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MONTHLY TECHNICAL PROGRESS REPORT

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FOR THE MONTH OF FEBRUARY 1979

SOLAR CENTRAL RECEIVER HYBRID POWER SYSTEM

ISSUE DATE: MARCH 1979

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EXECUTIVE SUMMARY

The three best regions for marketing a solar hybrid plant were studied. These are: East South Central, Rocky Mountain, and Pacific regions. The "base load" and "intermediate load" markets appear to be approximately 90 giga watts.

The economic analysis made by SRI shows that a coal fired hybrid plant is economically competitive with pure coal plants for fuel escalation rates above 9% per year. For example: at 10% per year escalation the hybrid plant BBEC is 67 mils/Kwh compared to 70.7 mils/Kwh for a typical coal plant.

The optimization studies conducted by McDonnell Douglas on the field geometry, tower height, and receiver dimensions are converging on an optical tower height of 120 m, 7,332 heliostats and a receiver which is 10 m in diameter and 12 m high. One more iteration should fix the optical geometry for the 100 MWe plant with a solar multiple of 0.8.

The preliminary values of the performance and design data sheets for the 100 MWe 0.9 S.M. hybrid base line plant have been prepared.

TASK 1 - REVIEW AND ANALYSIS OF REQUIREMENTS DEFINITION

Complete.

TASK 2 - MARKET ANALYSIS

MARKET SIZE

Forecast Demand

Market size was estimated by a detailed analysis based on previous SRI projections of regional markets for electricity.* These projections were derived from a detailed and regionalized computer analysis of energy supply and demand in the U.S. and the price competition that determines the choice between fuels (or between fuels and electricity).

The analysis emphasized those fuels used in electricity production and those other fuels in competition with electricity. The nationwide electricity growth was projected at 5.3% for the period 1975-1985, and 3.8% for the period 1985-2000. This latter period is of greatest interest for this study, although the lower growth rate of 2.5% predicted by SRI for electricity growth over the period 2000-2022 will also have an impact on the long-term solar hybrid markets.

Examination of the projected regional growth rates in conjunction with solar insolation maps led to a selection of the East South Central, Rocky Mountain and Pacific regions as having the best potential for solar hybrid systems. (Best insolation, best growth.)

The three regional demand (sales) forecasts were subdivided into state demand estimates for 1986, 1989, and 2001 using reported 1976 sales and recent sales trends as guides. The states analyzed were those with growth

*"Fuel and Energy Price Forecasts," EPRI-433. Electric Power Research Institute, Palo Alto, California, 1977

potential and favorable insolation. Line losses (7%) were added to the state sales to obtain generation load requirements. Average capacity factors were estimated for each state. These factors include the reserve margins actually maintained by the utility. These factors as for the state-by-state distribution of regional sales were based on 1976 data and projected forward, using recent trends as guidance. It was assumed in the projection that capacity factors would be improved with the installation of modern equipment selected with the idea of obtaining improved on-line availability and performance as this is now a major utility industry concern. The overall generation allocation for each state was divided into requirements for base, intermediate, and peak load service. By dividing the hours of use for each load type into the proportion of generating capacity, the total capacity required to satisfy the load was derived. The average allocation of capacity was base 50%, intermediate 31%, and peak 19%. These allocations are hypothetical and can only be used as rough guides. A utility will operate its units as base, intermediate, or peak load, depending on need, the unit capability and the direct cost of power. The low cost generation unit (or mix of units) will be preferred by the dispacher.

The study was extended in the same manner to the major utilities in each state selected. The selection again was based on growth and insolation characteristics. The states and utilities selected are shown in Table I. Adjustments to sales were necessary in those utilities cases with sales in more than one state. The individual utility requirements were adjusted for interchange. The sales figures finally used were for sales within the service areas. This excluded sales to other privately owned utilities (thereby removing interchange). Sales to municipally owned organizations were included in the sales base as these generally are sales within the territory, are expected to continue, and are not to organizations with large generating capability. Entitlements, i.e., sales by governmental organizations to preferred customers, were included in available peak capacity, as indicated below. Correction for average line loss experienced by each utility were applied to sales to calculate capacity requirements.

TABLE I

UTILITIES EXAMINED AS POTENTIAL MARKETS FOR HYBRID POWER PLANTS

State	Utilities
Arizona	Arizona Public Service Company
	Salt River Project Agricultural Improvement and Power District
California	Los Angeles Department of Water & Power
	Pacific Gas & Electric Company
	Sacramento Municipal Utility District
	San Diego Gas & Electric Company
	Southern California Edison Company
Colorado	Public Service Company of Colorado
Kansas	Kansas Power & Light Company
Louisiana	Central Louisiana Electric Co., Inc.
	Louisiana Power & Light Company
	New Orleans Public Service, Inc.
	Southwestern Electric Power Company
Nevada	Nevada Power Company
	Sierra Pacific Power Company
New Mexico	Public Service Company of New Mexico
Texas	Central Power & Light Company
	Community Public Service Company
	Dallas Power & Light Company
	El Paso Electric Company
	Gulf States Utilities Company
	Houston Lighting & Power Company
Utah	Utah Power & Light Company

Needed Capacity

Existing capacity by state and utility was obtained from EEI and FERC data. This was corrected for each category: base, intermediate, peak for:

- Announced additions (+)
- Expected retirements (after 30 years) (-)
- Expected transfers from base (-, +) to intermediate (units $<$ 400 MW and $>$ 15-years old).
- Entitlements (+)

The corrected capacity was compared with the expected requirements. Deficits between existing and required capacity are interpreted as the total market available to electric generating equipment.

Typical data for a single utility is shown in Table II. Table III summarizes the various state demands. These data, in this table, are explained below.

In Table III, Column 3 sets out the current generating capacity of utilities considered within each state. The forecast capacity needed for each utility in the Years 1986, 1989, and 2001 is set forth in Columns 4 to 6. The capacity available is the current capacity plus announced additions and entitlements, less expected retirements. This is set forth in Columns 7 to 9. The additional capacity that must be installed to meet the expected load is set forth in Columns 10 and 11. In some cases the existing capacity plus planned additions is surplus to the utilities own needs in the Year 1985 and even in 2001. In these cases, no additional capacity is needed. In cases where there is surplus capacity in 1986 or 1989, but a deficit in 1989 or 2001, respectively, only the deficit portion of the change in capacity need is entered in Columns 10 and 11.

TABLE II

PROJECTED CAPACITY REQUIREMENTS OF A MAJOR UTILITY, GW

	BASE	INTERMEDIATE	PEAK	TOTAL
Installed, 1977	5.6	3.5	1.9	11.0
Required for Load, 1986	9.7	6.1	3.8	19.1
Installed Capacity, 1986[1]	8.1	3.6	7.1	18.1
Additional Capacity Required	1.6	2.5	(3.3)[2]	
Required for Load, 1989	11.1	6.9	4.2	22.0
Installed Capacity, 1989[1]	8.5	3.4	7.1	19.0
Additional Capacity Required	2.6	3.5	(2.9)[2]	---
Required for Load, 2001	17.0	10.6	6.6	3.0
Installed Capacity, 2001[1]	10.9	1.1	7.1	19.0
Additional Capacity Required	6.1	9.5	(0.5)	---
Additions Requirements, 1989-2001	3.5	6.0	---	---

(1) Net of current, announced additions, retirements, and transfers.

(2) Surplus, no additions required.

TABLE III

PROJECTED CAPACITY AND REQUIREMENTS, SUM OF MAJOR UTILITIES, SELECTED STATES, GW

STATE	CURRENT CAPACITY	CAPACITY NEEDED			CAPACITY AVAILABLE (PRESENT PLANS)			ADDITIONAL CAPACITY REQUIRED TOTAL POTENTIAL MARKET	
		1986	1989	2001	1986	1989	2001	1986-1989	1989-2001
Arizona									
Base	3.5	4.2	4.7	7.2	6.7	7.9	8.9		None
Intermediate	1.1	2.6	3.0	4.5	3.1	3.0	2.0		2.5
Peak	2.2	1.6	1.8	2.8	1.8	1.9	2.1		0.7
California									
Base	16.7	26.1	29.5	44.2	20.0	23.0	24.4	6.4	13.3
Intermediate	8.4	16.5	18.4	28.8	13.3	11.8	5.9	3.4	15.3
Peak	6.9	10.1	11.4	17.2	15.6	15.7	15.6		1.6
Colorado									
Base	1.2	1.8	2.2	3.8	2.8	3.2	3.2		0.6
Intermediate	0.8	0.5	1.4	2.4	1.6	1.5	1.3		1.1
Peak	0.6	0.6	0.8	1.4	0.5	0.5	0.5	0.1	0.6
Kansas									
Base	0.8	1.6	1.7	1.9	1.7	1.7	1.7		0.2
Intermediate	0.4	1.0	1.0	1.2	0.7	0.7	0.4		0.5
Peak	0.5	0.6	0.7	0.6	0.7	0.6	0.5	0.1	0.1
Louisiana									
Base	5.7	8.3	9.7	15.5	10.3	10.3	8.7		6.8
Intermediate	2.6	5.3	6.2	9.9	3.1	2.7	1.4	1.3	5.0
Peak	1.3	3.3	3.7	5.8	0.7	0.4	0.1	0.7	3.4
Nevada									
Base	1.2	1.0	1.2	1.6	1.1	1.4	1.4		0.2
Intermediate	0.4	0.7	0.7	1.0	1.2	1.1	0.3		0.7
Peak	0.4	0.4	0.4	0.6	1.1	1.1	1.2		---

TABLE III

(Concluded)

STATE	CURRENT CAPACITY	CAPACITY NEEDED 1986	CAPACITY NEEDED 1989	CAPACITY NEEDED 2001	CAPACITY AVAILABLE (PRESENT PLANS) 1986	CAPACITY AVAILABLE (PRESENT PLANS) 1989	CAPACITY AVAILABLE (PRESENT PLANS) 2001	ADDITIONAL CAPACITY REQUIRED TOTAL POTENTIAL MARKET 1986-1989	ADDITIONAL CAPACITY REQUIRED TOTAL POTENTIAL MARKET 1989-2001
New Mexico									
Base	0.6	0.5	0.6	0.8	1.7	2.1	2.7		---
Intermediate	0.2	0.3	0.4	0.5	---	---	---		0.1
Peak	0.1	0.2	0.2	0.2	0.2	0.2	---	0.1	0.2
Texas									
Base	24.1	39.2	44.2	63.9	39.9	42.5	36.2	1.7	26.0
Intermediate	11.6	24.4	28.1	40.1	11.7	11.5	5.9	3.9	17.6
Peak	6.3	15.1	17.1	24.7	6.7	4.6	2.0	4.1	10.2
Utah									
Base	1.4	1.6	1.7	2.5	3.0	4.3	4.3		---
Intermediate	0.6	1.0	1.1	1.6	0.8	0.7	0.3	0.2	0.7
Peak	0.3	0.6	0.6	0.9	0.2	0.2	0.2		0.3

The base and possibly the intermediate load markets indicated in Columns 10 and 11 are of primary importance. Preliminary economic calculations indicate the importance of high load factor operation of the hybrid. The projected need for base load units in the states examined during the Period 1989-2001 amounts to 49.6 GW, and for intermediate units, 41 GW. The base load capacity demand is thus approximately 500 units of the referenced 100-MWe design.

It must be remembered that some utilities have made plans to export power to deficient states, such as California. The apparent surplus of capacity in the exporting states is thus artificial. The deficit in capacity in importing states is identically in error. Thus, the overall requirements are in balance. As the presumed major exporting and importing regions have locations with similar insolation characteristics, the overall market projection is accurate.

Special Considerations

Much, if not all, of California's need for additional capacity is contained within utility systems located in areas of favorable insolation. California has a few large systems with good transmission and interconnection. This is not true of Texas. There are many utilities and interconnections which are more complicated. The Houston Lighting service area is generally located in areas with relatively poor direct normal solar insolation. Houston Lighting capacity need makes up 25-30% of the total estimated need for base and intermediate power. Satisfaction of this demand by hybrid solar installations will require either (a) economic operation in a relatively unfavorable area, or (b) plant location in West Texas, accompanied by transmission (or displacement of load across intervening systems). Further consideration of these options is planned.

Early Replacement of Capacity

The investigation of market size was extended to consider the effect of oil and gas shortages and/or Government requirements for early retirement of this capacity. Early retirement would increase the total market available to solar hybrid units. The effect is illustrated in Table IV. In it, requirements over the Period 1989-2001 for three typical utilities are set forth. For these sample utilities, the market size would increase from 40 to over 100% if early retirement was instituted. It appears that the influence of Government intervention in the market will be an important consideration in estimating market size as well as share.

