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A User's Manual For DELSOL2: A Computer Code For Calculating the Optical Performance and Optimal System Design For Solar-Thermal Central-Receiver Plants

MASTER

T. A. Dellin, M. J. Fish, C. L. Yang

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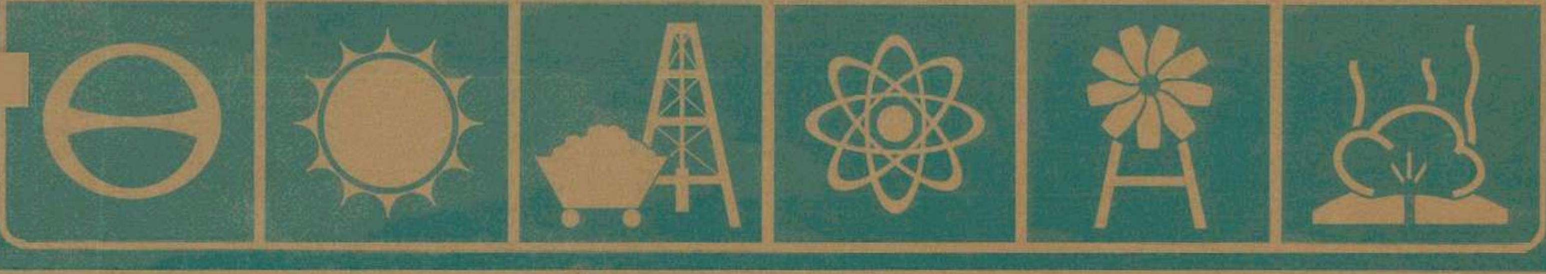

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A USER'S MANUAL FOR DELSOL2: A COMPUTER CODE FOR CALCULATING THE OPTICAL PERFORMANCE AND OPTIMAL SYSTEM DESIGN FOR SOLAR-THERMAL CENTRAL-RECEIVER PLANTS

Theodore A. Dellin
Systems Development Division
Sandia National Laboratories, Albuquerque – 9511100

Miriam J. Fish
Thermal Sciences Division
Sandia National Laboratories, Livermore – 9511238

Christine L. Yang
Large Power Systems Division
Sandia National Laboratories, Livermore – 9511238

ABSTRACT

DELSOL2 is a revised and substantially extended version of the DELSOL computer program (SAND79-8215) for calculating collector field performance and layout, and optimal system design for solar thermal central receiver plants. The code consists of a detailed model of the optical performance, a simpler model of the non-optical performance, an algorithm for field layout, and a searching algorithm to find the best system design. The latter two features are coupled to a cost model of central receiver components and an economic model for calculating energy costs. The code can handle flat, focused and/or canted heliostats, and external cylindrical, multi-aperture cavity, and flat plate receivers. The program optimizes the tower height, receiver size, field layout, heliostat spacings, and tower position at user specified power levels subject to flux limits on the receiver and land constraints for field layout. The advantages of speed and accuracy characteristic of Version I are maintained in DELSOL2.

ACKNOWLEDGMENTS

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I. Introduction

A USER'S MANUAL FOR DELSOL2

I. Introduction

In central receiver systems, a large number of individually tracking mirrors, called heliostats, are used to concentrate sunlight on a receiver at the top of a tower. These systems have the potential to deliver thermal energy over a wide range of power levels and temperatures. Applications include central station electric power generation, industrial process heat and production of fuels and chemicals. Analytical techniques are required because it is impractical to investigate experimentally the wide ranges of design and application alternatives for central receivers. Furthermore, the analysis must be computer based because of: 1) the large number (i.e., thousands) of heliostats in many single system designs; 2) the strong time dependence of system performance due to the motion of the sun; and 3) the large number of options which have to be considered in optimal design. The DELSOL computer program was generated to fill the need for an accurate, but fast, easy to use and documented code for performance and design applications. Version I, which analyzed large power electric applications, was released in August 1978. The present Version II improves and extends the capabilities of Version I. Version II can handle both large and small power systems for electricity and process heat applications. The code consists of a detailed model of the optical performance, a simpler model of the non-optical performance, an algorithm for field layout, and a searching algorithm to find the best system design. The latter two features are coupled to a cost model of central receiver components and an economic model for calculating energy costs.

Figure I-1 indicates schematically how the components of DELSOL are used in the two general classes of application. In (A), the complete system design (which may have been previously optimized by DELSOL) is specified by the user and the code calculates the performance. Typical applications include design point evaluation and analysis of experiments at test facilities. In (B), the heliostat design, the range of system variables to be optimized, and the design constraints are specified by the user and the code calculates optimal designs for a range of power levels. Typical applications include system optimization and component design tradeoff studies.

As an optical performance tool, DELSOL simulates the effects of cosine, shadowing, blocking, atmospheric attenuation, spillage, and flux profiles. The code has several special features. First, the running time for a single performance calculation is much less than for other codes, such as MIRVAL (ref. 1), but with the same accuracy for most problems. Second, because of the analytical form of the spillage and flux, one annual performance calculation determines the performance for any tower height or receiver size. Other

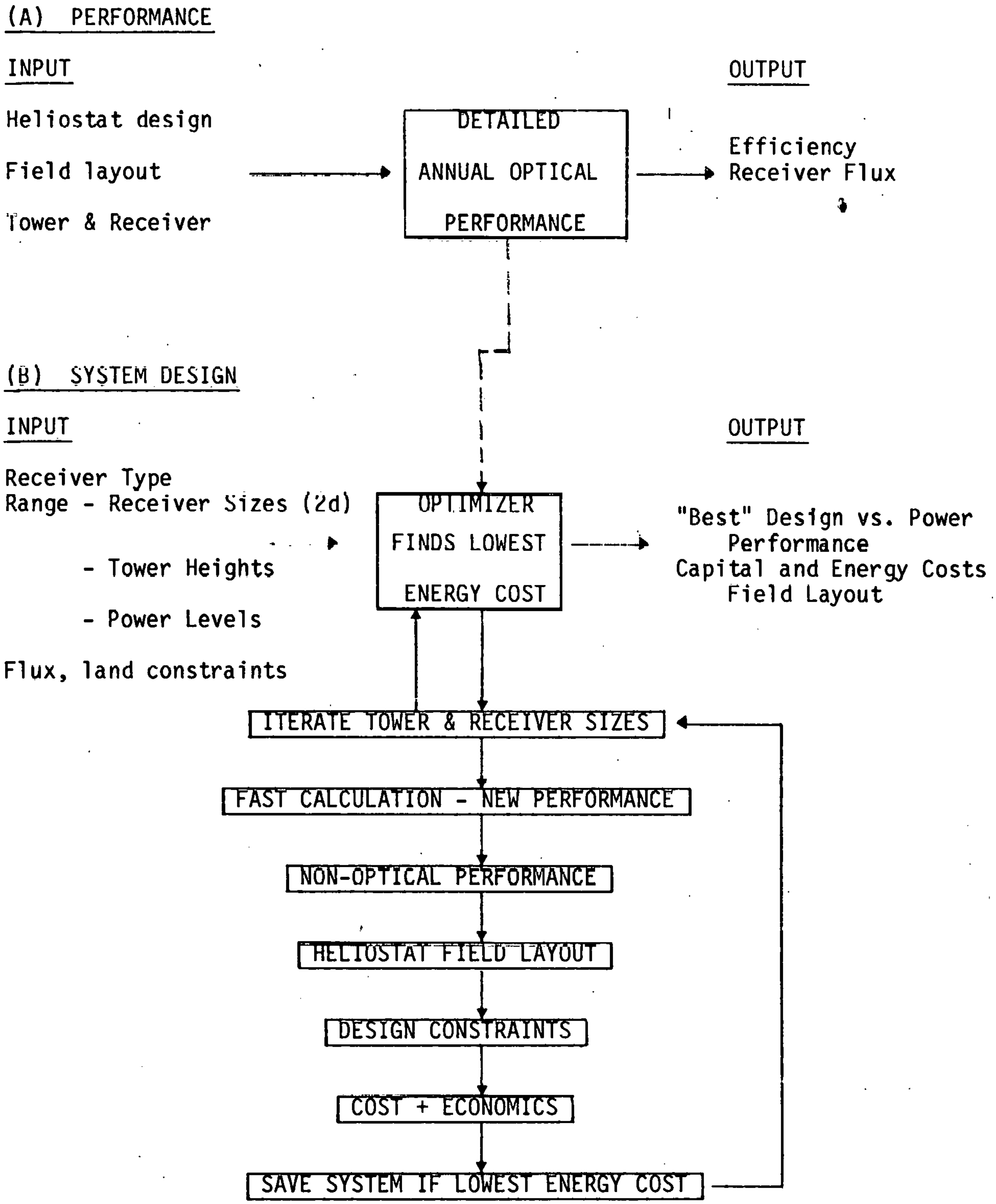


Figure I-1. Two General Types of Applications of DELSOL codes must perform a new calculation every time the system is varied. DELSOL, therefore, has a very significant advantage in the running time required for the large number of performance calculations necessary in design tradeoff and optimization studies. Third, DELSOL contains a very detailed description of the types of errors that can degrade the performance of heliostats. Finally, DELSOL is relatively easy to use. With minimal input, systems involving flat, focused, or canted heliostats with round or rectangular shapes, external, multiple aperture cavity, or multiple flat plate receivers, and variable aiming strategies can be analyzed.

As a system design tool, DELSOL determines the best combination of field layout, heliostat density, tower height, receiver size and tower position (land constrained system) based on the performance, total plant capital cost, and system energy cost. In this mode, the code can be used to define values of the key design parameters on which a detailed design can be based. The need for manually doing a succession of point designs in the order to identify an optimum is eliminated. The optimal design is evaluated by searching over a range of tower heights and two components of the receiver dimension (e.g., diameter and height of an external receiver) at the design point power level(s) to find the system with the minimum energy cost. The code is also capable of doing constrained optimizations in which the peak flux on the receiver is restricted below some maximum value and/or land availability is limited.

The development of DELSOL followed that of Sandia's other two central receiver performance codes, MIRVAL and HELIOS (refs. 1,2). The earlier codes have been used to validate the theory and programming in DELSOL. The agreement in performance predictions among the three codes is discussed in Section VII. While any one of the codes can, in principle, do the same kinds of problems, they have been developed with different purposes in mind and thus do not greatly overlap in use. HELIOS is specially adapted for analyzing experiments at Sandia's Central Receiver Test Facility. MIRVAL employs a Monte Carlo ray trace technique, giving it the potential to analyze very complex, but well defined systems. DELSOL has been developed with speed in mind; hence it typically requires much less computer time for performance calculation, and it can also readily handle the multiple performance calculations required for system design and optimization.

DELSOL is based in part on the performance/design approaches developed at the University of Houston (refs. 3,4), but with many important additions. The mathematical basis is an analytical Hermite polynomial expansion/convolution of moments method for predicting the images from heliostats (ref. 3). The method has been extended at Sandia to allow a more general representation of heliostat errors and to incorporate analytical scaling of the images as the tower height is varied (ref. 5). DELSOL also employs a method for optimizing heliostat densities similar to the Houston approach (ref. 4). The primary difference in the two codes is in their design/optimization capabilities. The Houston approach considers only one tower height and receiver size at a time. These variables must be optimized by manually rerunning the Houston codes until an optimum is located. In contrast, DELSOL automatically optimizes the tower height and receiver dimension (s), saving considerable user and computer time. (The user is cautioned, however, to provide his own values for the appropriate input variables if his system of interest differs significantly in size or cost/performance from the default system description in the code.)

II. Problem Geometry

II. Problem Geometry

II.A. Coordinate Systems and Angles

The geometry used in the calculations is shown in Figures II-1 and II-2. Polar (zenith) angles are measured from vertical. Azimuthal angles are measured clockwise from the south. There are four basic vectors and coordinate systems: $\hat{s}$, from the heliostat center to the center of the sun; $\hat{n}$, directed along the heliostat normal; $\hat{t}$, the reflected vector from the heliostat center to the aim point on the receiver; and $\hat{r}$, the outward surface normal of the receiver.

The orientation of the heliostats is determined by Snell's law: the angle of incidence equals the angle of reflection, i.e.,

$$\hat{n} \cdot \hat{s} = \hat{n} \cdot \hat{t} \tag{IIA-1}$$

Solving for $\hat{n}$ and $\hat{t}$ gives

$$\hat{n} = \frac{\hat{s} + \hat{t}}{\hat{s} + \hat{t}} \tag{IIA-2}$$

$$\hat{t} = 2(\hat{n} \cdot \hat{s})\, \hat{n} - \hat{s} \tag{IIA-3}$$

The five cartesian coordinate systems are listed in Table IIA-I. The $(\hat{i}_t, \hat{j}_t)$ plane of the reflection normal system is given the special name "image plane."

II.B. Zoning

In design optimization runs, DELSOL does not consider individually each of the thousands of heliostats required in large systems. Instead, the code calculates the performance at a set of field points. It is assumed that each field point represents the average performance in a surrounding zone of heliostats. For runs in which only the performance is calculated, the field can be described with the zoning approximation, or the coordinates of each individual heliostat can be defined.

<u>II.B-1. Zoning Options</u>--There are two options for zoning: 1) zoning that completely surrounds the tower and can be used with any receiver (INORTH=0); and 2) finer zoning of the area north of the tower which can be used <u>only</u> with a single north facing cavity or flat plate receiver (INORTH=1).

a) Surround Field (INORTH=0)

The field points are located on a regularly spaced radial-azimuthal grid surrounding the tower as shown in Figure II-3. There are NRAD values of

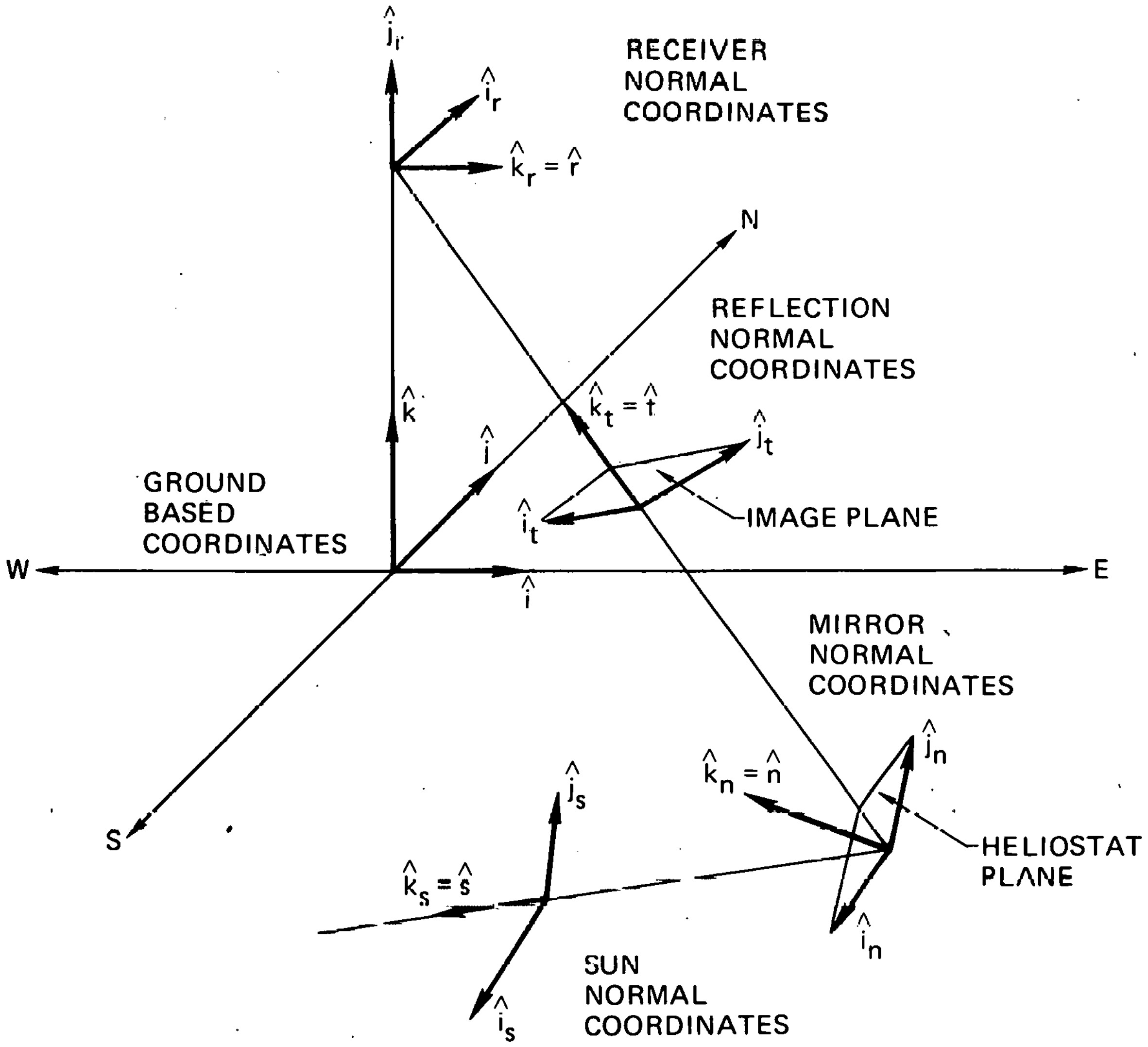


Figure II-1. Coordinate Systems for Field Performance Calculations

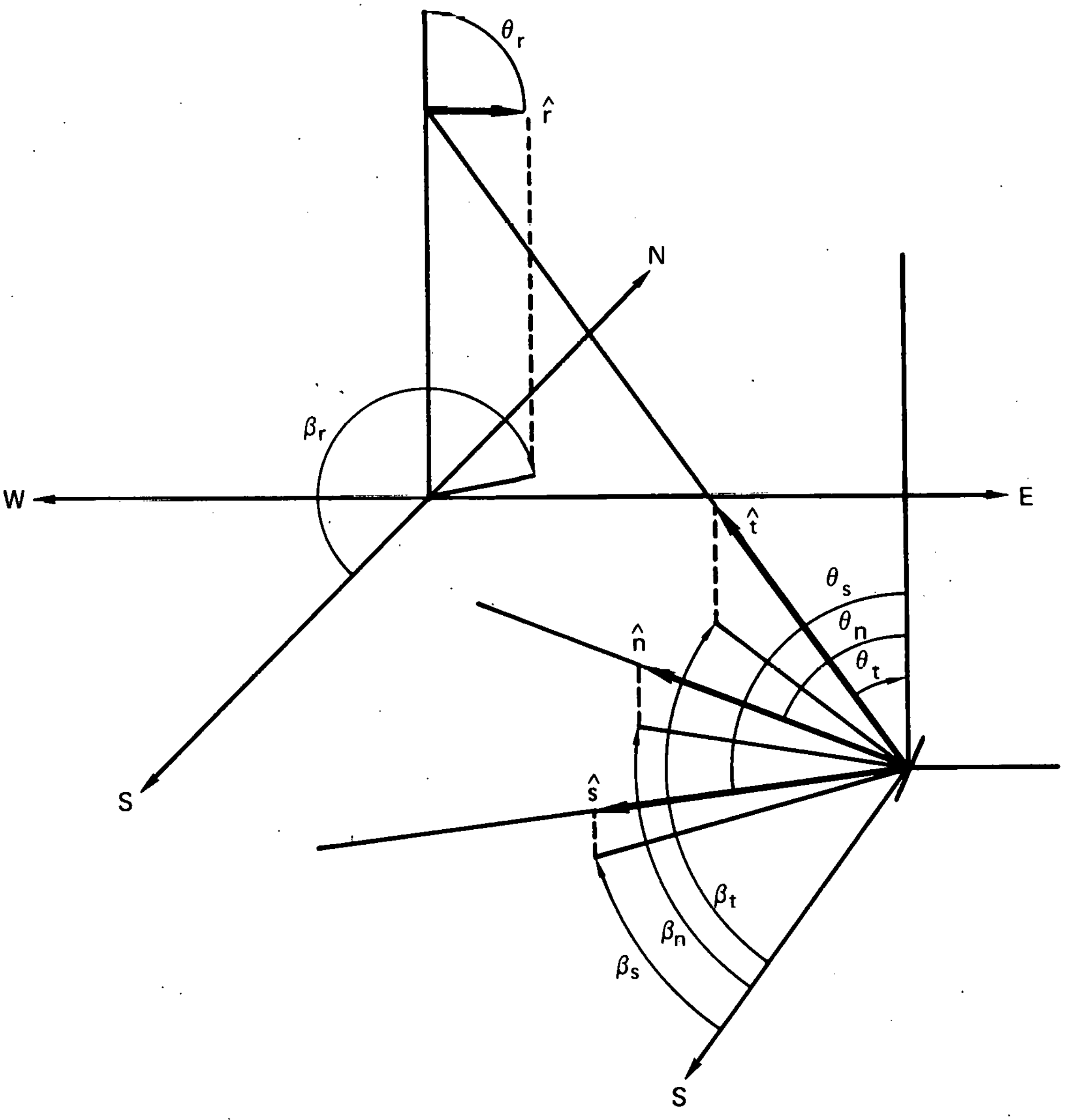


Figure II-2. Angles Associated with Sun, Mirror Normal, Reflection, and Receiver Normal Vectors

TABLE II.A-1
COORDINATE SYSTEMS

Name	Unit Vector	Value	Definition of Orientation
Ground Based	$\hat{i}$	x_g	Due south
	$\hat{j}$	y_g	Due west
	$\hat{k}$	z_g	Vertical, upward
Mirror Normal	$\hat{i}_n$	x_n	Horizontal, in plane of mirror
	$\hat{j}_n$	y_n	Vertically upward when normal is horizontal, in plane of mirror
	$\hat{k}_n = \hat{n}$	z_n	Mirror normal
Sun Normal	$\hat{i}_s$	x_s	Horizontal
	$\hat{j}_s$	y_s	Vertical at sunset
	$\hat{k}_s = \hat{s}$	z_s	Towards sun
Reflection Normal	$\hat{i}_t$	x	Horizontal
	$\hat{j}_t$	y	Upward
	$\hat{k}_t = \hat{t}$	z	Towards tower
Receiver Normal	$\hat{i}_r$	x_r	Horizontal, tangent to receiver surface
	$\hat{j}_r$	y_r	Upward, tangent to receiver surface
	$\hat{k}_r = \hat{r}$	z_r	Outward normal of receiver surface

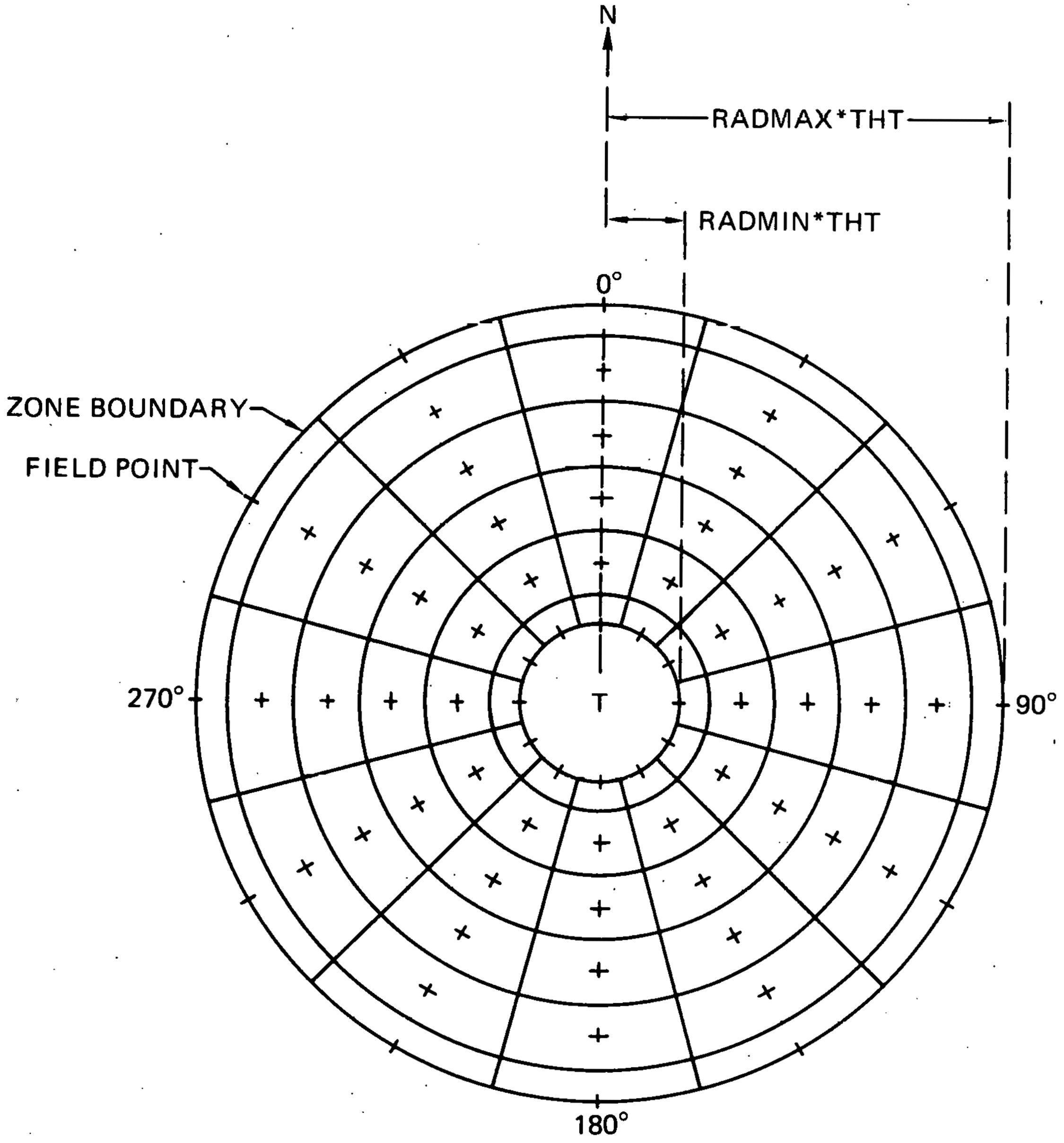


Figure II-3. Surround Field (INØRTH=0). Field Point (x's) and Field Zone Boundaries (Solid Lines) for NRAD = 6, NAZM = 12. Field azimuthal angle determined from clockwise rotation from north.

the radius from a minimum of RADMIN to a maximum of RADMAX (RADMIN and RADMAX in normalized units of tower height). There are NAZM values of the azimuthal angle with the first azimuthal value being due North. The total number of field points (and therefore, zones) is NRAD * NAZM. Observe that the field point is in the center of the zone except at the inner and outer radial boundaries where it is at the boundary.

Heliostats are located by specifying the value of the radius and the azimuthal angle of the tower vector $\underset{\sim}{t}$. $\phi_t = 0$ corresponds to a heliostat due North of the tower whose $\underset{\sim}{t}$ points due South. Similarly,

Angle ϕt	Location
0	N
45	NE
90	E
135	SE
180	S
225	SW
270	W
315	NW

b) North Field (INØRTH=1)

This option can be used only with a single north facing cavity or flat plate receiver. (In Namelist REC, IREC>0, NUMCAV=1, RAZM(1)=180.0.) The field points are located on a regularly spaced radial-azimuthal grid located north of the tower, as illustrated in Figure II-4. In addition, a "dummy" set of zones with field points due south of the tower is carried along. These southerly zones do not affect the calculations because they are automatically assigned zero intercept with north-facing receivers. The radial zoning is the same as that for the surround field (INØRTH=0). The azimuthal zones utilized are NAZM-1 in number and extend ± AMAXN degrees about the N-S axis. The default values produce 11 azimuthal zones each spanning 15° in the north part of the field. This gives half of the minimum 30° segment obtained when INØRTH=0. Default values are:

NAZM=12

AMAXN=82.5(°)

II.B-2. Field Options--The user has several options for the field performance calculation according to his choice of the parameter IUSERF in the FIELD namelist:

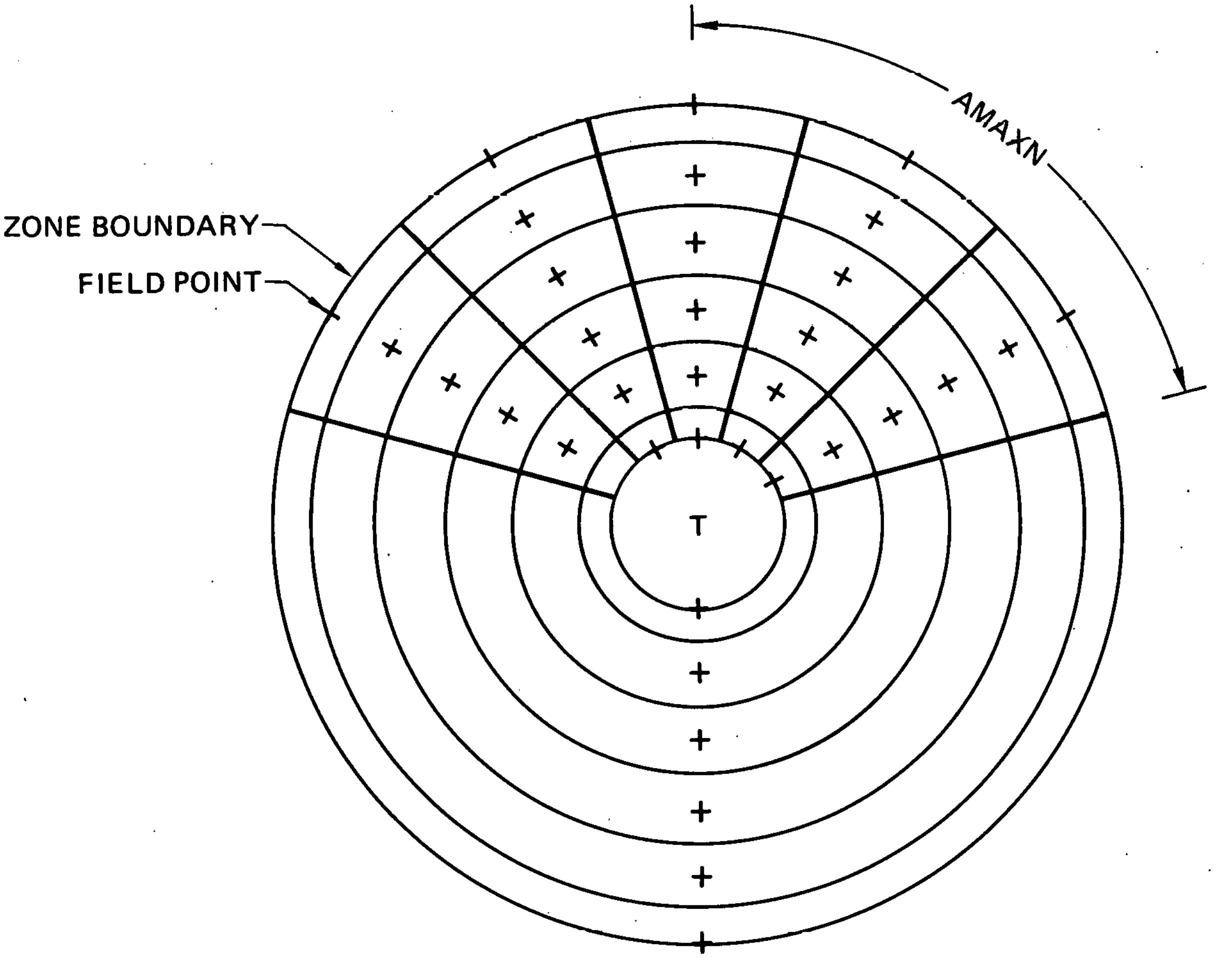


Figure II-4. North-only Field (INØRTH=1).
Field Points (x's) and Field Zone Boundaries (Solid Lines) for NRAD=6, NAZM=6, AMAXN=75. In actual problems, a larger NAZM and NRAD would probably be used.

a) IUSERF = 0

The user specifies RADMIN, RADMAX, NRAD, NAZM and INØRTH. No field boundaries are provided with this option. The code calculates and reports only the zone by zone performance for the symmetric grid defined by the five input variables above. Average field performance is meaningless in this case and therefore not calculated. This option must be used for a field buildup and optimization run (described in Section V).

b) IUSERF = 1

The code defined north biased surround field of Figure II-5 is used. User specifications of other field variables are ignored. The layout is typical of fields required for larger industrial or electrical power plants ($> \sim 250$ MW_{th} or 100 MW_e; ref. 6). Field averaged performance is calculated and reported. This option is not to be chosen for a design and optimization run.

c) IUSERF = 2

This option allows the user to define a field zone by zone. To specify such a field, the following variables must be defined: (1) RADMIN, RADMAX, NRAD, NAZM, INØRTH, and AMAXN (all described above) to set up the zoning; and (2) NRADMN, NRADMX, DENSIT, AZMSEP, and FLAND (described below) to characterize the field zone by zone. The user can always input this information on Namelist FIELD. In addition, if the user desires to do a performance calculation on a system optimized by DELSOL, two simpler methods of field input are available. First, the code will automatically carry out a performance calculation after a system optimization if IRERUN=1 in Namelist ØPT. All of the above variables will be set automatically by DELSOL (see Section VI-2). Second, the results of an optimization run can be written on a storage device (e.g., magnetic tape) by setting IØTAPE=1 in Namelist ØPT. At a later time all of the above variables can be read off this tape by setting ITAPE=2 on Namelist BASIC (see Section VI-2).

For the Lth azimuthal zone (L=1,NAZM) all radial zones are occupied from the minimum radial zone number, NRADMN(L), through the maximum radial zone number, NRADMX(L). If no zones are occupied in the Lth azimuthal zone, then NRADMN(L)=NRADMX(L)=0. The radial/azimuthal zone boundaries may not exactly match the boundaries of the user's field. The FLAND array can be used to trim the DELSOL zoning. If there is a land constraint (see Section II.B-4), FLAND will be calculated automatically by DELSOL. In the absence of a land constraint, the user may specify FLAND. For the (K,L) zone, FLAND(K,L) is the fraction of the land area in the (K,L) zone that is occupied by the heliostat field. If the whole zone is occupied, FLAND(K,L)=1.0; if half the zone is occupied, FLAND(K,L)=.5, etc. Field averaged performance is calculated and reported. This option cannot be used for a design and optimization run.

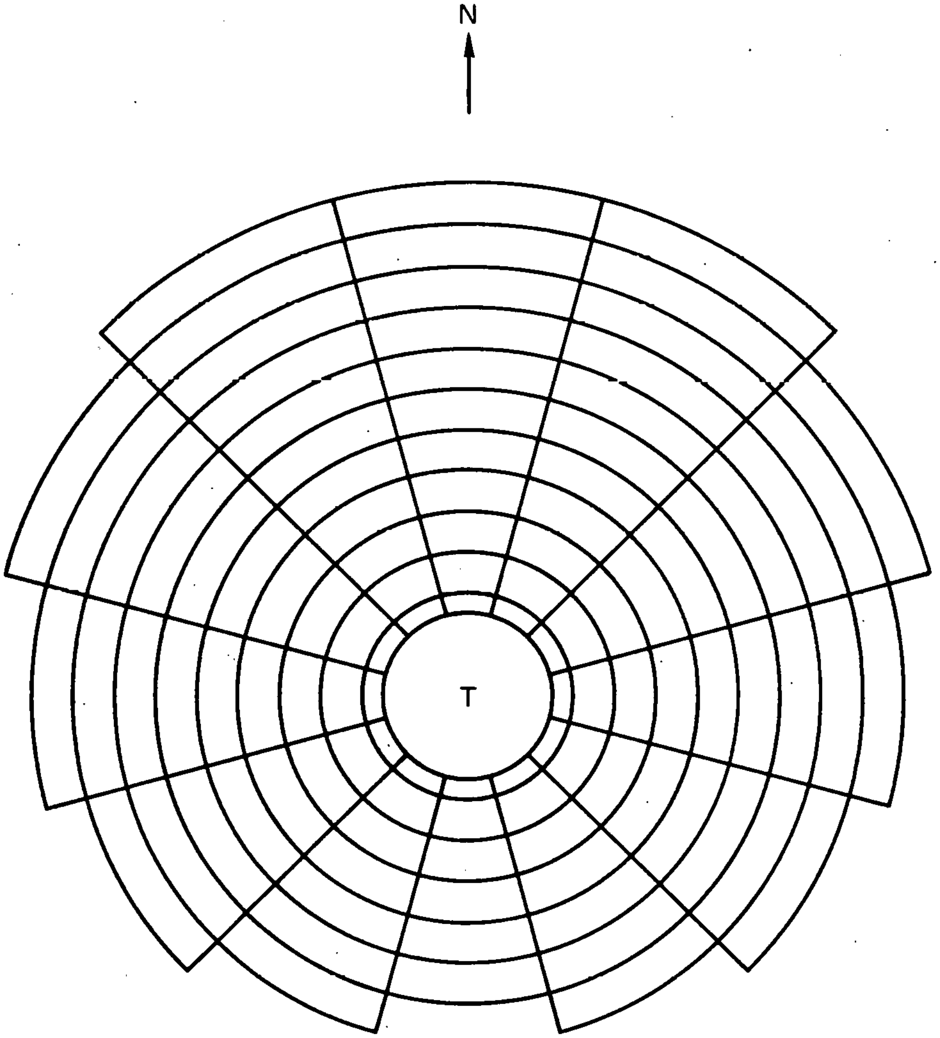


Figure II-5. Code Defined Field (IUSERF = 1). RADMIN = 0.80; RADMAX = 7.15; NAZM = 12; NRAD = 11. Letting I = 1, NAZM, boundaries are defined as follows:

I	NRADMN(I)	NRADMX(I)
1,2,12	1	11
3,11	1	10
4,10	1	9
5,9	1	8
6,8	1	7
7	1	6

d) IUSERF=3

This option allows the user to specify the x and y (east and north) coordinates of the base of every heliostat relative to the tower base. For the performance at a single time (IPRØB=2, Namelist BASIC), an asymmetrical heliostat field can be used. However, in order to calculate daily or annual performances the field must be symmetric about the N-S axis.

A special convention is used to group and number the heliostats. The heliostats are grouped into "rows" as illustrated in Figure II-6. In a field that surrounds the receiver the rows will usually be completely or partially filled circles. In a north-only field the rows will be arcs or lines. The rows do not intersect. The rows are numbered starting with the row nearest the tower and proceeding outward. Within each row the heliostats are numbered starting with the heliostat on the N/S line or just east of the N/S line. The numbering increases in a clockwise manner around the tower. Note that for a line or arc of heliostats (see row 4 in Figure IV-6) the number starts in the middle, proceeds to the eastern edge, goes to the western edge and then heads to the middle again. The code considers the shading and blocking by only those heliostats within ± two rows of the row in which the heliostat of interest is located.

Concerning the choice of NRAD and NAZM, the larger each is, the greater the number of zones, and hence, the greater the accuracy. The cost is increased computing time. The running time is approximately linear with the number of zones while the increase in accuracy with number of zones follows a "law of diminishing returns." The default values offer a good compromise:

NRAD = 12   INØRTH = 0

NAZM = 12   AMAXN = 82.5

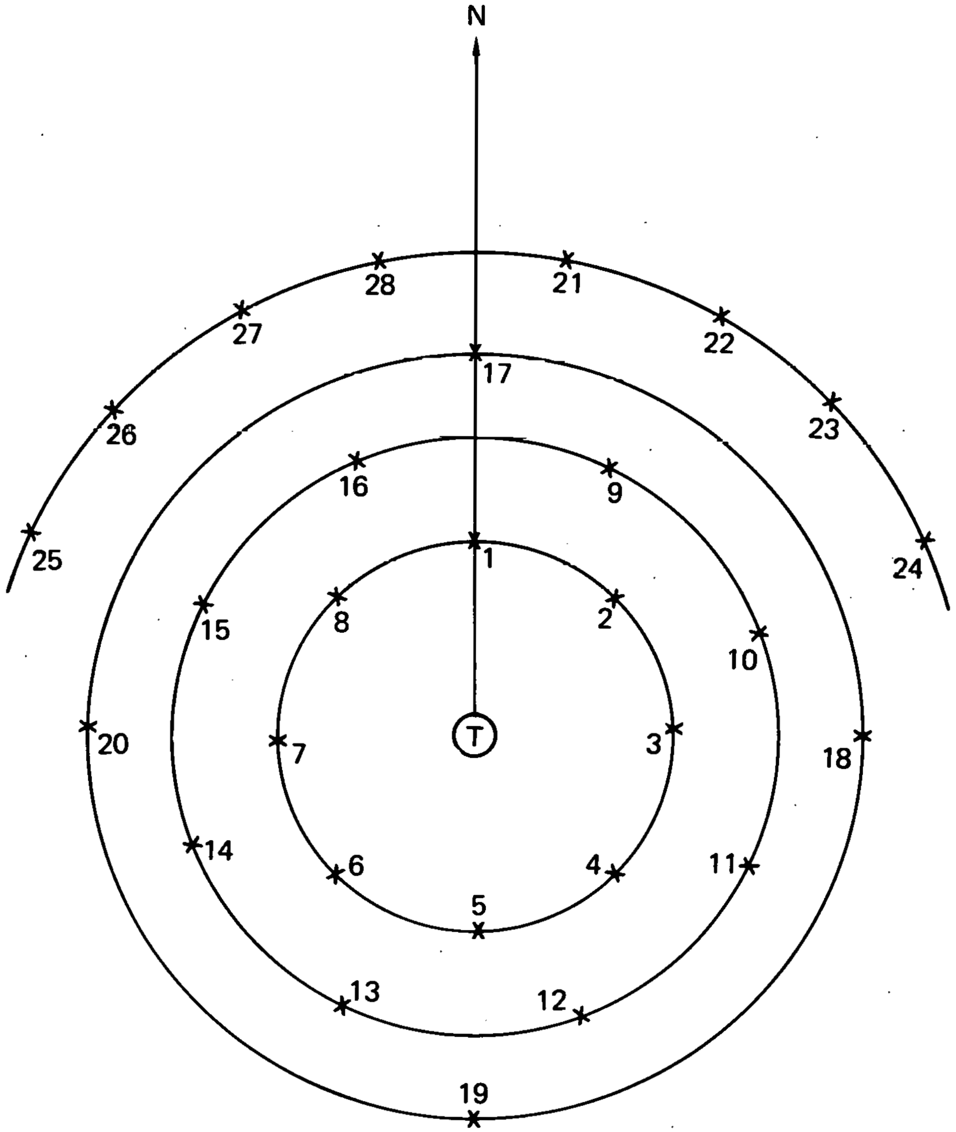
The default field option is the first one, and the default field limits encompass most designs:

IUSERF = 0

RADMIN = 0.75

RADMAX = 7.5

II.B-3. Rotating Fields--DELSOL can analyze central receiver systems that rotate (IRØTFL≠0). The rotation is synchronous with the azimuthal motion of the sun. An observer rotating with the field will only see the sun move vertically in one dimension. There is no apparent azimuthal motion of the sun. DELSOL also assumes that the receiver is in synchronous rotation. When using rotating fields, the azimuthal angle of the sun (when viewed from the field) always appears to be due south. (Note: In optimizing rotating field systems, DELSOL does not include the cost of the extra land required to allow the field to rotate.)



Row 1:	Heliostats	1- 8
2		9-16
3		17-20
4		21-28

Figure II-6. Schematic Diagram of Heliostat Numbering and "Rows" in an Individual Heliostat Field (IUSERF=3, Namelist FIELD)

II.B-4. Land Constrained Heliostat Field--DELSOL allows the user to subject the heliostat field (not including the tower) to an existing land constraint. If NLAND>0 (Namelist FIELD for performance calculations; Namelist 0PT for design optimizations), then all heliostats must be within one of NLAND user defined rectangles. The rectangles can have arbitrary size, displacement and orientation and may or may not overlap, as illustrated in Figure II-7. The center of the Ith rectangle is CLE(I) meters east and CLN(I) meters north of the first rectangle; therefore, CLE(1)=CLN(1)=0. ALP(I) is the angle, in degrees, that the sides of the Ith rectangle are rotated from the N-S and E-W axes. ALP(I) is positive for a clockwise rotation viewed from above. SLNS(I) and SLEW(I) are the length, in meters, of the sides of the Ith rectangle, which, prior to rotation by ALP(I), were parallel to the N-S and E-W axes, respectively.

In a land constrained field it is necessary to specify the location of the tower. In performance calculations a single tower position is considered. The center of the tower is YTOWER meters north and XTOWER meters east of the center of the first land constraint rectangle. In design optimization calculations DELSOL can search to find the optimum tower location. DELSOL considers NUMP0S equally spaced tower locations along a line from a first tower position of XTPST m east, YTPST m north to a final tower position XTPEND m east, YTPEND m north.

II.C. Heliostat Pattern and Density

It is assumed that the heliostats are arranged in the radial stagger pattern illustrated in Figure II-8. They lie on isoazimuthal and isoradial lines. The local heliostat density, ρ, (i.e., the ratio of mirror area to land area) is related to the local row spacing, ΔR, and azimuthal spacing, ΔAz, by the equation:

$$\rho = \frac{\text{DENSMR} \times \text{WM} \times \text{HM}}{(\Delta R \Delta Az/2)} * \text{R0UND} \qquad \text{(II.C-1)}$$

where DENSMR = fraction of mirror area of a heliostat whose overall dimensions are WM x HM;

WM = heliostat width (m);

HM = heliostat height (m).

$$\text{R0UND} = \begin{cases} 1.0 & \text{rectangular heliostats} \\ \pi/4 & \text{circular heliostats} \end{cases}$$

The choice of heliostat density is indicated by the value of the parameter

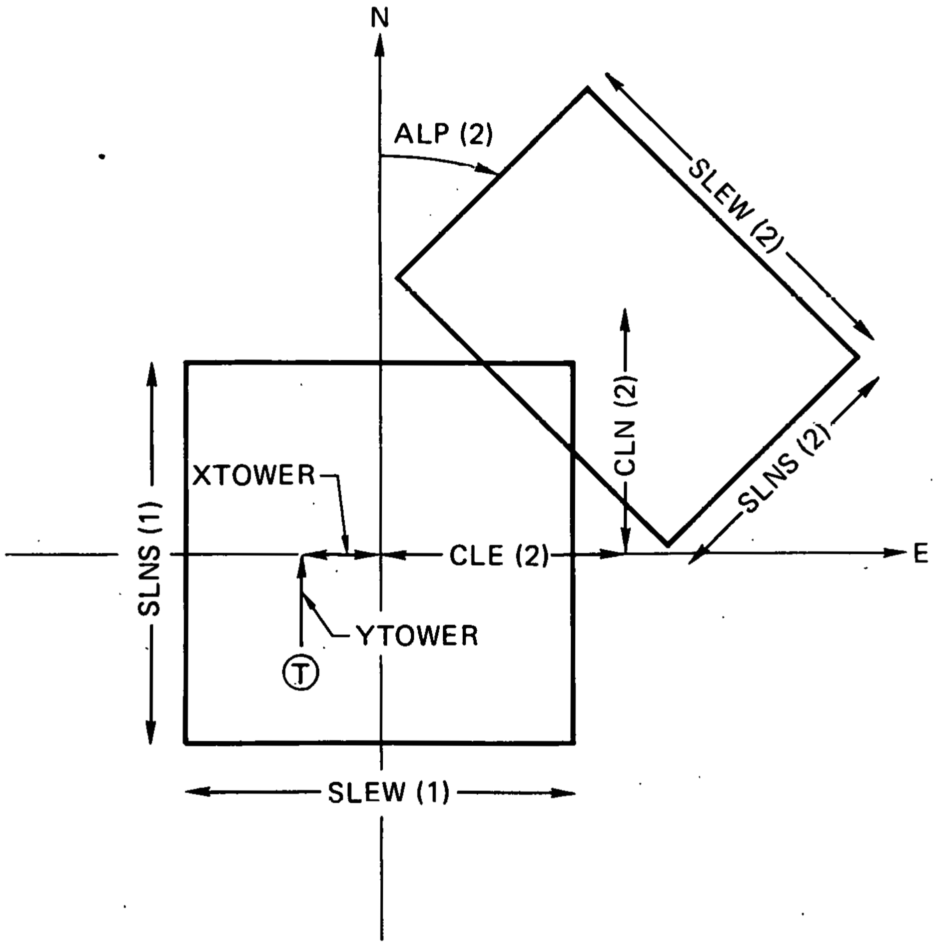


Figure II-7. Example of a Land Constraint with NLAND=2. T is the tower location. In a design optimization run several T positions along a line can be searched to find the optimum position.

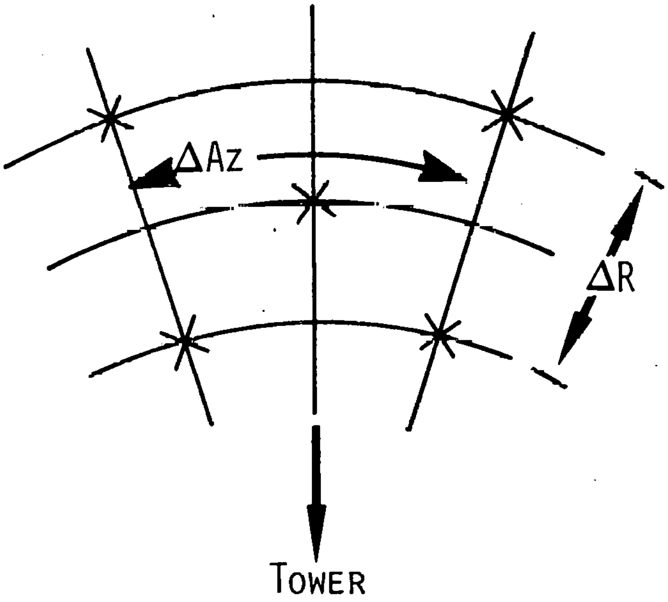


Figure II-8. Radial Stagger Arrangement of Heliostats. x's mark individual heliostat location

IDENS. For IDENS = 1 or 2, the values of ΔR and ΔAz are curve fits to optimized field layouts reported by the University of Houston (refs. 4,6,7) with a correction factor dependent on tower height for applications to small systems.

a) IDENS = 1 High reflectivity (~ 0.9), rectangular heliostats

$$\Delta R = (1.14424 \cot \Theta_L - 1.0935 + 3.0684\ \Theta_L - 1.1256\ \Theta_L^2)\ \mathrm{HM} \qquad \text{(II.C-2)}$$

$$\Delta Az = \left(1.7491 + 0.6396\ \Theta_L + \frac{0.02873}{\Theta_L - 0.04902}\right) \mathrm{WM}\ \frac{2*\mathrm{RADIUS}}{2*\mathrm{RADIUS}-\mathrm{HM}*\Delta R}\ \mathrm{K(THT)} \qquad \text{(II.C-3)}$$

where $\mathrm{K(THT)} = \left(1 - \frac{\mathrm{HM}*\Delta R}{2*\mathrm{THT}*\mathrm{RADIUS}}\right)^{-1}$

and $\Theta_L = \frac{\pi}{2} - \Theta_t$ (see Figure II-2). RADIUS (in meters) is the radius from the tower base and HM is the height of the heliostat (in meters).

b) IDENS = 2 Low reflectivity (~ 0.6), round heliostats

ΔR same as in equation (II.C-2)

$$\Delta Az = \left(1.6097 + 0.2966\ \Theta_L + \frac{0.01914}{\Theta_L - 0.01234}\right) \mathrm{WM}\ \frac{2*\mathrm{RADIUS}}{2*\mathrm{RADIUS}-\mathrm{HM}*\Delta R}\ \mathrm{K(THT)} \qquad \text{(II.C-4)}$$

c) IDENS = 3 User defined, zone by zone

ρ is specified by DENSIT(K,L), and $\Delta Az/2$ by AZMSEP(K,L) in the FIELD namelist.

Note that when IDENS=1 or 2 the azimuthal spacing and therefore the density depend on the tower height, THT.

The ΔR and ΔAz spacings from the above equations are tested to insure that the mechanical limits on adjacent heliostats are not exceeded; i.e., that adjacent heliostats will not hit each other in any combination of orientations. If the mechanical limits are violated, then the azimuthal spacing is adjusted to accommodate the full exclusion circle of the heliostat.

II.C-1. Slip Planes--The individual placement of heliostats in a radial layout pattern given only the zone average ΔR and ΔAz leads to a complication as one moves radially inward from the center of the zone. Heliostats on successive rows become more compressed until they incur an unacceptable increase in shading and blocking (or reach mechanical limits for the zones close to the tower). The problem can be alleviated by removing a fixed ratio (1-1/FSLIP) of the heliostats in the unacceptably compressed row, and restarting the layout pattern based on the new number of heliostats in the row. Figure II-9 illustrates this interruption in the layout pattern for the default 4/3 slip (FSLIP=1.33); the circular row at which the adjustment is made is called

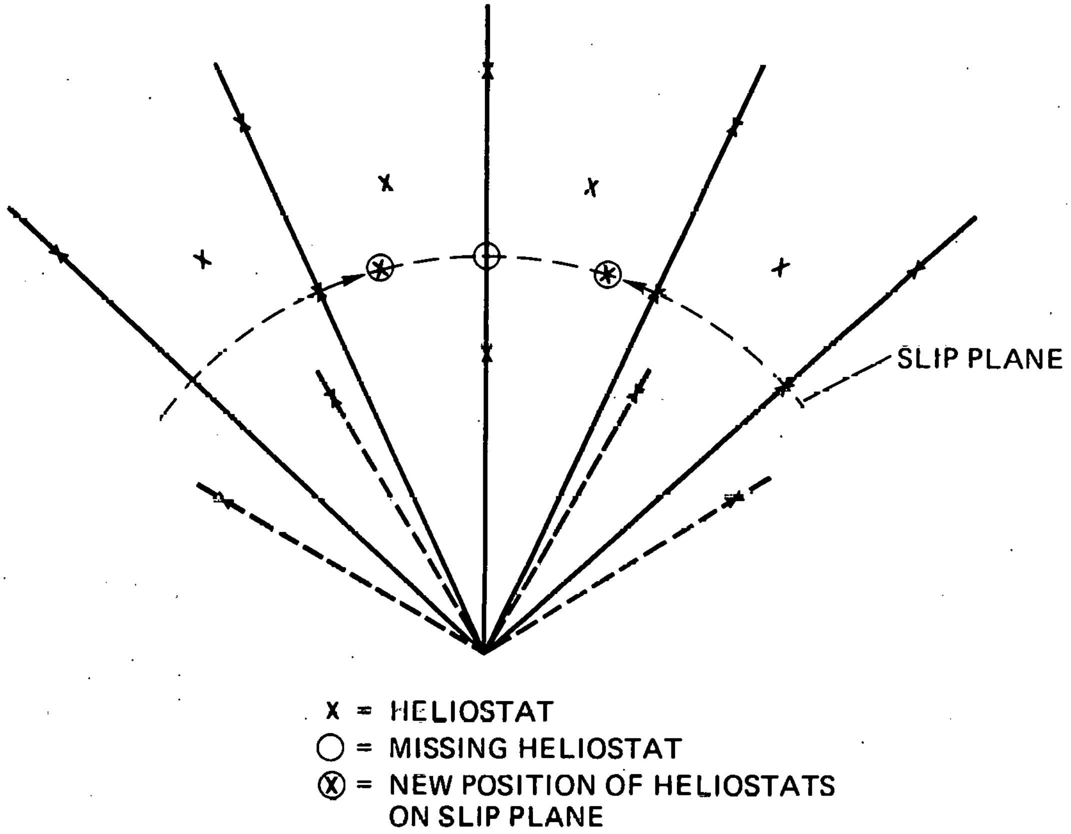


Figure II-9. Slip Planes in a Radial Stagger Layout (FSLIP=4/3) the "slip plane" in analogy with discontinuities in crystal structures. The number of rows between slip planes increases as the radius increases and as the tower height increases. (See ref. 8 for additional discussion on slip planes.)

DELSOL calculates a zone by zone correction to account for the heliostat number change at a slip plane. The user specifies the slip ratio, FSLIP in namelist FIELD, i.e., the number of heliostats present on the slip plane row before any are removed divided by the number remaining after removal. The default value for FSLIP (=4/3) is a satisfactory one for most intermediate to small systems. By choosing a very large value for FSLIP (e.g., 100), the user effectively eliminates the slip plane correction in the code.

II.D. Time Steps

DELSOL will calculate the performance at a single time, over a single day, on a user defined matrix of sun positions, or over the year according to the value of IPR0B (Namelist BASIC).

II.D-1. IPR0B=0 or 4, Annual Performance--DELSOL calculates the performance at a finite number of times during the year and integrates to get daily and annual averages. The problem is simplified by the daily and seasonal symmetry of clear sky insolation, described in Section III-A. Only the half year between winter and summer solstice and the times between noon and sunset need to be sampled. NYEAR equally spaced days starting at Dec. 21 and ending on June 21 are considered as illustrated in Table II.D-1. At each of these days the time is varied from solar noon on in steps of HRDEL hours, also shown in Table II.D-1. The last time step at each day is taken as the time when the sun angle, θ_s, is ASTART degrees from the vertical.

II.D-2. IPR0B=1, Single Calculational Day--DELSOL calculates the performance only on the UDAY (Namelist BASIC) day of the year. No annual average is calculated. The time steps are controlled by HRDEL as described under IPR0B=0.

II.D-3. IPR0B=2, Single Calculational Time--DELSOL calculates the performance only at UTIME hours past solar noon (UTIME is negative in the morning) on the UDAY day of the year (both Namelist BASIC).

II.D-4. IPR0B=3, Matrix of Sun Angles--Instead of calculating performances at certain specified times with this option allows the user to obtain the performance at certain specified sun angles. NUAZ values of the azimuthal angle, UAZ, and NUEL values of the zenith angle, UZEN, are considered in all possible pairwise combinations.

II.D-5. Selection of NYEAR, HRDEL, Reference Times--Both accuracy and calculational time of the performance (but not the optimization calculational time) increase with the number of day and hourly time steps. Fortunately, a

Table II.D-1. Time Steps

Days of the Year Sampled

Calculational Day	Day of the Year NYEAR = 3	 NYEAR = 5
1	354.75	354.75
2	81.0	35.375
3	172.25	81.0
4		126.625
5		172.25

NOTE: Day 354.75 is winter solstice

" 81.0 is spring equinox

" 172.25 is summer solstice

Hours after Solar NOON Sampled*

Calculational Time Step	HRDEL = 1. Day = 354.75	 Day = 81.	 Day = 172.25	HRDEL = 2. Day = 354.75	 Day = 81.	 Day = 172.25
1	0.	0.	0.	0.	0.	0.
2	1.	1.	1.	2.	2.	2.
3	2.	2.	2.	3.3	4.	4.
4	3.	3.	3.		4.8	5.8
5	3.3	4.	4.			
6		4.8	5.			
7			5.8			

*ASTART = 75°

relatively few days (3-5) and a reasonable time step (1 hour) appear to produce accuracies better than 1%. Generally, it is better to decrease HRDEL than increase NYEAR when attempting to increase accuracy.

Two times of the year have special significance. First, REFTIM hours past noon on the REFDAY day of the year is called the reference time. This is the time of the year which is used to determine the design point power levels of the system, as described in Section V.A-1. Second, HCANT hours past noon of the DCANT day is used to determine the off-axis canting of heliostats, if any, as described in Section II.E-2. Note: The reference time must correspond to one calculational time. The canting time has no such restriction. In addition, daily start-up and shutdown times are determined by the user specified zenith angle, ASTART.

Default values are:

NYEAR = 5

HRDEL = 1.0

ASTART = 75.0(°)

REFTIM = 0.0 (noon)

REFDAY = 81.0 (equinox)

HCANT = 0.0

DCANT = 81.0

II.D-6. Time Averages--DELSOL computes daily and annual averages of the total performance and the individual performance terms. These time averages are weighted according to the following table:

Quantity	Weighting
cosine	insolation
shadowing	" x cos
blocking	" x " x shadowing
attenuation	" x " x " x blocking
spillage	" x " x " x " x atten.

To illustrate this weighting the average blocking from time t_1 to time t_2 is

$$<\text{block}> = \frac{\int_{t_1}^{t_2} \text{block}(t)\ \text{shadow}(t)\ \text{cosine}(t)\ \text{insolation}(t)\ dt}{\int_{t_1}^{t_2} \text{shadow}(t)\ \text{cosine}(t)\ \text{insolation}(t)\ dt}$$

The same type of weighting is used in averaging the performance for a user defined field.

II.E. Heliostats

Either rectangular (IR0UND=0) or circular (IR0UND=1) mirror shapes (Figure II-10(A) and (B)) can be accomodated by the code. The overall dimensions of the heliostat, WM and HM, enclose the mirrored surface, the edge supports, and cutouts or slots, if any. The fraction of the area defined by WM and HM which actually reflects sunlight is specified by the parameter DENSMR. The user has the option of generating more accurate images from canted heliostats by specifying the size and location of the cant panels (ICPANL=1, Namelist HSTAT). This option is highly recommended in small systems. The width and height of the reflective surface of each cant panel are WPANL and HPANL meters, respectively (Figure II-10(C)). The center of the Ith cant panel is displaced from the pivot point (center of heliostat) by HXCANT(I) meters parallel to the horizontal edge of the heliostat and HYCANT(I) meters parallel to the vertical edge of the heliostat.

The reflectivity, given by the value of RMIRL, represents the time averaged value and not the value just after washing. RMIRL should also include transmission losses due to any enclosure surrounding the heliostat. (See also Section III.E-2.) The heliostats are assumed to have altitude-azimuth drive systems pivoted at the center of the mirrored surface.

II.E-1. Heliostat Error Sources--The performance of heliostats is degraded by several error sources. Care must be taken with the input of these terms because different reports often use different descriptions for the same errors. Specifically, a distinction must be made between an error source (e.g., backlash in the azimuthal motor drive) and the effect of the error source (i.e., the magnitude of the displacement and/or distortion of the heliostat image on the receivers). The latter, the effect of the error source, depends on the geometry between sun, heliostat, and receiver. Thus, a heliostat with a constant error source will provide variable effects on the image at different times of the year for the same field position, or at different field positions for the same time of the year, due to the changing relative positions of the sun and receiver.

Consider the example of the effect of a constant backlash error in the azimuthal drive in otherwise perfect heliostats. At noon on any given day of the year, a heliostat located due north of the tower will produce a larger displacement of the image on the receiver than its counterpart at the same distance due south. In fact, as heliostats in the south field approach a horizontal orientation (i.e., mirror normal $\hat{n}$ vertical), errors in the azimuthal drive produce no displacement in the image on the receiver.

Given that heliostats will be mass produced and assembled, it is assumed in DELSOL that the error sources are essentially the same for each heliostat regardless of field location. Hence, the user supplies as input the magnitude of the sources of error (e.g., motor inaccuracies, surface distortions), and the code calculates the time and field dependent effects of these sources. (This is identical to the approach in MIRVAL and HELIOS (refs. 1,5).)

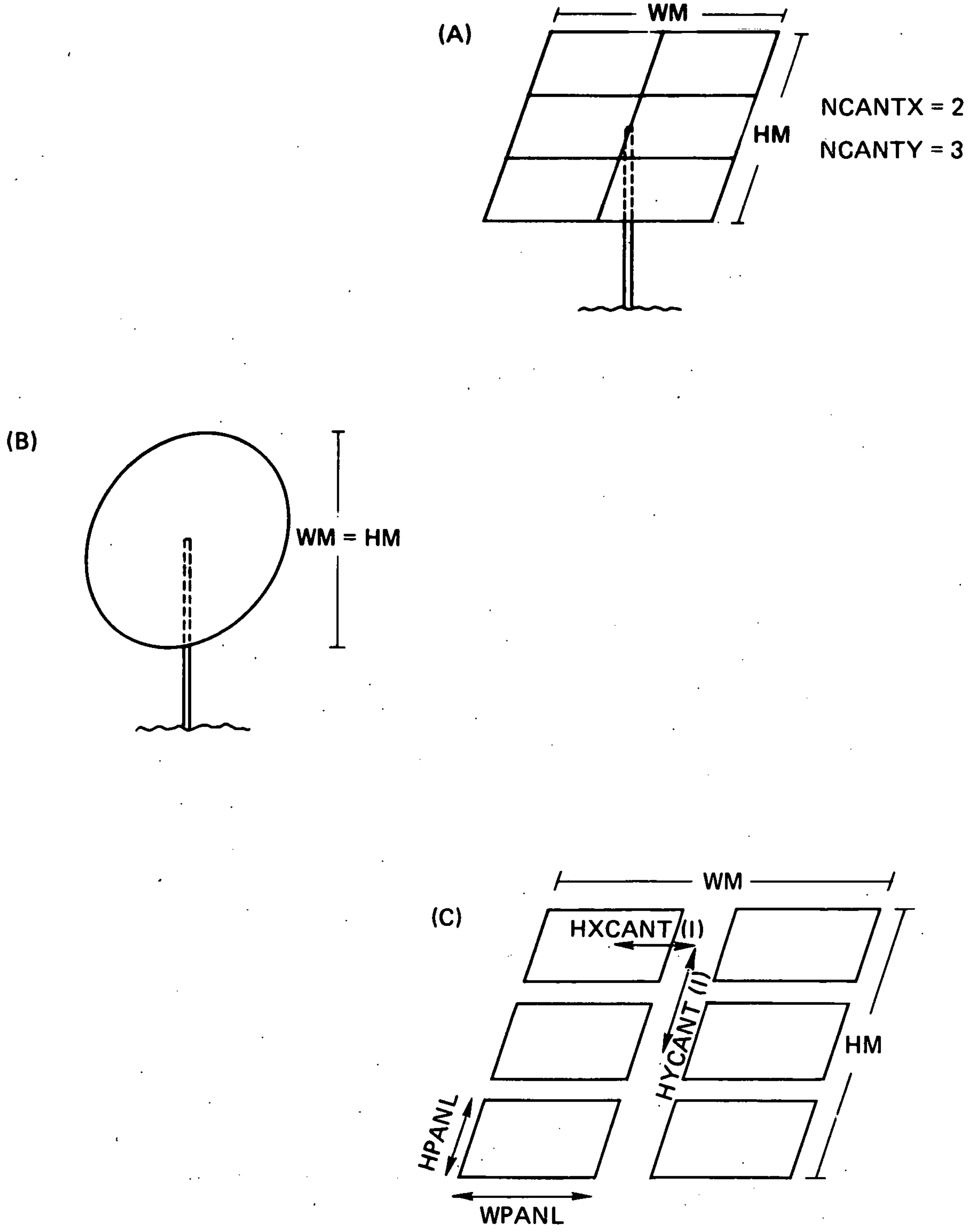


Figure II-10. Types of Heliostats. (A) Canted, rectangular heliostat with 2 cant divisions along the width and 3 along the height; (B) Circular heliostat with WM=HM=diameter; (C) Canted heliostat defined for more accurate image calculation (ICPANL=1)

The sources of heliostat errors can be grouped into three types according to the variable used to describe the error distribution. Each type produces different qualitative and quantitative effects on the position and profile of the heliostat image. Normal probability distributions characterized by standard deviations in two perpendicular directions are assumed. The three error groups, typical sources, and the coordinate systems in which they are defined are listed in Table II.E-1. The default values are also included, and are consistent with a fairly accurate, high reflectivity mirror.

II.E-2. Focusing and Canting--The size of the image produced by a heliostat on the receiver is determined by the finite size of the sun, the heliostat performance errors, and the size of the heliostat, as illustrated in Figure II-11(A). Reducing the contribution of heliostat size can lead to a smaller image size, and in turn, lower spillage, smaller receivers, and lower receiver radiation and convection losses. DELSOL simulates the two methods, focusing and canting, employed to reduce image size by decreasing the contribution from heliostat size.

