD DISSIPATION

A method of dissipating the hydrostatic head in the receiver downcomer was required. Pressurized tanks and baffles were considered too expensive. Since control valves are normally sized to absorb one-third of the total system pressure drop, it was determined that the control valve in the receiver loop could be used for both control and head dissipation. Since constant-speed pumps are utilized, the valve must be designed to produce a greater pressure drop as the flowrate decreases. The valve inlet pressure at maximum flow is

$$P_{\substack{valve\\inlet}} = \text{(Downcomer static head)} - \text{(Frictional loss, receiver to valve)}$$

At minimum flow, since the frictional loss is negligible,

$$P_{\substack{valve\\inlet}} = \text{(Downcomer static head)} + \text{(Increase in pump discharge)} + \text{(Frictional loss, pump to valve)}$$

The design outlet pressure from the valve is specified as 0.97 $\pm$0.2 bar gage plus the frictional loss from the valve to the tank. The pressure drop required through the valve can be determined as a function of flow rate, as illustrated in Figure 7-2 for the receiver control valve in the 3.5-year

Table 7-1. Pump Developed Head

Receiver Feed Pump

	3.5 Year	4.5 Year	6.5 Year
Line Diameter, cm	7.79	7.79	6.27
Velocity, m/s	2.6	2.0	2.2
Equivalent Length, m	81.7	81.7	94.8
Pressure Drop, bars			
Line	1.5	0.8	1.4
Receiver	5.7	3.1	3.0
Elevation	8.8	8.8	8.1
Total	16.0	12.7	12.5

Steam Generator Feed Pump

	3.5 Year	4.5 Year	6.5 Year
Line Diameter, cm	6.27	6.27	5.25
Velocity (max), m/s	2.6	2.0	2.0
Equivalent Length, m	82.3	81.7	76.2
Pressure Drop, bars			
Line	1.7	0.9	1.1
Steam Generator	1.4	0.8	0.4
Static	1.3	1.3	0.6
Total	4.4	3.0	2.1

system. Results for the 4.5- and 6.5-year programs are presented in Volume III, Section 4.6.1.3. In order to prevent cavitation, the critical flow factor of the valve will have to be on the order of 0.97.

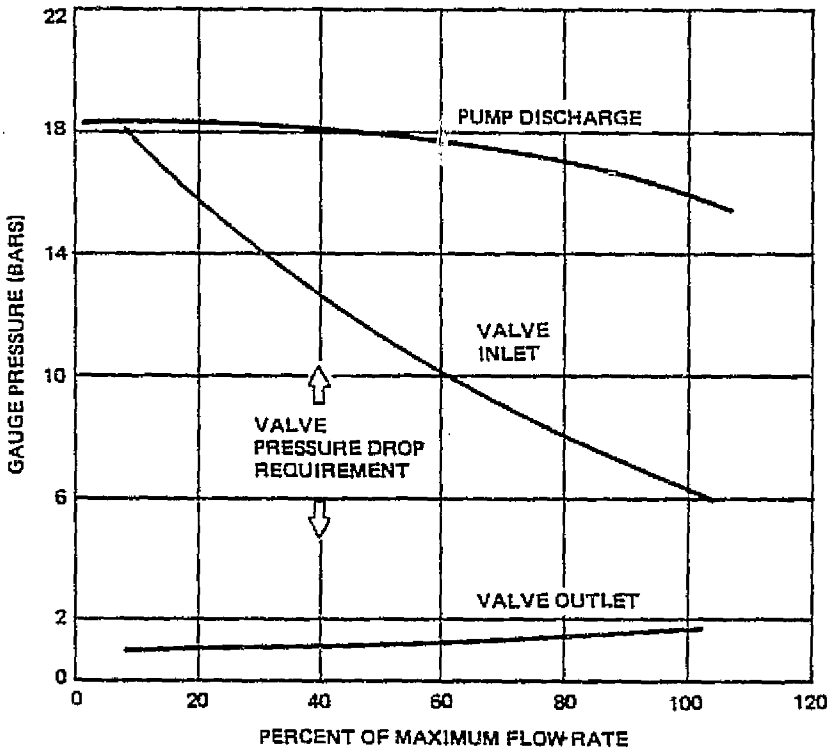


Figure 7-2. Pressure Proof Characteristics of the Receiver Control Valve (3.5-Year System)

7.3 HEAT LOSSES

Heat losses from pipelines to the environment will be reflected in increased storage and heliostat requirements. Equations given in Section 6.1.2 were used assuming 10.2 cm of calcium silicate insulation. An ambient temperature of 15.5°C and an outside heat transfer coefficient of 11.4 W/m^2 - °C were assumed. Line lengths were estimated from the configurations shown in Figure 7-1.

7.3.1 Steady State Losses

Following normal daily operation, salt will drain from the lines. Steady state losses were therefore assumed to occur for 10 hours in the receiver loop and 14 hours in the steam generator circuit. Results are shown in Table 7-2.

Table 7-2. Piping Steady State Thermal Losses (Daily Operation)

	Receiver Riser	Receiver Downcomer	Steam Generator Feed	Steam Generator Return
Design Length, m	50.6	55.5	12.8	18.9
3.5-Year Program				
ΔT, °C	244	439	439	244
k, W/m - °C	0.062	0.073	0.073	0.062
q, kW	3.9	9.0	1.9	1.3
Total Loss:	174 kWh/day			
4.5-Year Program				
ΔT, °C	272	494	494	272
k, W/m - °C	0.064	0.076	0.076	0.064
q, kW	4.5	10.6	2.2	1.5
Total Loss:	203 kWh/day			
6.5-Year Program				
ΔT, °C	272	522	522	272
k, W/m - °C	0.064	0.078	0.078	0.064
q, kW	4.3	9.7	3.0	1.5
Total Loss:	203 kWh/day			

7.3.2 Transient Losses

Following shutdown, the lines can only cool down to specified control temperatures, at which time trace heating will be initiated.

Based on daily duty cycles of 10 and 14 operating hours for the receiver loop and steam generator loop, respectively, the receiver riser and downcomer will have 14 hours to cool down at night before operation begins the following morning. The steam generator feed and return lines will cool for 10 hours. The hot lines do not reach the heater control temperature within these periods, as shown in Figure 7-3, for the 3.5-year system. The capacitance of the insulation was included in the analysis. Calcium silicate has a

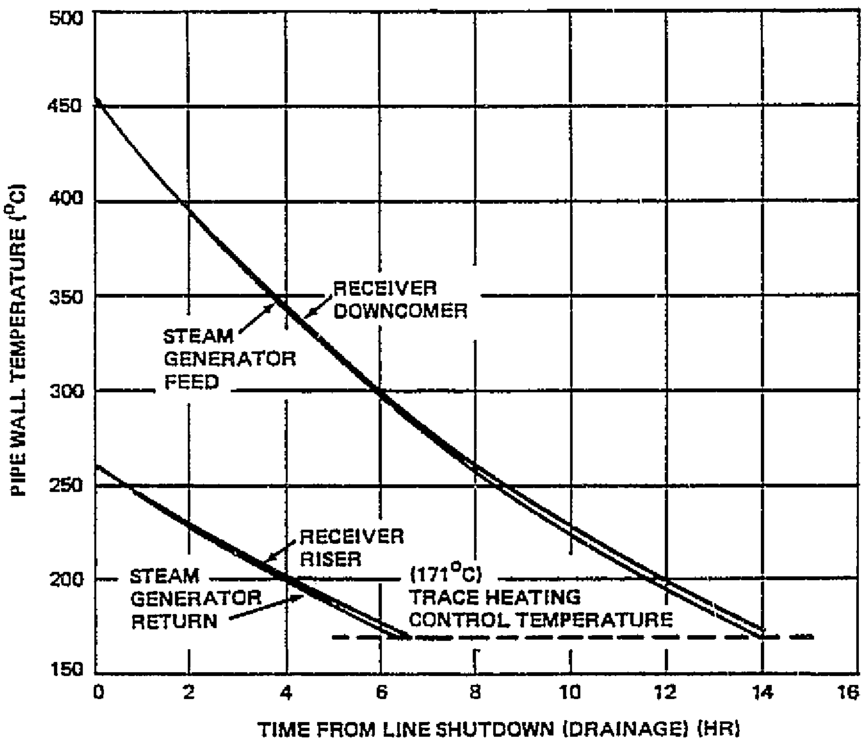


Figure 7-3. Pipeline Cooldown Transients (3.5-Year System)

specific heat of 0.20 to 0.22 cal/g-°C and a density of 208 kg/m^3. Transient losses are summarized in Table 7-3. In the 6.5-year system, there are no losses shown for the low temperature lines since the control temperature is the same as the operating temperature (288°C) and trace heaters on these lines will be initiated immediately following shutdown.

7.3.3 Total Daily Line Thermal Losses

The total thermal losses experienced by the energy transport system are shown below:

	3.5 Year	4.5 Year	6.5 Year
Steady State Loss, kWh/day	174	203	203
Transient Loss, kWh/day	76	92	45
Total Thermal Loss, kWh/day	240	295	248

Table 7-3. Line Cooldown Loses (Transient)

	Receiver Riser	Receiver Downcomer	Steam Generator Feed	Steam Generator Return
3.5-Year Program				
Pipe loss, kWh	6.5	24.3	4.4	1.9
Insulation Loss, kWh	6.8	24.1	5.2	2.3
Maximum total loss: 75.5 kWh/day				
4.5-Year Program				
Pipe loss, kWh	8.5	27.7	5.0	2.4
Insulation loss, kWh	9.0	27.6	8.5	3.1
Maximum total loss: 91.6 kWh/day				
6.5-Year Program				
Pipe loss, kWh	0	15.8	3.4	0
Insulation loss, kWh	0	19.5	6.1	0
Maximum total loss: 44.8 kWh/day				

7.4 TRACE HEATING

Trace heating can be accomplished electrically or with steam. A comparative study was carried out which considered the cost impact on the collector subsystem of providing the necessary trace heating energy which could be compared to the cost of the trace heating equipment. For the steam heating case, additional heliostats were included to furnish a surplus energy to thermal storage which could be utilized as the necessary source of energy. For the electrical trace heating approach, it was assumed that the collector subsystem was sized to provide sufficient energy so that the surplus electrical output would cover the resistance heating demand (even though the demand would normally occur after the plant had been shut down for the day). This latter approach includes the effects of cycle conversion efficiency. It was also assumed that the trace heating would be initiated when the component temperature decayed to the specified temperatures (171°C for Hitec and 288°C for the binary HTS). Based on an annual heater requirement of 7,010 kWh, a summary of the impact of trace heating on collector subsystem costs is shown in Table 7-4 for the two approaches. It is seen that in both cases, less than a single equivalent heliostat would have to be added to offset the trace heating requirements. The indicated cost data favors the steam approach by $1,100. However, this value must offset the additional expense associated with installing the trace heating lines to all components as well as the water/steam circulation equipment.

Preliminary estimates indicate that a much more substantial cost difference would be required to offset the additional steam equipment cost. An exact number has not been determined as all steam trace heating components would have to be specified in detail. As a result, electrical trace heating was selected for the baseline system configuration.

Table 7-4. Impact of Trace Heating on Collector Subsystem Costs for the 3.5-Year Program

	Trace heating method	
	Steam	Electrical
Required trace heating power (kW)	2.9	2.9
Annual trace heating energy (kWH)	7,010	7,010
Additional collector capability (kWh)	7,010	26,960*
Fraction of total annual collection	0.0005	0.0018
Equivalent additional heliostats	0.10	0.37
Equivalent additional heliostat cost**	$400	$1,500

*26% assumed conversion cycle efficiency

**Assumes $4,000 per heliostat

NOTE: Comparison excludes costs of installing trace heaters or water/steam piping and circulation equipment.

7.4.1 Trace Heater Configuration

Trace heating requirements were determined from the system configurations shown in Figure 7-1. Allowances were made for valves and equivalent lengths for the various circuits and are given in Table 7-5.

Trace heating losses were calculated, based on operational times required at night after the lines had cooled to 171°C (or 288°C in the 6.5-year system). Data used in calculating trace heater requirements are given in Table 7-6. Lines not indicated do not cool down to control temperatures before morning operations begin.

Table 7-5. Trace Heating Circuits

		Equivalent length, m	
Line*	Description	3.5/4.5 Year	6.5 Year
1	Receiver downcomer	57.0	53.9
2	Receiver riser	51.5	55.2
3	Steam generator return	18.9	21.0
4	Steam generator feed	14.3	19.5
5	Steam generator startup	12.5	14.0
6	Receiver startup	4.9	5.5
7	Transfer line	5.2	8.5
8	Transfer line	4.0	-

*Numbers refer to lines shown in Volume III, Figure 4.6-3.

Table 7-6. Trace Heating Losses

3.5-Year Program (171°C)

Line	2	3	6 and 8
Diameter	8.9	7.3	8.9
Loss, kW	2.4	0.8	0.4
Operating time, hr	7.5	3.8	3.5
Total loss, kWh	18.2	3.0	1.4

Total system loss = 22.6 kWh/day

4.5-Year Program (171°C)

Line	2	3	6 and 8
Diameter, cm	8.9	7.3	8.9
Loss, kW	2.4	0.8	0.4
Operating time, hr	6.0	2.3	2.3
Total loss, kWh	14.5	1.8	0.9

Total system loss = 17.3 kWh/day

6.5-Year Program (288°C)

Line	2	1	3	4	5	6 and 7
Diameter, cm	7.3	7.3	6.0	6.0	6.0	7.3
Loss, kW	4.4	4.3	1.5	1.4	1.0	1.1
Operating time, hr	14	4.7	10	1.3	5.4	9.2
Total loss, kWh	61.7	20.2	15.2	1.8	5.4	10.3

Total system loss = 113.8 kWh/day

Section 8
POWER CONVERSION SUBSYSTEM ANALYSES AND TRADE STUDIES

Analyses and trade studies of the power conversion subsystem (PCS) are described in this section.

8.1 TURBINE-GENERATOR SELECTION

The selection of an appropriate prime mover type was addressed in the early portion of this study and in the technical reviews. A survey of the availability, performance, reliability, and cost of various types of prime movers was made and presented in Volume II, Section 3. Other factors taken into account in the selection process include ease of startup and shutdown, low maintenance costs, and flexibility in power output.

Performance/cost trades showed the steam rankine cycle to have an advantage over organic rankine cycles and Brayton cycles. This advantage would increase as power output was increased beyond 1 MWe. In addition, the steam turbine is a proven design with high reliability and is readily available over a wide range of power levels. The steam turbine was therefore selected as the most appropriate prime mover.

The search for high efficiency steam turbines has led to two options, the first being state-of-the-art axial flow steam turbines readily available for use in the 3.5- and 4.5-year programs. The second option is a radial outflow turbine which promises to have a higher performance than the axial machines, but requires development, eliminating it as a feasible candidate for the 3.5- and 4.5-year programs.

Axial Turbine

Using the results of the survey and the specified steam conditions for the 3.5- and 4.5-year programs, the candidate axial turbines were reduced to three.

A summary of the operating parameters and cost of the candidate turbine-generators for the 3.5- and 4.5-year programs is presented in Table 8-1. It is obvious from this summary that all the turbine-generators are quite similar in most respects. This includes the ancillary equipment that would be provided with the turbine-generator set and mounted on a common baseplate. Typically, this ancillary equipment would include:

- Oil reservoir
- Gear-driven oil pump
- Motor-driven oil pump
- Oil cooler
- Governing valve
- Emergency stop valve
- Overspeed trip
- Alarms
- Instrumentation

In addition, the condenser can be mounted on the same baseplate.

Table 8-1. Axial Turbine Candidates for the 3.5- and 4.5-Year Programs

No. of stages	5	8	8-10
Rotor speed, RPM	10,000	10,000	10,000
Expansion efficiency, % (to mechanical)	0.68	0.71	0.71
Maximum output, kW	1,800	3,000	3,300
Approximate cost, dollars	410,000	500,000	455,000
Package includes	Condenser, Generator, Steam Jet Ejector, Lube Oil System, Control System	Condenser, Generator, Steam Jet Ejector, Lube Oil System, Control System	Condenser, Generator, Vacuum Pump Lube Oil System, Control System

The selection of a high efficiency, multi-stage marine turbine capable of operating at high temperature was accomplished by a simple trade study comparing the cost of extra collectors to the savings in turbine cost for lower performance multistage and single stage turbines.

In order to select the preferred turbine-generator from the candidates available, a cost-performance trade study was made. This was accomplished using the following two assumptions:

A. The overall cycle efficiency is directly proportional to the turbine expansion efficiency.

B. The most sensitive and largest cost element affected by small variations in cycle efficiency is the number of heliostats.

The potential for a reduction in cost of each kilowatt for the PCS is apparent from Table 8-1 which gives the maximum power production capability of the turbines at rated steam conditions. The same turbine built for 3,000 kW would cost only marginally more than one built for 1,000 kW output. Based on vendor budget costs for the remainder of the PCS, the total cost of the PCS would increase by approximately 50% or the cost/kW be reduced by 50%. It is apparent that significant cost savings can be realized by increasing the output power of the PCS.

The radial outflow turbine, as designed by Energy Technology Inc. (ETI), offers significant performance and cost advantages over the axial flow turbines being considered.

Since the steam is introduced at the center and expands radially outward, the low volumetric flow stages have a small diameter and the higher volumetric flow stages are at a larger diameter. The single rotor disc can have a large number of stages resulting in subsonic steam velocities. This results in a high efficiency which is insensitive to load and maintains good efficiency at off-design speeds.

Interstage steam leakage is reduced by the elimination of axial shaft seals necessary in axial machines and the use of fully shrouded blade rows with multiple labyrinth interstage seals. The radial outflow design should also be able to tolerate much high moisture levels in the exhaust (up to 15%) without encountering blade erosion problems. Provisions can also be made for multiple extraction ports to provide for regenerative feedwater heating.

In addition to the above performance advantages, the radial outflow turbine has the potential for significant manufacturing and cost advantages in comparison with axial machines. The single rotor disc is mounted on the shaft in an overhung arrangement, leading to reduced housing and sealing requirements and a much more easily balanced shaft than with axial machines. Blade manufacturing costs are greatly reduced, since the blades are untwisted in a radial flow design.

Expansion efficiencies ranging from 80 to 85% are predicted for the ETI turbine, depending on the tightness of tolerances and amount of testing permitted. Individual stage performances are presented in Table 8-2 as computed by ETI. This design has the ability to expand steam to 15% moisture as illustrated in the high temperature, high efficiency design. This ability also contributes to high cycle efficiencies in addition to the improved expansion efficiencies. The physical design of the unit will permit up to five uncontrolled extractions for feedwater heating to enhance cycle performance.

The auxiliary equipment to be provided with all turbines will include a double reduction gearbox, steam throttle valve and emergency shutoff valve, oil lubrication pump, oil cooler, filter and piping. In addition a pressurized oil reservoir will be provided to ensure oil pressure if the oil pump fails. Lubrication requirements are given below.

ETI Turbine/Gearbox Lubrication Requirements

Oil Flow Rate	60 liters/min (16 GPM)
Oil Pump Power (approx)	1.1 kW (1.5 HP)
Cooling Required	24 kW_t (81,400 Btu/hr)
Cooling Water Flow Rate	76 liters/min (20 GPM)
Cooling Water Pump Power (approx)	0.45 kW (0.6 HP)

Table 8-2. Radial Turbine Design for 6.5-Year Program

Design Specifications:

Turbine inlet	510°C (950°F), 121 bars (1,750 psia)
Turbine exhaust	0.084 bars (2.5 in. Hg A)
Shaft speed	12,000 RPM
Overall efficiency	0.850
Power output	1169 kW

Individual Stage Performance:

Number	Exit Pressure (Bars)	Exit Enthalpy (Btu/lb)	Total-Static Efficiency*
1	66.2	3256	0.631
2	37.2	3154	0.697
3	21.4	3051	0.770
4	12.2	2946	0.832
5	6.76	2842	0.896
6	4.07	2758	0.925
7	2.28	2668	0.940
8	1.15	2568	0.941
9	0.51	2456	0.937
10	0.20	2335	0.938
11	0.084	2228	0.939

*Includes penalty for wet steam

8.2 POWER GENERATION CYCLE OPTIMIZATION

The basic power conversion subsystem designs reflect an attempt to develop an optimized cost effectivity design. For the short-term development systems, the design is constrained to the use of state-of-the-art equipment.

One of the issues involved in the cycle optimization concerns the choice of the number of regenerative feedwater heaters and the specification of the extraction pressure and final feedwater temperature. For the 3.5-year system employing an existing axial turbine, these choices are somewhat limited due to the fact that only a single turbine extraction port is available.

Two alternate configurations which were considered are shown in Figure 8-1. Since only a single turbine extraction is available, both of the options shown have the same cycle efficiency. The key issue involves the ability of the deaerator to provide all of the feedwater heating required to raise the feedwater temperature to 163°C, which is the minimum temperature acceptable at the steam generator inlet (20°C above the fresh salt freeze point). Most larger deaerators are not designed to add significant sensible energy to the feedwater since their primary purpose is to remove dissolved gas from the feedwater. With such a deaerator, adjacent low and high pressure heaters would be required to provide the necessary sensible heat addition.

During part load operation, the extraction pressure falls below that required to maintain the final feedwater temperature at 171°C. Each of the two options is configured with a turbine bypass line to ensure that the 171°C temperature is maintained at all times. During periods when the turbine is operating at full load, no turbine bypass flow will be required for either of the two options.

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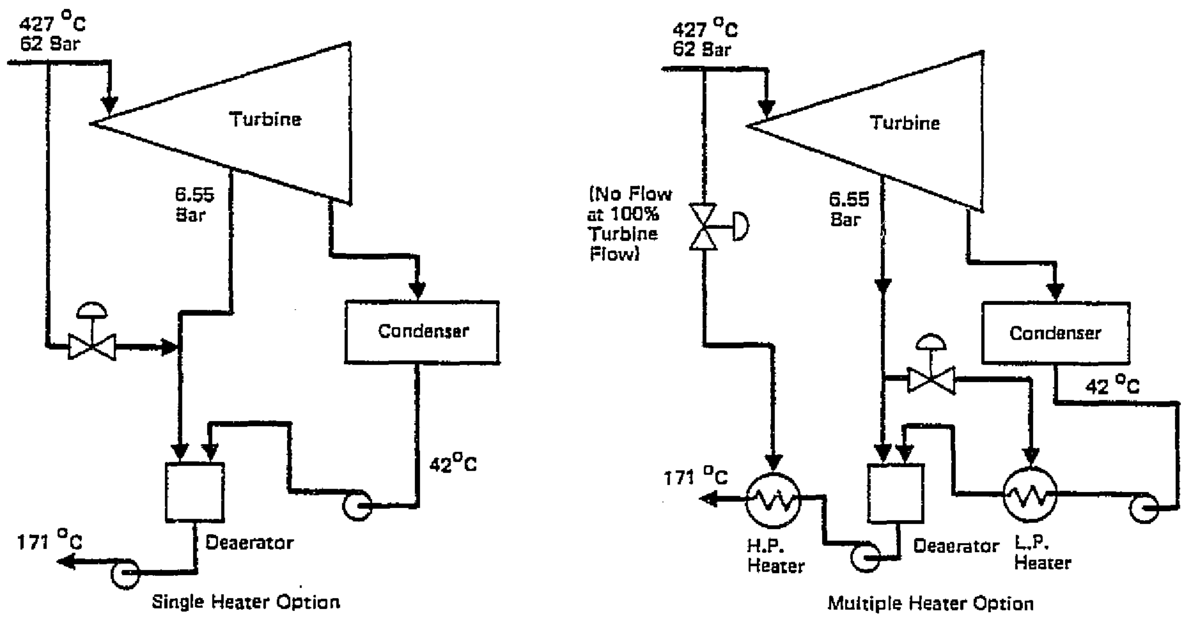

Figure 8-1. Design Options for 3.5-Year Axial Turbine System

Clearly from a cost and complexity standpoint, the single heater option is preferred. Representatives of Chicago Heater Company were contacted concerning the feasilibity of the single heater design. They foresaw no special problems in constructing and operating a deaerator in accordance with the proposed scheme. They also felt that it would not be necessary to desuperheat the turbine bypass steam before its introduction into the deaerator. This is a potential area of concern since the steam would be ~370°C downstream of the pressure reducing valve which is higher than the normal 343°C design limit for carbon steel. The representatives from a commercial heater company felt that a carbon steel design could be used which would accept the slightly higher steam temperature. They stressed that the bid specification should specify flows, temperatures, and pressures under full load conditions using extraction steam and at part load using turbine bypass steam since the deaerator will have to be designed to accommodate both conditions.

For the 6.5-year program utilizing the radial outflow turbine, options exist concerning the number of and pressure of turbine extraction ports. Two factors were considered in establishing the extraction pressures. First, it is desirable for maximum thermodynamic efficiency to increase the feedwater temperature in approximately equal steps through the heater train. This is constrained to some extent by the steam conditions available at the turbine extraction ports which is controlled by the expansion which occurs across each stage of the turbine. The compromise between these two factors resulted in the extraction pressures and cycle diagram using five feedwater heaters shown in Figure 8-2.

The number of extractions and feedwater heaters specified in the design are the result of a trade study conducted comparing the cost of the heaters to the cost of the energy saved due to higher cycle efficiency. Included in the cost of heaters is the heater, insulation, instrumentation, piping and valves and the labor required to install the above items. The cost of energy is determined by using the cost of heliostats, tower, and receiver for the experimental plant. The results of this study are presented in Figure 8-3 and show that the four heater cycle and five heater cycle are nearly identical. Since the commercial version is expected to have five heaters, the five heater cycle has been selected for the experimental plant.