Comments

It is clear that there is sufficient demand for new electric generating units in solar favorable regions to justify the development of hybrid solar electric units if the units meet economic standards. As many units will be needed, calculations of cost of electricity from the units should be made on the basis of Nth plant as well as 1st plant costs.

The demand is concentrated in areas with different insolation characteristics. Thus, estimates of electricity cost from the hybrid solar units should be developed with the capital costs or solar efficiencies that would be appropriate if the units were located in these two regions. The calculation would also consider the effect of using coals appropriate to the separate regions. Texas Lignite, Western Interior Basin, Black Mesa, Unita Basin, and San Juan Basin coals would be appropriate.

Comparative Economics - Preliminary Data

As a first step in establishing the relative competitiveness of hybrid solar systems with others that might be used to fill the electric power demand in the regions studied, SRI compared existing estimates for other systems with preliminary values for the hybrid solar plant.

TABLE IV

COMPARISON OF UTILITY CAPACITY ADDITION REQUIREMENTS UNDER NORMAL AND ACCELERATED RETIREMENT DURING PERIOD 1989-2001, GW

UTILITY	CURRENT CAPACITY	MARKET NORMAL CONDITIONS	AVAILABLE CAPACITY NORMAL CONDITIONS 1989	AVAILABLE CAPACITY NORMAL CONDITIONS 2001	AVAILABLE CAPACITY ACCELERATED RETIREMENT	TOTAL MARKET ACCELERATED CONDITIONS	ADDITIONAL MARKET ACCELERATED CONDITIONS 1989-2001
Southern California Edison							
Base	7.0	6.4	7.9	7.2	4.2	9.4	3.0
Intermediate	2.4	5.9	4.9	2.6	---	8.5	2.6
Peak	3.6	2.2	4.2	4.2	2.4	4.0	1.8
TOTAL	13.0	24.5				21.9	
Arizona Public Service Co.							
Base	1.3	---	2.8	3.1	3.1	---	---
Intermediate	0.5	0.9	2.1	1.0	0.5	1.4	0.5
Peak	1.1	0.2	0.8	1.0	0.3	0.4	0.2[1]
TOTAL	2.9	1.1				1.8	
Houston Lighting & Power Co.							
Base	5.2	8.1	10.8	8.1	6.1	14.2	2.0
Intermediate	3.1	4.5	2.2	1.0	0.4	4.9	0.6
Peak	2.1	2.3	0.9	0.7	---	3.0	0.7
TOTAL	10.4	14.9				22.1	

(1) Only 0.2 GW needed to fill estimated peak load.

The economic bases for comparison and the methods of computation are not exactly the same as those set forth in the requirements definition documents. The economic assumptions used are set forth in Table V. The computational method, EUTEBEC, that was used is modeled after the standard JPL-EPRI methodology, but has some differences in assumptions regarding utility costing and rate establishing procedures. These assumptions give rise to higher levelized busbar costs for electricity than the standard JPL-EPRI or BUCKS methodologies.

SRI estimates of electric power production costs were initially drawn from several related studies. The assumptions were recently normalized to obtain a consistent base for capital and operating costs and for unit efficiency. These data were used to compute the costs shown in the right hand columns of Table VI. Costs of electricity from the 100 MW all coal and the 100-MW hybrid coal solar plant were based on Rockwell data; all plant costs were for Nth units. These latter data must be considered preliminary and subject to revision. Nevertheless, it would appear that if the basic design hybrid system is considered as a base load unit it is reasonably competitive with other coal fired units--with the exception of a unit fired with subbituminous coal and operating without flue gas desulfurization. It cannot compete with the assumed base load nuclear plant, but the political fate of nuclear power is uncertain.

Turbine Selection

Complete.

Solar Energy System Optimization

During the past reporting period, material was generated and presented in the quarterly review. Included in this progress report is a discussion of charts presented in the review which were not previously reported on in earlier progress reports pertaining to the field optimization effort.

TABLE V

FINANCIAL ASSUMPTIONS

Base Year for Costs	1978
Year of First Investment	1985
Year of Commercial Operation	1990
System Lifetime	30 Years
Rated Output	100 MW
Depreciation Option	Sum-of-the-Years' Digits
Depreciation Lifetime	22 Years
Debt/Equity Ratio	50/50
Corporate Debt Interest Rate	8 %
Rate of Return	12 %
Federal and State Taxes	50 %
Other Taxes, Investment Tax Credit, and Insurance	0 %
Capital Expenditure Escalation Rate	10 % per Year
O&M Cost Escalation Rate	8 % per Year
Fuel Cost Escalation Rate	6, 8, 10, 15 % per Year
Base Capital Cost (in 1978 Dollars)	
Coal, Hybrid — First Commercial	128 Million
Oil, Hybrid — First Commercial	116 Million
Gas, Hybrid — First Commercial	113 Million
Coal, Hybrid — Nth Commercial	106 Million
Coal Only	97 Million
Deflator Used in Converting 1990 Levelized Electricity Costs to 1978 Dollars	8 % per Year

TABLE VI

PRELIMINARY LEVELIZED POWER COSTS: ALTERNATE POWER SYSTEMS
MILLS PER kWh, 1978 DOLLARS
1990 START UP

FUEL ESCALATION RATE	COAL SOLAR HYBRID 100 MW	BITUMINOUS COAL, 70% CF				SUB BITUMINOUS COAL w/o FGD, 500 MW, 70%	NUCLEAR 1000 MW, 65% CF	ADVANCED GAS TURBINE 100 MW, 15% CF
		FGD 100 MW	FGD 500 MW	FLUID BED 500 MW	COAL GAS,CC 500 MW			
6	50.6	45.2	47.1	53.7	62.1	36.2		
8	57.7	54.8	55.6	62.6	70.5	44.9		82.2
10	67.0	70.7						108.7
OTHER							42.9	

In response to a discussion, which follows, pertaining to the effect of fixed costs on the optimization, an additional review of the costs included in the fixed cost model was made. The subsequent analysis of these costs revealed that two of the components of the fixed cost, namely, the costs associated with Design and Support Engineering and Indirect A&E, were based on first plant costs. For the sake of consistency, these costs were updated (reduced) to reflect estimates for Nth plant (the basis for other costs used in the optimization). The following summarizes these changes:

Item	1st Plant (10^6 \$)	Nth Plant (10^6 \$)
Design and Support Engineering	1.84	1.0
Indirect A&E	1.43	.70
Total Fixed Cost	4.19	2.62

Other work initiated during this reporting period was a master control review of the preliminary P and I.D. The following areas were identified as requiring further definition and explanation.

1) Coordinated control of sodium supply to receiver and heater.
2) Sodium flow control to superheater and reheater.
3) Feedwater control; drum level control and superheater/reheater H_2O regulation as a function of turbine pressure or flow.

Clarification of these items will be made during the next reporting period to allow further definition and analyses of the master control system.

The following is a discussion of the previously unreported on charts presented in the quarterly review.

TABLE VII

FAVORS LARGER TOWERS	FAVORS SMALLER TOWERS
o LARGE FIXED COST	o ZERO FIXED COST
o TOWER COST SUB QUADRATIC	o TOWER COST SUPER QUADRATIC
o RESTRICTED OR EXPENSIVE LAND	o LARGE BEAM SPREAD
FAVORS LARGER RECEIVERS	**FAVORS SMALLER RECEIVERS**
o LOW RECEIVER COST/M^2	o HIGH RECEIVER COST/M^2
o LOW RECEIVER LOSSES/M^2	o HIGH RECEIVER LOSSES/M^2
o LARGE FLAT HELIOSTAT	o HIGH PERFORMANCE HELIOSTAT
o SEVERE ABERRATIONS	o SMALLER HELIOSTAT
o LARGE BEAM SPREAD	
FAVORS LARGER FIELD	**FAVORS SMALLER FIELDS**
o EXPENSIVE RECEIVER SS	o EXPENSIVE HELIOSTATS
o CHEAP HELIOSTATS	o CHEAP RECEIVER SS
o CHEAP LAND AND WIRE	o EXPENSIVE LAND OR WIRE
o LOW ATMOSPHERIC ATTENUATION	o HIGH ATMOSPHERIC ATTENUATION
	o RESTRICTED AREA
	o HIGH COST COMPETITION

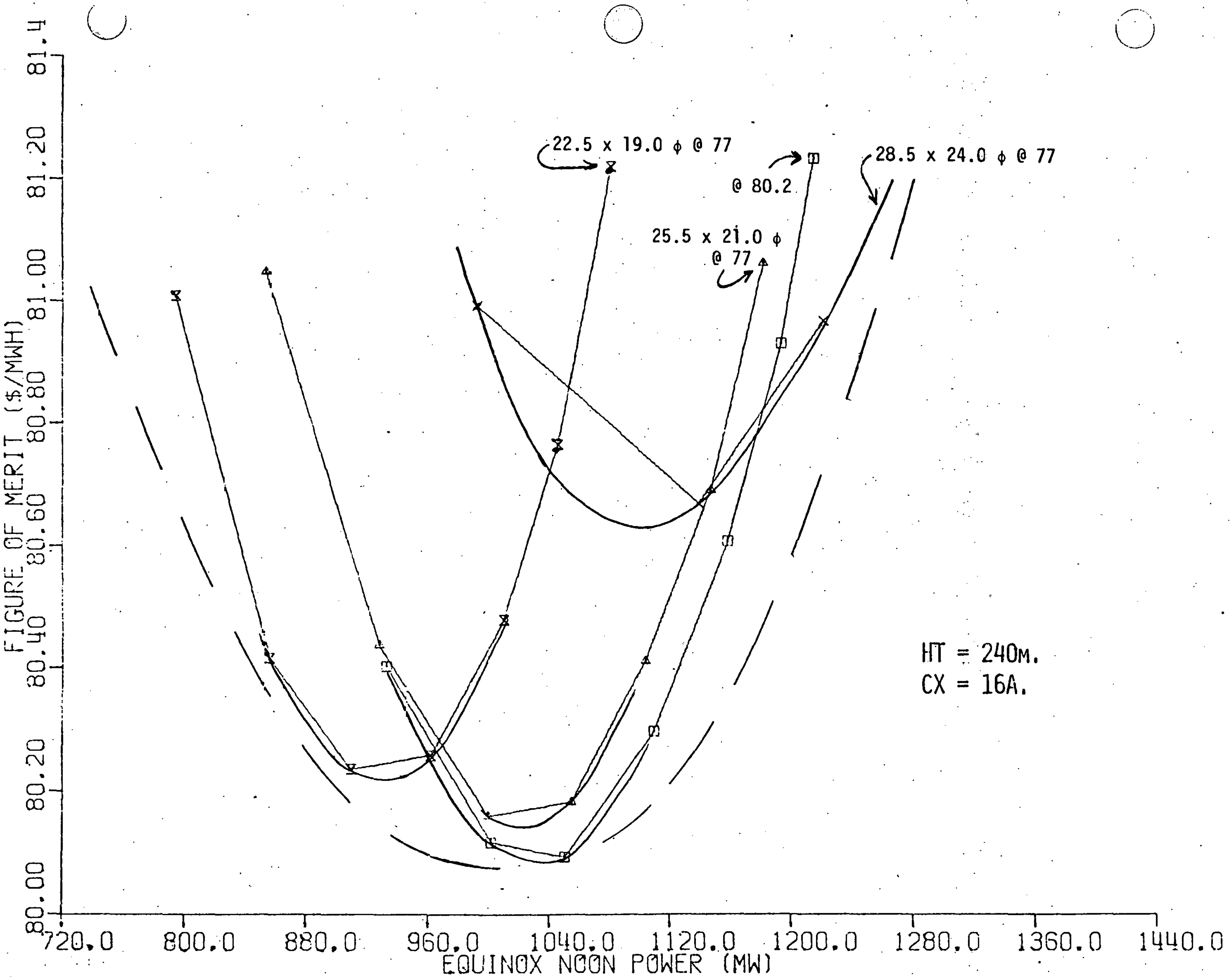
By way of introduction, Table VII lists the parameters that influence field optimization.

Tower, receiver, and field size are each influenced by numerous factors. For example, restricted or expensive land favors a taller tower so blocking will be reduced and heliostats packed more densely. Simultaneously, it favors a smaller field (compared to a baseline system) because the peripheral heliostats use ground inefficiently. In contrast, cheap land favors a larger field, limited primarily by beam spillage and atmospheric attenuation; the heliostats can be distributed sparsely, as required by the necessity to eliminate blocking. A larger field may allow the required power level to be reached with a shorter tower.

The chart should be used with some wisdom to distinguish between drivers favoring smaller systems versus those favoring a smaller tower, or receiver or field irrespective of system size.

The last item, high cost competition, for example, should really be applied to smaller systems, as competition at 10 MWe may be a diesel at 10 ¢/kW hr, compared to a coal plant at 2 ¢/kW hr for a 500 MWe system.