In focusing, the mirror panels are concave in a manner such that rays from the center of the sun reflected from any point on the mirror panel hit the same point on the receiver, as shown in Figure II-11(B). A canted heliostat is divided into a number of submirrors. Each submirror is displaced relative to the others such that rays from the center of the sun reflected from analogous points of the submirrors all converge to the same point on the receiver, as indicated in Figure II-11(C). Thus, perfect focusing results in the minimum size image by eliminating the contribution of heliostat size to the reflected image. Perfect canting approximates perfect focusing by reducing the total heliostat size to that of a single submirror. The greater the number of canted submirrors for a given size heliostat, the smaller the contribution of heliostat size to the image. In other words, canting is a Fresnel approximation to focusing. (Note also that the submirrors of a canted heliostat can each be focused in 0 to 2 dimensions.)

The curvature or displacement required for focusing or canting depends on the angles between the heliostat, sun, and receiver, and is therefore time dependent. For most heliostat designs the curvature cannot be varied, and the heliostat will be perfectly focused or canted for only the one or two times of the year when the sun is in the correct position. At all other times, the heliostat will produce "off-axis aberration" of the image; i.e., distortions of the ideal image due to off-design operation.

The most common choice for the curvature of a rigid heliostat is a symmetrical "on-axis" focusing or cant. In this case, the heliostat is perfectly focused or canted at a point along the heliostat optical axis, $\hat{n}$, when the sun is positioned along $\hat{n}$, (i.e., $\hat{n} = \hat{s}$ in Figure II-1). When the sun is in other positions ($\hat{n} \neq \hat{s}$), there will be off-axis aberations.

A second possibility is an asymmetric curvature such that the heliostat is perfectly focused or canted for a specific sun position (defined by the HCANT hour past noon on the DCANT day of the year). In this case the relative positions of sun, heliostat, and receiver are important because in general, the focal point will not lie along $\hat{n}$. This "off-axis" cant or focus results in off-axis aberrations when the sun position differs from that specified by (HCANT, DCANT).

TABLE II.E-1

HELIOSTAT ERROR SOURCES

Type	Error Distribution*	Typical Sources	Default Values (rad)
Heliostat angles	Θ_n, β_n	Tracking errors in open-loop drive systems	σ_{Θ_n} (SIGEL) = 0.00075
		Foundation motion	σ_{β_n} (SIGAZ) = 0.00075
Surface normal	x_n, y_n	Mirror waviness	σ_{x_n} (SIGSX) = 0.001
		Panel alignment errors	σ_{y_n} (SIGSY) = 0.001
Reflected vector	x, y	Tracking errors in closed-loop drive systems	σ_x (SIGTX) = 0.000
		Atmospheric refraction	σ_y (SIGTY) = 0.000
		Tower sway	

*Each distribution is of the form:

$$P(da, db) = (2\pi \sigma_a \sigma_b)^{-1} \exp \quad -\frac{1}{2} \left(\frac{da}{\sigma_a}\right)^2 - \frac{1}{2} \left(\frac{db}{\sigma_b}\right)^2 \quad .$$

where a,b = variable pair defined above,

P = probability of displacements, da and db, from the nominal values of a and b.

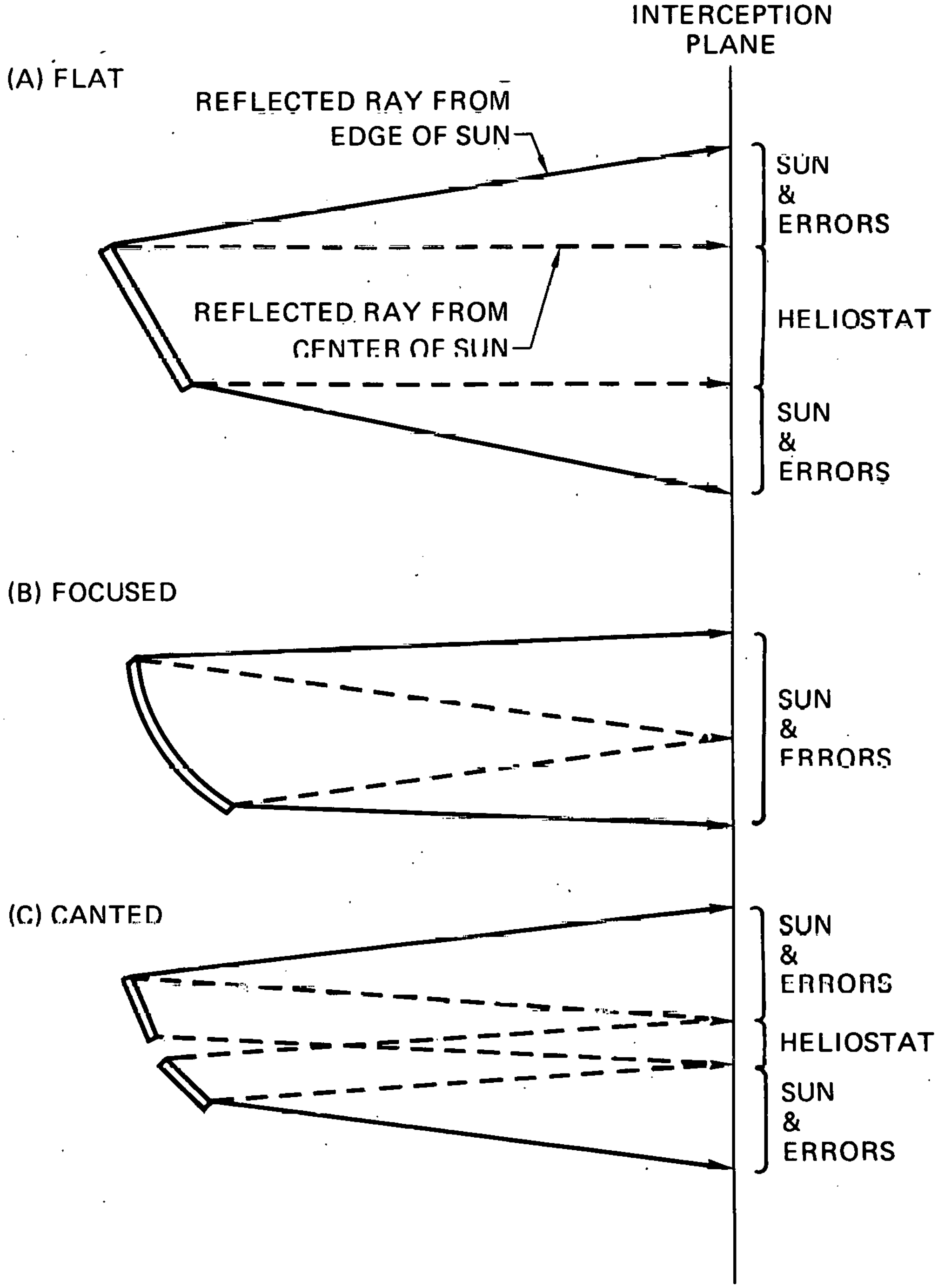


Figure II-11. Schematic of Images Formed by (A) Flat, (B) Focused, and (C) Canted Heliostats

On a yearly average, off-axis aberrations are less with an on-axis than off-axis cant or focus. Moreover, the symmetry of the on-axis cant or focus allows for a simpler manufacturing procedure. However, at the time specified by (HCANT, DCANT), an off-axis cant or focus produces a smaller image and higher flux density. This may be useful in test facilities where the number of helisotats is small, and periodic readjustment of their canting or focusing is possible. DELSOL allows both on- and off-axis canting but only on-axis focusing.

For canting several options are available according to the choice of the parameters ICANT, NCANTX, and NCANTY. There are NCANTX times NCANTY equally sized submirrors per heliostat with NCANTX (NCANTY) submirrors along the $\hat{i}_n$ ($\hat{j}_n$) edge of the heliostat, as shown in Figure II-6(A). The larger NCANTX and NCANTY, the more closely a canted heliostat approximates a focused heliostat. Uncanted heliostats are specified by ICANT=0 and have only one sub-mirror equal to the heliostat itself; therefore, NCANTX=1 and NCANTY=1. Fields in which each heliostat is individually canted off-axis on the HCANT hour past noon and the DCANT day of the year (default - noon, equinox, Mar. 21) are specified by ICANT=3. Heliostat fields in which every heliostat is focused "on-axis" with a focal length equal to its slant range is specified by the parameter ICANT=-1. Finally, fields in which heliostats have "on-axis" canting with user defined focal lengths (= RCANT (K) tower heights) are specified by ICANT=1. (This option can be used to produce a single cant for the whole field.)

Independent of canting, the mirror or submirrors can be focused in 0-2 dimensions. If the mirror is curved along the $\hat{i}_n$ ($\hat{j}_n$) direction then the parameter XF0CUS=1.0 (YF0CUS=1.0). Thus, no focusing is specified by XF0CUS=0.0, YF0CUS=0.0. 1-d focusing is specified by XF0CUS=1., YF0CUS=0., or XF0CUS=0., YF0CUS=1; 2-d focusing is specified by XF0CUS=1., YF0CUS=1. The parameter IF0CUS determines the specification of the focal lengths. DELSOL automatically sets the focal length equal to the slant range when IF0CUS=0. User defined focal lengths, XF0CAL and YF0CAL, can be read in when IF0CUS=1.

II.E-3. Default Heliostat--The default heliostat is a high reflectivity square advanced design with a single cant and focus.

IR0UND = 0

WM = 7.4 (m)

HM = 7.4 (m)

DENSMR = 0.897

RMIRL = 0.89

SIGAZ = SIGEL = 0.00075

SIGSX = SIGSY = 0.001

SIGTX = SIGTY = 0.

ICANT = 1

NCANTX = 2

NCANTY = 6

RCANT = 12*7.15

XF0CUS = YF0CUS = 1.0

IF0CUS = 1

XF0CAL = YF0CAL = 12*7.15

II.F. Tower and Receiver

DELSOL considers three types of receivers as illustrated in Figure II-12: external cylinders, multiple aperture cavities, and multiple flat plates. Flat plate receivers are specified in the same manner as cavity receivers. The tower height, THT, is defined as the elevation of the middle of the external receiver, cavity aperture, or flat plate above the pivot point of the heliostat. To get the height above ground, the elevation above ground of the pivot point must be added to THT.

The size of external cylindrical receivers (IREC=0) is specified by the height, H, and width or diameter, W. The apertures on cavity receivers are specified by giving their dimensions, orientation, and displacement from the tower centerline. For rectangular apertures (IREC=2), one edge is horizontal of length RX and the other perpendicular edge has a length RY. For elliptical apertures (IREC=1), one axis is horizontal with length RX and the other axis has a length RY. The orientation of the apertures is specified by the $\hat{r}$ vector which is the outward surface normal at the center of a surface stretched across the aperture. It is assumed that all apertures are oriented such that an extension of the $\hat{r}$ vectors will go through the tower centerline at the same point. (See Figure II-2.) θ_r (RELV) is the polar angle of $\hat{r}$; it equals 90° if the cavity aperture is vertical and is greater than 90° if the cavity faces downward. β_r (RAZM) is the azimuthal angle; $\beta_r = 180°$ if the aperture faces North. The width W of the cavity structure is taken as twice the horizontal distance from the center of the cavity aperture to the tower centerline. In multiple aperture cavities, the same receiver width and tower height apply to all apertures (i.e., a horizontal circle can be passed through the aperture centers). The height H is the total vertical distance of the heat absorbing unit in the cavity above the bottom of the cavity aperture. A total of NUMCAV ($\leq$ 4) apertures can be specified. Single or multiple flat plate receivers with rectangular (IREC=3) or elliptical (IREC=4) shapes are specified in an identical manner to a single or multiple cavity receiver with rectangular or elliptical apertures.

In designing cavity receivers it is necessary to describe the configuration within the cavity in order to determine the cost of the receiver. DELSOL assumes that the inside of the cavity is a section of a vertical cylinder centered on the aperture as shown in Figure II-13. The relative depth RWCAV(I) of the heat absorbing surface inside the Ith aperture is specified as the ratio of the radius of the cavity to the receiver radius, W/2. The height of the cylindrical heat absorbing surface is chosen so as to intercept all of the image that passes through the aperture from the nearest and farthest possible heliostat. The height is therefore a function of the minimum and maximum heliostat positions within the sector of the field seen by the cavity, the aperture height, RY, the orientation of the aperture, RELV, the tower height, THT, and the relative diameter of the heat absorbing surface.

II.G. Heliostat Aiming

DELSOL has several options for aiming the heliostats at different points on the receiver. The "smart" aiming options, described below, are generally

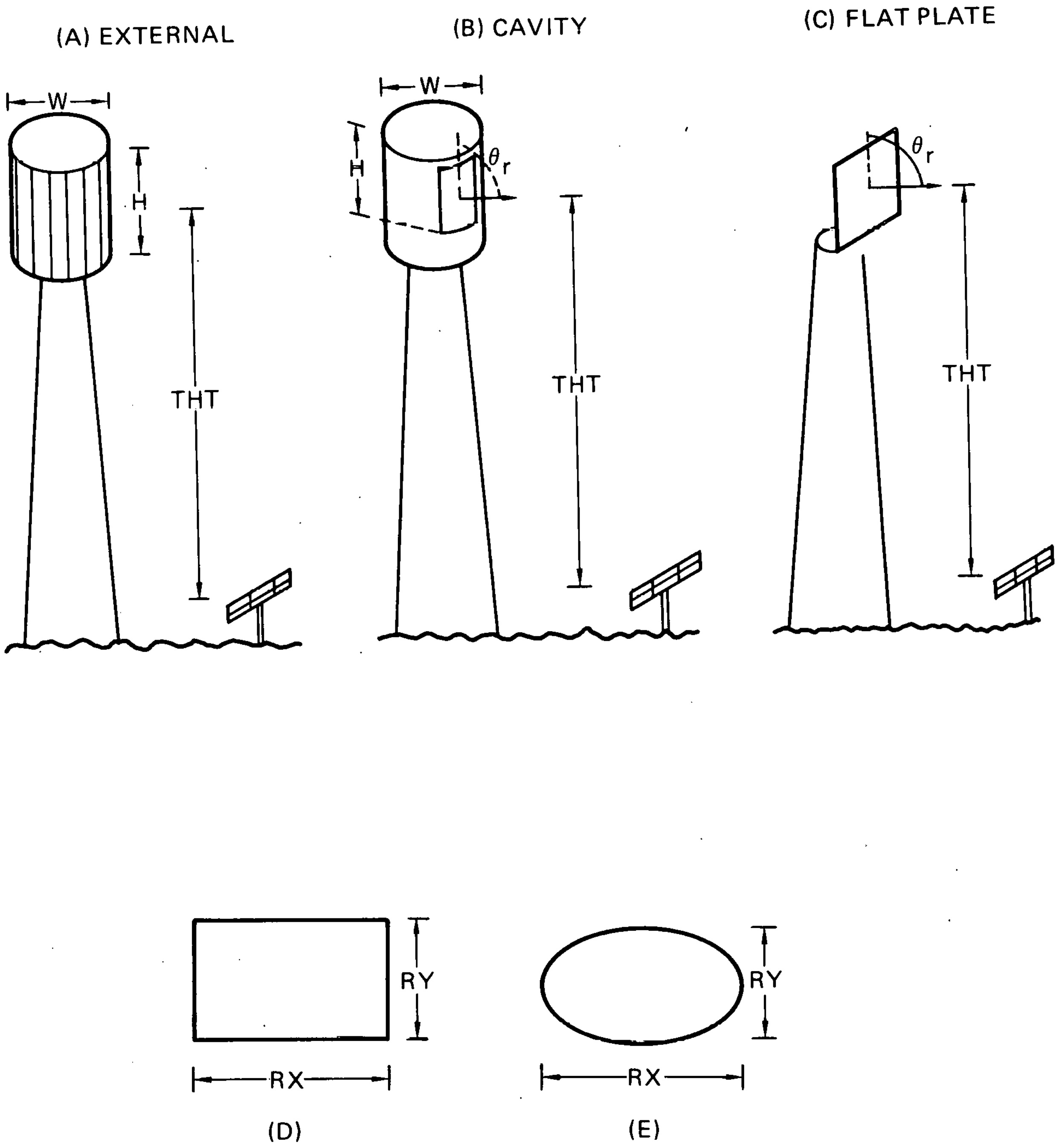


Figure II-12. Types of Receivers. (A) External Cylindrical; (B) Cavity with Single Aperture; (C) Single Flat Plate; (D) Rectangular Aperture or Flat Plate; (E) Elliptical Aperture or Flat Plate

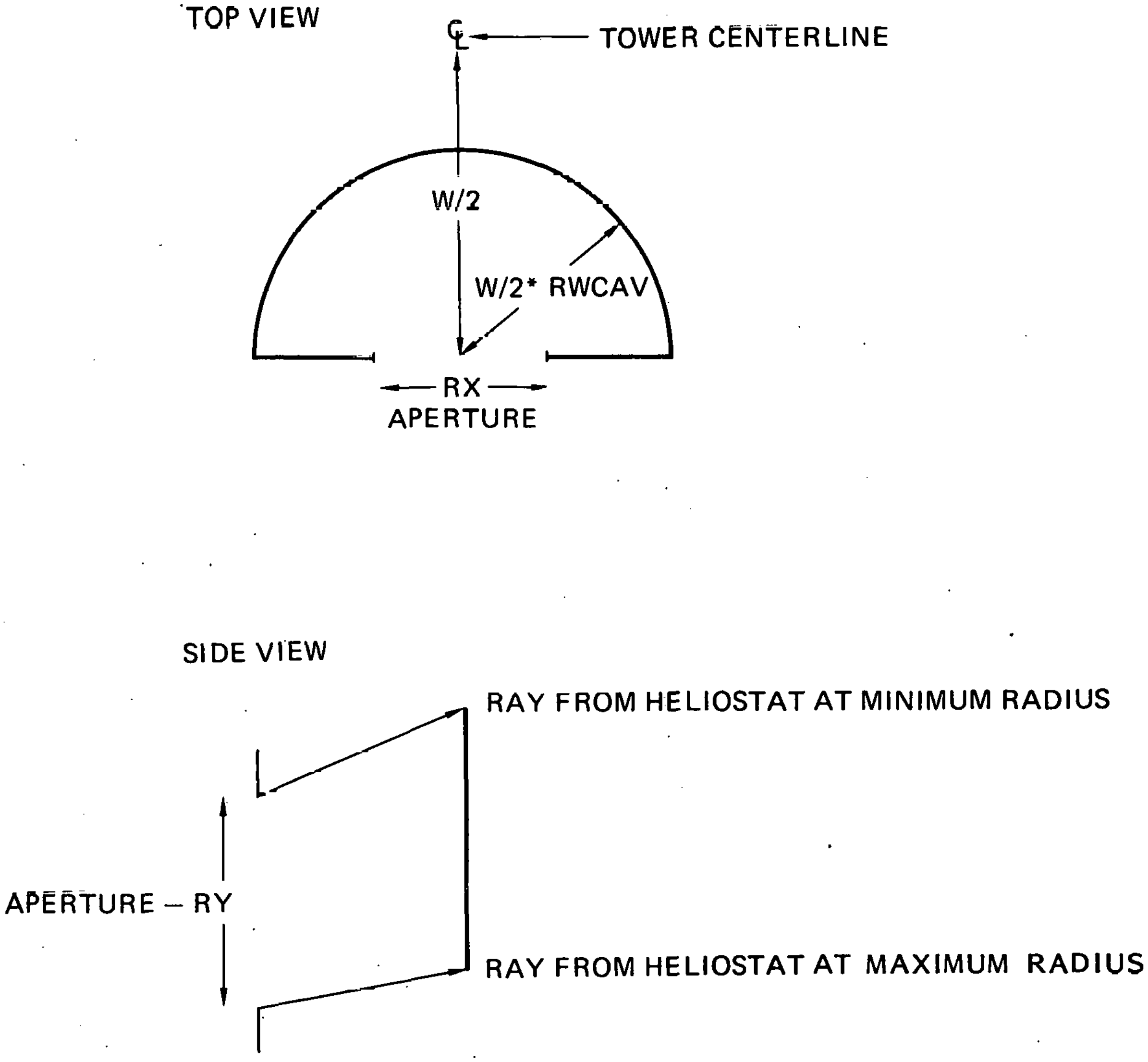


Figure II-13. Heat Absorbing Surface Within a Cavity. It is modeled as a segment of a right circular cylinder centered on the cavity aperture.

required when trying to design flux limited receivers. The options are controlled by the IAUT0P parameter in Namelist REC and illustrated in Figure II-14. All "smart" aiming options are time dependent; i.e., the number of aim points can change over the year if the image changes.

II.G-1. Single Aim Point (IAUT0P=0)--This is the simplest of all aiming options. All heliostats are pointed at the center (when viewed from the heliostat surface) of the receiver (Fig. II-14(A)). This option produces the maximum flux on the receiver.

II.G-2. One-Dimensional "Smart" Aiming (IAUT0P=1)--The heliostat images are spread out along the "height" of the receiver or aperture until the spillage starts to increase. As seen in Figure II-14(B) the smaller images of the inner heliostats can be spread out over more aim points than the larger images of the outer heliostats. This option reduces both the peak flux and flux gradients on the receiver. This is the "smart" aiming option to use with external receivers (IREC=0) and with cavity or flat plate receivers of elliptical shape (IREC=1 or 3). Since the size of the images from the heliosats can change with time (especially in small systems) the 1-d smart aiming also changes with time.

II.G-3. Two-Dimensional "Smart" Aiming (Rectangular Cavity Apertures or Flat Plates Only, IAUT0P=2)--This option is similar to IAUT0P=1 except that the images are spread out in two dimensions as shown in Figure II-14(C). This results in even smaller peak fluxes than IAUT0P=1. However, this option should only be used with rectangular cavities (IREC=2), or rectangular flat plates (IREC=4). If used with elliptical receivers the spillage will increase. Furthermore, if used with external cylinders much of the flux will be incident on the receiver at grazing angles where the absorption is poor.

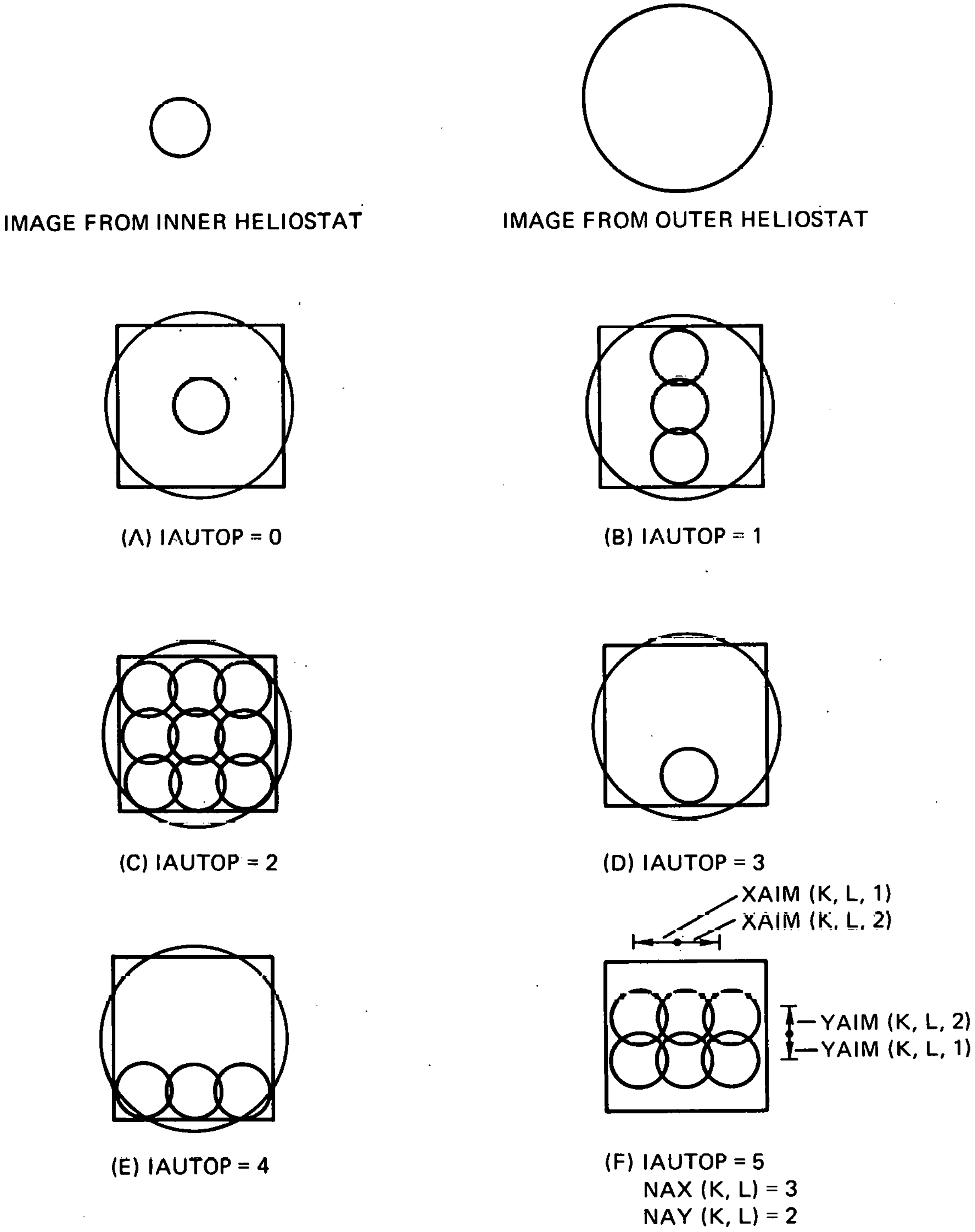
II.G-4. Single Aim Point at the Lower Part of the Receiver (IAUT0P=3)--The heliostats are aimed as close to the bottom of the receiver as is possible without increasing spillage significantly as shown in Figure II-14(D). There are several reasons for considering this strategy. First, if the fluid enters from the bottom the peak fluxes will occur near the colder (and presumably stronger) end of the piping. The penalty is increased radiation and convection losses since the average receiver temperature is increased. However, if the fluid enters from the top the radiation and convection losses are minimized, but the peak flux occurs near the hot end of the tube.

II.G-5. One-Dimensional Aiming at the Lower Part of the Receiver (IAUT0P=4)--Same as IAUT0P=3 except that the images are spread out along the top of the receiver as shown in Figure II-14(E).

II.G-6. User Defined Aiming Strategy (IAUT0P=5)--A user defined aiming strategy can be defined for each zone through the variables NAY(K,L), NAX(K,L), YAIM(K,L,M), XAIM(K,L,M), and NUMPT(K,L) where K=1, NRAD, L=1, NAZM, M=1,2. Each zone has a rectangular grid of NAX by NAY points with the grid limits set by XAIM and YAIM. Figure II-14(F) gives an example for this case.

II.H. Flux Density Distribution

DELSOL has the option of calculating the flux density on an arbitrary planar or vertical cylindrical surface (IFLX = 1, Namelist NLFLUX). The flux



(A) IAUTOP = 0

(B) IAUTOP = 1

(C) IAUTOP = 2

(D) IAUTOP = 3

(E) IAUTOP = 4

(F) IAUTOP = 5
NAX (K, L) = 3
NAY (K, L) = 2

Figure II-14. Aiming Options.

on complex receivers composed of several planar and/or cylindrical surfaces can be mapped by several executions of the program. For cavity receivers the flux surfaces are assumed to be behind the apertures. DELSOL tests each flux point to insure that it can be seen through the aperture from the heliostat being calculated (i.e., that the flux point is not shadowed by the outside of the cavity). In addition, for multiple aperture cavities, DELSOL allows the user to specify the aperture(s) through which the reflected sunlight can reach the flux surface (ICAVF, Namelist NLFLUX). This latter feature can be used to account for the possibility that the flux surface may be blocked by the internal structure of the cavity.

The flux from a heliostat is found by projecting the flux point along the $-\hat{t}$ direction (i.e. back towards the heliostat) to the image plane whose origin is the aimpoint on the receiver. The Hermite series (Equation III. D-1) is evaluated and multiplied by $-\hat{f} \cdot \hat{t}$ where $\hat{f}$ is the normal of the flux surface at the flux point. For multiple aimpoints this procedure is repeated for each aimpoint. To represent accurately the flux from a zone of heliostats, the code uses the average flux from a number of heliostats spanning the zone and not just a single heliostat located at the field point. The flux from a field of heliostats is obtained by summing the flux from the zones within the field. The single time of the year at which the flux is calculated is determined by the user (IFX0UT).

II.H-1. Specification of Flux Points--The flux points are specified by giving their location in ground based coordinates relative to the receiver "center" and by defining the direction of the outward normal on the side of the surface upon which the flux is incident. The receiver center is on the tower centerline a distance THT (Namelist REC) above the plane of the heliostat pivots (i.e., at the same elevation as the middle of the external receiver or the middle of the cavity aperture or flat plate). The program provides four options for automatically generating a 2-d grid of equally spaced flux points: (1) the outer surface of a vertical cylinder (IFLAUT=1); (2) the inner surface of a hollow vertical cylinder (IFLAUT=2); (3) one side of an arbitrarily oriented plane (IFLAUT=3); or (4) code generated grid on the heat absorbing surface (IFLAUT=4).

If IFLAUT=1 the points are generated on the outside of a cylinder of diameter DIAMF meters. The center of the vertical cylinder is XFC meters to the east, YFC meters to the north and ZFC meters up with respect to the receiver center. There are NXFLX flux points around the circumference from a minimum surface normal azimuth of FAZMIN degrees to a maximum of FAZMAX degrees (see Fig. II-15). The north side of the cylinder has an azimuth of 180°, east 270°, etc. There are NYFLX values of the height of the flux point relative to ZFC from a minimum of FZMIN meters to a maximum of FZMAX meters.

If IFLAUT=2 the points are on the inside of a hollow vertical cylinder. All the variables have the same meaning as above except that since the surface normals are on the inside of the cylinder, the azimuth on the north side is 0° and not 180° as it is for IFLAUT=1, and the east side azimuth is 90° not 270°, etc. (i.e., the direction of the north side azimuth is south, etc.), as shown in Figure II-15.

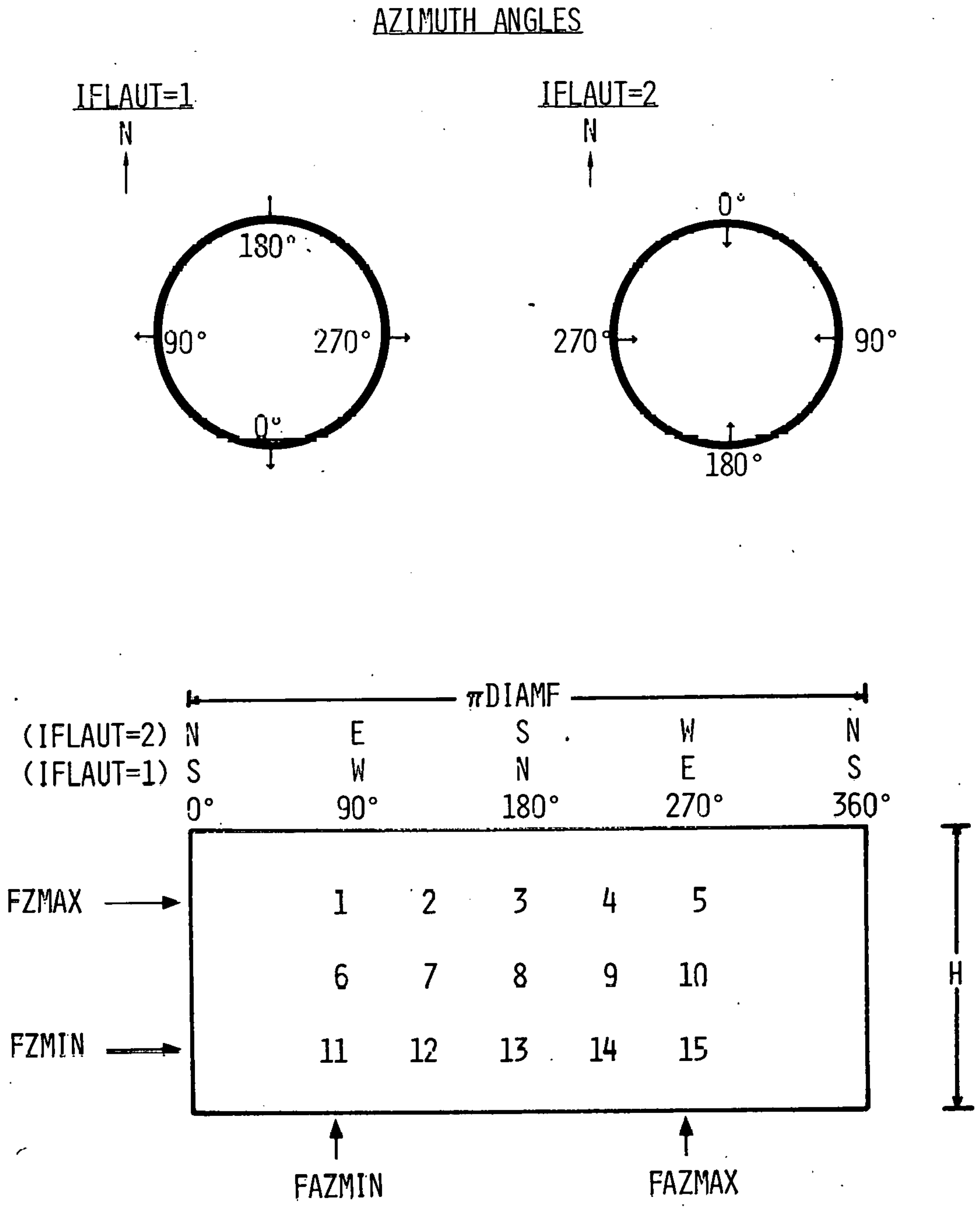


Figure II-15. Flux Points on a Cylinder. For IFLAUT=1, the points are on the outside of the cylinder and for IFLAUT=2, the points are on the inside. In this Figure NXFLX = 5, NYFLX = 3. Point number NMXFLX = M + (N-1)*NXFLX, where M = 1, NXFLX and N = 1, NYFLX. For clarity, the receiver has been "unfolded" and laid flat in (c).

If IFLAUT=3 the flux points are located on a plane. The outward surface normal $\hat{f}$ on the side of the plane on which the flux is incident makes a polar angle of POLF degrees with the vertical and an azimuthal angle of AZMF degrees with respect to the south direction (these angles are defined in an analogous manner to the angles of the $\hat{n}$, $\hat{s}$, $\hat{t}$, and $\hat{r}$, vectors in Figure II-2). A cartesian coordinate system ($\hat{i}_f$, $\hat{j}_f$, $\hat{k}_f$) is constructed with $\hat{k}_f = \hat{f}$, $\hat{i}_f$ in the plane and horizontal and $\hat{j}_f$ in the plane and pointing up when $\hat{k}_f$ is horizontal (Figure II-16). The origin of this coordinate system is XFC meters to the E, YFC meters to the N, and ZFC meters up with respect to the center of the receiver. There are NXFLX equally spaced values of the flux points along the $\hat{i}_f$ axis from a minimum of FAZMIN meters to a maximum of FAZMAX meters. Similarly, there are NYFLX equally spaced values of the flux points along the $\hat{j}_f$ axis from a minimum of FZMIN meters to a maximum of FZMAX meters.

If IFLAUT=4 the flux points are located automatically by the code on the heat absorbing surface of the receiver. If the default choices for NXFLX, FAZMIN, FAZMAX, NYFLX, FZMIN, and FZMAX are used with this option, a single point on the center of the north facing heat absorbing surface will be generated. While this is usually the logical point to test for a flux limit for external and flat plate receivers, it is usually too high for a cavity (see Sample Problem 2 in Appendix B for an example). For cavities, the user should test several points along the centerline of the back wall in order to locate and properly design for the maximum flux.

II.H-2. Flux Constrained System Designs--Many receiver designs have to impose flux limitations on the receiver surface to meet lifetime requirements. DELSOL provides the option for designing systems with a peak flux constraint. The flux at NFLXMX points is calculated at the design point as the field is being built up. If the flux limit (FLXLIM) is exceeded, no more zones are added. In calculating the flux during design studies, it is assumed that the relative shape of the flux profile at the design point is the same as the relative shape of the annual average flux profile.

When the receiver size is iterated, the location of the flux points is scaled in such a way that they remain at the same relative position on the receiver. For external receivers, a width and height of the receiver, W and H, are specified on the 2nd REC Namelist (just before the OPT Namelist in the optimization input group). The flux points are specified by using IFLAUT=1 with XFC=YFC=ZFC=0 and DIAMF=W. Generally, the peak flux occurs at the middle of the north side of the receiver so that only one flux point is tested (this is generated by using all the default values in Namelist NLFLUX). The azimuthal location of the flux point(s) is unchanged as the receiver size is varied. The height of the flux points is given by

$$\text{Height of flux point} = (\text{Initial location})\ \frac{H_{it}}{H}$$

where H_{it} is the current iterated receiver height. For example, if the flux point is chosen as 3/4 of the way up the receiver on the NE side it will remain in this relative position as W and/or H is varied.

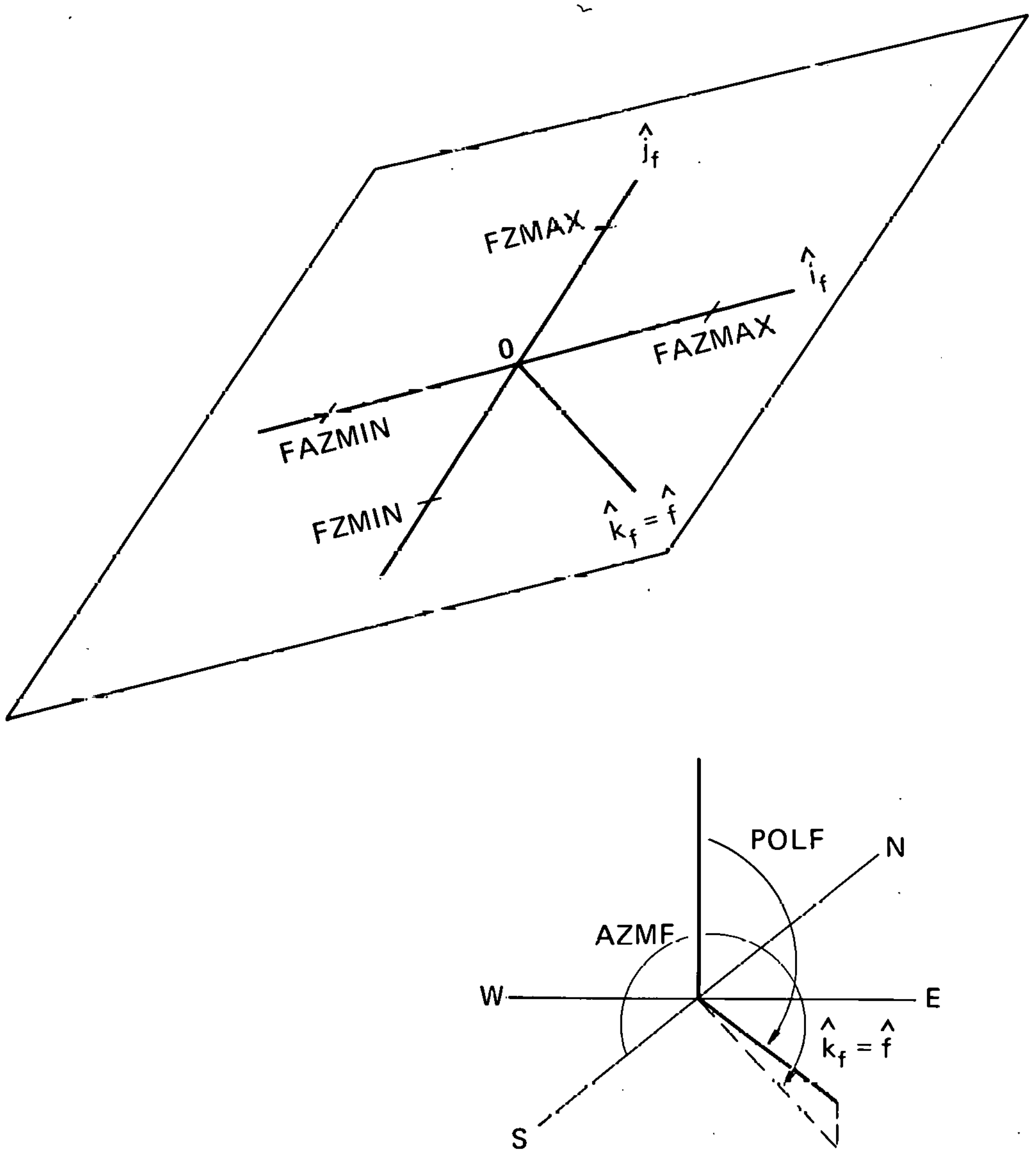


Figure II-16. Flux Points on a Plane. The origin 0 is displaced (XFC, YFC, ZFC) from the receiver surface and the normal f has a polar angle POLF and an azimuthal angle AZMF. The i_f-axis is in the plane and horizontal. The j_f axis is in the plane and pointing upward. The limits of the 2-D grid of equally spaced points are shown.

For cavity receivers, the locations of the flux points scale with W and the height of the heat absorbing surface based or RADMIN and RADMAX

$$(x, y) = (x, y)_{initial} \frac{W_{it}}{W}$$

$$z = z_{initial} \frac{HCAV_{it}}{HCAV_{initial}}$$

where W_{it} is the current iterated width, and $HCAV_{it}$ is the height of the heat absorbing surface based on current values of THT, W, and RY. The surface normal at the flux point is held constant.

For a single flat plate receiver the flux points are specified by IFLAUT=3 with POLF=RELV(1), AZMF=RAZM(1), ZFC=0, XFC=$-W_{\star}$ SIN (AZMF) and YFC=$-W_{\star}$ COS(AZMF) where W is the diameter defined in Namelist REC. The spacing of the flux points along the $\hat{i}_f$ axis scale with RX(1) and along the $\hat{j}$ axis with RY(1), i.e.

$$x_{f_{it}} = x_f \frac{RX(1)_{it}}{RX(1)}$$

$$y_{f_{it}} = y_f \frac{RX(1)_{it}}{RX(1)}$$

where RX(1) and RY(1) are the values of the receiver dimensions from Namelist REC, $RX(1)_{it}$ and $RY(1)_{it}$ are the values used in the iteration, and x_f and y_f are the coordinates of the flux points generated by the values in Namelist NLFLUX. Generally, the peak flux occurs in the center of the flat plate.

For flux limited external or flat plate receivers automatic aiming (IAUTØP=1, Namelist REC) must be used. In design calculations the REC Namelist appears twice, once in the Performance Group and once in the Layout/ Optimization Group (Table A.A.-1). To save computer time do not use automatic aiming on the first REC Namelist, only on the second REC Namelist (the one immediately before the ØPT Namelist). Similarly, the NLFLUX Namelist appears twice. Again to save time do not calculate any fluxes on the first NLFLUX Namelist only on the second one (after the ØPT Namelist).

III. Performance Calculation

III. Performance Calculation

III.A. Seasonal and Daily Variation of Sun Position; Sunshape

III.A-1. Position of the Sun--The sun position vector $\hat{s}$ is specified by (Θ_s, β_s) as illustrated in Figure II-2. Ignoring refraction effects in the atmosphere, Θ_s and β_s can be calculated by (refs. 9,10):

$$\cos\Theta_s = \sin\lambda \sin\delta + \cos\lambda \cos\delta \cos\tau \qquad \text{(III.A-1)}$$

$$\sin\beta_s = \sin\tau \cos\delta / \sin\Theta_s \qquad \text{(III.A-2)}$$

where λ = latitude (>0 in northern hemisphere),

τ = hour angle measured from noon (>0 in afternoon; 15° per hour),

δ = declination.

δ is determined by:

$$\sin\delta = \sin(23.442274°) \sin\beta_{se} \qquad \text{(III.A-3)}$$

where $\beta_{se}(\text{radians}) = \beta_{so} + 0.007133 \sin\beta_{so}$ (III.A-4)

$+ 0.032680 \cos\beta_o - 0.000318 \sin 2\phi_o$

$+ 0.000145 \cos 2\phi_o$ (ref. 11)

and

$$\phi_o = \frac{2\pi(\text{DAY}+284.)}{365.24} \qquad \text{(III.A-5)}$$

The effect of atmospheric refraction is to make the sun's apparent zenith angle Θ_s' (i.e., the zenith angle observed through the atmosphere) less than the true zenith angle Θ_s. The correction is given by a numerical fit (ref. 12):

$$\Delta\Theta_s(\text{radians}) = \Theta_s - \Theta_s' \qquad \text{(III.A-6)}$$

$$= A * (\Theta_s/B)**(C+D*\Theta_s) - E$$

where $A = .004013327$

$B = .06476916$

$C = -.66956539$

$D = .019276169$

$E = -.00051297$

$\Delta\Theta_s$ is multiplied by the relative atmospheric pressure (PRES or DPRES, Namelist BASIC) to account for the effect of altitude. It is the apparent sun angle, not the actual sun angle, that is tracked by the heliostats.

The default latitude is that for Barstow, CA:

$\lambda(\text{PLAT}) = 35.0°$.

III.A-2. Insolation--The extraterrestrial insolation of the sun, S_0, including the effect of eccentricity of the earth's orbit, is given by (ref. 13):

$$S_0\ (\text{kw/m}^2) = 1.353 + 0.045 \cos\left(2\pi\,\frac{\text{DAY} + 10.0}{365.0}\right) \qquad \text{(III.A-7)}$$

where DAY = day of the year.

The position of the sun is symmetric about the summer and winter solstices. The code ignores the small change in declination during each day and assumes that sun position is symmetric about noon.

DELSOL assumes clear sky models to predict the direct normal insolation at the surface, S. Insolation is decreased by transmission through the atmosphere. Losses depend on such factors as the weather, air mass traversed, and altitude, which determine the extent of photon absorption and scattering. The result is that part of the direct insolation is converted to a diffuse form which cannot be concentrated by the heliostats. The annual energy predicted by the clear sky models is corrected for weather effects as described below. The parameter INSØL controls the insolation model choice.

a) INSØL = 0, Meinel Model (ref. 14)

$$S = S_0\left\{(1. - 0.14\ \text{ALT})\exp(-0.347(\sec\Theta_s)^{0.678}) + 0.14\ \text{ALT}\right\} \qquad \text{(III.A-8)}$$

where S_0 is given by equation (III.A-4) and ALT is the altitude in km.

b) INSØL = 1, Hottel Model (ref. 15)

$$S = S_0\left(a + b\exp(-c\sec\Theta_s)\right) \qquad \text{(III.A-9)}$$

where $a = 0.4237 - 0.00821\ (6. - \text{ALT})^2$

$$b = 0.5055 + 0.00595\ (6.5 - ALT)^2$$

$$c = 0.2711 + 0.01858\ (2.5 - ALT)^2$$

c) INSOL = 2, Constant Insolation

$$S = SOLCON \text{ (constant specified in BASIC namelist)} \qquad \text{(III.A-10)}$$

d) INSOL = 3, Allen Model (ref. 16)

$$S = S_0 \left\{1.0 - 0.263 \left(\frac{DH20+2.72}{DH20+5.0}\right)(m*DPRES)^{\gamma}\right\} \qquad \text{(III.A-11)}$$

where m = air mass correction

DH20 = precipitable water overhead (mm)

DPRES = atmospheric pressure/sea level atmospheric pressure

$$\gamma = 0.367 \left[\frac{DH20+11.53}{DH20+7.88}\right]$$

The air mass correction, m, depends on the zenith angle, θ_s, according to:

$$m = \frac{1}{\cos\theta_s} \qquad (\theta_s < 60°)$$

$$m = \frac{1}{\cos\theta_s} - 41.972213(90-\theta_s)^{\beta} \qquad (\theta_s \geq 60°) \qquad \text{(III.A-12)}$$

$$\text{where } \beta = -2.0936381-0.04117341(90-\theta_s)+0.000849854(90-\theta_s)^2 \qquad \text{(III.A-13)}$$
(ref. 17)

Note that the altitude of the site affects the insolation via the relative pressure DPRES.

e) INSOL = 4, Moon Model (ref. 16)

$$S = S_0 \{0.183 \exp(-m*DPRES/0.48) + 0.715 \exp(-m*DPRES/4.15) + .102\} \qquad \text{(III.A-14)}$$

The above equations are plotted in Figure III-1 for ALT=0. The default values give yearly insolation corresponding to a Barstow, CA, location (ref. 18):

INSOL = 0	DPRES = PRES = 1.0
ALT = 0.65	DH20(I) = H20 = 20.0

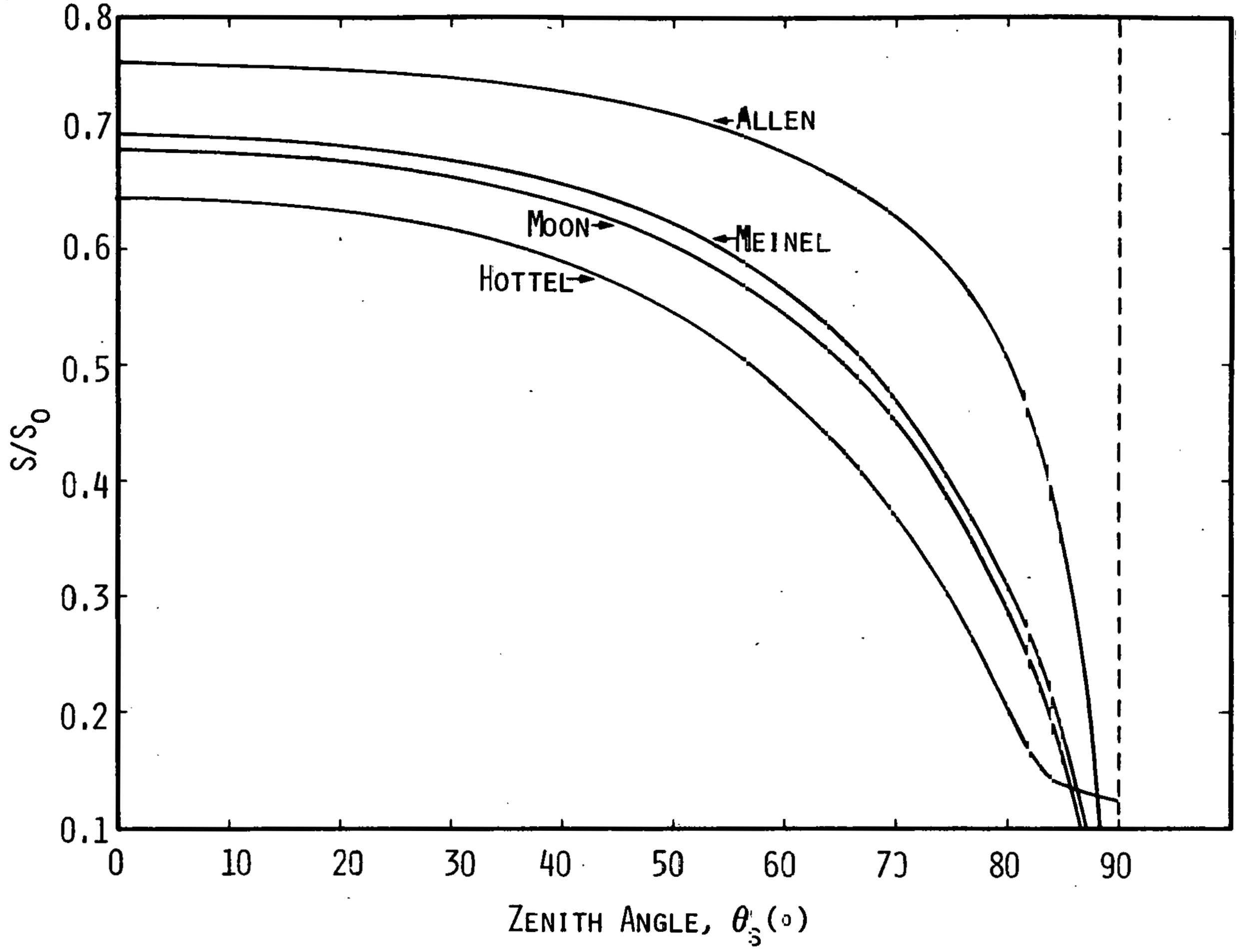


Figure III-1. Ratio of Incident to Extraterrestrial Insolation, S/S_0, as a Function of Solar Zenith Angle (Sea Level)

III.A-3. Time Dependent Weather Effects--DELSOL allows the user to define the weather characteristics of the site being analyzed. The weather factors can be defined separately for each of the NYEAR calculational days (IWEATH=1, Namelist BASIC) or can be held constant over the year (IWEATH=0). The weather affects both performance and design calculations.

a) Cloudiness

The energy produced on the Ith calculational day is multiplied by DWEATH(I) (IWEATH=1) or WEATH (IWEATH=0) to correct for the probability that some insolation will be lost due to cloudiness. The default values are consistent with a Barstow, CA location:

DWEATH(I) = WEATH = 0.83

b) Atmospheric Pressure

The atmospheric pressure divided by sea level atmospheric pressure on the Ith calculational day is given by DPRES(I) (IWEATH=1) or PRES(IWEATH=0). The relative atmospheric pressure affects the refraction of sunlight in the atmosphere, and its influence is accounted for in the Allen and Moon insolation models.

c) Precipitable Water

The precipitable water overhead (in mm) on the Ith calculational day is given by DH20(I) (IWEATH=1) or H20 (IWEATH=0). This quantity is used only in the Allen insolation model (INS0L=3).

III.A-4. Sunshape--The image of the extraterrestrial sun is limb darkened; i.e., the insolation decreases toward the edge. The size and shape of the solar intensity is further modified by the very small angle scattering in the earth's atmosphere. In general, the size of the solar image increases as the total insolation decreases because of increased scattering. The shape of the solar image is important in its effects on the spillage and flux calculations. The sunshape models available in DELSOL are set by the choice of parameter NSUN.

a) NSUN = 0, Point Sun

A point sun, while unrealistic, has been useful for debugging the field performance calculation and for studying the effects of heliostat size and errors on the images projected on the receiver.

b) NSUN = 1, Limb Darkened Sun

This is one of the simpler models for a limb darkened sun described by (ref. 3):

$$S(r) = \begin{cases} S_o\,(1.0 - 0.5138(r/R)^4) & (r \leq R) \\ 0.0 & (r > R) \end{cases} \qquad \text{(III.A 15)}$$

where r = angle subtended between the center of the sun to some point toward the edge (<R), in rad;

R = maximum angle subtended,

= (4.65×10^{-3})

c) NSUN = 2, Square Wave Sun

The intensity is constant to r = R (= 4.65 mrad), and then drops to zero:

$$S(r) = \begin{matrix} S_o & (r \leq R) \\ 0 & (r > R) \end{matrix} \qquad \text{(III.A-16)}$$

d) NSUN = 3, User Specified Sunshape

The user specifies the intensity vs. angle in a circularly symmetric sunshape. There are NSUNPT pairs of values of intensity, SUNI, vs. angle from the center of the sun, SUNR. The angles are in ascending order and the first angle must be zero (i.e., the center of the sun). πr*SUNI(r)dr gives the power from the sun within a differential circular ring from r to r+dr.

The default in the code is the limb darkened model (NSUN = 1).

III.B. Cosine Effect

In general, heliostats are not perpendicular to the incident direct insolation. The total power reflected per unit area of heliostat is proportional to the cosine $\hat{n} \cdot \hat{s} = \hat{n} \cdot \hat{t}$. The analytical formulas for the heliostat orientation and the cosine are derived in reference 19. The amount of energy reflected by a heliostat, S_r, is therefore:

$$S_r = S \times (\hat{n} \cdot \hat{s}) \times \mathrm{RMIRL} \qquad \text{(III.B-1)}$$

where

$$\hat{n} \cdot \hat{s} = \frac{1}{2}\left(1 + \cos\Theta_s \cos\Theta_t + \sin\Theta_s \sin\Theta_t \cos(\beta_t - \beta_s)\right)^{1/2} \qquad \text{(III.B-2)}$$

The angles are defined in Figure II-2.

III.C. Shadowing and Blocking

Shadowing occurs when one heliostat is in the shadow of one or more neighbors. Blocking occurs when a part of the unshaded region of the heliostat cannot be seen from the receiver because of its neighbors. Shadowing and blocking are strongly time and position dependent.

Shadowing (blocking) is calculated by projecting the neighboring heliostats along the sun (tower) direction onto the plane of the heliostat being considered. The area shaded (blocked) is then calculated analytically. Twelve nearest neighbors are considered in the calculation.

Two options are provided for overlapping of shadowing and blocking on a heliostat. For ISB=0 (Namelist HSTAT) the shading and blocking are assumed to never overlap. This is generally the case except at low sun angles. This approximation is an upper bound on shading and blocking losses. For ISB=1 the shading and blocking are assumed to always overlap. This approximation is a lower bound on the losses. The default choice is the conservative one (ISB=0).

III.C-1. Effect of Slip Planes on Shadowing and Blocking--As explained in II.C-1, heliostats have to be removed from slip planes in radial stagger layout patterns. These missing heliostats will reduce the shadowing and blocking. DELSOL assumes that the shadowing and blocking losses are reduced by the fraction of missing heliostats/total heliostats in a zone. For example, if 5% of the heliostats are missing, a 10% shadowing loss would be reduced to 9.5%.

III.C-2. Tower Shadow--DELSOL calculates the effect of the shadow cast by the tower and receiver. The tower and receiver shadow is modeled as that cast by a vertical cylinder of height TOWL meters (above the plane of heliostat pivots) and diameter of TOWD meters. Both values scale with THT. The default values are consistent with THT and W:

TOWL = 175.0 m
TOWD = 10.0 m

III.D. Flux Density and Spillage

The details of the theoretical method for calculating the flux in DELSOL is given in references 3 and 5. The flux distribution from a heliostat, normalized to unit power, is represented analytically by a truncated expansion in Hermite polynomials:

$$F(x,y) = (2\,\alpha_x\,\alpha_y)^{-1} \exp\left(-\frac{1}{2}\left(\frac{x}{\alpha_x}\right)^2 - \frac{1}{2}\left(\frac{y}{\alpha_y}\right)^2\right) \left(\sum_{i=0}^{6}\ \sum_{j=0}^{6-i} A_{ij}\, H_i\left(\frac{x}{\alpha_x}\right) H_j\left(\frac{y}{\alpha_y}\right)/i!\ j!\right) \qquad \text{(III.D-1)}$$

where α_x, α_y, and A_{ij} are calculated from the projection of the heliostat on the receiver, the sunshape, and the heliostat performance error distribution, and x and y are the coordinates in the plane of the reflected image (Table II.A-1). The H's are Hermite polynomials, the first three of which are:

$$H_0(x) = 1$$

$$H_1(x) = x \tag{III.D-2}$$

$$H_2(x) = x^2-1$$

In reference 5 it is shown that the A_{ij} and α's have a simple power law dependence on the tower height, THT. Therefore, once the flux is found for one tower height, it is straightforward to calculate the dependence for other tower heights. Furthermore, since Eq. (III.D-1) describes the flux over the entire image plane, the flux can be projected onto any receiver as long as the receiver dimensions are small compared to the slant range.

It is assumed that the total energy in the flux distribution is reduced by shadowing and blocking, but that the spatial distribution is taken as proportional to that of an unshaded and unblocked heliostat. This is generally justified because shadowing and blocking losses are usually small and the convolution of the mirror shape with the sunshape and errors reduces the effect of shadowing and blocking on the flux profile.

The ability to use one flux calculation to predict the flux from a given heliostat design on any tower or receiver is the main strength of DELSOL.

The speed of the Hermite method results from the fact that a severely truncated polynomial (6th order) expansion is an accurate approximation to the flux density. As discussed in reference 5, the accuracy of the Hermite method increases as the error sources of heliostat performance and/or their effect on the flux profile become larger. Specifically, DELSOL becomes more accurate in predicting the flux and spillage when: (1) the errors increase; (2) the slant range increases; or (3) the size of the heliostat is reduced (either physically or effectively by focusing or canting).

To calculate the fraction of the flux intercepted by the receiver, equation (III.D-1) must be integrated over the projection of the receiver on the image plane. The resulting two dimensional integral can be evaluated analytically in one dimension and numerically, using a 16 point Gaussian quadrature, in the other.

III.D-1. More Accurage Images from Canted Heliostats--The normal method used in DELSOL is a single Hermite series to represent the heliostat's image. When the heliostat to receiver distance is small this can result in a blurring of the sharp edges of the image. A slower running option which calculates a more accurate image is available for canted heliostats (INDC=1 in Namelist HSTAT). The location of the center of the image from each cant panel is calculated. Then a separate Hermite series is used to represent the image from each cant panel. This option can only be used in performance calculations with a single aimpoint at the center of the receiver (IAUTØP=1, Namelist REC). Its affect on an optimized system can be determined by rerunning a performance calculation on the optimized system with INDC=1.

III.E. Time Independent Losses

The hourly and seasonal variation of: a) atmospheric attenuation from the heliostat to the receiver, b) receiver radiation and convection losses, and c) piping insulation losses, are assumed negligible. In addition, mirror and receiver reflectivity, the thermal to electric conversion efficiency, and parasitic loads are represented by constant time averaged values.

III.E-1. Atmospheric Attenuation: Heliostat to Receiver--The seasonal variation of atmospheric attenuation at ground level for the test locations of Barstow and Albuquerque (based on constant visibility) is reported to be small (ref. 20) and is ignored in DELSOL. However, the effects of local altitude and visibility are not. DELSOL offers two options, identified by the user's choice of the parameter IATM in the BASIC namelist:

1) IATM = 0 Clear day, Barstow (visibility = 23 km)

$$\text{Loss (\%)} = 0.6739 + 10.46\ R - 1.70\ R^2 + 0.2845R^3 \text{ (ref. 15)} \qquad \text{(III.E-1)}$$

2) IATM = 1 Hazy day, Barstow (visibility = 5 km)

$$\text{Loss (\%)} = 1.293 + 27.48\ R - 3.394\ R^2 \text{ (ref. 15)} \qquad \text{(III.E-2)}$$

3) IATM = 2 User defined attenuation

$$\text{Loss (fraction)} = \text{ATM1} + \text{ATM2}\ R + \text{ATM3}\ R^2 + \text{ATM4}\ R^3 \qquad \text{(III.E-3)}$$

where R is the slant range (heliostat to receiver) in km. The first two equations are graphically presented in Figure III-2. Similar equations for Albuquerque are also given in reference 20, but these are not currently available as an option in the code. The default choice is the clear day model:

IATM = 0

III.E-2. Mirror and Receiver Reflectivity--While it is known that mirror reflectivity can degrade between washings (ref. 21), it is assumed constant along with receiver re-reflectivity. Default values are (namelist variable name in parentheses):

Mirror reflectivity (RMIRL) = 0.89 (glass, average between washings; ref. 16)

Receiver absorption (RRECL) = 0.965 (=1.0- receiver reflectivity; default value for external molten salt design)

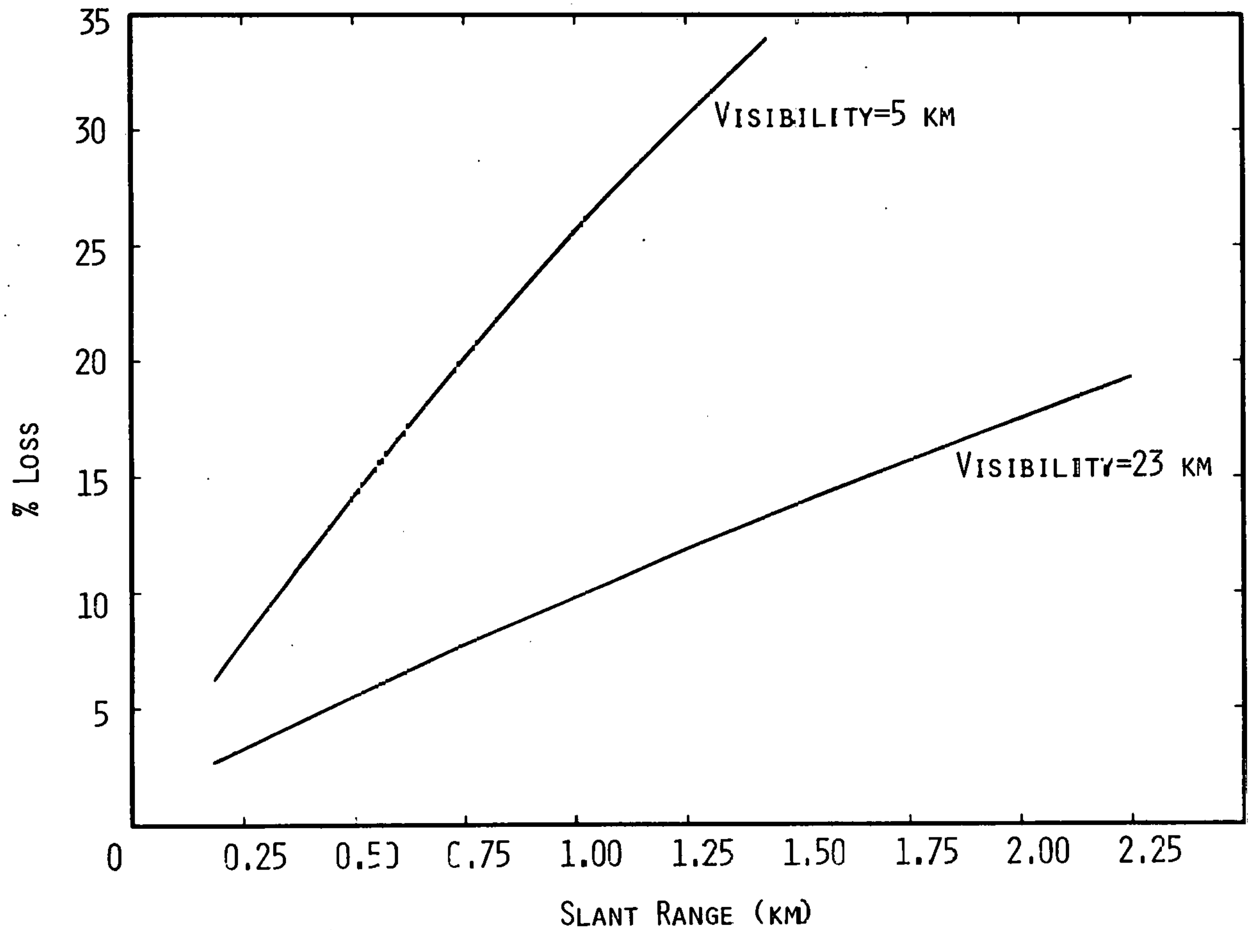


Figure III-2. Atmospheric Attenuation for Low and High Visibility, Barstow

III.E-3. Radiation and Convection Losses from the Receiver--Both the design point and a yearly average efficiency are calculated based on the assumption that the power loss due to radiation and convection is proportional to either: 1) the area of an external receiver, or 2) the total aperture area in a cavity design; i.e.,

$$P_{LOST,R} = \alpha_R A_R \tag{III.E-4}$$

where A_R = external receiver, total aperture, or total flat plate area,

α_R = proportionality factor.

In other words, $P_{LOST,R}$ is the same at any time of the day or year. Implicit in the assumption is that the same temperature profile is maintained on the receiver at all times and for any receiver size by adjusting the fluid flow rate, and that convective losses vary insignificantly with time.

Letting $\eta_{RC,R,DP}$ be the design point efficiency based on receiver radiation and convection losses, then:

$$\begin{aligned} \eta_{RC,R,DP} &= \frac{P_{th,R} - P_{LOST,R}}{P_{th,\,R}} \\ &= 1 - \frac{\alpha_R A_R}{P_{th,\,R}} \end{aligned} \tag{III.E-5}$$

where $P_{th,R}$ = gross thermal power absorbed by the receiver at the design point.