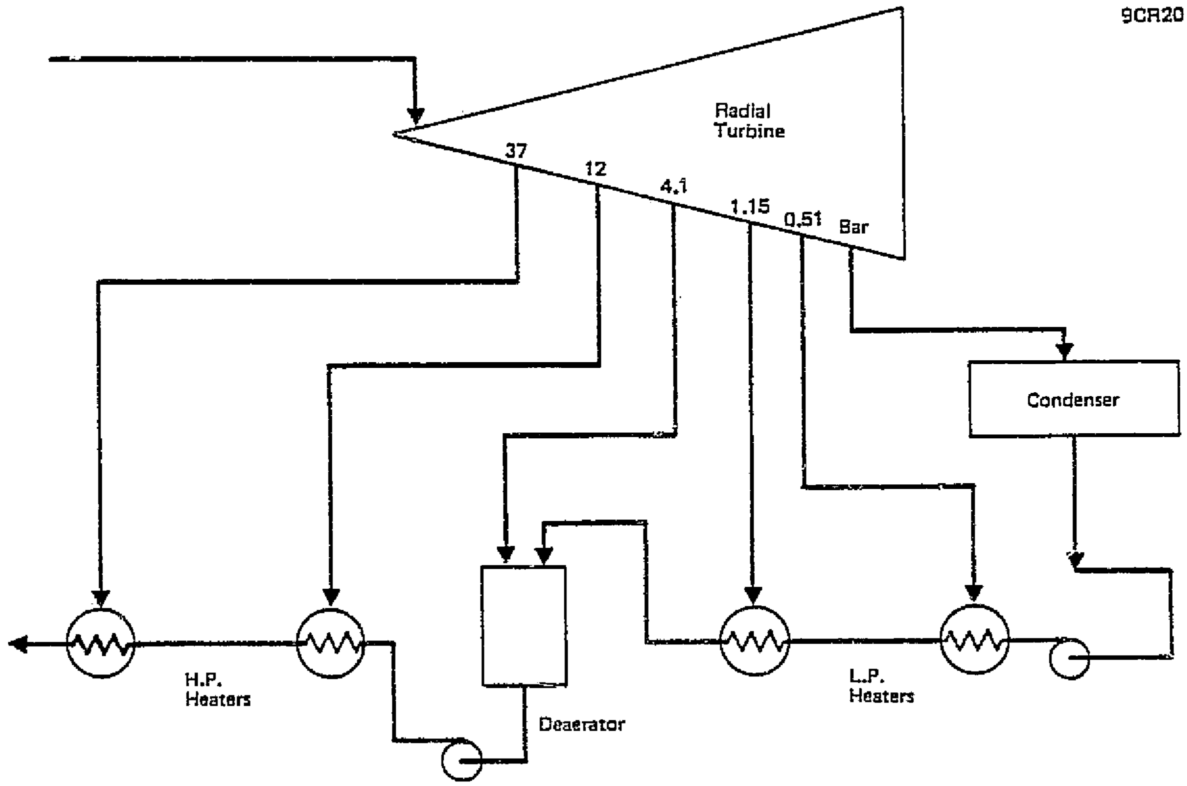

Figure 8-2. Power Conversion for 6.5-Year System Based on a Radial Turbine

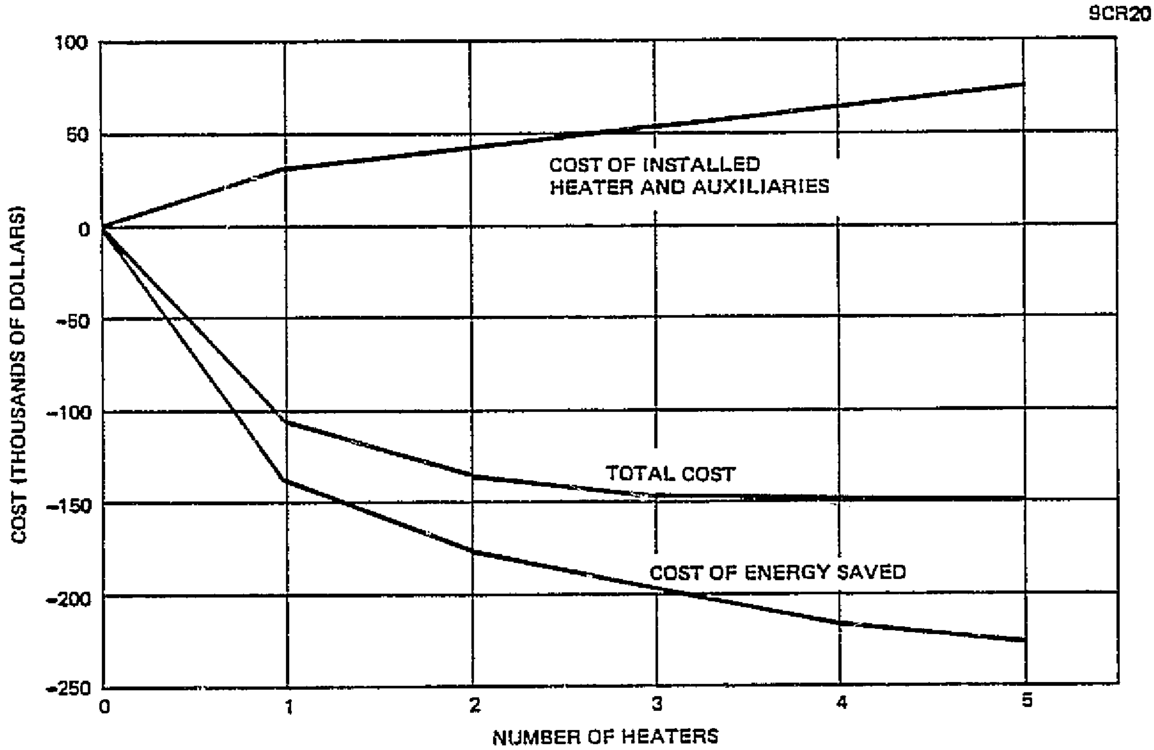

Figure 8-3. Feedwater Heater Optimization

8.3 STEAM GENERATOR

The steam generator types considered for this application are described below.

A. A once-through steam generator. A spiral-wound annulus of tubing contains the water/steam and is bathed by salt on the shell side. Water enters the tubing at one end, boils as it passes through the tubing and exits as super heated vapor.

B. A separate preheater, natural recirculation boiler with steam drum, and a separate superheater. The water/steam is contained on the tube side of the heat exchangers, the salt on the shell side.

C. A separate preheater, kettle boiler, and superheater. The water/steam is on the tube side in the preheater and superheater and on the shell side in the kettle boiler.

The design selected for use is the separate preheater, natural recirculation boiler and superheater. This type of unit offers distinct operational advantages over a once-through steam generator. These advantages include:

- Reduced feedwater purity requirements
- Easier startup (A turbine bypass circulation loop is not required)
- Easier control of outlet pressure and temperature due to separation of boiler and superheater
- Less danger of moisture entering turbine

The kettle boiler is impractical at the high steam pressures being used due to the required thickness of the shell walls.

The availability and feasibility of the selected type of steam generator has been confirmed by both domestic and foreign manufacturers.

A preliminary analysis of the steam generator design parameters was accomplished to facilitate cost estimates and provide inputs to general arrangement drawings. A plot of the Hitec/HTS and water/steam temperatures versus percentage of enthalpy change is given for each of the three programs in Figures 8-4 to 8-6. The resultant design parameters and requirements are listed in Table 8-3 for the three experimental programs.

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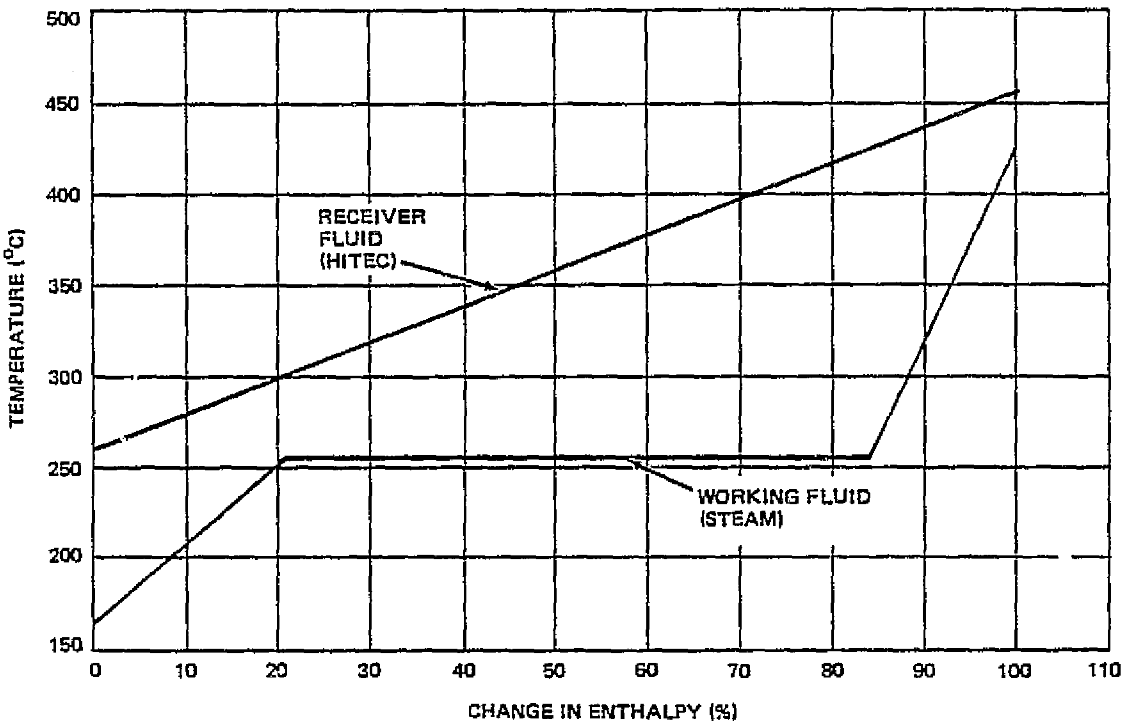

Figure 8-4. Enthalpy Change Diagram (3.5-Year Program)

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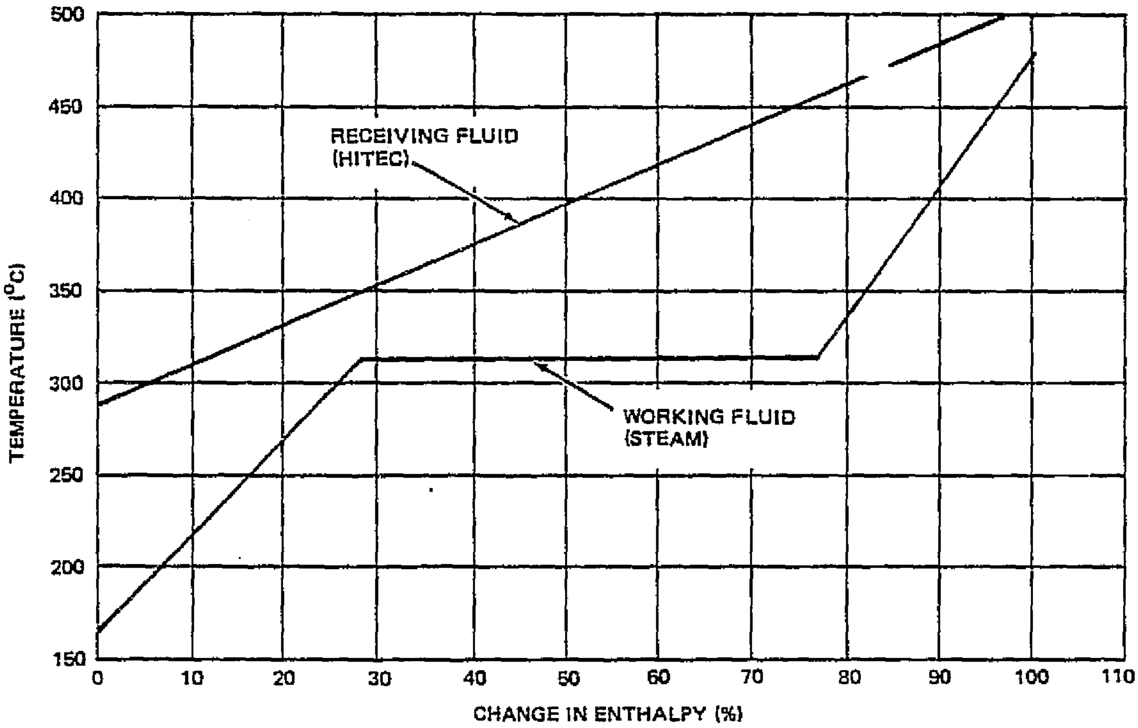

Figure 8-5. Enthalpy Change Diagram (4.5-Year Program)

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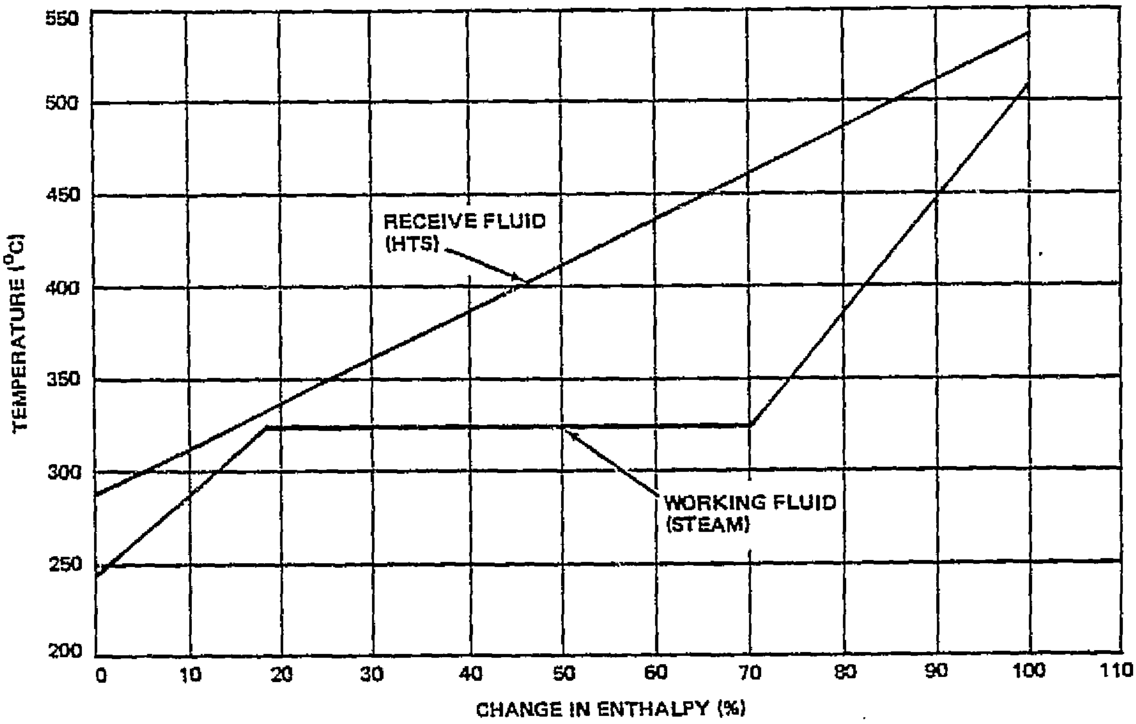


Figure 8-6. Enthalpy Change Diagram (6.5-Year Program)

Table 8-3. Steam Generator Design Parameters

Program time	3.5 Year	4.5 Year	6.5 Year
Preheater			
Type	Two-pass U-tubes with longitudinal baffle, Type CFU		
LMTD* °C(°F)	67 (120)	76 (137)	23 (42)
U Value ** kW/hr-m^2-°C (Btu/hr-ft^2-°F)	---------------1.13 (200)------------------		
Duty, MW_t (Btu x 10^{-6})	0.89 (3.0)	1.0 (3.4)	0.5 (1.7)
Tube area m^2 (ft^2)	11.6 (125)	11.6 (125)	18.8 (200)

* LMTD - Log mean temperature difference

** U Value - Overall heat transfer coefficient

Table 8-3. Steam Generator Design Parameters (Continued)

Program Time	3.5 Year	4.5 Year	6.5 Year
Boiler			
Type	Natural recirculation with steam drum		
LMTD* °C(°F)	94 (170)	81 (146)	49 (88)
U Value ** kW/hr-m^2-°C (Btu/hr-ft^2-°F)	-------------1.28 (225)-------------------		
Duty, MW_t (Btu x 10^{-6})	2.67 (9.10)	1.75 (5.97)	1.47 (5.00)
Tube area m^2 (ft^2)	22.1 (238)	16.9 (182)	23.2 (250)
Superheater			
Type	2-pass U-tube with longitudinal baffle, Type CFU		
LMTD* °C(°F)	81 (145)	71 (128)	65 (117)
U Value** kW/hr-m^2-°C (Btu/hr-ft^2-°F)	--------------0.993 (175)-----------------		
Duty, MW_t (Btu x 10^{-6})	0.68 (2.32)	0.83 (2.83)	0.86 (2.94)
Tube area m^2 (ft^2)	8.4 (91)	11.7 (126)	13.4 (144)

8.4 BOILER FEEDWATER QUALITY

Stearns-Roger carried out a study of issues related to boiler feedwater quality. The purpose of the study was to:

A. Review industrial/utility boiler water quality requirements and verify their applicability to a 1 MW plant.

B. Assess the impact of cyclic operation on water quality and equipment requirements.

C. Evaluate potential design options for the feedwater loop.

D. Define cost impacts.

The study assumed a recirculating drum-type steam generator which is the baseline configuration for each of the candidate EE No. 1 systems. If a once-through steam generator design were adopted, the water quality requirements would be more stringent than those considered in this study. The results of the study are presented below.

8.4.1 General Feedwater Treatment Considerations

References 8-1 and 8-2 provide general discussions of recommended feedwater and boiler water concentrations, and list recommended limits.

Only very low concentrations of corrosion products such as iron and copper are permitted, since these materials deposit upon heat transfer surfaces in the boiler. Most of the iron and copper present in boiler feedwater exist as suspended solids in the form of the respective oxides; however, a portion of these materials will be present in the form of dissolved ions. In either case, they form insoluble deposits once introduced into the boiler. They do not remain suspended in the boiler water and accordingly, cannot be removed by blowdown. For this reason, it is necessary to establish limits for their concentration in the feedwater rather than in the boiler water.

Conversely, limits have been established in the boiler water for such constituents as silica, hydroxyl alkalinity, and total dissolved solids because, with some qualifications, these do not deposit in the boiler, and their concentrations can be controlled by blowdown, assuming that they are reasonably low in the feedwater. The primary reason for limiting these concentrations is to assure high steam purity. The steam purity limits shown in References 8-3 and 8-4 are extremely stringent, and were established subsequent to the establishment of the boiler water limits in the earlier references. They imply that more stringent boiler water limits may now be needed. However, there is a significant lack of data regarding steam purity levels at varying boiler water concentrations.

The most common water treatment approach for utility boilers is coordinated phosphate-pH control in which an elevated pH is achieved by the maintenance of a mixture of disodium phosphate and trisodium phosphate in relatively low concentrations in the boiler water. The elevated pH provides corrosion protection as well as some buffering against acid attack in the event of cooling water contamination of the condensate, which can reduce boiler water pH. The phosphate also provides a measure of protection against condensate contamination, precipitating as a relatively loose deposit small amounts of calcium, which would otherwise form a scale. In addition, formation of free hydroxide is prevented. This is desirable since concentration of hydroxide under deposits or at other dead spots in the boiler will result in caustic attack of the steel.

A disadvantage of coordinated phosphate-pH control is that the need to maintain a phosphate residual in the boiler, however low, increases the potential for steam contamination. An alternative approach is utilization of what is termed "all volatile treatment." With this approach, only volatile materials such as hydrazine, neutralizing amines, and ammonia are employed. Since no protection against condensate contamination is provided, such treatment is quite risky without full flow condensate polishing. Assuming good control utilization of full flow condensate polishing and all-volatile treatment will assure steam of suitable purity for turbine operation.

Full flow condensate polishing with all volatile treatment is essential for once-through steam generators since such units cannot be blown down, and all solids entering the unit will either deposit in the steam generator or contaminate the steam.

8.4.2 Cyclic Operation

Reference 8-5 addresses problems associated with cyclic operation such as would be encountered with the unit under discussion. Operation would be similar to that described in the introduction of this reference as "B-Peaking Mode of Two-Shifting." Specifically, the potential for formation of undue concentrations of corrosion products in the condensate and feedwater systems of such units is much greater than for base loaded units because of the increased opportunity for air inleakage. (The term "preboiler" in this reference refers to the condensate and feedwater system.) As the paper indicates, Combustion Engineering recommends that cycling units have an auxiliary subloop of 25% capacity for preboiler cleanup to reduce suspended solids (primarily corrosion products) and oxygen levels to suitable low levels after startup. Even with such a subloop, cyclic units will accumulate more internal deposits than an equivalent base loaded unit, and will require more frequent chemical cleaning. By implication, without the use of such a loop, cleaning requirements would be excessive.

A full flow, deep bed condensate polisher was assumed for this unit rather than a 25% side loop since, considering the low condensate flow rate, the cost of such a unit would not be significantly greater than for a unit rated at 25%. The full flow unit would have the additional advantage of permitting boiler operation with all volatile treatment rather than coordinated phosphate-pH control, reducing the potential for turbine problems because of contaminated steam.

Four steam cycle configurations are now under consideration for the subject plant (three versions of EE No. 1 and the commercial unit). Two of these employ axial turbines with a single tray-type deaerator. The other two employ radial turbines with a deaerator, two closed low pressure heaters and two closed high pressure heaters. Operation without cleanup provisions is feasible with the axial turbine approaches, since considerably less opportunity for introduction of corrosion products into the preboiler cycle exists with systems involving a single, closed high pressure feedwater heater.

In the cases involving radial turbines, the quantity of metal exposed to the condensate and feedwater is significantly greater, and the design should include provisions for coping with the high corrosion product load encountered with cyclic operation. This was the principal reason for inclusion of the condensate polisher in the preliminary design.

Reference 8-5 also describes the importance of maintaining a low oxygen environment in the preboiler during cleanup to promote the formation of magnetite, which is more readily removed by condensate polishing than is ferric oxide. The absence of auxiliary steam for deaeration prior to startup eliminates this capability, meaning that cleanup will be delayed. This can be partially compensated for by utilizing a full flow condensate polisher instead of a side loop.

An alternative would involve the use of titanium tubes in the condenser, and stainless steel tubes in the feedwater heaters. Titanium would be recommended for the condenser tubes because of the susceptibility of stainless steel tubes to concentration cell corrosion on the circulating water side should they become partially covered with sediment while the system is shut down.

Utilization of stainless steel tubes in high pressure feedwater heaters is relatively limited because of the expense. Accordingly, very little data is available concerning iron pickup from such systems. This lack of data compels us to not recommend this approach.

8.4.3 Boiler Feedwater Conclusions

Full flow condensate polishing will be used for either of the two radial turbine cycles because of the number of feedwater heaters employed, and because of the particularly strong susceptibility of low pressure heater drips to corrosion products pickup. It will also be used in the axial turbine cycles to enhance reliabilty/availability of EE No. 1. A powdered resin unit will be used for this function.

8.5 NIGHTTIME CONDITIONING

An evaluation of alternate nighttime procedures was also conducted to determine the preferred procedure to be employed during nighttime nonoperating periods. Three alternate approaches were considered: (1) total shutdown - no conditioning systems operating, (2) steam blanketing, and (3) GN_2 pressurization.

The critical issues include

- Thermal cycling of components
- Potential air inleakage and resulting hardware corrosion
- Acceptable rate for subsequent morning startup
- Required ancillary equipment
- Required operator involvement

8.5.1 Total Shutdown

Total system shutdown employs no conditioning procedures and equipment. As a result, the hot equipment is allowed to soak down in temperature and in turn must be reheated to its operating temperature during subsequent morning startup. This approach maximizes the thermal cycling and stress problems for the turbine.

Since the local vapor pressure can drop well below atmospheric pressure through most of the water/steam loop, chances for air leakage into the loop are high. The oxygen which enters the loop subsequently attacks the carbon steel surfaces resulting in significant corrosion. On the other hand, this approach requires no additional ancillary equipment and completely eliminates the need for any operator involvement during shutdown periods.

8.5.2 Steam Blanketing

The blanketing steam option uses low grade steam to maintain an elevated temperature and pressure in those elements of the water/steam loop which normally operate above atmospheric pressure (deaerator, pipes, steam generator, and turbine seals). The low pressure in the condenser is maintained by continuing the operation of the vacuum equipment to prevent atmospheric leakage. Since this approach maintains the water/steam loop conditions somewhat near the actual operating conditions, rapid morning startup can be accomplished with a minimum level of thermal cycling.

The use of blanketing steam requires auxiliary equipment in the form of additional lines, valves, regulators, and drains to distribute and control the blanketing steam. The steam generator may be designed to serve as the source of the steam as long as thermal energy can be drawn from the thermal storage. This approach requires an additional low-flow salt pump for nighttime operation. Since only low grade steam is required, the thermal energy could be extracted from the cold tank or low temperature zone of a thermocline design, the latter approach requiring an additional manifold to be located some distance above the bottom manifold in the thermocline storage tank. In the event that stored thermal energy is not available, a standby boiler would be required.

From an operational standpoint, the use of blanketing steam requires the highest level of nighttime equipment operation. As discussed above, water/steam circulation, salt circulation, and condenser vacuum equipment must be operated during this period. This approach will require a more sophisticated level of standby control and may require the presence of an operator, depending on the code requirements for the steam generator and auxiliary boiler.

8.5.3 GN_2 Pressurization

The use of pressurized GN_2 eliminates much of the operational concerns and equipment costs associated with the blanketing steam approach. In this approach, the entire water/steam loop is pressurized with an inert environment to prevent air inleakage and resulting corrosion. Since the condenser is also pressurized, the vacuum equipment is shut down. In addition, there is no need for the circulation of either water/steam or salt.

From the standpoint of subsequent morning startup, the condenser vacuum must be reestablished and the GN_2 must be vented from the loop. Since the GN_2 does not maintain the operating thermal environment within the loop, the startup must be controlled to minimize the problems associated with thermal cycling.

Since the approach of total system shutdown is felt to be unacceptable because of the problems associated with air inleakage and corrosion, some type of nighttime conditioning is required. Of the two conditioning approaches, the pressurized GN_2 approach is preferred because of lower cost for ancillary equipment, operational simplicity, and potential for unattended operation.

8.6 PUMP REDUNDANCY

A study has carried out to assess the cost impact associated with pump redundancy. The study considered the condensate pump as defined by requirements for the 3.5-year development system. Four cases were considered: (1) a single 100% capacity pump, (2) two 100% capacity pumps in parallel, (3) two 50% capacity pumps, and (4) three 50% capacity pumps. For each of these cases, both carbon and stainless steel were treated (stainless steel would be appropriate if inline condensate polishers were not used in the loop).

The analysis considered both pump and piping costs as well as costs associated with the electrical supply. They were based on information available for a Gould VIC model 6ALC pump and drive. The pump would be similar for both the 100% and 50% with 27 and 22 stages being required respectively for the two applications. With this design, the 100% capacity pump would have an efficiency of 62% while the 50% capacity pump would have an efficiency of 46%.

The cost breakdown is contained in the following tabulation.