Optimization results will be shown for a range of focal heights [(receiver ℄ elevation -4.0 m) = 120, 150, 180, 240 m]. For each case, a range of external cylindrical receiver sizes have been investigated, e.g., on Figure 1, 28.5 m tall by 24.0 m diameter. Each "parabolic" curve represents the output figure of merit versus design point power for a range of field size (i.e., trim lines) for a specific input figure of merit (FOM - system cost/annual thermal output in MWh, $/a MWht). A completely optimized system would have an input figure of merit equal to the output figure of merit achieved at the low power on the curve, e.g., on Figure 1 at 80.1 and 1040, the input figure of merit was 80.2, very close to convergence. By investigating a range of input conditions



22.5 x 19.0 ϕ @ 77
@ 80.2
28.5 x 24.0 ϕ @ 77
25.5 x 21.0 ϕ
@ 77
HT = 240M.
CX = 16A.
FIGURE OF MERIT ($/MWH)
80.00
80.20
80.40
80.60
80.80
81.00
81.20
81.4
720.0
800.0
880.0
960.0
1040.0
1120.0
1200.0
1280.0
1360.0
1440.0
EQUINOX NOON POWER (MW)

FIGURE 1

(receiver dimensions and input figure of merit), an envelope of achievable output figure of merits versus equinox noon power is obtained for each focal height (vertical distance from receiver centerline to the plane of the heliostat center points).

In Figure 1, we see that a 240 m focal height with a 16 acre central exclusion area leads to an equinox noon power output of 1000 MWt and a minimum figure of merit of 80.1 $/a MWht for a receiver about 25 m tall and 20 to 21 m in diameter.

In Figure 2, if the performance envelopes are plotted for each focal height considered, an envelope of envelopes is defined which is indicative of the performance which could be achieved if the optimum focal height were chosen for a desired equinox noon power and then the correct receiver size were selected. Note that at lower powers (< 500 MWt) this baseline design curve begins to rise and at 200 MWt it is very steep. Reasons for this rise will be discussed later. Because of this rising design curve, the smaller systems cannot be optimized in the usual way; the minimum of the "parabolic" design envelope does not represent the contact with the baseline design curve. Rather this contact occurs on the low power side of the envelope where it defines the baseline design envelope.

Figure 3

The consequence of this rising baseline design curve is that the critical portion of the envelope for the smaller systems is not the bottom of the "parabola," but the left side, i.e., the area of contact. Consequently, the design data for the smaller systems concentrates on defining the left side of the "parabolas." This is accomplished most effectively by using an input figure of merit substantially less than the output, or converged, value. Thus, for the 150 m focal height case, the definitive curves have an input figure of merit of 65 rather than 80. At 150 m, the exclusion area in the center of the field has been scaled to 12.5 acres and the optimum receiver would be about 15 m tall

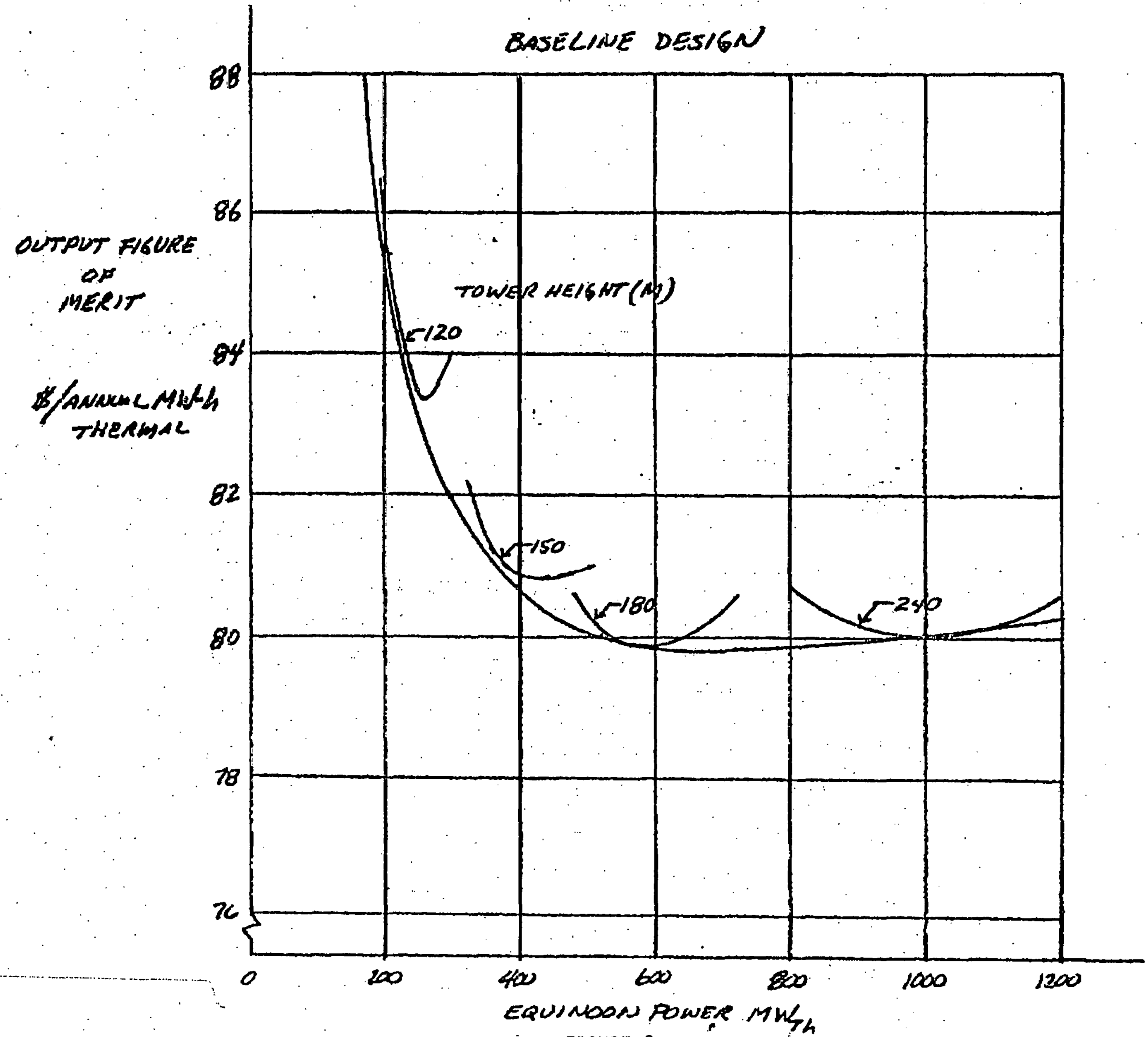
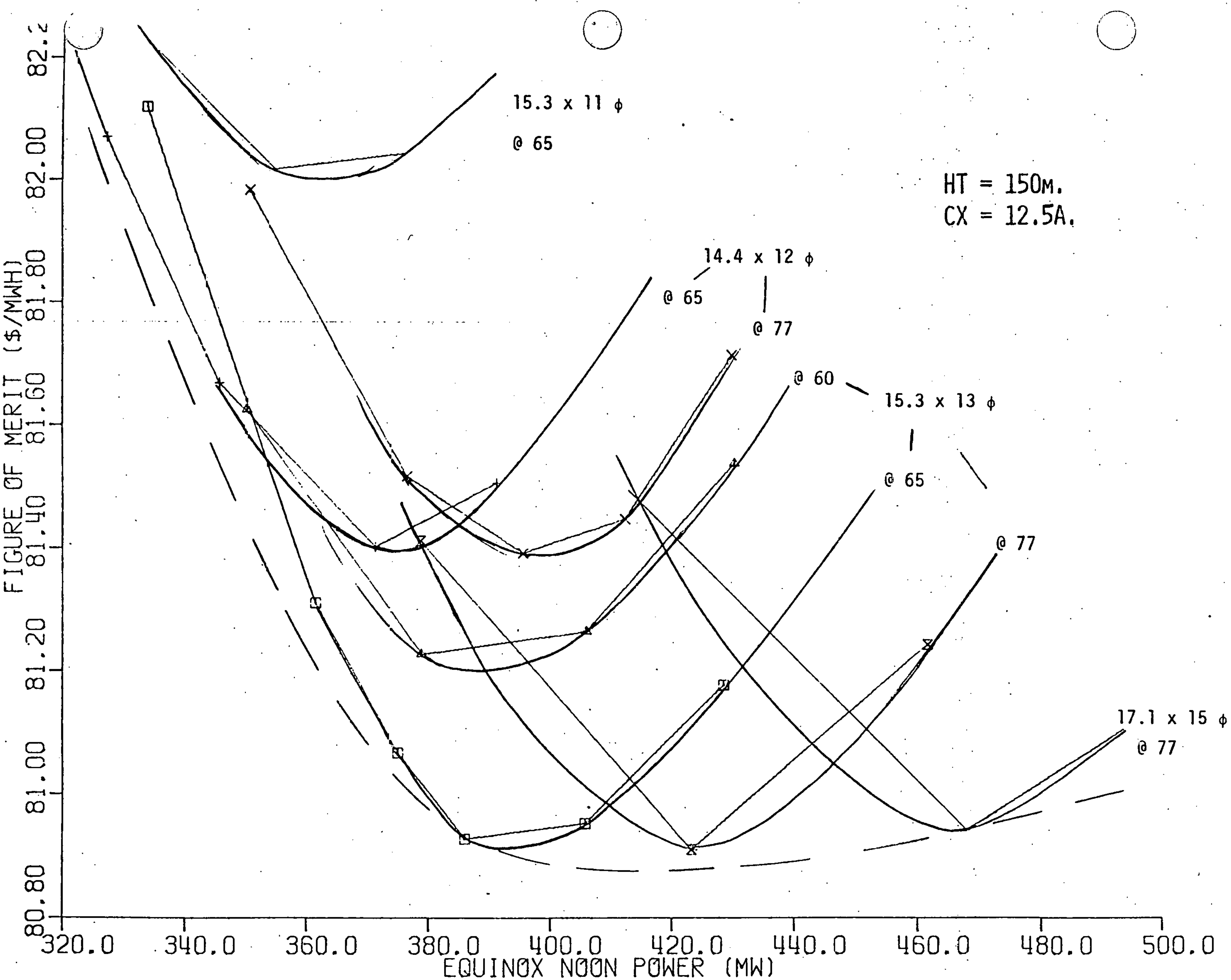

BASELINE DESIGN
OUTPUT FIGURE OF MERIT
$/ANNUAL MWh THERMAL
TOWER HEIGHT (M)
120
150
180
240
88
86
84
82
80
78
76
0
200
400
600
800
1000
1200
EQUINOON POWER MWTh

FIGURE 2



15.3 x 11 ϕ
@ 65
HT = 150M.
CX = 12.5A.
14.4 x 12 ϕ
@ 65
@ 77
@ 60
15.3 x 13 ϕ
@ 65
@ 77
17.1 x 15 ϕ
@ 77
FIGURE OF MERIT ($/MWH)
80.80
81.00
81.20
81.40
81.60
81.80
82.00
82.2
320.0
340.0
360.0
380.0
400.0
420.0
440.0
460.0
480.0
500.0
EQUINOX NOON POWER (MW)

FIGURE 3

by 12.5 m in diameter. The contact point with the baseline design curve occurs at a figure of merit of 81.2 and an equinox noon power of 360 MWt. In contrast, the lowest figure of merit for this focal height is 80.9 at 420 MWt.