Similarily, let $\eta_{RC,R,AVG}$ be the yearly average efficiency, its value is given by:

$$\begin{aligned} \eta_{RC,R,AVG} &= \frac{E_{TOT,R} - (H_{OP} \times P_{LOST,R})}{E_{TOT,R}} \\ &= 1 - \frac{H_{OP} \times \alpha_R A_R}{E_{TOT,R}} \end{aligned} \tag{III.E-6}$$

where $E_{TOT,R}$ = total gross energy absorbed by the receiver per year,

H_{OP} = total number of hours of plant operation in direct, non-storage mode.

α_R is determined from some reference design for which the radiation and convection losses have been calculated in more detail. Rearranging equation (III.E-5),

$$\alpha_R = (1 - \eta^{\circ}_{RC,R}) \frac{P^{\circ}_{th,R}}{A^{\circ}_R} \qquad \text{(III.E-7)}$$

where the variables have the same meaning as above and the ° superscript refers to the reference. Current default values correspond to an external molten salt receiver with flow from the bottom to the top of the receiver panels; $\eta^{\circ}_{RC,R}$ should be calculated based on average ambient conditions (wind speed, temperature, etc.).

$\eta^{\circ}_{RC,R}$ (REFRC) = 0.83

$P^{\circ}_{th,R}$ (REFTHP) = 4.17×10^8 watts

A°_R (AREF) = 2165.0 m^2

III.E-4. Insulation Losses in Piping Runs--Only single module designs are considered, and the following two assumptions are made:

1) The hot piping run can be expressed as some constant, ℓ_{PH}, times the tower height, so that the total length is:

$$L_P = \ell_{PH} \times THT \qquad \text{(III.E-8)}$$

ℓ_{PH} should include the ground run to storage and the electric generating subsystem (EPGS) plus any necessary expansion allowances. The default value is based on an advanced salt design with storage and EPGS within one THT of the base of the tower plus a 30% increase for expansion:

ℓ_{PH} (FPLH) = 2.6

2) The pipe diameter, D_P, scales directly with the square root of the flow rate, which is, in turn, directly proportional to the design thermal power delivered to the downcomer from the receiver. Referring to the previous section for nomenclature:

$$D_p = \beta_p(\eta_{RC,R,DP} P_{th,R})^{\frac{1}{2}} \qquad \text{(III.E-9)}$$

where β_p = proportionality factor.

Piping losses are assumed to be proportional to the total pipe area. At the design point:

$$P_{LOST,P} = \alpha_p L_p (\pi D_p) \tag{III.E-10}$$

where α_p = proportionality factor. Combining equations (III.E-8), (III.E-9), and (III.E-10), and defining $\alpha_p' = \pi\alpha_p\beta_p$,

$$P_{LOST,P} = \alpha_p' \ell_{PH} THT \, (\eta_{RC,R,DP} \, P_{th,R})^{\frac{1}{2}} \tag{III.E-11}$$

Following the approach in the previous section, we let $\eta_{P,DP}$ be the piping thermal efficiency at the design point, so that:

$$\begin{aligned} \eta_{P,DP} &= \frac{\eta_{RC,R,DP} P_{th,R} - P_{LOST,P}}{\eta_{RC,R,DP} \, P_{th,R}} \\ &= 1 - \alpha_p' \ell_{PH} THT (\eta_{RC,R,DP} P_{th,R})^{-1/2} \end{aligned} \tag{III.E-12}$$

In analogous fashion, the yearly average piping efficiency, $\eta_{P,AVG}$, is calculated assuming that $P_{LOST,P}$ is constant through the year:

$$\begin{aligned} \eta_{P,AVG} &= \frac{E_{TOT,P} - H_{OP} \times P_{LOST,P}}{E_{TOT,P}} \\ &= 1 - \frac{H_{OP} \times \alpha_p' \ell_{PH} THT (\eta_{RC,R,DP} P_{th,R})^{1/2}}{E_{TOT,P}} \end{aligned} \tag{III.E-13}$$

where $E_{TOT,P}$ = total energy delivered to piping per year (= $\eta_{RC,R,AVG} E_{TOT,R}$),

H_{OP} = same as previous section.

As with finding α_R in the previous section, α_p' is based on a reference design for which a detailed calculation is available. Rearranging equation (III.E-12), and denoting the reference design values with a superscript ° we get:

$$\alpha_p' = \frac{(1 - \eta_p^\circ)(\eta_{RC,R}^\circ P_{th,R}^\circ)^{\frac{1}{2}}}{L_p^\circ} \tag{III.E-14}$$

Current default values are based on a salt design ($\eta^{\circ}_{RC,R}$ and $P^{\circ}_{th,R}$ given above):

$$\eta^{\circ}_{p}\ (\mathrm{REFPIP}) = 0.998$$

$$L^{\circ}_{p}\ (\mathrm{REFLP}) = 170.0\ \mathrm{m}$$

III.E-5 Thermal/Electric Conversion Efficiency--There are two options for the design point thermal to electric conversion efficiency, $\eta_{TE,REF}$, identified by the user's choice of the parameter ITHEL:

1) ITHEL = 0 $\eta_{TE,REF}$ constant at all design point power levels; value specified by the user.

2) ITHEL ≠ 0 $\eta_{TE,REF}$ varies with gross design point electrical output based on reported plant performance and designs (refs. 22-24).

The fit for option (2) is plotted in Figure III-3. For calculating total yearly electrical energy production, the yearly average thermal to electric conversion efficiency, $\eta_{TE,AVG}$, is expressed as some fraction, f_{EFF}, of the design point value in order to account for off design operation of the turbine plant:

$$\eta_{TE,AVG} = f_{EFF}\eta_{TE,REF} \tag{III.E-16}$$

Default values are:

ITHEL = 0

$$\eta_{TE,REF}(\mathrm{ETAREF}) = 0.42$$

$$f_{EFF}(\mathrm{FEFF}) = 0.95$$

III.E-6. Process Heat Production--In design problems where only thermal energy is desired (i.e., no electrical production), the code can be flagged through variable IPH to override automatically the default electrical conversion calculation. A non-zero value of IPH in namelist NLEFF will set the following variables to the indicated values:

ETAREF = 1.0 (Section III.E-5)

FEFF = 1.0 (Section III.E-5)

CEPGS = 0.0 (Section IV.A-10)

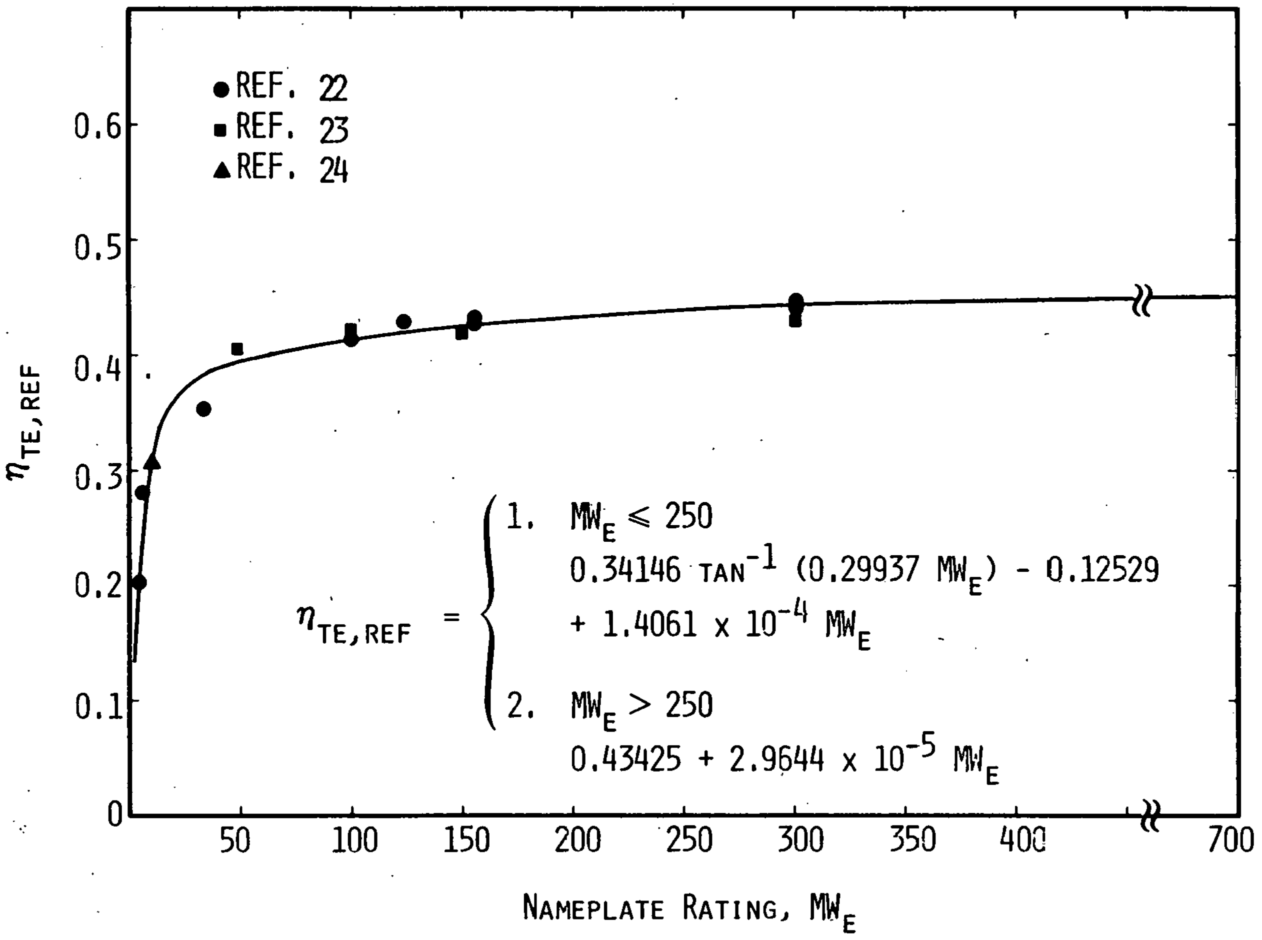


Figure III-3. Design Point Thermal to Electric Conversion Efficiency as Function of Turbine/Generator Nameplate Rating

REFPRL = 0.0

FSP = 0.0

FEP = 0.0

Output energy costs remain in mills/kw-hr, and energy headings in MW_e (although this is now the same as MW_{th}).

III.E-7. Storage Efficiency--Round trip losses through storage are accounted for through variable EFFSTR, which is the net thermal efficiency, or (1.0 - round trip loss), of the energy sent to storage. The default value is consistent with a few hours of high temperature nitrate salt storage.

EFFSTR = 0.99

III.E-8. Parasitic Loads--The power rating and net yearly energy production of the plant include parasitic load factors (PL). At the design point:

$$MW_{E,net} = (1 - PL_{REF})\ MW_{E,gross} \tag{III.E-17}$$

Over the year:

$$KW\text{-}HR_{net} = (1 - PL_{AVG})\ KW\text{-}HR_{gross} \tag{III.E-18}$$

where $KW\text{-}HR_{gross}$ includes an assumed weather outage.

PL_{REF} and PL_{AVG} differ from each other because operation from storage requires less power than daytime receiver operation in which the heliostats and tower pump are used. Assuming that storage operation requires some fraction, f_s, of the design point parasitic load,

$$PL_{AVG} = \frac{Hr_{REC}PL_{REF} + Hr_{STOR}f_sPL_{REF}}{Hr_{REC} + Hr_{STOR}} \tag{III.E-19}$$

where Hr_{REC} = hrs/day of receiver operation,

= HROP/365 (Section III.E-3)

Hr_{STOR} = hrs/day of storage operation

$= \dfrac{\text{Energy stored}}{MW_{E,gross}/\eta_{TE,REF}}$ (also see "Cost Model" section for discussion of energy stored calculation)

An additional parameter, FEP, is specified as the fraction of REFPRL required for operation of the turbine/generator subsystem. When a detailed performance calculation of a user defined field is carried out (see Chapter VI), FEP is required for energy accounting during those time steps when the field is still operating, but is no longer able to supply full turbine power requirements.

Default values are based on an advanced salt system:

$$PL_{REF} \text{ (REFPRL)} = 0.10$$

$$f_s \text{ (FSP)} = 0.5$$

$$\text{FEP} = 0.0$$

IV. System Cost and Economics

IV. System Cost and Economics

While DELSOL can be used to calculate field performance only, as described in earlier sections, it also has capabilities for total system design. In DELSOL an optimal system design is that combination of tower height, receiver size, and field layout which gives the lowest system energy cost at a given design power level and solar multiple*. In order to calculate the energy cost, both system performance, as discussed in previous sections, and system capital and operating costs must be determined. The subsystem cost models for estimating the total capital cost and the economic model for calculating the levelized energy cost are discussed below.

IV.A. Cost Model

The total capital cost, CC_T, is calculated as the sum of the costs of several subsystems:

$$\begin{aligned} CC_T = (&CC_{HEL} + CC_{LAND} + CC_{WIRE} \\ &+ CC_{TOW} + CC_{REC} \\ &+ CC_{PUMP} + CC_{PIPE} + CC_{STORAGE} + CC_{HTXCHG} + CC_{EPGS} \\ &+ CC_{FIXED}) \\ &\times (1.0 + DI + CONT + SPTS) \end{aligned} \qquad \text{(IV.A-1)}$$

As discussed in detail in Chapter 5, the optimization scheme considers one tower height/receiver size combination at a time and then builds up the heliostat field zone by zone until the desired power level(s) at the specified solar multiple is achieved for that tower and receiver. Capital cost components can be grouped according to that point in the field build-up at which they are calculated. The line grouping of the costs above is to clarify those which are similarly calculated. The tower and receiver costs (CC_{TOW}, CC_{REC}) are fixed by the values of tower height and receiver dimensions for each pass through the field buildup subroutine MAX. Heliostat, land, and wiring costs (CC_{HEL}, CC_{LAND}, CC_{WIRE}), are updated with each zone added in the field build-up. The power (i.e., system size) related costs of piping, pumping, storage, heat exchangers, and EPGS (CC_{PIPE}, CC_{PUMP}, $CC_{STORAGE}$, CC_{HTXCHG}, CC_{EPGS}, respectively) are calculated as each design level is reached. It is assumed that certain fixed costs (CC_{FIXED}), e.g., master control, administration

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*The solar multiple specifies total system collection and storage size. It is the factor multiplying the minimum requirement for thermal power at the base of the tower to meet the specified power delivered to the process at the design point. Thus, a solar multiple of 1.0 means that the field, receiver, and tower are designed to deliver only that power to meet design point requirements. A solar multiple of two means that the design point thermal power at the base of the tower is twice that required for the defined plant rating. In this case the excess is stored.

buildings, roads, etc., are common to all the systems. Factors for distributable and indirect costs (DI) to cover architectural and engineering services, contractor fees, and temporary facilities, for contingencies (CONT), and for spare parts (SPTS) are added to the basic capital cost of the major component subsystems. Values are expressed as a fraction of the total direct costs. Current default values are based on nth plant design and construction:

DI (EXT) = 0.16

CONT (CONT) = 0.12

SPTS (SPTS) = 0.01

The individual capital cost models are described below. User supplied cost parameters should include materials, fabrication, and field installation, and subcontractor fees and contingencies, if any. The default values are consistent with a 100 $MW_{E,net}$ salt design using a high reflectivity glass heliostat (ref. 25). Should the user desire to set any subsystem cost to zero to eliminate its contribution to the system design, then the input cost parameters, not the size or scaling parameters, should be set to zero.

IV.A-1. Heliostats

$$CC_{HEL} = C_H \left(\frac{\$}{m^2 \text{ mirror area}}\right) \text{ x total mirror area}$$

$$= C_H \sum^{\text{zones}} \text{zone mirror area} \qquad \text{(IV.A-2)}$$

Zone mirror area is determined from the zone density and land area. Default C_H (CH) = $75.00/$m^2$ applies to a high reflectivity glass heliostat. (This value of $75/$m^2$ for glass heliostats is consistent with stated cost goals for large scale production.)

IV.A-2. Land

$$CC_{LAND} = C_L \left(\frac{\$}{m^2 \text{ land}}\right) \text{ x total land area}$$

$$= C_L \sum^{\text{zones}} \text{zone land area} \qquad \text{(IV.A-3)}$$

C_L should include site preparation costs. Default C_L (CL) = $1.30/$m^2$.

IV.A-3. Wiring

$$C_{WIRE} = \sum^{zones} (C_{W,R} R_i + C_{W,\Delta R} \Delta R_i + C_{W,\Delta Az} \Delta Az_i) \times \text{\# heliostats in zone i} \qquad \text{(IV.A-4)}$$

where R_i = radial distance from the tower base to zone i;

ΔR_i = average row spacing in zone i;

ΔAz_i = average spacing between heliostats on the same row in zone i.

This model was supplied with the field performance results from reference 6. It is designed to penalize heliostats placed farther out due to requirements of larger (or more) primary cables as the field grows radially from the tower, and longer plowed in secondary line runs as the mirror density decreases with distance from the tower. From the defined zoning and density option in namelists FIELD and ØPT, R_i, ΔR_i, and ΔAz_i are known. Default values for the wiring cost parameters are:

$C_{W,R}$ (CWR) = \$0.0475/m

$C_{W,\Delta R}$ (CWDR) = \$0.4889/m

$C_{W,\Delta Az}$ (CWDA) = \$13.20/m

IV.A-4. Tower

$$CC_{TOW} = C_{TOW1} + C_{TOW2} \, THT_B + C_{TOW3} \, THT_B^{X_{TOW}} \qquad \text{(IV.A-5)}$$

where THT_B = base tower height (m);

X_{TOW} = exponent greater than 1 (usually between 1.8-2.2).

THT_B is the actual tower height from the ground to the bottom of the receiver; it is related to THT by

$$THT_B = THT + HM/2.0 - H/2 \qquad \text{(IV.A-6)}$$

where HM = height of a heliostat;

H = height of the receiver.

The user has 2 options for calculating the cost of the tower:

a) ITHT = 0; cost based on Sandia studies (ref. 26):

$THT_B \geq 120$ (concrete tower)

$$C_{TOW}(\$) = 3.02864 \times 10^6 - 2.33415 \times 10^4\ THT_B + 1.47152 \times 10^2\ THT_B^2$$

$THT_B < 120$ (steel tower)

$$C_{TOW}(\$) = 1.6292 \times 10^2\ THT_B^2$$

b) ITHT = 1; user supplies values for CT0W1, CT0W2, CT0W3, XT0W in namelist NLC0ST.

The tower cost for option a) is plotted in Figure IV-1. The default is option a): ITHT = 0.

IV.A-5. Receiver

a) External and flat plate receivers:

$$CC_{REC} = C_{REC,REF} \left(\frac{A_{REC}}{A_{REC,REF}}\right)^{X_{REC}} \qquad (IV.A-7)$$

where $C_{REC,REF}$ = cost of a reference design ($);

$A_{REC,REF}$ = heat transfer area of the reference design, same as in tower cost model (external receiver, m^2);

A_{REC} = heat transfer area of receiver being evaluated, same as in tower cost model (external receiver, m^2).

X_{REC} = scaling exponent for receivers, ≤ 1.0.

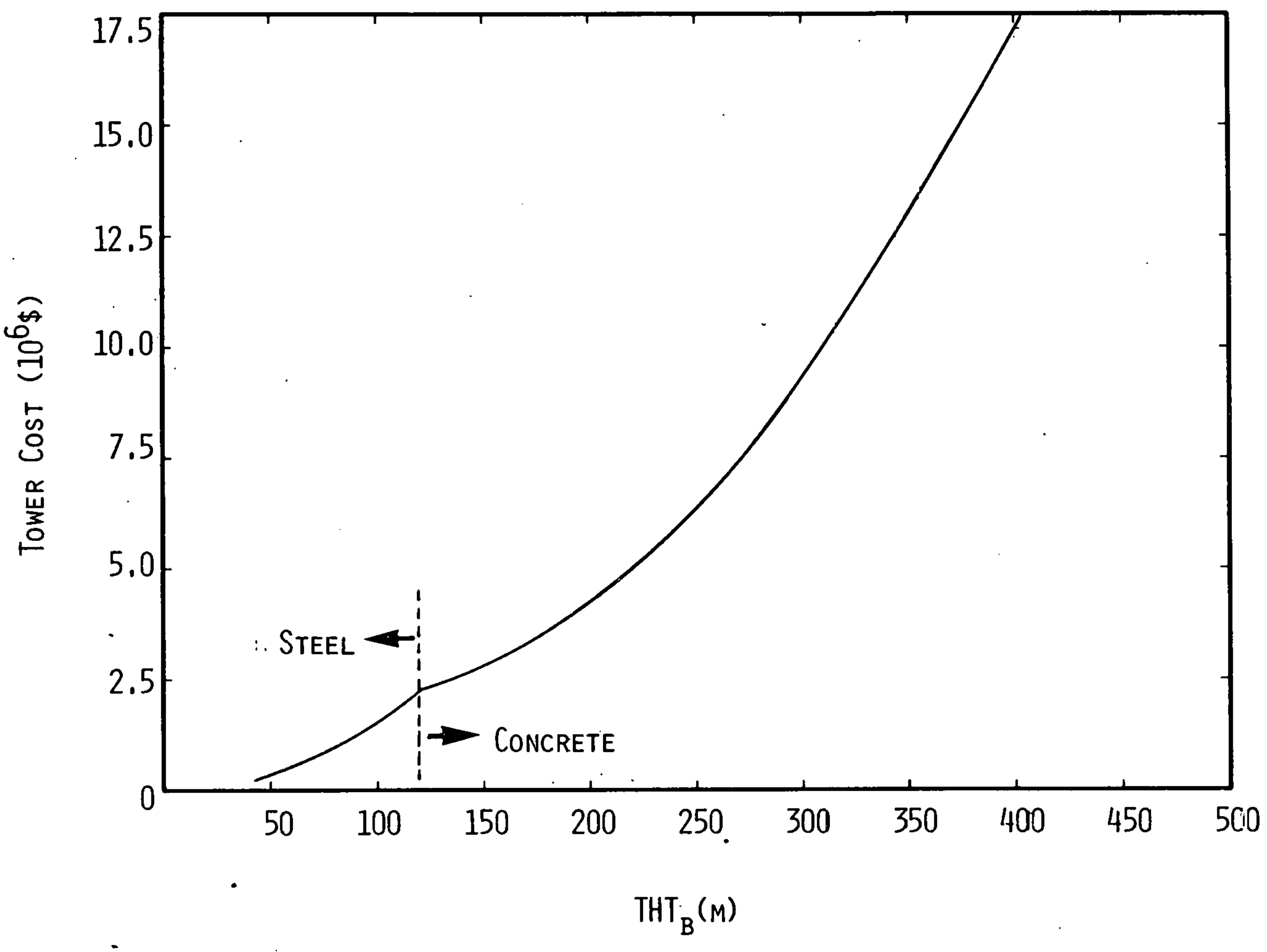


Figure IV-1. Tower Cost Predicted for ITHT = 0

The equation is of a form commonly used in the chemical process industries (refs. 27,28), and the scaling with area results from the fact that the receiver is a specially designed heat exchanger. For external receivers the area is simply the product of π times the diameter (W) times the height (H). For a flat plate receiver the area is RX*RY. Default values are for an external cylindrical salt receiver:

$$C_{REC,REF} \text{ (CREC1)} = \$4.21 \times 10^6$$

$$A_{REC,REF} \text{ (ARECREF)} = 2.165 \times 10^3 \text{ m}^2$$

$$X_{REC} \text{ (XREC)} = 0.8$$

b) Cavity receivers--The cost equation is of the same form as equation (IV.A-6) above for external and flat plate receivers. The height of the heat absorbing surface is calculated so that at the given cavity depth, W/2 x RWCAV, a ray from the nearest heliostat through the center of the aperture intersects the top of the surface. A ray entering the bottom of the aperture from the farthest heliostat determines the bottom of the heat absorbing surface. The equation used to calculate the height of the heat absorbing surface for each cavity is:

$$\text{HCAV} = (\text{THT+RY/2xSIN(180.-RELV)}) \times \left(\frac{\text{RMIN-W/2+W/2xRWCAV}}{\text{RMIN - W/2}}\right) - (\text{THT-RY/2xSIN(180.-RELV)}) \times \left(\frac{\text{RMAX-W/2+W/2xRWCAV}}{\text{RMAX-W/2+RY/2xCOS(180.-RELV)}}\right) \tag{IV.A-8}$$

where RMIN and RMAX are the local minimum and maximum radii for the optimized field.

The circumferential width of the heat absorbing surface is that portion of the cylindrical surface which can be seen through the aperture by the section of the field active for the cavity. Rays from the nearest heliostats on the boundaries of this sector are used to calculate the fraction of the surface seen (see Fig. IV-2b). As discussed in Section V.A-3(c), the height of the cavity will be extremely sensitive to the choice of RADMIN. The user may find it necessary to rerun the code with values of RADMIN larger than the default in order to obtain a reasonable value for H.

IV.A-6. Pumps

$$CC_{PUMP} = C_{RP} + C_{SP} \tag{IV.A-9}$$

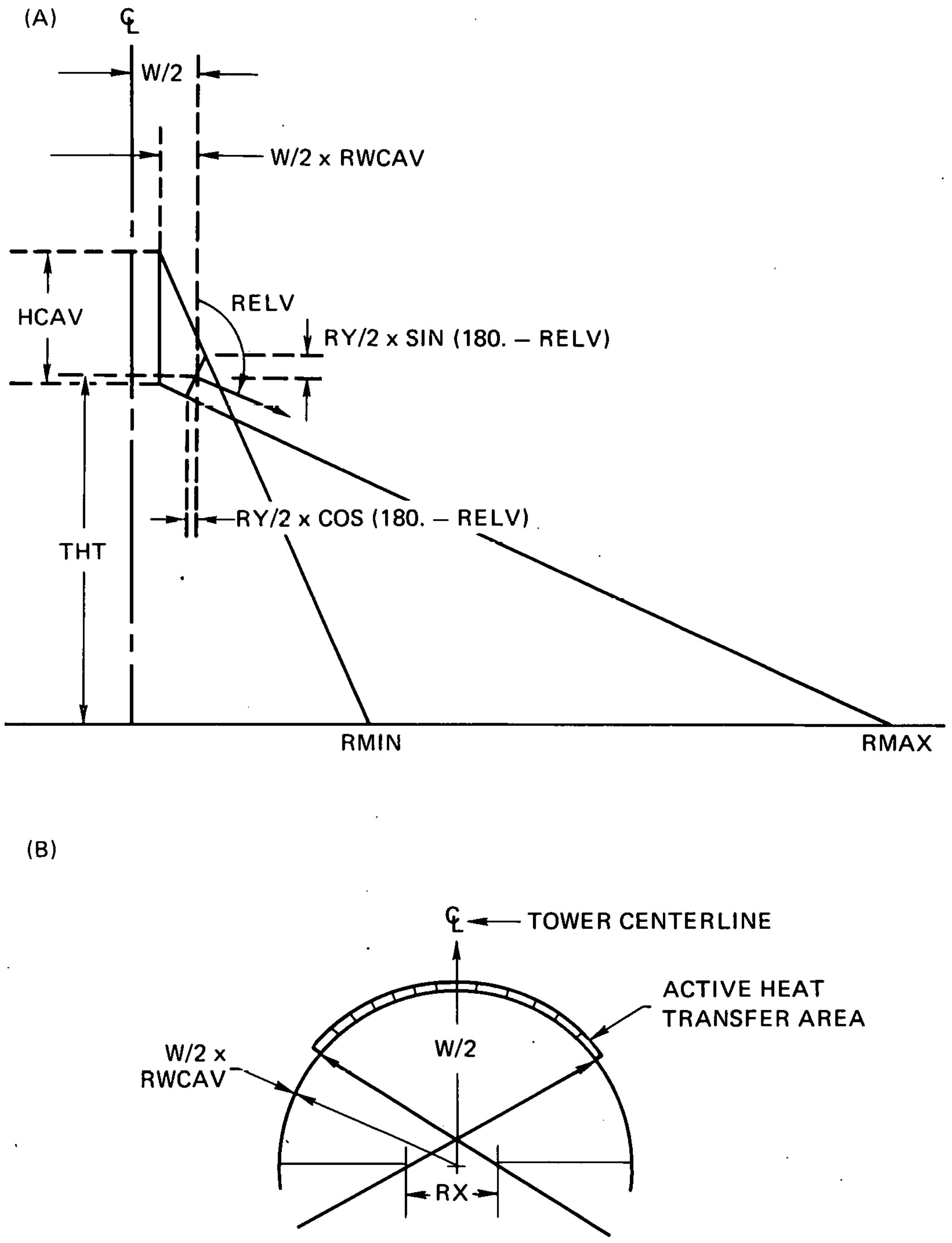


Figure IV-2. a) Schematic illustrating the relation of the height of the back wall of a cavity to other system dimensions

b) Assumed shape of the heat transfer surface in a cavity where C_{RP} = receiver/tower pump cost;

C_{SP} = storage pump cost

The scaling parameter for pump costs is the product of the head times the capacity (ref. 27). We assume a reference design for each pumping system. For the receiver pump, the head is proportional to the tower height, and the flow rate is the total fluid flow, i.e., EPGS and storage requirement, which is proportional to the solar multiple times the thermal power transferred in the heat exchangers. For the storage pump, the head is assumed to change negligibly from the reference design, and the flow rate is proportional to the thermal power only (i.e., EPGS requirement). These assumptions lead to the following equation for the pumping costs:

$$CC_{PUMP} = C_{RP,REF} \left(\frac{THT \times SM \times P_{th}}{THT_{RP,REF} \times SM_{RP,REF} \times P_{th,RP,REF}}\right)^{x_{RP}} \qquad (IV.A-10)$$

$$+ C_{SP,REF} \left(\frac{P_{th}}{P_{th,SP,REF}}\right)^{x_{SP}}$$

where $C_{RP,REF}$ = cost of reference receiver/tower pump ($);

THT = tower height (m);

SM = solar multiple;

P_{th} = thermal power to EPGS (watts);

$THT_{RP,REF}$ = tower height for reference receiver pump design (m);

$SM_{RP,REF}$ = solar multiple for reference receiver pump design;

$P_{th,RP,REF}$ = thermal power to EPGS in reference receiver pump system (watts);

x_{RP} = scaling exponent for receiver pump;

$C_{SP,REF}$ = cost of reference storage pump ($);

$P_{th,SP,REF}$ = thermal power to EPGS in reference storage pump system (watts);

x_{SP} = scaling exponent for storage pump.

Default values are for a molten salt system:

$C_{RP,REF}$(CRPREF) = \$0.671 x 10^6

$THT_{RP,REF}$(TRPREF) = 170.0 m

$SM_{RP,REF}$(SMRP) = 1.5

$P_{th,RP,REF}$(PRPREF) = 2.6 x 10^8 watts

x_{RP}(XRP) = 0.85*

$C_{SP,REF}$(CSPREF) = \$1.51 x 10^5

$P_{th,SP,REF}$(PSPREF) = 3.0 x 10^8 watts

x_{SP}(XSP) = 0.15**

IV.A-7. Pipes

$$CC_{PIPE} = THT(\ell_{PH}\ C_{HOT,REF} + \ell_{PC}\ C_{COLD,REF})\ \left(\frac{D}{D_{REF}}\right)^{X_{PIPE}} \qquad \text{(IV.A-11)}$$

where ℓ_{PH} = multiplier on THT to give total hot piping run as described in Section III.E-4;

$C_{HOT,REF}$ = reference hot pipe cost, including pipe, insulation, fittings, hangars, supports, installation (\$/m);

ℓ_{PC} = multiplier on THT to give total cold piping run (can be different from ℓ_{PH} if expansion allowance is less);

$C_{COLD,REF}$ = reference cold pipe cost, as above (\$/m);

D = pipe diameter (m);

D_{REF} = reference pipe diameter (m).

(See ref. 29 for pipe cost scaling relation.)

The pipe diameter is assumed to scale with the square root of the flow rate, which is in turn proportional to the product of the solar multiple times the design point thermal power delivered to the process:

$$\frac{D}{D_{REF}} = \left(\frac{SM \times P_{th}}{SM_{PIPE,REF} \times P_{th,PIPE,REF}}\right)^{1/2} \qquad \text{(IV.A-12)}$$

---

*Capacity x head large (ref. 27).
**Capacity x head small (ref. 27).

Thus,

$$CC_{PIPE} = THT\ (\ell_{PH}\ C_{HOT,REF} + \ell_{PC}\ C_{COLD,REF})\ \left(\frac{SM \times P_{th}}{SM_{PIPE,REF} \times P_{th,PIPE,REF}}\right)^{x_{PIPE}/2} \qquad (IV.A\text{-}13)$$

Default values are based on a molten salt design in which hot and cold runs are the same length (allowing the total reference cost to be put in either $C_{HOT,REF}$ or $C_{COLD,REF}$):

ℓ_{pH}(FPLH) = 2.6

ℓ_{pC}(FPLC) = 2.6

$C_{HOT,REF}$(CHPREF) = $\$1.32 \times 10^{4}$

$C_{COLD,REF}$(CCPREF) = \$0.0/m

$SM_{PIPE,REF}$(SMPI) = 1.5

$P_{th,PIPE,REF}$(PPIREF) = 2.6×10^{8} watts

x_{PIPE}(XPI) = 1.06 (ref. 23)

IV.A-8. Storage

$$CC_{STORAGE} = n_{STOR}\left(C_{TK,REF}\left(1 + \frac{n_{EMPTY}}{n_{STOR}}\right)\left(\frac{V'_{TK}}{V_{TK,REF}}\right)^{x_{ST}} + C_{MED,REF}\ \frac{V'_{TK}}{V_{TK,REF}}\right) \qquad (IV.A\text{-}14)$$

where n_{STOR} = number of storage tanks, or hot/cold pairs;

n_{EMPTY} = number of spare tanks;

$C_{TK,REF}$ = reference storage media containment cost (including hot and cold tank pair, if so designed, insulation, foundation, valving, etc.) (\$);

$C_{MED,REF}$ = reference storage media cost (\$);

V'_{TK} = tank volume (m^3);

$V_{TK,REF}$ = reference tank volume (m^3);

x_{ST} = scaling exponent for tanks.

n_{STOR} is determined from an assumed maximum volume per tank:

$$n_{STOR} = \frac{V_{STOR}}{V_{TK,MAX}}$$

where V_{STOR} = total volume required for storage (m^3);

$V_{TK,MAX}$ = maximum tank volume (m^3),

and for non-integer values, n_{STOR} is rounded to the next highest integer. The total storage volume is related directly to the energy in storage:

$$V_{STOR} = V_{TK,REF} \left(\frac{E_{STOR}}{E_{STOR,REF}} \right) \quad \text{(IV.A-15)}$$

where E_{STOR} is the energy in storage. The individual tank volume is:

$$V'_{TK} = \frac{V_{STOR}}{n_{STOR}} \quad \text{(IV.A-16)}$$

assuming that multiple tanks will be constructed of equal volume. (Note: Since $V_{TK,MAX}$ is a user supplied value, it can be chosen sufficiently large if only a single tank design is desired.)

In DELSOL storage is initially sized for the excess energy production on the longest day, June 21st. The calculation of E_{STOR} is illustrated in Figure IV-3. Its value is determined by a numerical integration to give the shaded area in the figure. The nominal number of hours of storage is simply E_{STOR} divided by P_{DES}. This storage size is used in the optimum total system design. However, this simplified approach often leads to a larger than optimal size storage system. The user is therefore given the option of rerunning a given design in a detailed performance calculation in which the storage size is incrementally decreased until a minimum energy cost is found. The details of this option are discussed in Section V.A-7.
Default values are based on a salt hot tank/cold tank design:

n_{EMPTY}(EMPTY) = 0.0

$C_{TK,REF}$(CSTREF) = \$4.593 x 10^6

$C_{MED,REF}$(CSTRMD) = \$3.22 x 10^6

$V_{TK,REF}$(VSTREF) = 4.078 x 10^3 m^3

x_{ST}(XST) = 0.6 (ref. 23)

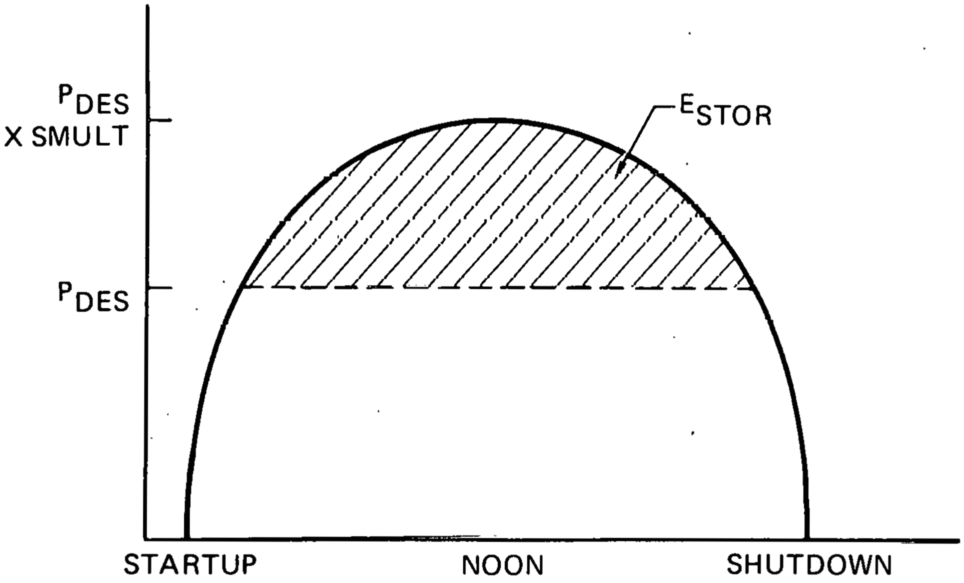


Figure IV-3. Energy to storage is the excess energy produced above the design point requirement; it is given by the hatched area. The reference time in this example is noon

$$V_{TK,MAX}(VMAX) = 1.23 \times 10^4 \ m^3$$

$$E_{STOR,REF}(ESTREF) = 9.0 \times 10^8 \text{ watt-hrs}$$

IV.A 9. Heat Exchangers

1. ICHE = 0 ; cost scales with thermal power:

$$CC_{HTXCHG} = C_{HE,REF} \left(\frac{P_{th}}{P_{th,HE,REF}} \right)^{X_{HE,P}} \quad \text{(IV.A-17)}$$

where $C_{HE,REF}$ = reference heat exchanger subsystem cost ($);

$P_{th,HE,REF}$ = reference design thermal power (watts);

$x_{HE,P}$ = scaling exponent

Default values are based on proposed molten salt designs, and the total subsystem cost includes an evaporator, superheater, and reheater:

$$C_{HE,REF} \text{ (CHEREF)} = \$1.525 \times 10^6$$

$$P_{th,HE,REF} \text{ (PHEREF)} = 3.0 \times 10^8 \text{ watts}$$

$$x_{HE,P} \text{ (XHEP)} = 0.8$$

2. ICHE≠0; cost scales with individual heat exchanger areas:

$$CC_{HTXCHG} = n_{PH} C_{PH,REF} \left(\frac{A'_{PH}}{A_{PH,REF}} \right)^{x_{HE,A}} + n_{EV} C_{EV,REF} \left(\frac{A'_{EV}}{A_{EV,REF}} \right)^{x_{HE,A}}$$

$$+ n_{SH} C_{SH,REF} \left(\frac{A'_{SH}}{A_{SH,REF}} \right)^{x_{HE,A}} + n_{RH} C_{RH,REF} \left(\frac{A'_{RH}}{A_{RH,REF}} \right)^{x_{HE,A}} \quad \text{(IV.A-18)}$$

where subscripts PH, EV, SH, RH refer to the preheater, evaportator, superheater, and reheater, respectively, and:

n_i = number of type i heat exchangers;

$C_{i,REF}$ = reference cost of single type i heat exchanger ($);

A_i = area of heat exchanger i (m^2);

$A_{i,REF}$ = area of reference type i heat exchanger (m^2);

$x_{HE,A}$ = scaling exponent.

n_i is calculated from a specified maximum area $A_{i,MAX}$ for a type i heat exchanger:

$$n_i = \frac{A_i}{A_{i,MAX}} \qquad \text{(IV.A-19)}$$

where

$$A_i = A_{i,REF} \left(\frac{P_{th}}{P_{th,i,REF}} \right) \qquad \text{(IV.A-20)}$$

and

$$A_i' = \frac{A_i}{n_i} \qquad \text{(IV.A-21)}$$

For non-integer values of n_i in equation (IV.C-19), it is rounded to the next highest integer. Default values are based on sodium hockey stick designs (ref. 30), and no preheater is included. (Salt heat exchangers have not yet been studied in detail by the authors for costing according to this option.) Also, $A_{i,MAX}$ is set sufficiently large so that only single units will be built.

$C_{PH,REF}$ (CPHREF) = $0.0

$A_{PH,REF}$ (APHREF) = 1.0 m^2

$A_{PH,MAX}$ (APHMAX) = 10^{10} m^2

$P_{th,PH,REF}$ (PPHREF) = 1.0 watt

$C_{EV,REF}$ (CEVREF) = $\$3.77 \times 10^6$

$A_{EV,REF}$ (AEVREF) = 1300.0 m^2

$A_{EV,MAX}$ (AEVMAX) = 10^{10} m^2

$P_{th,EV,REF}$ (PEVREF) = 2.6×10^8 watts

$C_{SH,REF}$ (CSHREF) = \$1.24 x 10^6

$A_{SH,REF}$ (ASHREF) = 400.0 m^2

$A_{SH,MAX}$ (ASHMAX) = 10^{10} m^2

$P_{th,SH,REF}$ (PSHREF) = 2.6 x 10^8 watts

$C_{RH,REF}$ (CRHREF) = \$1.38 x 10^6

$A_{RH,REF}$ (ARHREF) = 310.0 m^2

$A_{RH,MAX}$ (ARHMAX) = 10^{10} m^2

$P_{th,RH,REF}$ (PRHREF) = 2.6 x 10^8 watts

$x_{HE,A}$ (XHEA) = 0.6

IV.A-10. Electric Power Generating Subsystem (EPGS)

$$CC_{EPGS} = C_{EPGS,REF} \left(\frac{\eta_{TE,REF} \, P_{th}}{P_{EPGS,REF}} \right)^{x_{EPGS}} \qquad \text{(IV.A-22)}$$

where $C_{EPGS,REF}$ = cost of reference EPGS subsystem (turbine plant and electric plant) (\$);

$P_{EPGS,REF}$ = gross power rating of reference subsystem (watts);

$\eta_{TE,REF}$ = design point thermal to electric conversion efficiency (see section III.E-5).

Default values assume a 112 $MW_{E,\ gross}$ output and constant $\eta_{TE,REF}$ for all power levels.

$C_{EPGS,REF}$ (CEGREF) = \$27.3 x 10^6

$P_{EPGS,REF}$ (PEGREF) = 1.12 x 10^8 watts

$\eta_{TE,REF}$ (ETAREF) = 0.42

x_{EPGS} (XEPGS) = 0.8

Note: This cost is automatically set to zero for a user specified industrial process heat design (IPH $\neq$ 0 in namelist NLEFF).

IV.A-11. Fixed Costs--It is asumed that regardless of plant size, all plants have some common field costs (e.g., buildings and roads, master control, etc.). The default is estimated from a 100 $MW_{E,net}$ salt system.

$$CC_{FIXED}\ (CFIXED) = \$7.0 \times 10^6$$

IV.B. Calculating the Levelized Energy Cost

Based on the total capital cost, CC_T, estimated from the models discussed in the previous section, a levelized (or discounted average) cost of energy over the lifetime of the plant is calculated as follows (ref. 31,32):

1) The total investment at startup, $CC_{ST\text{-}UP,T,}$ will be the current capital cost estimate, CC_T, escalated to the first year of construction, Y_{CON}, plus the interest on the borrowed investment during construction, i_{DC}:

$$CC_{ST\text{-}UP,T} = (1.0 + i_{DC})\ (1 + ESC)^{(Y_{CON} - 1981)} CC_T \qquad \text{(IV.B-1)}$$

In current dollars,

$$CC_{ST\text{-}UP,81\$} = \frac{CC_{ST\text{-}UP,T}}{(1 + r_{inf})^{(Y_{CON} - 1981)}} \qquad \text{(IV.B-2)}$$

where r_{inf} is the general rate of inflation (not necessarily equal to the capital escalation rate).

2) The levelized energy cost includes both capital recovery and operating and maintenance charges. The O&M charges are calculated as a levelized percentage of the capital cost; DELSOL splits O&M charges into heliostat and non-heliostat rates:

$$LEC = \frac{(FCR \times CC_{ST\text{-}UP,T}) + (O\&M_{H,LEV} \times CC_{ST\text{-}UP,H}) + (O\&M_{BAL,LEV} \times CC_{ST\text{-}UP,BAL})}{PF \times (1 - PL_{AVG}) \times KW\text{-}HR}$$

(IV.B-3)

where FCR = fixed charge rate, i.e., annual charge against the capital investment to account for returns to shareholders, taxes and insurance, depreciation, debt cost, discount rate;

$O\&M_{H,LEV}$ = levelized heliostat O&M rate;

$CC_{ST\text{-}UP,H}$ = heliostat subsystem capital investment at startup (includes land and wiring);

$O\&M_{BAL,LEV}$ = levelized balance of plant O&M rate;

$CC_{ST\text{-}UP,BAL}$ = balance of plant capital investment at startup;

PF = plant factor for scheduled maintenance;

PL_{AVG} = average parasitic load, as a fraction of the gross plant output (see also section III.E-6);

KW-HR = net total yearly energy production (kw-hr) at 100% plant factor; i.e., no scheduled shutdowns, but weather outage included.

<u>IV.B-1. Fixed Charge Rate</u>--The user is allowed one of two options for the fixed charge rate, FCR:

1. <u>IFCR = 0</u>; user specified value of FCR (value of DISRT should be consistent).
2. <u>IFCR ≠ 0</u>; FCR calculated by DELSOL based on user supplied values of economic parameters.

$$FCR = PTI + \frac{(1.0-ITC)-(ITR \times DEP)}{(1.0-ITR)f_{DIS}} \tag{IV.B-4}$$

where PTI = annual property tax and insurance rate;

ITC = investment tax credit;

ITR = income tax rate;

DEP = depreciation allowance, discussed below;

f_{DIS} = discount factor, discussed below.

a) Depreciation Schedules--With option b) above (IFCR≠0), the user is allowed one of two choices for calculating the depreciation allowance:

1) IDEP=1; straight line schedule:

$$DEP = \sum_{y=1}^{Y_{DEP}} \frac{(1.0/Y_{DEP})}{(1.0+r_{dis})^y} \tag{IV.B-5}$$

where Y_{DEP} = depreciation life of the solar plant (yrs);

r_{DIS} = discount rate (see below).

2) IDEP=2; sum-of-years digits schedule

$$DEP = \sum_{y=1}^{Y_{DEP}} \frac{2(Y_{DEP}-y+1)}{Y_{DEP}(Y_{DEP}+1)(1+r_{DIS})^y} \tag{IV.B-6}$$

b) Discount Rate and Discount Factor--The discount rate r_{DIS} is the effective cost of money to the owner and includes both debt cost and return on equity requirements according to:

$$r_{DIS} = [(1.0-ITR) \times f_D \times i_D] + (1.0-f_D) \times ROE \tag{IV.B-7}$$

where f_D = debt fraction;

i_D = debt cost (interest rate on borrowed capital);

ROE = before tax return on equity.

(Note that r_{DIS} = ROE for f_D = 0; i.e., 100% equity financed projects.)

The discount factor is:

$$f_{DIS} = \sum_{y=1}^{Y_{OP}} \frac{1.0}{(1.0+r_{DIS})^y} \tag{IV.B-8}$$

where Y_{OP} = economic operating life of the plant (yrs).

IV.B-2. Levelized O&M Rates--The levelized O&M rates are determined from the initial rate, $O\&M_i$; the yearly inflation and discount rates, r_{inf} and r_{dis}, respectively; and the plant operating life, Y_{op}:

$$O\&M_{LEV} = \frac{\sum_{y=1}^{Y_{op}} \frac{O\&M_y}{(1 + r_{dis})^y}}{\sum_{y=1}^{Yop} \frac{1}{(1 + r_{dis})^y}}$$

$$= \frac{O\&M_i \sum_{y=1}^{Yop} \frac{(1 + r_{inf})^y}{(1 + r_{dis})^y}}{\sum_{y=1}^{Yop} \frac{1}{(1 + r_{dis})^y}} \qquad \text{(IV.B-9)}$$

Default values are:

i_{DC} (AFDC) = 0.15 (5-year construction period)

ESC (ESC) = 0.08

Y_{CON}-1981(NYTC0N) = 0 (plant construction begins now)

r_{inf} (RINF) = 0.08

IFCR = 0

FCR (FCR) = 0.159

$O\&M_{h,i}$ (RH0M) = 0.015

$O\&M_{BAL,i}$(RNH0M) = 0.015

PF(PF) = 1.0

r_{DIS}(DISRT) = 0.0996

PIT(PTI) = 0.025

ITC(TC) = 0.10

ITR(TR) = 0.48

f_D(FDEBT) = 0.543

i_D(RDEBT) = 0.11

ROE(ROE) = 0.15

IDEP = 2

Y_{DEP}(NDEP) = 24

Y_{OP}(NYØP) = 30

V. System Optimization

V. System Optimization

V.A Optimization Variables

DELSOL can perform an efficient search for the combination of system design variables that minimizes the levelized energy cost (LEC). The design parameters which can be automatically varied by DELSOL are listed in Table V.1. The design parameters that are held constant during an optimization search are listed in Table V.2. This second set of variables can be optimized by performing several DELSOL optimizations, each run having different values for these variables. In addition, DELSOL can optimize the system design subject to constraints on the receiver fluxes and on the land available for the heliostat field. (Unless indicated otherwise all variables mentioned in Section V are in Namelist ØPT.)

V.A-1. Design Point Power Level--DELSOL can simultaneously optimize systems at NUMØPT (≤ 20) equally spaced discrete design point power levels from a minimum value of PØPTMN to a maximum value of PØPTMX watts. The design point occurs at REFTIM hours past solar noon on the REFDAY day of the year (namelist BASIC). The insolation at the design point is REFSOL kw/m^2 (namelist BASIC). In Version 1 of DELSOL it was recommended that even if the user desired only one design power, he should also specify lower design powers in order to speed up the search algorithm. This is no longer true in Version 2. If only one power level is desired, then the user should specify only one power level.

V.A-2. Tower Height--DELSOL can search over NUMTHT (≤ 20) equally spaced discrete values of the tower height from a minimum value of THTST m to a maximum value of THTEND m. The user is reminded that tower height is defined in DELSOL as the elevation of the midpoint of the receiver above the plane of the heliostat pivot (see Figure II-12).

V.A-3. Receiver Dimensions--DELSOL can search independently over two receiver variables. The choice of the variables depends on the type of receiver.

a) External Receiver--The first receiver variable for an external receiver is the diameter W. There are NUMREC (≤ 20) equally spaced discrete values of W from a minimum of WST meters to a maximum of WEND meters. The second receiver variable is the ratio of the receiver height H to the receiver width W. There are NUMHTW (≤ 20) equally spaced discrete values of H/W from a minimum of HTWST to a maximum of HTWEND.

b) Flat Plate Receiver(s)--The first receiver variable for a flat plate receiver is the horizontal dimension of the first flat plate, RX(1). There are NUMREC (≤ 20) equally spaced discrete values of RX(1) from a minimum of WST meters to a maximum of WEND meters. The second receiver variable is the ratio of the first plate's vertical dimension to its horizontal dimension, RY(1)/RX(1). There are NUMHTW (≤ 20) equally spaced discrete values of RY(1)/RX(1) from a minimum of HTWST to a maximum of HTWEND.

TABLE V.A-1.

DESIGN PARAMETERS VARIED DURING OPTIMIZATION

Note that some of the variables can have only discrete values (e.g., either 100 m or 120 m tower heights) while others are varied continuously.

- Design point power level (discrete values)
- Tower height (discrete values)
- Receiver dimensions (discrete values)
    - External cylinder
      Height and diameter
    - Flat plate(s)
      Height and width
    - Cavity(ies)
      Height and width of aperture
      -or-
      Width of aperture and depth of cavity
- Tower location for land constrained system (discrete values)
- Field boundaries (continuous values)
- Heliostat spacings (continuous values)
- Storage capacity at a given solar multiple (discrete values)

TABLE V.A-2.

DESIGN PARAMETERS HELD CONSTANT DURING A SINGLE DESIGN OPTIMIZATION RUN

These parameters can be optimized only by doing several runs, each with a different value for the parameter of interest.

- Site
  - Latitude
  - Insolation
  - Weather
  - Atmospheric attenuation
- Field
  - Type (surround or north-only zoning)
  - Heliostat layout pattern
  - Minimum and maximum radial boundaries
- Heliostat
  - All design parameters
- Receiver
  - Receiver type (external cylinder or flat plate or cavity)
  - Orientation of cavity aperture or flat plate
  - Ratio of dimensions of 2nd, 3rd, 4th apertures or flat plates (if any) to that of the 1st
- Solar Multiple

In the case of multiple flat plate receivers all receiver dimensions are assumed proportional to the first receiver's dimensions. RX2TRX, RX3TRX, RX4TRX are the ratios of the second, third and fourth plate's horizontal dimension to the first plate's horizontal dimension. The vertical/horizontal ratio, RYTRX, is assumed the same for all plates.

c) Cavity Receivers--Cavity receivers are more complicated to design than other receiver types. Not only must the size of the aperture be determined, but also the depth of the cavity and the size of the heat exchanger surface within the cavity. These are more design parameters than DELSOL can vary at one time. Therefore, a single automatic optimization of a cavity receiver is not possible. However, DELSOL has the capability to run a series of optimization and performance runs that will lead to a good cavity design. Different pairs of receiver variables are selected in sequence. First, the width of the aperture and depth of the cavity are optimized (IØPTUM-2). Second, the aspect ratio of the aperture is optimized (IØPTUM=1). Finally, performance runs are used to generate flux maps within the cavity so that the user can manually fine tune the shape of the heat absorbing surface. Each of these steps is described below in more detail.

The first step in optimizing a cavity is to determine the aperture width and cavity depth by specifying IØPTUM=2. DELSOL searches NUMREC equally spaced discrete values of the width of the first aperture, RX(1), from a minimum value of WST meters to a maximum value of WEND meters. The second receiver variable is the diameter W of the horizontal circle containing the cavity apertures. Since the depth of the Ith cavity is proportional to W (RWCAV(I), Namelist REC), the second receiver variable also varies the cavity depth. There are NUMHTW discrete equally spaced values of the width, W, from a minimum of HTWST meters to a maximum value of HTWEND meters. W (and hence the cavity depths WxRWCAV(I)) is determined entirely by the receiver flux limits. There is no performance advantage (for a fixed aperture size) to making the cavity deeper. However, there is a cost penalty for making the cavity deeper since the size of the heat exchanger surface grows as discussed in section IV.A-5(b). Therefore, DELSOL will not increase the depth of the cavity above the minimum value allowed in the search, HTWST x RWCAV(I), unless it is forced to by a flux constraint.

The second step in optimizing a cavity is to fine tune the width and aspect ratio of the apertures by specifying IØPTUM=1. During this step the constant width, W, specified on the REC Namelist should be set equal to the optimum W found in the first step. With IØPTUM=1 the first receiver variable is again the width of the first aperture, RX(1). However, the second receiver variable is now the dimensionless aspect ratio of the aperture, RY(1)/RX(1). There are NUMHTW (< 20) equally spaced values of the aspect ratio from a minimum value of HTWST to a maximum value of HTWEND.

The final step is to fine tune the shape of the heat exchanger surface within the cavity. As described in Sections II.H and IV.A-5 the heat absorbing surface is modeled as a segment of right circular cylinder centered on the cavity aperture. The size of the cylinder is made big enough so that the image from any heliostat that might be used in building up the optimal field will be intercepted. However, DELSOL seldom uses all of the heliostats that might be added to the field. Therefore, it is possible that parts of the heat exchanger surface may be receiving little or no flux. To check this the user should rerun detailed performance calculations of the optimum system to generate flux maps on the heat absorbing surface. The user can then manually trim the heat absorber to eliminate areas whose amount of energy collected is not justified by the cost.

The user should also be aware that the height of the heat absorbing surface is very sensitive to the minimum radius (RADMIN, Namelist FIELD), as seen in equation (IV.A-8). While it is desirable to use the high performance heliostats near the tower it may not be cost effective because of the increased receiver costs. The user should try repeating the optimization with a different RADMIN to investigate the sensitivity to this effect.

V.A-4. Tower Position (Land Constrained Only)--In a system with a land constraint, DELSOL will search for the optimal position for the tower. The tower does not have to be within the land constraint, only the heliostats must be within the constraint. The code considers NUMP0S (< 20) equally spaced discrete positions of the tower from (XTPST,YTPST) to (XTPEND,YTPEND). XTPST and XTPEND (YTPST and YTPEND) are in units of meters east (north) of the center of the first land constraint rectangle. (See Sections II.B-4 and V.B-2 for more discussion on land constrained systems.)

V.A-5. Heliostat Field Boundaries--DELSOL will optimize the boundaries of the heliostat field. The heliostat field is always constrained to lie within the zoning defined by the user (II.B). In addition, the heliostat field can be subjected to a land constraint as discussed in Section V.B-2.

V.A-6. Heliostat Spacings--DELSOL has an option for optimizing the spacing of heliostats within each zone (IH0PT=1 in Namelist 0PT). The optimization has three constraints: (1) the layout pattern is always a radial stagger; (2) the optimized densities and aspect ratios cannot be more than + 20% from the initial densities and aspect ratios defined in Namelist FIELD (range is set by DH0PT in Namelist BASIC); and (3) the tower height cannot be optimized simultaneously with optimizing heliostat spacings (see Section V.G.).

V.A-7. Storage Capacity--As mentioned in section IV.A-8, DELSOL will initially size storage based on the longest operating day in order to avoid the necessity of detailed energy flow accounting while optimizing other system design parameters. However, in systems with large amounts of storage and/or expensive storage concepts, it may be more cost effective to decrease the storage capacity at the expense of discarding (or not collecting) some of the energy from the field. DELSOL allows the user the option to carry out this suboptimization of the storage size given the optimum design from subroutine MAX for the rest of the system.

First the user "turns on" the option by setting ISTR to some non-zero value in Namelist 0PT, and also by defining the NSTR equally spaced sizes from zero to maximum capacity to be evaluated. The user must also specify the detailed performance rerun option (IRERUN=1) as discussed in Chapter VI since storage size optimization takes place in conjunction with the detailed energy flow accounting of this option. Further the user is restricted to a single power level for rerun and hence storage optimization.

The default values (ISTR=0, NSTR=1) allow no storage optimization. Rerunning a specified optimum design for detailed performance would give, in this case, system performance for the maximum size storage capacity determined initially.

V.B. Constraints on System Design

DELSOL can accommodate flux limits on the receiver and/or land availability limitations in system design optimization.

V.B-1. Receiver Flux Constraint--DELSOL allows the user to limit the flux at the design point at NFLXMX (< 4) points on the receiver surface. The maximum allowed values are specified by FLXLIM(I) W/m^2 (I=1, NFLXMX). The flux points are initially defined relative to the receiver described in the REC namelist immediately preceeding the 0PT namelist. The following steps should be used in setting up a flux limited design run:

(1) Define the type of receiver desired on the REC Namelist preceeding the 0PT namelist.

(2) Set up a grid of flux points on the heat absorbing surface of this receiver (in Namelist NLFLUX following Namelist 0PT). The user is cautioned here to be careful in defining the correct flux surface, as it may not necessarily coincide with the receiver surface (e.g., cavity aperture plane). The option IFLAUT=4 automatically sets up a flux surface which is usually the one of interest, i.e., a single point at the north center of an external receiver or the center of the first flat plate or heat absorbing surface of the first cavity.

(3) Choose NFLXMX (< 4) points from the grid of flux points defined in step (2) at which the flux limits are to be tested. Specify the number of each point in the NMXFLX(I) array (I=1, NFLXMX) in Namelist NLFLUX following Namelist 0PT).

(4) Specify the maximum value of the flux at each point in units of W/m^2 in the FLXLIM(I) array (I=1, NFLXMX) of Namelist NLFLUX following Namelist 0PT. The peak flux limit may differ at different points because of varying tube temperatures, etc.

(5) For external or flat plate receivers select an appropriate automatic "smart" aiming option (Section II.G, Namelist REC). "Smart" aiming is optional for cavity receivers.

(6) For external or flat plate receivers, allow the height to width ratio, H/W, to vary. For cavity receivers allow the diameter W, and hence the cavity depth, RWCAV(I)*W, to vary.

As the receiver size is varied the flux point remains at the same relative position on the receiver surface as illustrated in Figure V-1. For external receivers each flux point remains at the same azimuth angle, same fraction of the height, and on the cylinder surface (provided it was initially on the cylinder surface). For flat plate receivers the flux point remains at the

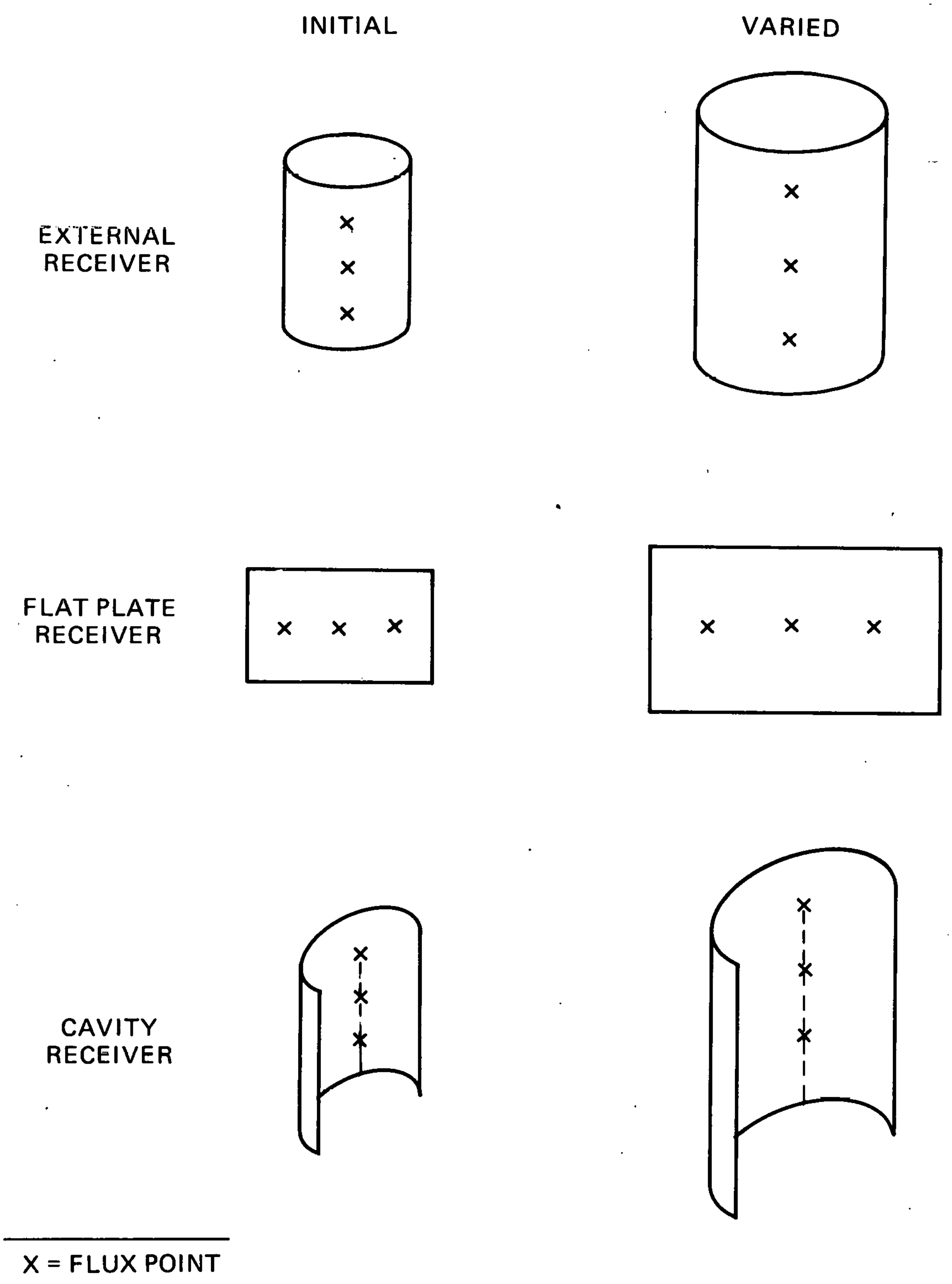


Figure V-1. Location of Flux Points as Receiver Dimensions are Varied. Flux points remain at the same relative position as the receiver size is varied.

same fraction of the height and same fraction of the width. For cavity receivers the flux surface is taken as the inside of a vertical cylinder centered on the first aperture. The displacements of flux points relative to the center of the first aperture scale with the height of the heat absorbing surface, calculated according to equation IV. A-8.

The fluxes at the NFLXMX receiver points will generally be less than the maximum values allowed, FLXLIM(I). This results from the fact that the receiver size is being varied in discrete steps and not continually. To come closer to a given flux limit the user can use more closely spaced receiver sizes, or the flux limit can be set slightly higher than actually desired since the flux from the optimum will generally be below the limit.

V.B-2. Heliostat Field Land Constraint--DELSOL allows the heliostat field to be constrained within a number of arbitrarily oriented rectangles. The input defining the land constraint is described in Section II.B-4. As mentioned above, with a land constraint it is necessary to search for the optimal location of the tower with respect to the constraint. Only the heliostat locations are constrained. The code does not require the tower to be within the land constraint. However, the user should make sure that land is available for the tower.

There is an additional complication in land constrained designs when the thermal energy is not used at the base of the tower. In repowering or process heat applications the thermal energy may have to be transported to a point near the edge of the land constraint. DELSOL does not consider the cost or losses in the piping run from the tower position to the use point. The user may want to fold in these effects manually. For example, consider a rectangular land constraint whose sides are parallel to the N/S and E/W directions. DELSOL will generally prefer to locate the tower south of the center of the land constraint. Suppose, however, that the thermal energy is required at the northern boundary of the field. It may then be cost effective to move the tower further north from the DELSOL optimum if the savings in the pipe run may more than offset the increased cost of thermal energy at the tower base.

V.C. Searching Algorithm

DELSOL has to consider NUMTHT x NUMREC x NUMHTW x NUMPØS combinations of tower height, receiver sizes and tower positins in searching for the minimum energy costs. Figure V-2 shows a schematic of the optimization search. There are four nested iterations of the discrete system variables: tower height, first receiver variable, second receiver variable and tower position. Since the zone by zone performances does not depend on the tower location, these performances are calculated outside of the tower position loop. For each set of system variables an optimal field is built up. At each design point power level attained in the field build-up, the levelized energy cost is tested to see if it is a new minimum. If it is a new minimum, the system design, performance and costs are saved. When the iterations are complete, the lowest energy cost system from the allowed system variations is known at each power level.

Considering every possible combination of system variables (IALL=1) is an inefficient way to find the optimum system(s). DELSOL, therefore, has the default option (IALL = 0) to do a "smart" search over the receiver variables.