One 100% Pump	Carbon Steel	Stainless Steel
Pump	$ 5,000	$18,000
Piping	1,830	3,730
Electrical Supply	400	400
Total Cost	$ 7,230	$22,130
Two 100% Pumps		
Pump	$10,000	$36,000
Piping	3,660	7,460
Electrical Supply	800	800
Total Cost	$14,460	$44,260

Two 50% Pumps		
Pumps	$ 9,000	$31,000
Piping	2,880	6,380
Electrical Supply	800	800
Total Cost	$12,680	$38,180
Three 50% Pumps		
Pumps	$13,500	$46,500
Piping	4,320	9,570
Electrical Supply	1,200	1,200
Total Cost	$19,020	$57,270

The economic superiority of the single 100% capacity carbon steel pump clearly is apparent. Based on previous availability analysis, the need for pump redundancy has not been justified, as a result, the 100% capacity carbon steel pump was selected for the baseline system design.

8.7 HEAT REJECTION METHODS

A study was carried out to compare alternate methods for plant heat rejection. Issues of interest included capital cost, parasitic power requirements, and impacts on turbine back pressure. Three heat rejection approaches were considered:

A. Wet cooling tower
B. Dry cooling tower
C. Direct contact dry cooled condenser

The wet cooling tower employs a water loop which carries the heat of condensation from the condenser located at the turbine exhaust to the cooling tower. The heated water then cascades down the tower walls which allows evaporation to remove the heat from the water. The resulting minimum water temperature approaches the local wet-bulb temperature. Tower mounted fans are used to enhance the air circulation through the tower.

The dry cooling tower equipment operates in a fashion similar to the wet cooling tower with the exception that the cooling water circuit is a completely closed loop. As a result, air forced through the tower passes over a heat transfer surface and allows the cooling water temperature to approach the local dry-bulb temperature.

The direct contact dry cooled condenser employs a series of heat transfer surfaces as an integral part of the condenser. Air forced over these surfaces condenses the steam directly. The condensation temperature and pressure are controlled by the local dry-bulb temperature.

The cost and parasitic power requirements for the three alternate heat rejection approaches are summarized in the following table for equipment sized to reject 3 MWt.

	Wet Tower	Dry Tower	Direct Contact
Cost			
Condenser	$ 3,000	$ 3,000	$155,000
Vacuum System	11,000	11,000	
Tower	25,000	118,000	--
Water Treatment	22,000	22,000	--
Water Circulation	4,500	4,500	--
Total	$65,500	$158,500	$155,000
Parasitic Power			
Fan	15 kW	90 kW	58 kW
Pump	9 kW	15 kW	--

If cooling water is available, the cost and parasitic power advantages of the wet tower make it the obvious choice for heat rejection. An additional benefit of wet cooling is the lower turbine back pressure which can be maintained, resulting in a higher turbine cycle efficiency. A typical condenser pressure for a wet tower is 2.5 in Hg as opposed to 5.0 in Hg for a dry cooling system. The wet tower heat rejection equipment was selected and physical features are presented in Volume III, Section 4.7.

8.8 COOLING TOWER MAKEUP WATER REQUIREMENTS

The cooling tower makeup water requirement is the sum of the cooling tower evaporation rate, drift rate, and blowdown rate. The tower blowdown rate is given by

$$\text{Blowdown, BD} = \frac{E + D\,(1-C)}{C-1}$$

where

E = Evaporation rate

D = Drift rate

C = Number of cycles concentration

The tower evaporation can be assumed to be equal to approximately three-fourths of 1% of the circulating water flow for every 5.6°C (10°F) of cooling range. Thus, for the design conditions, the evaporation rate is approximately 2,400 kg/hr.

The drift rate for normal wind conditions can be assumed to be 0.01% of the circulating water flow, or 29 kg/hr. The number of cycles that can be maintained will depend on the makeup water quality but a typical number of cycles is six, resulting in a blowdown rate of 480 kg/hr and a total water consumption of 2,909 kg/hr.

8.9 CONTROL VALVE ACTUATOR SELECTION

A comparative evaluation between pneumatic and electrical valve actuators was made to determine the preferred approach for the power conversion subsystem.

Penumatic actuators have many features which resulted in their selection as the preferred approach. They are by far the most common and best suited for the linear stroking action of globe-type control valves. They are low friction devices and through simple spring adjustment have a definite position for every air pressure valve. This eliminates the need for a separate positioner which is normally required on electrically driven actuators.

An additional advantage for the pneumatic actuator occurs in the event of a power failure. Since they operate off of a compressed air reservoir, their operation will be uninterrupted. The electrical actuators on the other hand would experience a loss of power for the 10 to 15 sec period required to bring the standby diesel generator on line. As a result, the electrically operated valves would move to their normal failed position. The alternative would be to tie the electrical actuators to the uninterruptible power supply (UPS) which would add to the cost of the UPS equipment.

If the control valve is located at a significant distance from the compressed air reservoir, valve responsiveness may be compromised due to the long line lengths through which the supply air must pass. For these applications, electrically operated valves may be preferred. However, for the design conditions anticipated for the 1 MW system, sufficiently short line lengths are involved so that the pneumatic actuators are clearly superior.

From a cost standpoint, the pneumatic actuators are also superior. The principal elements are a pneumatic regulator, diaphragm, bonnet, and spring. By contrast, an electrical actuator requires an electric motor, positioner, speed reduction gearing, and a crank assembly to convert rotary motion into linear motion if such a control motion is required for the control valve. If a rotary motion is sufficient for control valve operation as for example with a butterfly control valve, the crank assembly may be eliminated.

Section 9
PLANT CONTROL SUBSYSTEM ANALYSES

Analyses and tradeoffs performed for the plant control subsystem were conducted in the following categories:

- Receiver control analysis
- HAC Computer tradeoff analysis
- Plant control system tradeoff analysis

The receiver control analysis was conducted to define a receiver control system design with sufficient bandwidth to reject the effects of disturbances and maintain a control system implementation that is simple and reliable.

The tradeoff analysis for the heliostat array controller computer was conducted to minimize implementation costs and evaluate the hardware throughput to accommodate concurrent collector control and plant control supervisory operations.

A trade analysis was performed to evaluate commercially available plant control systems that could be adapted to automatic control application for a small power plant with modularity that allows growth from the manually controlled 3.5-year plant to a completely automatic unattended commercial plant.

9.1 RECEIVER CONTROL ANALYSIS

The primary requirement for the receiver control system is that it maintain the desired fluid outlet temperature within a desired operating band in the presence of disturbances, either from variation in insolation or from flow anomalies.

9.1.1 Control Simulation

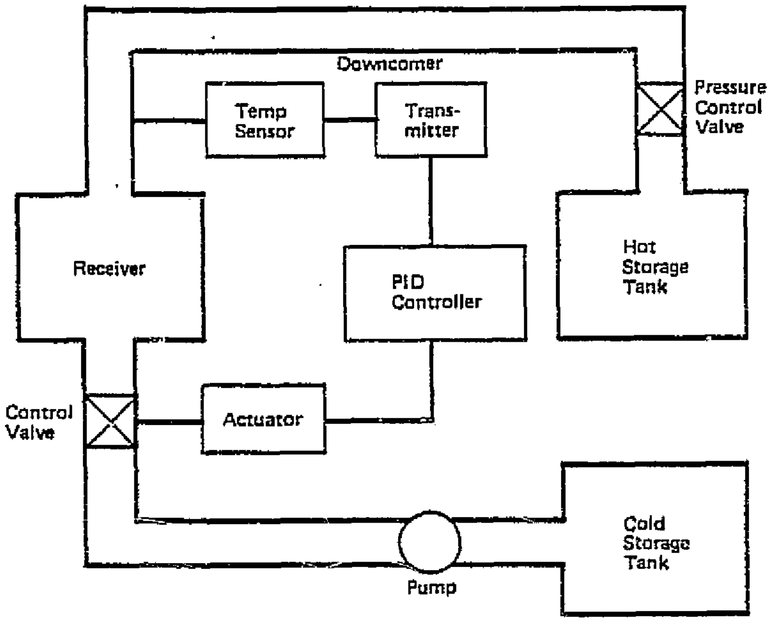
Due to the nature of the central receiver design (large thermal capacitance and long absorption tubes), the receiver open-loop plant response is rather slow ($\approx$100 sec time constants) relative to the nature of the insolation disturbances ($\approx$10 sec). It is the goal to design a receiver control system with sufficient bandwidth to reject the effects of disturbances while maintaining a control system implementation that is relatively simple and reliable.

A candidate is shown in Figure 9-1. The receiver outlet temperature is controlled by sensing outlet fluid temperature and regulating the receiver inlet flow by means of a PID controller, control valve, and actuator. A typical linearized model of this control system is also presented in Figure 9-1.

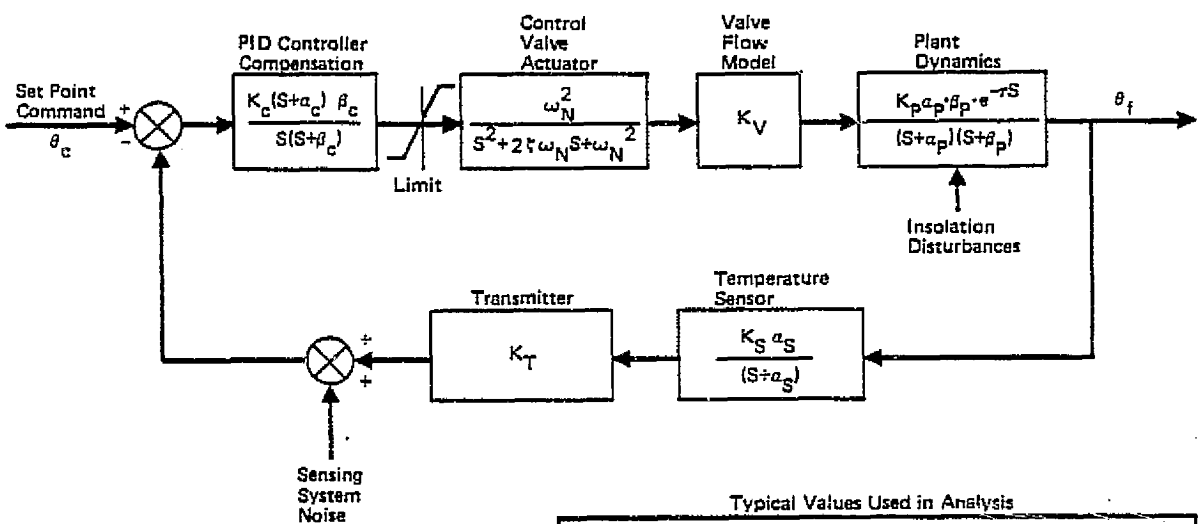
The plant dynamics of the receiver is simplified for linear analysis purposes into the two first order systems cascaded with an equivalent system transport lag. The first order time constants are the equivalent roots resulting from the effects of coupling the dynamics of the wall, the fluid and the flowrate phenomena. Typical values used for initial control system design and sizing are shown in Figure 9-1.

A dynamic simulation of the receiver loop was generated to support the design of the receiver control system and also for evaluating the receiver response to insolation disturbances. The physical configuration of the receiver system is shown in Figure 9-2. The mathematical model of the receiver is a lumped parameter model where the receiver is divided into sections and energy and mass balance equations are derived in Figure 9-2 for each section.

Typically each section of the receiver is characterized by a wall and a fluid temperature node with the driving functions being a variable insolation on the receiver wall and a modulated fluid flowrate both in and out of each section. Nonlinear effects such as independent flux profile for each section, nonlinear film coefficients and variable receiver losses are included in the model.



Receiver Control Configuration



Typical Values Used in Analysis

K_p = -14.7°C/(kg/Sec)	$K_S = K_T = 1$
K_V = -15.1 (kg/Sec)/cm	$K_C = 0.035$
ω_N^2 = 3.14 Rad/Sec	α_C = 0.01 Rad/Sec
ζ = 0.7	$\alpha_p = 0.012$; β_p = 0.6 Rad/Sec
$\alpha_S >$ 0.5 Rad/Sec	S — Laplace Operator

Figure 9-1. Control System Block Diagram (Linear Representation)

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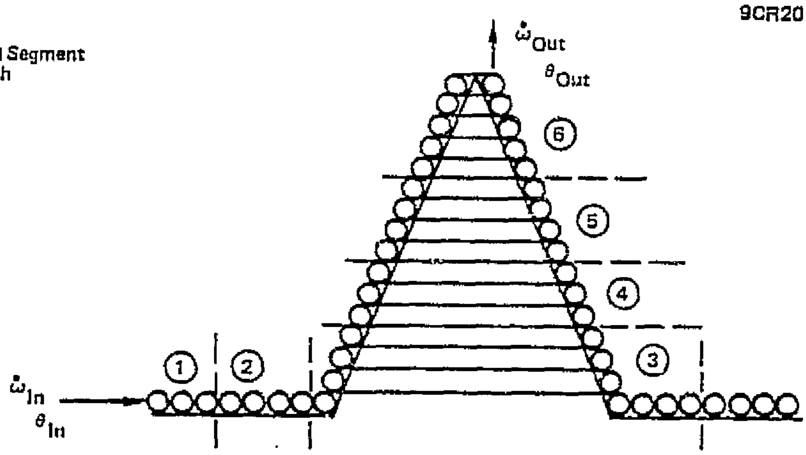
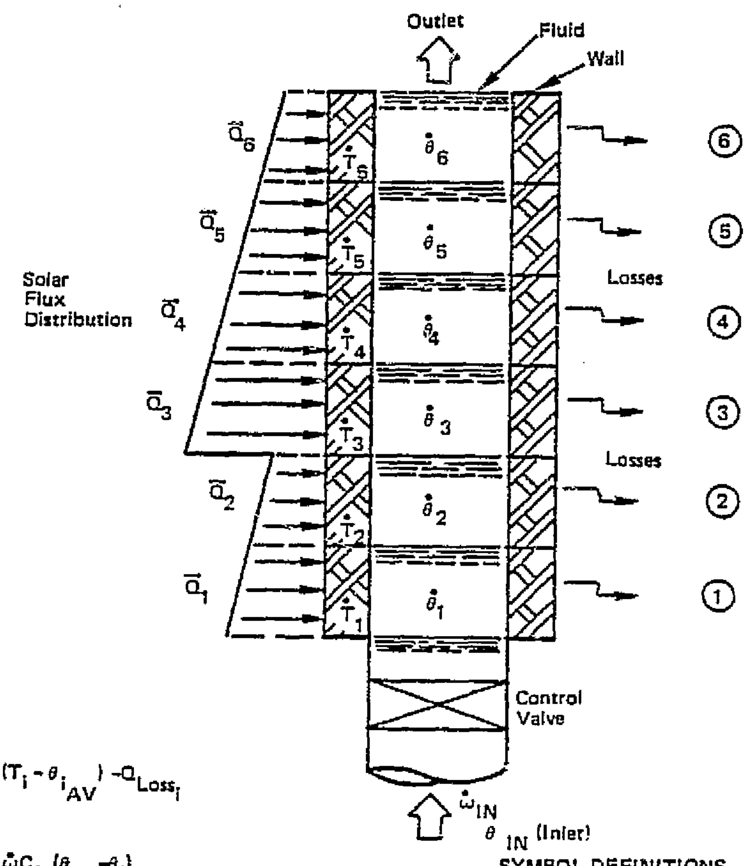
ⓧ Denotes Lumped Segment For Math Model



Typical Receiver Physical Configuration

Receiver Math Model Features

- Receiver Modeled as a Continuous Length of Pipe Lumped into "N" Segments
- Each Segment Modeled as a Wall and a Fluid Temperature Node
- Variable Insolation an Each Segment
- Variable Heat Transfer Coefficients and Heat Losses
- Simulated Control Valve, Temperature Sensor and Controller



Typical Differential Equations for "ith" Segment

Wall

$$M_{W_i} C_{W_i} \dot{T}_{W_i} = \bar{Q}_i A_{W_i} - \bar{h}_i A_{F_i} (T_i - \theta_{i_{AV}}) - Q_{Loss_i}$$

Fluid

$$M_{F_i} C_{F_i} \dot{\theta}_i = \bar{h}_i A_{F_i} (T_i - \theta_{i_{AV}}) + \dot{\omega} C_{f_i} (\theta_{i-1} - \theta_i)$$

Transport Delay

$$\theta_{c-1} = \theta_{c-1} = f(\tau);\ \tau = \frac{\text{Node Length}}{\text{Fluid Velocity}}$$

$f(\tau)$ ~ Digital Mechanization of a Pure Time Delay

SYMBOL DEFINITIONS

θ —	Fluid Temp
T —	Wall Temp
$\bar{Q}$ —	Solar Flux
M —	Mass
C —	Specific Heat
A —	Area
$\bar{h}$ —	Average Film Coeff (Variable)
$\dot{\omega}$ —	Flow Rate
W —	Wall Subscript
F —	Fluid Subscript
• —	Denotes Derivative

Figure 9-2. Receiver Simulation Model

Section lengths, mass properties, and thermal characteristics are assumed constant throughout each section but may vary from section to section. The temperature is assumed to be uniform within each section and therefore, for a model of a long slender tube, multiple sections must be incorporated into the model. The differential equations for each section are similar in form and the total receiver simulation consists of coupling or cascading these sections together until sufficient modes are included as an approximation to the distributed system. The effects of the time delay associated with the temperature propagation along the slender tube is approximated by a pure time delay. This transport delay function is modeled digitally and the governing delay time τ is a function of the ratio of node length to fluid velocity within the tube. The total receiver simulation is completed by the addition of models of the valve and sensor dynamic characteristics and the control law and control dynamics.

This simulation is implemented into a digital computer using the FORTRAN IV language. Capability for preselected number of sections for the receiver model is provided within the simulation so that the sensitivity of the results can be easily evaluated as a function of the arbitrary number of sections selected for the receiver. For preliminary analysis and evaluation, the receiver has been divided into six distinct sections.

A typical open loop response of the receiver to a step change in flowrate is shown in Figure 9-3 and demonstrates the relatively slow response of the receiver without controls. Addition of a control loop significantly increases the response of the receiver to disturbances. Using the preliminary control system model as described in Figure 9-1 and the receiver simulation, a typical closed loop control system response was evaluated for a relatively short period insolation disturbance. The system configuration and response is as shown in Figure 9-4. The control system gain and compensation have been adjusted for a relatively high gain (high bandwidth) system and the receiver outlet temperature variation is within 5° of the desired value for a 50% uniform variation in input insolation.

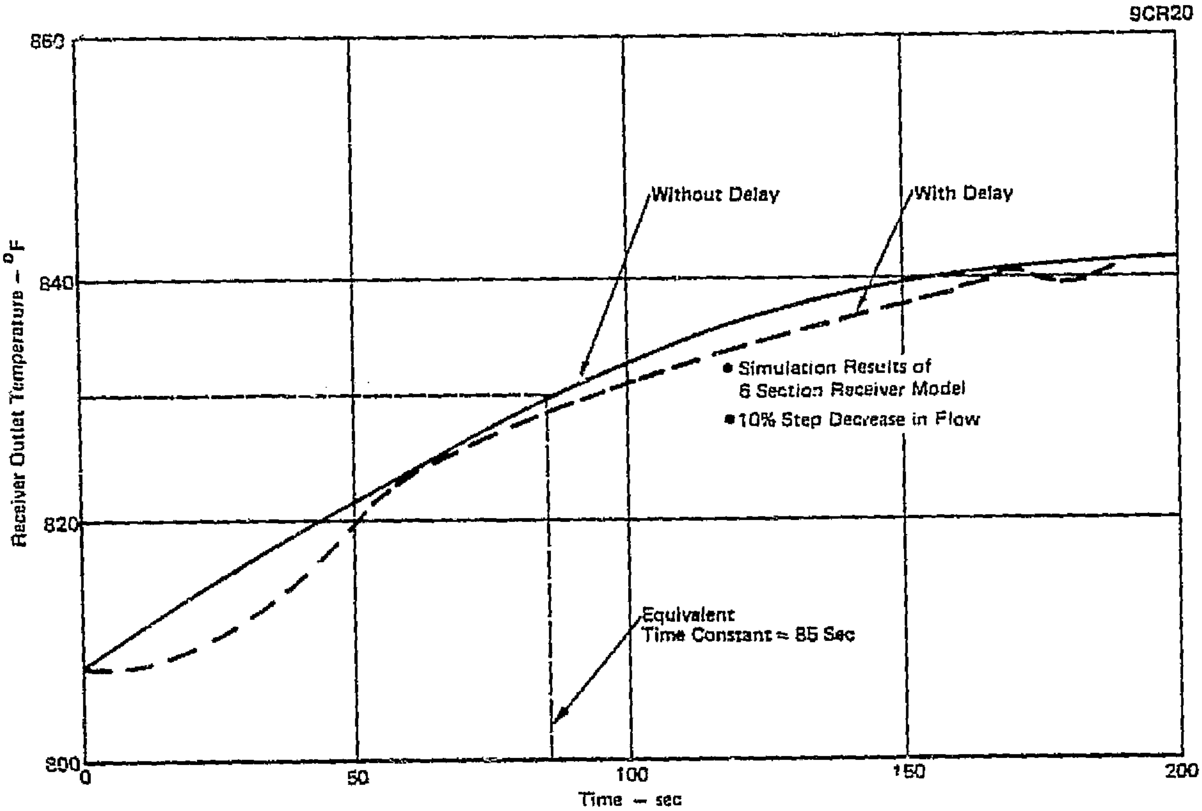


Figure 9-3. Receiver Response to a Step Decrease in Flow - No Control

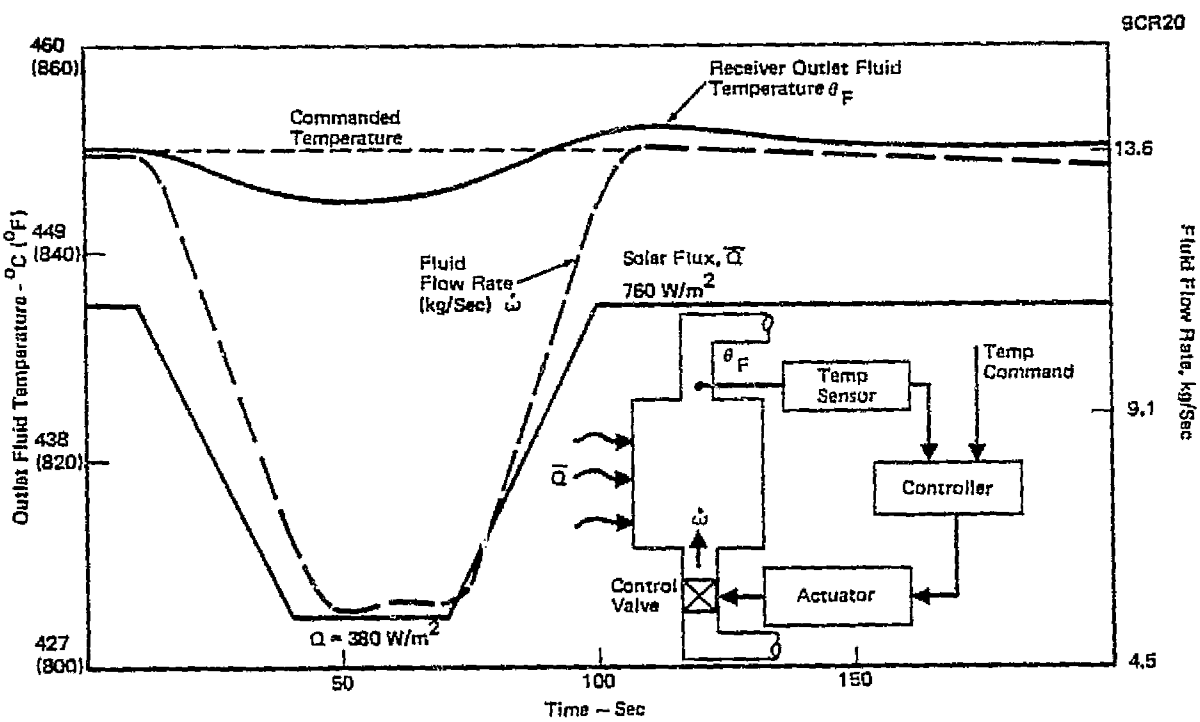


Figure 9-4. Receiver Response to all Insolation Transient – With Control

9.1.2 Receiver Control Considerations

The receiver control system compensation for this receiver model consists of proportional plus integral compensation to provide good steady state response characteristics and with sufficient loop gain (closed-loop bandwidth) to reject insolation disturbances. Phase lag contributed by a transport delay will result in a decrease in bandwidth based on stability considerations and degrade system performance. Additional lead-lag control system compensation can be implemented however to offset the additional phase lag due to this effect and to maintain the closed-loop bandwidth. The plant dynamic characteristics (gain and phase lag) are highly a function of receiver flowrate. A significant penalty in control system disturbance rejection capability or in closed-loop stability is paid if the control system gains and times are not variable with flowrate.

For example, if the control gains are set for good disturbance rejection (high gains) a significant penalty is stability is paid during low flux, low flow conditions characteristic of startup. A potential can exist for an oscillation during startup. A typical startup transient is shown for both high gain/low gain control systems in Figure 9-5. The low gain system exhibits a much more stable control response and a faster time to achieve rated temperature than the high gain system. Therefore, lower gains are desirable at lower flows. At the higher flux and higher flow conditions a high gain is desirable to reject short term and small amplitude disturbances. Therefore, to achieve a desirable control system response over the full range of operating conditions the control system gains and control time constants must be varied based on the operating condition.

9.1.3 Receiver Transient Response to Disturbances

The receiver control system must be designed to achieve a stable, well controlled response when subjected to both large signal and small signal disturbances. A typical large signal disturbance is due to the passage of an opaque cloud over the collector field (0-100%) while a small signal disturbance might be due to partial clouds or heliostat variations.