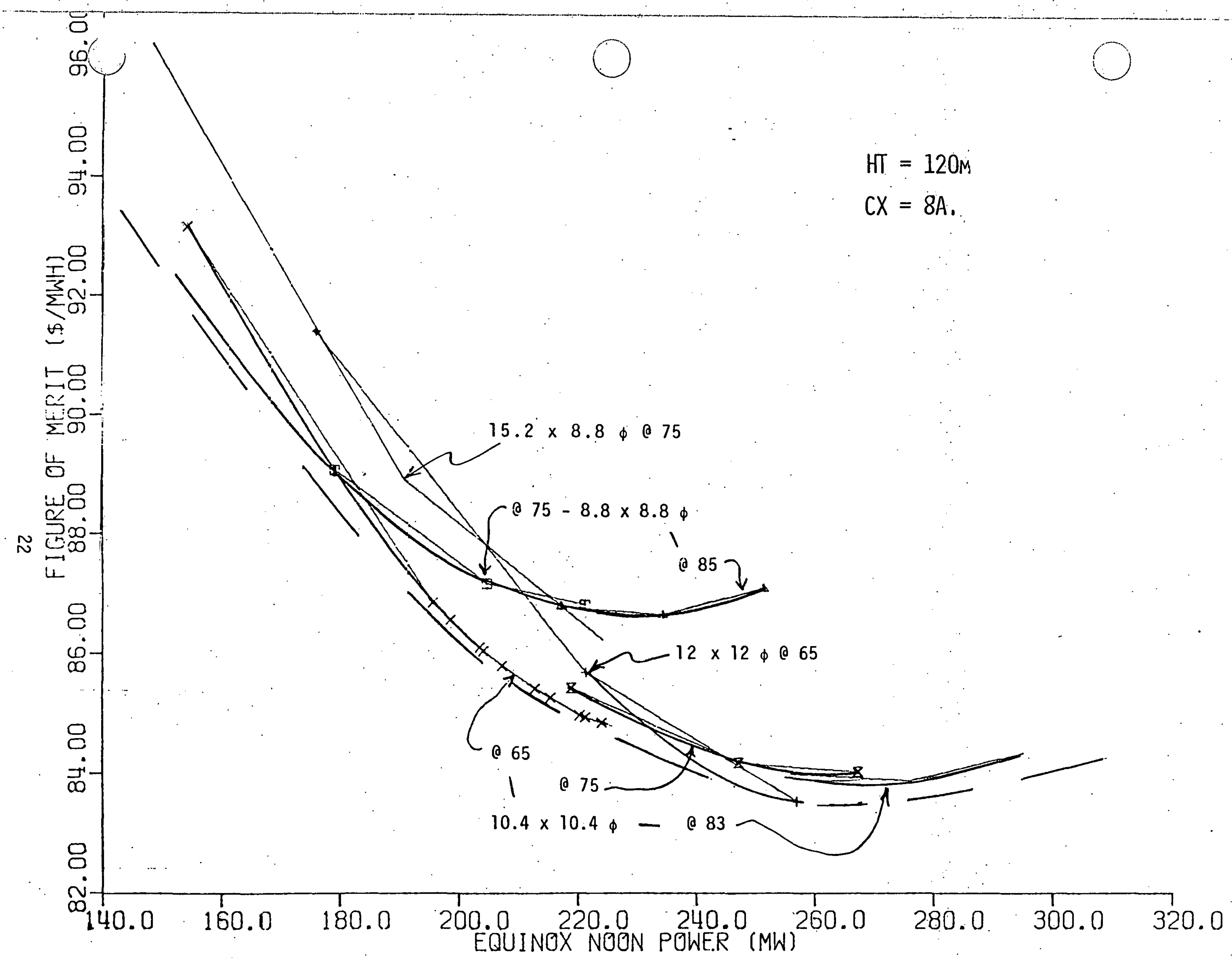
Figure 4

For a 120 m focal height, the baseline design curve is rising so fast that the ordinate has been compressed 10 fold relative to the previous curves. With an eight-acre exclusion area, this system provides the required 208 MWt essentially at the point of contact with the baseline design curve. An input figure of merit of 65 has been used to reduce the system size below the 260 MWt achieved for an optimized system at this focal height.

At this point in the study (early) we had a receiver cost algorithm which favored "square" receivers so our optimal receiver was 10.4 m tall by 10.4 m diameter. The more recent algorithm gives essentially the same cost of this size receiver, but favors tall, thin receivers. Consequently, we estimate the final optimal receiver will be more nearly 12 m tall by 10 m diameter.

Table VIII is a performance summary page from the best constrained system providing the desired 208 MWt at the equinox noon design point with an insolation of 950 W/m^2. On the upper right is given the number of heliostats required, the total glass area and the total land area (the ratio gives an average glass density of 21.7 percent). The three matrices show the east half-field of the cellwise design. Each cell has an area of 15 $H^2/4$ = 18,000 m^2. The tower is centered in the cell marked with a zero in the middle of the leftmost column.

The "trim control" matrix (of 4's) shows the cell occupation number in quarters, three corresponding to a cell which lies 75 percent inside of the useful heliostat field. In the "limits" matrix, the 3's indicate cells in which mechanical limits have been active in defining the heliostat spacing (three refers to the diagonal neighbor).


HT = 120M
CX = 8A.
15.2 x 8.8 ϕ @ 75
@ 75 - 8.8 x 8.8 ϕ
@ 85
12 x 12 ϕ @ 65
@ 65
@ 75
10.4 x 10.4 ϕ — @ 83
FIGURE OF MERIT ($/MWH)
EQUINOX NOON POWER (MW)
82.00
84.00
86.00
88.00
90.00
92.00
94.00
96.00
140.0
160.0
180.0
200.0
220.0
240.0
260.0
280.0
300.0
320.0
FIGURE 4

22

TRIM CONTROL   LIMITS

00000000	00000000
00000000	00000000
44410000	00000000
44442000	00000000
44444200	00000000
44444400	00000000
44444400	00000000
34444400	33000000
03444400	03000000
44444300	33000000
44443000	00000000
44420000	00000000
11100000	00000000
00000000	00000000

TABLE VIII

MAX. NUMBER OF HELIOS./CELL= 367.0 ; HGLASS/DMIR**2 = 0.8963

7332. HELIOS AHELI= 54.7263 ASEG= 54.7263

; TOTAL GLASS = 0.35967E 06

; TOTAL LAND = 0.16560E 07

* * * * * * * * * * * * * * NUMBER OF HELIOSTATS PER CELL* * * * * * * * * * * * * * ; HT = 120.0 METERS

0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.
46.6	91.9	86.9	19.9	0.	0.	0.	0.
57.6	112.4	105.8	95.9	42.2	0.	0.	0.
71.6	139.7	128.4	114.4	98.4	41.4	0.	0.
92.6	177.6	157.7	134.4	113.3	93.4	0.	0.
128.6	236.5	194.1	155.3	125.7	102.2	0.	0.
117.4	310.7	233.5	173.9	135.1	107.5	0.	0.
0.	233.6	252.4	180.4	138.0	108.5	0.	0.
156.8	321.9	229.1	170.6	132.1	78.1	0.	0.
125.3	226.6	183.1	146.3	88.3	0.	0.	0.
83.4	161.3	142.8	60.2	0.	0.	0.	0.
14.6	29.2	26.9	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

PERFORMANCE SUMMARY AND COST BREAKDOWN FOR OPTIMIZED COLLECTOR FIELD - TRIM LINE AT 0.960

EQNOON POWER = 218.903 207.068 IN MW - (SCALED TO 950 W/M2)
ANNUAL ENERGY = 506.465 IN GWH
FIXED COSTS = 4.8030 IN $M
TOWER COST = 9.1788 2.4388 4.2298 0.9428 1.5674 IN $M FOR 950. EQUINOON POW
LAND COST = 2.4012 IN $M
WIRING COST = 1.1786 IN $M
HELIOSTAT COST = 20.7064 25.8821 31.0578 IN $M
TOTAL COST = 38.2680 43.4437 48.6194 IN $M
FIGURE OF MERIT= 75.559 85.778 95.998 IN $/MWH , FOR AN INPUT OF 65.000 USING HELIOSTAT

The "number of heliostats per cell" matrix represents a sum over the right and left half-fields, thus, although only the right half-field is depicted, the heliostat number is 7,332. Variations in heliostat packing across the field are obvious, although the heliostats in those cells with trim control numbers < 4 (i.e., at the perimeter of the field) are packed into a fraction of a cell.

The performance summary shows first the equinox noon power delivered to sodium using the University of Houston's insolation model (about 1002 W/m^2) and then the Sandia dictated 950 W/m^2. The annual energy is all collected when the sun is above 10^o elevation. Monthly, the long term average values appropriate to the southwestern desert of cloud cover, turbidity and precipitable water are used in developing this estimate. The fixed costs include the cost of preparing the central exclusion area for construction. The tower cost gives first the total, then the costs of the tower, the receiver, the vertical plumbing and the riser pump. The land cost includes only the heliostat field. The wiring cost includes the present value of the O&M components associated with azimuthal spacing (Category 3). The heliostat cost is given for a baseline case and ± 20 percent. Thus, we are interested in the center column, where the "heliostat cost" is based on an area cost of 71.96 $\$/m^2$. This includes a capital cost of 60.12 $\$/m^2$ and O&M of 11.84 $\$/m^2$. The Figure of Merit is the output value, computed as the ratio of the Total Cost divided by the Annual Energy. The input figure of merit is listed to the right.

The extent of the heliostat field is defined by the trim control matrix which is set by the trim control to include those cells with a trim ratio greater than that defined by the "trim line," given as 0.960 in this case. The trim line should be close to unity at the design power for an optimal constrained system.

By taking outputs at several trim lines, a range of system sizes is defined, allowing interpolation to an exact desired point. In Figure 5, we see a set of such interpolation curves for our design case. The

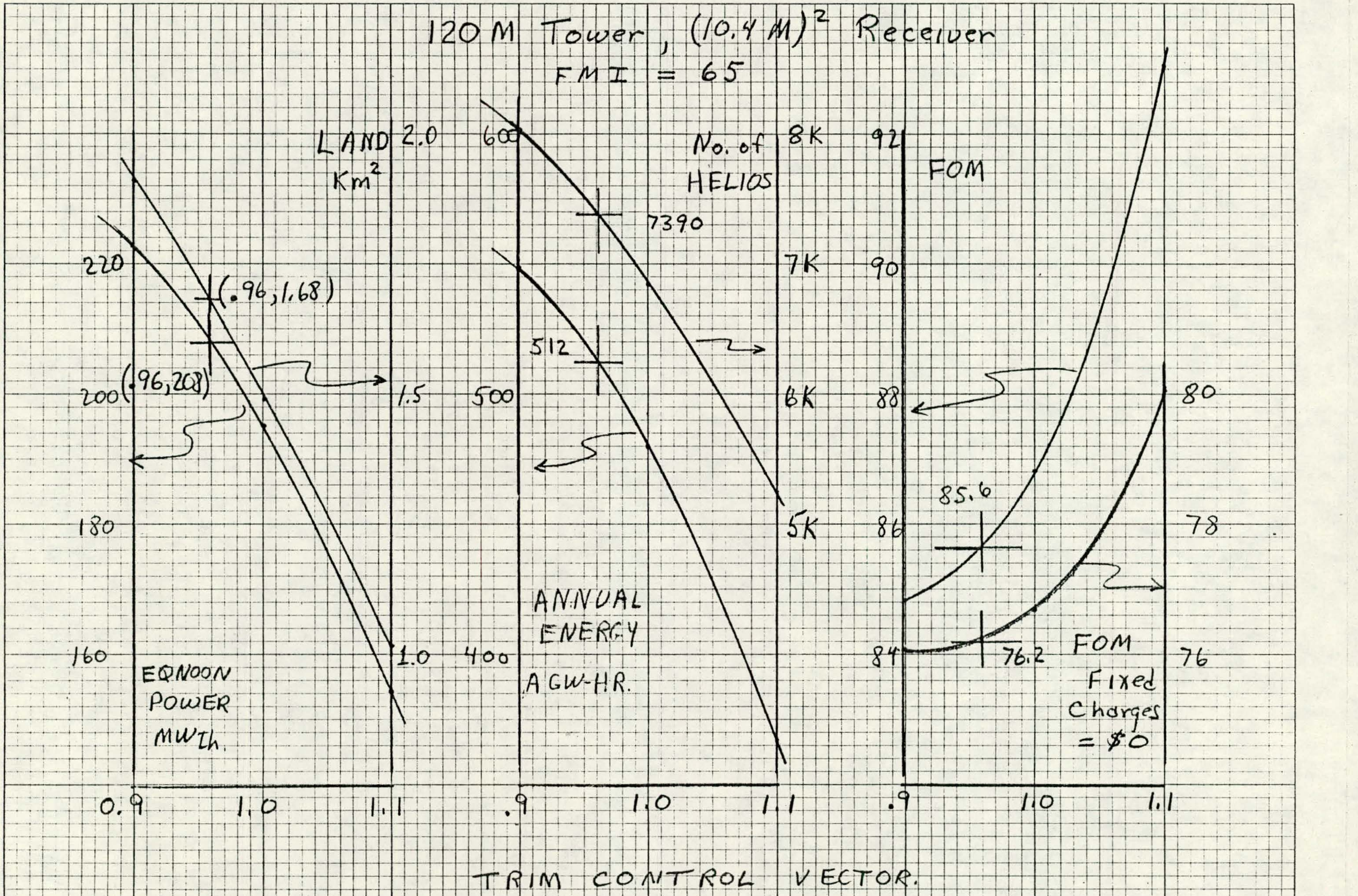

120 M Tower, (10.4 M)² Receiver
FMI = 65
LAND Km²
2.0
1.5
1.0
220
200
180
160
(.96, 1.68)
(.96, 208)
EQNOON POWER MWth
600
500
400
512
7390
No. of HELIOS
8K
7K
6K
5K
ANNUAL ENERGY
AGW-HR.
92
90
88
86
84
FOM
85.6
76.2
80
78
76
FOM Fixed Charges = $0
0.9
1.0
1.1
.9
1.0
1.1
.9
1.0
1.1
TRIM CONTROL VECTOR.