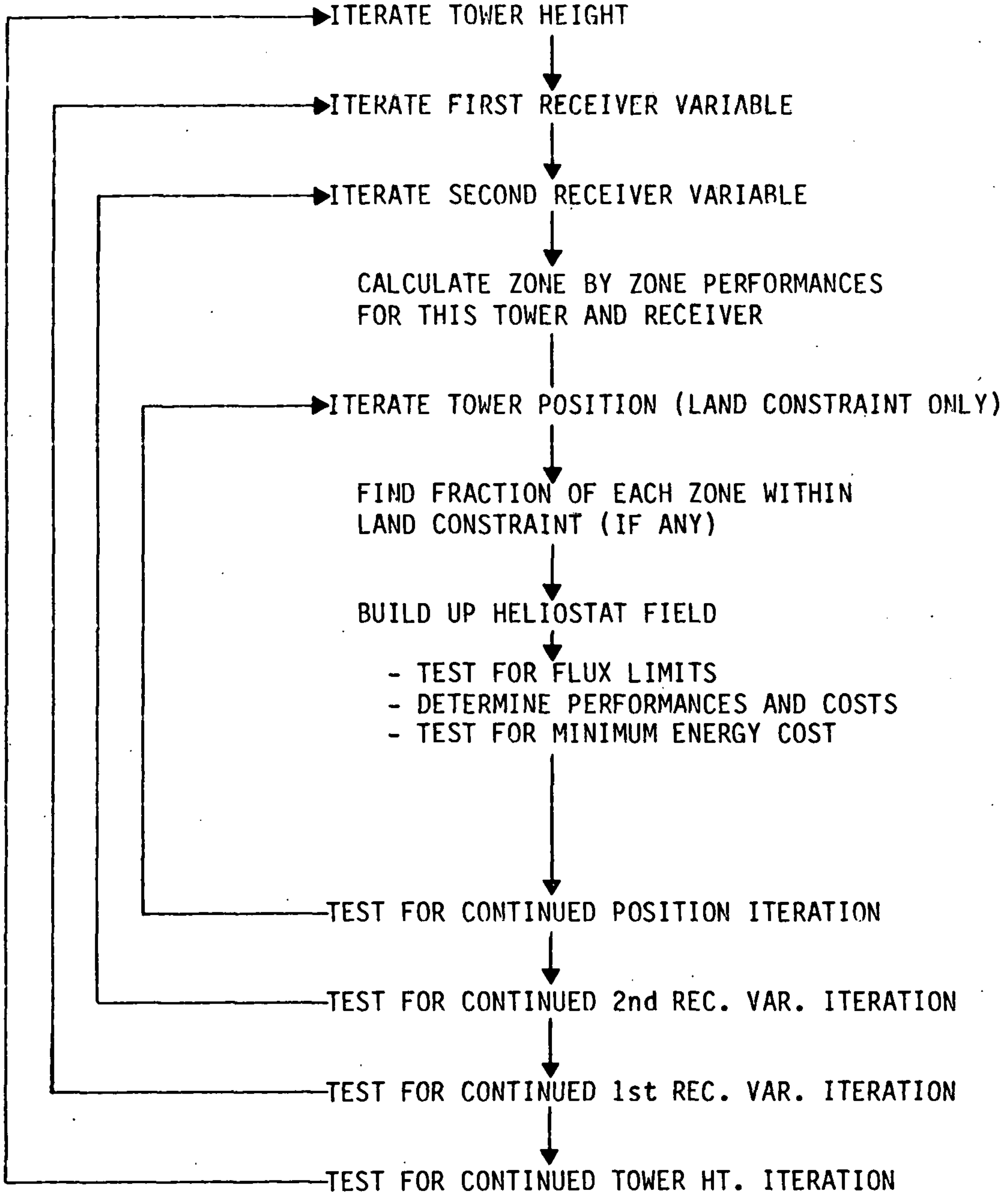


Figure V-2. Schematic of Optimization Search

Smart searching tries to consider the minimum set of system variables necessary to find the optimum system(s). The search algorithm attempts to start iterating a variable at a value greater than its minimum allowed value and to stop iterating a variable before it reaches its maximum allowed value. The search strategy follows from the assumptions that: (1) there is a single, well defined, minima in each variable; and (2) the optimum tower height and receiver size increases when the power level increases. The existence of a single minima allows DELSOL to stop iterating a variable when the energy cost is increasing at every power level that can be reached by changing that variable. The increase of optimum receiver size with power level allows DELSOL to use the minimum optimum receiver size at a lower power level as the starting point for the next power level. (For example, suppose the user has allowed receiver sizes of 10, 11, 12...20. At THT = 150 the minimum receiver size that is an optimum for any power level is 12. Then when doing the next tower height, say THT = 160, instead of starting to search at receivers of size 10, DELSOL will start searching at a receiver size of 12.)

DELSOL also contains tests to avoid searching over systems that cannot meet the minimum power of interest. If a given tower height is too small to meet the minimum design power level, DELSOL automatically skips to the next tower height without searching (in vain) for the optimum receiver size.

Flux limited receiver designs complicate the search strategy. None of the methods for restricting the seach can be applied until the flux constraint is satisfied. For example, DELSOL will increase the receiver size as long as there is a flux limit even though the energy costs are increasing. Flux limited receiver optimizations have to search over more cases than the corresponding non-flux limited receiver optimizations. It is particularly important to use the coarse grid/fine grid strategy described at the end of this chapter when optimizing with a flux limit.

A detailed summary of the optimization search is provided as output. The user can follow the optimization strategy by analyzing this information. In addition, the information on the search can give a good indication of the sensitivity of the energy costs, performances, etc. to variation of the design parameters (e.g., if 150 m is the optimum tower height but the user would like to know what the system costs would be at 160 m or 140 m this information is available).

V.D. Scaling Performance

As shown in Figure V-2, DELSOL must recalculate the zone by zone annual average and design point optical performances at each new tower height and receiver size. The code does this by "scaling" the results of a detailed initial performance calculation. Some minor assumptions are made during the scaling of the performance with tower height and receiver size. The user can check the effect of these assumptions by rerunning a detailed performance calculation of the optimized system.

V.D-1. Cosine--The field points remain at the same relative position (e.g., 2 tower heights north) as the tower height is varied. The angles between the sun, heliostat and receiver are the same and therefore the cosine is not a function of the tower height. The very small change in the cosine as the receiver width from the tower centerline is varied is ignored.

V.D-2. Shadowing and Blocking--The actual shadow cast by a heliostat in the same relative field position is independent of the tower height. However, the displacement of heliostats relative to each other in radial layouts depends on the ratio of the heliostat dimension to the tower height. Hence, the shadowing and blocking has a small dependence on the tower height. The code, however, neglects this effect. For large systems, i.e., heliostat dimension/tower height << 1, this approximation is excellent. In smaller systems, the effect can be noticable, but the generally small amount of shadowing and blocking even in these systems does not significantly effect overall system performance and energy costs. In a small system design run, the user is advised to select a tower height for the initial performance run (THT in first REC Namelist) within the range to be searched in the optimization. For example, if the default heliostat (7.4 m x 7.4 m) is used in a small system design where tower heights of 30 to 50 m are being tested, the default value of 175 m for THT should be replaced with 40 m in the initial performance run.

V.D-3. Atmospheric Attenuation--The atmospheric attenuation is exactly recalculated for every tower height and receiver.

V.D-4. Spillage and Flux--The variation of the annual average flux from each zone with tower height is given analytically in the extended Hermite polynomial expansion technique used in DELSOL. The coefficients of the tower height dependence are determined in the initial performance calculation and then used during the optimization to calculate the flux.

V.D-5. Design Point Performance--The design point, cosine, shadowing, blocking and atmospheric attenuation are scaled in exactly the same manner as the corresponding annual average quantities, as described above. However, the fluxes and spillages at the design point are not recalculated, but assumed equal to the annual average fluxes and spillages. This is generally a very good approximation.

V.E. Building up the Optimal Heliostat Field

V.E-1. No Heliostat Density Optimization--In this case DELSOL does not try to vary the default or user defined heliostat fields. A performance/cost ratio, PCR, is determined for each zone:

$$PCR_{k,\ell} = \frac{\eta_{F,k,\ell}}{C_{H,k,\ell}} \qquad (V.E-1)$$

where k = radial zone index,

ℓ = azimuthal zone index,

$\eta_{F,k,\ell}$ = yearly average field efficiency in zone (k,ℓ),

$C_{H,k,\ell}$ = cost of putting 1 m^2 of reflective surface in zone (k,ℓ) relative to the same cost for zone (1,1).

In more detail,

$$\eta_{F,k,\ell} = \eta_{COS,k,\ell} \times \eta_{SHAD,k,\ell} \times \eta_{BLOCK,k,\ell} \times \eta_{ATM,k,\ell} \times \eta_{INT,k,\ell}$$

where η_{COS} = cosine efficiency = 1.0 - cosine loss

η_{SHAD} = shadowing efficiency = 1.0 - shadowing loss

η_{BLOCK} = blocking efficiency = 1.0 - blocking loss

η_{ATM} = atmospheric transmittance = 1.0 - atmospheric attenuation

η_{INT} = receiver interception factor = 1.0 - spillage

The relative mirror cost is comprised of three parts:

$$C_{H,k,\ell} = \frac{C_{HEL,k,\ell} + C_{LAND,k,\ell} + C_{WIRE,k,\ell}}{C_{HEL,1,1} + C_{LAND,1,1} + C_{WIRE,1,1}} \qquad \text{(V.E-2)}$$

where $C_{HEL} = \frac{\$}{m^2 \text{ mirror area}}$ for total heliostat structure, equal for all heliostats in the field;

$C_{LAND} = \frac{\$}{m^2 \text{ land}} \times \frac{1}{\text{mirror density per zone}}$; less dense zones have greater associated land costs per heliostat;

$C_{WIRE} = \frac{\$}{\text{heliostat}} \times \frac{1}{\text{glass area/hel.}}$; the "\$/heliostat" varies with local density (greater secondary wiring costs with lower densities) and distance from the tower (greater primary wiring costs as the field gets larger), as discussed in the wiring cost model section (IV.A-3).

After calculation of $PCR_{k,\ell}$, a call is made to subroutine MAX where the actual field build-up is carried out. First, the zones are ranked from best to worst PCR. Then the zones are added one at a time, starting with the most cost effective, i.e., the one with the highest PCR. As each zone is added, the reference (design point) thermal power to the receiver, the annual energy production from the field, and the total field costs (heliostats, land, and wiring) are updated. Also, the power dependent receiver and piping radiation and convection losses are re-calculated to determine the net electrical power production. When each design power of interest (as specified by P0PTMN, P0PTMX, and NUM0PT in namelist 0PT) is reached, the remaining plant capital costs and corresponding levelized energy cost (LEC) are calculated. MAX will return to 0PTCAL when any of the following three constraints are encountered:

1) all specified design powers have been achieved;

2) all design powers have not been achieved, but adding all remaining zones will not reach the next highest design power;

3) a specified flux limit is reached (in this case the code can reiterate with the "smart" aimpoint strategy described in section II.G if a single aimpoint had been the original choice).

V.E-2. Heliostat Density Optimization--DELSOL has an option (IH0PT=1) to optimize the heliostat separations within each zone. In many problems the default densities are adequate. However, if the field costs or heliostat shape are very different from the DELSOL default values, then heliostat spacing optimization may be important. In all cases it is prudent to optimize periodically heliostat separations to see if this produces significant improvement in the energy cost. The mathematical details of heliostat optimization are derived by Lipps (ref. 4). DELSOL bases its heliostat optimization on these equations and assumptions.

A completely general optimization of the coordinates of every heliostat is not practical. Following the approach in reference 4, the following assumptions are made in order to simplify the problem:

(1) the heliostat layout pattern within any one zone is determined by two parameters: the "average" radial separation ΔR and the "average" azimuthal separation ΔAz;

(2) the shadowing and blocking in a zone are determined only by the layout parameters for that zone;

(3) the optimum layout parameters to produce a given amount of annual energy will be determined. These may or may not be the optimum layout parameters to produce a given design power. This subtle point is discussed in more detail below;

(4) the maximum deviation of the optimized ΔR and ΔAz is constrained to be within a specified window around the initial ΔR and ΔAz defined for each zone in Namelist BASIC. The size of the window is controlled by DHOPT in Namelist BASIC.

Since the energy cost is not very sensitive to the heliostat spacings, the effect of the simplifying assumptions is minimal in most practical problems.

DELSOL must generate considerable information about the shading and blocking as a function of heliostat position in order to optimize the separations. During the initial performance calculation the code does 25 shadowing and blocking calculations for each zone. The calculations are done on a 5x5 grid of heliostat separations. One side of the grid has constant density lines; the other side has constant aspect ratio lines (= $.5\Delta R^2 - .5\Delta Az^2$). The grid is used to interpolate the performances and performance derivatives with respect to separation required in heliostat spacing optimization. The grid is centered on the density and aspect ratio determined for each zone by the ΔR and ΔAz defined in Namelist FIELD. The size of the grid is determined by DHOPT (Namelist BASIC). The larger DHOPT the farther the heliostat separations are allowed to vary from the initial values in searching for the optimum. However, the larger DHOPT, the larger are the potential errors in interpolation and differentiation.

To prepare for field buildup, the code does four preliminary calculations for every zone. First, it finds the "best" aspect ratio at each density. If the land and wiring costs are negligible, the best aspect ratio at a given density would be the aspect ratio that gives the minimum shading and blocking. Second, it finds the density that gives the maximum average performance/cost ratio (PCR) for that zone. When the zone is first added to the field it will be at this density. Third, DELSOL finds the marginal value of increasing the density beyond the density that optimizes the average PCR. The marginal value is defined as the change in the busbar energy cost for adding or subtracting one heliostat from that zone. The marginal values decrease with density beyond the density that optimizes the average PCR. These marginal values determine how the density in the zone is increased during field buildup after the zone has been added to the field. Finally, when the first three calculations are completed for every zone, DELSOL ranks the zones accordingly from maximum to minimum average PCR. This ranking determines the order in which zones will be added to the field.

Field buildup proceeds as follows:

(1) The zone with the best average PCR is added to the field;

(2) The unused zone with the best average PCR is added to the field and the density of all zones already in the field is increased. The number of heliostats to be added to each zone already in the field is determined by requiring that the marginal value of adding one more heliostat to any zone is the same. (If the marginal values were unequal an optimum field would not exist since the energy cost could be lowered by moving a heliostat from a lower to a higher marginal value zone.)

(3) Step (2) is repeated until: (a) all design powers are achieved; (b) a flux limit constraint is exceeded; or (c) all the zones have been added to the field.

V.E-3. Optimizing for Annual Energy vs. Optimizing for Design Point Performance--Characterizing the time dependent output of a central receiver system is difficult. The usual convention is to specify a design point power, P_{DES}. However, there are a whole range of systems with the same design point power which produce different amounts of annual energy, E, and different energy costs. Conversely, there are systems with the same E but with different P_{DES}'s. This leaves DELSOL with a subtle identity crisis. While DELSOL seeks to design a system to meet a specified P_{DES}, it optimizes the system to produce a given E at the minimum energy cost. To find the system with a given P_{DES}, DELSOL designs systems optimized for increasing E's until a system is reached with the design power of interest.

Optimizing the system for a given annual energy E does not guarantee that the system will be the optimal system for the design power P_{DES} that corresponds to E. Consider the following example (these numbers are for illustrative purposes only; they are not actual output):

System	Heliostat Optimization	Annual Energy	Design Power	Energy Cost
1	No	100.	50.	80
2	No	110.	55.	78
3	No	110.	50.	79
4	Yes	90.	50.	81
5	Yes	100.	55.	79
6	Yes	110.	60.	77

Cases 1 and 2 are systems that are optimized to produce annual energies of 100. and 110. The corresponding design powers are 50 and 55, respectively. Consider now Case 3. Case 3 is not the optimum system to produce an E = 110 because its energy cost (79) is higher than Case 2 (78). However, Case 3 produces the design power P_{DES} = 50 at a lower cost than Case 1. The reason that Case 3 is better than Case 1 for P_{DES} = 50 is that the energy cost (which depends on E, not P_{DES}) is falling rapidly with increasing E due to the effect of non-field costs. The field layout in Case 3 is different from Case 1. In Case 3 the heliostats have a larger annual efficiency/design efficiency ratio in order to produce more annual energy at the design point.

Consider now optimizing the heliostat spacings. This is done in Cases 4-6. Notice that optimizing the heliostat spacing has reduced the energy cost at a fixed amount of annual energy (Case 5 vs. Case 1 or Case 6 vs. Case 2). However, the heliostat optimization has not decreased the energy cost for the cases of P_{DES} = 50 (Case 4 vs. Case 1) and P_{DES} = 55 (Case 5 vs. Case 2). The explanation is again that after heliostat optimization the design powers correspond to a lower annual energy E and the energy cost is dropping with E. Heliostat spacing optimization is doing what it is designed to do: lowering the energy cost at a fixed E. Unfortunately, this does not always result in a lower cost at a fixed P_{DES}. It can be disconcerting to observe occasionally that the energy cost at a fixed P_{DES} increases after trying to optimize heliostat spacings. However, if the user plots the output on an energy cost vs. annual energy basis, then the improvement with heliostat spacing optimization can be seen.

In practice the difference in the energy costs between optimizing for a given annual energy vs. optimizing for a given design point are small (< 1%). The difference disappears if the non-field costs are relatively small or if the energy cost is not changing with E. Why doesn't DELSOL offer the option of finding the system optimized to produce a given P_{DES}? Because it is much more complicated and the small improvements are generally not significant.

V.F. Sensitivity of Energy Costs to Variation of Design Parameters

Generally, the cost of energy is not very sensitive to modest variations of the design parameters away from the optimal values determined by DELSOL. It is important for the user to remember that the minima are shallow. First, the broad optimum means that a very fine (and time consuming) grid of variables is not needed. Second, the designer has the freedom to vary the system to maximize other considerations besides cost of energy. For example, DELSOL may select a large height to width ratio for a flux limited external receiver. However, a more modest aspect ratio may be desired for engineering or other reasons. The optimization can be repeated with smaller H/W ratios in order to see what the cost of energy penalty is. The energy cost differential may be so small that the other design considerations dominate and a smaller H/W ratio than the DELSOL minimum will be selected.

Small changes in the input generally produce small changes in the energy cost but can produce large changes in the optimum value of the design parameters. This is also a consequence of the shallow minima in the energy cost vs. design variables. This effect is often the source of consternation among users. It seems counter-intuitive to many people that one can set out to design systems for the same application and yet wind up with significantly different designs just because of some small differences in the input variables. If one were to compare energy costs, however, the different designs would probably be nearly identical on a cost basis.

V.G. Running Optimization Calculations

An outline for designing a system using DELSOL is given in Table V.G-1. Step I is the definition of the system design and is often the most time consuming step for the user. Specification of the site, field boundaries, heliostat design and receiver type are generally straightforward. However, determining the receiver thermal losses and the system costs can be much more involved. The radiation and convection losses depend on receiver geometry; receiver material and temperature. The system costs depend on the technology and application. Detailed cost estimation may be required to generate the input to DELSOL. In addition to the direct capital costs, operating and maintenance costs must be estimated. Finally, the economic parameters suitable to the consumer of the system have to be specified.

TABLE V.G-1.
STEPS IN DESIGNING A SYSTEM

I. Define system
  - Heliostat type; receiver type; flux limits; field boundaries
  - Non-optical performance parameters: receiver losses; EPGS
  - Costs appropriate to technology and application

II. Initial performance calculation
  - Use a guess for optimum tower height
  - Save results for other optimizations using this heliostat, site, tower height

III. Coarse optimization (can be done at same time as II)
  - Limited number of widely spaced optimization variables
  - If optimum value(s) of a design variable(s) is at the minimum or maximum value allowed in search for optimum, increase the range of values searched and do another coarse optimization

IV. Fine optimization
  - Use a finer grid of optimization variables centered on results of III
  - Reuse initial performance results from II unless tower height is very different

V. Heliostat density optimization
  A. New initial performance calculation
    - Use optimum tower height from IV
    - Use default densities or optimized densities from similar system optimization
  B. Optimization (can be done at same time as VA)
    - Do not vary tower height
    - Choose a fine grid of receiver sizes
  C. Converge density optimization
    - If optimum heliostat layout is very different from initial layout used in VA repeat VA and VB using the optimum densities from VB as the input densities for VA

VI. Detailed performance calculation of optimum system
  - Do a user defined field performance calculation of optimum system
  - Optimize storage capacity if desired

VII. Investigate Other Design Concepts (optional)
  - Repeat I-VI with different heliostat or receiver type, different working fluid

VIII. Non-energy cost design considerations
  - Energy cost is generally insensitive to small perturbations from optimal system
  - If other considerations suggest deviating from DELSOL optimal design, run DELSOL to calculate energy cost of modified system

Step II is the initial performance calculation. This initial calculation will be scaled to give the performance of the different systems considered in searching for the optimum design. The initial performance calculation fixes the values of the constant design parameters listed in Table V.A-2. The results of this initial performance can be saved (ITAPE=1, Namelist BASIC) to be used in subsequent design calculations that have the same values for the constant design parameters.

Steps III and IV are the coarse and fine optimization searches. It is generally more efficient to do this two step optimization search. A search over a coarse grid of optimization variables locates an approximate optimum design rapidly. This is followed by a search over a fine grid of optimization variables centered on the coarse grid optimum.

The user must be certain that an optimum has been found. The user defines the range for each optimization variable. If the optimum value for a variable selected by DELSOL is at the minimum or maximum of the user defined range, an optimum may not have been found. For that variable the user should rerun the optimization with a wider range of values for that variable.

Step V is the optional optimization of the heliostat densities. DELSOL can simultaneously optimize the heliostat densities and receiver dimensions. However, DELSOL cannot vary the tower height while optimizing the densities. Therefore, the user must first perform steps III and IV to find the optimum tower height with constant heliostat densities. This optimum tower height is then used to optimize the heliostat densities and fine tune the optimum receiver size determined in IV. The optimization of densities requires a new initial performance calculation (Step VA) unless the user was lucky enough to have used the optimum tower height from step IV when doing the initial performance calculation in step II. The results of step VA are then used in step VB to optimize the densities and receiver sizes. DELSOL limits its search for the optimum densities to a window centered on the initial densities used in step VA. If the optimum heliostat separations output from step VB are very different from the input separations to step VA then these two steps should be repeated until the heliostat separations converge. At each iteration in the convergence the optimum heliostat separations from step VB are used as the input separations in step VA.

Finally, the optimum system from step I-V can be further analyzed to determine the optimum storage capacity simultaneously with obtaining detailed performance information (Step VI).

The process can then be repeated to evaluate other technology options and/or non-economic considerations deemed important.

VI. Tape Options

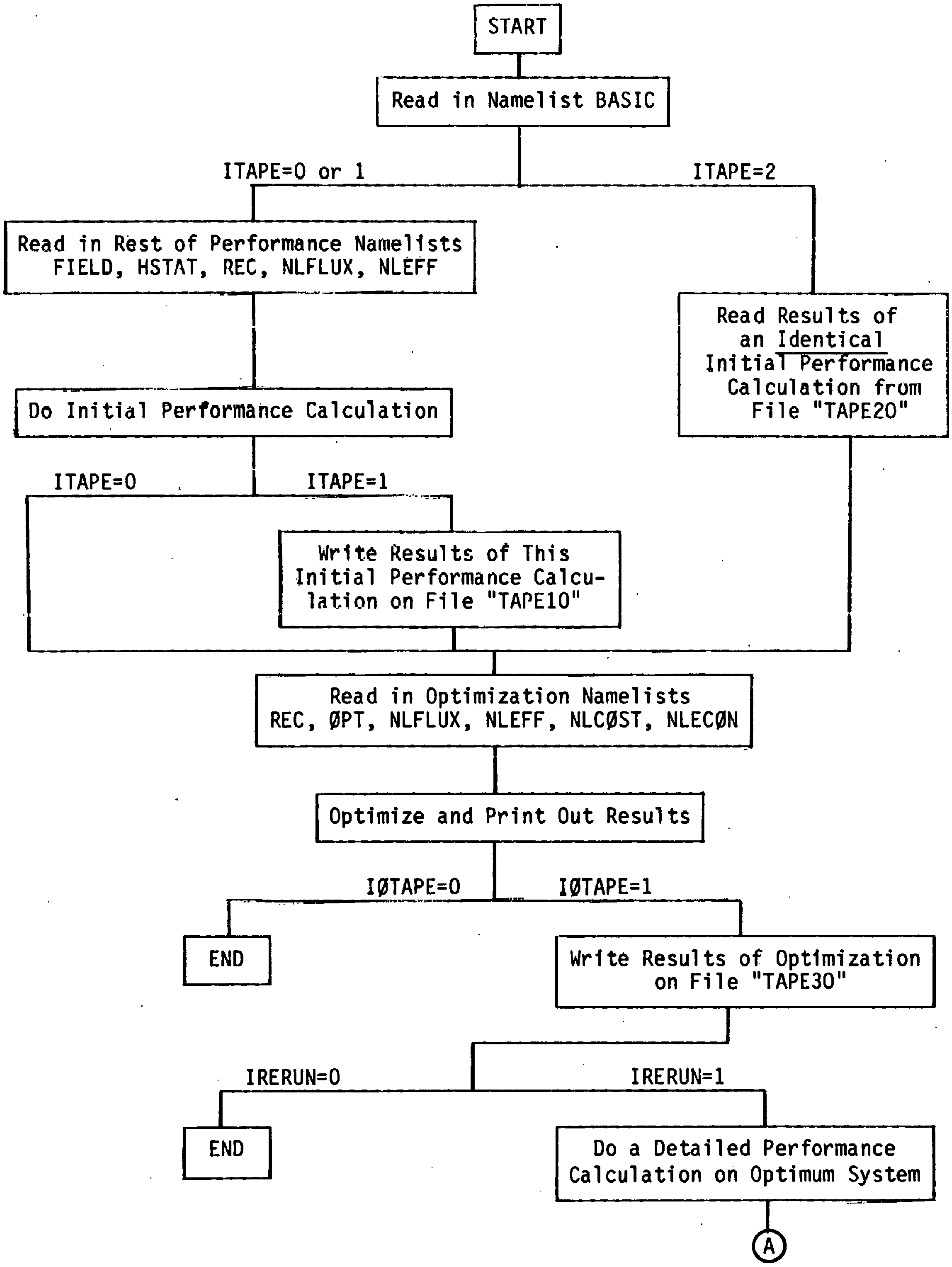
VI.A. Saving and Reusing the Initial Performance Calculation

Every optimization run requires the results of a detailed initial performance calculation. The initial performance calculation must have the same site characteristics, type of zoning and heliostat design desired for the optimization run. In addition, for small systems with radial heliostat layout pattern the tower height used in the initial performance calculation should be within the range of tower heights used in the optimization (see Section V.D-2). Even with these constraints, it is common to use the same initial performance calculation for several different design optimizations. For example, the user may want to consider several different types of receivers for the same application. In these cases it would be wasteful of computer time to repeat the same initial performance calculation for each design study. Therefore, an option has been provided in DELSOL to allow the user to save the results of an initial performance calculation for use in any number of subsequent design optimizations. Use of this option can result in large savings in computer time.

Figure VI-1 illustrates the options for the initial performance calculations. In all cases the first Namelist, BASIC, is always read. The value of ITAPE on Namelist BASIC determines which branch is followed. For ITAPE = 0 or 1 the remaining performance Namelists are read in and the initial performance calculation is executed. For ITAPE = 0 nothing else happens and the code begins reading in the optimization Namelists. However, if ITAPE = 1 the results of the initial performance calculation are written on a temporary file called TAPE10. The user must make a permanent (e.g., tape or disk) copy of TAPE10 for future use. In the future when the user wishes to reuse this initial performance calculation a copy of this information is attached to the program as local file TAPE20, and ITAPE=2 is specified on Namelist BASIC. No other performance Namelists (i.e., FIELD...NLEFF) are read in. When ITAPE=2 is specified, DELSOL prints a short summary of the information on the tape, skips the initial performance calculation and proceeds directly to the optimization calculations. The next Namelist read is the REC Namelist that begins the optimization group of Namelists.

VI.B. Saving and Rerunning Optimum System Designs

It is common to need to do detailed performance calculations on a system DELSOL has optimized. The user could manually transfer the optimum design from the printed output to punched cards to use as input to a DELSOL performance calculation. However, DELSOL provides two options to make it easier to do performance calculations on an optimized system. First, a performance calculation can be done in the same run that optimizes the system (IØTAPE=1 and IRERUN=1, Namelist ØPT). Second, the optimization results can be saved and performance calculation(s) run at a later time (IØTAPE=1, Namelist ØPT). This latter option gives the user a permanent record of optimized systems which can be used for a number of purposes (e.g., as input to a user provided plotting program).



See Figure VI-2

Figure VI-1. Options on Initial Performance Calculation

The options for saving and rerunning systems are illustrated in Figures VI-1 and VI-2. As seen in the lower part of Figure VI-1 when DELSOL has finished optimizing a system the optimum design(s) are written on a temporary file called TAPE30. The user must make a permanent (e.g., tape or disk) copy of TAPE30 for future use. To read the optimized system for a performance calculation the user attaches a temporary copy of TAPE30 to the program and specifies ITAPE=3 on Namelist BASIC. When IRERUN=1 DELSOL does not stop after the optimization is completed. Instead, the program starts a new performance calculation using the optimized system. Note that both options can be used simultaneously.

Both options for rerunning optimized designs automatically supply input of the optimum system description. Specifically, the following are defined:

site (latitude, weather, insolation, etc.)

field (number and type of zones, heliostat layout)

heliostat (dimensions, reflectivity, canting, focusing)

receiver (type and dimensions)

tower height

flux points (only if flux was calculated during performance)

The user therefore does not have to define these variables. Generally, when rerunning a system the only variables that the user redefines are: (1) type of problem (e.g., single time, single day, annual); (2) flux calculation if different from optimization (generally more flux points are desired); or (3) the option for more accurate heliostat images (INDC=1, Namelist HSTAT) which may be important in small systems.

The user must select the design point power level(s) to be saved or rerun. DELSOL allows the user to simultaneously optimize up to 20 design point power levels. However, the code writes a detailed field description of a maximum of only five of these power levels on TAPE30. The user selects these power levels via the IPLFL(I) parameters in Namelist 0PT. When using I0TAPE=1, all non-zero IPLFL(I) power levels are written on TAPE30 to be stored for future use. When reading TAPE30 either for IRERUN=1 or in a later run in which the permanent file from an earlier TAPE30 write option is attached, the user specifies which of these power levels is to be used in the performance calculations (TDESP, Namelist BASIC). Only one power level is evaluated per run.

TAPE30 is a free format written file. The order of information on TAPE30 is given in Table VI.B-1.

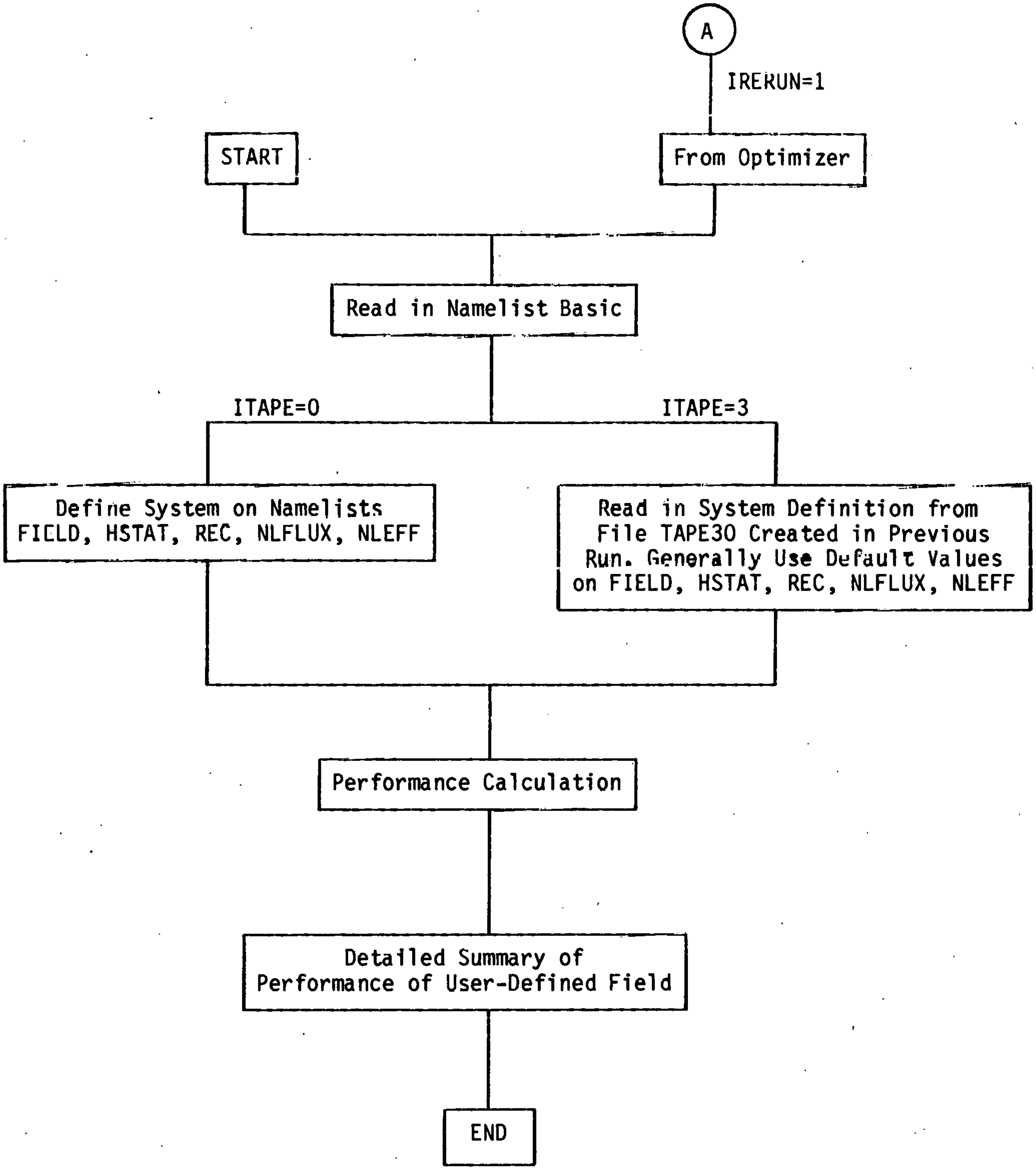


Figure VI-2. Options on Performance Calculation

TABLE VI.B-1.
OUTPUT FROM OPTIMIZATION RUN STORED ON TAPE30

a) Common to all power levels

Variable	Namelist or Definition
WM,HM	HSTAT
IR0UND	"
ICANT	"
NCANTX,NCANTY	"
R0UND	
ASTAT	Surface area of heliostat including gaps (=WMxHM)
AMIRR0R	Total mirror area in field
NRAD	FIELD
NAZM	"
RMIRL	HSTAT
DENSMR	"
XF0CUS	"
YF0CUS	"
SIGAZ,SIGEL	"
SIGSX,SIGSY	"
SIGTX,SIGTY	"
HEAD	Hollerith heading (title) of job
IF0CUS	HSTAT
XF0CAL	"
YF0CAL	"
HCANT	"
DCANT	"
RADMIN,RADMAX	FIELD
RCANT	HSTAT
RANGE	Slant range
ILAY	FIELD
RF0CUS	HSTAT
INDC	"
IR0TFL	FIELD
REFS0L	BASIC
ATM1,ATM2,ATM3, ATM4,IATM	"
IN0RTH,AMAXN	FIELD
PLAT	BASIC
ALT	"
REFDAY,REFTIM	"
NSUNPT,SUNR,SUNI,NSUN	"
ICPANL,WPANL,HPANL, HXCANT,HYCANT	HSTAT
NUMCAV,IREC,RELV,RAZM	REC
RRECL	"
IAUT0P	"
II	Total number of designs written on TAPE30 ($\leq$5)
HR0P	Total annual hours of plant operation

WEATH,DPRES,DH20, DWEATH,IWEATH	BASIC
ALP	FIELD
ASTART	BASIC
REFTHP,AREF,REFRC	NLEFF
REFLP,REFPIP,FPL	"
ITHEL,ETAREF,FEFF	"
REFPRL,FSP	"
PF	"
SMULT	"
CCMUL,CCMULY,CCMULC	Multipliers on direct capital cost
FCR,RH0ML,RNH0ML	Economic parameters
CSTREF,VSTREF,ESTREF,XST CSTRMD,VMAX	NLC0ST
ISTR,NSTR	0PT

b) Power level specific for detailed performance calculation (1 set for each power saved)

SAVE3	Power level
NTMIN(K),NTMAX(K) (K=1,NAZM)	Minimum, maximum zone occupied
AZMTR(L),DENTR(L) (L=1,NLAND)	Azimuthal separation, density
FLAND,XT0WER,YT0WER,SLEW, SLNS,CLE,CLN,NLAND	FIELD,0PT
THT	REC
RX,RY,W,H,RWCAV	"
T0WD,T0WL	"
ACW0SY,ACW0SC	Capital cost without storage (escalated, current)
EST0R	Maximum storage capacity
XFC,YFC,ZFC,DIAMF, P0LF,AZMF	NLFLUX
NXFLX,FAZMIN,FAZMAX, NYFLX,FZMIN,FZMAX	"

c) Arrays for plotting (all power levels: N=1,NP)

NP	Total number power levels (≤ 20)
Y2(N)	Power levels
ALLBUSC(N)	Levelized energy costs (current $)
HSTSAVE(N)	Number of heliostats
ARESAVE(N)	Total land area (km^2)
ALLCC(N)	Total capital cost
ALLPCL(N)	% capital cost in land
ALLPCW(N)	" wiring
ALLPCH(N)	" heliostats
ALLPCT(N)	" tower
ALLPCR(N)	" receiver
ALLPCPI(N)	" piping
ALLPCPU(N)	" pumps
ALLPCS(N)	" storage
ALLPCEG(N)	" turbine/generator

ALLPCHX(N)	% capital cost in steam generators
ALLPCFX(N)	" fixed costs
ALLTØTE(N)	Overall system total efficiency
ALLHR(N)	Hours of storage
ALLKWHR(N)	Net energy production
ALLCØS(N)	Cosine
ALLSAB(N)	Shadowing and blocking (net efficiency)
ALLATM(N)	Atmospheric transmittance
ALLSPL(N)	Intercept
ALLRCR(N)	Annual average receiver efficiency (radiation and convection)
ALLRCP(N)	Annual average piping efficiency
ALLTØTH(N)	Overall system thermal efficiency
ALLETA(N)	Average thermal to electric conversion efficiency
ALLFLUX(N,I) (I=1,4)	Design point flux on receiver at point I

VI.C. Saving a Compiled Version of DELSOL

Since DELSOL is a large program, the time involved in compiling the FORTRAN statements into machine language is non-negligible. It is recommended, therefore, that the user save (on a tape or disk) a permanent copy of a compiled version of DELSOL. The user will then only need to recompile if changes are made to the FORTRAN statements of DELSOL.

VII. Comparison of DELSOL, MIRVAL and HELIOS Performance Predictions

The performance predictions of the MIRVAL, HELIOS and DELSOL computer codes are all in good agreement. A small system comparison is presented in this section since larger heliostat size/tower height ratios produce greater (but not necessarily significant) errors in the DELSOL predictions. The agreement of DELSOL in this more difficult application is good.

The system considered is a preliminary design for the CESA-1 (Central Energia Solar de Almeria) plant being built in Almeria, Spain. The complete system description, including heliostat coordinates, and details of the HELIOS and MIRVAL calculations are given in reference 33. A summary of the system is given in Table VII.1. The DELSOL calculations were performed using the option in which the individual heliostat coordinates are specified in Namelist FIELD. Two calculational times are considered: 10 AM and 4 PM on winter solstice. The 4 PM case involves an extreme sun zenith angle of 82°, which leads to considerable off-axis abberation of the canted heliostat images.

At the time of the comparisons MIRVAL and HELIOS used different descriptions of the heliostat errors. MIRVAL used a 1.65 mrad error in each component of the surface normal (corresponding to the DELSOL variables SIGSX and SIGSY). HELIOS used a 3.3 mrad (=2x1.65 mrad) error in each component of the reflected vector (SIGTX and SIGTY). These two error descriptions are not exactly equivalent whenever the cosine < 1. For the 10 AM case the DELSOL calculation was done twice: once with the MIRVAL error description and once with the HELIOS error description.

The final complication in the comparisons is a difference in defining the effect of the individual loss terms. The cosine, spillage, total power and flux definitions are identical. However, there is a small difference between DELSOL and the other two codes in defining the shadowing/blocking and between DELSOL and HELIOS (but not MIRVAL) in defining attenuation. Comparisons of shadowing/blocking and attenuation are therefore not as meaningful as comparing the other quantities.

The comparison of the power production is given in Table VII.2. The comparison of the flux distribution along a horizontal line through the aperture center is shown in Figure VII-1(a) (10 AM) and VII-1(b) (4 PM). The agreement is good. There are small differences (approximately 1% or less) in some of the predictions. These differences are not practically significant since the uncertainties in the input (e.g., heliostat errors) generally produce larger effects. The differences result from slightly different assumptions in the models, numerical errors, etc. For example, in Table VII.3 the DELSOL flux is symmetrical about the receiver center while the MIRVAL and HELIOS results show a slight asymmetry. The approximately 1% difference in the flux profiles results from the fact that in order to speed up the calculation DELSOL assumes that the mirror panels are canted symmetrically. In actuality, for canting at a fixed time (off-axis cant), the cant of the heliostat panels is slightly asymmetric because the sun angle is slightly different on each cant panel. MIRVAL and HELIOS include this small effect and therefore produce the small asymmetry in the image. The asymmetry would not arise for on-axis canting schemes.

TABLE VII.1

SYSTEM USED IN DELSOL, MIRVAL, HELIOS COMPARISON

Site:	37.099° N latitude
Field:	North only 282 Heliostats
Heliostats:	6.25 x 6.3 m (overall) 5 (horiz.) x 2 (vert.) cant panels Canted for noon on equinox
Receiver:	3.4 x 3.4 m squre, tilted aperture
Tower Height:	56.345 m
Insolation:	0.7 kW/m^2
Sunshape:	Rectangular

TABLE VII.2

COMPARISON OF PERFORMANCE PREDICTIONS FOR A SMALL SYSTEM

	10 AM				4 PM	
Code	MIRVAL	HELIOS	DELSOL	DELSOL	HELIOS	DELSOL
Error Type[1]	MIRVAL	HELIOS	MIRVAL	HELIOS	HELIOS	HELIOS
Cosine	.949	.949	.949	.949	.873	.873
Shadow + Block[2]	.925	.924	.920	.920	.651	.658
Atmospheric Attenuation	.973	.974	.973	.973	.974	.973
Spillage	.921	.922	.921	.917	.902	.888
Power on Receiver (MW•th)	4.79±.2	4.76±.1	4.76	4.74	2.99	3.02
Peak Flux ($MW\cdot th/m^2$)	-	1.83	-	1.82	.923	.922
Avg. Flux Around Peak ($MW\cdot th/m^2$)	1.68	1.63	1.66	1.62	-	-

---

[1] MIRVAL errors are 1.65 mrad in each surface component.
HELIOS errors are 3.30 mrad in each component of reflected ray.

[2] MIRVAL and HELIOS give an area loss, DELSOL gives an average area loss weighted by the cosine.

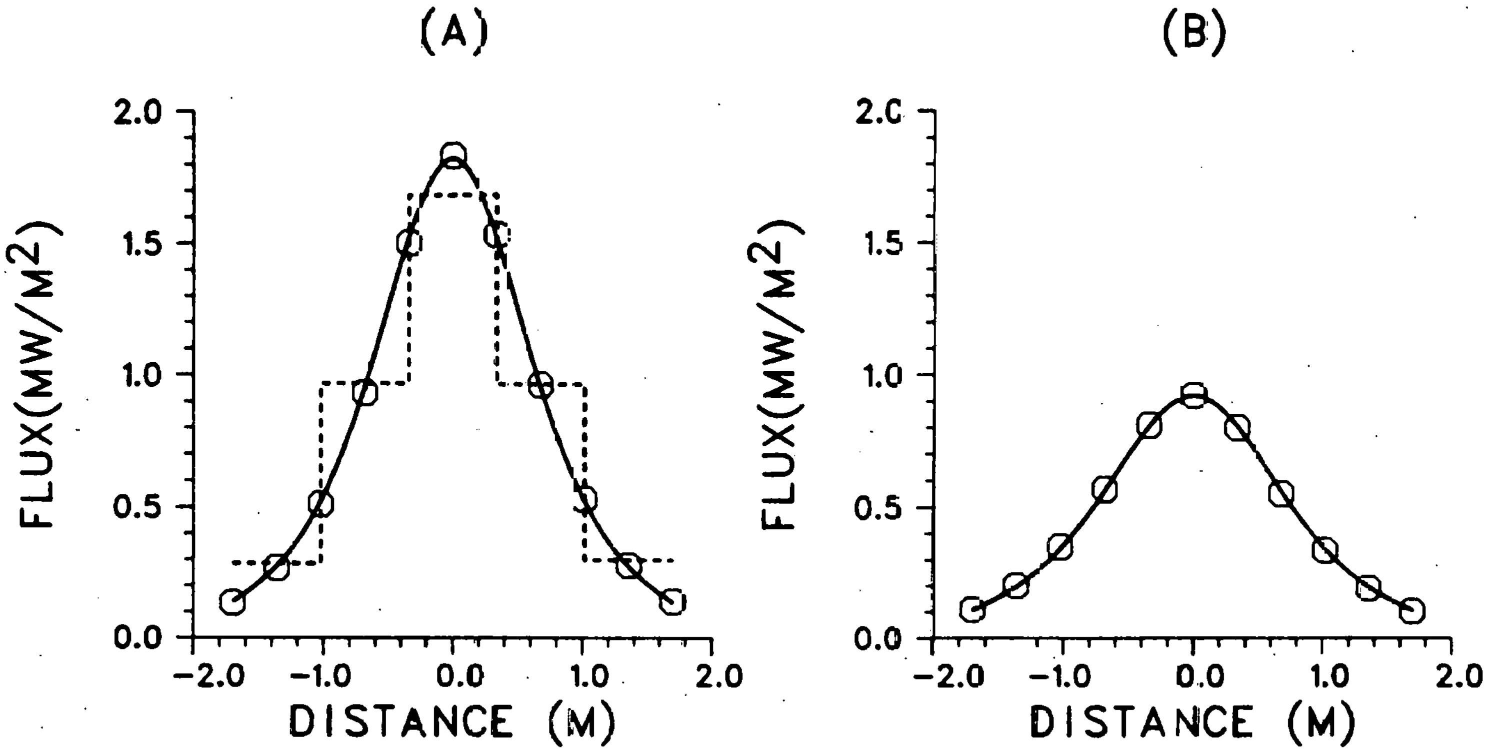


Figure VII-1. Comparison of DELSOL (solid line), MIRVAL (dashed histogram, 10 AM only) and HELIOS (O) predictions for the flux at 10 AM (A) and 4 PM (B) on Winter Solstice. Distance is measured along a horizontal line whose center coincides with the aperture center.

While the predictions are very close, the running times are very different. Users will probably find that DELSOL is 10-100 times faster than either MIRVAL or HELIOS.

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App. A - Input Cards

APPENDIX A--INPUT CARDS

The input to DELSOL is accomplished through the use of namelists. Namelists are convenient because any format can be used for the input variables, the variables can be specified in any order and the only variables that need defining are those which differ from the default values. The Namelists are grouped into similar types of variables (e.g. Namelist HSTAT contains all of the heliostat inputs).

There are two types of problems that are run on DELSOL: performance calculations and design optimization calculations. In a performance calculation the user defines a single system and DELSOL calculates the optical performance for this system at a single time or day and/or on an annual basis. In a design optimization calculation the user specifies the heliostat, receiver geometry, range of all the optimization variables and DELSOL searches for the set of optimization variables that minimizes the energy cost. In the design search DELSOL analytically "scales" the results of an initial performance calculation. These initial performance results can be generated in the same computer run as the design optimization or can be read off of a tape that has been generated during a previous computer run. Finally, the results of the design optimization can be automatically used as input to a detailed performance run or can be written on a tape for subsequent calculations or plotting.

The input cards for a performance calculation are listed in Table A.A-1. The first card is a title card. The six namelists that follow specify the system to be analyzed. If the user wants to read in the coordinates of the heliostats instead of specifying zones of heliostats, these data cards follow the NLEFF namelist. Finally the REC namelist with W=-100 terminates the problem.

The input cards for a design optimization calculation are shown in Table A.A-2. The first card is the title card. The next six namelists (BASIC.... NLEFF) define the initial performance calculation. The values of these cards fix the zoning, latitude, insolation model, heliostat design and heliostat focusing/aiming strategy to be used during the optimization. If these values will be used again in another design optimization calculation, the results should be saved. To do this, set ITAPE=1 in Namelist BASIC and store the local file generated, TAPE10, on a tape or disk. When this initial performance calculation is to be used in a subsequent design run, attach a copy of the stored data to DELSOL with the local file name TAPE20, set ITAPE=2 in Namelist BASIC and omit the FIELD, HSTAT, REC, NLFLUX, and NLEFF namelists that follow the BASIC namelist. The REC, 0PT, NLFLUX, NLEFF, NLC0ST, NLEC0N namelists define the optimization values. If a detailed performance calculation of the optimized design is required, set IRERUN=1 in

TABLE A.A-1.

INPUT CARDS FOR PERFORMANCE ONLY CALCULATION

Title Card (not a namelist)	
$BASIC$	
$FIELD$	
$HSTAT$	
REC	
$NLFLUX$	
$NLEFF$	
data cards for individual heliostat coordinates	(required only for calculations in which the user specifies the coordinates of each heliostat, IUSERFL=3 on Namelist FIELD)
$REC W=-100.$	(Termination card)

TABLE A.A-2.

INPUT CARDS FOR DESIGN OPTIMIZATION CALCULATION

Title Card
$BASIC$
$FIELD$
$HSTAT$
REC
$NLFLUX$
$NLEFF$

Omit if the initial performance run is a previous calculation stored on TAPE20 (ITAPE=2, Namelist BASIC)

REC
$ØPT$
$NLFLUX$
$NLEFF$
$NLCØST$
$NLECØN$
Title Card
$BASIC$
$FIELD$
$HSTAT$
REC
$NLFLUX$
$NLEFF$

Required only if an annual performance run is to be performed on the optimized design (IRERUN=1, Namelist ØPT)

$REC W=-100.$ Termination card

Namelist 0PT and provide the six namelists after the NLEC0N namelist as shown in Table A.A-2. Usually it is not necessary to define any variables in these namelists since the values have been already defined. Finally, all problems are terminated with a REC namelist with the value W=-100.

Descriptions of all namelist variables follow. Included are constraints on the variables, if any, and default values. References to the main text for further details appear by section number in parentheses at the right hand side of the page. Note that in the main text, if the code input variable name differs from the variable name used in the discussion, the input variable name is indicated in parentheses when default values are listed at the end of each section.

TITLE CARD

Columns 2-21	Short title with less than 20 spaces.

Namelist BASIC

IPR0B	Control parameter specifying type of performance calculation; note additional variables in namelist BASIC to be defined with each option. = 0, annual performance calculation based on NYEAR and HRDEL values; = 1, single day performance calculation defined by UDAY and HRDEL; = 2, single time performance calculation defined by UDAY and UTIME; = 3, performance calculation at user specified sun angles defined by NUAZ, NUEL, UAZ(M), and UEL(N) (this option with default values for angles can be used to generate input required for the STEAEC code). = 4, performance calculation for design/optimization run only, based on NYEAR and HRDEL; unnecessary spillage calculations eliminated in initial performance calculation. Constraint: IPR0B=4 for design run Default: IPR0B=0 (II.D)
NYEAR	Number of days in the half year used in the initial performance calculation. Constraints: $3 < NYEAR \le 9$; must be odd Default: NYEAR=5 (II.D-1,II.D-5)
HRDEL	Time step, in hours, used to calculate daily performance when IPR0B=0, 1, 4. Constraint: $HRDEL \ge 0.5$ Default: HRDEL = 1.0 (II.D-1,II.D-5)
UDAY	Day of the year for performance calculation when IPR0B= 1 or 2. Default: UDAY=81.0 (II.D-2,II.D-3)
UTIME	Hour past solar noon for performance calculation when IPR0B=2. Default: UTIME=0. (II.D-3)
NUAZ NUEL UAZ(M)(M=1,NUAZ) UEL(N)(N=1,NUEL)	Variables to specify sun angles for performance calculation when IPR0B=3. NUAZ (NUEL) azimuthal (zenith) angles with values of UAZ(M) (UEL(N)) degrees are defined; performance is calculated for the NUAZ x NUEL matrix of sun angles. Constraints: $NUAZ \le 20$, $NUEL \le 9$ Default: NUAZ=7 NUEL=6 UAZ=0., 30., 60., 75., 90., 110., 130. UEL=0.5, 25., 45., 65., 75., 85. (II.D-4)

DHOPT	During heliostat optimization the density and aspect ratio will be varied by no more than 1 ± DHOPT from the initial values. The larger DHOPT the wider the search for the optimum and the poorer the numerical approximations used in finding the optimum. Constraint: 0 < DHOPT ≤ 0.20 Default: DHOPT = 0.2 (V.A-6,V.E-2)
IPRINT(I) (I=1, NYEAR)	Control parameter for zone by zone output of performance calculation. The annual zone by zone performance is always printed. The average performance of a user defined field at all times is always printed. In addition, for the Ith day of the NYEAR days (if IPROB=1 or 2 the only day of the year is I=1), IPRINT(I) = 0, no zone by zone output for this day; = 1, daily average printed; = 2, each time step and daily average printed. If IPROB=3 then IPRINT(I) = 0, no zone by zone performance printed for the I zenith angle, UEL(I); = 2, zone by zone performance printed for every combination of the I solar zenith angle, UEL(I), and the NUAZ values of the solar azimuthal angle (UAZ(1)...UAZ(NUAZ). Default: IPRINT = 9*0
ITAPE	Control parameter for reading and writing tapes = 0, no reading or writing of tapes; = 1, output of performance run written on local file called TAPE10 to allow storage on most convenient permanent device for use in subsequent design calculations; this option eliminates need to duplicate initial performance calculation for different design runs when location and field options (latitude, dimensions, heliostat design, etc.) remain unchanged; = 2, initial performance input for design run read from local file called TAPE20 which is copied from the mass storage device used to store the data created in a previous performance run with ITAPE=1; input namelists FIELD, HSTAT, REC, NLFLUX, and NLEFF in performance group are omitted with this option (see Table A.A-2). The user must be sure that the latitude, insolation model, sunshape, and heliostat design read from TAPE20 are those desired in the present run. = 3, system input for performance calculation read from local file called TAPE30 which is copied from a mass storage device used to store the data created in a design/optimization

	run using IØTAPE=1 in namelist ØPT. The data includes field layout, heliostat design, receiver dimensions, tower height, etc. so that input namelist FIELD, HSTAT, REC, NLFLUX, and NLEFF need not redefine any of these values. Constraint: ITAPE = 2 for design calculations only Default: ITAPE = 0 (II.B-2,V.G,VI.A,VI.B)
TDESP	Power level, in MW, of optimized system stored on TAPE30 to be rerun in detailed performance calculation. Constraint: ITAPE = 3 Default: TDESP = 100.0 (MW) (VI.B)
PLAT	Latitude, in degrees, of solar plant location. Constraints: 0 < PLAT < 90.0 (northern hemisphere) Default: PLAT = 35.0 (°) (Barstow) (III.A-1)
ALT	Altitude, in km, of solar plant location. Default: ALT = 0.65 (III.A-2)
INSØL	Parameter specifying insolation vs. time model: Note additional variables in namelist BASIC to be defined with each option: = 0, Meinel model; value for ALT required; = 1, Hottel model; value for ALT required; = 2, constant equal to SØLCØN; = 3, Allen model; values for PRES or DPRES, and H20 or DH20 required; = 4, Moon model; values for PRES or DPRES required. Default: INSØL = 0 (III.A-2)
SØLCØN	Value of constant insolation, in kw/m^2, used with INSØL=2 option. Constraint: INSØL=2 Default: SØLCØN=0.95 (kw/m^2) (III.A-2)
IWEATH	Control parameter for site dependent weather factors: = 0, uniform weather factor for entire year; defined by WEATHER if INSØL = 0, 1, 2 or by PRES (INSØL = 3, 4) and H20 (INSØL = 3); = 1, varying weather factor for each of the NYEAR calculational days defined by DWEATH(I) if INSØL = 0, 1, 2 or by DPRES(I) (INSØL = 3,4) and DH20(I) (INSOL = 3). Constraint: If IWEATH = 0, define WEATHER, PRES, and/or H20 for site. If IWEATH = 1, define DWEATH,DPRES, and/or DH20 for site. Default: IWEATH = 0 (III.A-3)

WEATH DWEATH(I) (I=1,NYEAR)	Fraction of energy calculated from the clear sky insolation models when INSOL = 0, 1, 2 that is actually produced due to weather effects. WEATH is the uniform correction for cloudiness on an annual basis (IWEATH = 0); DWEATH(I) is the individual correction for cloudiness to the Ith calculational day. Default: WEATH = 0.83 DWEATH = 9*0.83 (III.A-3)
H2O DH2O(I) PRES DPRES(I) (I=1,NYEAR)	Site specific atmospheric conditions. H2O is the constant mm of percipitable water in the atmosphere (IWEATH=0). DH2O(I) is the individual mm of percipitable water on the Ith calculational day (IWEATH=1). PRES is the constant relative atmospheric pressure compared to sea level, 760 mm of Hg (IWEATH=0). DPRES(I) is the relative atmospheric pressure on the Ith day (IWEATH=1). Default: H2O = DH2O(I) = 20.0 PRES = DPRES(I) = 1.0 (III.A-1,III.A-2,III.A-3)
NSUN	Control parameter specifying sunshape model: = 0, point sun (unrealistic, but useful for debugging); = 1, limb darkened sun, U. of Houston form; = 2, square wave sun; = 3, user defined sunshape through variables NSUNPT, SUNI, SUNR. Default: NSUN = 1 (III.A-4)
NSUNPT SUNI(I) SUNR(I) (I=1,NSUNPT)	Variables for defining sunshape: NSUNPT is number of pairs of points of sun intensity, SUNI (arbitrary units) vs. angle from the center of the sun, SUNR (radians). Points do not have to be equally spaced. Constraints: NSUN = 3 NSUNPT ≤ 50 Points start at center of sun; i.e., SUNR(1) = 0. Points decrease monotonically with increasing radius. Default: None. (III.A-4)
REFDAY	Day of the year chosen for the design point; day 1 is January 1st. REFDAY = UDAY if IPROB = 1 or 2 (automatically set by code); = 354.75, winter solstice (~Dec. 21); = 81.0, equinox (Mar. 21); = 172.25, summer solstice (~June 21). Constraint: REFDAY must occur on one of the days determined by NYEAR if IPROB = 0 or 4. Default: REFDAY = 81.0 (II.D-5,V.A-1)

REFTIM	Design point hour on or past noon on the REFDAY of the year. If IPRØB = 2, REFTIM is set equal to UTIME by code. Constraint: REFTIM must be an integer multiple of HOURDEL. Default: REFTIM = 0.0 (noon) (II.D-5,V.A-1)
REFSØL	Design point insolation, in kw/m^2. Default: REFSØL = 0.95 (kw/m^2) (V.A-1)
ASTART	Maximum sun angle, in degrees, with respect to the vertical at which the plant will begin operation. Default: ASTART = 75.0 (°) (II.D-5)
IATM	Control parameter specifying atmospheric attenuation model: = 0, 25 km visibility, Barstow, CA; = 1, 5 km visibility, Barstow, CA; = 2, user defined through variables ATM1, ATM2, ATM3, ATM4. Default: IATM = 0 (III.E-1)
ATM1 ATM2 ATM3 ATM4	Variables for defining attenuation according to: Fractional loss = $ATM1 + ATM2*R + ATM3*R^2 + ATM4*R^3$ where R is the slant range (km) from the heliostat to the receiver. Constraint: IATM = 2 for user defined variables. Default: ATM1 = 0.006789 ATM2 = 0.1046 ATM3 = -0.0170 ATM4 = 0.002845 (III.E-1)

Namclist FIELD

NAZM	Number of zone divisions azimuthally around the tower. Constraint: NAZM ≤ 12; NAZM, even. Default: NAZM = 12 (II.B-1)
NRAD	Number of zone divisions in the radial direction from the tower. Constraint: NRAD ≤ 13 Default: NRAD = 12 (II.B-1)
RADMIN RADMAX	Minimum and maximum radial position of heliostats, expressed in normalized units of distance based on the tower height, THT (REC namelist). Default: RADMIN = 0.75 RADMAX = 7.5 (II.B-1)
INØRTH	Control parameter for surround vs. north-only field (used primarily in small systems) = 0, Surround field with equally spaced azimuthal zones surrounding the tower; = 1, Finer zoning of the north part of the field set by AMAXN. Constraint: If INØRTH = 1, IREC > 0 NUMCAV = 1 RAZM(1) = 180.0 in namelist REC. Default: INØRTH = 0 (II.B-1)
AMAXN	Maximum angle, in degrees, from north-south axis for north field zoning option (INORTH = 1). There are (NAZM-1) zones from -AMAXN to +AMAXN(°) about the north-south axis; remaining zone is a "dummy" for the south part of the field. Constraint: INØRTH = 1 Default: AMAXN = 82.5(°) (II.B-1)
ILAY	Control parameter for heliostat layout pattern: = 0, radial stagger (only option at present) Default: ILAY = 0 (II.C)
IDENS	Parameter specifying heliostat density; options 1 and 2 based on U. of Houston results: = 1, high reflectivity (~ 0.9) rectangular heliostats; = 2, low reflectivity (~ 0.6) round heliostats; = 3, user specified (see below). Default: IDENS = 1 (II.C)
IUSERF	Parameter specifying field option for initial performance calculation:

	= 0, circular field defined by NAZM, NRAD, RADMIN, RADMAX; only zone by zone performance reported; = 1, code defined north biased field of Figure II-4; = 2, user defined field specified zone by zone (see below); = 3, user defined field specified by individual heliostat coordinates (see below). <u>Constraint:</u> IUSERF = 0 for optimization run <u>Default:</u> IUSERF = 0 (II.B-2)
IHPR	Parameter controlling the printout of the coordinates of the individual heliostats for the IUSERF=3 option. = 0, no coordinates printed = 1, coordinates printed <u>Default:</u> IHPR=0
NLAND	Parameter specifying land constrained field parameters NLAND = 0 No land constraint. > 0 Land available for heliostat field constrained to NLAND rectangles defined by ALP, CLE, CLN, SLEW, SLNS, XTØWER, YTØWER. <u>Constraint:</u> NLAND ≤ 5 <u>Default:</u> NLAND = 0 (II.B-4)
ALP(I) CLE(I) CLN(I) SLEW(I) SLNS(I) XTØWER YTØWER (I=1,NLAND)	Variables defining land constraints for field layout: ALP(I) = angle (°) of rotation of Ith rectangle from N-S and E-W axes (> 0 clockwise viewed from above); CLE(I),CLN(I) = displacements (m) east and north, respectively, of center of Ith rectangle relative to the 1st; SLEW(I),SLNS(I) = length (m) of sides of Ith rectangle parallel to E-W and N-S axes, respectively, prior to rotation; XTØWER,YTØWER = tower coordinates (m) east and north, respectively, with center of first land constraint rectangle. <u>Constraint:</u> NLAND > 0 <u>Default:</u> ALP = 5*0.0 CLE,CLN = 5*0.0 SLEW,SLNS = 5*0.0 XTØWER,YTØWER = 0.0 (II.B-4)
FLAND(K,L) (K=1,NRAD) (L=1,NAZM)	Fraction of the area of the (K,L) zone that can be used for heliostats. If a land constraint is specified (preceding variables) then DELSOL will calculate FLAND. FLAND can also be used to adjust the field trim or to simulate partial cloud cover. <u>Default:</u> FLAND = 156*1.0 (II.B-2,II.B-4)

IR0TFL	Parameter specifying heliostat rotation. = 0, stationary heliostat field; = 1, heliostat field rotates synchronously with the sun in such a way that the sun appears to have no azimuthal motion. To simulate rotating fields DELSOL sets the azimuthal angle of the sun to be always due south of the tower. Default: IR0TFL = 0 (II.B-3)

The following variables require definition only if IDENS = 3:

DENSIT(K,L)	Density (i.e., mirror area to ground area ratio) in zone (K,L) where K specifies the radial position and L the azimuthal position. Constraint: $0.0 \le \text{DENSIT} \le 1.0$ (II.B-2,II.C) Default: DENSIT = 156*1.0 (i.e., user must specify values)
AZMSEP(K) (K=1, NRAD)	1/2 center to center azimuthal separation of heliostats in normalized units of heliostat widths (= $\Delta Az/2*W*M$). Default: AZMSEP = 13*1.05 (II.B-2,II.C)

The following variables require definition only if IUSERFL = 2:

NRADMN(L) NRADMX(L) (L=1, NAZM)	Boundaries of the user defined field. For the Lth azimuthal zone, NRADMN(L) is the number of the radial zone occupied closest to the tower, and NRADMX(L) is the number of the radial zone occupied farthest from the tower. If no zones are occupied, NRADMN(L) = NRADMX(L) = 0. Constraint: NRADMN, NRADMX $\le$ NRAD Maximum number of heliostats per row = 648 Default: NRADMN = 12*1 NRADMX = 12*1 (II.B-2)
FSLIP	Ratio determining slip plane correction; in radial stagger layouts, excess shadowing and blocking is alleviated by periodically placing n heliostats on a row where n+1 heliostats would have been based on zone-wise ΔR and ΔAz values. FSLIP is the ratio of (n+1)/n. Constraint: FSLIP > 1.0 Default: FSLIP = 4./3. (II.C-1)

The following input cards are required only if IUSERF = 3 (User defined heliostat field specified by giving individual heliostat coordinates):

NOTE: These input cards follow NLEFF (see Table A.A-1). These cards are not Namelists, they are input with the format specified below.

Card	Column	Format	Description
1	1-40	4A10	Alphanumeric heading to identify field
2	1-10	I10	Total no. of heliostats in field
	11-20	I10	Total no. of rows in field
3	1-10	I10	Number of row
	11-20	I10	Number of heliostats in row, starting with first row
4	1-10	F10.4	Displacement of 1st heliostat in this row heliostat east of tower (m)
	11-20	F10.4	Displacement of 1st heliostat in this row heliostat north of tower (m)
	21-30	F10.4	Not used at present
	31-40	F10.4	Aim point horizontal displacement (m)
	41-50	F10.4	Aim point "vertical" displacement (m)
	51-60	F10.4	Focal length (1/2 radius of curvature) (m)
5+			Repeat card 4 for all heliostats in this row
6			Repeat cards 3, 4, 5+ for each row

(II.B-2)

Namelist HSTAT

WM HM	Width (WM) and height (HM), in meters, of the rectangular or circular boundary of the heliostat, including any edge supports or enclosures. Default: WM = 7.4(m) HM = 7.4(m) (II.C,II.E)
ICPANL	Parameter for optional specification of location of individual cant panels: = 0, no panel input = 1, individual panel location set by WPANL, HPANL, HXCANT, HYCANT (for more accurate images in small systems) Default: ICPANL = 0 (II.E)
WPANL HPANL HXCANT(I) HYCANT(I) (I=1,NCANTX*NCANTY)	Variables defining individual cant panels; size WPANL(m) wide, HPANL(m) high in heliostat plane; center of Ith panel HXCANT(I) m from heliostat center parallel to horizontal edge, HYCANT(I) m parallel to vertical edge. Constraint: ICANPL = 1 Default: WPANL = 3.70 (II.E) HPANL = 1.23 HXCANT = 6*1.4, 6*(-1.4) HYCANT = 3.08, 1.85, 0.62, -0.62, -1.85, -3.08, 3.08, 1.85, 0.62, -0.62, -1.85, -3.08
DENSMR	Ratio of mirror area to total area of the heliostat defined by WM x HM. Default: DENSMR = 0.897 (II.C,II.E)
IR0UND	Heliostat shape parameter. = 0, rectangular = 1, round Default: IR0UND = 0 (II.E)
RMIRL	Average reflectivity of the mirrored surface, including transmission losses in the dome, if present. Default: RMIRL = 0.89 (II.E, III.E-2)
SIGEL SIGAZ	Standard deviations, in radians, of the normal error distribution of the elevation angle (SIGEL) and azimuthal angle (SIGAZ). Constraint: SIGAZ+SIGSX+SIGTX>0 SIGEL+SIGSY+SIGTY>0 Default: SIGEL = 0.00075 (rad) SIGAZ = 0.00075 (rad) (II.E-1)
SIGSX SIGSY	Standard deviations, in radians, of the normal error distribution of the heliostat reflective surface normal; SIGSX is in the horizontal direction, SIGSY in the direction perpendicular to the SIGSX direction (vertical when the heliostat is vertical).