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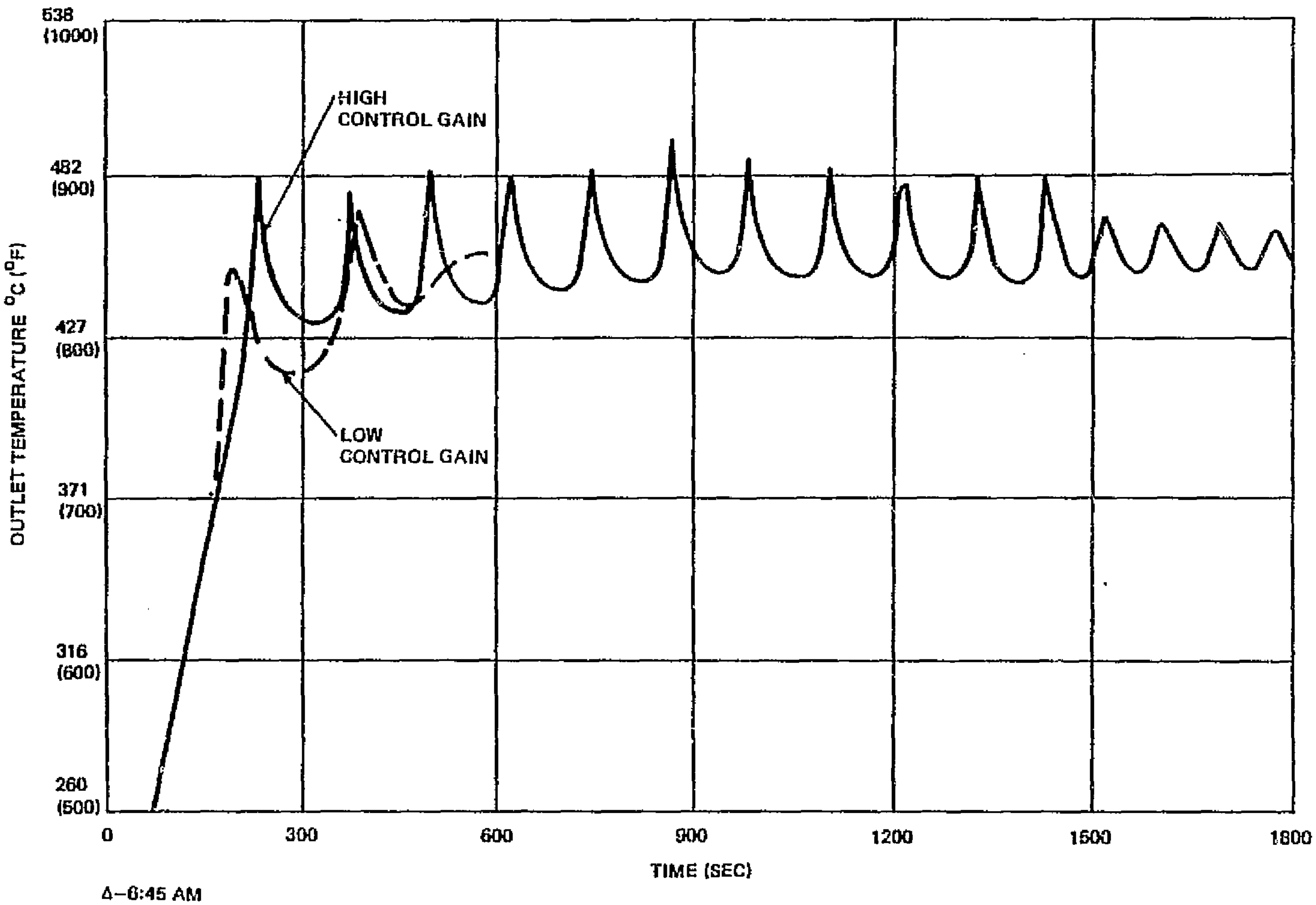

Figure 9-5. Receiver Morning Startup

A simulated response to a cloud blackage transient (0 to 100% variation in 10 sec) is shown in Figure 9-6. A simulated receiver cooldown and recovery transient are shown. For a 100% blockage cloud transient and recovery, the response was stable and maintained the peak temperature over-shoot to within 468°C (875°F). The recovery transient requires approximately 120 sec and a temperature ramp command must be implemented during the recovery phase to minimize overshoot. The temperature command ramp can be mechanized and initiated within the master control system based on system flowrates, outlet temperature and/or temperature error. This simulated response demonstrates that a single temperature control loop can maintain control of the receiver under rather severe variations in solar flux.

The receiver control system can also reject small signal variations in insolation. Using the receiver simulation the receiver control system was subjected to a ± 10% sinusoidal variation in insolation at frequencies from 0.1 to 0.01 Hz. The receiver controller maintains the outlet temperature to within ± 4.5°C (8°F) of the commanded temperature. A summary of this small signal disturbance rejection capability is shown in Figure 9-7.

9.1.4 Conclusions

A preliminary control system design and simulation was developed during the Phase I effort. The results substantiate that a simple single loop PID controller is adequate for controlling the receiver during startup, typical and severe cloud blockage transients as well as small signal variations in solar flux. It is also concluded that it is necessary to adjust controller gains time constants and the temperature set point as a function of the operating conditions in order to maintain a stable desirable response with a wide range of operating conditions.

9.2 HAC COMPUTER TRADEOFF ANALYSIS

The heliostat array controller provides the automatic coordinated control of the collectors. The hardware and software for this function have been designed and implemented in a MODCOMP Classic 7861 computer for installation in the Solar Power 10 MWe Pilot Plant to be constructed at Daggett, California.

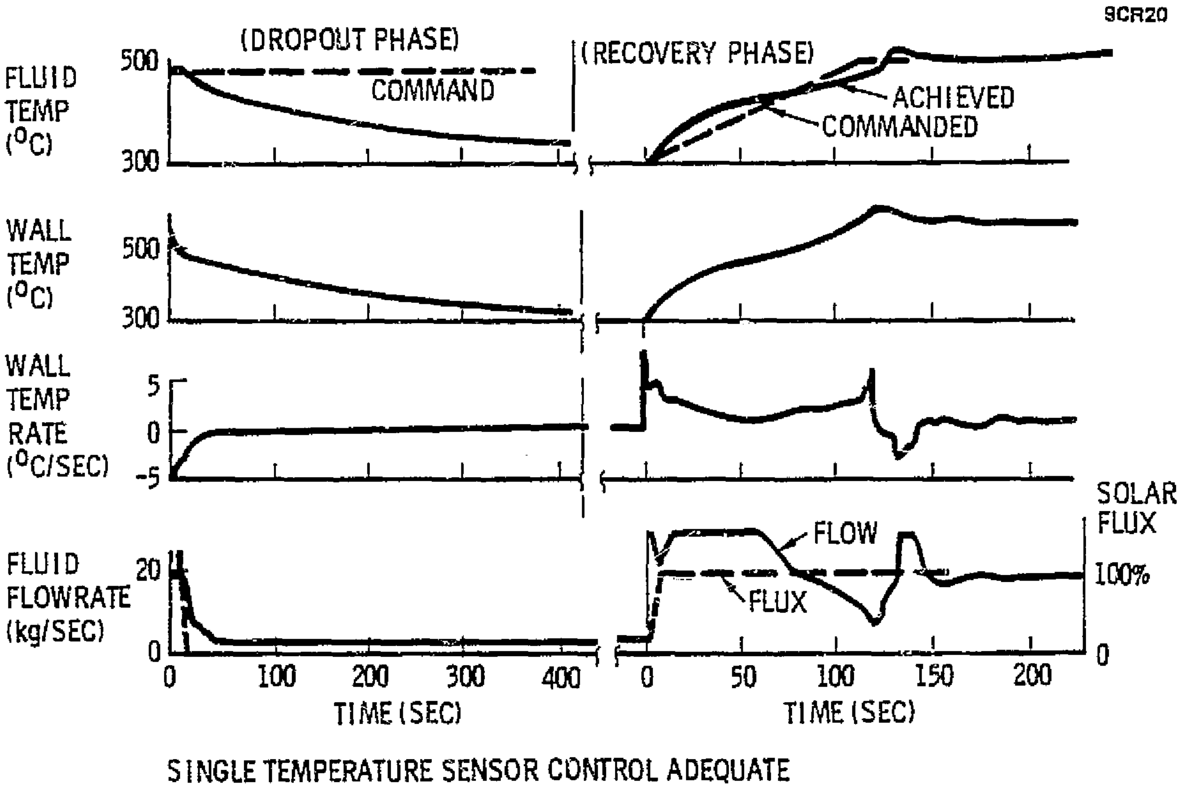

Figure 9-6. Receiver Response-Insolation Dropout

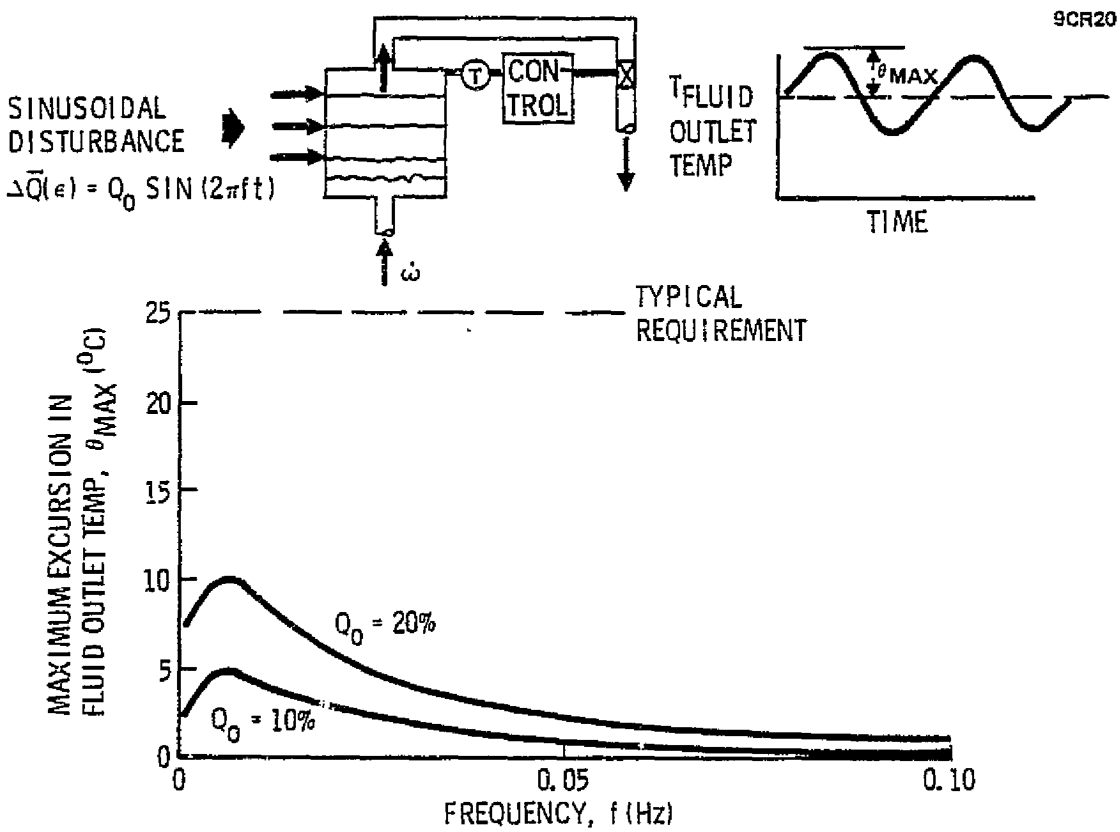

Figure 9-7. Receiver Loop Disturbance Rejection Capability (Sinusoidal Inputs)

The hardware was sized for this application considering a collector field in excess of 1,600 heliostats.

EE No. 1 would require approximately 200 or less heliostats and therefore it was necessary to determine; (1) can a more cost effective computer size and type be used for HAC functions and still provide minimum hardware and software development risks for the 3.5-year program and; (2) can a single computer system provide the collector control functions of the HAC the HFC and the supervisory functions of plant control in a real-time multitasking concurrent mode of processor operation.

The analysis considered: (1) a scaled-down version of the MODCOMP Classic 7863 computer used for the 10 MWe Solar Pilot Plant; (2) a different MODCOMP computer (Model 7810-4) having lesser performance and expansion capability than the Classic 7863 but software compatible; and (3) a computer system of a different manufacturer (DEC LSI 11-2) that was compatible with and commercially available for a CAMAC (computer aided measurement and control system), a candidate process control system evaluated for plant control.

An analysis was performed to determine the instruction throughput requirements for the aggregate of the three software tasks (i.e., HAC, HFC and plant control). This analysis used previous analyses conducted for the HAC and HFC and applied an estimated instruction execution set and number of instructions for plant control supervisory functions.

A modified Gibson mix of instructions shown in Table 9-1 was considered typical of the percentage mix of instructions for the Plant supervisory control function. The size of the plant control supervisory function was estimated based on the number of plant control and monitor functions summarized in Table 9-2 and assuming that a complete cycle through the plant application code would occur once every second.

The computer system performance for each candidate was estimated using timing data from the instruction set and compared with the expected aggregate performance required (K operations, per second) to execute the computer code in 2 seconds.

Table 9-1. Modified Gibson Instruction Mix

Instruction	Percent of mix
Load/store — double precision	35.6
Add — single precision	8.0
Multiply — single precision	5.3
Divide — single precision	1.1
Add — floating point	3.5
Multiply — floating point	1.9
Divide — floating point	0.8
Compare — logic	21.3
Branch	15.8
Miscellaneous	6.7
	100 Instructions

The computer applications code was determined for the three applications and was used in the sizing of the computer configuration memory along with the operating system code, the data base and table requirements. The computer and required peripherals were sized and priced. To this price was added the nonrecurring software implementation costs expected for conversion of existing HAC computer codes to the new computer configurations.

The throughput data were summarized and compared. This summary is shown in Table 9-3 and Figure 9-8. The cost differences for the MODCOMP 7810-4 and LSI 11-2 hardware were insignificant when considering the software code conversion costs although the LSI-11 hardware cost were only 60% of the MODCOMP 7810 costs and 35% of the MODCOMP 7861 costs.

The LSE 11-2 configuration has the second best performance capability but provides the largest risk to the short 8-month development period of the 3.5-year program. The risk is in the development and conversion of existing HAC software on a new machine that uses a different operating system, has differences in FORTRAN IV instruction SRT, requires a completely new assembly language code for all I/O drivers and new equipment familiarization and learning by the programmers.

Table 9-2. Plant Control and Measurements Summary

Subsystem	Measurement		Number of measurements/location	
Concentrator	Temperature		24	Receiver absorber tube wall temperatures
	Postion		2	Receiver manifold wall temperatures
			8	Receiver absorber housing wall temperatures
			4	Receiver track heating sections
			4	Receiver absorber door positions and drive
			2	Receiver safety/relief valves
			609	Heliostat 3 axes drive positions
Energy storage	Temperature		24	Hot/cold tank wall temperatures
	Pressure		6	Hot/cold tank level
	Level		2	Hot/cold tank fluid pressure
			4	Hot/cold tank ullage pressure (GN_2)
			6	Hot/cold tank fluid temperature
Energy transport	Temperature		1	Receiver feed pump motor current
	Flow		1	Receiver panel flow
	Position		2	Receiver control valve positions
	Current		4	Receiver pipe tracing heating temperatures
			4	Hot/cold tank control valve positions
			2	Energy transport pipe temperatures
			2	Energy transport pipe trace heater state
			8	Energy fluid to steam generator pipe temperatures
			3	Energy fluid to steam generator heater state
			2	Energy fluid mixing/hot flow
			1	Hot/cold energy fluid mixing temperature
Power conversion	Temperature			
	Flow	Voltage	2	Boiler steam flow
	Level	Current	1	Boiler H_2O level
	Position	Frequency	1	Boiler H_2O temperature
	Speed		3	High pressure heater levels
	Phase		3	High pressure heater temperatures
			3	High pressure heater pressures
			1	Low pressure heater level
			1	Low pressure heater temperature

Table 9-2. Plant Control and Measurements Summary (Continued)

Subsystem	Measurement	Number of measurements/location	
Power conversion (Con't)		1	Low pressure heater pressure
		1	Turbine governing valve pressure
		1	Turbine emergency stop valve position
		2	Turbine speed
		1	Turbine generator synchronization phase
		10	Turbine auxillary system starts
		1	Compressor vacuum
		1	Generator current
		1	Generator voltage
		1	Generator frequency
Balance of plant	Temperature	1	Demineralizer/polisher H_2O flow
	Pressure	1	Demineralizer/polisher conductivity
	Flow	1	Demineralizer/polisher contrnt
	Level	1	Demineralizer/polisher drain valve position
	Position	1	Boiler feed chemical tank level
	Voltage	2	Boiler feed chemical tank pressure
	Current	2	Boiler feed chemical tank pump state
		1	Ammonia feed tank level
		1	Ammonia feed tank pressure
		1	Hydrazine feed tank level
		1	Hydrazine feed tank pressure
		1	Cooling tower blow down valve position
		1	Cooling tower acid feed valve position
		1	Cooling tower acid feed pressure
		1	Cooling tower chemical tank level
		1	Cooling tower chemical tank feed pump state
		2	Closed cooling H_2O pump state
		2	Closed cooling H_2O pump pressure
		1	Turbine lube oil heater temperature
		1	Generator air cooling temperature
		6	Station/substation power voltage
		6	Station/substation power current
		7	Station/substation power breaker positions

Table 9-2. Plant Control and Measurements Summary (Continued)

Subsystem	Measurement	Number of measurements/location	
Balance of plant (Con't)		2	Facility air pressure
		1	Facility air compressor motor state
		1	Weather station temperature
		1	Weather station wind direction
		1	Weather station wind velocity
		1	Weather station humidity
		2	Weather station insulation

Table 9-3. Computer Throughput and Memory Sizing, Summary, Heliostat Array Control Computer (HAC) 3.5-Year Program

Task	Data	Instructions	Ops/sec fixed point	Ops/sec floating point
Operating system (Max III)		12,000		
Executive functions	100	200	5,000	
Scheduler			3,600	
Data acquisition and control	812	67	1,206	
Man-machine S/W	1,000	220	2,900	
Steady state mode (one)			1,163	
Mode transition control (one)	1,000		200	
Plant subsystem monitors	5,255	1,062	2,036	3,376
Plant performance calculations (background only)	1,000	3,000		
One-line diagnostics	170	650		
Totals	9,337	17,199	16,105	3,376

Total memory req = 26,536

Throughput req = 16,105 fixed point type instructions

= 3,376 floating point type instructions

Note: HFC reqmts
Add: Fixed Pt: 53.7 KOPS
Flt Pt: 7.4 KOPS

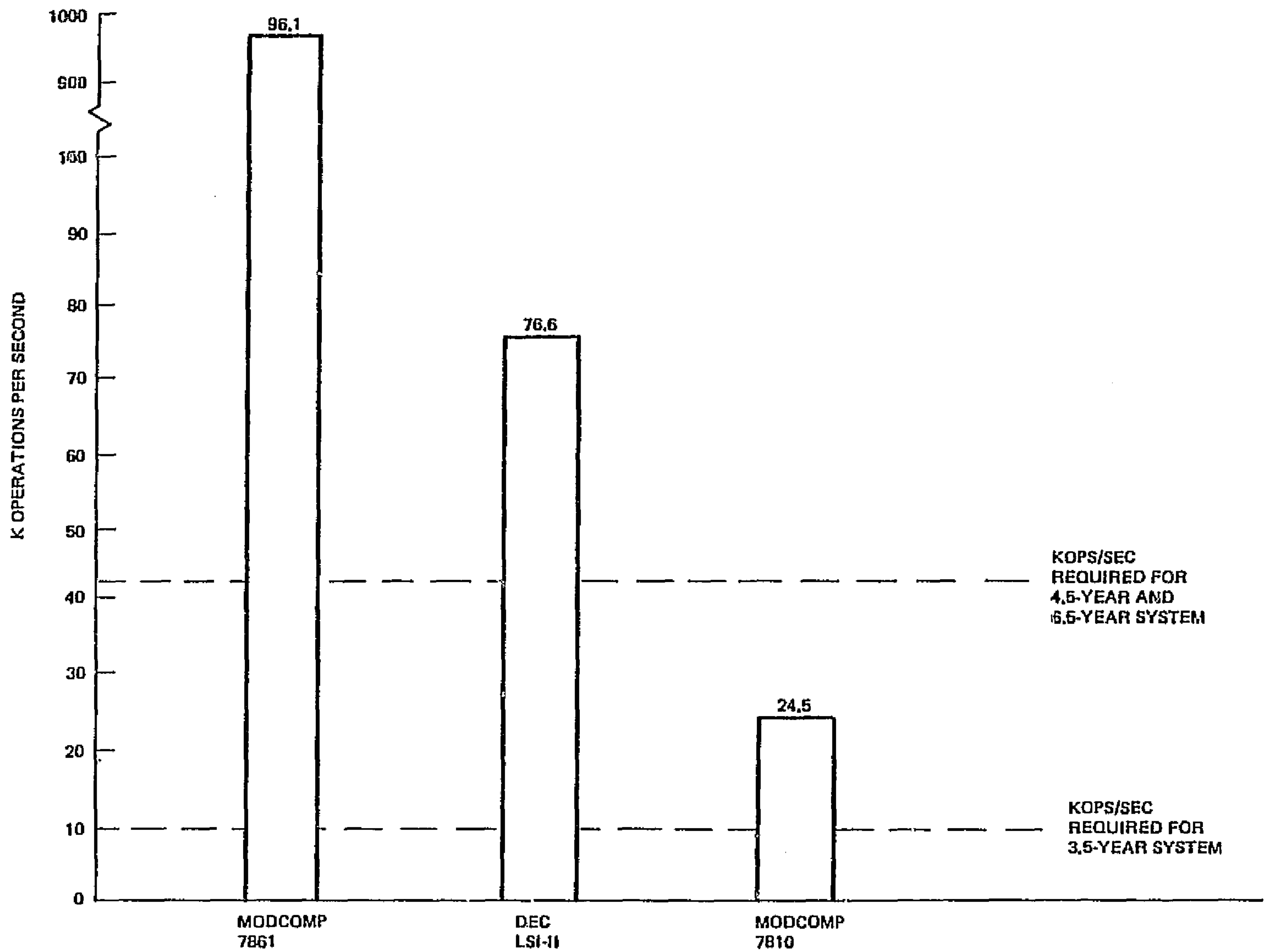

Figure 9-8. HAC Throughput Analysis Summary

The tradeoff analysis shows the MODCOMP 7810-4 provides adequate performance for the 3.5-year program at a lower cost than the equipment used for the 10 MWe Solar Power Pilot Plant and there is a high degree of software compatibility between the two machines. The LSE 11-2 computer would be selected for the 4.5-year, 6.5-year and commercial programs since: (1) the longer development times of these programs negate risk, (2) the development cost is the same; (3) the MODCOMP 7810 computer cannot meet throughput requirements for these programs (HFC functions added to HAC); and (4) the LSI-11 hardware would be more economical for commercialization.

9.3 PLANT CONTROL SYSTEM TRADEOFF ANALYSIS

The goal of the commercial program is to provide complete unattended automatic operation of the plant with a provision that allows an operator to control the plant in a degraded manual mode or an intermediate semiautomatic mode.

In the manual mode of operation, the supervisory processor would not be available, hence, the operator controls each event sequence, commands each action and makes all decisions. It is important in the implementation of manual control operation that a single operator not be burdened to the point that he cannot adequately control the plant. Of parallel importance, should the redundant computer systems fail in automatic control (loss of power for example) the plant remains in a stable safe condition. Therefore, the manual control provisions must provide built-in logic to aid manual control operations and provide control stability at each control point if the operator or automatic system fails.

Modern process control systems provide these capabilities and offer distributed digital supervisory control techniques. However, the market place for most of these systems is in the large utilities and large batch process industries such as textile, petrochemical, and food. A large entry level cost is associated with the procurement of these systems since their operation is usually based on high cost color graphic intelligent operator terminals, and includes unwanted flexibilities and capabilities in the basic configurations (i.e., high quantity entry level packaging, redundancy, interface adaptations for user functions and auxiliary test and display hardware, etc.).

Smaller control systems exist in the programmed logic controller (PLC) category and are reasonably priced. However, these systems contain very limited arithmetic capability and are not equipped to handle three mode controller functions (PID) that require sophisticated feedback, feed forward, cascade and adaptive control algorithms. Consequently, the use of these systems for this plant are not attractive.

A survey of systems for process control functions revealed two candidates that would satisfy the requirements of (1) distributed supervisory digital control, (2) three mode controller capability, (3) simple operator interface, (4) programmable logic and arithmetic function control, (5) interface to a host process computer, (6) low entry level modularity, (7) growth capability, (8) reasonable entry level costs for small systems, and (9) commercially available. The Texas Instruments PM 550 system and the CAMAC system architecture were analyzed and a tradeoff study performed.

CAMAC hardware is developed from an international interface standard adopted by IEEE in their IEEE specification 583-1975. The hardware is very modular and is built by a variety of vendors in the USA and Europe. A typical CAMAC control system block diagram that would satisfy the architecture design for this application is shown in Figure 9-9.

A block diagram of the Texas Instrument PM 550 control system is shown in Figure 9-10.

The trade analysis compared both systems in the following categories: For the 3.5-year system capacity.

- Hardware cost
- Software cost
- Growth/Exapndability
- Programmability (Difficulty)
- Modularity
- Distributed Control Allocation
- Three Mode Control Capability

Equipment allocations that satisfy the 3.5-year system requirements are shown in Tables 9-4 and 9-5. A summary of this comparison is shown in Table 9-6.

The summary shows the PM 550 system provides satisfactory allocations in each of the compared categories at substantially reduced costs for hardware and software development. The PM 550 system was selected for the EEl application.