FIGURE 5

leftmost curve shows the origin of the trim line of 0.960, as this is the number required to deliver 208 MWt. Comparison with the previous figure shows that the three point interpolation curves drawn here were not perfect, missing the actual design values by 1/2 to 1 percent.

The performance summary page for the optimal converged design at a 120 m focal height is shown in Table IX. The power level is 276 MWt and the output figure of merit (corrected to the new receiver cost model) is 83.87 $/a MWh (but see Figure 3).

Figure 6

The steep rise of the baseline design curve for systems smaller than 400 MWt is of interest. A first order study of the effect of the fixed cost is shown in the lower curve. The actual fixed cost was subtracted from the total cost and the figure of merit recomputed for appropriate cases. The resulting curve is substantially lower, and shows a minimum in the range of 300 to 600 MWt cf 500 to 1000 MWt for the baseline design. The curve below 300 MWt is not very well defined because the design studies for the 120 m case concentrated on defining the point of contact with the baseline design curve, i.e., the left side of the design envelope, rather than the bottom. Thus, these two envelopes may still come down somewhat more. Following a reevaluation of the rationale for the fixed cost assignment, the 120 m case will be reevaluated to achieve the final system design. Subsequently, the new "baseline design" curve will be defined.

The effect of visual range (atmospheric absorption between the heliostat and the receiver) on the shape of the baseline design was investigated by going to an extremely poor visibility figure of 15 km for the average annual visual ranges. The 240, 180 and 120 m focal height cases were recalculated. Obviously, larger systems suffer somewhat, with a minimum occurring between 375 and 750 MWt. However, see the next figure.

NGON = ; MAX. NUMBER OF HELIOS./CELL= 367.0 ; AHELI/DMIR**2 = 0.8963 ; TOTAL GLASS 0.52053E

TRIM CONTROL LIMITS 10612. HELIOS AHELI= 54.7263 ASEG= 54.7263 ; TOTAL LAND = 0.25560E

10000000	00000000
44430000	00000000
44444100	00000000
44444400	00000000
44444430	00000000
44444440	00000000
44444441	00000000
34444442	33000000
03444441	00000000
44444440	03000000
44444430	00000000
44444400	00000000
44443000	00000000
44310000	00000000

TABLE IX

* * * * * * * * * * * * * NUMBER OF HELIOSTATS PER CELL * * * * * * * * * * * * ; HT = 120.0 METERS

8.7	0.	0.	0.	0.	0.	0.	0.
42.3	83.6	80.1	56.0	0.	0.	0.	0.
51.0	100.7	96.4	89.0	80.9	17.8	0.	0.
62.0	122.1	115.2	105.6	94.0	82.4	0.	0.
77.4	150.2	139.3	124.3	108.6	93.4	59.4	0.
99.5	191.9	169.8	146.1	123.5	103.6	87.2	0.
139.6	256.2	210.3	168.8	138.0	113.0	93.6	19.1
117.3	311.4	256.8	190.2	149.0	120.1	97.8	39.6
0.	236.8	283.1	200.7	153.7	122.4	98.9	19.9
157.9	321.3	264.1	192.9	149.6	119.7	95.9	0.
151.4	275.2	218.6	170.4	136.6	110.7	67.3	0.
106.3	202.0	173.9	144.9	119.7	98.1	0.	0.
77.9	152.0	137.8	118.8	75.4	0.	0.	0.
57.8	113.8	79.4	23.4	0.	0.	0.	0.

PERFORMANCE SUMMARY AND COST BREAKDOWN FOR OPTIMIZED COLLECTOR FIELD - TRIM LINE AT 1.000

EQNOON POWER = 291.577 275.970 IN MW - (SCALED TO 950 W/M2)
ANNUAL ENERGY = 685.525 IN GWH
FIXED COSTS = 4.8000 IN $M
TOWER COST = 9.7207 2.4388 4.1045 1.0884 2.0890 IN $M FOR 950. EQUINOON POWER
LAND COST = 3.7062 IN $M 4.9193
WIRING COST = 1.6985 IN $M
HELIOSTAT COST = 29.9669 37.4574 44.9478 IN $M
TOTAL COST = 49.8924 57.3828 64.8732 IN $M
FIGURE OF MERIT= 72.780 83.706 94.633 IN $/MWH , FOR AN INPUT OF 83.000 USING HELIOSTAT COS

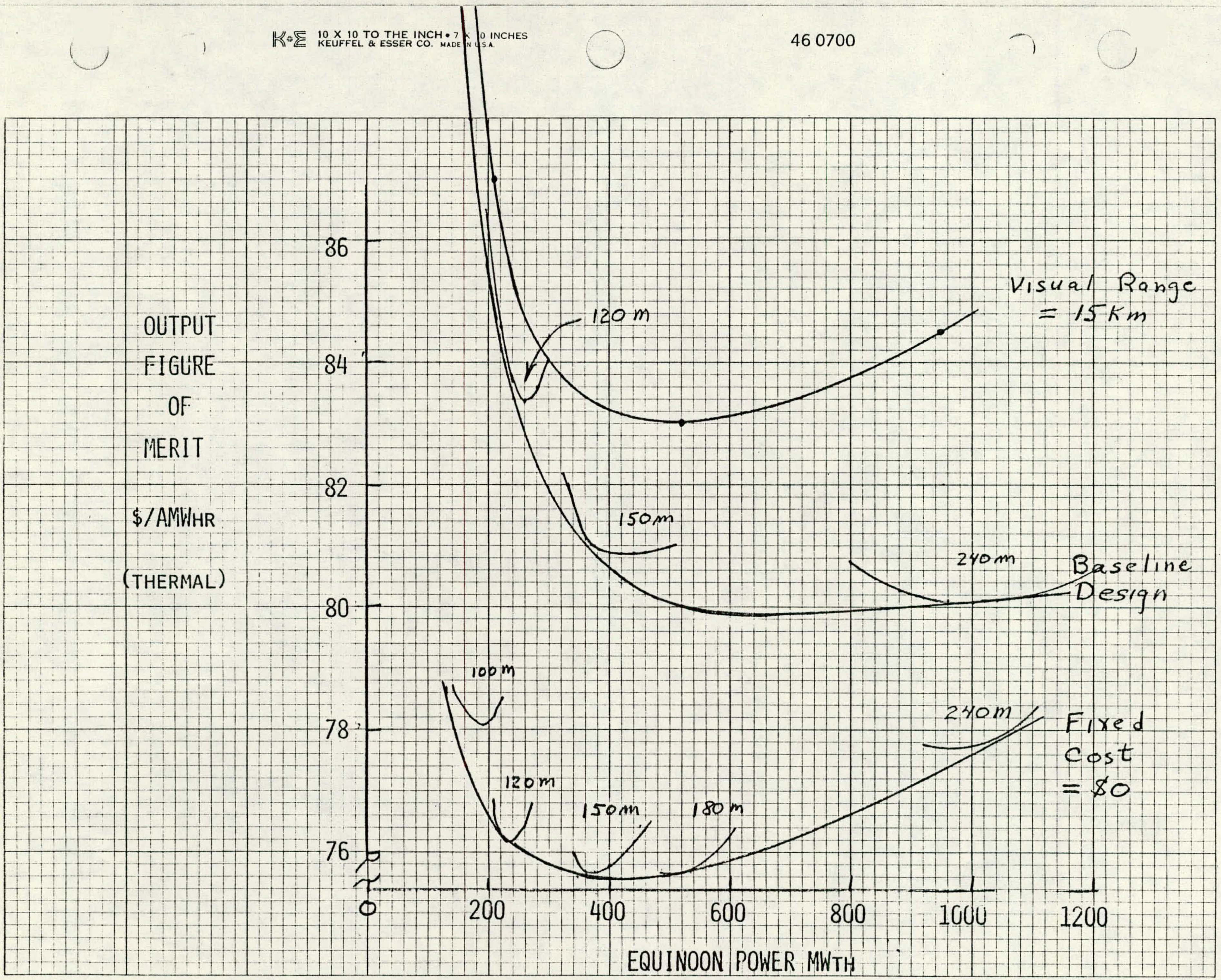

OUTPUT
FIGURE
OF
MERIT
$/AMWHR
(THERMAL)
86
84
82
80
78
76
0
200
400
600
800
1000
1200
EQUINOON POWER MWTH
Visual Range
= 15 Km
120 m
150m
240m
Baseline
Design
100m
120m
150m
180m
240m
Fixed
Cost
= $0

FIGURE 6

To determine if a visual range of 15 km (10 miles) makes any sense in a desert environment, the 1962 Albuquerque data take "sanitized" by Eldon Boes was analyzed. Table X was generated giving the number of hours in which a given visual range and fraction of sky cover coexisted. The leftmost column in the table corresponds to perfectly cloudless hours, and we see that of the 2,051 such hours, 220 had visual ranges of 50 miles (80 km) and 1,723 had visual ranges of 60 miles or greater (100 km). In contrast, most of the days with short visual range were associated with high cloud cover.

Alongside and below the table we have calculated the several reasonable sums, percentages, and cumulative percentages. "Beam hours" is taken as the product of (1 - sky cover) and the total number of occurrences. We can see from this computation that 95 percent of the annual daylight hours had a visual range of 30 miles (50 km) or greater, and 96 percent of the hours with over 50 percent clear sky had a visual range of 40 miles (64 km) or greater. It is also useful to note that 94 percent of the "beam hours" satisfy this condition. Thus, it appears that our standard visual range of 50 km may considerably <u>over estimate</u> the atmospheric attenuation of reflected light, and that 75 km might be a more realistic estimate. Surely 15 km is not of program interest: we chose it only to be certain of showing an effect in the parametric study.

PERFORMANCE SPECIFICATIONS

The preliminary values of the performance and design specifications have been prepared. These are in the form of Design Data Sheets and are given in the Appendix.

714-G.35/jjs/sjh

TABLE X

1962 ALBUQUERQUE (BOES)

VISUAL MILES	SKY COVER S 0.	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	Σ	%	% (cum)	Σ (S≤.5)	% (S≤.5)	% (cum)
1	0	0	0	0	1	1	0	1	0	0	9	12	.3	100	2	.1	100
2	0	0	0	0	1	1	0	1	1	0	9	13	.3	99.7	2	.1	100
4	0	0	0	0	0	0	2	0	1	1	12	16	.3	99.4	0	0	99.8
10	2	1	2	6	6	2	1	1	3	4	38	66	1.4	99.1	19	.6	99.8
15	5	1	7	0	2	0	1	3	2	1	20	42	.9	97.7	15	.5	99.2
20	15	5	3	3	1	0	0	0	7	8	33	75	1.6	96.8	27	.9	98.7
25	5	0	0	0	0	0	0	1	0	0	3	9	.2	95.2	5	.2	97.8
30	20	5	3	5	2	5	7	8	8	12	75	150	3.2	95.0	40	1.3	97.6
35	5	1	1	0	0	2	0	2	2	1	3	17	.4	91.8	9	.3	96.3
40	46	15	12	12	13	5	9	17	21	35	80	265	5.6	91.4	103	3.3	96.0
45	10	3	1	5	1	1	1	0	1	1	5	29	.6	85.8	21	.7	92.7
50	220	44	41	34	27	41	32	62	69	80	203	853	17.8	85.2	407	13.0	92.0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	67.4	0	0	79
60	1723	278	143	156	97	84	92	136	156	131	217	3213	67.4	67.4	2481	79	79
Σ	2051	353	213	221	151	142	145	232	271	274	707	4760	100		3131	100	
%	43	7	4	5	3	3	3	5	6	6	15	100					
% (cum)	43	50	54	59	62	65	68	73	79	85	100						

APPENDIX

RECEIVER SUBSYSTEM

Rockwell International
Energy Systems Group

DESIGN DATA SHEET	TITLE Solar Central Receiver Hybrid Receiver Subsystem	NUMBER
PREPARED BY	APPROVED BY	PAGE 1 of 14
	WBS NO.	DATE

NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
		Receiver Subsystem					
		Nominal Thermal Power	MWt	260			
		Maximum Thermal Power	MWt	TBD			
		Receiver Temperature					
		- In	^{o}C (^{o}F)	288 (550)			
		- Out	^{o}C (^{o}F)	593 (1100)			
		Flow Rate - Max Receiver	Kg/hr (lb/hr)	2.43×10^6 (5.36×10^6)			
		- Max Steam Generator	Kg/hr (lb/hr)	2.43×10^6) (5.36×10^6)			
		Volume of Sodium in Subsystem	m^3 (gals)	202 (53,000)			
		Weight of Sodium in Subsystem	kg (lb)	172,000 (379,000)			
		Pump Outlet Pressure	MN/m^2 (psia)	1.57 (230)			
		Pump Inlet Pressure	MN/m^2 (psia)	0.10 (15)			
		Total Radiation and Convection Loss	%	9% at Peak Power 12.5% at 50% Power			