	Constraint: Same as SIGEL, SIGAZ Default: SIGSX = 0.001 (rad) SIGSY = 0.001 (rad) (II.E-1)
SIGTX SIGTY	Standard deviations, in radians, of the normal error distribution of the reflected vector; caused by atmospheric refraction, tower sway, etc. SIGTX is in the horizontal direction; SIGTY in the direction perpendicular to the SIGTX direction. Constraint: Same as SIGEL, SIGAZ Default: SIGTX = 0.000 (rad) SIGTY = 0.000 (rad) (II.E-1)
ICANT	Canting parameter: = 0, no canting; = -1, individual on-axis cant at a distance equal to the slant range; = 1, user defined on-axis canting. The canting is specified by the RCANT array defined below; (can be used to produce a single cant for the whole field). = 3, individual off-axis cant at time defined below by DCANT, HCANT. Default: ICANT = 1 (II.E-2)
NCANTX NCANTY	Number of submirror panels in a canted heliostat equals NCANTX times NCANTY; there are NCANTX panels in the $\hat{i}_n$ direction, NCANTY in the $\hat{j}_n$ direction. Constraint: NCANTX*NCANTY $\leq$ 25 Default: NCANTX = 2 NCANTY = 6 (II.E-2)
HCANT DCANT	Parameters defining off-axis cant; heliostats are canted at HCANT hours past noon on the DCANT day of the year. Default: HCANT = 0.0 DCANT = 81.0 (II.D-5, II.E-2)
RCANT(K) (K=1, NRAD)	Focal length, in units of tower heights, THT (Namelist REC), at which all heliostats in the Kth radial zones are canted; can be used to define one canting for the whole field. Constraint: ICANT = 1 Default: RCANT = 13*7.15 (II.E-2)
XFØCUS YFØCUS	Parameters specifying focusing or no focusing of mirror panel or subpanels (submirrors can be focused as well as canted). XFØCUS specifies focusing in the i_n direction, YFØCUS in the j_n direction. XFØCUS or YFØCUS = 0.0 No focusing in corresponding direction XFØCUS or YFØCUS = 1.0 Focusing in corresponding direction

	Default: XFØCUS = 1.0 (III.E-2) YFØCUS = 1.0
IFØCUS	Types of focusing: = 0, individual focus with focal length equal to the slant range; = 1, user defined focal length determined by XFØCAL and YFØCAL if zoning is used or focal length read off of individual heliostat data cards if this is an individual heliostat field (IUSERFL = 3, Namelist FIELD); (can be used to produce a single focal length for the whole field). Constraint: XFØCUS = YFØCUS = 1.0 Default: IFØCUS = 1 (II.E-2)
XFØCAL(K) YFØCAL(K) (K=1, NRAD)	User defined focal lengths for the Kth radial zone (note: the focal length = 1/2 radius of curvature); XFØCAL(K) is the focal length in units of tower heights (THT in namelist REC) in the i_n direction and YFØCAL(K) is in the j_n direction. Default: XFØCAL = 13*7.15 YFØCAL = 13*7.15 (II.E-2)
INDC	Control parameter for more accurate heliostat images during performance only calculations: = 0, regular images; = 1; separate image generated from each cant panel instead of a single image from the whole heliostat. This significantly increases the running time. This option can only be used with a performance calculation and cannot be used in design optimization calculations. Constraint: INDC = 0 for a design calculation IAUTØPT = 0 (Namelist REC) if INDC = 1 ICANPL = 1 if INDC = 1 Default: INDC = 0 (III.D-1)
ISB	Parameter controlling overlapping of shadowing and blocking: = 0, no overlap. Most conservative assumption as shading and blocking losses are maximized. = 1, complete overlap. Lower bound on shading and blocking losses. Default: ISB = 0 (III.C)

Namelist REC

THT	"Tower height." The elevation, in meters, of the center of external receiver or of the cavity aperture above the heliostat pivot point, not ground level. Default: THT = 175.0 (m) (II.F)
TØWL TØWD	The shadow cast by the tower and receiver is modeled as the shadow cast by a cylinder that is TØWL meters tall (measured above the heliostat pivot points) and has a diameter of TØWD meters. Default: TØWL = 175.0, TØWD = 10.0 (m) (III.C)
IREC	Parameter specifying type of receiver: = 0, vertical cylindrical external receiver; = 1, cavity with aperture(s) of elliptical cross section; = 2, cavity with aperture(s) of rectangular cross section. = 3, elliptical shape flat plate receiver(s) = 4, rectangular shape flat plate receiver(s) Default: IREC = 0 (II.F)
W	Diameter, in meters, of an external receiver. For flat plates or cavities, W is twice the horizontal distance from the center of the aperture or flat plate to the tower centerline. Default: W = 16.0 (m) (II.F)
H	Height, in meters, of an external receiver. For cavities H is the height of the top of the heat absorbing surface above the bottom of the cavity. Not needed for flat plates. Default: H = 16.0 (m) (II.F)
RRECL	Fraction of the incident power absorbed by the receiver before radiation and convection losses, but after receiver reflection loss: $\text{RRECL} = \frac{\text{Power incident - Power reflected}}{\text{Power incident}}$ Default: RRECL = 0.965 (III.E-2)
IAUTØP	Control parameter identifying aiming strategy: = 0, single aim point at center of receiver; = 1, code calculated time dependent 1-d "smart" aiming strategy; heliostat images are spread out along the "height" of the receiver or aperture to reduce the peak flux and flux gradients with no increase in spillage.

This option should be used with external cylinder, elliptical flat plate and elliptical aperture cavity receivers with flux limits (Namelist NLFLUX);

= 2, same as 1 except that the images are spread out in 2-d. This option should be used only with rectangular flat plate or rectangular aperture receivers with flux limits;

= 3, time dependent aiming strategy to reduce radiation/convection losses, to reduce thermal-mechanical damage, or to minimize the size of a heat absorbing surface inside a cavity. For each zone the image is centered across the "width" of the receiver or aperture and is positioned as close to the bottom of the receiver as possible without increasing spillage significantly;

= 4, same as 3 except the images are spread out along the width of the receiver. This option should only be used with a rectangular flat plate or rectangular aperture receiver;

NAY(K,L)
NAX(K,L)
XAIM(K,L,M)
YAIM(K,L,M)
NUMPT(K,L)
(K=1,NRAD)
(L=1,NAZM)

= 5, user defined, time independent, uniform aiming. For the (K,L) zone the aim points are arranged in a rectangular grid that is in the plane of the cavity aperture or flat plate or is in the plane that is tangent to the external receiver at the azimuthal angle of the zone. There are NAX(K,L) aim points along the horizontal direction from a minimum value of XAIM(K,L,1) meters to a maximum value of XAIM(K,L,2) meters. Similarly, there are NAY(K,L) aim points along the "vertical" direction from a minimum value of YAIM(K,L,1) meters to a maximum value of YAIM(K,L,2) meters. Note that this option should only be used for performance runs.

Constraint: Maximum of 25 user defined aim points/zone. Code will only automatically generate up to 100 aim points.
IREC = 2 or 4 if IAUTOPT = 2 or 4
IPROB ≠ 4 (namelist BASIC) if IAUTOPT = 5

Default: IAUTOP = 0
NUMPT(K,L) = NAX(K,L) = NAY(K,L) = 1
XAIM(K,L,M) = YAIM(K,L,M) = 0 (II.G, II.H-2)

For cavities or flat plates, the following must be defined:

NUMCAV

Number of apertures in cavity receiver or number of flat plate receivers.
Constraint: NUMCAV ≤ 4
Default: NUMCAV = 1 (II.F)

RELV(I) RAZM(I)	Orientation of $\hat{r}$ vector; i.e., outward normal of surface stretched across the aperture or flat plate receiver. For the Ith (I=1, NUMCAV) aperture, RELV(I) is the polar angle, Θ_r, and RAZM(I) the azimuthal angle, β_r, both in degrees (see Figure II-1 in main text). $\text{RELV(I)} = \begin{cases} 90.0^\circ & \text{Vertical} \\ >90.0^\circ & \text{Down facing} \end{cases}$ $\text{RAZM(I)} = \begin{cases} 0.0^\circ & \text{South facing} \\ 90.0^\circ & \text{West facing} \\ 180.0^\circ & \text{North facing} \\ 270.0^\circ & \text{East facing} \end{cases}$ <u>Constraint</u>: RAZM(I) < 360. Angles must be in order clockwise. <u>Default</u>: RELV = 4*90.0 (°) RAZM = 180., 270., 0., 90. (°) (II.F)
RX(I) RY(I) (I=1, NUMCAV)	Dimensions, in meters, of Ith cavity aperture or flat plate receiver. RX(I) is the horizontal dimension, and RY(I) perpendicular to RX(I). <u>Default</u>: RX = 4*6.0 (m) RY = 4*6.0 (m) (II.F,V.A-3)
RWCAV(I) (I=1,NUMCAV)	Ratio of the radius of the vertical cylindrical heat absorbing surface centered on the Ith aperture to the radius, W/2, of the receiver. This option is used only with cavity receivers and allows the cavities to have different depths. The greater RWCAV the larger the heat exchanger surface within the cavity and the lower the peak flux. <u>Default</u>: RWCAV = 4*1.0 (II.F,IV.A-5,V.A-3)

Namelist NLFLUX

IFLX	Parameter specifying flux calculation. For performance runs flux calculations are made at the one time of the year specified by IFXØUT. For optimization runs, flux calculations are made only at the design point. = 0, no flux calculations; = 1, flux calculations desired. Constraint: IFLX = 1 if any IFXØUT ≠ 0 Default: IFLX = 0 (II.H, V.B-1,V.D-5)
IFXØUT(I,J) (I=1, NYEAR; J=1, 16)	Parameter allowing selection of the one time of the year at which the flux is calculated. For the Jth time step (i.e., (J-1)*HRDEL hours past noon) on the Ith day (I=1 at winter solistice, = (NYEAR + 1)/2 at equinox, = NYEAR at summer solistice, etc.), IFXØUT: = 0, no flux calculated at this time; = 1, total flux from user defined field (i.e., IUSERF = 1 or 2 in FIELD namelist) calculated and reported for this time; = -1, flux from every zone printed plus total flux if IUSERF = 2 at this single time. Constraint: One IFXØUT ≠ 0 for flux maps in performance runs, including reruns. All IFXØUT = 0 if IFLX = 0. Default: IFXØUT = 144*0 (II.H)
IFLAUT	Parameter specifying the type of surface on which a grid of flux points will be automatically generated. In all cases the "center" of the receiver is on the tower centerline THT meters (Namelist REC) above the plane of the heliostat pivots. IFLAUT = 4 is generally the best option:
XFC YFC ZFC PØLF AZMF DIAMF	=1, points are on the outside surface of a cylinder with a vertical axis. The cylinder has a diameter of DIAMF meters and is offset by XFC meters to the east, YFC meters to the north and ZFC meters up from the "receiver center". This option with DIAMF=W (Namelist REC) and XFC=YFC=ZFC=0 generates the flux points on the surface of an external receiver. =2, same as = 1 except the points are on the inside surface of a hollow vertical cylinder. =3, points are on a plane. The center of the origin that is used to define the grid of flux points is XFC meters to the east, YFC meters to the north and ZFC meters up from the "receiver center". The outward surface normal of the plane on the side that the flux is incident has an azmithal angle of

AZMF (North = 180°, E = 270° etc.) and a polar angle PØLF (90° = vertical, > 90° downward facing).

= 4, automatic generation of the flux points on the heat absorbing surface of the receiver specified in the REC Namelist.

Note: For multiple aperture cavity or multiple flat plate receivers, flux calculations can be made for only one heat absorbing surface at a time.

External Cylinder Receiver (IREC = 0)
The flux points are located on the outside of a cylinder whose DIAMF = W and XFC = YFC = ZFC = 0. If the default values of NXFLX, FAZMIN, FAZMAX, NYFLX, FZMIN, FZMAX are used then a single flux point on the center of the north side of the cylinder will be generated.

Cavity Receiver (IREC = 1 or 2)
The flux points are located on the inner surface of a vertical cylinder centered on the first aperture DIAMF = W*RWCAV(1), XFC = -(W/2.)*SIN(RAZM(1)), YFC = -(W/2)*CØS(RAZM(1)). If the default values of NXFLX, FAZMIN, FAZMAX, NYFLX, FZMIN, FZMAX then a single flux point is generated in the center of the heat absorbing surface of the first cavity aperture at a height equal to the height of the center of the heat absorbing surface; it is further assumed that the first aperture faces north.

Flat Plate Receiver (IREC = 3 or 4)
The flux points are located on the surface of the first flat plate receiver. XFC = -(W/2.)*SIN(RAZM(1)), YFC = -(W/2.)*CØS(RAZM(1)), ZFC = 0., PØLF = RELV(1), and AZMF = RAZM(1). If the default values of NXFLX, FAZMIN, FAZMAX, NYFLX, FZMIN, FZMAX are used then a single flux point is generated at the center of the first plate, assumed to be facing north.

Default: IFLAUT=4

XFC=YFC=ZFC=0.0 (m)
PØLF=90.0(°)
AZMF=180.0 (°)
DIAMF=16.0 (m) (II.H-1, II.H-2,V.B-1)

NXFLX
FAZMIN
FAZMAX

IFLAUT=1 or 2
Number of divisions around the circumference of the cylinder for automatically generated grid of flux points, NXFLX; points equally spaced at azimuthal angles starting at

FAZMIN and ending at FAZMAX (in degrees); angles increase clockwise when viewed from above the receiver:

	IFLAUT=1	IFLAUT=2
0° or 360°	→ South	North
90°	→ West	East
180°	→ North	South
270°	→ East	West

IFLAUT=3
NXFLX equally spaced points along a horizontal axis of the the plane defined by (XFC, YFC, ZFC, P0LF, AZMF) from a minimum value of FAZMIN meters to a maximum value of FAZMAX meters.

Constraint: FAZMAX $\geq$ FAZMIN (Note that in some cases with IFLAUT=1 or 2 it may be necessary to add 360° to FAZMAX).
NXFLX*NYFLX $\leq$ 169

Default: NXFLX = 1
FAZMAX = 180.0 (°)
FAZMIN = 180.0 (°) (II.H-1)

NYFLX FZMIN FZMAX	Number of divisions along the "height" of the surface (H if IREC=0, RY if IREC≠0) used for automatically generated grid of flux points, NYFLX; points equally spaced from FZMIN to FZMAX, in meters; measured from the origin, up being positive. Constraint: FZMAX $\geq$ FZMIN NXFLX*NYFLX $\leq$ 169 Default: NYFLX = 1 FZMIN = 0.0 (m) FZMAX = 0.0 (m) (II.H-1) NOTE: For cavity receivers, FZMIN=FZMAX= center of height of the heat absorbing surafce.
ICAVF(I) (I=1, NUMCAV)	Parameter specifying aperture(s) through which incident light can reach the flux surface under consideration: = 0, no light reaches flux surface from aperture I; ≠ 0, light reaches flux surface from aperture I. Constraint: IREC = 1 or 2 Code default values apply to first aperture. Default: ICAVF = 1,0,0,0 (II.H)

The following are specified only for layout/optimization runs:

NFLXMX NMXFLX(I) (I=1, NFLXMX)	NFLXMX points on the receiver tested during field layout to check if FLXLIM limit exceeded; these are a subset of the NXFLX by NYFLX points defined above.

NMXFLX(I) identifies the exact point to be evaluated, as follows (see Figure (II-10).

If M = azimuthal location between 1 and NXFLX
N = vertical location between 1 and NYFLX

then $NMXFLX(I) = M + (N-1)*NXFLX$

Constraints:
$NFLXMX \le 4$
$NFLXMX \le NXFLX*NYFLX$
$NMXFLX(I) \le NXFLX*NYFLX$

Default:
NFLXMX = 1
NMXFLX = 1 (II.H-2,V.B-1)

FLXLIM(I) (I=1,NFLXMX)	Maximum allowed flux on the receiver in W/m^2 at NMXFLX(I) flux point. Default: FLXLIM(1) = 0.6E+06 FLXLIM(I) (I=2,NFLXMX) = 1.0 E+10 (II.H-2,V.B-1)

Namelist NLEFF

REFTHP	Gross thermal power (watts) absorbed by a reference receiver (area AREF) before receiver and piping radiation and convection losses. Constraint: Data should be for same type receiver (i.e., external, cavity, etc.) as in REC namelist. Default: REFTHP = 4.17 x 10^8 (watts) (III.E-3)
AREF	Reference receiver area (m^2); for cavities, this should be total aperture area. Default: AREF = 2165.0 (m^2) (III.E-3)
REFRC	Fraction of REFTHP transferred to receiver working fluid after radiation and convection losses. Default: REFRC = 0.83 (III.E-3)
REFLP	Reference pipe length (m) for calculating piping insulation losses. Default: REFLP = 170.0 (m) (III.E-4)
REFPIP	Fraction of REFRC*REFTHP delivered to storage and EPGS after piping losses. Default: REFPIP = 0.998 (III.E-4)
FPLH	Factor multiplying tower height to give total hot piping run in a single module. Default: FPLH = 2.6 (III.E-4, IV.A-7)
FPLC	Factor multiplying tower height to give total cold piping run in a single module (may be different from FPLH if expansion allowance different). Default: FPLC = 2.6 (IV.A-7)
ITHEL	Parameter for design point thermal/electric conversion efficiency: = 0, efficiency assumed constant at all design power levels, value specified by ETAREF; ≠ 0, efficiency varies with design power level as described in Figure III-3. Default: ITHEL = 0 (III.E-5)
ETAREF	Design point thermal/electric conversion efficiency; constant at all power levels (only used when ITHEL = 0). Default: ETAREF = 0.42 (III.E-5,IV.A-5)
FEFF	Fraction of design point efficiency describing average off-design operation. Default: FEFF = 0.95 (III.E-5)

REFPRL	Design point parasitic load, expressed as a fraction of the gross electrical output. Default: REFPRL = 0.065 (III.E-8)
FSP	Fraction of design point parasitic load required for operation from storage. Default: FSP = 0.5 (III.E-8)
FEP	Fraction of design point parasitic load for operation electrical generating pumps (feedwater pumps, cooling tower, etc.). Default: FEP = 0.0 (III.E-8)
EFFSTR	Round trip efficiency through storage. Default: EFFSTR = 0.99 (III.E-7)
PF	Plant factor; expected fraction of the year in which the plant will be on line. The default value is commonly used for comparing solar technologies. In a realistic calculation of busbar energy cost, PF should be some value less than 1.0. Default: PF = 1.00 (IV.B)
SMULT	Solar multiple at design point; 1/SMULT of the thermal power at the base of the tower goes directly to the industrial or electrical process at the design point; the rest is sent to storage. Constraint: SMULT ≥ 1.0 Default: SMULT = 1.5 (IV)
IPH	Parameter identifying industrial process heat run instead of electrical plant run: =0, electrical plant; output in MW_e, mills/kw-hr, etc. ≠0, industrial process heat; code automatically sets ETAREF=1.0, FEFF=1.0, REFPRL=0.0, CEGREF=0.0. Default: IPH = 0 (III.E-6)

Namelist ØPT*

IHØPT	Control parameter for optimizing the heliostat densities. = 0, no heliostat density optimization. The default densities (which are a function of the tower height) are used. The heliostat field boundaries are optimized; = 1, heliostat densities are optimized. Constraint: Tower height cannot be varied if IHØPT = 1. Default: IHØPT = 0 (V.A-6,V.E-2)
NUMTHT THTST THTEND	In optimization run, NUMTHT discrete, equally spaced values of the tower height are tested from THTST to THTEND (in meters). If NUMTHT = 1, then the tower height is set equal to THT specified in the REC namelist; THTST and THTEND need not be specified. Constraints: THTST $\leq$ THTEND 1 $\leq$ NUMTHT $\leq$ 20 Default: NUMTHT = 1 THTST = 75.0 (m) THTEND = 400.0 (m) (I,V.A,V.A-2)
NUMREC WST WEND	External receivers (IREC = 0 in REC namelist): NUMREC discrete, equally spaced values of the diameter tested from WST to WEND (in meters). If NUMREC = 1, the only value of the diameter considered is that defined by W in the REC namelist. Cavity (IREC = 1, 2) and Flat Plate (IREC = 3,4) Receivers: NUMREC discrete, equally spaced values of the horizontal dimension of the first aperture or flat plate, RX(1), tested from WST to WEND (in meters). If NUMREC = 1, the only value considered is that defined for RX(1) in the REC namelist. Constraints: WST $\leq$ WEND 1 $\leq$ NUMREC $\leq$ 20 Default: NUMREC = 1 WST = 8.0 (m) WEND = 26.0 (m) (I,V.A,V.A-3)
NUMHTW HTWST HTWEND IØPTUM	External receivers (IØPTUM = 1): NUMHTW equally spaced values of the receiver height to diameter ratio (H/W) tested from HTWST to HTWEND. If NUMHTW = 1, only the ratio defined by H and W in namelist REC is used. Cavity and flat plate receivers (IØPTUM = 1): NUMHTW equally spaced values of the ratio of the height to width, RY(1)/RX(1), of the first cavity or flat plate tested from HTWST to HTWEND. If NUMHTW = 1, only the ratio defined by RX(1) and RY(1) on Namelist REC is used. The width W is held constant. Cavity receivers (IØPTUM = 2): NUMHTW equally spaced values of W tested from HTWST to HTWEND. If NUMHTW = 1, only the W defined by namelist REC is used. The aspect

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*For all design/optimization runs, set IPRØB = 4 in namelist BASIC.

	ratios of the cavity apertures, RY(I)/RX(I) are held constant. This option is appropriate for a flux limited cavity receiver. Constraints: HTWST < HTWEND $1 < \text{NUMHTW} \leq 20$ Default: NUMHTW = 1 HTWST = 1.0 HTWND = 1.0 I0PTUM = 1 (II.F,V.A,V.A-3,V.B-1)
RYTRX RX2TRX RX3TRX RX4TRX	Cavity and flat plate receivers: RYTRX is the ratio RY(I)/RX(I), assumed the same for all apertures or flat plates. RX2TRX is the ratio RX(2)/RX(1), etc. (See REC namelist for definitions of RX's and RY's.) Default: RYTRX = 1.0 RX2TRX = 1.0 RX3TRX = 1.0 RX4TRX = 1.0 (II.F,V.A-3)
NUM0PT P0PTMN P0PTMX	NUM0PT equally spaced net electrical design power levels from P0PTMN to P0PTMX (in watts) considered for optimal design. Constraint: $1 < \text{NUM0PT} < 20$ P0PTMN < P0PTMX Cost models not necessarily accurate below ~ 10^7 watts. Default: NUM0PT = 20 P0PTMN = 2.0×10^7 (watts) P0PTMX = 4.0×10^8 (watts) (I, V.A, V.A-1)
NUMP0S XTPST YTPST XTPEND YTPEND	In a land constrained design (NLAND > 0, below) NUMP0S discrete, equally spaced values of the tower location relative to the origin used to describe the land constraints are tested. The tower positions lie along a line specified by the coordinates of the first tower position (XTPST m east, YTPST m north) and the last tower position (XTPEND m east, YTPEND m north). Constraint: $1 \leq \text{NUMP0S} \leq 20$ Default: NUMP0S = 1 XTPST = XTPEND = YTPST = YTPEND = 0.0 (I, V.A, V.A-4)
NLAND ALP(I) CLE(I) CLN(I) SLEW(I) SLNS(I) (I=1,NLAND)	Land constrained field parameters. NLAND = 0 No land constraint > 0 The land available for the heliostat at field is constrained to be within NLAND rectangles. CLE(I) and CLN(I) are the displacements in m to the east and north, respectively, of the center of the Ith

rectangle relative to the center of the first rectangle. ALP(I) is the angle in degrees that the Ith rectangle is rotated about its center from the N-S, E-W orientation (positive angles represent a clockwise rotation when viewed from above). SLEW(I) and SLNS(I) are the lengths of the sides of the Ith rectangle that, prior to rotation by ALP(I), were parallel to the E-W and N-S axes, respectively.

Constraint: NLAND < 5
Default: NLAND = 0
ALP, CLE, CLN, SLEW, SLNS = 0 (II.B-4, V.B-2)

SMULT

Solar multiple at design point; 1/SMULT of the thermal power at the base of the tower goes directly to the industrial or electrical process at the design point; the remainder is sent to storage.

Constraint: SMULT > 1.0
Default: SMULT = 1.5 (IV)

IPLFL(I)
(I=1, NUM0PT)

Parameter identifying the subset of the NUM0PT power levels at which field layouts are printed and descriptions of optimized system are written on TAPE30 if desired:

= 0, no field layout output for the Ith power level;
= 1, output generated for Ith power level.

Constraint: Maximum number of nonzero IPLFL's = 5
Default: IPLFL = 20*0 (VI.B)

IPR0PT

Parameter for detailed output of zone by zone field buildup (IPR0PT = -1 is strongly recommended):

= 0, output suppressed;
= 1, output printed. (Note: this option generates a large amount of output);
=-1, limited output printed during optimization. Shows some detail of search and provides useful ouptut even when program runs out of time.

Default: IPR0PT = -1 (App. B)

IH0PTP

Parameter for detailed print out of heliostat density optimization:

= 0, output suppressed
= 1, output printed (Note: this option generates a large amount of output).

Default: IH0PTP = 0 (App. B)

I0TAPE

Parameter specifying if user desires to write the results of an optimization run on TAPE30 to save as a permanent file, or to rerun for a detailed performance calculation, or both:

	= 0, no information written on TAPE30; = 1, information written on TAPE 30. Default: IØTAPE = 0 (II.B-2,VI.B)
IRERUN	Parameter for automatically rerunning a detailed performance calculation of an optimized system: = 0, no performance calculation; = 1, performance calculation of optimized system according to the choice of the non-zero IPLFL's (namelist ØPT) and TDESP (namelist BASIC). See Figure VI-2 and Table A.A-2 for required Namelists. Constraint: IØTAPE = 1 if IRERUN = 1. Default: IRERUN = 0 (II.B-2,VI.B)
IALL	Parameter controlling search algorithm: = 0, "smart" search (selected subset of THT, W, H, etc.); = 1, all possible combinations of optimization variables evaluated (long running times required). Default: IALL = 0 (V.C)
ISTR	Parameter identifying storage optimization in the detailed performance calculation of a DELSØL optimized design: = 0, no optimization on storage size; maximum size as determined in MAX used; ≠ 0, optimum storage size determined; NSTR discrete values between 0 and 1 times the maximum size determined in MAX are evaluated. Default: ISTR = 0 (V.A-7)
NSTR	Number of storage sizes, between 0 and 1 times the maximum size, evaluated to find optimum storage capacity for a given design. Default: NSTR = 1 (V.A-7)

Namelist NLCØST*

CH	Cost of heliostats excluding wiring; $\$/m^2$ mirror surface. Default: CH = 75.00 ($\$/m^2$) (IV.A-1)
CL	Cost of land including site preparation; $\$/m^2$. Default: CL = 1.30 ($\$/m^2$) (IV.A-2)
CWR CWDR CWDA	Wiring cost parameters; CW, total wiring cost in $/heliostat, given by $CW = CWR*RAD + CWDR*RSEP + CWDA*AZMSEP$ where RAD, RSEP, AZMSEP are calculated from variables in the FIELD namelist. Default: CWR = 0.0475 ($/m) CWDR = 0.4889 ($/m) CWDA = 13.20 ($/m) (IV.A-3)
ITHT	Parameter for tower cost: = 0, cost based on Sandia studies for concrete and steel towers; = 1, user supplied values for CTØW1, CTØW2, CTØW3, XTØW. Default: ITHT=0 (IV.A-4)
CTOW1 CTOW2 CTOW3 XTOW	Tower cost parameters; CTOW, tower cost in $, given by $CTOW = CTOW1 + CTOW2*THTB + CTOW3*THTB^{XTOW}$ where THTB is the actual tower height from the ground to the receiver base. Default: CTOW1 = 3.02864×10^6 ($) CTOW2 = -2.33415×10^4 ($/m) CTOW3 = 1.47152×10^2 ($\$/m^2$) XTOW = 2.0 (IV.A-4)
CREC1 ARECRF XREC	Receiver cost parameters; CREC, receiver cost in $, given by: $CREC = CREC1*(AREC/ARECRF)^{XREC}$ See text for definition of AREC and ARECRF for cavity designs. Default: CREC1 = 4.21×10^6 ($) ARECRF = 2165.0 ($m^2$) XREC = 0.8 (IV.A-5)

---

*All reference powers in the cost models refer to the power delivered to the process at the design conditions, not to the power at the base of the tower (unless the corresponding solar multiple is 1.0).

CRPREF
TRPREF
SMRP
PRPREF
XRP

Receiver/tower pump cost parameters; CRP, receiver pump cost in \$, given by:

$$CRP = CRPREF* \left(\frac{THT*SMULT*PTH}{TRPREF*SMRP*PRPREF}\right)^{XRP}$$

where THT is defined in namelist REC or OPT, SMULT in OPT, and PTH is the design thermal power delivered by the heat exchangers. The denominator consists of the corresponding terms for a reference design costing CRPREF.

<u>Default:</u> CRPREF = 0.671×10^6 (\$)
TRPREF = 170.0 (m)
SMRP = 1.5
PRPREF = 2.6×10^8 (watts)
XRP = 0.85 (IV.A-6)

CSPREF
PSPREF
XSP

Storage pump cost parameters; CSP, storage pump cost in \$, given by:

$$CSP - CSPREF*(PTH/PSPREF)^{XSP}$$

<u>Default:</u> CSPREF - 1.51×10^5 (\$)
PSPREF = 3.0×10^8 (watts)
XSP = 0.15 (IV.A-6)

CHPREF
CCPREF
SMPI
PPIREF
XPI

Piping cost parameters; CPIPE, piping cost in \$, consists of hot (CHPREF) and cold (CCPREF) pipe contributions. Each of these includes the pipe material itself, fittings, supports, insulation, and field erection costs.

$$CPIPE = THT*(FPLH*CHPREF+FPLC*CCPREF) * \left(\frac{SMULT*PTH}{SMPI*PPIREF}\right)^{XPI/2}$$

where FPLH and FPLC are defined in namelist NLEFF, THT in REC or OPT, SMULT in OPT on NLEFF. SMPI and PPIREF are the reference solar multiple and thermal power corresponding to the reference hot and cold pipe costs.

<u>Default:</u> CHPREF = 1.32×10^4 (\$/m)
CCPREF = 0.0 (\$/m)
SMPI = 1.5
PPIREF = 2.6×10^8 (watts)
XPI = 1.06 (IV.A-7)

CSTREF
CSTRMD
VSTREF
ESTREF
XST
VMAX
EMPTY

Storage cost parameters; CSTOR, total storage cost in \$, consists of media containment equipment (tanks with insulation, foundation; storage heat exchangers; etc.) and storage media costs.

$$CSTOR = N_{STOR}*(CSTREF*(1 + \frac{EMPTY}{N_{STOR}})*\left(\frac{V_{STOR}}{VSTREF}\right)^{XST}$$

$$+ CSTRMD*\left(\frac{V_{STOR}}{VSTREF}\right))$$

	where N_{STOR} = integer (VSTOR/VMAX) + 1 EMPTY = number spare tanks VSTOR = VSTREF*(ESTOR/ESTREF) V_{STOR} = VSTOR/N_{STOR} CSTREF ($) and CSTRMD ($) are reference containment and media costs, respectively, for a system of volume VSTREF (m^3) and stored energy capacity ESTREF (watt-hrs). VMAX (m^3) is the maximum practical volume. Default: CSTREF = 4.593×10^6 ($) CSTRMD = 3.22×10^6 ($) VSTREF = 1078.0 (m^3) ESTREF = 9.0×10^8 (watt-hrs) XST = 0.6 VMAX = 1.23×10^4 (m^3) EMPTY = 0.0 (IV.A-8)
ICHE	Parameter for heat exchanger cost: =0, cost scales with thermal power; ≠0, cost scales with individual heat exchanger areas. Default: ICHE = 0 (IV.A-9)
CHEREF PHEREF XHEP	Heat exchanger cost parameters for scaling with thermal power; CHTXCHG, total heat exchanger cost in $, given by: CHTXCHG = CHEREF*$(PTH/PHEREF)^{XHEP}$ where CHEREF ($) and PHEREF (watts) are the cost and associated thermal power of a reference design. Constraint: ICHE = 0 Default: CHEREF = 1.525×10^6 ($) PHEREF = 3.0×10^8 (watts) XHEP = 0.8 (IV.A-9)
Preheater: CPHREF APHREF PPHREF APHMAX Evaporator: CEVREF AEVREF PEVREF AEVMAX Superheater: CSHREF ASHREF PSHREF ASHMAX	Heat exchanger cost parameters for scaling with individual heat exchanger areas; CHTXCHG in $ given by: CHTXCHG = N_{PH}*CPHREF*$(APH'/APHREF)^{XHEA}$ + N_{EV}*CEVREF*$(AEV'/AEVREF)^{XHEA}$ + N_{SH}*CSHREF*$(ASH'/ASHREF)^{XHEA}$ + N_{RH}*CRHREF*$(ARH'/ARHREF)^{XHEA}$ where N_{PH} = integer (APH/APHMAX) + 1 APH = APHREF (PTH/PPHREF)

Reheater:
CRHREF
ARHREF
PRHREF
ARHMAX

XHEA

$$APH' = APH/N_{PH}$$

and similarly for the other heat exchangers. CPHREF ($) is the cost of a preheater of reference surface area APHREF (m^2) and thermal power rating PPHREF (watts), and similarly for the others. APHMAX is the maximum practical size preheater, etc.

Default: CPHREF = 0.0 (i.e., no preheater in default case)
APHREF = 1.0
PPHREF = 1.0
APHMAX = 10^{10}
CEVREF = 3.77 x 10^6 ($)
AEVREF = 1300.0 (m^2)
PEVREF = 2.6 x10^8 (watts)
AEVMAX = 10^{10} (m^2) (i.e., no size limit)
CSHREF = 1.24 x 10^6 ($)
ASHREF = 400.0 (m^2)
PSHREF = 2.6 x 10^8 (watts)
ASHMAX = 10^{10} (m^2)
CRHREF = 1.38 x 10^6 ($)
ARHREF = 310.0 (m^2)
PRHREF = 2.6 x 10^8 (watts)
ARHMAX = 10^{10} (m^2)
XHEA = 0.6 (IV.A-9)

CEGREF
PEGREF
XEPGS

EPGS cost parameters; CEPGS, total EPGS subsystem cost in $, given by:

$$CEPGS = CEGREF*(PTH*ETAREF/PEGREF)^{XEPGS}$$

where PEGREF is the nameplate rating (watts) for the reference turbine-generator costing CEGREF ($). ETAREF, the design thermal-electric conversion efficiency, is defined in namelist NLEFF.

Default: CEGREF = 27.3 x 10^6 ($)
PEGREF = 1.12 x 10^8 (watts)
XEPGS = 0.8 (IV.A-10)

CFIXED

Fixed costs associated with all plants independent of power level (master control, buildings and roads, etc.).

Default: CFIXED = 7.0 x 10^6 ($) (IV.A-11)

Namelist NLECON

CONT	Contingencies, expressed as a fraction of the total capital cost. Default: CONT = 0.12	(IV.A)
SPTS	Spare parts investment, also expressed as some fraction of the total capital cost. Default: SPTS = 0.01	(IV.A)
EXT	Distributable and indirect charges (contractor fees, A&E services, etc.), specified as a fraction of the total capital cost. Default: EXT = 0.16	(IV.A)
ESC	Yearly capital escalation rate, fraction between 0 and 1 (not %). Default: ESC = 0.08	(IV.B)
RINF	Yearly general inflation rate, fraction between 0 and 1. Default: RINF = 0.08	(IV.B)
NYTCON	Years to the beginning of the construction period from the year in which the capital cost estimate is made. Default: NYTCON = 0	(IV.B)
AFDC	Allowed funds during construction to cover interest charges, expressed as a fraction of the total capital cost. Default: AFDC = 0.15 (5-year construction period)	(IV.B)
IFCR	Parameter for determining the fixed charge rate, FCR: =0, FCR supplied by user or default value used; code does not calculate it; ≠0, FCR calculated by the code based on user supplied values for DISRT, PTI, TC, TR, FDEBT, RDEBT, ROE, IDEP, NDEP (see below). Default: IFCR = 0	(IV.B-1)
FCR	Fixed charge rate (fraction between 0 and 1); i.e., required yearly fractional recovery of total capital investment. Default: FCR = 0.159	(IV.B-1)
DISRT	Discount rate (between 0 and 1); must be consistent with value chosen for FCR if IFCR = 0. Default: DISRT = 0.0996	(IV.B-1)
PTI	Property tax and insurance rate, expressed as a fraction of the total capital cost. Default: PTI = 0.025	(IV.B-1)

TC	Investment tax credit expressed as a fraction of the total investment. Default: TC = 0.10	(IV.B-1)
TR	Income tax rate, expressed as a fraction, not %. Default: TR = 0.48	(IV.B-1)
FDEBT	Fraction of debt financing. Default: FDEBT = 0.543	(IV.B-1)
RDEBT	Debt cost; i.e., appropriate interest rate for borrowed funds, expressed as a fraction, not %. Default: RDEBT = 0.11	(IV.B-1)
R0E	Before tax return on equity, expressed as a fraction, not %. Default: R0E = 0.15	(IV.B-1)
IDEP	Parameter identifying depreciation schedule to be used: -1, straight line method; =2, sum-of-years digits method. Default: IDEP - 2	(IV.B-1)
NDEP	Depreciation period (in years) of solar plant equipment. Default: NDEP = 24	(IV.B-1)
NY0P	Operating life (years) of a plant for investment recovery. Default: NY0P = 30	(IV.B)
RH0M	Heliostat operating and maintenance charge, expressed as a fraction of field related capital costs. Default: RH0M = 0.015	(IV.B-2)
RNH0M	Balance of plant O&M charge, expressed as a fraction of non-field related capital costs. Default: RNH0M = 0.015	(IV.B-2)

App. B. - Sample Input and Output

APPENDIX B--SAMPLE INPUT AND OUTPUT

The following pages illustrate DELSOL output in conjunction with sample problems of interest to most users.

Sample Problem 1 - Optimization of an External Receiver Design; Saving the Initial Performance

Problem Statement

The optimum external molten salt receiver design at power levels of 75 to 150 MWe with no storage is desired. An incident flux level of 0.85 MW/m^2 is not to be exceeded anywhere on the receiver. The default heliostat can be used. The initial performance data should be saved for subsequent calculations, and the optimized field layouts should be printed.

Input Cards

```
SAMPLE PROBLEM 1
$BASIC IPRØB=4, ITAPE=1$
$FIELD$
$HSTAT$
$REC$
$NLFLUX$
$NLEFF$
$REC IAUTØP=1$
$ØPT NUMTHT=6, THTST=100., THTEND=200., NUMREC=6, WST=8., WEND=18.,
     NUMHTW=3, HTWST=1.0, HTWEND=2.0, NUMØPT=4, PØPTMN=75.E+06,
     PØPTMAX=150.E+06, SMULT=1.0, IPLFL=4*1$
$NLFLUX IFLX=1, FLXLIM=0.85E+06$
$NLEFF SMULT=1.0$
$NLCØST$
$NLECØN$
$REC W=-1.$
```

Analysis of Input

For the initial performance calculation in a design/optimization run IPRØB=4 is specified; the data is saved on local file TAPE10 by setting ITAPE=1. (A permanent file is made with the control card appropriate to the user's computer system.) Since the solar subsystems are the same technology as the code defaults and the desired power levels are close to the default, no changes are necessary for the remaining performance input. Note that there is no need for automatic aiming or flux calculations in the initial performance calculation.

The next set of cards is read at the start of the optimization calculation. At this point input changes are necessary to calculate fluxes and test for flux limits. "IAUTØP=1" on the REC card specifies the 1-dimensional smart aiming option required for a flux limited external receiver design. In the $ØPT$ namelist, tower height and receiver dimensions are varied over a range compatible with the range of power levels. The variation in receiver height to width is specified because optimum system designs for this type problem generally result in designs of greater height to width to allow spreading of the flux. "IFLX=1" in $NLFLUX$ turns on the flux calculation and the flux limit is set by FLXLIM. Since the maximum flux will occur at the center of the north panel for the default design point, only that one point need be tested. The default values in NLFLUX insure that this is the point at which the flux is calculated and compared to FLXLIM.

The absence of storage is handled by setting SMULT=1.0 (no additional energy collected) in both $ØPT$ and $NLEFF$. It is not necessary to set the reference costs to zero because the code will calculate zero storage costs if no energy is available to charge storage.

Comments on Output

The first part of the output consists of the performance namelists (pp. B-3 to B-11) followed by summaries of the heliostat design (p. B-12) and receiver (p. B-13) used in the initial performance calculation, of the zone by zone density and heliostat count (pp. B-14 and B-15), insolation table (pp. B-16 and B-17), and the zone by zone yearly average performance (pp. B-18 and B-19). The optimization namelists follow (pp. B-20 to B-28), then a summary of the optimization variables and design constraints (p. B-29). The default choice of IPRØPT in $ØPT$ produces the abbreviated list (partly shown on pp. B-30 to B-31) indicating the combinations of optimization variables searched along with pertinent information related to each set considered.

The optimization results are then tabulated in a series of readily tractable tables (pp. B-32 to B-45). Note in the system design summary (p. B-32) that all design variables fall within the ranges searched except for the receiver height in the 75 and 100 MWe cases, which is at the maximum height to width. While the energy cost will change little, the user may want to rerun this case to allow consideration of larger height to width ratios. Note also in the field layout summary (pp. B-38 to B-44) that the field extends to RADMAX in all cases for a number of azimuthal zones. The user should rerun with a larger value for RADMAX to allow the code more flexibility in zone selection for field build-up.

```
&BASIC

IPROB    = 4,

NYEAR    = 5,

MODEL    = .1E+01,

UDAY     = .81E+02,

UTIME    = 0.0,

NUAZ     = 7,

NUEL     = 6,

UAZ      = 0.0, .3E+02, .6E+02, .75E+02, .9E+02, .11E+03, .13E+03, 0.0, 0.0,      0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0,

UEL      = .5E+00, .25E+02, .45E+02, .65E+02, .75E+02, .85E+02, 0.0, 0.0, 0.0,

CHOPT    = .2E+00,

IPRINT   = 0, 0, 0, 0, 0, 0, 0, 0, 0,

ITAPE    = 1,

TDESP    = .1E+03,

PLAT     = .35E+02,

ALT      = .65E+00,

INSOL    = 0,

SOLCON   = .95E+00,

IWEATH   = 0,

WEATH    = .83E+00,

DWEATH   = .83E+00, .83E+00, .83E+00, .83E+00, .83E+00, .83E+00, .83E+00,        .83E+00, .83E+00,

H2O      = .2E+02,

DH2O     = .2E+02, .2E+02, .2E+02, .2E+02, .2E+02, .2E+02, .2E+02, .2E+02,       .2E+02,

PRES     = .1E+01,

DPRES    = .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,       .1E+01,

NSUN     = 1,

NSUNPT   = 0,

SUNI     = 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,

SUNR     = 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,

REFDAY   = .81E+02,
```

```
REFTIM  = 0.0,
REFSCL  = .95E+02,
ASTART  = .75E+02,
IATM    = 0,
ATM1    = .6789E-02,
ATM2    = .1046E+00,
ATM3    = -.17E-01,
ATM4    = .2845E-02,
$END
```

```
$FIELD

NAZM    = 12,

NRAD    = 12,

RADMIN  = .75E+00,

RADMAX  = .75E+01,

INORTH  = 0,

AMAXN   = .825E+02,

ILAY    = 0,

IDENS   = 1,

IUSERF  = 0,

IMPR    = 0,

NLAND   = 0,

ALP     = 0.0, 0.0, 0.0, 0.0, 0.0,

CLE     = 0.0, 0.0, 0.0, 0.0, 0.0,

CLN     = 0.0, 0.0, 0.0, 0.0, 0.0,

SLEW    = 0.0, 0.0, 0.0, 0.0, 0.0,

SLNS    = 0.0, 0.0, 0.0, 0.0, 0.0,

XTOWER  = 0.0,

YTOWER  = 0.0,

FLAND   = .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,

IROTFL  = 0,

DENSIT  = .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,      .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,
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```
         .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,          .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,

AZMSEP = .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01,
         .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01,
         .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01,
         .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01,
         .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01,
         .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01,
         .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01,
         .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01,
         .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01,
         .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01,
         .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01,
         .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01,
         .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01,
         .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01, .105E+01,
         .105E+01, .105E+01,

NPADMN   = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,

NPADMX   = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,

FSLIP    = .13333333333333E+01,

$END
```

```
$HSTAT

WM       = .74E+01,

HM       = .74E+01,

ICPANL   = 0,

WPANL    = .37E+01,

HPANL    = .123E+01,

HXCANT   = .14E+01, .14E+01, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, -.14E+01,   -.14E+01, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,

HYCANT   = .308E+01, .185E+01, .62E+00, -.62E+00, -.185E+01, -.308E+01, 0.0,     0.0, 0.0, 0.0, .308E+01, .185E+01,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,

DENSMR   = .897E+00,

IROUND   = 0,

RMIRL    = .89E+00,

SIGEL    = .75E-03,

SIGAZ    = .75E-03,

SIGSX    = .1E-02,

SIGSY    = .1E-02,

SIGTX    = 0.0,

SIGTY    = 0.0,

ICANT    = 1,

NCANTX   = 2,

NCANTY   = 6,

HCANT    = 0.0,

DCANT    = .81E+02,

RCANT    = .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01,
           .715E+01, .715E+01,

XFOCUS   = .1E+01,

YFOCUS   = .1E+01,

IFOCUS   = 1,

XFOCAL   = .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01,
           .715E+01, .715E+01,

YFOCAL   = .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01,
           .715E+01, .715E+01,

INOC     = 0,
```

```
$END
$REC

THT      = .175E+03,

TOWL     = .175E+03,

TOWD     = .1E+02,

IREC     = 0,

W        = .16E+02,

H        = .16E+02,

PRECL    = .965E+00,

IAUTOP   = 0,

NAY      = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,  1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
           1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,  1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
           1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,  1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
           1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,  1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
           1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,

NAX      = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,  1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
           1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,  1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
           1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,  1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
           1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,  1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
           1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,

XAIM     = 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,

YAIM     = 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,

NUMPT    = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,  1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
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```
          1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,  1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
          1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,  1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
          1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
 NUMCAV  = 1,
 RELV    = .9E+02, .9E+02, .9E+02, .9E+02,
 RAZM    = .18E+03, .27E+03, 0.0, .9E+02,
 RX      = .6E+01, .6E+01, .6E+01, .6E+01,
 RY      = .6E+01, .6E+01, .6E+01, .6E+01,
 RWCAV   = .1E+01, .1E+01, .1E+01, .1E+01,
 &END
```

```
$NLFLUX
IFLX     = 0,
IFXOUT   = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
           0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
           0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
           0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
           0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
IFLAUT   = 4,
XFC      = 0.0,
YFC      = 0.0,
ZFC      = 0.0,
POLF     = .9E+02,
AZMF     = .18E+03,
DIAMF    = .16E+02,
NXFLX    = 1,
FAZMIN   = .18E-03,
FAZMAX   = .18E+03,
NYFLX    = 1,
FZMIN    = 0.0,
FZMAX    = 0.0,
ICAVF    = 1, 0, 0, 0,
NFLXMX   = 1,
NMXFLX   = 1, 2, 3, 4,
FLXLIM   = .6E+06, .1E+07, .1E+07, .1E+07,
$END
```

```
$INLEFF
REFTHP  = .417E+09,
AREF    = .2165E+04,
REFRC   = .83E+00,
REFLP   = .17E+03,
REFPIP  = .998E+00,
FPLH    = .26E+01,
FPLC    = .26E+01,
ITHEL   = 0,
ETAREF  = .42E+00,
FEFF    = .95E+00,
REFPRL  = .65E-01,
FSP     = .66E+00,
FEP     = 0.0,
EFFSTP  = .1E+01,
PF      = .1E+01,
SMULT   = .15E+01,
IPH     = 0,
$END

CONSTANT LOSSES - MIRROR= .890 REC REFL= .965 TOTAL= .859
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                    HELIOSTAT



RECTANGULAR HELIOSTAT - WIDTH =  7.40 M, HEIGHT =  7.40M
        OVERALL AREA/HSTAT= 54.760 M2, REFLECTIVE AREA/HSTAT= 49.120 RATIO (REFLECTIVE/TOTAL)= .897


THE SHADOWING AND BLOCKING ARE ASSUMED NOT TO OVERLAP




THE HELIOSTAT PERFORMANCE ERRORS HAVE NORMAL DISTRIBUTIONS WITH STANDARD DEVIATIONS OF
          NAME   VARIABLE EFFECTED       STD. DEV (RAD)
         SIGAZ - AZIMUTH ANGLE                .00075
         SIGEL - ELEVATION ANGLE              .00075
         SIGSX - HSTAT SURFACE, HORIZ.        .00100
         SIGSY - HSTAT SURFACE, VERT.         .00100
         SIGTX - REFLECTED RAY, HORIZ.       0.00000
         SIGTY - REFLECTED,RAY, VERT.        0.00000


THE  12 MIRROR PANELS ARE CANTED ON-AXIS WITH THE FOLLOWING FOCAL LENGTHS - RADIAL ZONE  FOCAL LENGTH(M)
                                                                              1             1251.3
                                                                              2             1251.3
                                                                              3             1251.3
                                                                              4             1251.3
                                                                              5             1251.3
                                                                              6             1251.3
                                                                              7             1251.3
                                                                              8             1251.3
                                                                              9             1251.3
                                                                             10             1251.3
                                                                             11             1251.3
                                                                             12             1251.3
         NO. OF PANELS IN HORIZ. DIRECTION=  2 VERT. DIRECTION =  6


MIRROR PANELS FOCUSED IN TWO DIMENSIONS
         FOCAL LENGTHS DEFINED BY USER


DELSOL DEFAULT LIMB DARKENED SUNSHAPE
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                    RECEIVER



TOWER HEIGHT=175.00 M ABOVE PLANE OF HELIOSTAT PIVOTS


THE TOWER SHADOW IS CALCULATED USING A CYLINDER OF HEIGHT= 175.0 M AND DIAMETER = 10.0 M

EXTERNAL RECEIVER - CYLINDER HT.= 16.00  DIAM.= 16.00 M


SINGLE AIM POINT AT THE CENTER OF THE RECEIVER OR APERTURE
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                    ZONING


NO USER DEFINED FIELD


HELIOSTATS ARE LAID OUT IN A RADIAL STAGGER PATTERN


                    FIELD RADIUS MAX= 7.50 MIN=  .75 STEP=  .61 TOWER HEIGHTS


     NOTE - THE UNITS OF THE RADIAL SEPARATION ARE THE NUMBER OF HELIOSTAT HEIGHTS, HM=  7.42 METERS
          - THE UNITS OF THE AZIMUTHAL SEPARATION ARE THE NUMBER OF HELIOSTAT WIDTHS, WM=  7.40 METERS


     NOTE - THE RADIUS OF THE HELIOSTAT IS GIVEN IN UNITS OF THE TOWER HEIGHT=175.00 METERS
     NOTE - MISS. H IS THE FRACTION OF THE ZONE AVAILABLE IN RADIAL LAYOUTS BECAUSE OF SLIP PLANES
     NOTE - FR LAND IS THE FRACTION OF THE LAND WITHIN A ZONE THAT IS AVAILABLE DUE TO LAND CONSTRAINTS OR FIELD TRIM


RADIUS              AZIMUTHAL ANGLE OF HELIOSTAT, NORTH=0, EAST=90
                      0.       30.       60.       90.      120.      150.      180.      210.      240.      270.      300.      330.


  .75   DENSITY      .440      .440      .440      .440      .440      .440      .440      .440      .440      .440      .440      .440
  .75   MISS. H      .939      .939      .939      .939      .939      .939      .939      .939      .939      .939      .939      .939
  .75   RAD SEP     1.634     1.634     1.634     1.634     1.634     1.634     1.634     1.634     1.634     1.634     1.634     1.634
  .75   AZM SEP     1.248     1.248     1.248     1.248     1.248     1.248     1.248     1.248     1.248     1.248     1.248     1.248
  .75   FR LAND     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000
  .75   HSTATS     37.4      37.4      37.4      37.4      37.4      37.4      37.4      37.4      37.4      37.4      37.4      37.4


 1.36   DENSITY      .406      .406      .406      .406      .406      .406      .406      .406      .406      .406      .406      .406
 1.36   MISS. H      .956      .956      .956      .956      .956      .956      .956      .956      .956      .956      .956      .956
 1.36   RAD SEP     1.942     1.942     1.942     1.942     1.942     1.942     1.942     1.942     1.942     1.942     1.942     1.942
 1.36   AZM SEP     1.139     1.139     1.139     1.139     1.139     1.139     1.139     1.139     1.139     1.139     1.139     1.139
 1.36   FR LAND     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000
 1.36   HSTATS    106.0     106.0     106.0     106.0     106.0     106.0     106.0     106.0     105.0     106.0     106.0     105.0


 1.98   DENSITY      .354      .354      .354      .354      .354      .354      .354      .354      .354      .354      .354      .354
 1.98   MISS. H      .963      .963      .963      .963      .963      .963      .963      .963      .963      .963      .963      .963
 1.98   RAD SEP     2.329     2.329     2.329     2.329     2.329     2.329     2.329     2.329     2.329     2.329     2.329     2.329
 1.98   AZM SEP     1.088     1.088     1.088     1.088     1.088     1.088     1.088     1.088     1.088     1.088     1.088     1.088
 1.98   FR LAND     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000
 1.98   HSTATS    135.0     135.0     135.0     135.0     135.0     135.0     135.0     135.0     135.0     135.0     135.0     135.0


 2.59   DENSITY      .301      .301      .301      .301      .301      .301      .301      .301      .301      .301      .301      .301
 2.59   MISS. H      .965      .965      .965      .965      .965      .965      .965      .965      .965      .965      .965      .965
 2.59   RAD SEP     2.803     2.803     2.803     2.803     2.803     2.803     2.803     2.803     2.803     2.803     2.803     2.803
 2.59   AZM SEP     1.063     1.063     1.063     1.063     1.063     1.063     1.063     1.063     1.063     1.063     1.063     1.063
 2.59   FR LAND     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000     1.000
 2.59   HSTATS    150.9     150.9     150.9     150.9     150.9     150.9     150.9     150.9     150.9     150.9     150.9     150.9


 3.20   DENSITY      .256      .256      .256      .256      .256      .256      .256      .256      .256      .256      .256      .256
 3.20   MISS. H      .967      .967      .967      .967      .967      .967      .967      .967      .967      .967      .967      .967
 3.20   RAD SEP     3.337     3.337     3.337     3.337     3.337     3.337     3.337     3.337     3.337     3.337     3.337     3.337
 3.20   AZM SEP     1.052     1.052     1.052     1.052     1.052     1.052     1.052     1.052     1.052     1.052     1.052     1.052
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3.20    HSTATS     158.6   158.6   158.6   158.6   158.6   158.6   158.6   158.6   158.6   158.6   158.6   158.6

3.82    DENSITY     .219    .219    .219    .219    .219    .219    .219    .219    .219    .219    .219    .219
3.82    MISS. H     .967    .967    .967    .967    .967    .967    .967    .967    .967    .967    .967    .967
3.82    RAD SEP    3.910   3.910   3.910   3.910   3.910   3.910   3.910   3.910   3.910   3.910   3.910   3.910
3.82    AZM SEP    1.048   1.048   1.048   1.048   1.048   1.048   1.048   1.048   1.048   1.048   1.048   1.048
3.82    FR LAND    1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
3.82    HSTATS     161.9   161.9   161.9   161.9   161.9   161.9   161.9   161.9   161.9   161.9   161.9   161.9

4.43    DENSITY     .189    .189    .189    .189    .189    .189    .189    .189    .189    .189    .189    .189
4.43    MISS. H     .967    .967    .967    .967    .967    .967    .967    .967    .967    .967    .967    .957
4.43    RAD SEP    4.510   4.510   4.510   4.510   4.510   4.510   4.510   4.510   4.510   4.510   4.510   4.510
4.43    AZM SEP    1.051   1.051   1.051   1.051   1.051   1.051   1.051   1.051   1.051   1.051   1.051   1.051
4.43    FR LAND    1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
4.43    HSTATS     162.6   162.6   162.6   162.6   162.6   162.6   162.6   162.6   162.6   162.6   162.6   162.6

5.05    DENSITY     .166    .166    .166    .166    .166    .166    .166    .166    .166    .166    .166    .166
5.05    MISS. H     .967    .967    .967    .967    .967    .967    .967    .967    .967    .967    .967    .957
5.05    RAD SEP    5.128   5.128   5.128   5.128   5.128   5.128   5.128   5.128   5.128   5.128   5.128   5.128
5.05    AZM SEP    1.056   1.056   1.056   1.056   1.056   1.056   1.056   1.056   1.056   1.056   1.056   1.056
5.05    FR LAND    1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
5.05    HSTATS     161.9   161.9   161.9   161.9   161.9   161.9   161.9   161.9   161.9   161.9   161.9   151.9

5.66    DENSITY     .146    .146    .146    .146    .146    .146    .146    .146    .146    .146    .146    .146
5.66    MISS. H     .967    .967    .967    .967    .967    .967    .967    .967    .967    .967    .967    .967
5.66    RAD SEP    5.760   5.760   5.760   5.760   5.760   5.760   5.760   5.760   5.760   5.760   5.760   5.760
5.66    AZM SEP    1.065   1.065   1.065   1.065   1.065   1.065   1.065   1.065   1.065   1.065   1.065   1.065
5.66    FR LAND    1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
5.66    HSTATS     160.3   160.3   160.3   160.3   160.3   160.3   160.3   160.3   160.3   160.3   160.3   160.3

6.27    DENSITY     .130    .130    .130    .130    .130    .130    .130    .130    .130    .130    .130    .130
6.27    MISS. H     .967    .967    .967    .967    .967    .967    .967    .967    .967    .967    .967    .967
6.27    RAD SEP    6.401   6.401   6.401   6.401   6.401   6.401   6.401   6.401   6.401   6.401   6.401   6.401
6.27    AZM SEP    1.077   1.077   1.077   1.077   1.077   1.077   1.077   1.077   1.077   1.077   1.077   1.077
6.27    FR LAND    1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
6.27    HSTATS     158.1   158.1   158.1   158.1   158.1   158.1   158.1   158.1   158.1   158.1   158.1   158.2

6.89    DENSITY     .117    .117    .117    .117    .117    .117    .117    .117    .117    .117    .117    .117
6.89    MISS. H     .967    .967    .967    .967    .967    .967    .967    .967    .967    .967    .967    .967
6.89    RAD SEP    7.050   7.050   7.050   7.050   7.050   7.050   7.050   7.050   7.050   7.050   7.050   7.050
6.89    AZM SEP    1.092   1.092   1.092   1.092   1.092   1.092   1.092   1.092   1.092   1.092   1.092   1.092
6.89    FR LAND    1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
6.89    HSTATS     155.5   155.5   155.5   155.5   155.5   155.5   155.5   155.5   155.5   155.5   155.5   155.5

7.50    DENSITY     .105    .105    .105    .105    .105    .105    .105    .105    .105    .105    .105    .105
7.50    MISS. H     .967    .967    .967    .967    .967    .967    .967    .967    .967    .967    .967    .967
7.50    RAD SEP    7.705   7.705   7.705   7.705   7.705   7.705   7.705   7.705   7.705   7.705   7.705   7.705
7.50    AZM SEP    1.108   1.108   1.108   1.108   1.108   1.108   1.108   1.108   1.108   1.108   1.108   1.108
7.50    FR LAND    1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
7.50    HSTATS      74.7    74.7    74.7    74.7    74.7    74.7    74.7    74.7    74.7    74.7    74.7    74.7
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                    INSOLATION AND SUN POSITION

INSOLATION CALCULATED USING MEINEL   MODEL



DAY OF THE YEAR =354.750  DECLINATION OF SUN (DEG)= -23.44 DAILY CLEAR SKY INSOLATION (KWH/M2)=   5.25
                     THE AVERAGE CORRECTION TO CLEAR SKY INSOLATION TO ACCOUNT FOR CLOUDINESS=  .830
                      MM OF WATER=  20.00 ATMOSPHERIC PRESSURE/SEA LEVEL=  1.000

       TIME =  0.0  INSOLATION(KW/M2)=   .858 TRUE ZENITH ANGLE =  58.44  OBSERVED ZENITH=  58.41 SUN AZIMUTH =   0.00
       TIME =  1.0  INSOLATION(KW/M2)=   .844 TRUE ZENITH ANGLE =  60.15  OBSERVED ZENITH=  60.12 SUN AZIMUTH =  15.89
       TIME =  2.0  INSOLATION(KW/M2)=   .797 TRUE ZENITH ANGLE =  64.99  OBSERVED ZENITH=  64.96 SUN AZIMUTH =  30.41
       TIME =  3.0  INSOLATION(KW/M2)=   .697 TRUE ZENITH ANGLE =  72.35  OBSERVED ZENITH=  72.29 SUN AZIMUTH =  42.91
       TIME =  3.3  INSOLATION(KW/M2)=   .648 TRUE ZENITH ANGLE =  75.00  OBSERVED ZENITH=  74.94 SUN AZIMUTH =  46.34

DAY OF THE YEAR = 35.375  DECLINATION OF SUN (DEG)= -16.09 DAILY CLEAR SKY INSOLATION (KWH/M2)=   6.36
                     THE AVERAGE CORRECTION TO CLEAR SKY INSOLATION TO ACCOUNT FOR CLOUDINESS=  .830
                      MM OF WATER=  20.00 ATMOSPHERIC PRESSURE/SEA LEVEL=  1.000

       TIME =  0.0  INSOLATION(KW/M2)=   .898 TRUE ZENITH ANGLE =  51.09  OBSERVED ZENITH=  51.07 SUN AZIMUTH =   0.00
       TIME =  1.0  INSOLATION(KW/M2)=   .887 TRUE ZENITH ANGLE =  53.04  OBSERVED ZENITH=  53.02 SUN AZIMUTH =  18.13
       TIME =  2.0  INSOLATION(KW/M2)=   .849 TRUE ZENITH ANGLE =  58.49  OBSERVED ZENITH=  58.46 SUN AZIMUTH =  34.30
       TIME =  3.0  INSOLATION(KW/M2)=   .772 TRUE ZENITH ANGLE =  66.57  OBSERVED ZENITH=  66.53 SUN AZIMUTH =  47.77
       TIME =  3.9  INSOLATION(KW/M2)=   .642 TRUE ZENITH ANGLE =  75.00  OBSERVED ZENITH=  74.94 SUN AZIMUTH =  57.46

DAY OF THE YEAR = 81.000  DECLINATION OF SUN (DEG)=    .65 DAILY CLEAR SKY INSOLATION (KWH/M2)=   8.24
                     THE AVERAGE CORRECTION TO CLEAR SKY INSOLATION TO ACCOUNT FOR CLOUDINESS=  .830
                      MM OF WATER=  20.00 ATMOSPHERIC PRESSURE/SEA LEVEL=  1.000

       TIME =  0.0  INSOLATION(KW/M2)=   .942 TRUE ZENITH ANGLE =  34.35  OBSERVED ZENITH=  34.34 SUN AZIMUTH =   0.00
       TIME =  1.0  INSOLATION(KW/M2)=   .934 TRUE ZENITH ANGLE =  37.09  OBSERVED ZENITH=  37.07 SUN AZIMUTH =  25.42
       TIME =  2.0  INSOLATION(KW/M2)=   .909 TRUE ZENITH ANGLE =  44.28  OBSERVED ZENITH=  44.27 SUN AZIMUTH =  45.73
       TIME =  3.0  INSOLATION(KW/M2)=   .860 TRUE ZENITH ANGLE =  54.15  OBSERVED ZENITH=  54.12 SUN AZIMUTH =  60.74
       TIME =  4.0  INSOLATION(KW/M2)=   .767 TRUE ZENITH ANGLE =  65.41  OBSERVED ZENITH=  65.38 SUN AZIMUTH =  72.24
       TIME =  4.8  INSOLATION(KW/M2)=   .627 TRUE ZENITH ANGLE =  75.00  OBSERVED ZENITH=  74.94 SUN AZIMUTH =  80.03

DAY OF THE YEAR =126.625  DECLINATION OF SUN (DEG)=  16.72 DAILY CLEAR SKY INSOLATION (KWH/M2)=   9.55
                     THE AVERAGE CORRECTION TO CLEAR SKY INSOLATION TO ACCOUNT FOR CLOUDINESS=  .830
                      MM OF WATER=  20.00 ATMOSPHERIC PRESSURE/SEA LEVEL=  1.000

       TIME =  0.0  INSOLATION(KW/M2)=   .950 TRUE ZENITH ANGLE =  18.28  OBSERVED ZENITH=  18.27 SUN AZIMUTH =   0.00
       TIME =  1.0  INSOLATION(KW/M2)=   .944 TRUE ZENITH ANGLE =  22.66  OBSERVED ZENITH=  22.65 SUN AZIMUTH =  40.05
       TIME =  2.0  INSOLATION(KW/M2)=   .925 TRUE ZENITH ANGLE =  32.39  OBSERVED ZENITH=  32.38 SUN AZIMUTH =  63.38
       TIME =  3.0  INSOLATION(KW/M2)=   .889 TRUE ZENITH ANGLE =  43.96  OBSERVED ZENITH=  43.95 SUN AZIMUTH =  77.29
       TIME =  4.0  INSOLATION(KW/M2)=   .827 TRUE ZENITH ANGLE =  56.13  OBSERVED ZENITH=  56.11 SUN AZIMUTH =  87.31
       TIME =  5.0  INSOLATION(KW/M2)=   .715 TRUE ZENITH ANGLE =  68.40  OBSERVED ZENITH=  68.36 SUN AZIMUTH =  95.78
       TIME =  5.5  INSOLATION(KW/M2)=   .612 TRUE ZENITH ANGLE =  75.00  OBSERVED ZENITH=  74.94 SUN AZIMUTH = 100.14

DAY OF THE YEAR =172.250  DECLINATION OF SUN (DEG)=  23.44 DAILY CLEAR SKY INSOLATION (KWH/M2)=  10.02
                     THE AVERAGE CORRECTION TO CLEAR SKY INSOLATION TO ACCOUNT FOR CLOUDINESS=  .830
                      MM OF WATER=  20.00 ATMOSPHERIC PRESSURE/SEA LEVEL=  1.000

       TIME =  0.0  INSOLATION(KW/M2)=   .947 TRUE ZENITH ANGLE =  11.56  OBSERVED ZENITH=  11.55 SUN AZIMUTH =   0.00
       TIME =  1.0  INSOLATION(KW/M2)=   .941 TRUE ZENITH ANGLE =  17.42  OBSERVED ZENITH=  17.42 SUN AZIMUTH =  52.47
       TIME =  2.0  INSOLATION(KW/M2)=   .924 TRUE ZENITH ANGLE =  28.47  OBSERVED ZENITH=  28.47 SUN AZIMUTH =  74.19
       TIME =  3.0  INSOLATION(KW/M2)=   .892 TRUE ZENITH ANGLE =  40.57  OBSERVED ZENITH=  40.56 SUN AZIMUTH =  85.92
       TIME =  4.0  INSOLATION(KW/M2)=   .838 TRUE ZENITH ANGLE =  52.85  OBSERVED ZENITH=  52.83 SUN AZIMUTH =  94.52
       TIME =  5.0  INSOLATION(KW/M2)=   .746 TRUE ZENITH ANGLE =  65.00  OBSERVED ZENITH=  64.96 SUN AZIMUTH = 102.08
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        TIME =  5.8  INSOLATION(KW/M2)=   .606 TRUE ZENITH ANGLE =  75.00  OBSERVED ZENITH=  74.94 SUN AZIMUTH = 118.37
YEARLY INSOLATION (KWATT-HOUR/M2)   - CLEAR SKY = 2902.1  TIMES WEATHER FACTOR OF .83 GIVES NET OF 2408.7

HRS OPERATION PER YEAR= .28475+04
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                         YEARLY AVERAGE PERFORMANCE

SAMPLE PROBLEM 1


 TOTAL PERFORMANCE INCLUDES REFLECTIVITIES BUT NOT RADIATION AND CONVECTION LOSSES


THIS PERFORMANCE CALCULATION IS ONLY USED AS INPUT FOR DESIGN OPTIMIZATION - ALL SPILLAGES ARE SET = 1.0



RADIUS                AZIMUTHAL ANGLE OF HELIOSTAT, NORTH=0, EAST=90
                          0.      30.      60.      90.     120.     150.     180.
  .75    COSINE         .929     .920     .897     .865     .834     .813     .805
  .75    SPILL         1.000    1.000    1.000    1.000    1.000    1.000    1.000
  .75    ATTEN          .972     .972     .972     .972     .972     .972     .972
  .75    SHADOW         .912     .896     .914     .914     .939     .942     .951
  .75    BLOCK         1.000    1.000    1.000    1.000    1.000    1.000    1.000
  .75    TOTAL          .707     .688     .684     .659     .654     .639     .639


 1.36    COSINE         .914     .901     .865     .818     .774     .743     .733
 1.36    SPILL         1.000    1.000    1.000    1.000    1.000    1.000    1.000
 1.36    ATTEN          .964     .964     .964     .964     .964     .964     .964
 1.36    SHADOW         .921     .917     .926     .930     .943     .954     .958
 1.36    BLOCK          .997     .998     .998     .998     .997     .998     .999
 1.36    TOTAL          .695     .683     .662     .629     .603     .586     .581


 1.98    COSINE         .897     .882     .840     .785     .733     .699     .687
 1.98    SPILL         1.000    1.000    1.000    1.000    1.000    1.000    1.000
 1.98    ATTEN          .956     .956     .956     .956     .956     .956     .956
 1.98    SHADOW         .931     .949     .942     .947     .956     .966     .977
 1.98    BLOCK          .992     .994     .994     .994     .992     .992     .992
 1.98    TOTAL          .680     .683     .645     .606     .571     .550     .546


 2.59    COSINE         .884     .868     .822     .762     .707     .670     .658
 2.59    SPILL         1.000    1.000    1.000    1.000    1.000    1.000    1.000
 2.59    ATTEN          .947     .947     .947     .947     .947     .947     .947
 2.59    SHADOW         .951     .969     .959     .966     .971     .977     .983
 2.59    BLOCK          .990     .991     .991     .991     .989     .987     .986
 2.59    TOTAL          .677     .678     .636     .594     .552     .525     .518


 3.20    COSINE         .875     .858     .810     .747     .689     .651     .638
 3.20    SPILL         1.000    1.000    1.000    1.000    1.000    1.000    1.000
 3.20    ATTEN          .938     .938     .938     .938     .938     .938     .938
 3.20    SHADOW         .972     .978     .974     .976     .979     .983     .983
 3.20    BLOCK          .991     .991     .991     .991     .989     .985     .985
 3.20    TOTAL          .679     .669     .629     .581     .537     .507     .497


 3.82    COSINE         .868     .850     .800     .735     .676     .637     .624
 3.82    SPILL         1.000    1.000    1.000    1.000    1.000    1.000    1.000
 3.82    ATTEN          .929     .929     .929     .929     .929     .929     .929
 3.82    SHADOW         .982     .982     .985     .986     .985     .988     .981
 3.82    BLOCK          .992     .992     .992     .991     .989     .986     .986
 3.82    TOTAL          .676     .660     .621     .573     .525     .495     .481
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4.43    COSINE        .863     .844     .794     .727     .666     .626     .613
4.43    SPILL        1.000    1.000    1.000    1.000    1.000    1.000    1.000
4.43    ATTEN         .920     .920     .920     .920     .920     .920     .920
4.43    SHADOW        .986     .986     .992     .992     .989     .989     .982
4.43    BLOCK         .994     .994     .993     .993     .991     .987     .987
4.43    TOTAL         .668     .654     .617     .566     .516     .484     .469

5.05    COSINE        .858     .840     .788     .720     .659     .618     .605
5.05    SPILL        1.000    1.000    1.000    1.000    1.000    1.000    1.000
5.05    ATTEN         .911     .911     .911     .911     .911     .911     .911
5.05    SHADOW        .987     .989     .995     .995     .993     .990     .982
5.05    BLOCK         .996     .995     .994     .994     .992     .989     .989
5.05    TOTAL         .661     .647     .610     .557     .508     .474     .460

5.66    COSINE        .855     .836     .784     .715     .652     .612     .599
5.66    SPILL        1.000    1.000    1.000    1.000    1.000    1.000    1.000
5.66    ATTEN         .903     .903     .903     .903     .903     .903     .903
5.66    SHADOW        .988     .991     .996     .997     .994     .991     .982
5.66    BLOCK         .998     .997     .995     .995     .994     .991     .990
5.66    TOTAL         .653     .640     .602     .550     .500     .466     .452

6.27    COSINE        .852     .833     .780     .711     .648     .607     .594
6.27    SPILL        1.000    1.000    1.000    1.000    1.000    1.000    1.000
6.27    ATTEN         .895     .895     .895     .895     .895     .895     .895
6.27    SHADOW        .989     .992     .998     .998     .995     .991     .983
6.27    BLOCK         .999     .998     .996     .996     .995     .993     .992
6.27    TOTAL         .646     .634     .595     .543     .493     .459     .445

6.89    COSINE        .849     .830     .777     .707     .644     .603     .589
6.89    SPILL        1.000    1.000    1.000    1.000    1.000    1.000    1.000
6.89    ATTEN         .887     .887     .887     .887     .887     .887     .887
6.89    SHADOW        .989     .993     .998     .999     .997     .992     .983
6.89    BLOCK        1.000     .999     .997     .997     .997     .994     .994
6.89    TOTAL         .640     .627     .589     .536     .487     .453     .439

7.50    COSINE        .847     .828     .775     .704     .640     .599     .586
7.50    SPILL        1.000    1.000    1.000    1.000    1.000    1.000    1.000
7.50    ATTEN         .879     .879     .879     .879     .879     .879     .879
7.50    SHADOW        .990     .994     .999    1.000     .998     .993     .984
7.50    BLOCK        1.000    1.000     .998     .998     .998     .996     .995
7.50    TOTAL         .633     .621     .582     .530     .481     .447     .433
```

```
$REC

THT     = .175E+03,

TOWL    = .175E+03,

TOWD    = .99999999999999E+01,

IREC    = 0,

W       = .16E+02,

H       = .16E+02,

RRECL   = .965E+00,

IAUTOP  = 1,

NAY     = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
          0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0,
          0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0,
          0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0,
          0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1,

NAX     = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
          0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0,
          0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0,
          0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0,
          0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1,

XAIM    = 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
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          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
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          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
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          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,

YAIM    = 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
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          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
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          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
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          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
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          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
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NUMPT   = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
```

```
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          0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0,
          0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1,

 NUMCAV  = 1,

 RELV    = .9E+02, .9E+02, .9E+02, .9E+02,

 RAZM    = .18E+03, .27E+03, 0.0, .9E+02,

 RX      = .6E+01, .6E+01, .6E+01, .6E+01,

 RY      = .6E+01, .6E+01, .6E+01, .6E+01,

 RWCAV   = .1E+01, .1E+01, .1E+01, .1E+01,

 $END
```

```
$OPT
IHOPT    = 0,
NUMTHT   = 6,
THTST    = .1E+03,
THTEND   = .2E+03,
NUMPEC   = 6,
WST      = .8E+01,
WEND     = .18E+02,
NUMHTW   = 3,
HTWST    = .1E+01,
HTWEND   = .2E+01,
IOPTUM   = 1,
RYTRX    = .1E+01,
RX2TRX   = .1E+01,
RX3TRX   = .1E+01,
RX4TRX   = .1E+01,
NUMOPT   = 4,
POPTMN   = .75E+08,
POPTMX   = .15E+09,
NUMPOS   = 1,
XTPST    = 0.0,
YTPST    = 0.0,
XTPEND   = 0.0,
YTPEND   = 0.0,
NLAND    = 0,
ALP      = 0.0, 0.0, 0.0, 0.0, 0.0,
CLE      = 0.0, 0.0, 0.0, 0.0, 0.0,
CLN      = 0.0, 0.0, 0.0, 0.0, 0.0,
SLEW     = 0.0, 0.0, 0.0, 0.0, 0.0,
SLNS     = 0.0, 0.0, 0.0, 0.0, 0.0,
SMULT    = .1E+01,
IPLFL    = 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
```

```
IFRCPT  = -1,
IHCPTP  = 0,
IOTAPE  = 0,
IREPUN  = 0,
IALL    = 0,
ISTR    = 0,
NSTR    = 1,
$END
```

```
$NLFLUX

IFLX     = 1,

IFXOUT   = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
           0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0.
           0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
           0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
           0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,

IFLAUT   = 4,

XFC      = 0.0,

YFC      = 0.0,

ZFC      = 0.0,

POLF     = .9E+02,

AZMF     = .18E+03,

DIAMF    = .16E+02,

NXFLX    = 1,

FAZMIN   = .18E+03,

FAZMAX   = .18E+03,

NYFLX    = 1,

FZMIN    = 0.0,

FZMAX    = 0.0,

ICAVF    = 1, 0, 0, 0,

NFLXMX   = 1,

NMXFLX   = 1, 2, 3, 4,

FLXLIM   = .85E+06, .1E+09, .1E+09, .1E+09,

$END
```

```
$NLEFF
REFTHP  = .417E+09,
AREF    = .2165E+04,
REFRC   = .83E+00,
REFLP   = .17E+(3,
REFPIP  = .998E+00,
FPLH    = .26E+01,
FPLC    = .26E+C1,
ITHEL   = 0,
ETAREF  = .42E+00,
FEFF    = .95E+60,
REFPRL  = .65E-01,
FSP     = .66E+C0,
FEP     = 0.0,
EFFSTR  = .1E+01,
PF      = .1E+01,
SMULT   = .1E+01,
IPH     = 0,
$ENC
```

```
 &NLCOST
 CP       = .75E+02,
 CL       = .13E+01,
 CWR      = .475E-01,
 CWDR     = .4889E+00,
 CWDA     = .132E+02,
 ITHT     = 0,
 CTOW1    = .302864E+07,
 CTOW2    = -.233415E+05,
 CTOW3    = .147152E+03,
 XTOW     = .2E+01,
 CREC1    = .421E+07,
 ARECRF   = .2165E+04,
 XREC     = .8E+00,
 CRPREF   = .671E+06,
 TRPREF   = .17E+03,
 SMRP     = .15E+01,
 PRPREF   = .26E+09,
 XRP      = .85E+00,
 CSPREF   = .151E+06,
 PSPREF   = .3E+09,
 XSP      = .15E+00,
 CHPREF   = .132E+05,
 CCPREF   = 0.0,
 SMPI     = .15E+01,
 PPIREF   = .26E+09,
 XPI      = .106E+01,
 CSTREF   = .4593E+07,
 CSTRMD   = .322E+07,
 VSTREF   = .4078E+05,
 ESTREF   = .9E+09,
 XST      = [illegible]E+00,
```

```
VMAX     = .123E+05,
EMPTY    = 0.0,
ICHE     = 0,
CHEREF   = .1525E+07,
PHEREF   = .3E+09,
XHEP     = .8E+00,
CPHREF   = 0.0,
APHREF   = .1E+01,
PPHREF   = .1E+01,
APHMAX   = .1E+11,
CEVREF   = .377E+07,
AEVREF   = .13E+04,
PEVREF   = .26E+09,
AEVMAX   = .1E+11,
CSHREF   = .124E+07,
ASHREF   = .4E+03,
PSHREF   = .26E+09,
ASHMAX   = .1E+11,
CRHREF   = .138E+07,
ARHREF   = .31E+03,
PPHREF   = .26E+09,
ARHMAX   = .1E+11,
XHEA     = .6E+00,
CEGREF   = .273E+08,
PEGREF   = .112E+09,
XEPGS    = .8E+00,
CFIXED   = .7E+07,
$END
```

```
$NLECON
CONT     = .12E+00,
SPTS     = .1E-01,
EXT      = .16E+00,
ESC      = .8E-01,
RINF     = .8E-01,
NYTCON   = 0,
AFDC     = .15E+00,
IFCR     = 0,
FCR      = .15903E+00,
DISRT    = .996E-01,
PTI      = .25E-01,
TC       = .1E+00,
TR       = .48E+00,
FDEBT    = .5431E+00,
RDEBT    = .11E+00,
ROE      = .15E+00,
IDEP     = 2,
NDEP     = 24,
NYDP     = 30,
RHOM     = .15E-01,
RNHOM    = .15E-01,
$END
```