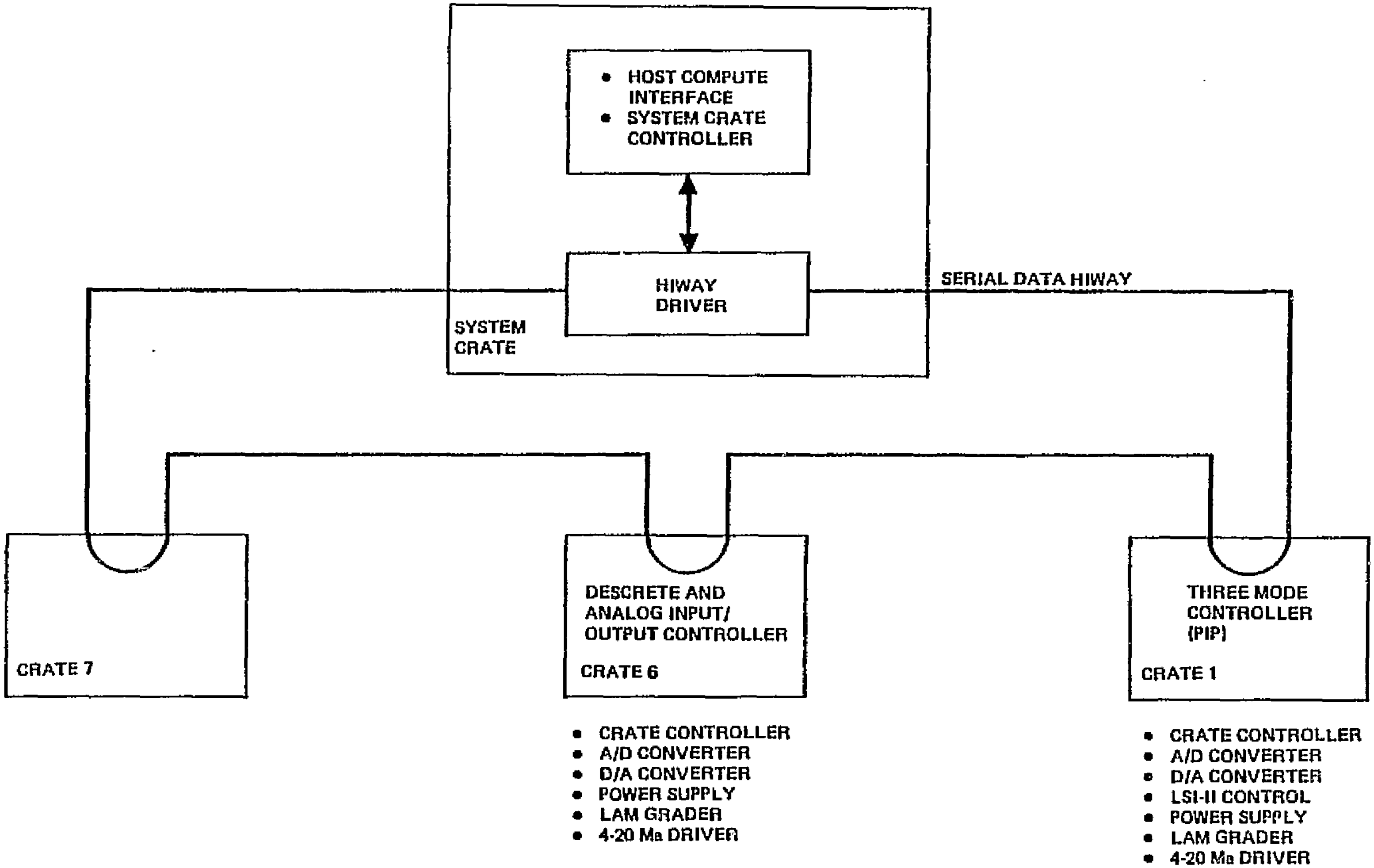

Figure 9-9. Typical CAMAC Control System Block Diagram

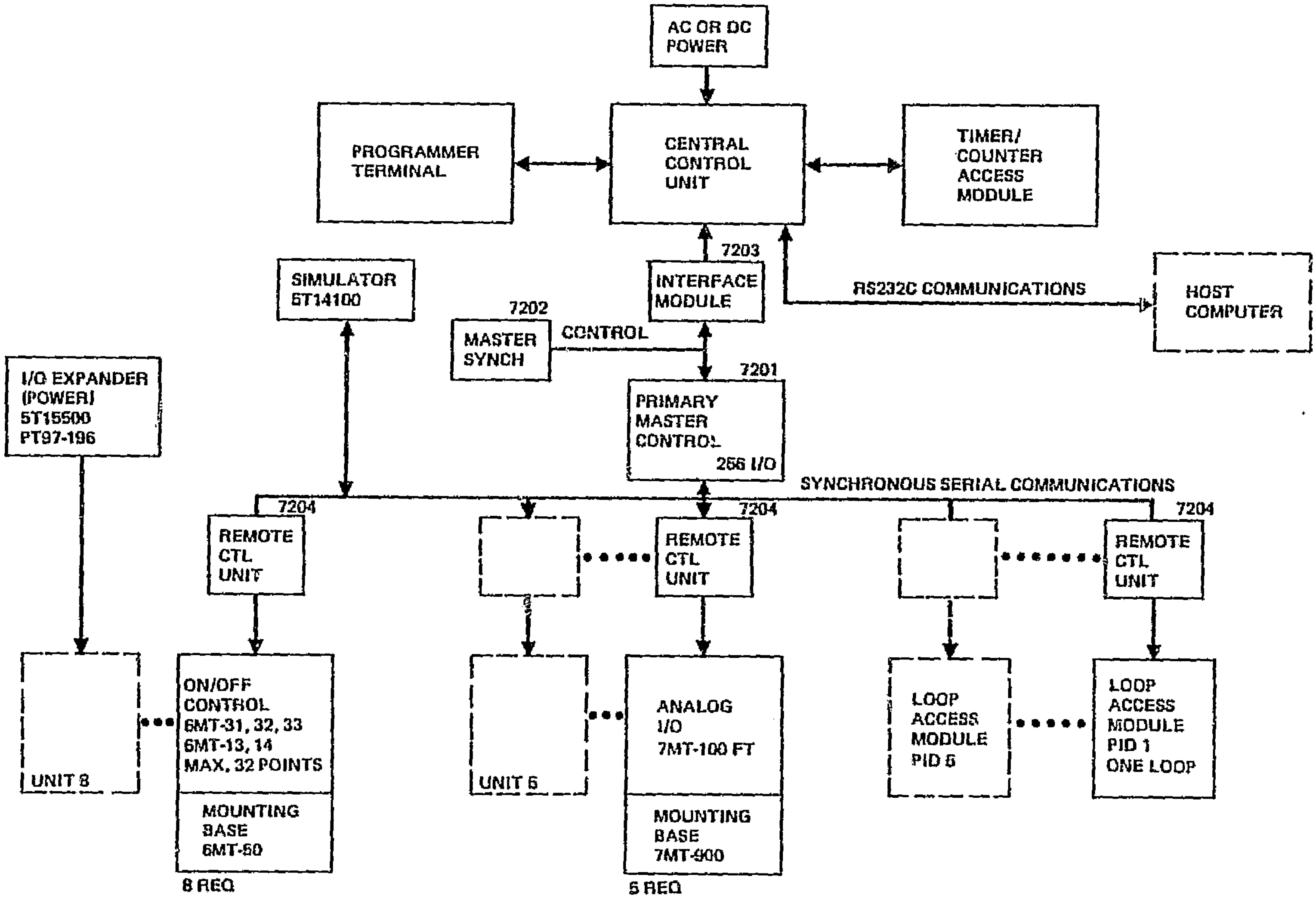

Figure 9-10. TI PM550 Control System Block Diagram

Table 9-4. Hardware Description 3.5-Year Control System

Qty	Part no.	Description	Manufacturer
1	PM550-300	Programmer with keyboard and display	Texas Instrument
1	PM550-100	Central control unit	Texas Instrument
1	PM550-220	Power supply	Texas Instrument
1	PM500-410	Timer/counter access module	Texas Instrument
1	PM550 (5TI14100)	Simulator	Texas Instrument
5	PM550-400	Loop access modules	Texas Instrument
8	6MT-50	Mounting base	Texas Instrument
2	6MT-33	8 channel input/output interface	Texas Instrument
7	6MT-31	16 channel input interface	Texas Instrument
4	6MT-32	16 channel output interface	Texas Instrument
1	5TI-5500	Input/output expander for 6MT system	Texas Instrument
5	7MT-900	Mounting base	Texas Instrument
26	7MT-100	4-20 Ma input modules	Texas Instrument
1	QJ648-AY	Software—RSX-IIS operating system	Standard Engineering
1	6220	Software—basic	Kinetic Systems

Table 9-5. Hardware Description CAMAC Control System

Qty	Model no.	Description	Manufacturer
1	3970-Z1A	MODCOMP system driver	Kinetic Systems
1	3960-Z1A	System crate controller	Kinetic Systems
1	3992-Z1B	Serial hiway driver	Kinetic Systems
7	1875-D6B	U-Port bit serial cable with return path	Kinetic Systems
6	3952-Z1A	Type L-2 serical crate controller	Kinetic Systems
12	3510-A1A	16 channel scanning A/D converter	Kinetic Systems
2	3110-P1A	5 channel, 16-bit D/A converter	Kinetic Systems
9	3080-A1B	8 bit output registar with AC switches	Kinetic Systems
7	3473-A1C	24 bit change-of-state input register	Kinetic Systems
6	3924-F1A	LAM encoder for serial system	Kinetic Systems
6	3125-A1A	4-20 Ma output driver	Kinetic Systems
2	MIK-11/1	LSI controller (PID)	Standard Engineering
2	KEV II	Extended arithmetic option	Standard Engineering
1	5330	5 conductor shielded cable — 2500 ft	Allied

Table 9-6. Plant Controller Comparison

	216,415 Programmable Controller	304,675 CAMAC
Cost:		
Hardware:	1 (unit of currency)	1.8 (units of currency)
Software:	1000 mhrs	2360 mhrs
Expandability limits:	256 descrete I/O functions 256 analog inputs 256 analog outputs 8 PID three mode controllers (Small system—limited growth expansion)	64 crates — each crate handlers 24 single or multidevice functions
Programmability:	Simple high level language Non-programmer capability	Requires professional Programmer
Modularity:	Single and multidevice packaging	Single and multidevice packaging can
Peripherals:	Requires stand-alone host computer for printing, plotting, and mass storage	adapt printing plotting and mass Storage is stand-alone system
Hardware fail-over:	No hardware redundance available	Fail over hardware capability between and within crates: dual transmission link available
Distributed control:	Serial data hiway Max. throughput ≈ 120 chan/sec 2500 ft maximum data highway length	Serial data hiway Max throughput ≈ 16,000 ch/sec No maximum data hiway Length restrictions

Section 10
HITEC/HTS STATE-OF-THE-ART AND APPLICATIONS

10.1 HITEC/HTS CHARACTERISTICS

Hitec and HTS (draw salt) have been used for years in industrial situations as a heat transfer medium. Characteristics of the nitrate based salts are discussed below.

10.1.1 Hitec Properties

Hitec was developed in the 1930's by DuPont Chemical Company. It is a white granular solid which turns yellow when melted. It is a eutectic mixture of potassium nitrate 53%, sodium nitrite 40%, and sodium nitrate 7%. Properties of the material are given in Table 10-1.

Hitec is used because it has a relatively low melting point, high heat transfer coefficient, thermal stability, and low cost. It is nonfouling, nonflammable, nonexplosive and evolves no toxic vapors under normal conditions. It has a low degree of corrosivity and can be used with carbon steel up to 454°C (850°F). Maximum operating temperature is 538°C (1,000°F). The vapor pressure below 450°C is essentially zero.

Although very stable up to high temperatures, the salt undergoes a slow thermal breakdown of the nitrite to nitrate:

$$5\,NaNO_2 \longrightarrow 3NaNO_3 + Na_2O + N_2$$

In contact with air, the nitrite is slowly oxidized by atmospheric oxygen:

$$2NaNO_2 + O_2 \longrightarrow 2NaNO_3$$

Carbon dioxide can be absorbed to form carbonates and water to form alkali metal hydroxides. These reactions tend to raise the freezing point and can be eliminated by using a nitrogen cover gas.

10.1.2 HTS (Draw Salt)

Draw salt is a binary eutectic consisting of potassium nitrate 54% and sodium nitrate 46%. It possesses most of the properties of Hitec but melts at a higher temperature (220°C) and is less expensive as shown in Table 10-1. It appears to be more stable, especially at the maximum operating temperature of 593°C (1,100°F). The major decomposition reactions are:

$$NaNO_3 = 2\ NaNO_2 + O_2$$

and $$KNO_3 = 2\ KNO_2 + O_2$$

Table 10-1 Physical Properties of HITEC and HTS (Draw Salt)

Property	Hitec	HTS
Composition, wt.%	$40NaNO_2$, $7NaNO_3$, $53KNO_3$	$46NaNO_3$, $54KNO_3$
Melting point, °C (°F)	142 (288)	220 (428)
Density, kg/m^3		
At 260°C	1,890	1,921
AT 540°C	1,680	1,733
Specific heat, J/kg-°K	1,560	1,560
Viscosity, Pa/sec		
At 260°C	0.0043	0.0043
At 540°C	0.0012	0.0011
Thermal conductivity, W/m-°K	0.61	0.57
Heat transfer coefficient, W/m^2-°K	4,600-16,700	4,300-15,600
Latent Heat of Fusion, J/gm	81.4	81.4
Cost (approx) $/kg	0.77	0.53

10.2 HITEC/HTS APPLICATIONS

Heat transfer salt has been safely used in numerous applications in the chemical and petroleum process industries as well as metallurgical metal treatment fields. A number of companies were contacted which are familiar with the handling of molten salt. They included companies which utilize molten salt in various processes, those that supply the material and also companies which design and construct total heat transfer salt systems. Topics related to molten salt handling which were discussed included operating experience, equipment, maintenance, safety, salt stability, and corrosion.

10.2.1 Operating Experience

In the majority of operations, Hitec is used as a heat recovery fluid for fixed bed reactors. Hitec is pumped from a salt tank, through the reactor where it picks up heat from the exothermic reaction, and to a steam generator to be cooled. From here it flows back to the tank to be recycled. Some companies have been using salt since 1940 in this type operation. Many steam generators have been built which utilize molten salt, some of which have been operating for over 10 years.

10.2.2 Equipment

Pumps used for molten salt applications are of the submerged vertical-centrifugal design. Most frequently the cantilever type is used to that contact is avoided between the molten salt and pump bearings or packing. Submerged bearings are also used extensively with no problems. Standard piping and valves (with asbestos gaskets) are used. Joints are welded where possible and ring joint flanges are used otherwise. Most systems utilize steam trace heating and calcium silicate insulation on all salt lines. Instrumentation usually consists of temperature transducers installed in thermowells.

10.2.3 Maintenance

In all cases maintenance of salt systems is minimal. At most, the submerged bearing pumps may have to be pulled once a year for repacking. This, however, is usually more a result of using steam as a cover gas rather than a salt related problem.

10.2.4 Safety

Other than a "burnthrough" caused by overheating salt to 650°C (1,202°F), no unusual safety problems were reported. The only safety procedures involved minimizing leaks and organic materials of construction since the hot salt will support combustion. In an industrial facility which was visited, a leaking joint was left unrepaired for several weeks and still appeared to present no real concern. All other companies appeared to have no leakage problems at all.

10.2.5 Salt Stability

As discussed in Section 10.1, Hitec is subject to various reactions at operating temperatures. Most industrial systems use steam as a cover gas since it is readily available. This leads to the formation of sodium hydroxide from the decomposition of sodium nitrite. This results in increased corrosion and melting points. In some situations, the melting point is monitored weekly and fresh salt is added if the melting point exceeds 180°C. This does not occur rapidly and one system required no makeup between 1969 and 1972. Other companies use no cover gas at all and arbitrarily add salt from "time to time." Some never replace salt in their systems. Using nitrogen as a cover gas should give maximum control of side reactions resulting in minimal salt replacement.

10.2.6 Corrosion

The majority of chemical and petroleum process industries operate below 450°C (842°F) and use carbon steel exclusively. They all report no unusual corrosion problems. The literature indicates that corrosion rates on carbon steel are on the order of 0.1 to 0.4 mm/yr between 450°C and 538°C.

Some systems have operated up to 594°C (1100°F) using stainless 316.

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8-1 Feedwater Quality in Modern Industrial Boilers - A Consensus of Proper Current Operating Practices - D. Simon, International Water Conference Proceedings, 1975.

8-2 Water Treatment for High Pressure Drum Type Boilers - Babcock and Wilcox, Brochure, 1973.

8-3 Turbine Steam Purity - General Electric, 1976 Bulletin.

8-4 Transfer of Chemicals in Steam Power Systems - O. Jonas (Westinghouse) Combustion, March 1977.

8-5 Water Treatment Practices for Cyclic Operation of Utility Boilers - F. Gabrielli and W.R. Sylvester, International Water Conference Proceedings, 1978.

APPENDIX A

PHASE II AND PHASE III COST ESTIMATES

Appendix A covers the cost estimates and associated cost methodology and rationale developed for the three Phase II and III program schedule alternatives of Engineering Experiment Number One. The resulting estimates are encouraging and certainly support a projection of economic viability for Small Central Receiver Systems. The analysis has been supported through the development of a cost data package on important material and equipment unit costs, fabrication and installation hours, cost sensitivities, and direct support, efficiency and overhead factors. Following an overview of the cost results, groundrules and costing approach, further details are provided on Phase II design costs, and Phase III costs by subsystem. This is followed by a section listing the CBS, applied costing factors and list of material unit costs.

A.1 Overview

Costs developed for the three programs, although conceptual, have been carried to a fairly credible depth of analysis, especially for Phase III.

Costing Results - Results for the three potential Engineering Experiment I programs are summarized below in 1978 dollars:

	Program ($x10^6)		
Cost Element	3.5 Year	4.5 Year	6.5 Year
Design and Development (Phase II)	$2.2	$3.8	$6.6
Investment (Phase III)			
Collector	$2.9	$2.1	$1.8
Power Conversion	$1.6	$1.6	$1.4
Energy Transport	$ .2	$ .2	$ .1
Energy Storage	$ .5	$ .4	$ .2
Control	$ .4	$ .4	$ .5
Balance*	$2.7	$2.8	$2.8
Total Investment	$8.3	$7.5	$6.8
Test & Evaluation (Phase III)	$ .7	$ .6	$ .7
Contingency on Phase III	$2.3	$2.0	$1.9
Total EEI	$13.5	$13.9	$16.0

*Indirects, Distributables, Land & Yard, and Miscellaneous Equipment

Design and development costs which include preliminary and detail design, subsystem test hardware and experimental tests increase rapidly as the program schedule is extended. This reflects the introduction of more advanced hardware requiring development and the longer time allowed for development and testing. This increase is countered in part by reduced hardware costs mainly because there are fewer heliostats and a smaller receiver required due to the increased efficiencies of the more advanced systems. Costs for power conversion and energy transport and storage also go down somewhat for the 6-1/2 year program reflecting the introduction of the radial outflow turbine and the dual media storage concept. Test and evaluation costs which appear fairly steady are actually the net of increased technical support costs and reduced costs for operations, maintenance and follow-on spares on the advanced programs. Finally, contingency is applied at 25 percent of overall Phase III costs and varies with the hardware costs.

Groundrules and Approach - The following major groundrules and assumptions have been considered during cost analysis:

1. Minimum development and schedule risk in accordance with hardware selection.
2. Costs in 1978 dollars and bid rates.
3. Maximum use of prior study data base for solar hardware costs and development of factors for common system cost elements.
4. Manufactured equipment costing based on detail estimating procedures and factors.
5. Maximum use of the industrial base for purchased parts and specialized forming operations.
6. Use of vendor quotes for conventional equipment.
7. Development program manufacturing support practice and associated factors.
8. Equal duration procurement, manufacturing, installation, checkout, test and evaluation for all three Phase III programs.
9. Maintenance cost based on failure rates and FMEA's.
10. Continuous manning of operations 24 hours a day and 7 days a week.
11. Nominal 8 percent fee across the board plus integrator's fee.

The translation of these guidelines to a costing approach varies for each subsystem depending on its relative cost value and the nature of available engineering, manufacturing, logistics and cost data, as well as the characteristics of the responsible contractor's business. Of the most costly subsystems, the collector is the least "tried", but the heliostat, which accounts for almost 90 percent of collector cost, has been the subject of considerable prior government study so that expected costs are well documented. Thus, the major share of collector cost analysis has been directed toward costing the receiver unit, the tower and minor heliostat modifications. These cost elements are state-of-the-art designs and employ common materials, purchase parts and manufacturing techniques for which vendor quotes and estimating standards and factors are readily available.

The next most important hardware cost category, power conversion, as well as the less costly energy storage, energy transport and plant control subsystem, in the main, utilize off-the-shelf equipment. The equipment is assembled and installed in typical power plant or process plant configurations. This has allowed the use of equipment quotes, standards, construction estimating manuals and Stearns-Roger experience factors to arrive at costs with reasonable confidence.

Much of the "other" category contains elements that may be estimated using experience factors also compiled by Stearns-Roger. The remainder of this category is made up of miscellaneous equipment and initial spare parts for which vendor quotes are available and Solar Integrator costs which have been determined based on manloads.

Design and development and test and evaluation costs are based on engineering judgement concerning the impact of requirements with the exception of the direct operation and maintenance (O&M) of the experimental plant. Plant operation costs are based on operator/engineer and technician manloading. Maintenance costs are based on failure rates, the failure modes and effects analysis, the implied maintenance actions, available maintenance equipment, and the projected initial spares inventory.

Further details concerning the cost estimates and the costing approach are provided in the subsections that follow, starting with Phase II costs.

A.2 Phase II Design and Development Costs

The following table provides further breakout of the projected Phase II design and development costs:

Cost Element	Program ($x10^6)		
	3.5 Year	4.5 Year	6.5 Year
Design	$2.20	$2.45	$3.45
Development/Test	-	$1.35	$3.15

Due to the reduction in contractual scope, Phase II estimates have been developed by MDAC Project Engineering considering the available schedule and expected development requirements.

The design cost projections allow for system integration, heliostat design modifications, A&E effort, and design of all subsystems. The 3 1/2 year program employs equipment which is standard or will have been tested under programs. The one exception is the receiver, but the design is very conservative and well within the state-of-the-art. As a result, no development/test costs are indicated for the 3 1/2 year program.

The 4 1/2 and 6 1/2 year programs do include some development and testing. The 4 1/2 year program utilizes the extended schedule in order to test control automation techniques and to test a prototype receiver at the CRTF and verify the state-of-the-art technology utilized. The 6 1/2 year program, in addition to extending the receiver technology and control automation, incorporates the dual media storage concept and the Radial Outflow Turbine. Development/test costs for the turbine include the fabrication and test of a prototype turbine while thermal storage testing is mainly concerned with material compatibility verification for the dual media.

A.3 Phase III Hardware and Test and Evaluation Costs

Tables A1 , A2 and A3 present Phase III costs in the E-2 tables format specified by JPL. As requested, cost data are provided in 1978 dollars. Although costs have been accumulated in accordance with the JPL cost breakdown guide-

Table A1. 3.5 Year Program (E-2 Format)

ITEM	EFFICIENCY %	WEIGHTS lb (kg)	ESTIMATE 1978 $K	
			COMPONENTS	SUBTOTALS
COLLECTOR SUBSYSTEM				2911
1. SITE PREPARATION/FOUNDATION		1917(869)	120	
2. STRUCTURAL FRAMEWORK		137(62)	97	
3. REFLECTOR SURFACE AND SUPPORT		572(260)	693	
4. DRIVE MECHANISM AND LOCAL CONTROL		168 (76)	1083	
5. RECEIVER AND SUPPORT			352	
6. PIPES, VALVES, FITTINGS, etc.			62	
7. MISCELLANEOUS (EXPLAIN) — SUSTAINING ENGR			233	
8. FIELD INSTALLATION			244	
9. FIELD SUPERVISION			13	
10. SUBSYSTEM CHECKOUT/ADJUSTMENT			14	
POWER CONVERSION SUBSYSTEM				1586
1. HEAT ENGINE			400	
2. GENERATOR			34	
3. HEAT EXCHANGER/BOILERS/CONDENSERS			296	
4. CONTROL VALVES AND LOCAL CONTROL ELEMENTS AND PIPING			103	
5. PUMPS AND FANS			30	
6. HEAT REJECTION EQUIPMENT			87	
7. SUBSYSTEM BUILDINGS AND FACILITIES			182	
8. SWITCH GEAR, TRANSFORMERS, etc.			99	
9. CONCEPT PECULIAR (EXPLAIN)			—	
10. MISCELLANEOUS (EXPLAIN)			—	
11. FIELD INSTALLATION			329	
12. FIELD SUPERVISION			18	
13. SUBSYSTEM CHECKOUT/ADJUSTMENT			7	
ENERGY TRANSPORT SUBSYSTEM				189
THERMAL				
1. PIPING			10	
2. INSULATION			10	
3. CONTROL VALVES AND LOCAL CONTROL ELEMENTS			71	
4. FLUID PUMPS AND DRIVES			41	
5. SITE PREPARATION, FOUNDATIONS, AND PIPING SUPPORT ELEMENTS			3	
6. MISCELLANEOUS (EXPLAIN)			—	
7. FIELD INSTALLATION			50	
8. FIELD SUPERVISION			3	
9. SUBSYSTEM CHECKOUT/ADJUSTMENT			1	
ELECTRICAL				
1. WIRING (MATERIAL, SUPPORTS, TRENCHES, etc.)				
2. UTILITY INTERFACE SUBSTATION				
3. LOCAL CONTROL ELEMENTS				
4. MISCELLANEOUS (EXPLAIN)				
5. FIELD INSTALLATION				
6. FIELD SUPERVISION				
7. SUBSYSTEM CHECKOUT/ADJUSTMENT				
ENERGY STORAGE SUBSYSTEM				493
1. TANKS, INSULATION, STORAGE MEDIUM			190	
2. HEAT EXCHANGERS/BOILERS			—	
3. HEAT TRANSFER FLUID			173	
4. PUMPS, VALVES, PIPING, etc.			2	
5. LOCAL CONTROL ELEMENTS			—	
6. SITE PREPARATION/FOUNDATION			11	
7. MISCELLANEOUS (EXPLAIN)			—	
8. FIELD INSTALLATION			97	
9. FIELD SUPERVISION			5	
10. SUBSYSTEM CHECKOUT/ADJUSTMENT			5	
CONTROL SUBSYSTEM				
1. CONTROL SOFTWARE			53	
2. PROCESSORS/COMPUTERS			82	
3. SYSTEM CONTROL ELEMENTS FOR PLANT OPERATION			6	
4. SUBSYSTEM OPERATION CONTROL ELEMENTS			36	
5. CONTROL LINES TO SUBSYSTEMS AND PLANT CONTROL ELEMENTS			3	
6. BUILDINGS AND FACILITIES TO HOUSE EQUIPMENT			—	
7. MISCELLANEOUS (EXPLAIN) SUSTAINING ENGR			135	
8. FIELD INSTALLATION			41	
9. FIELD SUPERVISION			14	
10. SUBSYSTEM CHECKOUT/ADJUSTMENT			45	XXXXXXXX
DETAIL DESIGN				—
PLANT CONSTRUCTION MANAGEMENT				503
SPECIAL FEATURES				3008
RELATED ITEMS				1239
OTHER (BUILDINGS AND OTHER UTILITIES TO SUPPORT SYSTEM FUNCTIONS, etc.)				257
TESTING AND EVALUATION				665
TOTAL ESTIMATED COST				11265

Table A2. 4.5 Year Program (E-2 Format)