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Energy Systems Group

DESIGN DATA SHEET	TITLE Solar Central Receiver Hybrid Receiver Subsystem	NUMBER
PREPARED BY	APPROVED BY	
	WBS NO.	DATE

NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
		Receiver Subsystem (Cont.)					
		Steam Generator Units Sodium Side					
		Superheat - Temp In	°C (°F)	593 (1100)			Tube and Shell Hockey Stick
		- Temp Out	°C (°F)	462 (864)			
		- Power	MWt	76.1			
		Reheat - Temp In	°C (°F)	593 (1100)			Tube and Shell Hockey Stick
		- Temp Out	°C (°F)	462 (864)			
		- Power	MWt	35.3			
		Evaporator - Temp In	°C (°F)	462 (864)			Tube and Shell Hockey Stick
		- Temp Out	°C (°F)	288 (550)			
		- Power	MWt	148.6			
		Pumps - Number and Type		1			Fixed Speed, Double Suction Centrifugal, Single Stage
		Receiver - Size and Type	m x m (ft x ft)	12.3 x 12.3 (40.4 x 40.4)			External 24 Panel
		Large Valves, 51 cm (20") Block		2			CS, Riser and Pump Return
		51 cm (20") Check		1			CS, Riser
		25 cm (10") Block		1			SS, Downcomer
		41 cm (16") Control		1			SS, Superheater Control
		20 cm (8") Control		24			SS, Receiver Panel Control
		15 cm (6") Control		1			SS, Reheater Control

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DESIGN DATA SHEET	TITLE Solar Central Receiver Hybrid Receiver Subsystem	NUMBER
PREPARED BY / APPROVED BY	WBS NO.	PAGE 3 of 14 / DATE

NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
		<u>Receiver Subsystem</u> (Cont.)					
		Large Pipe Length, 51 cm (20")	m (ft)	305 (1000)			CS
		46 cm (18")	m (ft)	366 (1200)			CS and SS
		41 cm (16")	m (ft)	18 (60)			SS
		20 cm (8")	m (ft)	512 (1680)			CS and SS
		15 cm (6")	m (ft)	18 (60)			SS
		<u>Receiver Assembly</u>					
		Diameter	m (ft)	12.3 (40.4)			
		Height	m (ft)	12.3 (40.4)			
		Receiver Mid-Point Elevation	m (ft)	135 (443)			
		Receiver Maximum Elevation	m (ft)	141 (463)			
		Number of Absorber Panels		24			
		Receiver Weight					
		Total	kg (lb)	284,500 (624,000)			
		Pressure Parts	kg (lb)	74,900 (164,800)			
		<u>Absorber Panel</u>					
		Height	m (ft)	12.3 (40.4)			
		Width	m (ft)	1.6 (5.3)			
		Dry Weight, Pressure Parts	kg (lb)	1,455 (3,200)			
		Number of Tubes		85			
		Tube OD	cm (in.)	1.91 (0.75)			
		Tube ID	cm (in.)	1.65 (0.65)			

Rockwell International Energy Systems Group	DESIGN DATA SHEET	TITLE Solar Central Receiver Hybrid Receiver Subsystem	NUMBER
PREPARED BY	APPROVED BY		PAGE 4 of 14
		WBS NO.	DATE

NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TEN-TATIVE	FIRM	REFERENCES AND REMARKS
		Absorber Panel (Cont.)					
		Tube Material		CRES 304H			
		Solar Surface Coating		Pyromark			
		Panel Insulation	cm (in.)	15.2 (6)			Closed-Pore Fiberglass
		Thermal Expansion	cm (in.)	12.7 (5)			Flexible Tube Bends
		Absorptivity, Minimum		0.95			
		Peak Heat Flux	MW/m^2 (Btu/in^2-sec	1.5 (0.82)			
		Outlet Temperature	°C (°F)	593 (1100)			
		Inlet Temperature	°C (°F)	288 (550)			
		Maximum Tube Surface Temperature	°C (°F)	635 (1175)			
		Tower Assembly					
		Construction					Slip formed concrete
		Concrete Height	m (ft)	122 (400)			
		Diameter - Base	m (ft)	24 (80)			
		- Top	m (ft)	9.1 (30)			
		Wall Thickness - Base	m (ft)	0.46 (1.5)			
		- Top	m (ft)	0.25 (.83)			
		Mat - OD	m (ft)	39.6 (130)			
		- ID	m (ft)	9.1 (30)			
		- Thickness	m (ft)	3.0 (10)			

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DESIGN DATA SHEET

PREPARED BY	APPROVED BY	TITLE Solar Central Receiver Hybrid Receiver Subsystem	NUMBER
			PAGE 5 of 14
		WBS NO.	DATE

NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
		Riser					
		Nominal Pipe OD	cm (in.)	51 (20)			
		Nominal Wall Thickness		TBD			
		Material		CS			
		Design Temperature	^oC (^oF)	371 (700)			
		Design Pressure ANSI B31.1	MN/m^2 (psia)	2.76 (400)			
		Maximum Flow Rate	kg/h	2.43×10^6			
			(lb/h)	(5.36×10^6)			
		Velocity at Maximum Flow Rate	m/sec	3.8 (12.4)			
			(ft/sec)				
		Downcomer					
		Nominal Pipe OD	cm (in.)	25 (10)			
		Nominal wall thickness		TBD			
		Material		304H			
		Design Temperature	^oC (^oF)	593 (1100)			
		Design Pressure ANSI B31.1	MN/m^2 (psia)	2.76 (400)			
		Maximum Flow Rate	kg/h	2.43×10^6)			
			(lb/h)	5.36×10^6)			
		Velocity at Maximum Flow Rate	m/sec	16.6 (55)			
			(ft/sec)				

Rockwell International Energy Systems Group	DESIGN DATA SHEET	TITLE Solar Central Receiver Hybrid Receiver Subsystem	NUMBER
PREPARED BY	APPROVED BY		PAGE 6 of 14
		WBS NO.	DATE

NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TEN-TATIVE	FIRM	REFERENCES AND REMARKS
		Receiver Pump					
		Physical Description					
		Quantity		1			
		Number of Stages		2			
		Height, w/motor	m (ft)	6 (19.7)			
		Tank Size	m (ft)	1.83 x 3.66 (6 x 12)			
		Inlet Nozzle	m (in.)	61 (24)			
		Outlet Nozzle	m (in.)	51 (20)			
		Dry Weight Pump	kg (lb)	34,000 (75,000)			
		Motor					
		Size	MW (hp)	1.95 (2,630)			
		Dimensions w/coupling	m (ft)	1.3 x 2.8 (4 x 9)			
		Voltage	V	4160			
		Cooling		TBD			
		Weight	kg (lb)	7,300 (16,000)			

FORM 706-A REV. 6-78

Rockwell International
Energy Systems Group

DESIGN DATA SHEET

PREPARED BY	APPROVED BY	TITLE Sodium Central Receiver Hybrid Receiver Subsystem	NUMBER
		WBS NO.	PAGE 7 of 14
			DATE

NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TEN-TATIVE	FIRM	REFERENCES AND REMARKS
		Receiver Pump (Cont.)					
		Pump Operating Conditions					
		Developed Head	m (ft)	206 (675)			
		Flow Rate	kg/hr	2.43×10^6			
			(lb/hr)	(5.36×10^6)			
		Speed	rpm	700			
		Temperature	^oC (^oF)	288 (550)			
		Sodium Volume	m^3 (gal)	4.5 (1200)			
		NPSH	m (ft)	9.1 (30)			
		Speed Control	%	Fixed Speed			
		Pump Power (η = 78%)	MW (hp)	1.92 (2,610)			
		Design Conditions					
		Developed Head	m (ft)	211 (691)			
		Flow Rate	m^3/s (gpm)	0.8 (12,000)			
		Speed	rpm	700			
		Temperature	^oC (^oF)	300 (600)			
		NPSH (Minimum Required)	m (ft)	9.1 (30)			
		Code					Sect. VIII, Div. 1

Rockwell International
Energy Systems Group

DESIGN DATA SHEET

PREPARED BY	APPROVED BY	TITLE: Solar Central Receiver Hybrid Receiver Subsystem	NUMBER
		WBS NO.	PAGE
			DATE

NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
		Steam Generator - Evaporator					
		<u>Physical Description</u>					
		Quantity		1			
		Type					Tube & Shell Hockey Stick
		Height	m (ft)	29.0 (95)			
		Width	m (ft)	4.87 (16)			
		Shell diameter	m (in.)	1.22 (48)			
		Heat Transfer Area	m^2 (ft^2)	1305 (14,039)			
		Number of Tubes		1100			
		Tube Size	cm (in.)	1.59 (5/8)			
		Tube Wall Thickness	cm (in.)	0.19 (0.075)			
		Material		2-1/4 Cr - 1 Mo			
		Sodium Nozzle OD/Thickness	cm (in.)	91/2.5 (36/1.0)			
		Tubesheet Diameter/Thickness	cm (in.)	122/30.5 (48/12)			
		Steam Nozzle OD/Thickness	cm (in.)	201/3.8 (8/1.5)			
		Weight	kg (ton)	58,000 (64)			

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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
		Steam Generator - Evaporator (Cont.)					
		Operating Conditions					
		Sodium Side:					
		Flow	kg/hr	2.43×10^6			
			(lb/hr)	(5.36×10^6)			
		Inlet Temperature	^oC (^oF)	462 (864)			
		Outlet Temperature	^oC (^oF)	288 (500)			
		Pressure Drop	MN/m^2 (psi)	0.207 (30)			
		Duty	MWt	148.6			
		Water/Steam:					
		Flow	kg/hr	3.33×10^5			
			(lb/hr)	(7.32×10^5)			
		Inlet Temperature	^oC (^oF)	234 (453)			
		Outlet Temperature	^oC (^oF)	341 (646)			
		Pressure	MN/m^2 (psia)	15.06 (2185)			
		Pressure Drop	MN/m^2 (psi)	0.207 (30)			
		Design Conditions:					
		Pressure-Sodium Side	MN/m^2 (psig)	2.07 (300)			
		Pressure-Steam Side	MN/hr^2 (psig)	16.55 (2400)			

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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TEN-TATIVE	FIRM	REFERENCES AND REMARKS
		Steam Generator - Evaporator (Cont.)					
		Operating Conditions (Cont.)					
		Design Conditions (Cont.)					
		Temperature	^oC (^oF)	482 (900)			
		Code					ASME Section VIII, Div. 1
		Steam Generator - Superheater					
		Physical Description					
		Quantity		1			
		Type					Tube & Shell Hockey-Stick
		Height	m (ft)	27.7 (91)			
		Width	m (ft)	4.57 (15)			
		Shell Diameter	m (in.)	0.76 (30)			
		Heat Transfer Area	m^2 (ft^2)	402.8 (4334)			
		Number of Tubes		283			
		Tube Size	cm (in.)	1.91 (3/4)			
		Tube Wall Thickness	cm (in.)	0.335 (0.132)			
		Material		SS 304			
		Sodium Nozzle OD/Thickness	cm (in.)	45.7/2.54 (18/1.0)			

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PREPARED BY	APPROVED BY	TITLE Solar Central Receiver Hybrid Receiver Subsystem	NUMBER
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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
		Steam Generator - Superheater (Cont.)					
		Physical Description (Cont.)					
		Tubesheet Diameter/Thickness	cm (in.)	76.2/20.3 (30/8)			
		Steam Nozzle OD/Thickness	cm (in.)	20, 3/3 (8/1.2)			
		Weight	kg (ton)	20,000 (22)			
		Operating Conditions					
		Sodium Side					
		Flow	kg/hr (lb/hr)	1.67×10^6 (3.67×10^6)			
		Inlet Temperature	^oC (^oF)	593 (1100)			
		Outlet Temperature	^oC (^oF)	462 (864)			
		Pressure Drop	MN/m^2 (psi)	0.207 (30)			
		Duty (Mwt)		76.1			
		Water/Steam:					
		Flow	kg/hr (lb/hr)	3.32×10^5 (7.32×10^5)			
		Inlet Temperature	^oC (^oF)	341 (646)			
		Outlet Temperature	^oC (^oF)	538 (1000)			
		Pressure	MN/m^2 (psig)	13.0 (1880)			