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                   ----- OPTIMIZATION -----



DELSOL WILL DO A SMART SEARCH OVER THE OPTIMIZATION VARIABLES - NOT EVERY CASE WILL BE CALCULATED

NO OPTIMIZATION OF HELIOSTAT DENSITIES


THERE ARE  6 VALUES OF THE TOWER HEIGHT
          MINIMUM VALUE = 100.000
          MAXIMUM VALUE = 200.000



EXTERNAL CYLINDRICAL RECEIVER

THERE ARE  6 VALUES OF THE CYLINDER DIAMETER
          MINIMUM VALUE =   8.000
          MAXIMUM VALUE =  18.000

THERE ARE   3 VALUES OF THE HEIGHT TO WIDTH RATIO
          MINIMUM VALUE =   1.000
          MAXIMUM VALUE =   2.000



THERE ARE  4 VALUES OF THE DESIGN POINT POWER LEVEL IN MEGAWATTS ELECTRIC
          MINIMUM VALUE =  75.000
          MAXIMUM VALUE = 150.000



CONSTRAINTS ON DESIGN(IF ANY)



                      THE FLUX AT THE   1 POINT ON THE RECEIVER MUST BE LESS THAN     .850E+06 W/M2
          THE ORIGIN OF THE FLUX SURFACE IS PROPORTIONAL TO THE RECEIVER DIAMETER
          THE ORIGIN COORDINATES EXPRESSED AS FRACTIONS OF THE   REC. DIAMETER ARE, EAST= 0.000 NORTH= 0.000 UP= 0.000
          FLUX SURFACE IS THE OUTSIDE OF A CYLINDER WHOSE DIAMETER IS 1.000 TIMES THE RECEIVER DIAMETER
          THE FLUX POINTS HAVE A CONSTANT AZIMUTH AND A HEIGHT   THAT SCALES WITH REC. HT. (EXT. REC.) OR REC. DIAM.(CAV. REC.)
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 ITERATING, THT= 100.0 FIRST RECEIVER VARIABLE=  8.000 SECOND =  8.000
      MAX. DESIGN PT. PWR - THIS REC.=    63.09 ANY REC., THIS THT=   66.88, MINIMUM POWER OF INTEREST=    75.00
MAXIMUM POSSIBLE POWER =  63.09 MWE THIS IS LESS THAN THE  MINIMUM POWER OF INTEREST =  75.00 MWE NO FIELD BUILDUP

 ITERATING, THT= 120.0 FIRST RECEIVER VARIABLE=  8.000 SECOND =  8.000
      MAX. DESIGN PT. PWR - THIS REC.=    87.78 ANY REC., THIS THT=   98.04, MINIMUM POWER OF INTEREST=    75.00

NEXT ZONE WILL EXCEED THE FLUX AT THE 1 MAXIMUM FLUX POINT,DES. PWR=     8.31 LAST BREC=  0.00

 ITERATING, THT= 120.0 FIRST RECEIVER VARIABLE=  8.000 SECOND = 12.000
      MAX. DESIGN PT. PWR - THIS REC.=    91.69 ANY REC., THIS THT=   98.04, MINIMUM POWER OF INTEREST=    75.00

NEXT ZONE WILL EXCEED THE FLUX AT THE 1 MAXIMUM FLUX POINT,DES. PWR=   11.84 LAST BREC=  0.00

 ITERATING, THT= 120.0 FIRST RECEIVER VARIABLE=  8.000 SECOND = 16.000
      MAX. DESIGN PT. PWR - THIS REC.=    90.96 ANY REC., THIS THT=   98.04, MINIMUM POWER OF INTEREST=    75.00

NEXT ZONE WILL EXCEED THE FLUX AT THE 1 MAXIMUM FLUX POINT,DES. PWR=   33.40 LAST BREC=  0.00

 ITERATING, THT= 120.0 FIRST RECEIVER VARIABLE= 10.000 SECOND = 10.000
      MAX. DESIGN PT. PWR - THIS REC.=    93.22 ANY REC., THIS THT=   96.76, MINIMUM POWER OF INTEREST=    75.00

NEXT ZONE WILL EXCEED THE FLUX AT THE 1 MAXIMUM FLUX POINT,DES. PWR=   11.32 LAST BREC=  0.00

 ITERATING, THT= 120.0 FIRST RECEIVER VARIABLE= 10.000 SECOND = 15.000
      MAX. DESIGN PT. PWR - THIS REC.=    93.14 ANY REC., THIS THT=   96.76, MINIMUM POWER OF INTEREST=    75.00

NEXT ZONE WILL EXCEED THE FLUX AT THE 1 MAXIMUM FLUX POINT,DES. PWR=   29.31 LAST BREC=  0.00

 ITERATING, THT= 120.0 FIRST RECEIVER VARIABLE= 10.000 SECOND = 20.000
      MAX. DESIGN PT. PWR - THIS REC.=    91.24 ANY REC., THIS THT=   96.76, MINIMUM POWER OF INTEREST=    75.00
OPTIMUM - POWER=  75.0MWE, EFF= .212 FLUX=  .79 0.00 0.00 0.00MWT/M2, KWHR=    .164E+09, CAPITAL=  64.00M$, BUSBAR= 113.16

ADDING MORE ZONES WILL NOT REACH NEXT POWER LEVEL - LAST POWER=   75.97

 ITERATING, THT= 120.0 FIRST RECEIVER VARIABLE= 12.000 SECOND = 12.000
      MAX. DESIGN PT. PWR - THIS REC.=    93.63 ANY REC., THIS THT=   95.07, MINIMUM POWER OF INTEREST=    75.00

NEXT ZONE WILL EXCEED THE FLUX AT THE 1 MAXIMUM FLUX POINT,DES. PWR=   20.01 LAST BREC=113.16

 ITERATING, THT= 120.0 FIRST RECEIVER VARIABLE= 12.000 SECOND = 18.000
      MAX. DESIGN PT. PWR - THIS REC.=    91.57 ANY REC., THIS THT=   95.07, MINIMUM POWER OF INTEREST=    75.00
         - POWER=  75.0MWE, EFF= .211 FLUX=  .79 0.00 0.00 0.00MWT/M2, KWHR=    .163E+09, CAPITAL=  64.08M$, BUSBAR= 113.66

ADDING MORE ZONES WILL NOT REACH NEXT POWER LEVEL - LAST POWER=   75.98

 ITERATING, THT= 120.0 FIRST RECEIVER VARIABLE= 12.000 SECOND = 24.000
      MAX. DESIGN PT. PWR - THIS REC.=    88.72 ANY REC., THIS THT=   95.07, MINIMUM POWER OF INTEREST=    75.00
         - POWER=  75.0MWE, EFF= .202 FLUX=  .50 0.00 0.00 0.00MWT/M2, KWHR=    .163E+09, CAPITAL=  65.82M$, BUSBAR= 117.23

ADDING MORE ZONES WILL NOT REACH NEXT POWER LEVEL - LAST POWER=   75.12

 ITERATING, THT= 140.0 FIRST RECEIVER VARIABLE=  8.000 SECOND =  8.000
      MAX. DESIGN PT. PWR - THIS REC.=  113.07 ANY REC., THIS THT=  134.69, MINIMUM POWER OF INTEREST=    75.00

NEXT ZONE WILL EXCEED THE FLUX AT THE 1 MAXIMUM FLUX POINT,DES. PWR=     7.53 LAST BREC=117.23

 ITERATING, THT= 140.0 FIRST RECEIVER VARIABLE=  8.000 SECOND = 12.000
      MAX. DESIGN PT. PWR - THIS REC.=  121.65 ANY REC., THIS THT=  134.69, MINIMUM POWER OF INTEREST=    75.00

NEXT ZCN    LL EXCEED THE FLUX AT T     MAXIMUM FLUX POINT,DES. PW      10.47 LAST BREC=117.23
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 ITERATING, THT= 140.0 FIRST RECEIVER VARIABLE=  8.000 SECOND = 16.000
     MAX. DESIGN PT. PWR - THIS REC.=  121.98 ANY REC., THIS THT=  134.69, MINIMUM POWER OF INTEREST=   75.00

NEXT ZONE WILL EXCEED THE FLUX AT THE 1 MAXIMUM FLUX POINT,DES. PWR=   23.15 LAST RREC=117.23

 ITERATING, THT= 140.0 FIRST RECEIVER VARIABLE= 10.000 SECOND = 10.000
     MAX. DESIGN PT. PWR - THIS REC.=  124.35 ANY REC., THIS THT=  133.47, MINIMUM POWER OF INTEREST=   75.00

NEXT ZONE WILL EXCEED THE FLUX AT THE 1 MAXIMUM FLUX POINT,DES. PWR=   10.38 LAST RREC=117.23

 ITERATING, THT= 140.0 FIRST RECEIVER VARIABLE= 10.000 SECOND = 15.000
     MAX. DESIGN PT. PWR - THIS REC.=  127.50 ANY REC., THIS THT=  133.47, MINIMUM POWER OF INTEREST=   75.00

NEXT ZONE WILL EXCEED THE FLUX AT THE 1 MAXIMUM FLUX POINT,DES. PWR=   23.52 LAST RREC=117.23

 ITERATING, THT= 140.0 FIRST RECEIVER VARIABLE= 10.000 SECOND = 20.000
     MAX. DESIGN PT. PWR - THIS REC.=  125.38 ANY REC., THIS THT=  133.47, MINIMUM POWER OF INTEREST=   75.00

NEXT ZONE WILL EXCEED THE FLUX AT THE 1 MAXIMUM FLUX POINT,DES. PWR=   57.67 LAST RREC=117.23

 ITERATING, THT= 140.0 FIRST RECEIVER VARIABLE= 12.000 SECOND = 12.000
     MAX. DESIGN PT. PWR - THIS REC.=  128.11 ANY REC., THIS THT=  131.83, MINIMUM POWER OF INTEREST=   75.00

NEXT ZONE WILL EXCEED THE FLUX AT THE 1 MAXIMUM FLUX POINT,DES. PWR=   12.46 LAST RREC=117.23

 ITERATING, THT= 140.0 FIRST RECEIVER VARIABLE= 12.000 SECOND = 18.000
     MAX. DESIGN PT. PWR - THIS REC.=  127.15 ANY REC., THIS THT=  131.83, MINIMUM POWER OF INTEREST=   75.00

NEXT ZONE WILL EXCEED THE FLUX AT THE 1 MAXIMUM FLUX POINT,DES. PWR=   50.55 LAST RREC=117.23

 ITERATING, THT= 140.0 FIRST RECEIVER VARIABLE= 12.000 SECOND = 24.000
     MAX. DESIGN PT. PWR - THIS REC.=  124.38 ANY REC., THIS THT=  131.83, MINIMUM POWER OF INTEREST=   75.00
        - POWER=  75.0MWE, EFF= .208 FLUX=  .67 0.00 0.00 0.00MWT/M2, KWHR=   .159E+09, CAPITAL=  64.72M$, BUSBAR= 118.00
OPTIMUM - POWER= 100.0MWE, EFF= .210 FLUX=  .72 0.00 0.00 0.00MWT/M2, KWHR=   .218E+09, CAPITAL=  81.27M$, BUSBAR= 108.13

ADDING MORE ZONES WILL NOT REACH NEXT POWER LEVEL - LAST POWER=  101.47

 ITERATING, THT= 140.0 FIRST RECEIVER VARIABLE= 14.000 SECOND = 14.000
     MAX. DESIGN PT. PWR - THIS REC.=  128.28 ANY REC., THIS THT=  129.82, MINIMUM POWER OF INTEREST=   75.00

NEXT ZONE WILL EXCEED THE FLUX AT THE 1 MAXIMUM FLUX POINT,DES. PWR=   28.48 LAST RREC=108.13

 ITERATING, THT= 140.0 FIRST RECEIVER VARIABLE= 14.000 SECOND = 21.000
     MAX. DESIGN PT. PWR - THIS REC.=  125.08 ANY REC., THIS THT=  129.82, MINIMUM POWER OF INTEREST=   75.00
        - POWER=  75.0MWE, EFF= .208 FLUX=  .76 0.00 0.00 0.00MWT/M2, KWHR=   .159E+09, CAPITAL=  64.72M$, BUSBAR= 118.15
        - POWER= 100.0MWE, EFF= .211 FLUX=  .79 0.00 0.00 0.00MWT/M2, KWHR=   .217E+09, CAPITAL=  81.09M$, BUSBAR= 108.18
OPTIMUM - POWER= 125.0MWE, EFF= .206 FLUX=  .79 0.00 0.00 0.00MWT/M2, KWHR=   .280E+09, CAPITAL=  99.57M$, BUSBAR= 103.12

ADDING MORE ZONES WILL NOT REACH NEXT POWER LEVEL - LAST POWER=  125.08

 ITERATING, THT= 140.0 FIRST RECEIVER VARIABLE= 14.000 SECOND = 28.000
     MAX. DESIGN PT. PWR - THIS REC.=  121.21 ANY REC., THIS THT=  129.82, MINIMUM POWER OF INTEREST=   75.00
        - POWER=  75.0MWE, EFF= .196 FLUX=  .47 0.00 0.00 0.00MWT/M2, KWHR=   .157E+09, CAPITAL=  66.72M$, BUSBAR= 123.11
        - POWER= 100.0MWE, EFF= .200 FLUX=  .48 0.00 0.00 0.00MWT/M2, KWHR=   .216E+09, CAPITAL=  83.39M$, BUSBAR= 111.75

ADDING MORE ZONES WILL NOT REACH NEXT POWER LEVEL - LAST POWER=  100.84

 ITERATING, THT= 140.0 FIRST RECEIVER VARIABLE= 16.000 SECOND = 16.000
     MAX. DESIGN PT. PWR - THIS REC.=  126.71 ANY REC., THIS THT=  127.44, MINIMUM POWER OF INTEREST=   75.00

NEXT ZONE WILL EXCEED THE FLUX AT THE 1 MAXIMUM FLUX POINT,DES. PWR=   41.83 LAST RREC=111.75

 ITERATING, THT= 140.0 FIRST RECEIVER VARIABLE= 16.000 SECOND = 24.000
     MAX. DESIGN PT. PWR - THIS REC.=  121.85 ANY REC., THIS THT=  127.44, MINIMUM POWER OF INTEREST=   75.00
        - POWER=  75.0MWE, EFF= .198 FLUX=  .55 0.00 0.00 0.00MWT/M2, KWHR=   .157E+09, CAPITAL=  66.51M$, BUSBAR= 122.71
        - POWER= 100.0MWE, EFF= .202 FLUX=  .56 0.00 0.00 0.00MWT/M2, KWHR=   .216E+09, CAPITAL=  83.13M$, BUSBAR= 111.78
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                       SYSTEM DESIGN


    SAMPLE PROBLEM 1
    DESIGN POWER RANGE =  75.00 TO 150.00 MWE
    SOLAR MULTIPLE 1.00   FLUX LIMIT(S)=   .850E+06   .100E+09   .100E+09   .100E+09 W/M2

    DESIGN POINT, DAY= 81.000  HOURS PAST SOLAR NOON=  0.000    INSOLATION =  .9500 KW/M2

    DES.POWER  BUSBAR COST   TOWER HT  RECEIVER DIAM  RECEIVER HT  NO.HELIOSTATS  LAND AREA
      (MWE)    (MILLS/KWHR)    (M)         (M)           (M)                       (KM2)
       75.00      113.16      120.00      10.00         20.00            6990.      1.773
      100.00      108.13      140.00      12.00         24.00            9397.      2.335
      125.00      103.12      140.00      14.00         21.00           12285.      3.423
      150.00      100.97      160.00      16.00         24.00           14471.      3.779
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                          ANNUAL PERFORMANCE BREAKDOWN
CONSTANT - MIRROR REFLECTIVITY= .890   RECEIVER ABSORPTIVITY= .965

DES.POWER  COSINE  SHAD+BLOCK  ATM.TRANSMIT.  INTERCEPT  REC.RAD-CON  PIPING   TOTAL   THERMAL-  TOTAL
  (MWE)                                                                      THERMAL  ELECTRIC
   75.00    .779      .969          .947         .987        .883      .994    .532     .399     .212
  100.00    .781      .968          .940         .989        .875      .994    .525     .399     .210
  125.00    .746      .972          .935         .994        .898      .995    .516     .399     .206
  150.00    .762      .971          .931         .994        .888      .994    .519     .399     .207
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                    FLUX ON RECEIVER AT PONTS TESTED FOR MAXIMUM FLUX



DES.POWER(MWE)  FLUX PT. MAX.FLUX(W/M2)  FLUX PT. MAX.FLUX(W/M2)  FLUX PT. MAX.FLUX(W/M2)  FLUX PT. MAX.FLUX(W/M2)
     75.00          1        .795E+06
    100.00          1        .724E+06
    125.00          1        .788E+06
    150.00          1        .781E+06
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                   CAPITAL COST BREAKDOWN

DES.POWER   DIRECT CAP.COST                    PERCENT-
  (MWE)    (M$,CURRENT EST.)         LAND      WIRE     HEL       TOW       REC       PIPE      PUMP      STOR      FFGS      HTXCHG  FIXED

  75.00          64.00               3.60      1.56    40.24      3.56      2.44      4.41       .65      0.00     30.95      1.66    10.94
 100.00          81.27               3.74      1.69    42.59      3.08      2.58      4.72       .67      0.00     30.68      1.65     8.61
 125.00          99.57               4.47      1.86    45.45      2.54      2.14      4.33       .63      0.00     29.93      1.61     7.03
 150.00         115.48               4.25      1.90    46.16      2.49      2.28      4.70       .68      0.00     29.86      1.60     6.06
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                    ANNUAL ENERGY BREAKDOWN

PLANT FACTOR  WEATHER FACTOR  DES.PT.PAR.LOAD  AVG.PAR.LOAD
   1.000           .830             .065           .065

DES.POWER  OVERALL EFFICIENCY  HRS.STORAGE  TOT.KWHR PER YEAR  CAPACITY FACTOR
  (MWE)

   75.00          .212             0.00          .1640E+09            .250
  100.00          .210             0.00          .2180E+09            .249
  125.00          .206             0.00          .2800E+09            .256
  150.00          .207             0.00          .3317E+09            .252
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                     BBEC CALCULATION BREAKDOWN

CONTINGENCY  SPARE PARTS  INDIRECT  CAP.ESCALATION  INFLATION  NO.YRS  INT.DURING  FIXED CHG  LEV.HEL.O-M(PCT  LEV.BAL.O-M(PCT
        (PCT CAP.COSTS)               (PCT/YR)      (PCT/YR)  TO CONS. CONS(PCT) RATE(PCT/YR) HEL.CAP.COST)  OTHER CAP.COST)
   12.00        1.00        16.00       8.00          8.00       0        15.00      15.90            3.64             3.64

DES.POWER  TOT.CAP.COST EST.(M$)  TOT.INVESTMENT(M$)  TOT.INVESTMENT(M$)    $/KWE      BBEC(MILLS/KWHR)  BBEC(MILLS/KWHR)
  (MWE)    INDIR.,ETC.,INCLUDED   BY 1ST YR OPERATION      CURRENT $       CURRENT $  1ST YR OPERATION      CURRENT $

  75.00          82.57                   94.95                 94.95         1266.31        113.16             113.16
 100.00         104.84                  120.57                120.57         1205.71        108.13             108.13
 125.00         128.45                  147.72                147.72         1181.75        103.12             103.12
 150.00         148.97                  171.32                171.32         1142.14        100.97             100.97
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                         FIELD LAYOUT


DESIGN POWER(MWE)=    .750E+02
AZIMUTHAL ANGLE                 0.0         30.0         60.0         90.0        120.0        150.0        180.0
MIN. RADIAL ZONE NO.             1           1            1            1            1            1            1
MAX. RADIAL ZONE NO.            12          12           12           11            8            6            5


FIELD DESCRIPTION - LAND AREA(M2)=    .177E+07  MIRROR AREA =    .343E+06  NO. OF HSTATS=  6990.  AVERAGE DENSITY = .194


RADIUS                 AZIMUTHAL ANGLE OF HELIOSTAT, NORTH=0, EAST=90
                          0.      30.      60.      90.     120.     150.     180.


  .75    DENSITY         .430     .430     .430     .430     .430     .430     .430
  .75    MISS. H         .920     .920     .920     .920     .920     .920     .920
  .75    RAD SEP        1.634    1.634    1.634    1.634    1.634    1.634    1.634
  .75    AZM SEP        1.276    1.276    1.276    1.276    1.276    1.276    1.276
  .75    HSTATS          16.8     16.8     16.8     16.8     16.8     16.8     16.8
  .75    F LAND         1.000    1.000    1.000    1.000    1.000    1.000    1.000


 1.36    DENSITY         .400     .400     .400     .400     .400     .400     .400
 1.36    MISS. H         .941     .941     .941     .941     .941     .941     .941
 1.36    RAD SEP        1.942    1.942    1.942    1.942    1.942    1.942    1.942
 1.36    AZM SEP        1.155    1.155    1.155    1.155    1.155    1.155    1.155
 1.36    HSTATS          48.4     48.4     48.4     48.4     48.4     48.4     48.4
 1.36    F LAND         1.000    1.000    1.000    1.000    1.000    1.000    1.000


 1.98    DENSITY         .350     .350     .350     .350     .350     .350     .350
 1.98    MISS. H         .949     .949     .949     .949     .949     .949     .949
 1.98    RAD SEP        2.329    2.329    2.329    2.329    2.329    2.329    2.329
 1.98    AZM SEP        1.101    1.101    1.101    1.101    1.101    1.101    1.101
 1.98    HSTATS          61.9     61.9     61.9     61.9     61.9     61.9     61.9
 1.98    F LAND         1.000    1.000    1.000    1.000    1.000    1.000    1.000


 2.59    DENSITY         .298     .298     .298     .298     .298     .298     .298
 2.59    MISS. H         .953     .953     .953     .953     .953     .953     .953
 2.59    RAD SEP        2.803    2.803    2.803    2.803    2.803    2.803    2.803
 2.59    AZM SEP        1.074    1.074    1.074    1.074    1.074    1.074    1.074
 2.59    HSTATS          69.2     69.2     69.2     69.2     69.2     69.2     69.2
 2.59    F LAND         1.000    1.000    1.000    1.000    1.000    1.000    1.000


 3.20    DENSITY         .253     .253     .253     .253     .253     .253     .253
 3.20    MISS. H         .954     .954     .954     .954     .954     .954     .954
 3.20    RAD SEP        3.337    3.337    3.337    3.337    3.337    3.337    3.337
 3.20    AZM SEP        1.063    1.063    1.063    1.063    1.063    1.063    1.063
 3.20    HSTATS          72.9     72.9     72.9     72.9     72.9     72.9     72.9
 3.20    F LAND         1.000    1.000    1.000    1.000    1.000    1.000    1.000


 3.82    DENSITY         .217     .217     .217     .217     .217     .217     .217
 3.82    MISS. H         .955     .955     .955     .955     .955     .955     .955
 3.82    RAD SEP        3.910    3.910    3.910    3.910    3.910    3.910    3.910
 3.82    AZM SEP        1.059    1.059    1.059    1.059    1.059    1.059    1.059
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 3.82   F LAND      1.000   1.000   1.000   1.000   1.000   1.000   0.000


 4.43   DENSITY      .187    .187    .187    .187    .187    .187    .187
 4.43   MISS. H      .955    .955    .955    .955    .955    .955    .955
 4.43   RAD SEP     4.510   4.510   4.510   4.510   4.510   4.510   4.510
 4.43   AZM SEP     1.061   1.061   1.061   1.061   1.061   1.061   1.061
 4.43   HSTATS       74.7    74.7    74.7    74.7    74.7     0.0     0.0
 4.43   F LAND      1.000   1.000   1.000   1.000   1.000   0.000   0.000


 5.05   DENSITY      .164    .164    .164    .164    .164    .164    .164
 5.05   MISS. H      .955    .955    .955    .955    .955    .955    .955
 5.05   RAD SEP     5.128   5.128   5.128   5.128   5.128   5.128   5.128
 5.05   AZM SEP     1.067   1.067   1.067   1.067   1.067   1.067   1.067
 5.05   HSTATS       74.4    74.4    74.4    74.4    74.4     0.0     0.0
 5.05   F LAND      1.000   1.000   1.000   1.000   1.000   0.000   0.000


 5.66   DENSITY      .145    .145    .145    .145    .145    .145    .145
 5.66   MISS. H      .955    .955    .955    .955    .955    .955    .955
 5.66   RAD SEP     5.760   5.760   5.760   5.760   5.760   5.760   5.760
 5.66   AZM SEP     1.076   1.076   1.076   1.076   1.076   1.076   1.076
 5.66   HSTATS       73.7    73.7    73.7    73.7     0.0     0.0     0.0
 5.66   F LAND      1.000   1.000   1.000   1.000   0.000   0.000   0.000


 6.27   DENSITY      .129    .129    .129    .129    .129    .129    .129
 6.27   MISS. H      .955    .955    .955    .955    .955    .955    .955
 6.27   RAD SEP     6.401   6.401   6.401   6.401   6.401   6.401   6.401
 6.27   AZM SEP     1.088   1.088   1.088   1.088   1.088   1.088   1.088
 6.27   HSTATS       72.6    72.6    72.6    72.6     0.0     0.0     0.0
 6.27   F LAND      1.000   1.000   1.000   1.000   0.000   0.000   0.000


 6.89   DENSITY      .115    .115    .115    .115    .115    .115    .115
 6.89   MISS. H      .955    .955    .955    .955    .955    .955    .955
 6.89   RAD SEP     7.050   7.050   7.050   7.050   7.050   7.050   7.050
 6.89   AZM SEP     1.103   1.103   1.103   1.103   1.103   1.103   1.103
 6.89   HSTATS       71.5    71.5    71.5    23.6     0.0     0.0     0.0
 6.89   F LAND      1.000   1.000   1.000    .331   0.000   0.000   0.000


 7.50   DENSITY      .104    .104    .104    .104    .104    .104    .104
 7.50   MISS. H      .955    .955    .955    .955    .955    .955    .955
 7.50   RAD SEP     7.705   7.705   7.705   7.705   7.705   7.705   7.705
 7.50   AZM SEP     1.120   1.120   1.120   1.120   1.120   1.120   1.120
 7.50   HSTATS       34.3    34.3    34.3     0.0     0.0     0.0     0.0
 7.50   F LAND      1.000   1.000   1.000   0.000   0.000   0.000   0.000


DESIGN POWER(MWE)=    .100E+03
AZIMUTHAL ANGLE            0.0       30.0       60.0       90.0      120.0      150.0      180.0
MIN. RADIAL ZONE NO.         1          1          1          1          1          1          1
MAX. RADIAL ZONE NO.        12         12         12         10          8          6          5

FIELD DESCRIPTION - LAND AREA(M2)=   .234E+07  MIRROR AREA =   .462E+06  NO. OF HSTATS=  9397.  AVERAGE DENSITY = .198

RADIUS               AZIMUTHAL ANGLE OF HELIOSTAT, NORTH=0, EAST=90
                           0.      30.      60.      90.     120.     150.     180.
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  .75   MISS. H        .928    .928    .928    .928    .928    .928    .928
  .75   RAD SEP       1.634   1.634   1.634   1.634   1.634   1.634   1.634
  .75   AZM SEP       1.263   1.263   1.263   1.263   1.263   1.263   1.263
  .75   HSTATS         23.4    23.4    23.4    23.4    23.4    23.4    23.4
  .75   F LAND        1.000   1.000   1.000   1.000   1.000   1.000   1.000


 1.36   DENSITY        .403    .403    .403    .403    .403    .403    .403
 1.36   MISS. H        .948    .948    .948    .948    .948    .948    .948
 1.36   RAD SEP       1.942   1.942   1.942   1.942   1.942   1.942   1.942
 1.36   AZM SEP       1.147   1.147   1.147   1.147   1.147   1.147   1.147
 1.36   HSTATS         66.7    66.7    66.7    66.7    66.7    66.7    66.7
 1.36   F LAND        1.000   1.000   1.000   1.000   1.000   1.000   1.000


 1.98   DENSITY        .352    .352    .352    .352    .352    .352    .352
 1.98   MISS. H        .955    .955    .955    .955    .955    .955    .955
 1.98   RAD SEP       2.329   2.329   2.329   2.329   2.329   2.329   2.329
 1.98   AZM SEP       1.095   1.095   1.095   1.095   1.095   1.095   1.095
 1.98   HSTATS         85.2    85.2    85.2    85.2    85.2    85.2    85.2
 1.98   F LAND        1.000   1.000   1.000   1.000   1.000   1.000   1.000


 2.59   DENSITY        .299    .299    .299    .299    .299    .299    .299
 2.59   MISS. H        .958    .958    .958    .958    .958    .958    .958
 2.59   RAD SEP       2.803   2.803   2.803   2.803   2.803   2.803   2.803
 2.59   AZM SEP       1.069   1.069   1.069   1.069   1.069   1.069   1.069
 2.59   HSTATS         95.3    95.3    95.3    95.3    95.3    95.3    95.3
 2.59   F LAND        1.000   1.000   1.000   1.000   1.000   1.000   1.000


 3.20   DENSITY        .254    .254    .254    .254    .254    .254    .254
 3.20   MISS. H        .960    .960    .960    .960    .960    .960    .960
 3.20   RAD SEP       3.337   3.337   3.337   3.337   3.337   3.337   3.337
 3.20   AZM SEP       1.058   1.058   1.058   1.058   1.058   1.058   1.058
 3.20   HSTATS        100.2   100.2   100.2   100.2   100.2   100.2   100.2
 3.20   F LAND        1.000   1.000   1.000   1.000   1.000   1.000   1.000


 3.82   DENSITY        .218    .218    .218    .218    .218    .218    .218
 3.82   MISS. H        .960    .960    .960    .960    .960    .960    .960
 3.82   RAD SEP       3.910   3.910   3.910   3.910   3.910   3.910   3.910
 3.82   AZM SEP       1.054   1.054   1.054   1.054   1.054   1.054   1.054
 3.82   HSTATS        102.3   102.3   102.3   102.3   102.3   102.3     0.0
 3.82   F LAND        1.000   1.000   1.000   1.000   1.000   1.000   0.000


 4.43   DENSITY        .188    .188    .188    .188    .188    .188    .188
 4.43   MISS. H        .960    .960    .960    .960    .960    .960    .960
 4.43   RAD SEP       4.510   4.510   4.510   4.510   4.510   4.510   4.510
 4.43   AZM SEP       1.056   1.056   1.056   1.056   1.056   1.056   1.056
 4.43   HSTATS        102.8   102.8   102.8   102.8   102.8     0.0     0.0
 4.43   F LAND        1.000   1.000   1.000   1.000   1.000   0.000   0.000


 5.05   DENSITY        .165    .165    .165    .165    .165    .165    .165
 5.05   MISS. H        .960    .960    .960    .960    .960    .960    .960
 5.05   RAD SEP       5.128   5.128   5.128   5.128   5.128   5.128   5.128
 5.05   AZM SEP       1.062   1.062   1.062   1.062   1.062   1.062   1.062
 5.05   HSTATS        102.3   102.3   102.3   102.3    23.1     0.0     0.0
 5.05   F LAND        1.000   1.000   1.000   1.000    .226   0.000   0.000


 5.66   DENSITY        .145    .145    .145    .145    .145    .145    .145
 5.66   MISS. H        .960    .960    .960    .960    .960    .960    .950
 5.66   RAD SEP       5.760   5.760     760   5.760   5.760   5.760    .760
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 5.66   AZM SEP       1.071    1.071    1.071    1.071    1.071    1.071    1.071
 5.66   HSTATS        101.3    101.3    101.3    101.3      0.0      0.0      0.0
 5.66   F LAND        1.000    1.000    1.000    1.000    0.000    0.000    0.000


 6.27   DENSITY        .129     .129     .129     .129     .129     .129     .129
 6.27   MISS. H        .960     .960     .960     .960     .960     .960     .960
 6.27   RAD SEP       6.401    6.401    6.401    6.401    6.401    6.401    6.401
 6.27   AZM SEP       1.083    1.083    1.083    1.083    1.083    1.083    1.083
 6.27   HSTATS         99.9     99.9     99.9     99.9      0.0      0.0      0.0
 6.27   F LAND        1.000    1.000    1.000    1.000    0.000    0.000    0.000


 6.89   DENSITY        .116     .116     .116     .116     .116     .116     .116
 6.89   MISS. H        .960     .960     .960     .960     .960     .960     .960
 6.89   RAD SEP       7.050    7.050    7.050    7.050    7.050    7.050    7.050
 6.89   AZM SEP       1.098    1.098    1.098    1.098    1.098    1.098    1.098
 6.89   HSTATS         98.3     98.3     98.3      0.0      0.0      0.0      0.0
 6.89   F LAND        1.000    1.000    1.000    0.000    0.000    0.000    0.000


 7.50   DENSITY        .104     .104     .104     .104     .104     .104     .104
 7.50   MISS. H        .960     .960     .960     .960     .960     .960     .960
 7.50   RAD SEP       7.705    7.705    7.705    7.705    7.705    7.705    7.705
 7.50   AZM SEP       1.115    1.115    1.115    1.115    1.115    1.115    1.115
 7.50   HSTATS         47.2     47.2     47.2      0.0      0.0      0.0      0.0
 7.50   F LAND        1.000    1.000    1.000    0.000    0.000    0.000    0.000


DESIGN POWER(MWE)=   .125E+03
AZIMUTHAL ANGLE              0.0        30.0        60.0        90.0       120.0       150.0       180.0
MIN. RADIAL ZONE NO.          1           1           1           1           1           1           1
MAX. RADIAL ZONE NO.         12          12          12          12          12          12          12

FIELD DESCRIPTION - LAND AREA(M2)=   .342E+07  MIRROR AREA =   .603E+06  NO. OF HSTATS= 12285.  AVERAGE DENSITY = .176

RADIUS              AZIMUTHAL ANGLE OF HELIOSTAT, NORTH=0, EAST=90
                          0.      30.      60.      90.     120.     150.     180.


  .75   DENSITY        .435     .435     .435     .435     .435     .435     .435
  .75   MISS. H        .928     .928     .928     .928     .928     .928     .928
  .75   RAD SEP       1.634    1.634    1.634    1.634    1.634    1.634    1.634
  .75   AZM SEP       1.263    1.263    1.263    1.263    1.263    1.263    1.263
  .75   HSTATS         23.4     23.4     23.4     23.4     23.4     23.4     23.4
  .75   F LAND        1.000    1.000    1.000    1.000    1.000    1.000    1.000


 1.36   DENSITY        .403     .403     .403     .403     .403     .403     .403
 1.36   MISS. H        .948     .948     .948     .948     .948     .948     .948
 1.36   RAD SEP       1.942    1.942    1.942    1.942    1.942    1.942    1.942
 1.36   AZM SEP       1.147    1.147    1.147    1.147    1.147    1.147    1.147
 1.36   HSTATS         66.7     66.7     66.7     66.7     66.7     66.7     66.7
 1.36   F LAND        1.000    1.000    1.000    1.000    1.000    1.000    1.000


 1.98   DENSITY        .352     .352     .352     .352     .352     .352     .352
 1.98   MISS. H        .955     .955     .955     .955     .955     .955     .955
 1.98   RAD SEP       2.329    2.329    2.329    2.329    2.329    2.329    2.329
 1.98   AZM SEP       1.095    1.095    1.095    1.095    1.095    1.095    1.095
 1.98   HSTATS         85.2     85.2     85.2     85.2     85.2     85.2     85.2
 1.98   F LAND        1.000    1.000    1.000    1.000    1.000    1.000    1.000
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2.59   DENSITY      .299    .299    .299    .299    .299    .299    .299
2.59   MISS. H      .958    .958    .958    .958    .958    .958    .958
2.59   RAD SEP     2.803   2.803   2.803   2.803   2.803   2.803   2.803
2.59   AZM SEP     1.069   1.069   1.069   1.069   1.069   1.069   1.069
2.59   HSTATS       95.3    95.3    95.3    95.3    95.3    95.3    95.3
2.59   F LAND      1.000   1.000   1.000   1.000   1.000   1.000   1.000

3.20   DENSITY      .254    .254    .254    .254    .254    .254    .254
3.20   MISS. H      .960    .960    .960    .960    .960    .960    .960
3.20   RAD SEP     3.337   3.337   3.337   3.337   3.337   3.337   3.337
3.20   AZM SEP     1.058   1.058   1.058   1.058   1.058   1.058   1.058
3.20   HSTATS      100.2   100.2   100.2   100.2   100.2   100.2   100.2
3.20   F LAND      1.000   1.000   1.000   1.000   1.000   1.000   1.000

3.82   DENSITY      .218    .218    .218    .218    .218    .218    .218
3.82   MISS. H      .960    .960    .960    .960    .960    .960    .960
3.82   RAD SEP     3.910   3.910   3.910   3.910   3.910   3.910   3.910
3.82   AZM SEP     1.054   1.054   1.054   1.054   1.054   1.054   1.054
3.82   HSTATS      102.3   102.3   102.3   102.3   102.3   102.3   102.3
3.82   F LAND      1.000   1.000   1.000   1.000   1.000   1.000   1.000

4.43   DENSITY      .188    .188    .188    .188    .188    .188    .188
4.43   MISS. H      .960    .960    .960    .960    .960    .960    .960
4.43   RAD SEP     4.510   4.510   4.510   4.510   4.510   4.510   4.510
4.43   AZM SEP     1.056   1.056   1.056   1.056   1.056   1.056   1.056
4.43   HSTATS      102.8   102.8   102.8   102.8   102.8   102.8   102.8
4.43   F LAND      1.000   1.000   1.000   1.000   1.000   1.000   1.000

5.05   DENSITY      .165    .165    .165    .165    .165    .165    .165
5.05   MISS. H      .960    .960    .960    .960    .960    .960    .960
5.05   RAD SEP     5.128   5.128   5.128   5.128   5.128   5.128   5.128
5.05   AZM SEP     1.062   1.062   1.062   1.062   1.062   1.062   1.062
5.05   HSTATS      102.3   102.3   102.3   102.3   102.3   102.3   102.3
5.05   F LAND      1.000   1.000   1.000   1.000   1.000   1.000   1.000

5.66   DENSITY      .145    .145    .145    .145    .145    .145    .145
5.66   MISS. H      .960    .960    .960    .960    .960    .960    .960
5.66   RAD SEP     5.760   5.760   5.760   5.760   5.760   5.760   5.760
5.66   AZM SEP     1.071   1.071   1.071   1.071   1.071   1.071   1.071
5.66   HSTATS      101.3   101.3   101.3   101.3   101.3   101.3   101.3
5.66   F LAND      1.000   1.000   1.000   1.000   1.000   1.000   1.000

6.27   DENSITY      .129    .129    .129    .129    .129    .129    .129
6.27   MISS. H      .960    .960    .960    .960    .960    .960    .960
6.27   RAD SEP     6.401   6.401   6.401   6.401   6.401   6.401   6.401
6.27   AZM SEP     1.083   1.083   1.083   1.083   1.083   1.083   1.083
6.27   HSTATS       99.9    99.9    99.9    99.9    99.9    99.9    99.9
6.27   F LAND      1.000   1.000   1.000   1.000   1.000   1.000   1.000

6.89   DENSITY      .116    .116    .116    .116    .116    .116    .116
6.89   MISS. H      .960    .960    .960    .960    .960    .960    .960
6.89   RAD SEP     7.050   7.050   7.050   7.050   7.050   7.050   7.050
6.89   AZM SEP     1.098   1.098   1.098   1.098   1.098   1.098   1.098
6.89   HSTATS       98.3    98.3    98.3    98.3    98.3    98.3    98.3
6.89   F LAND      1.000   1.000   1.000   1.000   1.000   1.000   1.000
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  7.50   MISS. H        .960    .960    .960    .960    .960    .960    .960
  7.50   RAD SEP       7.705   7.705   7.705   7.705   7.705   7.705   7.705
  7.50   AZM SEP       1.115   1.115   1.115   1.115   1.115   1.115   1.115
  7.50   HSTATS         47.2    47.2    47.2    47.2    47.2    47.2    35.5
  7.50   F LAND        1.000   1.000   1.000   1.000   1.000   1.000    .751


DESIGN POWER(MWE)=    .150E+03
AZIMUTHAL ANGLE              0.0       30.0       60.0       90.0      120.0      150.0      180.0
MIN. RADIAL ZONE NO.          1          1          1          1          1          1          1
MAX. RADIAL ZONE NO.         12         12         12         12         11          8          7

FIELD DESCRIPTION - LAND AREA(M2)=    .378E+07  MIRROR AREA =   .711E+06  NO. OF HSTATS= 14471.  AVERAGE DENSITY = .188

RADIUS             AZIMUTHAL ANGLE OF HELIOSTAT, NORTH=0, EAST=90
                         0.     30.     60.     90.    120.    150.    180.


   .75   DENSITY        .438    .438    .438    .438    .438    .438    .438
   .75   MISS. H        .935    .935    .935    .935    .935    .935    .935
   .75   RAD SEP       1.634   1.634   1.634   1.634   1.634   1.634   1.634
   .75   AZM SEP       1.254   1.254   1.254   1.254   1.254   1.254   1.254
   .75   HSTATS         31.0    31.0    31.0    31.0    31.0    31.0    31.0
   .75   F LAND        1.000   1.000   1.000   1.000   1.000   1.000   1.000


  1.36   DENSITY        .405    .405    .405    .405    .405    .405    .405
  1.36   MISS. H        .953    .953    .953    .953    .953    .953    .953
  1.36   RAD SEP       1.942   1.942   1.942   1.942   1.942   1.942   1.942
  1.36   AZM SEP       1.142   1.142   1.142   1.142   1.142   1.142   1.142
  1.36   HSTATS         88.1    88.1    88.1    88.1    88.1    88.1    88.1
  1.36   F LAND        1.000   1.000   1.000   1.000   1.000   1.000   1.000


  1.98   DENSITY        .353    .353    .353    .353    .353    .353    .353
  1.98   MISS. H        .960    .960    .960    .960    .960    .960    .960
  1.98   RAD SEP       2.329   2.329   2.329   2.329   2.329   2.329   2.329
  1.98   AZM SEP       1.090   1.090   1.090   1.090   1.090   1.090   1.090
  1.98   HSTATS        112.3   112.3   112.3   112.3   112.3   112.3   112.3
  1.98   F LAND        1.000   1.000   1.000   1.000   1.000   1.000   1.000


  2.59   DENSITY        .300    .300    .300    .300    .300    .300    .300
  2.59   MISS. H        .963    .963    .963    .963    .963    .963    .963
  2.59   RAD SEP       2.803   2.803   2.803   2.803   2.803   2.803   2.803
  2.59   AZM SEP       1.065   1.065   1.065   1.065   1.065   1.065   1.065
  2.59   HSTATS        125.5   125.5   125.5   125.5   125.5   125.5   125.5
  2.59   F LAND        1.000   1.000   1.000   1.000   1.000   1.000   1.000


  3.20   DENSITY        .255    .255    .255    .255    .255    .255    .255
  3.20   MISS. H        .964    .964    .964    .964    .964    .964    .964
  3.20   RAD SEP       3.337   3.337   3.337   3.337   3.337   3.337   3.337
  3.20   AZM SEP       1.054   1.054   1.054   1.054   1.054   1.054   1.054
  3.20   HSTATS        131.9   131.9   131.9   131.9   131.9   131.9   131.9
  3.20   F LAND        1.000   1.000   1.000   1.000   1.000   1.000   1.000


  3.82   DENSITY        .218    .218    .218    .218    .218    .218    .218
  3.82   MISS. H        .964    .964    .964    .964    .964    .964    .964
  3.82   RAD SEP       3.910   3.910   3.910   3.910   3.910   3.910   3.910
  3.82   AZM SEP       1.051   1.051   1.051   1.051   1.051   1.051   1.051
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3.82   F LAND      1.000   1.000   1.000   1.000   1.000   1.000   1.000

4.43   DENSITY      .189    .189    .189    .189    .189    .189    .189
4.43   MISS. H      .965    .965    .965    .965    .965    .965    .965
4.43   RAD SEP     4.510   4.510   4.510   4.510   4.510   4.510   4.510
4.43   AZM SEP     1.053   1.053   1.053   1.053   1.053   1.053   1.053
4.43   HSTATS      135.3   135.3   135.3   135.3   135.3   135.3   135.3
4.43   F LAND      1.000   1.000   1.000   1.000   1.000   1.000   1.000

5.05   DENSITY      .165    .165    .165    .165    .165    .165    .165
5.05   MISS. H      .965    .965    .965    .965    .965    .965    .965
5.05   RAD SEP     5.128   5.128   5.128   5.128   5.128   5.128   5.128
5.05   AZM SEP     1.059   1.059   1.059   1.059   1.059   1.059   1.059
5.05   HSTATS      134.7   134.7   134.7   134.7   134.7   134.7     0.0
5.05   F LAND      1.000   1.000   1.000   1.000   1.000   1.000   0.000

5.66   DENSITY      .146    .146    .146    .146    .146    .146    .146
5.66   MISS. H      .965    .965    .965    .965    .965    .965    .965
5.66   RAD SEP     5.760   5.760   5.760   5.760   5.760   5.760   5.760
5.66   AZM SEP     1.068   1.068   1.068   1.068   1.068   1.068   1.068
5.66   HSTATS      133.3   133.3   133.3   133.3   133.3     0.0     0.0
5.66   F LAND      1.000   1.000   1.000   1.000   1.000   0.000   0.000

6.27   DENSITY      .130    .130    .130    .130    .130    .130    .130
6.27   MISS. H      .965    .965    .965    .965    .965    .965    .965
6.27   RAD SEP     6.401   6.401   6.401   6.401   6.401   6.401   6.401
6.27   AZM SEP     1.079   1.079   1.079   1.079   1.079   1.079   1.079
6.27   HSTATS      131.5   131.5   131.5   131.5   131.5     0.0     0.0
6.27   F LAND      1.000   1.000   1.000   1.000   1.000   0.000   0.000

6.89   DENSITY      .116    .116    .116    .116    .116    .116    .116
6.89   MISS. H      .964    .964    .964    .964    .964    .964    .964
6.89   RAD SEP     7.050   7.050   7.050   7.050   7.050   7.050   7.050
6.89   AZM SEP     1.094   1.094   1.094   1.094   1.094   1.094   1.094
6.89   HSTATS      129.4   129.4   129.4   129.4    81.1     0.0     0.0
6.89   F LAND      1.000   1.000   1.000   1.000    .627   0.000   0.000

7.50   DENSITY      .105    .105    .105    .105    .105    .105    .105
7.50   MISS. H      .964    .964    .964    .964    .964    .964    .964
7.50   RAD SEP     7.705   7.705   7.705   7.705   7.705   7.705   7.705
7.50   AZM SEP     1.111   1.111   1.111   1.111   1.111   1.111   1.111
7.50   HSTATS       62.2    62.2    62.2    62.2     0.0     0.0     0.0
7.50   F LAND      1.000   1.000   1.000   1.000   0.000   0.000   0.000
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                    CAPITAL COST OF THERMAL ENERGY NEAR THE BASE OF THE TOWER
                          COSTS INCLUDE FIELD, RECEIVER, TOWER , PIPING AND PUMPS
DES.ELEC.POWER  THERMAL POWER  CAP.COST
    (MWE)          (MWTH)      ($/KWTH)
     75.00         190.98       189.202
    100.00         254.64       188.515
    125.00         318.31       192.168
    150.00         381.97       188.882
```

Sample Problem 2 - Optimization of a Multi-Aperture Cavity and Storage Subsystem Size

Problem Statement

Both the receiver and storage size are to be optimized for a 125 MWe molten salt system with a solar multiple of 1.5. The receiver is a cavity design configured so that the north aperture is the largest, the south the smallest, and the east and west of intermediate size. The depth of each cavity varies in a similar fashion. A flux limit of 0.6 MW/m^2 is specified. A flux map of the optimum north cavity surface is required for subsequent detailed design studies. The optimized field layout should be printed and optimization data saved.

A reminder: As discussed in section V.A-3(c), optimum cavity receiver design should be carried out in two steps. First, the optimum depth of each cavity should be calculated, and in a second run, the optimum aperture size. These sequential runs are discussed in turn below.

A. Optimize Cavity Depth

Input Cards

```
SAMPLE PRØBLEM 2A
$BASIC ITAPE=2$
$REC IREC=2, RRECL=0.98, W=20., IAUTØP=2, NUMCAV=4,
     RWCAV=1.0,0.75,0.5,0.75$
$ØPT NUMTHT=4, THTST=160., THTEND=220., NUMREC=5, WST=14., WEND=22.,
     IØPTUM=2, NUMHTW=7, HTWST=30., HTWEND=45.0, RYTRX=1.0, RX2TRX=0.8,
     RX3TRX=0.6, RX4TRX=0.8, NUMØPT=1, PØPTMN=125.E+06, PØPTMX=125.E+06,
     IPLFL=1$
$NLFLUX IFLX=1, NXFLX=5, FAZMIN=135., FAZMAX=225., NYFLX=4, FZMIN=0.,
        FZMAX=13.3, NFLXMX=4, NMXFLX=3,8,13,18, FLXLIM=4*0.6E+06$
$NLEFF REFRC=0.937, AREF=881.$
$NLCØST CREC1=4.735E+06, ARECRF=1749.$
$NLECØN$
$REC W=-1.$
```

Analysis of Input

Since the problem statement is somewhat general, some choices must be made by the user. To begin with, no initial performance calculation is required since the data file created in Sample Problem 1 is suitable for this problem. For this option the user specifies ITAPE=2 in $BASIC$ (in addition to attaching the permanent file created in Problem 1 with the control statement(s) appropriate to his system). No other cards in the performance group are read. The REC card is the first of the optimization group and defines a cavity with 4 rectangular apertures (IREC=2, NUMCAV=4) and automatic 2-d aiming (IAUTØP=2). RRECL defines the receiver reflectivity appropriate for this cavity (ref. 34). Relative cavity depths are specified by RWCAV. (Note that the choice of RWCAV has been left up to the user. Values indicated here are reasonable ones, but could be varied according to the user's previous experience, added information about his problem and/or his curiosity concerning the sensitivity of the design to such factors). The value of W is chosen as a convenient basis for setting up the flux map in $NLFLUX$ to test for flux limits on the back wall of the cavity. The selection of the default values for RAZM sets the north facing cavity as the first one.

For optimizing cavity depth, the I0PTUM=2 option is specified. NUMREC, WST, and WEND then refer to the width of the first (north) aperture. NUMHTW, HTWST, and HTWEND define the width of the receiver and therefore the depth of the cavities. The aperture dimensions are varied by the ratios RYTRX, RX2TRX, RX3TRX, and RX4TRX. Other input variables in $0PT$ are analogous to those in Sample Problem 1.

Testing for flux limits on a cavity wall requires some care with the input data. The maximum angle active for the north cavity sets the width of the flux surface (FAZMIN,FAZMAX), and an estimate of the height of the cavity wall above the plane of the aperture center (FZMAX) is made based on RADMIN. A 20 point grid is set up with the 4 points (NFLXMX) along the centerline checked (NMXFLX=3,8,13,18) for a flux limit of 0.6 MW/m^2. As mentioned the flux map is referenced to the values of THT, W, RY and RELV in REC for scaling and is subsequently varied in the optimization search as THT, W, and RY vary.

Parameters for the reference receiver efficiency (REFRC and AREF in $NLEFF$) and cost (CREC1 and ARECRF in $NLC0ST$) are provided since the default values refer to an external receiver design (ref. 34).

Comments on Output

$BASIC$ is printed followed by the code generated list $FMTP$ from TAPE20 (pp. B-48 to B-52). The heliostat design is summarized (p. B-53) as in the previous example, but no initial performance data is given. The optimization namelists are printed (not included here, similar to previous example), a summary of the optimization parameters given (p. B-54), and the limited summary of the search printed (also not included here).

The design summary tables are similar to those of the previous example but modified now for the appropriate output cavity dimensions, and including a summary of the cavity design(pp. B-55 to B-64). As mentioned in Section V.A-3(C), the user may want to rerun the problem for a larger RADMIN to test the effect on cavity depth and height. The 4 flux points tested indicate a rather sharp rise in the flux at the third point tested (point 13 on the grid of flux points, roughly 1/3 of the way up the cavity). Again the user may want to rerun the problem with a finer grid in this region in order to locate more accurately the peak flux point. The appropriate output from 2A will now be used as input for 2B.