ITEM	EFFICIENCY %	WEIGHTS lb (kg)	ESTIMATE 1978 $K COMPONENTS	ESTIMATE 1978 $K SUBTOTALS
COLLECTOR SUBSYSTEM				2141
1. SITE PREPARATION/FOUNDATION		2151(976)	139	
2. STRUCTURAL FRAMEWORK		64 (29)	56	
3. REFLECTOR SURFACE AND SUPPORT		527(239)	370	
4. DRIVE MECHANISM AND LOCAL CONTROL		127(58)	826	
5. RECEIVER AND SUPPORT			331	
6. PIPES, VALVES, FITTINGS, etc.			62	
7. MISCELLANEOUS (EXPLAIN) — SUSTAINING ENGR			125	
8. FIELD INSTALLATION			206	
9. FIELD SUPERVISION			13	
10. SUBSYSTEM CHECKOUT/ADJUSTMENT			14	
POWER CONVERSION SUBSYSTEM				1597
1. HEAT ENGINE			400	
2. GENERATOR			34	
3. HEAT EXCHANGER/BOILERS/CONDENSERS			296	
4. CONTROL VALVES AND LOCAL CONTROL ELEMENTS AND PIPING			103	
5. PUMPS AND FANS			43	
6. HEAT REJECTION EQUIPMENT			87	
7. SUBSYSTEM BUILDINGS AND FACILITIES			182	
8. SWITCH GEAR, TRANSFORMERS, etc.			99	
9. CONCEPT PECULIAR (EXPLAIN)			—	
10. MISCELLANEOUS (EXPLAIN)			—	
11. FIELD INSTALLATION			329	
12. FIELD SUPERVISION			18	
13. SUBSYSTEM CHECKOUT/ADJUSTMENT			7	
ENERGY TRANSPORT SUBSYSTEM				174
THERMAL				
1. PIPING			10	
2. INSULATION			10	
3. CONTROL VALVES AND LOCAL CONTROL ELEMENTS			71	
4. FLUID PUMPS AND DRIVES			40	
5. SITE PREPARATION, FOUNDATIONS, AND PIPING SUPPORT ELEMENTS			3	
6. MISCELLANEOUS (EXPLAIN)			—	
7. FIELD INSTALLATION			39	
8. FIELD SUPERVISION			2	
9. SUBSYSTEM CHECKOUT/ADJUSTMENT			1	
ELECTRICAL				
1. WIRING (MATERIAL, SUPPORTS, TRENCHES, etc.)				
2. UTILITY INTERFACE SUBSTATION				
3. LOCAL CONTROL ELEMENTS				
4. MISCELLANEOUS (EXPLAIN)				
5. FIELD INSTALLATION				
6. FIELD SUPERVISION				
7. SUBSYSTEM CHECKOUT/ADJUSTMENT				
ENERGY STORAGE SUBSYSTEM				417
1. TANKS, INSULATION, STORAGE MEDIUM			170	
2. HEAT EXCHANGERS/BOILERS			—	
3. HEAT TRANSFER FLUID			133	
4. PUMPS, VALVES, PIPING, etc.			2	
5. LOCAL CONTROL ELEMENTS			—	
6. SITE PREPARATION/FOUNDATION			11	
7. MISCELLANEOUS (EXPLAIN)			—	
8. FIELD INSTALLATION			91	
9. FIELD SUPERVISION			5	
10. SUBSYSTEM CHECKOUT/ADJUSTMENT			5	
CONTROL SUBSYSTEM				369
1. CONTROL SOFTWARE			42	
2. PROCESSORS/COMPUTERS			82	
3. SYSTEM CONTROL ELEMENTS FOR PLANT OPERATION			6	
4. SUBSYSTEM OPERATION CONTROL ELEMENTS			41	
5. CONTROL LINES TO SUBSYSTEMS AND PLANT CONTROL ELEMENTS			3	
6. BUILDINGS AND FACILITIES TO HOUSE EQUIPMENT			—	
7. MISCELLANEOUS (EXPLAIN) — SUSTAINING ENGR			95	
8. FIELD INSTALLATION			41	
9. FIELD SUPERVISION			14	
10. SUBSYSTEM CHECKOUT/ADJUSTMENT			45	XXXXXXX
DETAIL DESIGN				---
PLANT CONSTRUCTION MANAGEMENT				410
SPECIAL FEATURES				2756
RELATED ITEMS				1383
OTHER (BUILDINGS AND OTHER UTILITIES TO SUPPORT SYSTEM FUNCTIONS, etc.)				264
TESTING AND EVALUATION				639
TOTAL ESTIMATED COST				10150

Table A2. 4.5 Year Program (E-2 Format)

ITEM	EFFICIENCY %	WEIGHTS lb (kg)	ESTIMATE 1978 $K	
			COMPONENTS	SUBTOTALS
COLLECTOR SUBSYSTEM				2141
1. SITE PREPARATION/FOUNDATION		2151(976)	139	
2. STRUCTURAL FRAMEWORK		64 (29)	56	
3. REFLECTOR SURFACE AND SUPPORT		527(239)	370	
4. DRIVE MECHANISM AND LOCAL CONTROL		127(58)	826	
5. RECEIVER AND SUPPORT			331	
6. PIPES, VALVES, FITTINGS, etc.			62	
7. MISCELLANEOUS (EXPLAIN) — SUSTAINING ENGR			125	
8. FIELD INSTALLATION			206	
9. FIELD SUPERVISION			13	
10. SUBSYSTEM CHECKOUT/ADJUSTMENT			14	
POWER CONVERSION SUBSYSTEM				1597
1. HEAT ENGINE			400	
2. GENERATOR			34	
3. HEAT EXCHANGER/BOILERS/CONDENSERS			296	
4. CONTROL VALVES AND LOCAL CONTROL ELEMENTS AND PIPING			103	
5. PUMPS AND FANS			43	
6. HEAT REJECTION EQUIPMENT			87	
7. SUBSYSTEM BUILDINGS AND FACILITIES			182	
8. SWITCH GEAR, TRANSFORMERS, etc.			59	
9. CONCEPT PECULIAR (EXPLAIN)			—	
10. MISCELLANEOUS (EXPLAIN)			—	
11. FIELD INSTALLATION			329	
12. FIELD SUPERVISION			18	
13. SUBSYSTEM CHECKOUT/ADJUSTMENT			7	
ENERGY TRANSPORT SUBSYSTEM				174
THERMAL				
1. PIPING			10	
2. INSULATION			10	
3. CONTROL VALVES AND LOCAL CONTROL ELEMENTS			71	
4. FLUID PUMPS AND DRIVES			40	
5. SITE PREPARATION, FOUNDATIONS, AND PIPING SUPPORT ELEMENTS			3	
6. MISCELLAENOUS (EXPLAIN)			—	
7. FIELD INSTALLATION			39	
8. FIELD SUPERVISION			2	
9. SUBSYSTEM CHECKOUT/ADJUSTMENT			1	
ELECTRICAL				
1. WIRING (MATERIAL, SUPPORTS, TRENCHES, etc.)				
2. UTILITY INTERFACE SUBSTATION				
3. LOCAL CONTROL ELEMENTS				
4. MISCELLANEOUS (EXPLAIN)				
5. FIELD INSTALLATION				
6. FIELD SUPERVISION				
7. SUBSYSTEM CHECKOUT/ADJUSTMENT				
ENERGY STORAGE SUBSYSTEM				417
1. TANKS, INSULATION, STORAGE MEDIUM			170	
2. HEAT EXCHANGERS/BOILERS			—	
3. HEAT TRANSFER FLUID			133	
4. PUMPS, VALVES, PIPING, etc.			2	
5. LOCAL CONTROL ELEMENTS			—	
6. SITE PREPARATION/FOUNDATION			11	
7. MISCELLANEOUS (EXPLAIN)			—	
8. FIELD INSTALLATION			91	
9. FIELD SUPERVISION			5	
10. SUBSYSTEM CHECKOUT/ADJUSTMENT			5	
CONTROL SUBSYSTEM				369
1. CONTROL SOFTWARE			42	
2. PROCESSORS/COMPUTERS			82	
3. SYSTEM CONTROL ELEMENTS FOR PLANT OPERATION			6	
4. SUBSYSTEM OPERATION CONTROL ELEMENTS			41	
5. CONTROL LINES TO SUBSYSTEMS AND PLANT CONTROL ELEMENTS			3	
6. BUILDINGS AND FACILITIES TO HOUSE EQUIPMENT			—	
7. MISCELLANEOUS (EXPLAIN) — SUSTAINING ENGR			96	
8. FIELD INSTALLATION			41	
9. FIELD SUPERVISION			14	
10. SUBSYSTEM CHECKOUT/ADJUSTMENT			45	XXXXXXX
DETAIL DESIGN				—
PLANT CONSTRUCTION MANAGEMENT				410
SPECIAL FEATURES				2756
RELATED ITEMS				1383
OTHER (BUILDINGS AND OTHER UTILITIES TO SUPPORT SYSTEM FUNCTIONS, etc.)				264
TESTING AND EVALUATION				639
TOTAL ESTIMATED COST				10150

C-3

Table A3. 6.5 Year Program (E-2 Format)

ITEM	EFFICIENCY %	WEIGHTS lb (kg)	ESTIMATE 1978 $K	
			COMPONENTS	SUBTOTALS
COLLECTOR SUBSYSTEM				1823
1. SITE PREPARATION/FOUNDATION		1749(793)	114	
2. STRUCTURAL FRAMEWORK		52(23)	45	
3. REFLECTOR SURFACE AND SUPPORT		428(194)	301	
4. DRIVE MECHANISM AND LOCAL CONTROL		104(47)	673	
5. RECEIVER AND SUPPORT			318	
6. PIPES, VALVES, FITTINGS, etc.			62	
7. MISCELLANEOUS (EXPLAIN) — SUSTAINING ENGR			101	
8. FIELD INSTALLATION			186	
9. FIELD SUPERVISION			12	
10. SUBSYSTEM CHECKOUT/ADJUSTMENT			11	
POWER CONVERSION SUBSYSTEM				1377
1. HEAT ENGINE			79	
2. GENERATOR			34	
3. HEAT EXCHANGER/BOILERS/CONDENSERS			275	
4. CONTROL VALVES AND LOCAL CONTROL ELEMENTS AND PIPING			114	
5. PUMPS AND FANS			91	
6. HEAT REJECTION EQUIPMENT			77	
7. SUBSYSTEM BUILDINGS AND FACILITIES			214	
8. SWITCH GEAR, TRANSFORMERS, etc.			99	
9. CONCEPT PECULIAR (EXPLAIN)			—	
10. MISCELLANEOUS (EXPLAIN)			—	
11. FIELD INSTALLATION			366	
12. FIELD SUPERVISION			20	
13. SUBSYSTEM CHECKOUT/ADJUSTMENT			8	
ENERGY TRANSPORT SUBSYSTEM				141
THERMAL				
1. PIPING			6	
2. INSULATION			9	
3. CONTROL VALVES AND LOCAL CONTROL ELEMENTS			64	
4. FLUID PUMPS AND DRIVES			24	
5. SITE PREPARATION, FOUNDATIONS, AND PIPING SUPPORT ELEMENTS			3	
6. MISCELLAENOUS (EXPLAIN)			—	
7. FIELD INSTALLATION			33	
8. FIELD SUPERVISION			1	
9. SUBSYSTEM CHECKOUT/ADJUSTMENT			1	
ELECTRICAL				
1. WIRING (MATERIAL, SUPPORTS, TRENCHES, etc.)				
2. UTILITY INTERFACE SUBSTATION				
3. LOCAL CONTROL ELEMENTS				
4. MISCELLANEOUS (EXPLAIN)				
5. FIELD INSTALLATION				
6. FIELD SUPERVISION				
7. SUBSYSTEM CHECKOUT/ADJUSTMENT				
ENERGY STORAGE SUBSYSTEM				249
1. TANKS, INSULATION, STORAGE MEDIUM			139	
2. HEAT EXCHANGERS/BOILERS			—	
3. HEAT TRANSFER FLUID			69	
4. PUMPS, VALVES, PIPING, etc.			2	
5. LOCAL CONTROL ELEMENTS			—	
6. SITE PREPARATION/FOUNDATION			4	
7. MISCELLANEOUS (EXPLAIN)			—	
8. FIELD INSTALLATION			33	
9. FIELD SUPERVISION			1	
10. SUBSYSTEM CHECKOUT/ADJUSTMENT			1	
CONTROL SUBSYSTEM				478
1. CONTROL SOFTWARE			87	
2. PROCESSORS/COMPUTERS			82	
3. SYSTEM CONTROL ELEMENTS FOR PLANT OPERATION			6	
4. SUBSYSTEM OPERATION CONTROL ELEMENTS			51	
5. CONTROL LINES TO SUBSYSTEMS AND PLANT CONTROL ELEMENTS			3	
6. BUILDINGS AND FACILITIES TO HOUSE EQUIPMENT				
7. MISCELLANEOUS (EXPLAIN) — SUSTAINING ENGR			149	
8. FIELD INSTALLATION			41	
9. FIELD SUPERVISION			14	
10. SUBSYSTEM CHECKOUT/ADJUSTMENT			45	XXXXXXX
DETAIL DESIGN				—
PLANT CONSTRUCTION MANAGEMENT				360
SPECIAL FEATURES				2599
RELATED ITEMS				1333
OTHER (BUILDINGS AND OTHER UTILITIES TO SUPPORT SYSTEM FUNCTIONS, etc.)				264
TESTING AND EVALUATION				696
TOTAL ESTIMATED COST				9320

lines, the alignment of costs associated with a central receiver system within the E-2 format may be somewhat confusing. For example, the Collector Site Preparation/Foundation category includes costs for not only the heliostat foundations, but also the tower base, piers, beams and deadmen. On the other hand, the tower structure is covered under Receiver and Support rather than item 2, structural framework which contains only costs for the heliostat pedestals. Subsection A.4 provides a breakdown of the cost elements contained in each of the E-2 line items as well as a reconcilliation to the DOE/Sandia Central Receiver cost breakdown structure.

The costs shown in the tables reflect the design configurations and manufacturing and logistics scenarios discussed in the main body of this volume. However, Table A4 has been included as a summary of the cost-driving technical characteristics. The remainder of this subsection provides further information by subsystem that may be helpful in understanding the costs shown in the tables.

A.3.1 Collector Subsystem

The Collector Subsystem contains the Receiver, Tower and Heliostat costs. Heliostat costs assume production in existing facilities with some modifications to the reflector and electronics. Costs are based on published DOE cost information which has been perturbed to add or delete tooling parts and labor in accordance with the altered design and production scenario. The production scenario assumes provision of mod kits which included the necessary spares, flanges and electronic components. Although a special reflector assembly area is necessary to handle the altered mirror curvature, cant angles and split beam (Barstow configuration), modifications to the electronics may be easily handled within the existing lines.

The Receiver cost estimates also assume use of existing production facilities. The absorber is vendor wound and welded and delivered to Rocketdyne's facilities in two sections. There, the sections are welded together and to the apex manifold and to the ancillary piping and manifolds. After a flow check, the absorber is shipped along with the preassembled support structure and housing. At the site, the absorber is assembled in the structure/housing, insulation is added and the whole assembly hoisted to the top of the tower with a mobile

TABLE A4

COST DRIVING CHARACTERISTICS

Item	PROGRAMS 3-1/2 Year	4-1/2 Year	6-1/2 Year
Heliostats	. 217 units	. 171 units	. 139 units
	. 45 m^2	. 49 m^2	. 49 m^2
	. Barstow production	. 2nd Generation Prod.	. 2nd Generation Prod.
Tower	. 39 m high	. Same	. Same
Receiver	. Guyed Steel Truss Stru.	. 26.1 m^2 SA	. 22.8 m^2 SA
	. 28.9 m^2 SA	. Same	. Same
	. Spiral Partial Cavity	. 316 CRES	. Incollay 800
	. 316 CRES Tubes	. 510°C O.T.	. 538°C O.T.
	. 454°C Outlet Temp.	. Same	. Same
	. Vendor wound tubes	. Same	. Same
Energy Storage and Transport	. Two tank -- SS	. Two Tank -- SS	. Duel Media
	. Hitec	. Hitec	. HTS
	. 17.1 MWHt Capacity	. 14.9 MWHt	. 12.5 MWHt
	. 454°C Max. Temp.	. 510°C	. 538°C
	. Vertical Submerged Pumps	. Same as 3-1/2	. Horizontal in-line pumps
Power Conversion	. Axial Marine Turbine	. Axial Marine Turbine	. Radial Outflow Turbine
	. 1 MWe nominal output	. Same	. Same
	. Inlet 427°C, 62 Bar	. 482°C, 103 Bar	. 510°C, 121 Bar
	. Standard ancillary equipment & piping	. Same	. Same
	. Fully Housed	. Same	. Same
Plant Control	. Standard Equipment	. Same	. Same
	. Automatic Mode Transitions	. +Automatic loop warmup and shut down	. +Automated turbine start up and shut down and other operations
Land & Yard Operations	. 8 acres	. 6.6 acres	. 5.5 acres
	. LRUs, 95% repairable	. Same	. Same
	. Special wash equipment	. Same	. Same

crane. Costs were developed by Rocketdyne based on conceptual drawings, engineering variable estimates, and a preliminary bill of materials using vendor quotes, category prices, and labor standards, pricing factors and 1978 bid rates. Field costs have been developed from resource loads of men, materials and installation equipment.

The tower costs have been developed by Stearns-Roger and include an elevator, aircraft strobe lights, a platform at the top and a caged ladder. However, the elevator cost is included under Related Items since it was selected because of the experimental nature of the plant. The structure is subassembled and shipped in six sections which are assembled along with the ancillary equipment using the mobile crane. Stearns-Roger has based their estimates on conceptual level parts and material take-offs, and have employed concrete and steel experience factors, vendor quotes and categories, and 1978 trade labor rates to arrive at costs.

A.3.2 Power Conversion

The power conversion subsystem costs have been estimated by Stearns-Roger for all but the turbine plant equipment based on vendor quotes for the mechanical, electrical and HFAC equipment and on experience factors for painting, instruments and concrete work. Piping is based on estimated quantities while the turbine/control building costs are based on volume and type of construction. The trubine equipment is based on vendor quotes solicited directly by MDAC.

A.3.3 Energy Storage and Energy Transport

Although presented as separate subsystem costs on the tables, energy storage and energy transport are very closely associated. These subsystems will be subcontracted and, in fact, the cost quotation from vendors that supply molton salt handling systems do not identify separate storage and transport elements. The cost breakout has been obtained by an independent MDAC analysis employing individual vendor equipment quotes and construction estimating manuals such as Richardson's, Mean's, Dodge Guide, and the National Construction Estimator. The results of the MDAC analysis were compared to the overall subsystem quotes and the SRE actuals for the Dual Media concept in order to verify cost breakdown. The costed scenario calls for factory constructed tanks which are shipped along with the associated pumps, valves and prefabricated insulation sections to the field site for final installation.

A.3.4 Control Subsystem

The plant control manufacturing scenario calls for the use of off-the-shelf equipment which is shipped to MDAC facilities in Huntington Beach. There it is assembled, integrated with the software, and checked out using MDAC's Systems Integration Laboratory. The equipment is then disassembled, shipped to site, reassembled and finally checked out. The costs are based on vendor quotes for the equipment lists and on manloading of engineers and technicians according to the schedules and tasks. MDAC-Huntington Beach labor rates and pricing factors have been applied in order to complete the costs.

A.3.5 Other Costs

A breakdown of other costs along with and indication of estimating methodology is provided in Table A5. As indicated, a large share of these costs are based on experience factors. These factors have been supplied by Stearns-Roger. Note that the costs covered by the distributables are developed for Balance of Plant (BOP) only. Field distributables for the solar related equipment are costed and accounted for under the individual subsystems.

A.3.6 Test and Evaluation

Table A6 presents a summary of test and evaluation costs. The costs are summarized by Major Hardware Functions. The control subsystem is included within Electric Plant Equipment while the Operations and Maintenance category contains those elements that can't be specifically identified with a hardware element.

The spares and repair parts costs are relatively small because the test operations last only one year and there is a large complement of initial spares. By far, the largest portion of the cost falls under the operations category. Well over half of this cost is for technical support during the test operations period. The remainder is for assuring plant operating coverage of at least two operator/engineers at all times, 7 days per week and 24 hours per day during the one year experimental test operations project.

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TABLE A5
ADDITIONAL COST BREAKDOWN

Cost Element	PROGRAM ($ x 10^3) 3.5 Year	4.5 Year	6.5 Year	Method of Costing
Plant Construction Manager	$ 503	$ 410	$ 360	Factor on total costs
Special Features				
Land and Rights	$ 40	$ 33	$ 28	Provided at $5000/acre
Grading & Gen. Excav.	24	24	24	Factor of PDR
Roads, fences & lighting	36	36	36	"
Sewer System	28	28	28	"
Yard and Storm drain	3	3	3	"
Field office personnel & service	69	69	76	Factor on BOP Field Labor
Insurance	54	54	60	"
Temporary Facilities	38	38	42	"
Temporary Equipment	127	127	140	"
Construction Services	68	68	73	"
Initial Spares	120	122	115	Equipment quotes and Spares Policy
A&E construction support	126	103	90	Factor on Total Costs
Startup and C/O	23	23	23	Manload
Contingency	2252	2028	1861	Factor on Grand Total
Subtotal	$ 3008	$ 2756	$ 2599	
Related Items				
Solar Integrator	$ 934	$ 900	$ 884	Manloads
Special Heliostat SCR Production Equipment	221	400	365	Conceptual Equipment Estimates
Elevator	84	84	84	Quote
Subtotal	$ 1239	$ 1383	$ 1333	
Other				
Transport & lifting Eq.	$ 110	$ 110	$ 110	Conceptual Equipment Estimates
Communication Eq.	1	1	1	Factor of PDR
Utilities & Fixtures	156	152	152	Factor of PDR
Subtotal	$ 267	$ 264	$ 264	

TABLE A6
TEST AND EVALUATION COSTS
(DOLLARS IN THOUSANDS)

5.5 YEAR PROGRAM 12.30.51.

WBS NUMBER AND TITLE	OPERATIONS AND MAINTENANCE					
	NON-LABOR			LABOR		
	SPARES	REP PT	OTHER	CORRECT	SCHED	TOTAL
GRAND TOTAL	$6.	$25.	$17.	$28.	$590.	$665.
SITE,STRUC,MISC E	0.	0.	0.	6.	14.	20.
TURBINE PLT EQ	1.	5.	1.	5.	18.	29.
ELECTRIC PLT EQ	0.	1.	6.	1.	0.	9.
HELIOSTAT EQUIP	4.	10.	1.	14.	21.	50.
RECEIVER EQ	1.	8.	0.	1.	1.	11.
THERMAL STRG EQ	0.	0.	0.	1.	3.	5.
DISTRIB & INDIR	0.	0.	0.	0.	0.	0.
OPERATION&MAINT	0.	0.	7.	0.	534.	541.

4.5 YEAR PROGRAM 12.18.13.

WBS NUMBER AND TITLE	OPERATIONS AND MAINTENANCE					
	NON-LABOR			LABOR		
	SPARES	REP PT	OTHER	CORRECT	SCHED	TOTAL
GRAND TOTAL	$5.	$19.	$11.	$19.	$585.	$639.
SITE,STRUC,MISC E	0.	0.	0.	5.	14.	19.
TURBINE PLT EQ	1.	8.	1.	5.	18.	32.
ELECTRIC PLT EQ	0.	1.	1.	1.	0.	3.
HELIOSTAT EQUIP	2.	2.	1.	6.	17.	28.
RECEIVER EQ	1.	8.	0.	1.	1.	11.
THERMAL STRG EQ	0.	0.	0.	1.	3.	5.
DISTRIB & INDIR	0.	0.	0.	0.	0.	0.
OPERATION&MAINT	0.	0.	7.	0.	534.	541.

6.5 YEAR PROGRAM 12.10.10.

WBS NUMBER AND TITLE	OPERATIONS AND MAINTENANCE					
	NON-LABOR			LABOR		
	SPARES	REP PT	OTHER	CORRECT	SCHED	TOTAL
GRAND TOTAL	$4.	$22.	$17.	$19.	$635.	$696.
SITE,STRUC,MISC E	0.	0.	0.	5.	14.	19.
TURBINE PLT EQ	2.	15.	1.	5.	20.	43.
ELECTRIC PLT EQ	0.	1.	7.	1.	0.	9.
HELIOSTAT EQUIP	2.	2.	1.	5.	14.	23.
RECEIVER EQ	1.	4.	0.	1.	1.	7.
THERMAL STRG EQ	0.	0.	0.	1.	3.	5.
DISTRIB & INDIR	0.	0.	0.	0.	0.	0.
OPERATION&MAINT	0.	0.	7.	0.	584.	591.

TABLE A6
TEST AND EVALUATION COSTS
(DOLLARS IN THOUSANDS)

3.5 YEAR PROGRAM 12.30.51.

WBS NUMBER AND TITLE	OPERATIONS AND MAINTENANCE					
	NON-LABOR			LABOR		
	SPARES	REP PT	OTHER	CORRECT	SCHED	TOTAL
GRAND TOTAL	$6.	$25.	$17.	$28.	$590.	$665.
SITE,STRUC,MISC E	0.	0.	0.	6.	14.	20.
TURBINE PLT EQ	1.	5.	1.	5.	18.	29.
ELECTRIC PLT EQ	0.	1.	6.	1.	0.	9.
HELIOSTAT EQUIP	4.	10.	1.	14.	21.	50.
RECEIVER EQ	1.	8.	0.	1.	1.	11.
THERMAL STRG EQ	0.	0.	0.	1.	3.	5.
DISTRIB & INDIR	0.	0.	0.	0.	0.	0.
OPERATION&MAINT	0.	0.	7.	0.	534.	541.

4.5 YEAR PROGRAM 12.18.13.

WBS NUMBER AND TITLE	OPERATIONS AND MAINTENANCE					
	NON-LABOR			LABOR		
	SPARES	REP PT	OTHER	CORRECT	SCHED	TOTAL
GRAND TOTAL	$ 5.	$ 19.	$ 11.	$ 19.	$585.	$ 639.
SITE,STRUC,MISC E	0.	0.	0.	5.	14.	19.
TURBINE PLT EQ	1.	8.	1.	5.	18.	32.
ELECTRIC PLT EQ	0.	1.	1.	1.	0.	3.
HELIOSTAT EQUIP	2.	2.	1.	6.	17.	28.
RECEIVER EQ	1.	8.	0.	1.	1.	11.
THERMAL STRG EQ	0.	0.	0.	1.	3.	5.
DISTRIB & INDIR	0.	0.	0.	0.	0.	0.
OPERATION&MAINT	0.	0.	7.	0.	534.	541.

6.5 YEAR PROGRAM 12.10.10.

WBS NUMBER AND TITLE	OPERATIONS AND MAINTENANCE					
	NON-LABOR			LABOR		
	SPARES	REP PT	OTHER	CORRECT	SCHED	TOTAL
GRAND TOTAL	$ 4.	$22.	$17.	$ 19.	$635.	$ 696.
SITE,STRUC,MISC E	0.	0.	0.	5.	14.	19.
TURBINE PLT EQ	2.	15.	1.	5.	20.	43.
ELECTRIC PLT EQ	0.	1.	7.	1.	0.	9.
HELIOSTAT EQUIP	2.	2.	1.	5.	14.	23.
RECEIVER EQ	1.	4.	0.	1.	1.	7.
THERMAL STRG EQ	0.	0.	0.	1.	3.	5.
DISTRIB & INDIR	0.	0.	0.	0.	0.	0.
OPERATION&MAINT	0.	0.	7.	0.	584.	591.