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PREPARED BY	APPROVED BY	TITLE Solar Central Receiver Hybrid Receiver Subsystem	NUMBER
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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TEN-TATIVE	FIRM	REFERENCES AND REMARKS
		Steam Generator - Superheater (Cont.)					
		Operating Conditions (Cont.)					
		Water/Steam: (Cont.)					
		Pressure Drop	MN/m^2 (psi)	1.77 (256)			
		Design Conditions:					
		Pressure-Sodium Side	MN/m^2 (psig)	2.07 (300)			
		Pressure-Steam Side	MN/m^2 (psig)	15.2 (2200)			
		Temperature	^oC (^oF)	593 (1100)			
		Code					ASME, Section VIII, Division I
		Steam Generator - Reheater					
		Physical Description					
		Quantity		1			
		Type					Tube & Shell Hockey-Stick
		Height	m (ft)	20.1 (66)			
		Width	m (ft)	5.49 (18)			
		Shell Diameter	m (in.)	0.81 (32)			
		Heat Transfer Area	m^2 (ft^2)	309.4 (3329)			
		Number of Tubes		163			
		Tube Size	cm (in.)	3.81 (1-1/2)			

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PREPARED BY	APPROVED BY	TITLE Solar Central Receiver Hybrid Receiver Subsystem	NUMBER
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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
		Steam Generator - Reheater (Cont.)					
		Physical Description (Cont.)					
		Tube Wall Thickness	cm (in.)	0.272 (0.107)			
		Material		SS 304			
		Sodium Nozzle OD/Thickness	cm (in.)	30.5/1.9 (12/.75)			
		Tubesheet Diameter/Thickness	cm (in.)	81.3/12.7 (32/5)			
		Steam Nozzle OD/Thickness	cm (in.)	16.8/15 (6.6/.6)			
		Weight	kg (ton)	22,000 (24)			
		Operating Conditions					
		Sodium Side:					
		Flow	kg/hr (lb/hr)	0.76×10^6 (1.68×10^6)			
		Inlet Temperature	^oC (^oF)	593 (1100)			
		Outlet Temperature	^oC (^oF)	462 (864)			
		Pressure Drop	MN/m^2 (psi)	0.207 (30)			
		Duty	MWt	35.3			

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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TEN-TATIVE	FIRM	REFERENCES AND REMARKS
		Steam Generator - Reheater (Cont.)					
		Operating Conditions (Cont.)					
		Water/Steam:					
		Flow	kg/hr	2.89×10^5			
			(lb/hr)	(6.36×10^5)			
		Inlet Temperature	^oC (^oF)	342 (647)			
		Outlet Temperature	^oC (^oF)	538 (1000)			
		Pressure	MN/m^2 (psia)	2.80 (406)			
		Pressure Drop	MN/m^2 (psi)	0.15 (22)			
		Design Conditions:					
		Pressure-Sodium Side	MN/m^2 (psig)	2.07 (300)			
		Pressure-Steam Side	MN/m^2 (psig)	3.65 (530)			
		Temperature	^oC (^oF)	593 (1100)			
		Code					ASME, Section VIII, Division I
		jlc:215					

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NON SOLAR SUBSYSTEM

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DESIGN DATA SHEET

PREPARED BY	APPROVED BY	TITLE	NUMBER
W. W. Willcox, ESG J. Slavens, B&W		Solar Central Receiver Hybrid Power System Fossil Heater	
		WBS NO.	PAGE 1 of 8 DATE February 13, 1979

NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
		Sodium Heater(s) Required	-	1			
		Fuel		Pulverized Coal			See Page 6 for coal characteristics
		Function Design Point: Steady-State					Economics and availability favor coal over oil, gas, and syngas. Oil can be used as an alternate fuel in case of a coal shortage (i.e., heater sized for coal firing).
		Heat Transfer to Sodium	MWt	265			
		Sodium Flow	kg/hr (lb/hr)	2.5×10^6 (5.4×10^6)			
		Sodium Pressure Drop	MN/m^2 (psi)	.483 ±.035 (70 ±5)			
		Sodium Pressure	MN/m^2 (psi)	1.277 (185)			
		Sodium Discharge Temperature	^oC (^oF)	593 (1100)			
		Sodium ΔT	^oC (^oF)	305 (550)			
		Combustion Efficiency	percent	87			Based on higher heatingr value and maximum sodium flow
		Availability	percent	90			
		Operating Conditions:					
		Continuously, Controllable Heat Transfer Range	MWt	53 265			
		Minimum Sodium Flow	kg/hr (lb/hr)	490,090 (1.08×10^6)			
		Sodium Flow Transient	%/sec.	1.0			

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DESIGN DATA SHEET

PREPARED BY W. W. Willcox, ESG; J. Slavens, B&W	APPROVED BY	TITLE Solar Central Receiver Hybrid Power System Fossil Heater	NUMBER
		WBS NO.	DATE February 13, 1979

NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
		Fuel Handling Equipment:		Direct feed from pulverizers to burners			This arrangement is chosen on the basis of economics. A unit turndown ratio of 5:1 can be achieved with half of the burners in operation.
		Combustion Equipment:					
		Total Heat Input From Fuel	MWt	304.7			
		Total Air	percent	115			NO_x considerations
		Fuel Feed Rate	Metric ton/hr (ton/hr)	49.9 (55)			(B&W standards)
		Pulverizers:					
		Type		ball and race			
		Number	ea.	4			
		Burners:					
		Type		dual register			Dual-register burners specified for NO_x control.
		Number	ea.	8			Burners and associated pulverizers are operated as complete units.
		Minimum Secondary Air Temperature	^oC (^oF)	260 (500)			
		Heat Input/Burner	(MWt)	38.09			
		Burner Arrangement	(2) horizontal rows (4) burners per row (2) burners (same row) per pulverizer				The arrangement was chosen to achieve the maximum unit turndown to add flexibility to shut down a complete burner row while maintaining good distribution.

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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
		Structural Design:					
		Useful Life	year	30			
		Structural Code					UCB Zone 3
		Pressure Vessel Code					ASME Section VIII Division 1
		Piping Code					ANSI B31.1
		Sodium Containment Material					TBD
		Sodium Corrosion Allowance	cm (in.)	.03 (0.01)			
		Environmental Conditions:					
		Wind Velocity	m/sec. (mph)	3.5 (8 ave. 55 max.)			A 10621, systems requirement definition
		Altitude	m (ft)	730 (2400)			
		Temperature	^oC (^oF)	-30 min. +50 max. (-20 min. 120 max.)			
		Rainfall	cm (in.)	101.6 (40 ave)			
		Seismic	g	0.2 horizonta 0.1 vertical			UCB Zone 3 (static analysis)
		Interfaces:					
		Main Sodium Inlet and Disch. Nozzles	cm x cm (in. x in.)	TBD			Welded -
		Vents and Drains - Size and Number	cm (in.)	TBD			
		Electric Power	kW	TBD			
		Emergency Power	kW	TBD			

NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TEN-TATIVE	FIRM	REFERENCES AND REMARKS
		Uninterruptable Power	kW	TBD			
		Fuel Oil - Size and Numner	cm (in.)	TBD			
		Nitrogen		TBD			
		Argon		TBD			
		Plant Control		TBD			
		Plant Protection		TBD			
		Natural Gas		TBD			
		Baseline Design Details:					
		Size:					
		Plan	m x m (ft x ft)	10 x 8.2 (33 x 27)			
		Height	m (ft)	27.4 (90)			
		Stack Height	m (ft)	(TBD)			
		Thermohydraulics:					
		Sodium Flow	kg/hr (lb/hr)	2.5×10^6 (5.4×10^6)			
		Sodium In-Out Temperature	^oC (^oF)	305-593 (550-1100)			
		Sodium In-Out Pressure	MN/m^2 (psig)	1.28-1.25 (185-115)			
		Heat Release	MWt	304.7			
		Heat Absorption - Radiant Section	MWt	121.9			
		Flux Density - Radiant Section	MWt/m^2	0.16			

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DESIGN DATA SHEET

PREPARED BY	APPROVED BY	TITLE	NUMBER
W. W. Willcox, ESG J. Slavens, B&W		Solar Central Receiver Hybrid Power System Fossil Heater	
		WBS NO.	PAGE 5 of 8 DATE February 13, 1979

NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
		Heat Absorption - Convection Section	MWt	143.1			
		Flux Density - Convection Section	MWt/m^2	.023			
		Air Preheat Exchange	MWt	26.4			
		Hot-Gas Flow	kg/hr (lb/hr)	454,540 (1×10^6)			
		Calculated Efficiency	percent	87			
		Radiation Loss	percent	.23			
		Flue Gas Temperature:	^oC (^oF)				
		Leaving Radiant Section		1149 (2100)			
		Leaving H.T. Convection		788 (1450)			
		Leaving L.T. Convection		371 (700)			
		Leaving Air Convection		149 (300)			
		Air Temperature:					
		Ambient		28 (83)			
		Leaving Air Heater		260 (500)			
		Sodium Temperature:					
		Inlet		288 (550)			
		Leaving L.T. Convection		372 (701)			
		Leaving Radiant Section		514 (958)			
		Leaving H.T. Convection		593 (1100)			

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TITLE	Solar Central Receiver Hybrid Power System Fossil Heater
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PREPARED BY	W. W. Willcox, ESG J. Slavens, B&W
APPROVED BY	

NEW REV	NO.	ITEM	DESIGN POINT UNIT	VALUE	TEN-TATIVE	FIRM	REFERENCES AND REMARKS
		Fuel Characteristics:					
		Type					ASTM Class III Group 2 coal (subbituminous)
		Origin					Colorado - Grant Mine
		Proximate Analysis (As-Fired)	wt %				
		Mositure		20.8			
		Volitile Material		30.0			
		Fixed Carbon		43.8			
		Ash		5.4			
		Heat Value (Higher)	kWt/kg (Btu/lb)	6.2 (9670)			
		Fuel Ultimate Analysis:	As-fired wt %				
		Ash		5.4			
		S		0.6			
		H_2		3.2			
		C		57.6			
		Mositure		20.8			
		N_2		1.2			
		O_2		11.2			

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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TEN-TATIVE	FIRM	REFERENCES AND REMARKS
		Heat Transfer Surface:					
		Tube OD	cm (in.)	2.2 (.875) 6.35 (2.5) 6.35 (2.5)			Radiant section H.T. convection section L.T. convection section
		Inside Film Coefficient	$W/cm/^oC$ ($Btu/hr/^oF/ft^2$)	26 (1500) 17.3 (1000) 17.3 (1000)			Radiant section H.T. convection section L.T. convection section
		Max. Tube Wall Temperature	^oC (^oF)	517 (963) 596 (1105) 374 (706)			Radiant section H.T. convection section L.T. convection section
		Number of Passes		1 21 56			Radiant section H.T. convection section L.T. convection section
		Overall Tube Length	m (ft)	22.9 (75) 89.6 (294) 186.6 (612)			Radiant section H.T. convection section L.T. convection section
		Total Contained Sodium Volume	m^3 (ft^3)	TBD			
		Forced-Draft Fans:					
		Number		1			
		Volumetric Flow	m^3/min (cfm)	6.27×10^7 (6.75×10^8)			
		Discharge Pressure	MN/m^2 (in H_2O)	TBD			
		Horsepower		TBD			
		RPM		TBD			

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PREPARED BY W. W. Willcox, ESG J. Slavens, B&W	APPROVED BY	TITLE Solar Central Receiver Hybrid Power System Fossil Heater
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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TEN-TATIVE	FIRM	REFERENCES AND REMARKS
		Induced-Draft Fans:					
		Number		1			
		Suction Pressure	MN/m^2 (in H_2O)	TBD TBD			
		Horsepower		TBD			
		RPM		TBD			
		Water Required	kg/sec. (gpm)	TBD			
		Electrical Power	kW/hr	TBD			
		Gas Recirculation Fan:					
		Number		1			
		Discharge Pressure	MN/m^2 (in H_2O)	TBD TBD			
		Horsepower		TBD			
		RPM		TBD			

SOLAR CENTRAL RECEIVER HYBRID POWER SYSTEM

COLLECTOR SUBSYSTEM

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DESIGN DATA SHEET

TITLE	NUMBER
SOLAR CENTRAL RECEIVER HYBRID COLLECTOR SUBSYSTEM	
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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
		General					
		Total Field Area (Excluding Central Exclusion)	$10^6 m^2$ ($10^6 ft^2$)	0.60 (6.0)			
		Number of Heliostats	--	8,464 Inverted			
		Total Mirror Area	$10^6 m^2$ ($10^6 ft^2$)	.126 (1.36)			
		Peak Power @ 950 w/m^2	MW	235			
		Annual Collectable Energy	MWH_t	547,000			
		Tower Height	m (ft)	129 (423)			
		Receiver Centerline Elevation	m (ft)	135 (443)			
		Heliostat Arrangement	--	Radial Stagger			
		Aim Strategy	--	1-Point Equator			
		Peak Receiver Heat Flux	MW/m^2	1.37			