```
 $BASIC
 IPPOB    = 0,
 NYEAR    = 5,
 HRDEL    = .1E+01,
 UDAY     = .81E+02,
 UTIME    = 0.0,
 NUAZ     = 7,
 NUEL     = 6,
 UAZ      = 0.0, .3E+02, .6E+02, .75E+02, .9E+02, .11E+03, .13E+03, 0.0, 0.0,      0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
            0.0, 0.0, 0.0, 0.0,
 UEL      = .5E+00, .25E+02, .45E+02, .65E+02, .75E+02, .85E+02, 0.0, 0.0, 0.0,
 DHOPT    = .2E+00,
 IPRINT   = 0, 0, 0, 0, 0, 0, 0, 0, 0,
 ITAPE    = 2,
 TDESP    = .1E+03,
 PLAT     = .35E+02,
 ALT      = .65E+00,
 INSOL    = 0,
 SOLCON   = .95E+00,
 IWEATH   = 0,
 WEATH    = .83E+00,
 DWEATH   = .83E+00, .83E+00, .83E+00, .83E+00, .83E+00, .83E+00, .83E+00,        .83E+00, .83E+00,
 H2O      = .2E+02,
 DH2O     = .2E+02, .2E+02, .2E+02, .2E+02, .2E+02, .2E+02, .2E+02, .2E+02,       .2E+02,
 PRES     = .1E+01,
 DPRES    = .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01, .1E+01,       .1E+01,
 NSUN     = 1,
 NSUNPT   = 0,
 SUNI     = 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
            0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
            0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
 SUNR     = 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
            0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
            0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
```

```
REFTIM  = 0.0,
REFSOL  = .95E+00,
ASTART  = .75E+02,
IATM    = 0,
ATM1    = .6789E-02,
ATM2    = .1046E+00,
ATM3    = -.17E-01,
ATM4    = .2845E-02,
$END
```

```
$EMTP

THT      = .175E+03,

WM       = .42285714285714E-01,

HM       = .42285714285714E-01,

IROUND   = 0,

NCANTX   = 2,

NCANTY   = 6,

ROUND    = .1E+01,

NRAD     = 12,

NAZM     = 12,

RMIRL    = .89E+00,

DENSMR   = .897E+00,

DENSIT   = .43987439231372E+00, .40573969863598E+00, .35409061477939E+00,        .30106435581927E+00, .25560588472659E+00,
           .21880992071432E+00, .18934003044309E+00, .16557690223725E+00,        .14616730504702E+00, .13008228850253E+00,
           .11655969166619E+00, .10503595061584E+00, .1E+01,                     .43987439231372E+00, .40573969863598E+00,
           .35409061477939E+00, .30106435581927E+00, .25560588472659E+00,        .21880992071432E+00, .18934003044309E+00,
           .16557690223725E+00, .14616730504702E+00, .13008228850253E+00,        .11655969166619E+00, .10503595061584E+00,
           .1E+01, .43987439231372E+00, .40573969863598E+00,                     .35409061477939E+00, .30106435581927E+00,
           .25560588472659E+00, .21880992071432E+00, .18934003044309E+00,        .16557690223725E+00, .14616730504702E+00,
           .13008228850253E+00, .11655969166619E+00, .10503595061584E+00,        .1E+01, .43987439231372E+00, .40573969863598E+00,
           .35409061477939E+00, .30106435581927E+00, .25560588472659E+00,        .21880992071432E+00, .18934003044309E+00,
           .16557690223725E+00, .14616730504702E+00, .13008228850253E+00,        .11655969166619E+00, .10503595061584E+00,
           .1E+01, .43987439231372E+00, .40573969863598E+00,                     .35409061477939E+00, .30106435581927E+00,
           .25560588472659E+00, .21880992071432E+00, .18934003044309E+00,        .16557690223725E+00, .14616730504702E+00,
           .13008228850253E+00, .11655969166619E+00, .10503595061584E+00,        .1E+01, .43987439231372E+00, .40573969863598E+00,
           .35409061477939E+00, .30106435581927E+00, .25560588472659E+00,        .21880992071432E+00, .18934003044309E+00,
           .16557690223725E+00, .14616730504702E+00, .13008228850253E+00,        .11655969166619E+00, .10503595061584E+00,
           .1E+01, .43987439231372E+00, .40573969863598E+00,                     .35409061477939E+00, .30106435581927E+00,
           .25560588472659E+00, .21880992071432E+00, .18934003044309E+00,        .16557690223725E+00, .14616730504702E+00,
           .13008228850253E+00, .11655969166619E+00, .10503595061584E+00,        .1E+01, .43987439231372E+00, .40573969863598E+00,
           .35409061477939E+00, .30106435581927E+00, .25560588472659E+00,        .21880992071432E+00, .18934003044309E+00,
           .16557690223725E+00, .14616730504702E+00, .13008228850253E+00,        .11655969166619E+00, .10503595061584E+00,
           .1E+01, .43987439231372E+00, .40573969863598E+00,                     .35409061477939E+00, .30106435581927E+00,
           .25560588472659E+00, .21880992071432E+00, .18934003044309E+00,        .16557690223725E+00, .14616730504702E+00,
           .13008228850253E+00, .11655969166619E+00, .10503595061584E+00,        .1E+01, .43987439231372E+00, .40573969863598E+00,
           .35409061477939E+00, .30106435581927E+00, .25560588472659E+00,        .21880992071432E+00, .18934003044309E+00,
           .16557690223725E+00, .14616730504702E+00, .13008228850253E+00,        .11655969166619E+00, .10503595061584E+00,
           .1E+01, .43987439231372E+00, .40573969863598E+00,                     .35409061477939E+00, .30106435581927E+00,
           .25560588472659E+00, .21880992071432E+00, .18934003044309E+00,        .16557690223725E+00, .14616730504702E+00,
           .13008228850253E+00, .11655969166619E+00, .10503595061584E+00,        .1E+01, .43987439231372E+00, .40573969863598E+00,
           .35409061477939E+00, .30106435581927E+00, .25560588472659E+00,        .21880992071432E+00, .18934003044309E+00,
           .16557690223725E+00, .14616730504702E+00, .13008228850253E+00,        .11655969166619E+00, .10503595061584E+00,
           .1E+01,

XFOCUS   = .1E+01,

YFOCUS   = .1E+01,

SIGAZ    = .75E-03,

SIGEL    = .75E-03,
```

```
SIGSX   = .1E-02,

SIGSY   = .1E-02,

SIGTX   = 0.0,

SIGTY   = 0.0,

HEAD    = -.16532166457741E+67, .23043579520479E-04, -.71738305547276E+58,      -.71738305547276E+58,

IFOCUS  = 1,

XFOCAL  = .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01,
          .715E+01, .715E+01,

YFOCAL  = .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01,
          .715E+01, .715E+01,

HRCEL   = .1E+01,

NYEAR   = 5,

HCANT   = 0.0,

DCANT   = .81E+02,

RADMIN  = .75E+00,

RADMAX  = .75E+01,

RCANT   = .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01,
          .715E+01, .715E+01,

WEATH   = .82999999999999E+00,

DWEATH  = .83E+00, .83E+00, .83E+00, .83E+00, .83E+00, .83E+00, .83E+00,        .83E+00, .83E+00,

IWEATH  = 0,

ILAY    = 0,

IATM    = 0,

ATM1    = .6789E+00,

ATM2    = .1046E+02,

ATM3    = -.17E+01,

ATM4    = .49787499999999E+02,

HCANT   = 0.0,

DCANT   = .81E+02,

RCANT   = .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01, .715E+01,
          .715E+01, .715E+01,

INCC    = 0,

IROTFL  = 0,

INSOL   = 0,

NSUN    = 1,
```

```
SUNI    = 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,

SUNP    = 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
          0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,

NYEAR   = 5,

HRDEL   = .1E+01,

INORTH  = 0,

AMAXN   = .825E+02,

RAD     = 0.0,

AZM     = 0.0, .3E+02, .6E+02, .9E+02, .12E+03, .15E+03, .18E+03, .21E+03,    .24E+03, .27E+03, .3E+03, .33E+03,
          0.0,

AZMSEP  = .12479699110328E+01, .1138579219524E+01, .10876771092882E+01,       .1062931237444E+01, .10517141265251E+01,
          .10484753727292E+01, .1050519365561E+01, .10564402361712E+01,       .10654796202867E+01, .10772376600953E+01,
          .10915334209133E+01, .11083347043249E+01, .105E+01,                 .12479699110328E+01, .1138579219524E+01,
          .10876771092882E+01, .1062931237444E+01, .10517141265251E+01,       .10484753727292E+01, .1050519365561E+01,
          .10564402361712E+01, .10654796202867E+01, .10772376600953E+01,      .10915334209133E+01, .11083347043249E+01,
          .105E+01, .12479699110328E+01, .1138579219524E+01,                  .10876771092882E+01, .1062931237444E+01,
          .10517141265251E+01, .10484753727292E+01, .1050519365561E+01,       .10564402361712E+01, .10654796202867E+01,
          .10772376600953E+01, .10915334209133E+01, .11083347043249E+01,      .105E+01, .12479699110328E+01, .1138579219524E+01,
          .10876771092882E+01, .1062931237444E+01, .10517141265251E+01,       .10484753727292E+01, .1050519365561E+01,
          .10564402361712E+01, .10654796202867E+01, .10772376600953E+01,      .10915334209133E+01, .11083347043249E+01,
          .105E+01, .12479699110328E+01, .1138579219524E+01,                  .10876771092882E+01, .1062931237444E+01,
          .10517141265251E+01, .10484753727292E+01, .1050519365561E+01,       .10564402361712E+01, .10654796202867E+01,
          .10772376600953E+01, .10915334209133E+01, .11083347043249E+01,      .105E+01, .12479699110328E+01, .1138579219524E+01,
          .10876771092882E+01, .1062931237444E+01, .10517141265251E+01,       .10484753727292E+01, .1050519365561E+01,
          .10564402361712E+01, .10654796202867E+01, .10772376600953E+01,      .10915334209133E+01, .11083347043249E+01,
          .105E+01, .12479699110328E+01, .1138579219524E+01,                  .10876771092882E+01, .1062931237444E+01,
          .10517141265251E+01, .10484753727292E+01, .1050519365561E+01,       .10564402361712E+01, .10654796202867E+01,
          .10772376600953E+01, .10915334209133E+01, .11083347043249E+01,      .105E+01, .12479699110328E+01, .1138579219524E+01,
          .10876771092882E+01, .1062931237444E+01, .10517141265251E+01,       .10484753727292E+01, .1050519365561E+01,
          .10564402361712E+01, .10654796202867E+01, .10772376600953E+01,      .10915334209133E+01, .11083347043249E+01,
          .105E+01, .12479699110328E+01, .1138579219524E+01,                  .10876771092882E+01, .1062931237444E+01,
          .10517141265251E+01, .10484753727292E+01, .1050519365561E+01,       .10564402361712E+01, .10654796202867E+01,
          .10772376600953E+01, .10915334209133E+01, .11083347043249E+01,      .105E+01, .12479699110328E+01, .1138579219524E+01,
          .10876771092882E+01, .1062931237444E+01, .10517141265251E+01,       .10484753727292E+01, .1050519365561E+01,
          .10564402361712E+01, .10654796202867E+01, .10772376600953E+01,      .10915334209133E+01, .11083347043249E+01,
          .105E+01, .12479699110328E+01, .1138579219524E+01,                  .10876771092882E+01, .1062931237444E+01,
          .10517141265251E+01, .10484753727292E+01, .1050519365561E+01,       .10564402361712E+01, .10654796202867E+01,
          .10772376600953E+01, .10915334209133E+01, .11083347043249E+01,      .105E+01, .12479699110328E+01, .1138579219524E+01,
          .10876771092882E+01, .1062931237444E+01, .10517141265251E+01,       .10484753727292E+01, .1050519365561E+01,
          .10564402361712E+01, .10654796202867E+01, .10772376600953E+01,      .10915334209133E+01, .11083347043249E+01,
          .105E+01,

$END



---- PERFORMANCE DATA FROM RUN TITLED  SAMPLE PROBLEM 1
```

```
                    HELIOSTAT



RECTANGULAR HELIOSTAT - WIDTH =  7.40 M, HEIGHT =  7.40M
         OVERALL AREA/HSTAT= 54.760 M2, REFLECTIVE AREA/HSTAT= 49.120 RATIO (REFLECTIVE/TOTAL)= .897


THE SHADOWING AND BLOCKING ARE ASSUMED NOT TO OVERLAP




THE HELIOSTAT PERFORMANCE ERRORS HAVE NORMAL DISTRIBUTIONS WITH STANDARD DEVIATIONS OF
           NAME   VARIABLE EFFECTED        STD. DEV (RAD)
          SIGAZ - AZIMUTH ANGLE                 .00075
          SIGEL - ELEVATION ANGLE               .00075
          SIGSX - HSTAT SURFACE, HORIZ.         .00100
          SIGSY - HSTAT SURFACE, VERT.          .00100
          SIGTX - REFLECTED RAY, HORIZ.        0.00000
          SIGTY - REFLECTED RAY, VERT.         0.00000


THE  12 MIRROR PANELS ARE CANTED ON-AXIS WITH THE FOLLOWING FOCAL LENGTHS - RADIAL ZONE  FOCAL LENGTH(M)
                                                                                1           1251.3
                                                                                2           1251.3
                                                                                3           1251.3
                                                                                4           1251.3
                                                                                5           1251.3
                                                                                6           1251.3
                                                                                7           1251.3
                                                                                8           1251.3
                                                                                9           1251.3
                                                                               10           1251.3
                                                                               11           1251.3
                                                                               12           1251.3
          NO. OF PANELS IN HORIZ. DIRECTION=  2 VERT. DIRECTION =  6


MIRROR PANELS FOCUSED IN TWO DIMENSIONS
          FOCAL LENGTHS DEFINED BY USER


DELSOL DEFAULT LIMB DARKENED SUNSHAPE
```

```
                                    ----- OPTIMIZATION -----


DELSOL WILL DO A SMART SEARCH OVER THE OPTIMIZATION VARIABLES - NOT EVERY CASE WILL BE CALCULATED

NO OPTIMIZATION OF HELIOSTAT DENSITIES


THERE ARE  4 VALUES OF THE TOWER HEIGHT
           MINIMUM VALUE = 160.000
           MAXIMUM VALUE = 220.000



CAVITY RECEIVER WITH 4 RECTANGULAR APERTURES

THERE ARE  5 VALUES OF THE HORIZONTAL DIMENSION, RX(1)
           MINIMUM VALUE =  14.000
           MAXIMUM VALUE =  22.000

THERE ARE  7 VALUES OF THE RECEIVER DIAMETER
            THE CAVITY OF THE  1 APERTURE HAS A DEPTH THAT IS  1.000 TIMES THE RECIEVER DIAMETER
            THE CAVITY OF THE  2 APERTURE HAS A DEPTH THAT IS   .750 TIMES THE RECIEVER DIAMETER
            THE CAVITY OF THE  3 APERTURE HAS A DEPTH THAT IS   .500 TIMES THE RECIEVER DIAMETER
            THE CAVITY OF THE  4 APERTURE HAS A DEPTH THAT IS   .750 TIMES THE RECIEVER DIAMETER
           MINIMUM VALUE =  30.000
           MAXIMUM VALUE =  45.000



THERE ARE  1 VALUES OF THE DESIGN POINT POWER LEVEL IN MEGAWATTS ELECTRIC
           MINIMUM VALUE = 125.000



CONSTRAINTS ON DESIGN(IF ANY)




                         THE FLUX AT THE   1 POINT ON THE RECEIVER MUST BE LESS THAN     .600E+06 W/M2


                         THE FLUX AT THE   2 POINT ON THE RECEIVER MUST BE LESS THAN     .600E+06 W/M2


                         THE FLUX AT THE   3 POINT ON THE RECEIVER MUST BE LESS THAN     .600E+06 W/M2


                         THE FLUX AT THE   4 POINT ON THE RECEIVER MUST BE LESS THAN     .600E+06 W/M2
            THE ORIGIN OF THE FLUX SURFACE IS PROPORTIONAL TO THE RECEIVER DIAMETER
            THE ORIGIN COORDINATES EXPRESSED AS FRACTIONS OF THE   REC. DIAMETER ARE, EAST=  .000 NORTH=  .500 UP= 0.000
            THE FLUX SURFACE IS THE INSIDE OF A CYLINDER WHOSE DIAMETER IS 1.000 TIMES THE RECEIVER DIAMETER
            THE FLUX POINTS HAVE A CONSTANT AZIMUTH AND A HEIGHT   THAT SCALES WITH REC. HT. (EXT. REC.) OR REC. DIAM.(CAV. REC.)
```

```
                SYSTEM DESIGN


SAMPLE PROBLEM 2A
DESIGN POWER RANGE = 125.00 TO 125.00 MWE
SOLAR MULTIPLE 1.50   FLUX LIMIT(S)=   .600E+06   .600E+06   .600E+06   .600E+06 W/M2

DESIGN POINT, DAY= 81.000  HOURS PAST SOLAR NOON=  0.000    INSOLATION =  .9500 KW/M2

DES.POWER  BUSBAR COST   TOWER HT  APERTURE WIDTH RECVR WIDTH  NO.HELIOSTATS  LAND AREA
  (MWE)    (MILLS/KWHR)    (M)          (M)           (M)                       (KM2)
  125.00     105.36       200.00       16.00         35.00          17293.      3.906
```

```
                  CAVITY CONFIGURATION


DESIGN                                                          CAVITY    HEAT ABSORBING SURFACE              CAVITY ANGLES
POWER    CAVITY     RAZM      RELV       PX        PY       DEPTH      TOP     BOTTOM   HEIGHT       MIN       MAX     TOTAL
(MWE)               (DEG)     (DEG)      (M)       (M)       (M)       (M)      (M)       (M)        (DEG)     (DEG)     (DEG)
125.00      1      180.00     90.00     16.00     16.00     17.50     35.47    -5.73     41.21      19.45    160.55    141.11
            2      270.00     90.00     12.80     12.80     13.13     26.85    -4.12     30.96      18.48    161.52    143.04
            3      360.00     90.00      9.60      9.60      8.75     18.32    -2.06     20.38      16.37    163.63    147.27
            4      450.00     90.00     12.80     12.80     13.13     26.85    -4.12     30.96      18.48    161.52    143.04

----- TOP, BOTTOM OF HEAT ABSORBING SURFACE RELATIVE TO TOP OF TOWER (CENTER OF APERTURE).
----- MIN, MAX CAVITY ANGLES MEASURED COUNTERCLOCKWISE FROM PLANE OF APERTURE  (ORIGIN AT CENTER OF APERTURE).
```

```
                    ANNUAL PERFORMANCE BREAKDOWN
CONSTANT - MIRROR REFLECTIVITY= .890   RECEIVER ABSORPTIVITY= .980

DES.POWER  COSINE  SHAD+BLOCK  ATM.TRANSMIT.  INTERCEPT  REC.RAD-CON  PIPING   TOTAL   THERMAL-  TOTAL
  (MWE)                                                                       THERMAL  ELECTRIC
  125.00    .787     .966          .925          .949        .952       .993    .551     .399     .220
```

```
                 FLUX ON RECEIVER AT PONTS TESTED FOR MAXIMUM FLUX


DES.POWER(MWE)  FLUX PT. MAX.FLUX(W/M2)  FLUX PT. MAX.FLUX(W/M2)  FLUX PT. MAX.FLUX(W/M2)  FLUX PT. MAX.FLUX(W/M2)
    125.00          1       .737E+04         2       .493E+05         3       .556E+06         4       .156E+06
```

```
                    CAPITAL COST BREAKDOWN

DES.POWER   DIRECT CAP.COST                  PERCENT-
  (MWE)    (M$,CURRENT EST.)        LAND     WIRE    HEL       TOW     REC      PIPE      PUMP     STOR    EPGS     HTXCHG  FIXED

 125.00          153.89             3.30     1.71   41.40      2.66   12.43     4.97       .52     8.06   19.37     1.04     4.55
```

```
                          ANNUAL ENERGY BREAKDOWN

PLANT FACTOR  WEATHER FACTOR  DES.PT.PAR.LOAD  AVG.PAR.LOAD
   1.000            .830            .065            .059

DES.POWER  OVERALL EFFICIENCY  HRS.STORAGE  TOT.KWHR PER YEAR  CAPACITY FACTOR
  (MWE)

  125.00          .220              3.25           .4235E+09           .387
```

```
                    BBEC CALCULATION BREAKDOWN

CONTINGENCY  SPARE PARTS  INDIRECT  CAP.ESCALATION  INFLATION  NO.YRS  INT.DURING  FIXED CHG  LEV.HEL.C-M(PCT  LEV.BAL.C-M(PCT
        (PCT CAP.COSTS)                (PCT/YR)      (PCT/YR)  TO CONS. CONS(PCT) RATE(PCT/YR) HEL.CAP.COST)  OTHER CAP.COST)
   12.00        1.00        16.00        8.00          8.00       0       15.00      15.90           3.64             3.64

DES.POWER  TOT.CAP.COST EST.(M$)  TOT.INVESTMENT(M$)  TOT.INVESTMENT(M$)    $/KWE     PBEC(MILLS/KWHR)  RBEC(MILLS/KWHE)
  (MWE)    INDIR.,ETC.,INCLUDED   BY 1ST YR OPERATION     CURRENT $        CURRENT $  1ST YR OPERATION     CURRENT $

  125.00        198.51                 228.29               228.29          1826.32        105.36            105.36
```

```
                    FIELD LAYOUT

DESIGN POWER(MWE)=    .125E+03
AZIMUTHAL ANGLE               0.0         30.0         60.0         90.0        120.0        150.0        180.0
MIN. RADIAL ZONE NO.           1            1            1            1            1            1            1
MAX. RADIAL ZONE NO.          12           11            9            9            7            5            5

FIELD DESCRIPTION - LAND AREA(M2)=    .391E+07  MIRROR AREA =    .849E+06  NO. OF HSTATS= 17293.  AVERAGE DENSITY = .217

RADIUS              AZIMUTHAL ANGLE OF HELIOSTAT, NORTH=0, EAST=90
                              0.     30.     60.     90.    120.    150.    180.

   .75    DENSITY        .443     .443     .443     .443     .443     .443     .443
   .75    MISS. H        .945     .945     .945     .945     .945     .945     .945
   .75    RAD SEP       1.634    1.634    1.634    1.634    1.634    1.634    1.634
   .75    AZM SEP       1.240    1.240    1.240    1.240    1.240    1.240    1.240
   .75    HSTATS         49.4     49.4     49.4     49.4     49.4     49.4     49.4
   .75    F LAND        1.000    1.000    1.000    1.000    1.000    1.000    1.000

  1.36    DENSITY        .407     .407     .407     .407     .407     .407     .407
  1.36    MISS. H        .961     .961     .961     .961     .961     .961     .961
  1.36    RAD SEP       1.942    1.942    1.942    1.942    1.942    1.942    1.942
  1.36    AZM SEP       1.134    1.134    1.134    1.134    1.134    1.134    1.134
  1.36    HSTATS        139.7    139.7    139.7    139.7    139.7    139.7    139.7
  1.36    F LAND        1.000    1.000    1.000    1.000    1.000    1.000    1.000

  1.98    DENSITY        .355     .355     .355     .355     .355     .355     .355
  1.98    MISS. H        .967     .967     .967     .967     .967     .967     .967
  1.98    RAD SEP       2.329    2.329    2.329    2.329    2.329    2.329    2.329
  1.98    AZM SEP       1.084    1.084    1.084    1.084    1.084    1.084    1.084
  1.98    HSTATS        177.7    177.7    177.7    177.7    177.7    177.7    177.7
  1.98    F LAND        1.000    1.000    1.000    1.000    1.000    1.000    1.000

  2.59    DENSITY        .302     .302     .302     .302     .302     .302     .302
  2.59    MISS. H        .969     .969     .969     .969     .969     .969     .969
  2.59    RAD SEP       2.803    2.803    2.803    2.803    2.803    2.803    2.803
  2.59    AZM SEP       1.060    1.060    1.060    1.060    1.060    1.060    1.060
  2.59    HSTATS        198.4    198.4    198.4    198.4    198.4    198.4    198.4
  2.59    F LAND        1.000    1.000    1.000    1.000    1.000    1.000    1.000

  3.20    DENSITY        .256     .256     .256     .256     .256     .256     .256
  3.20    MISS. H        .970     .970     .970     .970     .970     .970     .970
  3.20    RAD SEP       3.337    3.337    3.337    3.337    3.337    3.337    3.337
  3.20    AZM SEP       1.049    1.049    1.049    1.049    1.049    1.049    1.049
  3.20    HSTATS        208.5    208.5    208.5    208.5    208.5    208.5    208.5
  3.20    F LAND        1.000    1.000    1.000    1.000    1.000    1.000    1.000

  3.82    DENSITY        .219     .219     .219     .219     .219     .219     .219
  3.82    MISS. H        .971     .971     .971     .971     .971     .971     .971
  3.82    RAD SEP       3.910    3.910    3.910    3.910    3.910    3.910    3.910
  3.82    AZM SEP       1.046    1.046    1.046    1.046    1.046    1.046    1.046
  3.82    HSTATS        212.8    212.8    212.8    212.8    212.8
```

```
3.82    F LAND      1.000   1.000   1.000   1.000   1.000   0.000   0.000

4.43    DENSITY      .190    .190    .190    .190    .190    .190    .190
4.43    MISS. H      .971    .971    .971    .971    .971    .971    .971
4.43    RAD SEP     4.510   4.510   4.510   4.510   4.510   4.510   4.510
4.43    AZM SEP     1.048   1.048   1.048   1.048   1.048   1.048   1.048
4.43    HSTATS      213.7   213.7   213.7   213.7   213.7     0.0     0.0
4.43    F LAND      1.000   1.000   1.000   1.000   1.000   0.000   0.000

5.05    DENSITY      .166    .166    .166    .166    .166    .166    .166
5.05    MISS. H      .971    .971    .971    .971    .971    .971    .971
5.05    RAD SEP     5.128   5.128   5.128   5.128   5.128   5.128   5.128
5.05    AZM SEP     1.054   1.054   1.054   1.054   1.054   1.054   1.054
5.05    HSTATS      212.8   212.8   212.8   212.8     0.0     0.0     0.0
5.05    F LAND      1.000   1.000   1.000   1.000   0.000   0.000   0.000

5.66    DENSITY      .147    .147    .147    .147    .147    .147    .147
5.66    MISS. H      .971    .971    .971    .971    .971    .971    .971
5.66    RAD SEP     5.760   5.760   5.760   5.760   5.760   5.760   5.760
5.66    AZM SEP     1.063   1.063   1.063   1.063   1.063   1.063   1.063
5.66    HSTATS      210.7   210.7   210.7   145.9     0.0     0.0     0.0
5.66    F LAND      1.000   1.000   1.000    .692   0.000   0.000   0.000

6.27    DENSITY      .130    .130    .130    .130    .130    .130    .130
6.27    MISS. H      .971    .971    .971    .971    .971    .971    .971
6.27    RAD SEP     6.401   6.401   6.401   6.401   6.401   6.401   6.401
6.27    AZM SEP     1.074   1.074   1.074   1.074   1.074   1.074   1.074
6.27    HSTATS      207.8   207.8     0.0     0.0     0.0     0.0     0.0
6.27    F LAND      1.000   1.000   0.000   0.000   0.000   0.000   0.000

6.89    DENSITY      .117    .117    .117    .117    .117    .117    .117
6.89    MISS. H      .971    .971    .971    .971    .971    .971    .971
6.89    RAD SEP     7.050   7.050   7.050   7.050   7.050   7.050   7.050
6.89    AZM SEP     1.089   1.089   1.089   1.089   1.089   1.089   1.089
6.89    HSTATS      204.4   204.4     0.0     0.0     0.0     0.0     0.0
6.89    F LAND      1.000   1.000   0.000   0.000   0.000   0.000   0.000

7.50    DENSITY      .105    .105    .105    .105    .105    .105    .105
7.50    MISS. H      .971    .971    .971    .971    .971    .971    .971
7.50    RAD SEP     7.705   7.705   7.705   7.705   7.705   7.705   7.705
7.50    AZM SEP     1.105   1.105   1.105   1.105   1.105   1.105   1.105
7.50    HSTATS       98.3     0.0     0.0     0.0     0.0     0.0     0.0
7.50    F LAND      1.000   0.000   0.000   0.000   0.000   0.000   0.000
```

```
                         CAPITAL COST OF THERMAL ENERGY NEAR THE BASE OF THE TOWER
                                  COSTS INCLUDE FIELD, RECEIVER, TOWER , PIPING AND PUMPS
DES.ELEC.POWER  THERMAL POWER  CAP.COST
    (MWE)           (MWTH)      ($/KWTH)
    125.00           477.46      215.881
```

B. Optimize Aperture Size

Input Cards

```
SAMPLE PRØBLEM 2B
$BASIC ITAPE=2$
$REC IREC=2, RRECL=0.98, THT=200., W=35., IAUTØP=2, NUMCAV=4,
     RX=16.,12.8,9.6,12.8, RY=16.,12.8,9.6,12.8, RWCAV=1.,0.75,0.5, 0.75$
$ØPT NUMTHT=4, THTST=160., THTEND=220., NUMREC=5, WST=14., WEND=22.,
     NUMHTW=4, HTWST=0.75, HTWEND=1.5,
     NUMØPT=1, PØPTMN=125.E+06, PØPTMX=125.E+06, IPLFL=1, IØTAPE=1,
     IRERUN=1, ISTR=1, NSTR=11$
$NLFLUX IFLX=1, NXFLX=5, FAZMIN=135., FAXMAX=225., NYFLX=5, FZMIN=-5.,
       FZMAX=20., NFLXMX=4, NMXFLX=8,13,18,23, FLXLIM=4*0.6E+06$
$NLEFF REFRC=0.937, AREF=881.$
$NLCØST CREC1=4.735E+06, ARECRF=1749.$
$NLECØN$
PERFØRMANCE RERUN.
$BASIC ITAPE=3, TDESP=125.$
$FIELD$
$HSTAT$
$REC$
$NLFLUX IFLX=1, IFXØUT(3,1)=1$
$NLEFF$
$REC W=-1.$
```

Analysis of Input

As in Problem 2A, the performance data tape created in Problem 1 will suffice for initial performance input (ITAPE=2 in $BASIC$). For optimizing aperture size, the optimum cavity depth for the first aperture from Problem 2A becomes the input value for W in REC in Problem 2B. The tower height and aperture dimensions from the optimized design of Problem 2A are used so that the flux map can be referenced to the calculated values for the heat absorbing surface given in the cavity configuration summary. In $ØPT$ the tower height and aperture width ranges are kept the same as 2A although a narrower range around the optimum values of 2A would probably suffice in this problem. The aperture size variation is specified by selecting NUMHTW values of the first aperture height to width ratio (i.e., RYTRX is now varied by the code) from HTWST to HTWEND, and by using the default value for IØPTUM. The other three apertures will be sized by the same ratio and by the relative size with respect to the first aperture given by RX2TRX, RX3TRX, and RX4TRX, or defined by the RX's and RY's in REC, as done in this example. These are kept the same as in 2A. To save the optimization results on tape, the IØTAPE=1 option is set (and the appropriate catalog instructions are included in the control cards). For storage optimization, a detailed performance calculation is required (IRERUN=1), and the storage optimization is specified with ISTR=1 and NSTR=11 (i.e., the maximum storage size will be decreased in increments of 0.1). The flux map is redefined in $NLFLUX$ to span most of the height of the back wall determined in 2A; the bottom 4 points along the centerline are tested. Other inputs for the optimization group are the same as in 2A.

For a detailed performance calculation of the optimized system, the input set of Table A.A-2 is included. ITAPE=3 specifies that a user defined system is to be read from TAPE30, and TDESP indicates the power level in MW of the system to be analyzed. Since a flux map is desired, the flux calculation must be turned on (IFLX=1) and the time at which the calculation is to be carried out set (IFX0UT(3,1)=1 => flux map at the design point).

Comments on Output

Only the summary design tables and performance rerun output are shown here since the initial output is quite similar to Problems 1 and 2A. Note that the code chose the same system design as in Problem 2A. As mentioned in 2A, the user will probably want to rerun this problem with a finer grid of flux test points in the vicinity of the peak indicated here.

The detailed performance output for the optimized system follows the optimization summary tables. The redefined variables written on TAPE30 are printed in the $FMTP list and the input namelists for a performance run are listed (not shown here). Tables summarizing the heliostat (p. B-77), receiver (p. B-78), flux map (p. B-79), zoning (pp. B-80 to B-82), insolation and sun position (pp. B-83 and B-84), yearly average performance (pp. B-85 and B-86) and performance at each time step (p. B-87) follow. Design point power (p. B-88), annual power production at the optimum storage size (pp. B-89 to B-92), and the yearly average energy production are detailed in the next set of tables (p. B-93). Finally the flux calculation for the map specified is given (p. B-94).

```
                    SYSTEM DESIGN


SAMPLE PROBLEM 2B
DESIGN POWER RANGE = 125.00 TO 125.00 MWE
SOLAR MULTIPLE 1.50   FLUX LIMIT(S)=   .690E+06   .690E+06   .690E+06   .690E+06 W/M2

DESIGN POINT, DAY= 81.000  HOURS PAST SOLAR NOON=  0.000    INSOLATION =  .9500 KW/M2

DES.POWER  BUSBAR COST   TOWER HT  APERTURE WIDTH APERTURE HT  NO.HELIOSTATS  LAND AREA
  (MWE)    (MILLS/KWHR)    (M)          (M)           (M)                       (KM2)
  125.00      105.36      200.00       16.00         16.00         17293.       3.906
```

```
                    CAVITY CONFIGURATION

DESIGN                                                         CAVITY    HEAT ABSORBING SURFACE          CAVITY ANGLES
POWER    CAVITY     RAZM      RELV       RX         RY         DEPTH     TOP      BOTTOM    HEIGHT      MIN       MAX      TOTAL
(MWE)               (DEG)     (DEG)      (M)        (M)        (M)       (M)      (M)       (M)         (DEG)     (DEG)    (DEG)
125.00     1        180.00    90.00      16.00      16.00      17.50     35.47    -5.73     41.21       19.45     160.55   141.11
           2        270.00    90.00      12.80      12.80      13.13     26.85    -4.12     30.96       13.48     161.52   143.04
           3        360.00    90.00       9.60       9.60       8.75     18.32    -2.06     20.38       16.37     163.63   147.27
           4        450.00    90.00      12.80      12.80      13.13     26.85    -4.12     30.96       13.48     161.52   143.04

----- TOP, BOTTOM OF HEAT ABSORBING SURFACE RELATIVE TO TOP OF TOWER (CENTER OF APERTURE).
----- MIN, MAX CAVITY ANGLES MEASURED COUNTERCLOCKWISE FROM PLANE OF APERTURE  (ORIGIN AT CENTER OF APERTURE).
```

```
                  ANNUAL PERFORMANCE BREAKDOWN
CONSTANT - MIRROR REFLECTIVITY= .890   RECEIVER ABSORPTIVITY= .980

DES.POWER  COSINE  SHAD+BLOCK  ATM.TRANSMIT.  INTERCEPT  REC.RAD-CON  PIPING   TOTAL    THERMAL-  TOTAL
  (MWE)                                                                        THERMAL  ELECTRIC
  125.00    .787      .966          .925          .949        .952      .993    .551      .399     .220
```

```
                    FLUX ON RECEIVER AT PONTS TESTED FOR MAXIMUM FLUX


DES.POWER(MWE)  FLUX PT. MAX.FLUX(W/M2)  FLUX PT. MAX.FLUX(W/M2)  FLUX PT. MAX.FLUX(W/M2)  FLUX PT. MAX.FLUX(W/M2)
    125.00          1        .889E+05          2        .536E+06          3        .444E+06          4        .340E+05
```

```
                    CAPITAL COST BREAKDOWN

DES.POWER   DIRECT CAP.COST                    PERCENT-
  (MWE)    (M$,CURRENT EST.)          LAND     WIRE     HEL      TOW      REC      PIPE      PUMP      STOR     EPGS      HTXCHG  FIXED

 125.00          153.89               3.30     1.71    41.40     2.66    12.43     4.97       .52      8.06    19.37      1.04     4.55
```

```
                    ANNUAL ENERGY BREAKDOWN

PLANT FACTOR  WEATHER FACTOR  DES.PT.PAR.LOAD  AVG.PAR.LOAD
   1.000            .830            .065           .059

DES.POWER  OVERALL EFFICIENCY  HRS.STORAGE  TOT.KWHE PER YEAR  CAPACITY FACTOR
  (MWE)

  125.00         .220               3.25          .42355+09            .587
```

```
                 BBEC CALCULATION BREAKDOWN

CONTINGENCY  SPARE PARTS  INDIRECT  CAP.ESCALATION  INFLATION  NO.YRS  INT.DURING  FIXED CHG  LEV.HEL.O-M(PCT  LEV.BAL.O-M(PCT
            (PCT CAP.COSTS)              (PCT/YR)      (PCT/YR)  TO CONS. CONS(PCT) RATE(PCT/YR) HEL.CAP.COST)  OTHER CAP.COST)
   12.00        1.00        16.00        8.00          8.00        0       15.00      15.90            3.64            3.64

DES.POWER  TOT.CAP.COST EST.(M$)  TOT.INVESTMENT(M$)  TOT.INVESTMENT(M$)    $/KWE     BBEC(MILLS/KWHR)  BBEC(MILLS/KWHR)
  (MWE)    INDIR.,ETC.,INCLUDED   BY 1ST YR OPERATION      CURRENT $       CURRENT $  1ST YR OPERATION     CURRENT $

  125.00        198.51                 228.29                228.29         1826.32       105.36            105.36
```

```
                 FIELD LAYOUT


DESIGN POWER(MWE)=    .125E+03
AZIMUTHAL ANGLE               0.0         30.0         60.0         90.0        120.0        150.0        180.0
MIN. RADIAL ZONE NO.           1            1            1            1            1            1            1
MAX. RADIAL ZONE NO.          12           11            9            9            7            5            5


FIELD DESCRIPTION - LAND AREA(M2)=    .391E+07  MIRROR AREA =    .849E+06  NO. OF HSTATS= 17293.  AVERAGE DENSITY = .217


RADIUS              AZIMUTHAL ANGLE OF HELIOSTAT, NORTH=0, EAST=90
                          0.      30.      60.      90.     120.     150.     180.


   .75   DENSITY        .443     .443     .443     .443     .443     .443     .443
   .75   MISS. H        .945     .945     .945     .945     .945     .945     .945
   .75   RAD SEP       1.634    1.634    1.634    1.634    1.634    1.634    1.634
   .75   AZM SEP       1.240    1.240    1.240    1.240    1.240    1.240    1.240
   .75   HSTATS         49.4     49.4     49.4     49.4     49.4     49.4     49.4
   .75   F LAND        1.000    1.000    1.000    1.000    1.000    1.000    1.000


  1.36   DENSITY        .407     .407     .407     .407     .407     .407     .407
  1.36   MISS. H        .961     .961     .961     .961     .961     .961     .961
  1.36   RAD SEP       1.942    1.942    1.942    1.942    1.942    1.942    1.942
  1.36   AZM SEP       1.134    1.134    1.134    1.134    1.134    1.134    1.134
  1.36   HSTATS        139.7    139.7    139.7    139.7    139.7    139.7    139.7
  1.36   F LAND        1.000    1.000    1.000    1.000    1.000    1.000    1.000


  1.98   DENSITY        .355     .355     .355     .355     .355     .355     .355
  1.98   MISS. H        .967     .967     .967     .967     .967     .967     .967
  1.98   RAD SEP       2.329    2.329    2.329    2.329    2.329    2.329    2.329
  1.98   AZM SEP       1.084    1.084    1.084    1.084    1.084    1.084    1.084
  1.98   HSTATS        177.7    177.7    177.7    177.7    177.7    177.7    177.7
  1.98   F LAND        1.000    1.000    1.000    1.000    1.000    1.000    1.000


  2.59   DENSITY        .302     .302     .302     .302     .302     .302     .302
  2.59   MISS. H        .969     .969     .969     .969     .969     .969     .969
  2.59   RAD SEP       2.803    2.803    2.803    2.803    2.803    2.803    2.803
  2.59   AZM SEP       1.060    1.060    1.060    1.060    1.060    1.060    1.060
  2.59   HSTATS        198.4    198.4    198.4    198.4    198.4    198.4    198.4
  2.59   F LAND        1.000    1.000    1.000    1.000    1.000    1.000    1.000


  3.20   DENSITY        .256     .256     .256     .256     .256     .256     .256
  3.20   MISS. H        .970     .970     .970     .970     .970     .970     .970
  3.20   RAD SEP       3.337    3.337    3.337    3.337    3.337    3.337    3.337
  3.20   AZM SEP       1.049    1.049    1.049    1.049    1.049    1.049    1.049
  3.20   HSTATS        208.5    208.5    208.5    208.5    208.5    208.5    208.5
  3.20   F LAND        1.000    1.000    1.000    1.000    1.000    1.000    1.000


  3.82   DENSITY        .219     .219     .219     .219     .219     .219     .219
  3.82   MISS. H        .971     .971     .971     .971     .971     .971     .971
  3.82   RAD SEP       3.910    3.910    3.910    3.910    3.910    3.910    3.910
  3.82   AZM SEP       1.046    1.046    1.046    1.046    1.046    1.046    1.046
  3.82   HSTATS        212.8    212.8    212.8    212.8    212.8      0.0      0.0
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3.82   F LAND       1.000    1.000    1.000    1.000    1.000    0.       0.000

4.43   DENSITY       .190     .190     .190     .190     .190     .190     .190
4.43   MISS. H       .971     .971     .971     .971     .971     .971     .971
4.43   RAD SEP      4.510    4.510    4.510    4.510    4.510    4.510    4.510
4.43   AZM SEP      1.048    1.048    1.048    1.048    1.048    1.048    1.048
4.43   HSTATS       213.7    213.7    213.7    213.7    213.7      0.0      0.0
4.43   F LAND       1.000    1.000    1.000    1.000    1.000    0.000    0.000

5.05   DENSITY       .166     .166     .166     .166     .166     .166     .166
5.05   MISS. H       .971     .971     .971     .971     .971     .971     .971
5.05   RAD SEP      5.128    5.128    5.128    5.128    5.128    5.128    5.128
5.05   AZM SEP      1.054    1.054    1.054    1.054    1.054    1.054    1.054
5.05   HSTATS       212.8    212.8    212.8    212.8      0.0      0.0      0.0
5.05   F LAND       1.000    1.000    1.000    1.000    0.000    0.000    0.000

5.66   DENSITY       .147     .147     .147     .147     .147     .147     .147
5.66   MISS. H       .971     .971     .971     .971     .971     .971     .971
5.66   RAD SEP      5.760    5.760    5.760    5.760    5.760    5.760    5.760
5.66   AZM SEP      1.063    1.063    1.063    1.063    1.063    1.063    1.063
5.66   HSTATS       210.7    210.7    210.7    145.9      0.0      0.0      0.0
5.66   F LAND       1.000    1.000    1.000     .692    0.000    0.000    0.000

6.27   DENSITY       .130     .130     .130     .130     .130     .130     .130
6.27   MISS. H       .971     .971     .971     .971     .971     .971     .971
6.27   RAD SEP      6.401    6.401    6.401    6.401    6.401    6.401    6.401
6.27   AZM SEP      1.074    1.074    1.074    1.074    1.074    1.074    1.074
6.27   HSTATS       207.8    207.8      0.0      0.0      0.0      0.0      0.0
6.27   F LAND       1.000    1.000    0.000    0.000    0.000    0.000    0.000

6.89   DENSITY       .117     .117     .117     .117     .117     .117     .117
6.89   MISS. H       .971     .971     .971     .971     .971     .971     .971
6.89   RAD SEP      7.050    7.050    7.050    7.050    7.050    7.050    7.050
6.89   AZM SEP      1.089    1.089    1.089    1.089    1.089    1.089    1.089
6.89   HSTATS       204.4    204.4      0.0      0.0      0.0      0.0      0.0
6.89   F LAND       1.000    1.000    0.000    0.000    0.000    0.000    0.000

7.50   DENSITY       .105     .105     .105     .105     .105     .105     .105
7.50   MISS. H       .971     .971     .971     .971     .971     .971     .971
7.50   RAD SEP      7.705    7.705    7.705    7.705    7.705    7.705    7.705
7.50   AZM SEP      1.105    1.105    1.105    1.105    1.105    1.105    1.105
7.50   HSTATS        98.3      0.0      0.0      0.0      0.0      0.0      0.0
7.50   F LAND       1.000    0.000    0.000    0.000    0.000    0.000    0.000


          ----- OUTPUT WRITTEN ON LOCAL FILE TAPE30 - USER SHOULD STORE THIS DATA -----
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                         CAPITAL COST OF THERMAL ENERGY NEAR THE BASE OF THE TOWER
                                  COSTS INCLUDE FIELD, RECEIVER, TOWER , PIPING AND PUMPS
 DES.ELEC.POWER  THERMAL POWER  CAP.COST
     (MWE)           (MWTH)       ($/KWTH)
     125.00           477.46       215.881
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                    HELIOSTAT


RECTANGULAR HELIOSTAT - WIDTH =  7.40 M, HEIGHT =  7.40M
         OVERALL AREA/HSTAT= 54.760 M2, REFLECTIVE AREA/HSTAT= 49.120 RATIO (REFLECTIVE/TOTAL)= .897


THE SHADOWING AND BLOCKING ARE ASSUMED NOT TO OVERLAP




THE HELIOSTAT PERFORMANCE ERRORS HAVE NORMAL DISTRIBUTIONS WITH STANDARD DEVIATIONS OF
           NAME   VARIABLE EFFECTED       STD. DEV (RAD)
          SIGAZ - AZIMUTH ANGLE                .00075
          SIGEL - ELEVATION ANGLE              .00075
          SIGSX - HSTAT SURFACE, HORIZ.        .00100
          SIGSY - HSTAT SURFACE, VERT.         .00100
          SIGTX - REFLECTED RAY, HORIZ.       0.00000
          SIGTY - REFLECTED RAY, VERT.        0.00000

THE  12 MIRROR PANELS ARE CANTED ON-AXIS WITH THE FOLLOWING FOCAL LENGTHS - RADIAL ZONE  FOCAL LENGTH(M)
                                                                                  1           1430.0
                                                                                  2           1430.0
                                                                                  3           1430.0
                                                                                  4           1430.0
                                                                                  5           1430.0
                                                                                  6           1430.0
                                                                                  7           1430.0
                                                                                  8           1430.0
                                                                                  9           1430.0
                                                                                 10           1430.0
                                                                                 11           1430.0
                                                                                 12           1430.0
          NO. OF PANELS IN HORIZ. DIRECTION=  2 VERT. DIRECTION =  6


MIRROR PANELS FOCUSED IN TWO DIMENSIONS
          FOCAL LENGTHS DEFINED BY USER


DELSOL DEFAULT LIMB DARKENED SUNSHAPE
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                    RECEIVER



   TOWER HEIGHT=200.00 M ABOVE PLANE OF HELIOSTAT PIVOTS



   THE TOWER SHADOW IS CALCULATED USING A CYLINDER OF HEIGHT= 200.0 M AND DIAMETER = 11.4 M



                     CAVITY RECEIVER

    THERE ARE 4 APERTURES OR FLAT PLATES WITH RECTANGULAR SHAPES
           NUMBER 1 AZIMUTH=180.0 ELEVATION= 90.0 HORIZONTAL SIDE= 16.00 OTHER SIDE= 16.00
           NUMBER 2 AZIMUTH=270.0 ELEVATION= 90.0 HORIZONTAL SIDE= 12.80 OTHER SIDE= 12.80
           NUMBER 3 AZIMUTH=360.0 ELEVATION= 90.0 HORIZONTAL SIDE=  9.60 OTHER SIDE=  9.60
           NUMBER 4 AZIMUTH=450.0 ELEVATION= 90.0 HORIZONTAL SIDE= 12.80 OTHER SIDE= 12.80
             THE 1 AZIMUTAL ZONES  ANGLE=   0.0 ARE AIMED AT 1 APERTURES - NO.= 1 WT= 1.00, NO.=
             THE 2 AZIMUTAL ZONES  ANGLE=  30.0 ARE AIMED AT 1 APERTURES - NO.= 1 WT= 1.00, NO.=
             THE 3 AZIMUTAL ZONES  ANGLE=  60.0 ARE AIMED AT 1 APERTURES - NO.= 2 WT= 1.00, NO.=
             THE 4 AZIMUTAL ZONES  ANGLE=  90.0 ARE AIMED AT 1 APERTURES - NO.= 2 WT= 1.00, NO.=
             THE 5 AZIMUTAL ZONES  ANGLE= 120.0 ARE AIMED AT 1 APERTURES - NO.= 2 WT= 1.00, NO.=
             THE 6 AZIMUTAL ZONES  ANGLE= 150.0 ARE AIMED AT 1 APERTURES - NO.= 3 WT= 1.00, NO.=
             THE 7 AZIMUTAL ZONES  ANGLE= 180.0 ARE AIMED AT 1 APERTURES - NO.= 3 WT= 1.00, NO.=
             THE 8 AZIMUTAL ZONES  ANGLE= 210.0 ARE AIMED AT 1 APERTURES - NO.= 3 WT= 1.00, NO.=
             THE 9 AZIMUTAL ZONES  ANGLE= 240.0 ARE AIMED AT 1 APERTURES - NO.= 4 WT= 1.00, NO.=
             THE10 AZIMUTAL ZONES  ANGLE= 270.0 ARE AIMED AT 1 APERTURES - NO.= 4 WT= 1.00, NO.=
             THE11 AZIMUTAL ZONES  ANGLE= 300.0 ARE AIMED AT 1 APERTURES - NO.= 4 WT= 1.00, NO.=
             THE12 AZIMUTAL ZONES  ANGLE= 330.0 ARE AIMED AT 1 APERTURES - NO.= 1 WT= 1.00, NO.=

   THE CODE WILL AUTOMATICALLY CALCULATE A 2 DIMENSIONAL SMART AIMING FOR EACH ZONE AT EACH TIME STEP
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                    FLUX CALCULATION



                    FLUX POINTS ON  INSIDE OF CYLINDER OF RADIUS17.50 M CENTERED AT X=  .00 Y=17.50 Z= 0.00


     SEVERAL HELIOSTATS AT DIFFERENT POSITIONS WITHIN EACH  ZONE ARE USED IN GENERATING FLUXES


       HT(M)       AZIMUTH OF NORMAL(180 = NORTH FACING)
                 135.000   157.500   180.000   202.500   225.000


       20.000     1         2         3         4         5
       13.750     6         7         8         9        10
        7.500    11        12        13        14        15
        1.250    16        17        18        19        20
       -5.000    21        22        23        24        25


                    COORDINATES OF FLUX POINTS AND ANGLES OF SURFACE NORMALS

     NUMBER      COORDINATES IN METERS          POLAR     AZIMUTHAL
                EAST      NORTH        UP       ANGLE       ANGLE
        1      12.37       5.13     20.00       90.00      135.00
        2       6.70       1.33     20.00       90.00      157.50
        3        .00       0.00     20.00       90.00      180.00
        4      -6.70       1.33     20.00       90.00      202.50
        5     -12.37       5.13     20.00       90.00      225.00
        6      12.37       5.13     13.75       90.00      135.00
        7       6.70       1.33     13.75       90.00      157.50
        8        .00       0.00     13.75       90.00      180.00
        9      -6.70       1.33     13.75       90.00      202.50
       10     -12.37       5.13     13.75       90.00      225.00
       11      12.37       5.13      7.50       90.00      135.00
       12       6.70       1.33      7.50       90.00      157.50
       13        .00       0.00      7.50       90.00      180.00
       14      -6.70       1.33      7.50       90.00      202.50
       15     -12.37       5.13      7.50       90.00      225.00
       16      12.37       5.13      1.25       90.00      135.00
       17       6.70       1.33      1.25       90.00      157.50
       18        .00       0.00      1.25       90.00      180.00
       19      -6.70       1.33      1.25       90.00      202.50
       20     -12.37       5.13      1.25       90.00      225.00
       21      12.37       5.13     -5.00       90.00      135.00
       22       6.70       1.33     -5.00       90.00      157.50
       23        .00       0.00     -5.00       90.00      180.00
       24      -6.70       1.33     -5.00       90.00      202.50
       25     -12.37       5.13     -5.00       90.00      225.00
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                         USER DEFINED FIELD


FIELD DESCRIPTION - LAND AREA(M2  )=    .391E+07 MIRROR AREA=    .849E+06  NO. OF HSTATS = 17293. AVERAGE DENSITY =  .217
        NRADMIN      1      1      1      1      1      1      1      1      1      1      1      1
        NRADMAX     12     11      9      9      7      5      5      5      7      9      9     11

HELIOSTATS ARE LAID OUT IN A RADIAL STAGGER PATTERN

                       FIELD RADIUS MAX= 7.50 MIN=  .75 STEP=  .61 TOWER HEIGHTS

      NOTE - THE UNITS OF THE RADIAL SEPARATION ARE THE NUMBER OF HELIOSTAT HEIGHTS, HM=  7.40 METERS
           - THE UNITS OF THE AZIMUTHAL SEPARATION ARE THE NUMBER OF HELIOSTAT WIDTHS, WM=  7.40 METERS

      NOTE - THE RADIUS OF THE HELIOSTAT IS GIVEN IN UNITS OF THE TOWER HEIGHT=200.00 METERS
      NOTE - MISS. H IS THE FRACTION OF THE ZONE AVAILABLE IN RADIAL LAYOUTS BECAUSE OF SLIP PLANES
      NOTE - FR LAND IS THE FRACTION OF THE LAND WITHIN A ZONE THAT IS AVAILABLE DUE TO LAND CONSTRAINTS OR FIELD TRIM

RADIUS              AZIMUTHAL ANGLE OF HELIOSTAT, NORTH=0, EAST=90
                        0.     30.     60.     90.    120.    150.    180.    210.    240.    270.    300.    330.

   .75   DENSITY      .443    .443    .443    .443    .443    .443    .443    .443    .443    .443    .443    .443
   .75   MISS. H      .945    .945    .945    .945    .945    .945    .945    .945    .945    .945    .945    .945
   .75   RAD SEP     1.634   1.634   1.634   1.634   1.634   1.634   1.634   1.634   1.634   1.634   1.634   1.634
   .75   AZM SEP     1.240   1.240   1.240   1.240   1.240   1.240   1.240   1.240   1.240   1.240   1.240   1.240
   .75   FR LAND     1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
   .75   FIELDWT      .003    .003    .003    .003    .003    .003    .003    .003    .003    .003    .003    .003
   .75   HSTATS      49.4    49.4    49.4    49.4    49.4    49.4    49.4    49.4    49.4    49.4    49.4    49.4

  1.36   DENSITY      .407    .407    .407    .407    .407    .407    .407    .407    .407    .407    .407    .407
  1.36   MISS. H      .961    .961    .961    .961    .961    .961    .961    .961    .961    .961    .961    .961
  1.36   RAD SEP     1.942   1.942   1.942   1.942   1.942   1.942   1.942   1.942   1.942   1.942   1.942   1.942
  1.36   AZM SEP     1.134   1.134   1.134   1.134   1.134   1.134   1.134   1.134   1.134   1.134   1.134   1.134
  1.36   FR LAND     1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
  1.36   FIELDWT      .008    .008    .008    .008    .008    .008    .008    .008    .008    .008    .008    .008
  1.36   HSTATS     139.7   139.7   139.7   139.7   139.7   139.7   139.7   139.7   139.7   139.7   139.7   139.7

  1.98   DENSITY      .355    .355    .355    .355    .355    .355    .355    .355    .355    .355    .355    .355
  1.98   MISS. H      .967    .967    .967    .967    .967    .967    .967    .967    .967    .967    .967    .967
  1.98   RAD SEP     2.329   2.329   2.329   2.329   2.329   2.329   2.329   2.329   2.329   2.329   2.329   2.329
  1.98   AZM SEP     1.084   1.084   1.084   1.084   1.084   1.084   1.084   1.084   1.084   1.084   1.084   1.084
  1.98   FR LAND     1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
  1.98   FIELDWT      .010    .010    .010    .010    .010    .010    .010    .010    .010    .010    .010    .010
  1.98   HSTATS     177.7   177.7   177.7   177.7   177.7   177.7   177.7   177.7   177.7   177.7   177.7   177.7

  2.59   DENSITY      .302    .302    .302    .302    .302    .302    .302    .302    .302    .302    .302    .302
  2.59   MISS. H      .969    .969    .969    .969    .969    .969    .969    .969    .969    .969    .969    .969
  2.59   RAD SEP     2.803   2.803   2.803   2.803   2.803   2.803   2.803   2.803   2.803   2.803   2.803   2.803
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2.59     AZM SEP     1.060    1.060    1.060    1.060    1.060    1.060    1.060    1.060    1.060    1.060    1.060    1.060
2.59     FR LAND     1.000    1.000    1.000    1.000    1.000    1.000    1.000    1.000    1.000    1.000    1.000    1.000
2.59     FIELDWT      .011     .011     .011     .011     .011     .011     .011     .011     .011     .011     .011     .011
2.59     HSTATS     198.4    198.4    198.4    198.4    198.4    198.4    198.4    198.4    198.4    198.4    198.4    198.4


3.20     DENSITY      .256     .256     .256     .256     .256     .256     .256     .256     .256     .256     .256     .256
3.20     MISS. H      .970     .970     .970     .970     .970     .970     .970     .970     .970     .970     .970     .970
3.20     RAD SEP     3.337    3.337    3.337    3.337    3.337    3.337    3.337    3.337    3.337    3.337    3.337    3.337
3.20     AZM SEP     1.049    1.049    1.049    1.049    1.049    1.049    1.049    1.049    1.049    1.049    1.049    1.049
3.20     FR LAND     1.000    1.000    1.000    1.000    1.000    1.000    1.000    1.000    1.000    1.000    1.000    1.000
3.20     FIELDWT      .012     .012     .012     .012     .012     .012     .012     .012     .012     .012     .012     .012
3.20     HSTATS     208.5    208.5    208.5    208.5    208.5    208.5    208.5    208.5    208.5    208.5    208.5    208.5


3.82     DENSITY      .219     .219     .219     .219     .219     .219     .219     .219     .219     .219     .219     .219
3.82     MISS. H      .971     .971     .971     .971     .971     .971     .971     .971     .971     .971     .971     .971
3.82     RAD SEP     3.910    3.910    3.910    3.910    3.910    3.910    3.910    3.910    3.910    3.910    3.910    3.910
3.82     AZM SEP     1.046    1.046    1.046    1.046    1.046    1.046    1.046    1.046    1.046    1.046    1.046    1.046
3.82     FR LAND     1.000    1.000    1.000    1.000    1.000     .000     .000     .000    1.000    1.000    1.000    1.000
3.82     FIELDWT      .012     .012     .012     .012     .012    0.000    0.000    0.000     .012     .012     .012     .012
3.82     HSTATS     212.8    212.8    212.8    212.8    212.8       .0       .0       .0    212.8    212.8    212.8    212.8


4.43     DENSITY      .190     .190     .190     .190     .190     .190     .190     .190     .190     .190     .190     .190
4.43     MISS. H      .971     .971     .971     .971     .971     .971     .971     .971     .971     .971     .971     .971
4.43     RAD SEP     4.510    4.510    4.510    4.510    4.510    4.510    4.510    4.510    4.510    4.510    4.510    4.510
4.43     AZM SEP     1.048    1.048    1.048    1.048    1.048    1.048    1.048    1.048    1.048    1.048    1.048    1.048
4.43     FR LAND     1.000    1.000    1.000    1.000    1.000     .000     .000     .000    1.000    1.000    1.000    1.000
4.43     FIELDWT      .012     .012     .012     .012     .012    0.000    0.000    0.000     .012     .012     .012     .012
4.43     HSTATS     213.7    213.7    213.7    213.7    213.7       .0       .0       .0    213.7    213.7    213.7    213.7


5.05     DENSITY      .166     .166     .166     .166     .166     .166     .166     .166     .166     .166     .166     .166
5.05     MISS. H      .971     .971     .971     .971     .971     .971     .971     .971     .971     .971     .971     .971
5.05     RAD SEP     5.128    5.128    5.128    5.128    5.128    5.128    5.128    5.128    5.128    5.128    5.128    5.128
5.05     AZM SEP     1.054    1.054    1.054    1.054    1.054    1.054    1.054    1.054    1.054    1.054    1.054    1.054
5.05     FR LAND     1.000    1.000    1.000    1.000     .000     .000     .000     .000     .000    1.000    1.000    1.000
5.05     FIELDWT      .012     .012     .012     .012    0.000    0.000    0.000    0.000    0.000     .012     .012     .012
5.05     HSTATS     212.8    212.8    212.8    212.8       .0       .0       .0       .0       .0    212.8    212.8    212.8


5.66     DENSITY      .147     .147     .147     .147     .147     .147     .147     .147     .147     .147     .147     .147
5.66     MISS. H      .971     .971     .971     .971     .971     .971     .971     .971     .971     .971     .971     .971
5.66     RAD SEP     5.760    5.760    5.760    5.760    5.760    5.760    5.760    5.760    5.760    5.760    5.760    5.760
5.66     AZM SEP     1.063    1.063    1.063    1.063    1.063    1.063    1.063    1.063    1.063    1.063    1.063    1.063
5.66     FR LAND     1.000    1.000    1.000     .692     .000     .000     .000     .000     .000     .692    1.000    1.000
5.66     FIELDWT      .012     .012     .012     .008    0.000    0.000    0.000    0.000    0.000     .008     .012     .012
5.66     HSTATS     210.7    210.7    210.7    145.9       .0       .0       .0       .0       .0    145.9    210.7    210.7


6.27     DENSITY      .130     .130     .130     .130     .130     .130     .130     .130     .130     .130     .130     .130
6.27     MISS. H      .971     .971     .971     .971     .971     .971     .971     .971     .971     .971     .971     .971
6.27     RAD SEP     6.401    6.401    6.401    6.401    6.401    6.401    6.401    6.401    6.401    6.401    6.401    6.401
6.27     AZM SEP     1.074    1.074    1.074    1.074    1.074    1.074    1.074    1.074    1.074    1.074    1.074    1.074
6.27     FR LAND     1.000    1.000     .000     .000     .000     .000     .000     .000     .000     .000     .000    1.000
6.27     FIELDWT      .012     .012    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000     .012
6.27     HSTATS     207.8    207.8       .0       .0       .0       .0       .0       .0       .0       .0       .0    207.8


6.89     DENSITY      .117     .117     .117     .117     .117     .117     .117     .117     .117     .117     .117     .117
6.89     MISS. H      .971     .971     .971     .971     .971     .971     .971     .971     .971     .971     .971     .971
6.89     RAD SEP     7.050    7.050    7.050    7.050    7.050    7.050    7.050    7.050    7.050    7.050    7.050    7.050
6.89     AZM SEP     1.089    1.089    1.089    1.089    1.089    1.089    1.089    1.089    1.089    1.089    1.089    1.089
6.89     FR LAND     1.000    1.000     .000     .000     .000     .000     .000     .000     .000     .000     .000    1.000
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6.89   HSTATS     204.4   204.4      .0      .0      .0      .0      .0      .0      .0      .0      .0   204.4

7.50   DENSITY     .105    .105    .105    .105    .105    .105    .105    .105    .105    .105    .105    .105
7.50   MISS. H     .971    .971    .971    .971    .971    .971    .971    .971    .971    .971    .971    .971
7.50   RAD SEP    7.705   7.705   7.705   7.705   7.705   7.705   7.705   7.705   7.705   7.705   7.705   7.705
7.50   AZM SEP    1.105   1.105   1.105   1.105   1.105   1.105   1.105   1.105   1.105   1.105   1.105   1.105
7.50   FR LAND    1.000    .000    .000    .000    .000    .000    .000    .000    .000    .000    .000    .000
7.50   FIELDWT     .006   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
7.50   HSTATS     98.3      .0      .0      .0      .0      .0      .0      .0      .0      .0      .0      .0
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                    INSOLATION AND SUN POSITION


INSOLATION CALCULATED USING MEINEL   MODEL


DAY OF THE YEAR =354.750  DECLINATION OF SUN (DEG)= -23.44 DAILY CLEAR SKY INSOLATION (KWH/M2)=   5.25
                    THE AVERAGE CORRECTION TO CLEAR SKY INSOLATION TO ACCOUNT FOR CLOUDINESS=  .830
                     MM OF WATER=  20.00 ATMOSPHERIC PRESSURE/SEA LEVEL=  1.000

     TIME =  0.0  INSOLATION(KW/M2)=   .858 TRUE ZENITH ANGLE =  58.44  OBSERVED ZENITH=  58.41 SUN AZIMUTH =   0.00
     TIME =  1.0  INSOLATION(KW/M2)=   .844 TRUE ZENITH ANGLE =  60.15  OBSERVED ZENITH=  60.12 SUN AZIMUTH =  15.89
     TIME =  2.0  INSOLATION(KW/M2)=   .797 TRUE ZENITH ANGLE =  64.99  OBSERVED ZENITH=  64.96 SUN AZIMUTH =  30.41
     TIME =  3.0  INSOLATION(KW/M2)=   .697 TRUE ZENITH ANGLE =  72.35  OBSERVED ZENITH=  72.29 SUN AZIMUTH =  42.91
     TIME =  3.3  INSOLATION(KW/M2)=   .648 TRUE ZENITH ANGLE =  75.00  OBSERVED ZENITH=  74.94 SUN AZIMUTH =  46.34

DAY OF THE YEAR = 35.375  DECLINATION OF SUN (DEG)= -16.09 DAILY CLEAR SKY INSOLATION (KWH/M2)=   6.36
                    THE AVERAGE CORRECTION TO CLEAR SKY INSOLATION TO ACCOUNT FOR CLOUDINESS=  .830
                     MM OF WATER=  20.00 ATMOSPHERIC PRESSURE/SEA LEVEL=  1.000

     TIME =  0.0  INSOLATION(KW/M2)=   .898 TRUE ZENITH ANGLE =  51.09  OBSERVED ZENITH=  51.07 SUN AZIMUTH =   0.00
     TIME =  1.0  INSOLATION(KW/M2)=   .887 TRUE ZENITH ANGLE =  53.04  OBSERVED ZENITH=  53.02 SUN AZIMUTH =  18.13
     TIME =  2.0  INSOLATION(KW/M2)=   .849 TRUE ZENITH ANGLE =  58.49  OBSERVED ZENITH=  58.46 SUN AZIMUTH =  34.30
     TIME =  3.0  INSOLATION(KW/M2)=   .772 TRUE ZENITH ANGLE =  66.57  OBSERVED ZENITH=  66.53 SUN AZIMUTH =  47.77
     TIME =  3.9  INSOLATION(KW/M2)=   .642 TRUE ZENITH ANGLE =  75.00  OBSERVED ZENITH=  74.94 SUN AZIMUTH =  57.46

DAY OF THE YEAR = 81.000  DECLINATION OF SUN (DEG)=     .65 DAILY CLEAR SKY INSOLATION (KWH/M2)=   8.24
                    THE AVERAGE CORRECTION TO CLEAR SKY INSOLATION TO ACCOUNT FOR CLOUDINESS=  .830
                     MM OF WATER=  20.00 ATMOSPHERIC PRESSURE/SEA LEVEL=  1.000

     TIME =  0.0  INSOLATION(KW/M2)=   .942 TRUE ZENITH ANGLE =  34.35  OBSERVED ZENITH=  34.34 SUN AZIMUTH =   0.00
     TIME =  1.0  INSOLATION(KW/M2)=   .934 TRUE ZENITH ANGLE =  37.09  OBSERVED ZENITH=  37.07 SUN AZIMUTH =  25.42
     TIME =  2.0  INSOLATION(KW/M2)=   .909 TRUE ZENITH ANGLE =  44.28  OBSERVED ZENITH=  44.27 SUN AZIMUTH =  45.73
     TIME =  3.0  INSOLATION(KW/M2)=   .860 TRUE ZENITH ANGLE =  54.15  OBSERVED ZENITH=  54.12 SUN AZIMUTH =  60.74
     TIME =  4.0  INSOLATION(KW/M2)=   .767 TRUE ZENITH ANGLE =  65.41  OBSERVED ZENITH=  65.38 SUN AZIMUTH =  72.24
     TIME =  4.8  INSOLATION(KW/M2)=   .627 TRUE ZENITH ANGLE =  75.00  OBSERVED ZENITH=  74.94 SUN AZIMUTH =  80.03

DAY OF THE YEAR =126.625  DECLINATION OF SUN (DEG)=  16.72 DAILY CLEAR SKY INSOLATION (KWH/M2)=   9.55
                    THE AVERAGE CORRECTION TO CLEAR SKY INSOLATION TO ACCOUNT FOR CLOUDINESS=  .830
                     MM OF WATER=  20.00 ATMOSPHERIC PRESSURE/SEA LEVEL=  1.000

     TIME =  0.0  INSOLATION(KW/M2)=   .950 TRUE ZENITH ANGLE =  18.28  OBSERVED ZENITH=  18.27 SUN AZIMUTH =   0.00
     TIME =  1.0  INSOLATION(KW/M2)=   .944 TRUE ZENITH ANGLE =  22.66  OBSERVED ZENITH=  22.65 SUN AZIMUTH =  40.05
     TIME =  2.0  INSOLATION(KW/M2)=   .925 TRUE ZENITH ANGLE =  32.39  OBSERVED ZENITH=  32.38 SUN AZIMUTH =  63.38
     TIME =  3.0  INSOLATION(KW/M2)=   .889 TRUE ZENITH ANGLE =  43.96  OBSERVED ZENITH=  43.95 SUN AZIMUTH =  77.29
     TIME =  4.0  INSOLATION(KW/M2)=   .827 TRUE ZENITH ANGLE =  56.13  OBSERVED ZENITH=  56.11 SUN AZIMUTH =  87.31
     TIME =  5.0  INSOLATION(KW/M2)=   .715 TRUE ZENITH ANGLE =  68.40  OBSERVED ZENITH=  68.36 SUN AZIMUTH =  95.78
     TIME =  5.5  INSOLATION(KW/M2)=   .612 TRUE ZENITH ANGLE =  75.00  OBSERVED ZENITH=  74.94 SUN AZIMUTH = 100.14