A.4 Supporting Details

This section contains a more detailed listing of the cost breakdown structure (CBS) along with a reconcilliation to the DOE/Sandia Advanced Programs Central Receiver CBS. This is followed with the tables of Unit Material Costs and a table of Applied Costing Factors.

A.4.1 The Cost Breakdown Structure

Table A7 provides further insight concerning the cost elements that are costed under each line item of Table E-2. In many cases line items shown in Table A7 actually have been costed at a lower level. Table A8, which follows, provide a further depth concerning the inclusions under the Table E-2 categories.

Table A8 shows the DOE/Sandia Central Receiver CBS employed for Advanced Programs. This chart of accounts is the CBS actually employed in accounting for Phase III EEI costs for reasons of costing efficiency because the cost data base, experience factors, estimators, and subcontractors have related most directly, in the past, to this CBS for a Central Receiver System. This chart is arranged with the DOE/Sandia CBS numbers and indentured titles on the left and the Table E-2 acccount number in the right-hand column. A given cost is accumulated and carried over to the E-2 accounts shown in Table A7 wherever an E-2 account number appears opposite a line item in the DOE/Sandia CBS. However, the carried over cost may actually have been developed at lower levels in the indenture. An example of this is provided by the Heliostat Array Controller. Here, the cost is carried over to the E2 format as one line item, numbered 0502, but has been developed as the sum of a long list of equipment costs listed under the DOE/Sandia CBS number 4305010101 which corresponds to E-2 number 0502.

A.4.2 Material Unit Cost Tables

Tables A9 to A11 provide the list of unit material costs applied during the study. The costs indicated are in 1978 dollars and represent the vendor prices before factors for contractor's fee, visibility and rework factors have been applied.

TABLE A7

"TABLE E-2" COST BREAKDOWN STRUCTURE

01	COLLECTOR SUBSYSTEM
0101	SITE PREPARATION/FOUNDATION
	FOUND/SITE PREP (HELIOSTAT)
	TOWER BASE
	PIERS AND BEAMS (TOWER)
	DEADMAN (TOWER)
	REBAR (TOWER)
	EXCAVATION (TOWER)
	BACKFILL (TOWER)
0102	HELIO SUPP STRUCT
0103	REFLECTIVE UNIT
	REFLECTIVE SURFACE
	MIRROR BACK STRUCT
	ASSY & BOARD
0104	DRIVE MECHANISM AND LOCAL CONTROL
	DRIVE UNIT (COLLECTOR)
	CONTROL/INSTRMTEQ (COLLECTOR)
	INSTRUMENTS (RECEIVER)
	GEARS & BEARINGS (RECEIVER)
0105	RECEIVER AND SUPPORT
	ABSORBER
	ASSY & CO
	TUBE
	X-RAY
	INSULATION
	APEX MANIFOLD
	TRACE HEATING
	HOUSING AND STRUCTURE
	ASSY & CO
	STRUC STEEL
	ABSORBER COVER
	OUTSIDE COVER
	STEEL FLOOR
	TOWER
	SUBASSY ON GRND
	ERECTION IN AIR
	STRUCTURAL STELL
	BRIDGE CABLES
	CLEVIS AND CLAMPS
	PLATFORMS
	LIGHTING
	OBSTRUCTION LIGHT
	SAFETY LADDER
	LIGHTNING PROTEC

TABLE A7

"TABLE E-2" COST BREAKDOWN STRUCTURE

0106	PIPES, VALVES, FITTINGS (RECEIVER)
	ASSY & CO
	DISTRIB MANIFOLD
	INSULATION-PIPE
	PIPING
	VENT VALVE
	RELIEF VALVE
0107	MISCELLANEOUS
	HELIOSTAT
	PROTECT ENCL
	LIGHTNING PROT
	PACK & TRANSP
	DESIGN
	SUSTAINING ENGR.
0108	FIELD INSTALLATION
	HELIOSTAT
	HELIOSTAT
	SENSOR/CALIB EQ
	ELECTRICAL/DISTRIB
	RECEIVER
	TRANSPORTATION
	INSTALLATION
	TOWER
	SUBASSY ON GRND
	ERECTION IN AIR
	TOWER BASE
	PIERS AND BEAMS
	DEADMAN
	REBAR
0109	FIELD SUPPORT/SUPERVISION
0110	ALIGN HELIOSTATS/CHECKOUT
02	POWER CONVERSION SUBSYSTEM
0201	TURB & GRBX
0202	ELEC GENERATOR
0203	HEAT EXCHANGERS, BOILERS, CONDENSERS
	CONDENSER
	DEAERATOR
	HEATER 1
	HEATER 2
	HEATER 3
	HEATER 4
	COND STRG TANK
	WATER TRTMT EQ
	STEAM GENERATOR

TABLE A7

"TABLE E-2" COST BREAKDOWN STRUCTURE

0204	CONTROL VALVES, LOCAL CONTROL ELEMENTS & PIPING	
		PIPING
		INSTR AND CNTRLS
0205	PUMPS AND FANS	
		CIRC WATER PUMP
		COND EXHAUST PUMP
		COND TRFR PUMP
		SG FEED PUMP
		CONDENSATE PUMP
0206	HEAT REJECTION EQ	
		COOLING TOWER
		EVAP POND
0207	BUILDINGS AND FACILITIES	
		FOUNDATION
		SITE PREP
		STRUCTURE
		EVAP COOLER ASSY
		AIR INTAKE LOUVER
		SUPPLY AIR DUCT
		EXHT AIR LOUVERS
		HEAT PUMP 1
		DUCTWORK ETC
		HEAT PUMP 2
		HEAT PUMP 3
		ELEC UNIT HTR5KW
		ELEC UNIT HTR7.5W
		ELEC UNIT HTR10KW
		EXHAUST FAN 1
		EXHAUST FAN 2
		ELEC UNT HTR
0208	SWITCH GEAR, TRANSFORMERS, ETC.	
		MCS FEEDER BRKR
		SIZE 1 FVNR
		SIZE 2 FVNR
		SIZE 3 FVNR
		MOLDED CS BRKR
		METAL CLAD SWGR
		DIESEL GENERATOR
		AUX XFMR
		DISTRIB XFMR
		HELIO XFMR
		BATTERY
		CHARGER
		INVERTER
		SURGE PROTECTION
		LIGHTING
		CABLES
		TRAYS AND CONDUIT

TABLE A7

"TABLE E-2" COST BREAKDOWN STRUCTURE

0211	FIELD INSTALLATION
	TURB & GRBX
	COOLING TOWER
	CIRC WATER PUMP
	CONDENSER
	COND EXHAUST PUMP
	DEAERATOR
	HEATER 1
	HEATER 2
	HEATER 3
	HEATER 4
	COND TRFR PUMP
	SG FEED PUMP
	CONDENSATE PUMP
	COND STRG TANK
	PIPING
	INSTR AND CNTRLS
	WATER TRTMT EQ
	ELEC PLT LABOR
	STEAM GENERATOR
0212	FIELD SUPERVISION
0213	SUBSYSTEM CHECKOUT/ADJUSTMENT
03	ENERGY TRANSPORT SUBSYSTEM
0301	ENERGY TRANSPORT - THERMAL
	PIPING
	PIPING (RISER, DOWNCOMER)
	EXPANSION (RISER, DOWNCOMER)
	PIPING (THER. STRG.)
030102	INSULATION
	INSULATION (RECEIVER LOOP)
	TR HEAT/CONTROLLRS (RECEIVER LOOP)
	INSULATION (ST. GENERATOR LOOP)
	TR HEAT/CONTROLLRS (ST. GENERATOR LOOP)
030103	CONTROL VALVES AND LOCAL CONTROL ELEMENTS
	VALVES (RECEIVER FEED)
	VALVES (ST. GENERATOR FEED)
030104	FLUID PUMPS AND DRIVES
	PUMPS (RECEIVER FEED)
	PUMPS (ST. GENERATOR FEED)
030105	SITE PREPARATION, FOUNDATIONS, AND PIPING SUPPORT ELEMENTS
	SUPPORTS
030107	FIELD INSTALLATION
	PIPING (RISER, DOWNCOMER)
	INSULATION (RISER, DOWNCOMER)

TABLE A7

"TABLE E-2" COST BREAKDOWN STRUCTURE

	TR HEAT/CONTROLLRS (RISER, DOWNCOMER)
	VALVES "
	PUMP "
	PIPING (THERMAL STORAGE)
	INSULATION (THERMAL STORAGE)
	TR HEAT/CONTROLLRS "
	VALVES "
	PUMP "
030108	FIELD SUPERVISION
030108	SUBSYSTEM CHECKOUT/ADJUSTMENT
04	ENERGY STORAGE SUBSYSTEM
0401	TANKS, INSULATION, STORAGE MEDIUM
	STAINLESS STL TNK
	CARBON STL TANK
	MANIFOLDS
	INSULATION
	IMMERSION HTRS
	NITROGEN & TANKS
	REGULATOR
	CHECK VALUE
	RELIEF VALVE
	MANIFOLD
	FILTERS
	CONTROL VALVE
0403	HEAT TRANSFER FLUID
	HITEC
	IRON ORE
0404	PUMPS, VALVES, PIPING, ETC.
0406	SITE PREPARATION/FOUNDATION
0408	FIELD INSTALLATION
	STAINLESS STL TNK
	CARBON STL TANK
	IMMERSION HTRS
	HITEC
0409	FIELD SUPERVISION
0410	SUBSYSTEM CHECKOUT/ADJUSTMENT

TABLE A7

"TABLE E-2" COST BREAKDOWN STRUCTURE

05	CONTROL SUBSYSTEM
0501	CONTROL SOFTWARE
	SYSTEMS SOFTWARE
	APPLICATIONS SFTWR
	DOCUMENTATION
	SFTWR DEVLPMT/SPEC
0502	PROCESSORS/COMPUTERS
	HELIO-ARRAY-CONTROLR
	CLASSIC PROCESSOR
	BATTERY BACK UP
	DISK SUBSYST/CNTRL
	I/O CABLE, 10FT.
	150 CPS PRINTER
	PRINTER CABLE
	16 CHNL ASYNG CNTL
	HS. LINK
	LINK CABLE
	INTERNAL TIMER
	CABLE-INTERPROCSSR
	MAX III OPER SYST
	DOCUMENTATION
	CABINET
	INSTALLATION (SUB)
	CRT WITH KEYBOARD
	CRT CABLE
0503	SYS CNTRL ELEMNTS FOR PLANT OPERATION
	PROGRMMR/KYBRD/DSP
	CENTRL CONTRL UNIT
	POWER SUPPLY
	TIMR/COUNTR/ACCESS
	SIMULATOR
	PRIMARY MASTER
	MASTER SYNCH
	INTERFACE MODULE
	CNTRL PANELS/BRDS
0504	SUBSYS OPERATION CONTROL ELEMENTS
	LOOP ACCESS MODS
	MOUNTING BASE
	8 CHNL I/O INTERFC
	16 CHNL OUTPT INTF
	I/O EXPANDER
	MOUNTING BASE
	4-20MA INPUT MODS
	REMOTE CNTRL UNITS
	DESCRETE INPT MODS
	DESCRETE OUTPT MOD

TABLE A7

"TABLE E-2" COST BREAKDOWN STRUCTURE

0505	CNTRL LINES TO SUBSYSTS AND PLANT CNTRL ELEMENTS	
		CABLE-2500 FT
		PWR SPLY-CNTRL CNL
		PRGRMR-CNTRL CNTRL
		TIMR COUNTR-PWR SP
		CABLE-MB,SIM,I/O X
		LOOP ACCESS MODULE
		PWR SPLY-MOUNT BAS
		LOOP ACCESS MODULE
		LOOP ACCESS MODULE
0507	MISCELLANEOUS (HDWR DESIGN/ENGR)	
		REQUIREMENTS DEFN
		PLANT SIZING
		SYS ANAL/SIMULAT
		DRAWNGS/SPECS/MODS
		PROCUREMENT DEFN
		CNTRL SYS MGMT
0508	FIELD INSTALLATION	
0509	FIELD SUPERVISION	
0510	SUBSYST CHECKOUT/ADJUSTMENT	
06	DETAIL DESIGN	
07	PLANT CONSTRUCTION MANAGEMENT	
		HEADQUARTERS EXP
		ENG. CLERICAL SAL
		CONSULT & SERV
		COMPUTER
		SCHEDULING
		PURCH & EXPED
		ESTIMATING
		ACCOUNTING
		COMM & REPRO
		OVERHEAD
		FED & STATE TAX
08	SPECIAL FEATURES	
		LAND & RIGHTS
		GRADING, GEN EXC
		ROADS, FENCES & LIGHT
		SANITARY SEWER SY
		YARD & STORM DRAIN
		WATERFRONT IMPROVE
		ROADS TO PUB ROAD
		RAILWAY ACCESS
		WATERWAY ACCESS
		AIR ACCESS FACIL
		CTR FIELD OFF P&S

TABLE A7

"TABLE E-2" COST BREAKDOWN STRUCTURE

08 SPECIAL FEATURES (continued)

INSURANCE
TEMP CONSTR FACIL
TEMP CONSTR EQ
CONSTR SERVICES
FED & STATE TAX
FOREIGN DUTIES/TAX
INITIAL SPARES
CONDENSATE PUMP
PIPING
INSTR AND CNTRLS
POWER CABLES
CONTROL CABLES
HELIO CONTROLLER
FIELD CONTROLLER
MOTORS
HARMONIC DRIVE
LINERAR ACTUATOR
OPTICAL ENCOD, A3
OPTICAL ENCOD, EL
MIRROR MODULE
STOR MOTOR
STOR LIN ACT
FIELD CTL CABLE
FIELD PWR CABLES
AZ LIM SW
EL&STOW LIM SW
CIRBRKR & SW
HAC/FIELD CLT CAB
HAC/FIELD PWR CAB
STATION SERV EQ
INSTRUMENTS
REC VALVES
DOOR MOTOR
DOOR GBOX
SENSORS
HEATERS, IMER
VALVES
VALVES R
PUMPS
SENSORS
HEATERS, TRACE
CONSTR SUPPORT, A&E
STARTUP& C/O
CONTINGENCY
ESCALATION
INT. DUR CONSTR

TABLE A7

"TABLE E-2" COST BREAKDOWN STRUCTURE

09	RELATED ITEMS	
		DESIGN/ENGINEERING
		PRE PROD UNIT
		SITE ACTIVATION
		ELEVATOR (RECEIVER TOWR)
		SOLAR INTEGRATOR
		PROJECT MGMT
		SYSTEM ENGR
		SUB CTRS SERVICE
		SUST ENGR
		EQUIP INTEG
10	OTHER (BUILDINGS AND OTHER UTILITIES TO SUPPORT SYSTEM FUNCTIONS)	
		TRANS & LIFT EQ
		CRANES, HOISTS, ETS
		VEHICLE MAINT EQ
		RECEIVER EQ
		COLLECTOR EQUIP
		THERMAL STORAGE
		AIR SYSTEM
		WATER SYSTEM
		FURNISH & FIXTURE
		COMMUNICATION EQ
		OTHER
11	TESTING AND EVALUATION	
		OPERATIONS AND MAINTENANCE
		SITE (MAINTENANCE LABOR)
		BUILDINGS (MAINTENANCE LABOR)
		MISCELL EQUIPMT (MAINT. LABOR)
		TURBINE PLT E (MAINT. LABOR)
		TURBINE PLT EQ (SPARES AND REPAIR PARTS)
		CONDENSATE PUMP "
		PIPING "
		INSTR AND CNTRLS "
		ELECTRIC PLT E (MAINT. LABOR)
		ELECTRIC PLT EQ (SPARES AND REPAIR PARTS)
		STATION SERV EQ "
		HELIOSTAT EQUIP (MAINT. LABOR)
		MIRROR MODULE (SPARES AND REPAIR PARTS)
		HARMONIC DRIVE "
		LINEAR ACTUATOR "
		STOR LIN ACT "
		MOTORS "
		STOR MOTOR "
		OPTICAL ENCOD, A3 "
		OPTICAL ENCOD, EL "
		AZ LIM SW "
		EL&STOW LIM SW "
		POWER CABLES "

TABLE A7

"TABLE E-2" COST BREAKDOWN STRUCTURE

11	TESTING AND EVALUATION (continued)	
	FIELD POWER CABLES	(SPARES AND REPAIR PARTS)
	CIRBRKR & SW	"
	HAC/FIELD PWR CAB	"
	FIELD CONTROLLER	"
	CONTROL CABLES	"
	HELIO CONTROLLER	"
	FIELD CTL CABLE	"
	HAC/FIELD CLT CAB	"
	RECEIVER UNIT	(MAINT. LABOR)
	REC VALVES	(SPARES AND REPAIR PARTS)
	INSTRUMENTS	"
	DOOR MOTOR	"
	DOOR GBOX	"
	HEATERS, TRACE	"
	VALVES R	"
	PUMPS	"
	TOWER (MAINT. LABOR)	
	THERMAL STRG EQ (MAINT. LABOR)	
	HEATERS, IMER	(SPARES AND REPAIR PARTS)
	VALVES	"
	OPERATORS	
	TEST SUPPORT	
	MATERIALS - CONSUMABLES	

Table A8

ADVANCED CENTRAL RECEIVER COST BREAKDOWN

41.	SITE,STRUC,MISC E		
4101.	SITE		
410101.	LAND & RIGHTS	08	
41010101.	LAND & SURVEY		
41010102.	EASMENT & R-O-W		
41010103.	CLEARING & DEMOLIT		
410102.	YARD WORK		
41010201.	GRADING,GEN EXC	08	
41010202.	ROADS,FENCES&LIGHT	08	
4101020201.	ROADS		
4101020202.	SIDEWALKS		
4101020203.	PARKING		
4101020204.	RET WALL,BRIDGES		
4101020205.	FENCES AND GATES		
4101020206.	YARD LIGHTING		
41010203.	SANITARY SEWER SY	08	
4101020301.	CONNECTIONS TO SYS		
4101020302.	SEPTIC TANK		
4101020303.	DISTRIB BOX		
4101020304.	TILE FIELD(DRNS)		
4101020305.	PIPING,ETC		
41010204.	YARD & STORM DRAIN	08	
41010205.	WATERFRONT IMPROVE	08	
41010206.	ROADS TO PUB ROAD	08	
41010207.	RAILWAY ACCESS	08	
41010208.	WATERWAY ACCESS	08	
41010209.	AIR ACCESS FACIL	08	
4102.	BUILDINGS		
410201.	TURBINE BLDG		
41020101.	FOUND/SITE PREP		
4102010101.	FOUNDATION	0207	0211
4102010102.	SITE PREP	0207	
41020102.	STRUCTURE	0207	0211
41020103.	HVAC		
4102010301.	OPEN AREA C&V SYS		
410201030101.	EVAP COOLER ASSY	0207	
410201030102.	AIR INTAKE LOUVER	0207	
410201030103.	SUPPLY AIR DUCT	0207	
410201030104.	EXHT AIR LOUVERS	0207	
4102010302.	AC FOR OFFICES		
410201030201.	HEAT PUMP1	0207	
410201030202.	DUCTWORK ETC	0207	
410201030203.	HEAT PUMP2	0207	
410201030204.	HEAT PUMP3	0207	
4102010303.	OPEN AIR HEATING		
410201030301.	ELEC UNIT HTR5KW	0207	
410201030302.	ELEC UNIT HTR7.5KW	0207	
410201030303.	ELEC UNIT HTR10KW	0207	
4102010304.	MISC FANS & HTRS		
410201030401.	EXHAUST FAN1	0207	

Table A8

ADVANCED CENTRAL RECEIVER COST BREAKDOWN

410201030402.	EXHAUST FAN2	0207
410201030403.	ELEC UNT HTR	0207
410202.	ADMIN BLDGS	
410203.	WRHS/MTN BDG	
410204.	CONTROL BLDG	
4103.	MISCELL EQUIPMT	
410301.	TRANS&LIFT EQ	10
41030101.	CRANES,HOISTS,ETS	
4103010101.	TURB BLDG CRANE	
4103010102.	OTHER HOISTS	
41030102.	RAILWAY EQ	
41030103.	ROADWAY EQ	
41030104.	WATERCRAFT	
41030105.	VEHICLE MAINT EQ	
41030106.	RECEIVER EQ	
4103010601.	SCAFOLDING	
4103010602.	MISCL EQ	
41030107.	COLLECTOR EQUIP	
4103010701.	SERVICE LINK	
4103010702.	PANEL LIFT SLING	
4103010703.	FORKLIFT	
4103010704.	WASHING VEHICLE	
4103010705.	PICKUP TRUCK	
41030108.	THERMAL STORAGE	
4103010801.	ACCESS EQ	
410302.	COMMUNICATION EQ	10
41030201.	LOCAL COM SYS	
41030202.	SIGNAL/ALARM SYS	
410303.	OTHER	10
41030301.	AIR SYSTEM	
4103030101.	COMPRESSED AIR	
4103030102.	SUBATMOSPHERE AIR	
41030302.	WATER SYSTEM	
4103030201.	WATER SUPPLY PUMP	
4103030202.	FIRE PUMPS,DRIVES	
4103030203.	WATER CONDITN SY	
4103030204.	STOR TANKS/RES	
4103030205.	STATION SERV PUMPS	
4103030206.	DOMEST WATER TREAT	
4103030207.	DOMEST WATER PUMPS	
4103030208.	WATER HEATING EQ	
4103030209.	WATER DIST SYS	
41030303.	FURNISH&FIXTURE	
4103030301.	SAFETY EQ-FIRE,FA	
4103030302.	SHOP,LAB&TEST EQ	
4103030303.	OFFICE EQ & FURN	
4103030304.	ENVIRN MONITOR EQ	
4103030305.	DINING FACIL	
4103030306.	CLEANING EQ	
4103030307.	WELDING EQUIP	

Table A8

ADVANCED CENTRAL RECEIVER COST BREAKDOWN

4103030308.	TME OF DAY REF		
4103030309.	PEDESTAL LEV.FIXT		
4103030310.	PORTABLE CTRL UNIT		
42.	TURBINE PLT E		
4201.	TURBINE GEN E		
420101.	TURB & GRBX	0201	0211
420102.	ELEC GENERATOR	0202	
4202.	HEAR REJECTION E		
420201.	COOLING TOWER	0206	0211
420202.	EVAP POND	0206	
420203.	CIRC WATER PUMP	0205	0211
4203.	CONDENSING SYS E		
420301.	CONDENSER	0203	0211
420302.	COND EXHAUST PUMP	0205	0211
4204.	FEED HEATER E		
420401.	DEAERATOR	0203	0211
420402.	HEATER 1	0203	0211
420403.	HEATER 2	0203	0211
420404.	HEATER 3	0203	0211
420405.	HEATER 4	0203	0211
4205.	WATER CIRC/TRT E		
420501.	COND TRFR PUMP	0205	0211
420502.	SG FEED PUMP	0205	0211
420503.	CONDENSATE PUMP	0205	0211
420504.	COND STRG TANK	0203	0211
420505.	PIPING	0204	0211
420506.	INSTR AND CNTRLS	0204	0211
420507.	WATER TRTMT EQ	0203	0211
43.	ELECTRIC PLT E		
4301.	SWITCHGEAR EQ		
430101.	ELEC PLT LABOR	0211	
430102.	M CS FEEDER BRKR	0208	
430103.	SIZE 1 FVNR	0208	
430104.	SIZE 2 FVNR	0208	
430105.	SIZE 3 FVNR	0208	
430106.	MOLDED CS BRKR	0208	
430107.	METAL CLAD SWGR	0208	
4302.	STATION SERV E		
430201.	DIESEL GENERATOR	0208	
430202.	AUX XFMR	0208	
430203.	DISTRIB XFMR	0208	
430204.	HELIO XFMR	0208	
430205.	BATTERY	0208	
430206.	CHARGER	0208	
430207.	INVERTER	0208	
4303.	PROTECTION EQ		
430301.	SURGE PROTECTION	0208	
430302.	LIGHTING	0208	
4304.	WIRING & ELEC STR		
430401.	CABLES	0208	

Table A8

ADVANCED CENTRAL RECEIVER COST BREAKDOWN

430402.	TRAYS AND CONDUIT	0208
4305.	PLANT CONTROL	
430501.	HARDWARE	
43050101.	COMPUTRS-PERIFRLS	
4305010101.	HELIO-ARRAY-CNTRLR	0502
430501010101.	CLASSIC PROCESSOR	
430501010102.	BATTERY BACK UP	
430501010103.	DISK SUBSYST/CNTRL	
430501010104.	I/O CABLE, 10FT.	
430501010105.	150 CPS PRINTER	
430501010106.	PRINTER CABLE	
430501010107.	16 CHNL ASYNG CNTL	
430501010108.	HS. LINK	
430501010109.	LINK CABLE	
430501010110.	INTERNAL TIMER	
430501010111.	CABLE-INTERPROCSSR	
430501010112.	MAX III OPER SYST	
430501010113.	DOCUMENTATION	
430501010114.	CABINET	
430501010115.	INSTALLATION(SUB)	
430501010116.	CRT WITH KEYBOARD	
430501010117.	CRT CABLE	
43050102.	SYS CNTRL ELEMNTS	0503
4305010201.	PROGRMMR/KYBRD/DSP	
4305010202.	CENTRL CONTRL UNIT	
4305010203.	POWER SUPPLY	
4305010204.	TIMR/COUNTR/ACCESS	
4305010205.	SIMULATOR	
4305010206.	PRIMARY MASTER	
4305010207.	MASTER SYNCH	
4305010208.	INTERFACE MODULE	
43050103.	SUBSYS OP CNTRL EL	0504
4305010301.	LOOP ACCESS MODS	
4305010302.	MOUNTING BASE	
4305010303.	8 CHNL I/O INTERFC	
4305010304.	16 CHNL INPT INTRF	
4305010305.	16 CHNL OUTPT INTF	
4305010306.	I/O EXPANDER	
4305010307.	MOUNTING BASE	
4305010308.	4-20MA INPUT MODS	
4305010309.	REMOTE CNTRL UNITS	
4305010310.	DESCRETE INPT MODS	
4305010311.	DESCRETE OUTPT MOD	
43050104.	CNTRL PANELS/BRDS	0503
4305010401.	CONTROL CONSOLE	
43050105.	CNTRL LINES/CABLES	0505
4305010501.	CABLE-2500 FT	
4305010502.	PWR SPLY-CNTRL CNL	
4305010503.	PRGRMR-CNTRL CNTRL	
4305010504.	TIMR COUNTR-PWR SP	