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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TEN-TATIVE	FIRM	REFERENCES AND REMARKS
		Heliostat					
		Reflector Shape	--	Square			
		Reflector Envelope	m (ft)	7.0 x 7.0 (23.0 x 23.0)			
		Mirror Type		Second Surface, silvered fusion/float laminated glass			
		Mirror Area	m^2 (ft^2)	49.0 (527)			
		Average Reflectivity		0.91			
		Drive System					
		Elevation		Dual screw jacks 3 Ø, 480V ac			
		Azimuth		Harmonic drive 3 Ø, 480V ac			
		Reflected Beam Accuracy	(mr)	2.83			
		Drive Rate					
		Elevation	Deg/min	15			
		Azimuth	Deg/min	15			

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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TEN-TATIVE	FIRM	REFERENCES AND REMARKS
		Cant Range	m (ft)	1190 (3900)			
		Electrical Draw					
		Motor Running (Steady State)	amp	1.5			
		Motor Start Surge Current	amp	3.0			
		Time Average Power Draw (per Heliostat Incl Electronics)	Watts	~39			
		Individual Heliostat Availability	--	0.9999			
		Field Electronics					
		Primary Feeder Power	Voltage	4160			
		Primary Feeder Cable	Awg	#4			
		Secondary Feeder Power	Voltage	480			
		Data Network	--	Fiber Optics			

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jcs:4/1-3

SOLAR CENTRAL RECEIVER HYBRID POWER SYSTEM

THERMAL STORAGE SUBSYSTEM

ALL-SODIUM STORAGE

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DESIGN DATA SHEET

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APPROVED BY	
TITLE	Solar Central Receiver Hybrid Thermal Storage Subsystem
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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TEN-TATIVE	FIRM	REFERENCES AND REMARKS
		Thermal Storage Subsystem					
		Storage Material		Sodium			
		Number of Tanks		1			
		Thermal Storage Capacity	MWt	156			
		Maximum Charging Rate	MWt	260			
		Maximum Extraction Rate	MWt	260			
		Time at Maximum Extraction Rate	hr	0.6			
		Weight of Sodium in Subsystem	kg (lb)	1.5×10^6 (3.3×10^6)			
		Temperature - Cold Tank Storage	^oC (^oF)	288 (550)			
		Large Valves - 25.4-cm (10-in.) Block		2			CS and SS
		- 25.4-cm (10-in.) Drag		1			SS
		Large Pipe Length - 25.4 cm (10 in.)	in (ft)	73 (240)			CS, Standard Wall
		- 25.4 cm (10 in.)	in (ft)	107 (350)			SS, Standard Wall
		Low-Temperature Sodium Tank					
		Number		1			
		Type					Cylindrical API Type
		Diameter	m (ft)	17.5 (56)			
		Height	m (ft)	6.6 (21)			

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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
		<u>Low-Temperature Sodium Tank</u> (Continued)					
		Wall Thickness					
		Top	cm (in.)	0.64 (0.25)			
		Bottom	cm (in.)	2.5 (1.0)			
		Volume	m^3 (gal)	1,476 (3.9×10^5)			
		Tank Material					Carbon Steel
		Insulation, Roof, and Walls	cm (in.)	15.2 (6)			Calcium Silicate with Aluminum Weather Protection
		Base Insulation	m (ft)	1 (3)			Perlitic Concrete
		Electric Preheat-Temperature Maintenance	kW	274			Low Sodium Temperature
		Low Sodium Temperature	^oC (^oF)	288 (55)			
				Argon			
		Ullage Maintenance Unit					
		Ullage Pressure	MN/m^2 (psi)	0.0069 (1)			
		Pressurization Media					
		<u>High-Temperature Sodium Tank</u>					
		Type					Cylindrical Medium Pressure
		Diameter	m (ft)	17.5 (56)			
		Height	m (ft)	7.2 (23)			
		Wall Thickness					
		Top	cm (in.)	0.64 (0.25)			
		Bottom	cm (in.)	5.1 (2.0)			

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TITLE	Solar Central Receiver Hybrid Thermal Storage Subsystem
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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
		High-Temperature Sodium Tank (Continued)					
		Volume	m^3 (gal)	1,590 (4.2×10^5)			
		Tank Material, Thickness	cm (in.)	0.64 (0.25 - 2.5 (1.0)			Type 304 SS
		Insulation, Roof, and Walls	cm (in.)	30.5 (12)			Calcium Silicate with Aluminum Weather Protection
		Base Insulation	m (ft)	1 (3)			Perlitic Concrete
		Electric Preheat-Temperature Maintenance	kW	540			
		Number of High-Temperature Tanks		1			
		High Sodium Temperature	^oC (^oF)	593 (1,100)			
		Ullage Maintenance Unit		Argon			
		Ullage Pressure	MN/m^2 (psia)	1.4 (200)			
		Drag Valve					
		Location					Upstream of High-Temperature Sodium Storage Tank
		Type					Babcock-Wilcox Drag Valve with Velocity Control Elements Type SL II
		Size (nominal)	in.	10			

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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
		Drag Valve (Continued)					
		Flow Rate	m^3/s (gpm)	0.77 (12,200)			
		Pressure Drop	MN/m^2 (psi)	1.74 (253)			
		Pressure Rating	MN/m^2 (psi)	2.75 (400)			
		Temperature	^oC (^oF)	649 (1,200)			
		Flow Coefficient, C_v	$m^3/sec/\sqrt{MN/m^2}$ $(gpm/\sqrt{psi})$	.582 (767)			
		Operator					Yes--Type TBD
		Insulation	in.	8			Calcium Silicate
		Material					Stainless Steel; Inconel Velocity Control Elements
		Pressure Class					ANSI 2,500 lb

dmb:216

SOLAR CENTRAL RECEIVER HYBRID POWER SYSTEM

MASTER CONTROL SUBSYSTEM

Rockwell International
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DESIGN DATA SHEET

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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TEN-TATIVE	FIRM	REFERENCES AND REMARKS
N	1	Plant Central Control Console (1)					
		Length	ft	25			
		Depth	ft	2			
		Height	ft	4			
R	2	Control Processors (5)					
		Throughput	KOPS/sec	350			
		Primary Storage Capacity	16 bit words	48,000			
R	3	Secondary Control Processor Storage (5)					
		Capacity	Megabits	.25			
		Access Time	Msec	35			
		Latency	Msec	15			
N	4	Hardcopy Logger (2)					
		Characters	Per Line	132			
		Speed	Lines/Min	300			
N	5	Recorders, Magnetic (2)					
		Density	Bits/in.	500/800			
		Speed	in./sec	45			
N	6	Safing - Control Panel (1)	TBD	TBD			
N	7	Serial Digital Data Bus (2)					
		Throughout	<bits/sec	1500			
R	8	Color CRT Displays (5)					
		Raster Scan	No. Lines	256 x 512			
		Colors	No.	4			

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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
N	9	PID Controllers (100)					
		Microprocessor Loop Update Rate	Per sec	3			
		Scaling	%	0 - 100			
		Resolution	Bits	12			
		Output	MV	4-20			
N	10	Discrete Controllers (125)					
		Resolution	Bits	12			
		Output	MV	4-20			
N	11	Analog Data Acquisition (350)					
		Normal Rate	Chan/sec	350			
		Emergency Rate	Chan/sec	200,000			
		Resolution	Bits	12			
		Multiplexing	Type	Sequential			
N	12	Analog Outputs (TBD)	TBD	TBD			
N	13	Closed-Circuit Television (4)					
		Monitor Size	In.	19			
		Camera	TBD	TBD			
		Auto Pan/Tilt	Degrees	90			
		Zoom	TBD	TBD			
N	14	Uninterruptible Power Source					
		Ten input	V ac	115 ±10%			
		Regulated 10 output	V ac	115 ±2%			
		Storage Battery Capacity		.5			
		Derated Power	KVA	TBD			

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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TEN-TATIVE	FIRM	REFERENCES AND REMARKS
N	15	Time of Day Reference					
		Input-WWV Synch.	Hertz	1000			
		Output - Time of Day BCD Format	Bits	31			
N	16	Annunciator Panel	Functions	25			
N	17	Local Weather Station Wind					
		Barometric Pressure	MPH	80			
			Degrees	360			
		Humidity	in./HG	26-34			
		Solar Radiation	Percent/Rel	0-100			
		Precipitation	$9M/CM^2/min$	.36-2.0 microns			
		Temperature	in.	20			
			deg F	-15, +50			

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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
N	1	Video Camera System (4)					
		Self-Contained Camera including Environmental Housing and Sync Generator	Ambient Temp ^{0}C	-20 to +60			
			Weight -#	27			
			Volume -M^3	.34			
		Lens	Speed	f 2.8			
			Focal Length	32-320 MM Zoom			
N	2	Video Signal Processing System. Composite Video Input, Serial Digital Output. (4)					
		A/D Conversion	Word Length-bit	10			
			Conversion Time- S	32			
		Controller	TBD				
		Line Driver	Level - Diff Volts	0.25			
			Distance - M.	1500			

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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
N	3	Target Panels, Tower Mounted 1/4-in. Steel, Painted (4)	Size - M.	Approx. 12 x 12			
N	4	Target Instrumentation System (4)					
		Radiance Sensors	TBD				
		Shutter Controller	TBD				
		MUX - A/D	TBD				
N	5	Data Line - RG-11/U (5)	Avg. length M.	1000			

SOLAR CENTRAL RECEIVER HYBRID POWER SYSTEM

ELECTRIC POWER GENERATION

Rockwell International
Energy Systems Group

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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TEN-TATIVE	FIRM	REFERENCES AND REMARKS
		Turbine					
		Type					Tandem Compound, Double-Flow, Extraction, Condensing Turbine
		Rating (kWe)		112,000			
		Heater Extractions		6			
		Shaft Speed (rpm)		3,600			
		Last Stage Bucket Size, cm (in.)		58.4 (23)			
		Throttle Flow Control Mode					Steam Generator/Turbine Coordinated Control
		Generator					
		Generator Rating (kVA)		130,000			
		Power Factor		0.9			
		Output Voltage (V)		13,800			
		Frequency (hz)		60			
		Cooling					Hydrogen Cooled
		Exciter					Static Excitation System
		Shaft Speed (rpm)		3,600			
		Condenser					
		Type					Shell and Tube, Two-Pass
		Surface, m^2 (ft^3)		9,431 (101,500)			
		Tube Material		90-10 Copper			ASTM BIII, Alloy 706
		Tube Diameter OD, mm (in.)		22.2 (0.875)			

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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TENTATIVE	FIRM	REFERENCES AND REMARKS
		Condenser (Continued)					
		Tube Wall Thickness, mm (in.)		0.89 (0.035)			20 BWG
		Tube Length, Effect, m (ft)		8.54 (28)			
		Condenser Pressure, k/Pa (in.-HgA)		6.71 (2.0)			
		Heat Rejection, MW (Btu/hr)		1.73 (590×10^6)			
		Cooling Water Flow, m^3 (gpm)		5.3 (84,250)			
		Water Velocity, m/s (fps)		2.13 (7.00)			
		Cooling Water In, ^oC (^oF)		31.1 (88.0)			
		Cooling Water Out, ^oC (^oF)		39.0 (102.0)			
		Condenser Air Removal		-			Mechanical Vacuum Pump (Two-full capacity)
		Cooling Tower					
		Quantity		1			
		Type					Mechanical Draft, Cross Flow
		Number of Cells		5			
		Fan Motor Size, kW (hp)		5-150 (200)			
		Design Wet Bulb Temperature, ^oC (^oF)		23 (73.4)			
		Cold Water Temperature, ^oC (^oF)		31.1 (88.0)			
		Hot Water Temperature, ^oC (^oF)		39.0 (102.0)			
		Circulating Water Flow, m^3/s (gpm)		5.3 (84,250)			
		Heat Rejection, MW (Btu/hr)		173 (590×10^6)			

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NEW REV	NO.	ITEM	DESIGN POINT UNIT	DESIGN POINT VALUE	TEN-TATIVE	FIRM	REFERENCES AND REMARKS
		<u>Feedwater Heaters</u>					
		Low-Pressure Heater	Number	2			Horizontal, Stainless Steel Tubes, Carbon Steel Shell with Drain Cooler, Maximum Tube Side Pressure: 2.2 MPa (315 psia)
		Deaerator	Number	1			Stainless Steel Trays and Vent Condenser, Carbon Steel Shell, Horizontal Condensate Storage Section, 75.7 m^3 (20,000 gal), Pressure Rating: 0.45 MPa (65 psia)
		High-Pressure Heater	Number	3			Horizontal, Carbon Steel Tubes, Carbon Steel Shell with Drain Cooler, Maximum Tube Side Pressure: 17.23 MPa (2,500 psia)
		<u>Feedwater Treatment</u>					
		Equipment					
		- In-Line Polishing Demineralizers					Two Full-Capacity Units
		- Makeup Water Demineralizers					Two Full-Capacity Units
		Chemicals					
		- pH Control					Ammonia
		- Oxygen Scavenger					Hydrazine
		dmb:216					