DAY OF THE YEAR =172.250  DECLINATION OF SUN (DEG)=  23.44 DAILY CLEAR SKY INSOLATION (KWH/M2)=  10.02
                    THE AVERAGE CORRECTION TO CLEAR SKY INSOLATION TO ACCOUNT FOR CLOUDINESS=  .830
                     MM OF WATER=  20.00 ATMOSPHERIC PRESSURE/SEA LEVEL=  1.000

     TIME =  0.0  INSOLATION(KW/M2)=   .947 TRUE ZENITH ANGLE =  11.56  OBSERVED ZENITH=  11.55 SUN AZIMUTH =   0.00
     TIME =  1.0  INSOLATION(KW/M2)=   .941 TRUE ZENITH ANGLE =  17.42  OBSERVED ZENITH=  17.42 SUN AZIMUTH =  52.47
     TIME =  2.0  INSOLATION(KW/M2)=   .924 TRUE ZENITH ANGLE =  28.47  OBSERVED ZENITH=  28.47 SUN AZIMUTH =  74.19
     TIME =  3.0  INSOLATION(KW/M2)=   .892 TRUE ZENITH ANGLE =  40.57  OBSERVED ZENITH=  40.56 SUN AZIMUTH =  85.92
     TIME =  4.0  INSOLATION(KW/M2)=   .838 TRUE ZENITH ANGLE =  52.85  OBSERVED ZENITH=  52.83 SUN AZIMUTH =  94.52
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         TIME =  5.8  INSOLATION(KW/M2)=   .516 TRUE ZENITH ANGLE =  75.08  OBSERVER ZENITH=  74.94 SUN AZIMUTH = 108.37

    YEARLY INSOLATION (KWATT-HOUR/M2)    - CLEAR SKY = 2902.1  TIMES WEATHER FACTOR OF .83 GIVES NET OF 2408.7


    HRS OPERATION PER YEAR= .2847E+04
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                        YEARLY AVERAGE PERFORMANCE


PERFORMANCE FOR 125 MWE SYSTEM


 TOTAL PERFORMANCE INCLUDES REFLECTIVITIES BUT NOT RADIATION AND CONVECTION LOSSES




RADIUS              AZIMUTHAL ANGLE OF HELIOSTAT, NORTH=0, EAST=90
                           0.      30.      60.      90.     120.     150.     180.
  .75    COSINE          .930     .919     .901     .868     .835     .819     .811
  .75    SPILL           .990     .968     .917     .958     .921     .797     .868
  .75    ATTEN           .969     .969     .969     .969     .969     .969     .969
  .75    SHADOW          .912     .896     .911     .914     .940     .942     .950
  .75    BLOCK          1.000    1.000    1.000    1.000    1.000    1.000    1.000
  .75    TOTAL           .710     .673     .636     .642     .611     .519     .566

 1.36    COSINE          .915     .900     .869     .821     .774     .747     .737
 1.36    SPILL           .997     .995     .992     .996     .992     .946     .974
 1.36    ATTEN           .961     .961     .961     .961     .961     .961     .961
 1.36    SHADOW          .920     .917     .924     .930     .944     .953     .958
 1.36    BLOCK           .997     .998     .998     .998     .997     .998    1.000
 1.36    TOTAL           .702     .686     .666     .636     .605     .564     .576

 1.98    COSINE          .898     .881     .843     .786     .733     .701     .689
 1.98    SPILL           .995     .994     .992     .994     .992     .952     .977
 1.98    ATTEN           .951     .951     .951     .951     .951     .951     .951
 1.98    SHADOW          .930     .949     .941     .947     .956     .965     .977
 1.98    BLOCK           .992     .994     .994     .994     .993     .992     .993
 1.98    TOTAL           .685     .685     .649     .611     .573     .531     .543

 2.59    COSINE          .885     .867     .825     .763     .706     .672     .659
 2.59    SPILL           .994     .993     .987     .992     .989     .932     .963
 2.59    ATTEN           .941     .941     .941     .941     .941     .941     .941
 2.59    SHADOW          .951     .969     .959     .966     .971     .976     .983
 2.59    BLOCK           .991     .992     .992     .991     .990     .988     .988
 2.59    TOTAL           .681     .679     .636     .596     .551     .496     .506

 3.20    COSINE          .876     .857     .812     .748     .688     .652     .639
 3.20    SPILL           .993     .992     .976     .987     .979     .894     .934
 3.20    ATTEN           .931     .931     .931     .931     .931     .931     .931
 3.20    SHADOW          .972     .978     .975     .976     .979     .983     .983
 3.20    BLOCK           .991     .991     .991     .991     .989     .986     .986
 3.20    TOTAL           .680     .669     .621     .580     .530     .459     .470

 3.82    COSINE          .868     .849     .802     .736     .675    0.000    0.000
 3.82    SPILL           .992     .988     .952     .974     .959    0.000    0.000
 3.82    ATTEN           .921     .921     .921     .921     .921     .921     .921
 3.82    SHADOW          .982     .982     .985     .986     .984    0.000    0.000
 3.82    BLOCK           .993     .992     .992     .991     .990    0.000    0.000
 3.82    TOTAL           .675     .657     .599     .563     .507    0.000    0.000
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 4.43   SPILL          .987    .978    .913    .947    .924   0.000   0.000
 4.43   ATTEN          .911    .911    .911    .911    .911    .911    .911
 4.43   SHADOW         .986    .986    .992    .992    .989   0.000   0.000
 4.43   BLOCK          .994    .994    .993    .993    .991   0.000   0.000
 4.43   TOTAL          .664    .642    .569    .539    .479   0.000   0.000


 5.05   COSINE         .858    .839    .789    .721   0.000   0.000   0.000
 5.05   SPILL          .974    .955    .862    .907   0.000   0.000   0.000
 5.05   ATTEN          .902    .902    .902    .902    .902    .902    .902
 5.05   SHADOW         .987    .989    .995    .995   0.000   0.000   0.000
 5.05   BLOCK          .996    .995    .994    .994   0.000   0.000   0.000
 5.05   TOTAL          .647    .620    .529    .508   0.000   0.000   0.000


 5.66   COSINE         .855    .835    .785    .715   0.000   0.000   0.000
 5.66   SPILL          .949    .921    .801    .855   0.000   0.000   0.000
 5.66   ATTEN          .892    .892    .892    .892    .892    .892    .892
 5.66   SHADOW         .988    .991    .996    .997   0.000   0.000   0.000
 5.66   BLOCK          .998    .997    .995    .995   0.000   0.000   0.000
 5.66   TOTAL          .622    .591    .485    .472   0.000   0.000   0.000


 6.27   COSINE         .852    .832   0.000   0.000   0.000   0.000   0.000
 6.27   SPILL          .914    .876   0.000   0.000   0.000   0.000   0.000
 6.27   ATTEN          .883    .883    .883    .883    .883    .883    .883
 6.27   SHADOW         .989    .992   0.000   0.000   0.000   0.000   0.000
 6.27   BLOCK          .999    .998   0.000   0.000   0.000   0.000   0.000
 6.27   TOTAL          .592    .556   0.000   0.000   0.000   0.000   0.000


 6.89   COSINE         .850    .830   0.000   0.000   0.000   0.000   0.000
 6.89   SPILL          .869    .825   0.000   0.000   0.000   0.000   0.000
 6.89   ATTEN          .874    .874    .874    .874    .874    .874    .874
 6.89   SHADOW         .989    .993   0.000   0.000   0.000   0.000   0.000
 6.89   BLOCK         1.000    .999   0.000   0.000   0.000   0.000   0.000
 6.89   TOTAL          .557    .518   0.000   0.000   0.000   0.000   0.000


 7.50   COSINE         .848   0.000   0.000   0.000   0.000   0.000   0.000
 7.50   SPILL          .820   0.000   0.000   0.000   0.000   0.000   0.000
 7.50   ATTEN          .865    .865    .865    .865    .865    .865    .865
 7.50   SHADOW         .990   0.000   0.000   0.000   0.000   0.000   0.000
 7.50   BLOCK         1.000   0.000   0.000   0.000   0.000   0.000   0.000
 7.50   TOTAL          .519   0.000   0.000   0.000   0.000   0.000   0.000
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                    PERFORMANCE SUMMARY FROM USER DEFINED FIELD


            OPTICAL EFFICIENCY


      TOTAL EFFICIENCY INCLUDES REFLECTIVITIES, HELIOSTAT =  .890  RECEIVER =  .980


        DAY         HOUR      COSINE      SHADOW       BLOCK   ATM.TRANS.  SPILLAGE    TOTAL
      354.75        0.00        .810        .979        .999        .924        .949        .606
      354.75        1.00        .805        .972        .999        .924        .948        .597
      354.75        2.00        .790        .939        .999        .923        .947        .565
      354.75        3.00        .764        .856        .997        .922        .943        .495
      354.75        3.31        .755        .809        .996        .922        .942        .461

      354.75     AVERAGE        .792        .938        .998        .923        .947        .566

       35.38        0.00        .820        .994        .996        .925        .950        .622
       35.38        1.00        .814        .992        .997        .925        .950        .617
       35.38        2.00        .798        .980        .999        .925        .949        .598
       35.38        3.00        .772        .928        .998        .924        .946        .545
       35.38        3.86        .742        .793        .997        .922        .941        .444

       35.38     AVERAGE        .795        .959        .997        .924        .948        .581

       81.00        0.00        .832       1.000        .988        .926        .952        .632
       81.00        1.00        .826       1.000        .990        .926        .952        .629
       81.00        2.00        .810        .999        .993        .926        .951        .617
       81.00        3.00        .782        .991        .997        .926        .949        .593
       81.00        4.00        .746        .942        .998        .925        .946        .535
       81.00        4.80        .711        .799        .997        .924        .943        .430

       81.00     AVERAGE        .794        .978        .994        .926        .950        .591

      126.63        0.00        .832       1.000        .988        .927        .954        .633
      126.63        1.00        .826       1.000        .986        .927        .953        .628
      126.63        2.00        .810       1.000        .988        .927        .952        .616
      126.63        3.00        .784        .999        .993        .927        .951        .598
      126.63        4.00        .749        .985        .998        .927        .949        .565
      126.63        5.00        .707        .892        .998        .926        .946        .481
      126.63        5.54        .682        .802        .997        .925        .944        .415

      126.63     AVERAGE        .784        .980        .991        .927        .951        .585

      172.25        0.00        .828       1.000        .992        .927        .954        .634
      172.25        1.00        .823       1.000        .988        .927        .954        .627
      172.25        2.00        .807       1.000        .986        .927        .953        .613
      172.25        3.00        .782        .999        .991        .927        .951        .596
      172.25        4.00        .749        .992        .997        .927        .950        .569
      172.25        5.00        .709        .941        .998        .926        .947        .510
      172.25        5.84        .671        .803        .996        .925        .945        .409

      172.25     AVERAGE        .777        .983        .992        .927        .951        .583


         YEARLY AVERAGE         .788        .972        .994        .926        .950        .584
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                    ----- DESIGN POINT -----

 DAY=   81.00 TIME=    0.00 INSOLATION =   .950 KW/M2

GROSS POWER ONTO RECEIVER               520.768 MW-TH

REFLECTIVITY LOSS                        10.415 MW-TH
RADIATION/CONVECTION LOSS                20.153 MW-TH
PIPING LOSSES                             2.649 MW-TH

THERMAL POWER TOWER BASE                487.550 MW-TH

POWER TO STORAGE                        162.517 MW-TH

POWER TO TURBINE                        325.033 MW-TH
  THERM. TO ELEC. EFF.                     .420
GROSS ELECTRIC POWER                    136.514 MW-EL
ELECTRICAL PARASITICS                     8.873 MW-EL

NET ELECTRIC POWER                      127.641 MW-EL
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                  ANNUAL POWER PRODUCTION FROM USER DEFINED FIELD

THE DISPATCH STRATEGY FOR STORAGE IS TO RUN THE TURBINE AT ITS DESIGN POINT POWER WHENEVER POSSIBLE

ALL POWERS ARE IN MEGAWATT-THERMAL OR MEGAWATT ELECTRIC
INSOLATION UNITS ARE KILOWATTS/SQ.METER

THE STORAGE POWER HAS A NEGATIVE SIGN WHEN CHARGING AND A POSITIVE SIGN WHEN DISCHARGING

THE OPTIMUM STORAGE CAPACITY IS APPROXIMATELY 1.00 TIMES THE MAXIMUM SIZE
  TOTAL CAPITAL COST = 228.29(M$,1ST YR OPERATION)          TOTAL CAPITAL COST = 228.29(M$,CURRENT $)
  LEVELIZED ENERGY COST = 101.52 MILLS/KWHR       LEVELIZED ENERGY COST = 101.52 MILLS/KWHR(CURRENT $)

  DAY        HOUR     INSOL.   REC. PWR.   TWR. PWR.   STR. PWR.   HR. STR.    TURB. PWR.  GROSS EL.   EL. PAR.    NET EL.
 354.75     -3.250    .657    260.882     238.079       0.000       0.000     238.079      94.994     15.475      79.518
 354.75     -3.000    .697    293.125     270.322       0.000       0.000     270.322     107.859     17.571      90.288
 354.75     -2.750    .722    314.372     291.569       0.000       0.000     291.569     115.336     18.952      97.384
 354.75     -2.500    .747    336.362     313.560       0.000       0.000     313.560     125.110     20.381     104.729
 354.75     -2.250    .772    359.096     336.293      11.260        .002     325.033     136.514     21.127     115.387
 354.75     -2.000    .797    382.573     359.770      34.737        .020     325.033     136.514     21.127     115.387
 354.75     -1.750    .809    393.777     370.975      45.941        .051     325.033     136.514     21.127     115.387
 354.75     -1.500    .821    405.143     382.341      57.307        .091     325.033     136.514     21.127     115.387
 354.75     -1.250    .832    416.671     393.868      68.835        .139     325.033     136.514     21.127     115.387
 354.75     -1.000    .844    428.360     405.558      80.524        .197     325.033     136.514     21.127     115.387
 354.75      -.750    .847    431.694     408.891      83.858        .260     325.033     136.514     21.127     115.387
 354.75      -.500    .851    435.041     412.238      87.205        .326     325.033     136.514     21.127     115.387
 354.75      -.250    .854    438.400     415.598      90.564        .394     325.033     136.514     21.127     115.387
 354.75      0.000    .858    441.773     418.970      93.937        .465     325.033     136.514     21.127     115.387
 354.75       .250    .854    438.400     415.598      90.564        .536     325.033     136.514     21.127     115.387
 354.75       .500    .851    435.041     412.238      87.205        .604     325.033     136.514     21.127     115.387
 354.75       .750    .847    431.694     408.891      83.858        .670     325.033     136.514     21.127     115.387
 354.75      1.000    .844    428.360     405.558      80.524        .733     325.033     136.514     21.127     115.387
 354.75      1.250    .832    416.671     393.868      68.835        .791     325.033     136.514     21.127     115.387
 354.75      1.500    .821    405.143     382.341      57.307        .839     325.033     136.514     21.127     115.387
 354.75      1.750    .809    393.777     370.975      45.941        .879     325.033     136.514     21.127     115.387
 354.75      2.000    .797    382.573     359.770      34.737        .910     325.033     136.514     21.127     115.387
 354.75      2.250    .772    359.096     336.293      11.260        .928     325.033     136.514     21.127     115.387
 354.75      2.500    .747    336.362     313.560     -11.474        .923     325.033     136.514     35.071     101.443
 354.75      2.750    .722    314.372     291.569     -33.464        .906     325.033     136.514     35.071     101.443
 354.75      3.000    .697    293.125     270.322     -54.711        .872     325.033     136.514     35.071     101.443
 354.75      3.250    .657    260.882     238.079     -86.954        .817     325.033     136.514     35.071     101.443
 354.75      3.307    .648    253.735     230.932     -94.101        .801     325.033     136.514     35.071     101.443
 354.75      4.090   0.000      0.000       0.000     325.033       0.000     325.033     133.352      5.721     127.641


  35.38     -3.750    .659    255.850     233.047       0.000       0.000     233.047      92.936     15.148      77.838
  35.38     -3.500    .697    287.799     264.996       0.000       0.000     264.996     105.734     17.225      88.509
  35.38     -3.250    .734    321.622     298.819       0.000       0.000     298.819     119.229     19.423      99.806
  35.38     -3.000    .772    357.319     334.517       9.483        .001     325.033     136.514     21.127     115.387
  35.38     -2.750    .791    375.125     352.322      27.289        .015     325.033     136.514     21.127     115.387
  35.38     -2.500    .811    393.363     370.561      45.527        .043     325.033     136.514     21.127     115.387
  35.38     -2.250    .830    412.034     389.232      64.198        .085     325.033     136.514     21.127     115.387
  35.38     -2.000    .849    431.138     408.336      83.302        .142     325.033     136.514     21.127     115.387
  35.38     -1.750    .859    439.415     416.613      91.579        .209     325.033     136.514     21.127     115.387
  35.38     -1.500    .868    447.769     424.967      99.933        .283     325.033     136.514     21.127     115.387
  35.38     -1.250    .877    456.200     433.398     108.364        .363     325.033     136.514     21.127     115.387
  35.38     -1.000    .887    464.708     441.905     116.872        .450     325.033     136.514     21.127     115.387
  35.38      -.750    .890    467.213     444.410     119.377        .541     325.033     136.514     21.127     115.387
  35.38      -.500    .892    469.724     446.921     121.888        .633     325.033     136.514     21.127     115.387
  35.38      -.250    .895    472.242     449.439     124.406        .728     325.033     136.514     21.127     115.387
  35.38      0.000    .898    474.766     451.963     126.930        .825     325.033     136.514     21.127     115.387
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   35.38      .500     .892    469.724    446.921    121.888      1.016    325.033   136.514    21.127    115.387
   35.38      .750     .890    467.213    444.410    119.377      1.109    325.033   136.514    21.127    115.387
   35.38     1.000     .887    464.708    441.905    116.872      1.200    325.033   136.514    21.127    115.387
   35.38     1.250     .877    456.201    433.398    108.364      1.286    325.033   136.514    21.127    115.387
   35.38     1.500     .868    447.769    424.967     99.933      1.366    325.033   136.514    21.127    115.387
   35.38     1.750     .859    439.415    416.613     91.579      1.440    325.033   136.514    21.127    115.387
   35.38     2.000     .849    431.138    408.336     83.302      1.507    325.033   136.514    21.127    115.387
   35.38     2.250     .830    412.034    389.232     64.198      1.564    325.033   136.514    21.127    115.387
   35.38     2.500     .811    393.363    370.561     45.527      1.606    325.033   136.514    21.127    115.387
   35.38     2.750     .791    375.125    352.322     27.289      1.634    325.033   136.514    21.127    115.387
   35.38     3.000     .772    357.319    334.517      9.483      1.648    325.033   136.514    21.127    115.387
   35.38     3.250     .734    321.622    298.819    -26.214      1.638    325.033   136.514    35.071    101.443
   35.38     3.500     .697    287.799    264.996    -61.037      1.605    325.033   136.514    35.071    101.443
   35.38     3.750     .659    255.850    233.047    -91.986      1.547    325.033   136.514    35.071    101.443
   35.38     3.863     .642    242.068    219.266   -105.768      1.512    325.033   136.514    35.071    101.443
   35.38     5.340    0.000      0.000      0.000    325.033      0.000    325.033   133.362     5.721    127.641


   81.00    -4.750     .636    236.343    213.541      0.000      0.000    213.541    85.203    13.880     71.323
   81.00    -4.500     .680    271.416    248.613      0.000      0.000    248.613    99.197    16.160     83.037
   81.00    -4.250     .724    308.910    286.107      0.000      0.000    286.107   114.157    18.597     95.559
   81.00    -4.000     .767    348.825    326.023       .989       .000    325.033   136.514    21.127    115.387
   81.00    -3.750     .790    368.984    346.181     21.148       .009    325.033   136.514    21.127    115.387
   81.00    -3.500     .813    389.707    366.905     41.871       .033    325.033   136.514    21.127    115.387
   81.00    -3.250     .836    410.995    388.192     63.159       .073    325.033   136.514    21.127    115.387
   81.00    -3.000     .860    432.847    410.045     85.011       .130    325.033   136.514    21.127    115.387
   81.00    -2.750     .872    443.502    420.699     95.665       .200    325.033   136.514    21.127    115.387
   81.00    -2.500     .884    454.282    431.479    106.445       .277    325.033   136.514    21.127    115.387
   81.00    -2.250     .897    465.187    442.384    117.351       .363    325.033   136.514    21.127    115.387
   81.00    -2.000     .909    476.217    453.415    128.381       .458    325.033   136.514    21.127    115.387
   81.00    -1.750     .916    481.856    459.053    134.020       .559    325.033   136.514    21.127    115.387
   81.00    -1.500     .922    487.526    464.724    139.690       .664    325.033   136.514    21.127    115.387
   81.00    -1.250     .928    493.229    470.426    145.393       .774    325.033   136.514    21.127    115.387
   81.00    -1.000     .934    498.964    476.161    151.128       .888    325.033   136.514    21.127    115.387
   81.00     -.750     .936    500.773    477.971    152.937      1.005    325.033   136.514    21.127    115.387
   81.00     -.500     .938    502.586    479.784    154.750      1.123    325.033   136.514    21.127    115.387
   81.00     -.250     .940    504.403    481.600    156.567      1.243    325.033   136.514    21.127    115.387
   81.00     0.000     .942    506.222    483.419    158.386      1.364    325.033   136.514    21.127    115.387
   81.00      .250     .940    504.403    481.600    156.567      1.485    325.033   136.514    21.127    115.387
   81.00      .500     .938    502.586    479.784    154.750      1.605    325.033   136.514    21.127    115.387
   81.00      .750     .936    500.773    477.971    152.937      1.723    325.033   136.514    21.127    115.387
   81.00     1.000     .934    498.964    476.161    151.128      1.840    325.033   136.514    21.127    115.387
   81.00     1.250     .928    493.229    470.426    145.393      1.954    325.033   136.514    21.127    115.387
   81.00     1.500     .922    487.526    464.724    139.690      2.064    325.033   136.514    21.127    115.387
   81.00     1.750     .916    481.856    459.053    134.020      2.169    325.033   136.514    21.127    115.387
   81.00     2.000     .909    476.217    453.415    128.381      2.270    325.033   136.514    21.127    115.387
   81.00     2.250     .897    465.187    442.384    117.351      2.364    325.033   136.514    21.127    115.387
   81.00     2.500     .884    454.282    431.479    106.446      2.450    325.033   136.514    21.127    115.387
   81.00     2.750     .872    443.502    420.699     95.666      2.528    325.033   136.514    21.127    115.387
   81.00     3.000     .860    432.847    410.045     85.011      2.598    325.033   136.514    21.127    115.387
   81.00     3.250     .836    410.995    388.192     63.159      2.655    325.033   136.514    21.127    115.387
   81.00     3.500     .813    389.707    366.905     41.871      2.695    325.033   136.514    21.127    115.387
   81.00     3.750     .790    368.984    346.181     21.148      2.719    325.033   136.514    21.127    115.387
   81.00     4.000     .767    348.825    326.023       .989      2.728    325.033   136.514    21.127    115.387
   81.00     4.250     .724    308.910    286.107    -38.926      2.713    325.033   136.514    35.071    101.443
   81.00     4.500     .680    271.416    248.613    -76.420      2.668    325.033   136.514    35.071    101.443
   81.00     4.750     .636    236.343    213.541   -111.493      2.596    325.033   136.514    35.071    101.443
   81.00     4.804     .627    229.072    206.269   -118.764      2.577    325.033   136.514    35.071    101.443
   81.00     7.322    0.000      0.000      0.000    325.033      0.000    325.033   133.362     5.721    127.641


  126.63    -5.500     .620    221.306    198.503      0.000      0.000    198.503    79.203    12.903     66.300
  126.63    -5.250     .667    255.355    232.553      0.000      0.000    232.553    92.789    15.116     77.673
  126.63    -5.000     .715    291.838    269.036      0.000      0.000    269.036   107.345    17.487     89.858
  126.63    -4.750     .743    316.509    293.706      0.000      0.000    293.706   117.189    19.091     98.098
  126.63    -4.500     .771    342.176    319.374      0.000      0.000    319.374   127.430    20.759    106.671
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126.63   -4.250   .799   368.842   346.040    21.006    .006   325.033   136.514   21.127   115.387
126.63   -4.000   .827   396.506   373.703    48.670    .033   325.033   136.514   21.127   115.387
126.63   -3.750   .842   409.867   387.064    62.031    .076   325.033   136.514   21.127   115.387
126.63   -3.500   .858   423.446   400.643    75.610    .129   325.033   136.514   21.127   115.387
126.63   -3.250   .873   437.243   414.440    89.407    .192   325.033   136.514   21.127   115.387
126.63   -3.000   .889   451.257   428.455   103.421    .266   325.033   136.514   21.127   115.387
126.63   -2.750   .898   459.339   436.536   111.503    .349   325.033   136.514   21.127   115.387
126.63   -2.500   .907   467.490   444.687   119.654    .438   325.033   136.514   21.127   115.387
126.63   -2.250   .916   475.712   452.909   127.876    .533   325.033   136.514   21.127   115.387
126.63   -2.000   .925   484.004   461.201   136.168    .635   325.033   136.514   21.127   115.387
126.63   -1.750   .930   488.856   466.054   141.020    .741   325.033   136.514   21.127   115.387
126.63   -1.500   .934   493.732   470.930   145.896    .852   325.033   136.514   21.127   115.387
126.63   -1.250   .939   498.633   475.830   150.797    .966   325.033   136.514   21.127   115.387
126.63   -1.000   .944   503.557   480.755   155.721   1.083   325.033   136.514   21.127   115.387
126.63    -.750   .945   505.372   482.570   157.536   1.204   325.033   136.514   21.127   115.387
126.63    -.500   .947   507.190   484.387   159.354   1.326   325.033   136.514   21.127   115.387
126.63    -.250   .948   509.011   486.209   161.175   1.449   325.033   136.514   21.127   115.387
126.63    0.000   .950   510.836   488.033   163.000   1.574   325.033   136.514   21.127   115.387
126.63     .250   .948   509.011   486.209   161.175   1.698   325.033   136.514   21.127   115.387
126.63     .500   .947   507.190   484.387   159.354   1.822   325.033   136.514   21.127   115.387
126.63     .750   .945   505.372   482.570   157.536   1.944   325.033   136.514   21.127   115.387
126.63    1.000   .944   503.557   480.755   155.721   2.064   325.033   136.514   21.127   115.387
126.63    1.250   .939   498.633   475.830   150.797   2.182   325.033   136.514   21.127   115.387
126.63    1.500   .934   493.732   470.930   145.896   2.296   325.033   136.514   21.127   115.387
126.63    1.750   .930   488.856   466.054   141.020   2.406   325.033   136.514   21.127   115.387
126.63    2.000   .925   484.004   461.201   136.168   2.513   325.033   136.514   21.127   115.387
126.63    2.250   .916   475.712   452.909   127.876   2.615   325.033   136.514   21.127   115.387
126.63    2.500   .907   467.490   444.687   119.654   2.710   325.033   136.514   21.127   115.387
126.63    2.750   .898   459.339   436.536   111.503   2.799   325.033   136.514   21.127   115.387
126.63    3.000   .889   451.257   428.455   103.421   2.881   325.033   136.514   21.127   115.387
126.63    3.250   .873   437.243   414.440    89.407   2.955   325.033   136.514   21.127   115.387
126.63    3.500   .858   423.446   400.643    75.610   3.019   325.033   136.514   21.127   115.387
126.63    3.750   .842   409.867   387.064    62.031   3.072   325.033   136.514   21.127   115.387
126.63    4.000   .827   396.506   373.703    48.670   3.114   325.033   136.514   21.127   115.387
126.63    4.250   .799   368.842   346.040    21.006   3.141   325.033   136.514   21.127   115.387
126.63    4.500   .771   342.176   319.374    -5.660   3.139   325.033   136.514   35.071   101.443
126.63    4.750   .743   316.509   293.706   -31.327   3.125   325.033   136.514   35.071   101.443
126.63    5.000   .715   291.838   269.036   -55.997   3.091   325.033   136.514   35.071   101.443
126.63    5.250   .667   255.355   232.553   -92.481   3.034   325.033   136.514   35.071   101.443
126.63    5.500   .620   221.306   198.503  -126.530   2.950   325.033   136.514   35.071   101.443
126.63    5.542   .612   215.772   192.970  -132.064   2.933   325.033   136.514   35.071   101.443
126.63    8.408  0.000     0.000     0.000   325.033   0.000   325.033   133.362    5.721   127.641

172.25   -5.750   .621   222.028   199.226     0.000   0.000   199.226    79.491   12.950    66.541
172.25   -5.500   .663   253.545   230.743     0.000   0.000   230.743    92.066   14.998    77.068
172.25   -5.250   .704   287.151   264.349     0.100   0.000   264.349   105.475   17.183    88.292
172.25   -5.000   .746   322.847   300.044     0.000   0.000   300.044   119.718   19.503   100.215
172.25   -4.750   .769   342.466   319.663     0.000   0.000   319.663   127.546   20.778   106.767
172.25   -4.500   .792   362.663   339.860    14.827    .004   325.033   136.514   21.127   115.387
172.25   -4.250   .815   383.438   360.635    35.602    .024   325.033   136.514   21.127   115.387
172.25   -4.000   .838   404.791   381.988    56.955    .059   325.033   136.514   21.127   115.387
172.25   -3.750   .852   416.289   393.486    68.453    .107   325.033   136.514   21.127   115.387
172.25   -3.500   .865   427.945   405.143    80.109    .165   325.033   136.514   21.127   115.387
172.25   -3.250   .879   439.759   416.957    91.923    .231   325.033   136.514   21.127   115.387
172.25   -3.000   .892   451.731   428.929   103.895    .306   325.033   136.514   21.127   115.387
172.25   -2.750   .900   459.056   436.253   111.220    .389   325.033   136.514   21.127   115.387
172.25   -2.500   .908   466.439   443.636   118.603    .477   325.033   136.514   21.127   115.387
172.25   -2.250   .916   473.880   451.077   126.044    .571   325.033   136.514   21.127   115.387
172.25   -2.000   .924   481.379   458.577   133.543    .671   325.033   136.514   21.127   115.387
172.25   -1.750   .928   486.305   463.503   138.469    .776   325.033   136.514   21.127   115.387
172.25   -1.500   .933   491.257   468.454   143.421    .884   325.033   136.514   21.127   115.387
172.25   -1.250   .937   496.233   473.430   148.397    .996   325.033   136.514   21.127   115.387
172.25   -1.000   .941   501.234   478.431   153.398   1.112   325.033   136.514   21.127   115.387
172.25    -.750   .943   503.307   480.504   155.471   1.231   325.033   136.514   21.127   115.387
172.25    -.500   .944   505.384   482.582   157.549   1.352   325.033   136.514   21.127   115.387
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 172.25    -.250   .945   507.466   434.663   159.630     1.473   325.033   136.514    21.127   115.387
 172.25    0.000   .947   509.551   436.748   161.715     1.597   325.033   136.514    21.127   115.387
 172.25     .250   .945   507.466   434.663   159.630     1.721   325.033   136.514    21.127   115.387
 172.25     .500   .944   505.384   432.582   157.548     1.843   325.033   136.514    21.127   115.387
 172.25     .750   .943   503.307   430.504   155.471     1.963   325.033   136.514    21.127   115.387
 172.25    1.000   .941   501.234   478.431   153.398     2.082   325.033   136.514    21.127   115.387
 172.25    1.250   .937   496.233   473.430   148.397     2.198   325.033   136.514    21.127   115.387
 172.25    1.500   .933   491.257   468.454   143.421     2.310   325.033   136.514    21.127   115.387
 172.25    1.750   .928   486.305   463.503   138.469     2.418   325.033   136.514    21.127   115.387
 172.25    2.000   .924   481.379   458.577   133.543     2.523   325.033   136.514    21.127   115.387
 172.25    2.250   .916   473.880   451.077   126.044     2.623   325.033   136.514    21.127   115.387
 172.25    2.500   .918   466.439   443.636   118.603     2.717   325.033   136.514    21.127   115.387
 172.25    2.750   .910   459.356   436.253   111.229     2.805   325.033   136.514    21.127   115.387
 172.25    3.000   .892   451.731   428.929   103.895     2.888   325.033   136.514    21.127   115.387
 172.25    3.250   .879   439.759   416.957    91.923     2.963   325.033   136.514    21.127   115.387
 172.25    3.500   .865   427.945   405.143    80.109     3.039   325.033   136.514    21.127   115.387
 172.25    3.750   .852   416.289   393.486    68.453     3.087   325.033   136.514    21.127   115.387
 172.25    4.000   .838   404.791   381.988    56.955     3.135   325.033   136.514    21.127   115.387
 172.25    4.250   .815   383.438   360.635    35.602     3.171   325.033   136.514    21.127   115.387
 172.25    4.500   .792   362.663   339.860     0.000     3.187   325.033   136.514    21.127   115.387
 172.25    4.750   .769   342.466   319.663    -5.370     3.185   325.033   136.514    35.071   101.443
 172.25    5.000   .746   322.847   300.044   -24.989     3.173   325.033   136.514    35.071   101.443
 172.25    5.250   .704   287.151   264.349   -60.685     3.140   325.033   136.514    35.071   101.443
 172.25    5.500   .663   253.545   230.743   -94.291     3.080   325.033   136.514    35.071   101.443
 172.25    5.750   .621   222.028   199.226  -125.808     2.996   325.033   136.514    35.071   101.443
 172.25    5.844   .606   210.689   187.887  -137.147     2.958   325.033   136.514    35.071   101.443
 172.25    8.734  0.000     0.000     0.000   325.033     0.000   325.033   133.362     5.721   127.641
```

```
                   YEARLY AVERAGE PERFORMANCE


YEARLY INSOLATION                  2408.725 KW-HR/M2

GROSS ENERGY ONTO RECEIVER      1217590.738 MW-TH HR

REFLECTIVITY LOSS                 24351.815 MW-TH HR
RADIATION/CONVECTION LOSS         57370.652 MW-TH HR
PIPING LOSSES                      7542.033 MW-TH HR

THERMAL ENERGY AT TOWER BASE    1128326.239 MW-TH HR

ENERGY TO STORAGE                235555.059 MW-TH HR
  ROUND TRIP EFF.                    1.000
ENERGY DISCARDED                    181.011 MW-TH HR

ENERGY TO TURBINE FROM RECEIVER  892771.180 MW-TH HR
ENERGY TO TURBINE FROM STORAGE   235374.048 MW-TH HR
  THERM. TO ELEC. EFF.                 .399
GROSS ELECTRIC ENERGY            450129.946 MW-EL HR

ELECTRICAL PARASITICS             30429.116 MW-EL HR

NET ELECTRICAL PRODUCTION        439540.626 MW-EL HR
```

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                        FLUX CALCULATION


UNITS OF FLUX ARE KILOWATT/SQ. METER


THE FLUX IS CALCULATED FOR DAY=  81.00 HOUR=   0.00 INSOLATION=   .950 KW/M2

  HT(M)       AZIMUTH OF NORMAL(180 = NORTH FACING)


           135.000   157.500   180.000   202.500   225.000


  20.000  .235E+02  .267E+02  .298E+02  .267E+02  .235E+02
  13.750  .658E+02  .868E+02  .898E+02  .868E+02  .658E+02
   7.500  .322E+03  .525E+03  .531E+03  .525E+03  .322E+03
   1.250  .237E+03  .415E+03  .430E+03  .415E+03  .237E+03
  -5.000  .200E+02  .274E+02  .347E+02  .274E+02  .200E+02
```

Sample Problem 3 - User Defined Field with Individual Heliostat Coordinates

Problem Statement

The example of the CESA-1 system discussed in Chapter VII and Reference 33 is used here to illustrate the input and output of the IUSERF=3 option in $FIELD$. The performance and in particular, a flux map on winter solstice at 10 a.m. are desired. The insolation is 0.7 kw/m^2, and a square wave sun is assumed. Other information comes from reference 33.

Input Cards

```
SAMPLE PROBLEM 3
$BASIC IPRØB=2, UDAY=355., UTIME=-2., IPRINT=2,
       PLAT=37.099, INSØL=2, SØLCØN=0.7, NSUN=2,
       IATM=2, ATM1=0.679, ATM2=11.76, ATM3=-1.97,
       ATM4=0.$
$FIELD IUSERF=3$
$HSTAT WM=6.25, HM=8.3, ICANPL=1, WPANL=2.9 HPANL=1.25,
       HXCANT=5*-1.675, 5*1.675, HYCANT=2.525, 1.263,
       0.,-1.263, -2.525, 2.525, 1.263, 0.-1.263, -2.525,
       DENSMR=0.92063, RMIRL=0.85, SIGAZ=0., SIGEL=0.,
       SIGSX=0., SIGSY=0., SIGTX=0.0033, SIGTY=0.0033,
       ICANT=3, NCANTY=5, ISB=1$
$REC THT=56.345, TØWL=67.345, TØWD=11., IREC=4,
       W=10.8, RX=3.4, RY=3.4, IAUTØP=0, RELV=111.8$
$NLFLUX IFLX=1, IFXØUT(1,1)=1, IFLAUT=4, NXFLX=11,
       FAZMIN=-1.7, FAZMAX=1.7, NYFLX=11, FZMIM=-1.7,
       FZMAX=1.7$
$NLEFF$
SPANISH FIELD
      282          16
        1           7
   0.0000     45.0000
  10.0000     45.0000
  20.0000     45.0000
  30.0000     45.0000
 -30.0000     45.0000
 -20.0000     45.0000
 -10.0000     45.0000
        2          10
   5.0000     57.0000
                 etc.
$REC W=-1.$
```

Analysis of Input

The detailed input describing the site location, sunshape, atmospheric attenuation ($BASIC$), the heliostat ($HSTAT$), and tower and receiver (REC) are consistent with the system definition of reference 33. To calculate the performance and flux at a particular time, IPRØB=2, UDAY, and UTIME are specified in $BASIC$. IPRINT is set to 2 in order to get the single time results printed. IUSERF=3 in $FIELD$ sets up the code to do a run on a field with the individual heliostat coordinates defined. The values defined in

$NLFLUX$ are chosen for a fine gridded flux map. After $NLEFF$ comes the individual heliostat input in the format described in the $FIELD$ section of Appendix A. Only the first few values are shown here.

Comments on Output

The output is similar to that of other runs up to the zoning summary (p. B-97), which is now simply a flag that the individual coordinate option is employed. The performance summary of the heliostats in the 1st, 2nd, and 16th rows (pp. B-99 and B-100) are included here for illustration. Total field performance (p. B-101), the waterfall trace at the specified time (p. B-102), and the flux map (p. B-103) follow.

```
                    ZONING

INDIVIDUAL HELIOSTAT COORDINATES ARE SUPPLIED BY THE USER

THE LABEL OF THE FIELD =   SPANISH FIELD
THE   282 HELIOSTATS ARE GROUPED INTO  16 ROWS
```

```
                    INSOLATION AND SUN POSITION

 USER DEFINED SINGLE CALCULATION - DAY= 355.00 HOUR=-2.00
INSOLATION CALCULATED USING CONSTANT MODEL

      TIME = -2.0  INSOLATION(KW/M2)=   .700 TRUE ZENITH ANGLE =  66.81  OBSERVED ZENITH=  66.77 SUN AZIMUTH = -29.94
```

```
----- OPTICAL PERFORMANCE -----


 THE   1 ROW CONTAINS   7 HELIOSTATS

 IND. HSTAT NO.=    1 ROW =    1 EAST =   0.00 NORTH =  45.00  RADIUS=   .70THT, RANGE =  1.22 THT,  REC. AZM =  -.00 ELV= 35.10
   DAY         HOUR     AZ ANG     EL ANG     COSINE   SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -18.5      50.0      .944    1.000    1.000     .985    1.000     .763      1          1         0.00       0.00
 IND. HSTAT NO.=    2 ROW =    1 EAST =  10.00 NORTH =  45.00  RADIUS=   .72THT, RANGE =  1.24 THT,  REC. AZM = 14.17 ELV= 35.94
   DAY         HOUR     AZ ANG     EL ANG     COSINE   SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -27.2      49.3      .924    1.000    1.000     .985    1.000     .746      1          1         0.00       0.00
 IND. HSTAT NO.=    3 ROW =    1 EAST =  20.00 NORTH =  45.00  RADIUS=   .79THT, RANGE =  1.27 THT,  REC. AZM = 26.80 ELV= 38.22
   DAY         HOUR     AZ ANG     EL ANG     COSINE   SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -34.4      49.1      .901    1.000    1.000     .985    1.000     .727      1          1         0.00       0.00
 IND. HSTAT NO.=    4 ROW =    1 EAST =  30.00 NORTH =  45.00  RADIUS=   .88THT, RANGE =  1.33 THT,  REC. AZM = 37.15 ELV= 41.40
   DAY         HOUR     AZ ANG     EL ANG     COSINE   SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -39.7      49.2      .875    1.000    1.000     .984    1.000     .707      1          1         0.00       0.00
 IND. HSTAT NO.=    5 ROW =    1 EAST = -30.00 NORTH =  45.00  RADIUS=   .88THT, RANGE =  1.33 THT,  REC. AZM =-37.15 ELV= 41.40
   DAY         HOUR     AZ ANG     EL ANG     COSINE   SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00       4.2      54.0      .974     .207    1.000     .984    1.000     .163      1          1         0.00       0.00
 IND. HSTAT NO.=    6 ROW =    1 EAST = -20.00 NORTH =  45.00  RADIUS=   .79THT, RANGE =  1.27 THT,  REC. AZM =-26.80 ELV= 38.22
   DAY         HOUR     AZ ANG     EL ANG     COSINE   SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00      -1.9      52.5      .969     .458    1.000     .985    1.000     .358      1          1         0.00       0.00
 IND. HSTAT NO.=    7 ROW =    1 EAST = -10.00 NORTH =  45.00  RADIUS=   .72THT, RANGE =  1.24 THT,  REC. AZM =-14.17 ELV= 35.94
   DAY         HOUR     AZ ANG     EL ANG     COSINE   SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00      -9.6      51.1      .959    1.000    1.000     .985    1.000     .775      1          1         0.00       0.00


 THE   2 ROW CONTAINS  10 HELIOSTATS

 IND. HSTAT NO.=    8 ROW =    2 EAST =   5.00 NORTH =  57.00  RADIUS=   .92THT, RANGE =  1.36 THT,  REC. AZM =  5.53 ELV= 42.62
   DAY         HOUR     AZ ANG     EL ANG     COSINE   SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -20.5      53.4      .948     .871    1.000     .984    1.000     .667      1          1         0.00       0.00
 IND. HSTAT NO.=    9 ROW =    2 EAST =  15.00 NORTH =  57.00  RADIUS=   .95THT, RANGE =  1.38 THT,  REC. AZM = 16.21 ELV= 43.64
   DAY         HOUR     AZ ANG     EL ANG     COSINE   SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -26.5      53.0      .929     .870    1.000     .984    1.000     .652      1          1         0.00       0.00
 IND. HSTAT NO.=   10 ROW =    2 EAST =  25.00 NORTH =  57.00  RADIUS=  1.02THT, RANGE =  1.43 THT,  REC. AZM = 25.85 ELV= 45.50
   DAY         HOUR     AZ ANG     EL ANG     COSINE   SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -31.7      52.9      .907     .867    1.000     .984    1.000     .635      1          1         0.00       0.00
 IND. HSTAT NO.=   11 ROW =    2 EAST =  35.00 NORTH =  57.00  RADIUS=  1.11THT, RANGE =  1.49 THT,  REC. AZM = 34.15 ELV= 47.90
   DAY         HOUR     AZ ANG     EL ANG     COSINE   SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -35.9      53.0      .884    1.000    1.000     .983    1.000     .713      1          1         0.00       0.00
 IND. HSTAT NO.=   12 ROW =    2 EAST =  45.00 NORTH =  57.00  RADIUS=  1.22THT, RANGE =  1.57 THT,  REC. AZM = 41.09 ELV= 50.55
   DAY         HOUR     AZ ANG     EL ANG     COSINE   SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -39.1      53.3      .861    1.000    1.000     .983     .999     .693      1          1         0.00       0.00
 IND. HSTAT NO.=   13 ROW =    2 EAST = -45.00 NORTH =  57.00  RADIUS=  1.22THT, RANGE =  1.57 THT,  REC. AZM =-41.09 ELV= 50.55
   DAY         HOUR     AZ ANG     EL ANG     COSINE   SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00       6.1      58.5      .987    1.000    1.000     .983     .999     .795      1          1         0.00       0.00
 IND. HSTAT NO.=   14 ROW =    2 EAST = -35.00 NORTH =  57.00  RADIUS=  1.11THT, RANGE =  1.49 THT,  REC. AZM =-34.15 ELV= 47.90
   DAY         HOUR     AZ ANG     EL ANG     COSINE   SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00       2.3      57.3      .986     .000    1.000     .983    1.000     .000      1          1         0.00       0.00
 IND. HSTAT NO.=   15 ROW =    2 EAST = -25.00 NORTH =  57.00  RADIUS=  1.02THT, RANGE =  1.43 THT,  REC. AZM =-25.85 ELV= 45.50
   DAY         HOUR     AZ ANG     EL ANG     COSINE   SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00      -2.3      56.1      .983     .579    1.000     .984    1.000     .459      1          1         0.00       0.00
 IND. HSTAT NO.=   16 ROW =    2 EAST = -15.00 NORTH =  57.00  RADIUS=   .95THT, RANGE =  1.38 THT,  REC. AZM =-16.21 ELV= 43.64
   DAY         HOUR     AZ ANG     EL ANG     COSINE   SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00      -7.8      55.0      .975     .870    1.000     .984    1.000     .685      1          1         0.00       0.00
 IND. HSTAT NO.=   17 ROW =    2 EAST =  -5.00 NORTH =  57.00  RADIUS=   .92THT, RANGE =  1.36 THT,  REC. AZM = -5.53 ELV= 42.62
   DAY         HOUR     AZ ANG     EL ANG     COSINE   SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -14.1      54.1      .964     .871    1.000     .984    1.000     .678      1          1         0.00       0.00
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 INC. HSTAT NO.=  265 ROW =  15 EAST =  84.73 NORTH = 244.00  RADIUS=  4.49THT, RANGE =  4.60 THT,  REC. AZM = 19.55 ELV= 77.45
   DAY        HOUR     AZ ANG     EL ANG     COSINE    SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -23.9      70.4       .913      .989   1.000      .964      .761     .543       1          1         0.00       0.00
 INC. HSTAT NO.=  266 ROW =  15 EAST = 102.58 NORTH = 244.00  RADIUS=  4.61THT, RANGE =  4.72 THT,  REC. AZM = 23.26 ELV= 77.76
   DAY        HOUR     AZ ANG     EL ANG     COSINE    SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -25.7      70.3       .901      .994   1.000      .963      .733     .518       1          1         0.00       0.00
 INC. HSTAT NO.=  267 ROW =  15 EAST =-102.58 NORTH = 244.00  RADIUS=  4.61THT, RANGE =  4.72 THT,  REC. AZM =-23.26 ELV= 77.76
   DAY        HOUR     AZ ANG     EL ANG     COSINE    SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00      -3.2      72.2       .994     1.000   1.000      .963      .747     .586       1          1         0.00       0.00
 INC. HSTAT NO.=  268 ROW =  15 EAST = -84.73 NORTH = 244.00  RADIUS=  4.49THT, RANGE =  4.60 THT,  REC. AZM =-19.55 ELV= 77.45
   DAY        HOUR     AZ ANG     EL ANG     COSINE    SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00      -5.0      72.0       .992     1.000   1.000      .964      .772     .606       1          1         0.00       0.00
 INC. HSTAT NO.=  269 ROW =  15 EAST = -67.31 NORTH = 244.00  RADIUS=  4.40THT, RANGE =  4.51 THT,  REC. AZM =-15.75 ELV= 77.20
   DAY        HOUR     AZ ANG     EL ANG     COSINE    SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00      -6.9      71.9       .989     1.000   1.000      .965      .793     .620       1          1         0.00       0.00
 INC. HSTAT NO.=  270 ROW =  15 EAST = -50.19 NORTH = 244.00  RADIUS=  4.33THT, RANGE =  4.44 THT,  REC. AZM =-11.88 ELV= 76.99
   DAY        HOUR     AZ ANG     EL ANG     COSINE    SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00      -8.8      71.7       .985     1.000   1.000      .965      .808     .630       1          1         0.00       0.00
 INC. HSTAT NO.=  271 ROW =  15 EAST = -33.33 NORTH = 244.00  RADIUS=  4.28THT, RANGE =  4.39 THT,  REC. AZM = -7.95 ELV= 76.84
   DAY        HOUR     AZ ANG     EL ANG     COSINE    SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -10.7      71.5       .980     1.000   1.000      .965      .818     .635       1          1         0.00       0.00
 INC. HSTAT NO.=  272 ROW =  15 EAST = -16.63 NORTH = 244.00  RADIUS=  4.24THT, RANGE =  4.36 THT,  REC. AZM = -3.99 ELV= 76.74
   DAY        HOUR     AZ ANG     EL ANG     COSINE    SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -12.6      71.3       .973     1.000   1.000      .966      .824     .635       1          1         0.00       0.00


 THE  16 ROW CONTAINS  10 HELIOSTATS

 INC. HSTAT NO.=  273 ROW =  16 EAST =   8.83 NORTH = 259.00  RADIUS=  4.50THT, RANGE =  4.61 THT,  REC. AZM =  1.99 ELV= 77.48
   DAY        HOUR     AZ ANG     EL ANG     COSINE    SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -15.5      71.5       .961     1.000   1.000      .964      .787     .598       1          1         0.00       0.00
 INC. HSTAT NO.=  274 ROW =  16 EAST =  26.56 NORTH = 259.00  RADIUS=  4.53THT, RANGE =  4.63 THT,  REC. AZM =  5.98 ELV= 77.54
   DAY        HOUR     AZ ANG     EL ANG     COSINE    SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -17.4      71.3       .952     1.000   1.000      .964      .781     .587       1          1         0.00       0.00
 INC. HSTAT NO.=  275 ROW =  16 EAST =  44.38 NORTH = 259.00  RADIUS=  4.57THT, RANGE =  4.68 THT,  REC. AZM =  9.93 ELV= 77.66
   DAY        HOUR     AZ ANG     EL ANG     COSINE    SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -19.3      71.2       .942     1.000   1.000      .964      .770     .573       1          1         0.00       0.00
 INC. HSTAT NO.=  276 ROW =  16 EAST =  62.44 NORTH = 259.00  RADIUS=  4.64THT, RANGE =  4.74 THT,  REC. AZM = 13.83 ELV= 77.83
   DAY        HOUR     AZ ANG     EL ANG     COSINE    SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -21.2      71.0       .931     1.000   1.000      .963      .753     .554       1          1         0.00       0.00
 INC. HSTAT NO.=  277 ROW =  16 EAST =  80.82 NORTH = 259.00  RADIUS=  4.72THT, RANGE =  4.83 THT,  REC. AZM = 17.68 ELV= 78.05
   DAY        HOUR     AZ ANG     EL ANG     COSINE    SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -23.0      70.9       .919     1.000   1.000      .963      .732     .531       1          1         0.00       0.00
 INC. HSTAT NO.=  278 ROW =  16 EAST = -80.82 NORTH = 259.00  RADIUS=  4.72THT, RANGE =  4.83 THT,  REC. AZM =-17.68 ELV= 78.05
   DAY        HOUR     AZ ANG     EL ANG     COSINE    SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00      -5.9      72.3       .990     1.000   1.000      .963      .742     .580       1          1         0.00       0.00
 INC. HSTAT NO.=  279 ROW =  16 EAST = -62.44 NORTH = 259.00  RADIUS=  4.64THT, RANGE =  4.74 THT,  REC. AZM =-13.83 ELV= 77.83
   DAY        HOUR     AZ ANG     EL ANG     COSINE    SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00      -7.8      72.1       .987     1.000   1.000      .963      .761     .593       1          1         0.00       0.00
 INC. HSTAT NO.=  280 ROW =  16 EAST = -44.38 NORTH = 259.00  RADIUS=  4.57THT, RANGE =  4.68 THT,  REC. AZM = -9.93 ELV= 77.66
   DAY        HOUR     AZ ANG     EL ANG     COSINE    SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00      -9.7      72.0       .982     1.000   1.000      .964      .775     .602       1          1         0.00       0.00
 INC. HSTAT NO.=  281 ROW =  16 EAST = -26.56 NORTH = 259.00  RADIUS=  4.53THT, RANGE =  4.63 THT,  REC. AZM = -5.98 ELV= 77.54
   DAY        HOUR     AZ ANG     EL ANG     COSINE    SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -11.6      71.8       .976     1.000   1.000      .964      .784     .605       1          1         0.00       0.00
 INC. HSTAT NO.=  282 ROW =  16 EAST =  -8.83 NORTH = 259.00  RADIUS=  4.50THT, RANGE =  4.61 THT,  REC. AZM = -1.99 ELV= 77.48
   DAY        HOUR     AZ ANG     EL ANG     COSINE    SHADOW  BLOCK  ATM TRANS SPILLAGE   TOTAL NO. X AIM NO. Y AIM 1ST X AIM 1ST Y AIM
  355.00      -2.00     -13.5      71.6       .969     1.000   1.000      .964      .788     .604       1          1         0.00       0.00
```

```
                    PERFORMANCE SUMMARY FROM USER DEFINED FIELD

          OPTICAL EFFICIENCY

TOTAL EFFICIENCY INCLUDES REFLECTIVITIES, HELIOSTAT =  .850  RECEIVER =  .965

 DAY        HOUR      COSINE     SHADOW      BLOCK  ATM.TRANS. SPILLAGE     TOTAL
355.00     -2.00        .949       .927       .993       .973      .917      .639
```

```
                    ----- DESIGN POINT -----

 DAY=  355.00 TIME=    -2.00 INSOLATION =    .700 KW/M2

GROSS POWER ONTO RECEIVER                      4.741 MW-TH

REFLECTIVITY LOSS                               .166 MW-TH
RADIATION/CONVECTION LOSS                       .379 MW-TH
PIPING LOSSES                                   .064 MW-TH

THERMAL POWER TOWER BASE                       4.132 MW-TH

POWER TO STORAGE                               1.377 MW-TH

POWER TO TURBINE                               2.755 MW-TH
  THERM. TO ELEC. EFF.                         1.000
GROSS ELECTRIC POWER                           2.755 MW-EL
ELECTRICAL PARASITICS                           .179 MW-EL

NET ELECTRIC POWER                             2.576 MW-EL
```

```
                    FLUX CALCULATION


UNITS OF FLUX ARE KILOWATT/SQ. METER


THE FLUX IS CALCULATED FOR DAY= 355.00 HOUR=  -2.00 INSOLATION=    .700 KW/M2

  HT(M)        HORIZONTAL DISPLACEMENT IN FLUX PLANE(M)



               -1.700    -1.360    -1.020     -.680     -.340      .000      .340      .680     1.020     1.360     1.700


      1.700  .183E+02  .326E+02  .518E+02  .727E+02  .900E+02  .966E+02  .901E+02  .729E+02  .516E+02  .327E+02  .182E+02
      1.360  .368E+02  .657E+02  .106E+03  .154E+03  .195E+03  .212E+03  .196E+03  .155E+03  .107E+03  .659E+02  .367E+02
      1.020  .643E+02  .118E+03  .199E+03  .304E+03  .407E+03  .450E+03  .406E+03  .305E+03  .199E+03  .118E+03  .642E+02
       .680  .977E+02  .186E+03  .331E+03  .549E+03  .791E+03  .900E+03  .779E+03  .542E+03  .330E+03  .185E+03  .973E+02
       .340  .126E+03  .248E+03  .465E+03  .828E+03  .128E+04  .150E+04  .126E+04  .815E+03  .462E+03  .247E+03  .125E+03
      0.000  .138E+03  .274E+03  .523E+03  .954E+03  .152E+04  .182E+04  .152E+04  .954E+03  .523E+03  .274E+03  .138E+03
      -.340  .126E+03  .247E+03  .462E+03  .815E+03  .126E+04  .150E+04  .128E+04  .828E+03  .465E+03  .248E+03  .125E+03
      -.680  .973E+02  .185E+03  .330E+03  .542E+03  .779E+03  .900E+03  .791E+03  .549E+03  .331E+03  .186E+03  .977E+02
     -1.020  .642E+02  .118E+03  .199E+03  .305E+03  .406E+03  .450E+03  .407E+03  .304E+03  .199E+03  .118E+03  .643E+02
     -1.360  .367E+02  .659E+02  .107E+03  .155E+03  .196E+03  .212E+03  .195E+03  .154E+03  .106E+03  .657E+02  .368E+02
     -1.700  .182E+02  .327E+02  .516E+02  .729E+02  .901E+02  .966E+02  .900E+02  .727E+02  .518E+02  .326E+02  .183E+02
```

App. C. - Additional
Sample Input

APPENDIX C--ADDITIONAL SAMPLE INPUT DECKS

Flux Map on a Cavity Wall and Aperture

Examine the flux distribution on the east facing cavity of the 125 MW_e system from Sample Problem 2 of Appendix B. Obtain flux maps on both the heat absorbing surface and aperture.

A. Flux on the Heat Absorbing Surface

Input:

```
FLUX MAP ØN WALL
$BASIC ITAPE=3, TDESP=125.$
$FIELD$
$HSTAT$
$REC RX=12.8,9.6,12.8,16.0, RY=12.8,9.6,12.8,16.0,
     RAZM=270.,0.,90.,180., RWCAV=0.75,0.5,0.75,1.0$
$NLFLUX IFLX=1, IFXØUT(3,1)=1, NXFLX=9, FAZMIN=225., FAZMAX=315.,
        NYFLX=8, FZMIN=-4.0, FZMAX=26.0$
$NLEFF$
$REC W=-1.$
```

Analysis of Input

System data is read from the optimization data tape created in Sample Problem 2B (ITAPE=3, TDESP=125., plus the appropriate control card for attaching the file). In order to make calculations on the east cavity, the REC variables must be specified so that the east facing cavity is the first one. The optimized values for the aperture size (RX,RY) are used. IREC and IAUTØP are read from TAPE30.

For calculating the flux map, the design point has been selected, and the default value of IFLAUT signals that calculations will be made on the heat absorbing surface of the specified receiver. FZMIN,FZMAX are specified in keeping with values determined in the optimization run.

B. Flux on the Aperture

Input:

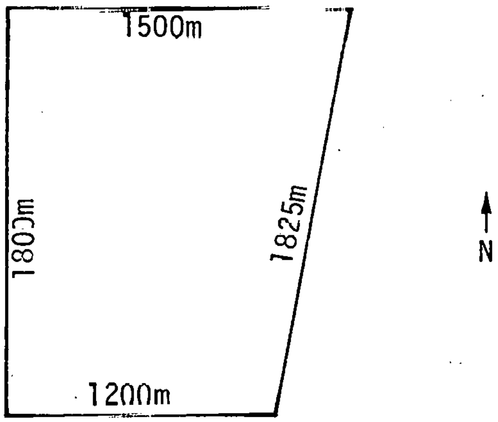
```
FLUX MAP ØN APERTURE
$BASIC ITAPE=3, TDESP=125.$
$FIELD$
$HSTAT$
$REC RX =12.8,9.6,12.8,16.0, RY=12.8,9.6,12.8,16.0,
     RAZM=270.,0.,90.,180., RWCAV=0.75,0.5,0.75,1.0$
$NLFLUX IFLX=1, IFXØUT(3,1)=1, IFLAUT=3, XFC=16.25, YFC=0., ZFC=0.,
        AZMF=270., NXFLX=9,FAZMIN=-6.4, FAZMAX=6.4, NYFLX=9,
        FZMIN=-6.4, FZMAX=6.4$
```

Analysis of Input

The input is similar to the calculation in the preceding example except for the definition of the aperture instead of the heat absorbing surface for the flux calculation. IFLAUT=3 is specified and appropriate values of XFC, YFC, ZFC, FZMIN, FZMAX are defined.

Land Constrained System Design

The following piece of land is available for a central receiver plant:



Determine the appropriate plant size for the area and optimal tower location.

Input:

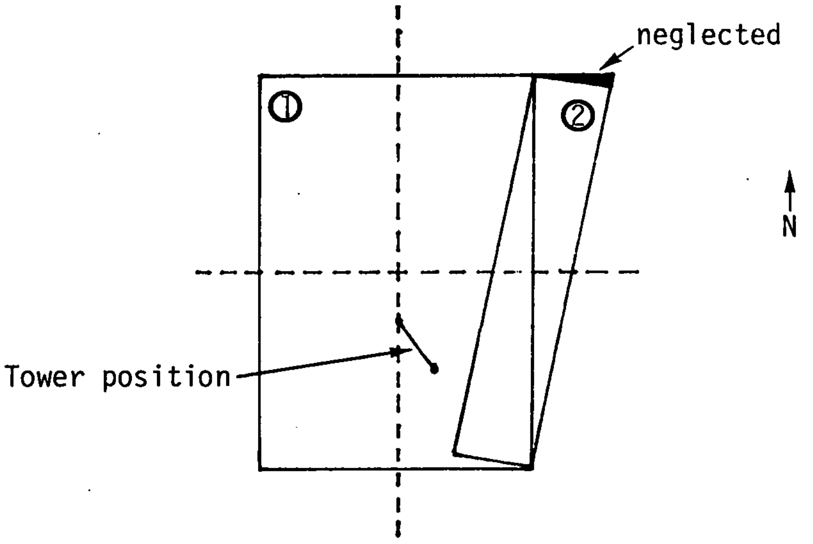
```
LAND CØNSTRAINT
$BASIC ITAPE=2$
$REC$
$ØPT NUMTHT=5, THTST=120., THTEND=200., NUMREC=5, WST=10., WEND=18.,
     NUMØPT=5, PØPTMN=250.E+06, PØPTMX=350.E+06, NUMPØS=4,
     XTPST=0., XTPEND=150., YTPST=-200., YTPEND=-400., NLAND=2, CLE=0.,
     600., CLN=0.,0., ALP=0.,9.5, SLNS=1800.,1775., SLEW=1200.,297.,
     IPLFL=4*1, SMULT=1.0$
$NLFLUX$
$NLEFF IPH=1$
$NLCØST$
```

```
$NLEC0N$
$REC W=-1.$
```

Analysis of Input

The vague problem statement requires a number of decisions to be made. First, a general idea of the plant size is made by comparing the available land are of ~ 2.4 km^2 with previously calculated unconstrained designs. The result is ~ 250 MW$_{th}$ delivered at the base of the tower (see output for Problem 1, Appendix B), and this then becomes a nominal value for determining the power levels searched. Tower height and receiver size ranges are chosen consistent with the power level range considered here. Furthermore, in this initial run, the problem is simplified to deal only with thermal power at the tower basis (IPH=1, SMULT=1.0) and non-flux limited external receiver designs.

The land constraint is handled by dividing the land into the two rectangles shown below and neglecting the small triangular area in the upper right hand corner:



Tower position is varied along the line indicated. The input parameters in $0PT$ define values based on the original dimensions of the land area. Subsequent iterations may be required to optimize tower position and receiver configuration.

Initial Distribution

Unlimited Release

Snamprogetti S.P.A.
Casella Postalle 12059
20100 Milano
Italy
Attn: Dr. Benedetti Alessio

Empresa Nacional de Ingenieria
Padilla 17
Madrid-6
Spain
Attn: Fernando Delgado

Department of Mechanical Engineering
Indian Institute of Science
Bangalore-560012
India
Attn: D. Suresh

Ecole Polytechnique
B.P. 6079 Station "A"
Montreal, Quebec
Canada H3C3A7
Attn: Prof. E. Bilgen

Geotechnical Research Centre
McGill University
817 Sherbrooke St. West
Montreal, Quebec
Canada
Attn: Tarek Galal

Instituto de Investiaciones Electricas
Apartado Postal 475
Cuernavaca, Morelos
Mexico
Attn: Dr. Eduardo Gleason Garcia

Instituto de Nuevas Energias
Apartado Postal 2012
Valencia
Spain
Attn: Javier Cañada Ribera

L.A.A.S.
7 Avenue du Colonel Roche
F31400 Toulouse
France
Attn: Prof. J. L. Abatut

DFVLR
Pfaffenwaldring 38-40
7000 Stuttgart 80
West Germany
Attn: Kurt J. Erhardt

Embassy of Australia
1601 Massachusetts Ave. N.W.
Washington, D.C. 20036
Attn: W. J. Wright

INTERATOM
Friedrich-Ebert-Straße
5060 Bergisch Gladbach 4
West Germany
Attn: Dr. Rolf Erdmann

Masinski Fakultet
Zavod za Procesnu Tehniku
I Zastitu Cistore Vazduha
71001 Sarajevo
Yugoslavia
Attn: Dr. O. Fabris

Olin Chemicals Group
275 Winchester Ave.
New Haven, CT 06511
Attn: S. L. Goldstein

ARCO Power Systems
7061 S. University-Suite 306
Littleton, CO 80122
Attn: Dave Gorman

Babcock and Wilcox
20 S. Van Buren Ave.
Barberton, OH 44203
Attn: O. W. Durrant

Boeing Engineering and Construction Co.
600 Andover Park West
Seattle, WA 98188
Attn: Cheryl Warner

McDonnell Douglas
5301 Bolsa Ave.
Huntington Beach, CA 92467
Attn: G. L. Keller M/S 14-3

Bechtel Group, Inc.
P. O. Box 3965
San Francisco, CA 94119
Attn: Robert Lessley
      Aileen Penn

Martin Marietta
P. O. Box 179
Denver, CO 80201
Attn: Paul Norris M/S C4000

Electric Power Research Institute
P. O. Box 10412
Palo Alto, CA 94303
Attn: John Bigger

General Electric Co.
1 River Road
Bldg. 23, Rm. 289
Schenectady, NY 12345
Attn: Stuart Schwartz

Rockwell International
Energy Systems Group
8900 DeSoto Ave.
Canoga Park, CA 91304
Attn: Janet Ives

Utah Power and Light Co.
P. O. Box 899
Salt Lake City, UT 84110
Attn: Don Grey

J.P.L.
4800 Oak Grove Dr.
Pasadena, CA 91103
Attn: Dr. J. M. Bowyer, M/S 507-228

Black and Veatch
P. O. Box 8405
Kansas City, MO 64114
Attn: S. L. Levy
D. C. Gray

Westinghouse Electric Co.
777 Penn Center Blvd.
Pittsburgh, PA 15235
Attn: John T. Day

Applied Solar Engineering, Inc.
P. O. Box 5148
San Antonio, TX 78201
Attn: Tom Wisneski

Water and Power Resources Service
P. O. Box 25007
Denver, CO 80225
Attn: R. L. Zelenka, Code 254

Exxon Enterprises Inc.
Solar Thermal Systems
P. O. Box 592
Florham Park, NJ 07932
Attn: Bob Garman

Battelle PNL
P. O. Box 999
Richland, WA 99352
Attn: S. P. Bird

Solar Energy Research Institute
1536 Cole Blvd.
Golden, CO 80401
Attn: John Thornton

Gibbs and Hill, Inc.
393 7th Ave.
New York, NY 10001
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