Table A8

ADVANCED CENTRAL RECEIVER COST BREAKDOWN

4305010505.	CABLE-MB,SIM,I/O X	
4305010506.	LOOP ACCESS MODULE	
4305010507.	PWR SPLY-MOUNT BAS	
4305010508.	LOOP ACCESS MODULE	
4305010509.	LOOP ACCESS MODULE	
43050107.	FIELD INSTALLATION	0508
43050108.	FIELD SUPERVISION	0509
43050109.	SUBSYST C/O ADJUST	0510
430502.	HDWR DESIGN/ENGR	
43050201.	REQUIREMNTS DEFN	0507
43050202.	PLANT SIZING	0507
43050203.	SYS ANAL/SIMULAT	0507
43050204.	DRAWNGS/SPECS/MODS	0507
43050205.	PROCUREMENT DEFN	0507
43050206.	CNTRL SYS MGMT	0507
430503.	CONTROL SOFTWARE	
43050301.	SYSTEMS SOFTWARE	0501
43050302.	APPLICATIONS SFTWR	0501
43050303.	DOCUMENTATION	0501
43050304.	SFTWR DEVLPMT/SPEC	0501
44.	HELIOSTAT EQUIP	
4401.	REFLECTIVE UNIT	0103
440101.	REFLECTIVE SURFACE	
44010120.	MIRROR MODULE	
440102.	MIRROR BACK STRUCT	
440103.	ASSY & BOARD	
4402.	DRIVE UNIT	0104
440201.	AZIMUTH	
44020116.	HARMONIC DRIVE	
440202.	ELEVATION	
44020217.	LINEAR ACTUATOR	
44020222.	STOR LIN ACT	
440203.	MOTORS	
44020315.	MOTORS	
44020321.	STOR MOTOR	
440204.	POS/LIMIT INDICAT	
44020418.	OPTICAL ENCOD,A3	
44020419.	OPTICAL ENCOD,EL	
44020425.	AZ LIM SW	
44020426.	EL&STOW LIM SW	
440205.	POWER SPLY/DIST	
44020511.	POWER CABLES	
44020524.	FIELD PWR CABLES	
44020527.	CIRBRKR & SW	
44020529.	HAC/FIELD PWR CAB	
440206.	ASSYDR/PED/ELECT	
4403.	CONTROL/INSTRMTEQ	0104
440301.	SENSOR/CCALIB EQ	
440302.	FIELD CONTROL	
44030214.	FIELD CONTROLLER	

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ADVANCED CENTRAL RECEIVER COST BREAKDOWN

440303.	CONTROL/SIG EQ	
44030312.	CONTROL CABLES	
44030313.	HELIO CONTROLLER	
44030323.	FIELD CTL CABLE	
44030328.	HAC/FIELD CLT CAB	
440304.	HELIO ARRAY CTRL	
4404.	FOUND/SITE PREP	0101
440401.	FOUNDATION	
440402.	SITE PREPARATION	
4405.	HELIO SUPP STR/PE	
440501.	HELIO SUPP STRUCT	0102
440502.	PROTECT ENCL	0107
440503.	LIGHTNING PROT	0107
4406.	FIELD ASSY & C/O	
440601.	HELIOSTAT	0108
440602.	SENSOR/CALIB EQ	0108
440603.	ELECTRICAL/DISTRIB	0108
440604.	ALIGN HELIOSTATS	0110
440605.	FIELD SUPPORT	0109
440606.	PARK & TRANSP	0107
4407.	DESIGN/ENGINEER'G	
440701.	DESIGN	0107
440702.	SUSTAINING ENGR	0107
440703.	PRE PROD UNIT	09
440704.	SITE ACTIVATION	09
45.	RECEIVER EQ	
4501.	RECEIVER UNIT	
450101.	ABSORBER UNIT	
45010101.	ASSY & CO	0105
45010102.	ABSORBER COIL	
4501010201.	TUBE	0105
4501010202.	X-RAY	0105
45010103.	INSULATION	0105
45010104.	APEX MANIFOLD	0105
45010105.	TRACE HEATING	0105
450102.	SUPPORT STRUC	
45010201.	ASSY & CO	0105
45010202.	STRUC STEEL	0105
45010203.	ABSORBER COVER	0105
45010204.	OUTSIDE COVER	0105
45010205.	STEEL FLOOR	0105
450103.	REC CIRCL EQ	
45010301.	ASSY & CO	0106
45010302.	REC PIPING E	
4501030201.	DISTRIB MANIFOLD	0106
4501030202.	INSULATION-PIPE	0106
4501030203.	PIPING	0106
45010303.	REC VALVES	
4501030301.	VENT VALVE	0106
4501030302.	RELIEF VALVE	0106

Table A8

ADVANCED CENTRAL RECEIVER COST BREAKDOWN

450104.	INSTR & CNTRLS		
45010401.	INSTRUMENTS	0104	
45010402.	GEARS & BEARINGS	0104	
4501040210.	DOOR MOTOR		
4501040211.	DOOR GBOX		
450105.	TRANSP,FIELD INSTL		
45010501.	TRANSPORTATION	0108	
45010502.	INSTALLATION	0108	
4502.	RIS/DWN/HORIZ PIPE		
450201.	PIPING	030101	030107
45020101.	PIPING/CARBON STL		
45020102.	PIPING/STAIN STL		
450202.	INSULATION		
45020201.	INSULATION	030102	030107
45020202.	TR HEAT/CONTROLLRS	030102	030107
4502020215.	SENSORS		
4502020216.	HEATERS,TRACE		
450203.	VALVES	030103	030107
45020301.	DRAG VALVE		
45020303.	REMOTE-ON-OFF		
450204.	PUMP	030104	030107
450205.	SUPPORTS	030105	
450206.	EXPANSION	030101	
4504.	TOWER		
450401.	STL TOWER ERECT		
45040101.	SUBASSY ON GRND	0105	0108
45040102.	ERECTION IN AIR	0105	0108
450402.	STRUCTURAL STEEL	0105	
450403.	GUY WIRES		
45040301.	BRIDGE CABLES	0105	
45040302.	CLEVIS AND CLAMPS	0105	
450404.	TOWER ACCESSORIES		
45040401.	PLATFORMS	0105	
45040402.	LIGHTING	0105	
45040403.	ELEVATOR	09	
45040404.	OBSTRUCTION LIGHT	0105	
45040405.	SAFETY LADDER	0105	
45040406.	LIGHTNING PROTEC	0105	
4505.	FOUND/SITE PREP		
450501.	FOUNDATION		
45050101.	TOWER BASE	0101	0108
45050102.	PIERS AND BEAMS	0101	0108
45050103.	DEADMAN	0101	0108
45050104.	REBAR	0101	0108
450502.	SITE PREP		
45050201.	EXCAVATION	0101	
45050202.	BACKFILL	0101	
46.	THERMAL STRG EQ		
4601.	MEDIA CONTNMT E		
460101.	STORAGE TANKS		

Table A8

ADVANCED CENTRAL RECEIVER COST BREAKDOWN

46010101.	STAINLESS STL TNK	0401	0408
46010102.	CARBON STL TANK	0401	0408
460102.	MANIFOLDS	0401	
460103.	INSULATION	0401	0408
460104.	IMMERSION HTRS	0401	0408
460105.	GN2 SYSTEM		
46010501.	NITROGEN & TANKS	0401	
46010502.	REGULATOR	0401	
46010503.	CHECK VALUE	0401	
46010504.	RELIEF VALVE	0401	
46010505.	MANIFOLD	0401	
46010506.	FILTERS	0401	
46010508.	CONTROL VALVE	0401	
4602.	MEDIA CIRC EQ	0404	
4603.	WRK FLUID CIRC EQ		
460301.	PIPING	030101	030107
46030101.	PIPING/CARBON STL		
46030102.	PIPING/STAIN STL		
460302.	INSULATION		
46030201.	INSULATION	030102	030107
46030202.	TR HEAT/CONTROLLRS	030102	030107
4603020210.	SENSORS		
4603020211.	HEATERS,IMER		
460303.	VALVES	030103	030107
46030302.	REMOTE-FL CONTROL		
46030303.	REMOTE-ON-OFF		
46030304.	MANUAL-ON-OFF		
46030305.	VALVE INSTALLATION		
460304.	PUMP	030104	030107
4604.	DISCHRG HEAT EXC		
460401.	STEAM GENERATOR	0203	0211
4606.	FOUNDATION/SITE P	0406	
4608.	MEDIA		
460801.	HITEC	0403	0408
460802.	IRON ORE	0403	
48.	DISTRIB & INDIR		
4801.	TEMPORARY EXPNSE		
480101.	CTR FIELD OFF P&S	08	
48010101.	SUPPORT OF CONSTR		
48010102.	CONSTR SUPER		
48010103.	ENGINNERING STAFF		
48010104.	ACCOUNTING STAFF		
48010105.	OTHER STAFF		
48010106.	OFFICES SUPPLIES		
48010107.	FURN,RENT,REPRO		
48010108.	MEDICAL,F.AID		
480102.	INSURANCE	08	
48010201.	LIAB,SITE INSUR		
48010202.	EQUIP, AUTO INSUR		
480103.	TEMP CONSTR FACIL	08	

Table A8

ADVANCED CENTRAL RECEIVER COST BREAKDOWN

48010301.	SITE ACCESS/IMPR	
48010302.	BUILD & STRUCT	
4801030201.	FIELD OFFICES	
4801030202.	WAREHOUSE,STOR	
4801030203.	MAINT SHOPS	
4801030204.	GUARD HOUSE/FENCE	
4801030205.	HOUSING	
4801030206.	OTHER	
48010303.	ELECT & WATER	
48010304.	COMMUNICATION EQ	
48010305.	AGGREGATE PLANT	
48010306.	CONCRETE BATCH PLT	
480104.	TEMP CONSTR EQ	08
48010401.	TRANS,LIFT,UNLOAD	
48010402.	WELDING EQ	
48010403.	AIR COMPRESSORS	
48010404.	STEAM GENERATORS	
48010405.	CHEM CLEAN FACIL	
48010406.	SCAFFLODS & ACCESS	
48010407.	BUILD FURN & FIXT	
48010408.	SIGNS,TOOLS,MISCL	
480105.	CONSTR SERVICES	08
48010501.	PURCH UTIL	
4801050101.	ELECT POWER	
4801050102.	WATER	
4801050103.	SEWAGE DISP	
4801050104.	STEAM	
4801050105.	COMPRESSED AIR	
4801050106.	FUEL	
4801050107.	TELE,TELEX,ETC	
4801050108.	REFUSE & WATER	
48010502.	SECURITY	
48010503.	EDUCAT & TRAIN	
48010504.	COMMON REC & STOR	
48010505.	SITE CLEANUP	
48010506.	O & M FACIL & EQ	
48010507.	SNOW REMOVAL	
48010508.	INSP&TEST OF MATS	
480106.	FED & STATE TAX	08
480107.	FOREIGN DUTIES/TAX	08
4802.	INITIAL SPARES	
480201.	TURBINE PLANT	
48020111.	CONDENSATE PUMP	08
48020112.	PIPING	08
48020113.	INSTR AND CNTRLS	08
480202.	COLLECTOR	
48020211.	POWER CABLES	08
48020212.	CONTROL CABLES	08
48020213.	HELIO CONTROLLER	08
48020214.	FIELD CONTROLLER	08

Table A8

ADVANCED CENTRAL RECEIVER COST BREAKDOWN

48020215.	MOTORS	08
48020216.	HARMONIC DRIVE	08
48020217.	LINEAR ACTUATOR	08
48020218.	OPTICAL ENCOD,A3	08
48020219.	OPTICAL ENCOD,EL	08
48020220.	MIRROR MODULE	08
48020221.	STOR MOTOR	08
48020222.	STOR LIN ACT	08
48020223.	FIELD CTL CABLE	08
48020224.	FIELD PWR CABLES	08
48020225.	AZ LIM SW	08
48020226.	EL&STOW LIM SW	08
48020227.	CIRBRKR & SW	08
48020228.	HAC/FIELD CLT CAB	08
48020229.	HAC/FIELD PWR CAB	08
480203.	ELECT PLANT	
48020311.	STATION SERV EQ	08
480204.	RECEIVER	
48020401.	INSTRUMENTS	08
48020403.	REC VALVES	08
48020410.	DOOR MOTOR	08
48020411.	DOOR GBOX	08
480205.	THERMAL STOR	
48020510.	SENSORS	08
48020511.	HEATERS,IMER	08
48020512.	VALVES	08
48020513.	VALVES R	08
48020514.	PUMPS	08
48020515.	SENSORS	08
48020516.	HEATERS,TRACE	08
4803.	A & E	
480301.	PRELIM DESIGN	06
480302.	DETAIL DESIGN	06
480303.	CONSTR SUPPORT	08
4804.	CONSTR MGMT	
480401.	DESIGN SUPP	06
480402.	CONSTR SUPPORT	07
48040201.	HEADQUARTERS EXP	
4804020101.	ENG,CLERICLA SAL	
4804020102.	CONSULT & SERV	
4804020103.	COMPUTER	
4804020104.	SCHEDULING	
4804020105.	PURCH & EXPED	
4804020106.	ESTIMATING	
4804020107.	ACCOUNTING	
4804020108.	COMM & REPRO	
48040202.	OVERHEAD	
48040203.	FED & STATE TAX	
4805.	STARTUP & C/O	08
4806.	SOLAR INTEGRATOR	4860

Table A8

ADVANCED CENTRAL RECEIVER COST BREAKDOWN

480601.	PROJECT MGMT	09
480602.	SYSTEM ENGR	09
480603.	SUBCTRS SERVICE	09
480604.	SUST ENGR	09
480605.	EQUIP INTEG FEE	09
4807.	CONTINGENCY	08
4808.	ESCALLATION	08
4809.	INT. DUR CONSTR	08
49.	OPERATION&MAINT	4900
4901.	OPERATIONS	4910
490101.	OPERATORS	08
490102.	TEST SUPPORT	08
4902.	MATERIALS	08

#

Table A-9

UNIT MATERIAL COSTS - SMALL POWER SYSTEM EXPERIMENT
(Sheet 1 of 6)

Element	Size	Unit	Unit Cost ($)
COLLECTOR SUBSYSTEM			
Receiver			
Plate, low-carbon (LC) steel		lb	0.28
Corrugation, LC steel		lb	0.82
Insulation, fiber glass batting		ft^2	0.36
Pipe, stainless steel (SS) SCH 40	1.0"	ft	4.83
Pipe, Incology 800	1.5"	ft	6.11
Pipe, SS SCH 40	3.0"	ft	15.55
Pipe, 4130 13 ga	2.0"	ft	2.50
Insulation, 3.0 in-thick Sheet SCH 40		ft^2	1.93
Insulation, pipe	3.0"	3-ft 1	9.04
Insulation, pipe	1.0"	3-ft 1	7.39
Insulation, pipe	8.0"	ft	5.77
Insulation, pipe	3.0"	ft	3.21
Insulation, pipe	14.0"	ft	15.66
I-Beams, 3.0-inch		lb	0.20
Gears & Bearings (Motor)		unit	1500.00
Trace Heating	1.5-3.0"	ft/in diam	23.27-28.41
Thermocouplers		unit	30.00
Heliostats			
Sheet, LC steel, galvanized	0.020	lb	0.24
Sheet, LC steel, galvanized	0.063	lb	0.257
Tube	10.0	lb	0.21
Channel, LC steel		lb	0.24
Tube		lb	0.266
Flange, steel		unit	180.00
Casting, Azimuth Drive		lb	0.90
Drive, Azimuth		unit	550.00
Bearing		unit	170.00

Table A- 9

UNIT MATERIAL COSTS - SMALL POWER SYSTEM EXPERIMENT

(Sheet 2 of 6)

Element	Size	Unit	Unit Cost ($)
Drive, Elevation		unit	300.00
Casting, Elevation		lb	0.88
Motor		unit	110.00
Concrete Foundation w/Reinforcements		yd^3	55.00
Tower			
Excavation		yd^3	2.00
Consolidated Backfill		yd^3	2.00
Concrete Foundation, Installed		yd^3	347.00
Structure Steel Tower, Installed		Ton	1,435.00
Guy Wires		ft	3.00
Paint, Applied		Ton	75.00
Service Platforms		ft^2	30.00
Safety Ladder		vert ft	33.00
Elevator		unit	78,544.00
Obstruction Lights		unit	16,000.00
Lightning Protection		unit	15,000.00
Lighting		per 12 ft	$225.00
ENERGY STORAGE SUBSYSTEM			
Immersion Heater		unit	3,617.00
GN_2 System			
Nitrogen		per tank	15.00
Regulator		unit	75.00
Check Valve		unit	25.00
Relief Valve		unit	125.00
Manifold		unit	387.00
Filters		unit	12.00
Hand Valve		unit	43.00
Control Valve		unit	65.00

Table A-9

UNIT MATERIAL COSTS - SMALL POWER SYSTEM EXPERIMENT

(Sheet 3 of 6)

Element	Size	Unit	Unit Cost ($)
Manifolds (Tank)			6,500.00
Tank Insulation (Subcontract)			
Hot		ft^3	22.73
Cold		ft^3	17.87
Iron Ore		ton	36.00
Hitec		lb	.36
Syltherm		gal	19.00
Caloria		lb	.13
Medium Transport		lb	.10
Rock & Sand		ton	19.00
Rock Transport		ton	5.00
Tank Insulation		ft^3	51.84
Tanks - LC		(Figure A-1)	
Tanks - SS		(Figure A-2)	
Pressurized Tank (A-285) 600 psi	4,400 ft^3	unit	100,000

Table A-9

UNIT MATERIAL COSTS - SMALL POWER SYSTEM EXPERIMENT

(Sheet 4 of 6)

Element	Size	Unit	Unit Cost ($)
ENERGY TRANSPORT SYSTEM/GENERAL PIPING			
Pipe, Low Carbon Steel SCH 40	2.0"	ft	3.01
Pipe, Low Carbon Steel SCH 40	2.5"	ft	3.01
Pipe, Low Carbon Steel SCH 40	3.0"	ft	3.83
Pipe, Stainless Steel	2.0"	ft	19.18
Pipe, Stainless Steel	2.5"	ft	19.18
Pipe, Stainless Steel	3.0"	ft	25.77
Trace Heating. Elec Resist Elements			
220°FΔ-270°FΔ	2.0-3.0"	ft	6.09
Piping Insulation, 4.0-in thick			
	2.0"	ft	39.15
	2.5"	ft	39.15
	3.0"	ft	43.15
Valves and Pumps		(Table A-11)	

Table A-9

UNIT MATERIAL COSTS - SMALL POWER SYSTEM EXPERIMENT

(Sheet 5 of 6)

Element	Size	Unit	Unit Cost ($)
PLANT CONTROL			
Classic Processor			9,500.00
Battery Back Up			450.00
Disk Subsystem/Control			9,800.00
I/O Cable		ft	32.50
Printer			3,870.00
16 Channel Asyng Control			4,020.00
HS. Link			2,060.00
Internal Timer			1,030.00
Cable - Interprocessor			196.00
Max III Oper. Syst.			1,580.00
Cabinet			1,150.00
Installation (Sub)			686.00
CRT with Keyboard			1,950.00
Programmer/Keyboard/Display			1,000.00
Central Control Unit			2,000.00
Power Supply			625.00
Timer/Counter/Access			775.00
Simulator			175.00
Primary Master			275.00
Master Synch			150.00
Interface Module			295.00
Loop Access Mods			875.00
Mounting Base			140.00
I/O Expander			375.00
4-20 MA Input Mods			450.00
Remote Control Units			235.00
Control Console			362.00
Cable		ft	0.25

Table A-9

UNIT MATERIAL COSTS - SMALL POWER SYSTEM EXPERIMENT

(Sheet 6 of 6)

Element	Size	Unit	Unit Cost ($)
CONSUMABLES			
Deionized Water		gal	.05
Cleaning Agent		gal	3.25
Gasoline		gal	.80
Diesel Gasoline		gal	.65
Cooling Tower and Boiler Makeup Water (Ordinary Tap Water)		gal	.0008
Cooling Tower Sulfuric Acid		gal	.75
Cooling Tower Sodium Hypochloride		gal	.70
Hydrazine		lb	5.50
Cooling Tower Scale Inhibitor		lb	3.30
Amine		gal	1.45
HCL		gal	.60
Caustic Soda		lb	.185
Powdered Resin		lb	2.65

Table A-10

POWER CONVERSION UNIT MATERIAL COST

Element	Program 3.5	4.5	6.5
Radial Outflow Turbine Gearbox			73,000
Axial Steam	370,000	370,000	
Generator	31,000	31,000	31,000
Cooling Tower	35,000	35,000	25,000
Circulating Water Pump	5,900	5,900	4,500
Condenser	9,000	9,000	4,000
Condenser Exhaust Pump	11,000	11,000	15,500
Deaerator	23,900	23,900	4,000
LP Heater #1	-	-	1,363
HP Heater #3	-	-	1,830
HP Heater #4	-	-	1,567
HP Heater #5	-	-	1,285
Condenser Transfer Pump	350	350	-
Steam Generator Feed Pump	5,730	17,500	17,500
Condensate Pump	4,800	4,800	11,500
Condensate Storage Tank	3,000	3,000	3,000
Steam Generator	87,500	87,500	87,500
Demineralizer	30,000	30,000	30,000
Condensate Polisher	32,000	32,000	32,000
Boiler Chemical Feed System	25,000	25,000	25,000
Cooling Tower Chem Feed System	18,000	18,000	18,000
Water Treatment Panel	28,000	28,000	28,000
Cooling Tower Control Panel	4,000	4,000	4,000
Iron Ore	ton	36.00	
Tank Insulation (Subcontract)		22.73	
Hot	ft^3	22.73	
Cold	ft^3	17.87	

Table A -11

PUMP & VALVE COSTS

VALVES						
Size, Material	2"CS	2"SS	2.5CS	2.5"SS	3"CS	3"SS
Psi	300	300	300	300	300	300
Remote, Flow Control	$1065	$1501	-	$1596	$1365	-
Remote (On, Off), Act 2-Way	1065	1501	1017	1826	1146	2169
Manual (Gate)	-	-	-	375	389	-
Control (Drag)	-	-	-	37500	-	45000

PUMPS					
Size, Material	2.0"CS	3.0"SS	3.0"SS	2.0"CS	2.5"SS
Flow Rate	196 GPM	127 GPM	104 GPM	105 GPM	69 GPM
Head Rise	(255 FT)	(53 FT)	(54 FT)	(241 FT)	(55 FT)
Oper Temp	500°F	850°F	850°F	550°F	1000°F
In Line	-	-	-	$4,103	$12,309
Submerged	$24,100	$8,328	$8,299	-	-

A.4.3 Applied Factors and Rates

Table A12 indicates the factors that have been applied to basic material and labor dollars in order to arrive at total costs. The factors vary by subsystem depending on the source and nature of the cost inputs. For example, Stearns-Roger estimates already include allowances for field efficiency, visibility and rework in a hot climate so that a contractor's fee and a distributable allocation is all that is necessary. The receiver unit, on the other hand, represents detail estimates so that a full factor load is required. These factors are based on experience for the types of equipment involved.

TABLE A 12

FACTORS APPLIED TO BASE COSTS

ELEMENT	LABOR HOURS PURPOSE	LABOR HOURS RATE	LABOR $ PURPOSE	LABOR $ RATE	MATERIAL $ PURPOSE	MATERIAL $ RATE
Receiver Unit	Plant		Plant		Fee	1.08
	Efficiency	1.25	Fee	1.08	Visibility	1.20
	Visibility	1.20	Rate with O/H	$35.00	Scrap & Rework	1.05
	Rework, shop Lias., In-scope Changes	1.17			Transport	1.05
	Mech. Engr, QC, Sust. tool, & Prod. Supp.	1.45				
	Field		Field			
	Efficiency	1.30	Fee	1.08		
	Visibility	1.20	Base Rate	$15.00		
	Shortages & Weather	1.15	Distributables	1.85		
	QC & Super	1.07				
Heliostat	As published	-	Plant w/Fee and O/H	$35.30	As published	-
			Field Assy. w/Fee & Distrib.	$27.10		
			Install w/Fee & Distrib.	$30.44		

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TABLE A12

FACTORS APPLIED TO BASE COSTS

ELEMENT	LABOR HOURS PURPOSE	LABOR HOURS RATE	LABOR $ PURPOSE	LABOR $ RATE	MATERIAL $ PURPOSE	MATERIAL $ RATE
Energy Storage	Visibility	1.10		-	Visibility	1.10
& Transport	Rework	1.05	Fee	1.08	Scrap & Rework	1.05
	Incremental		Base Rate		Fee	1.08
	fatigue	1.25	Storage	$20.00		
			Transport	$17.83		
			Trace heat	$17.02		
			O/H on S/Ctr.	1.10		
			Distributables	1.85		
Power Conversion	None Required	--	Fee	1.08	Fee	1.08
			Field Rate	$20.00		
			Distributables	**		
Buildings	None Required	--	Fee	1.08	Fee	1.08
			Field Rate	$15.00		
			Distributables	**		
Tower	None Required	--	Fee	1.08	Fee	1.08
			Field Rate	$15.00		
			Distributables	1.85		

** Covered in Distributables and indirects

TABLE A 12

FACTORS APPLIED TO BASE COST

ELEMENT	LABOR HOURS PURPOSE	LABOR HOURS RATE	LABOR $ PURPOSE	LABOR $ RATE	MATERIAL $ PURPOSE	MATERIAL $ RATE
Plant Control	Efficiency	1.25	Fee	1.08	Fee	1.08
	QA, Secretarial		Visibility	1.20	Plant Rate	
	and other support	1.22	Test Components	1.05	W/OH	$40.56
			Transport	1.05	Field Rate	
					W/OH	$25.74
O&M	Efficiency		Discard factor		Field Rate	$15.00
	Field	2.0	Average	.05	W/OH	
	Bench & Wash	1.18	Major Equip.	.02		
			Sensors & Instr.	1.00		
	Refix		Repair Cost Factor			
	Mechanical	1.10	Average	.40		
	Elect.	1.25	Major Equip.	.20		
			Hi-val Comp.			
			Equip.	.50		
Other Engineering	N/A	-	N/A	-	Plant Rate	
					W/Fee & OH	$43.80
Construction Mgr.			Factor on total	.08	Factor on total	.08
A&E			Factor on total	.08	Factor on total	.08