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The University of Houston Solar Central Receiver Code System: Concepts, Updates, and Start-Up Kits

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and the Energy Laboratory, University of Houston

ABSTRACT

The University of Houston Solar Central Receiver Code System, developed over the last 15 years, is a valuable tool for use in design studies and performance assessment of central receiver heliostat fields and their interaction with the receiver. The Code System was used to design Solar One (located in Barstow, CA) and has been used in other primary design studies. This report complements the original *User's Guides*. The Code System has been converted to standard FORTRAN 77 and is now principally maintained on a VAX 11/785 computer system, which greatly increases its portability and makes it more widely available. The Code System has been extensively used, developed, improved, and documented to a high state of reliability, adaptability, and user friendliness.

TO
Those Who Have Gone Before

Acknowledgments

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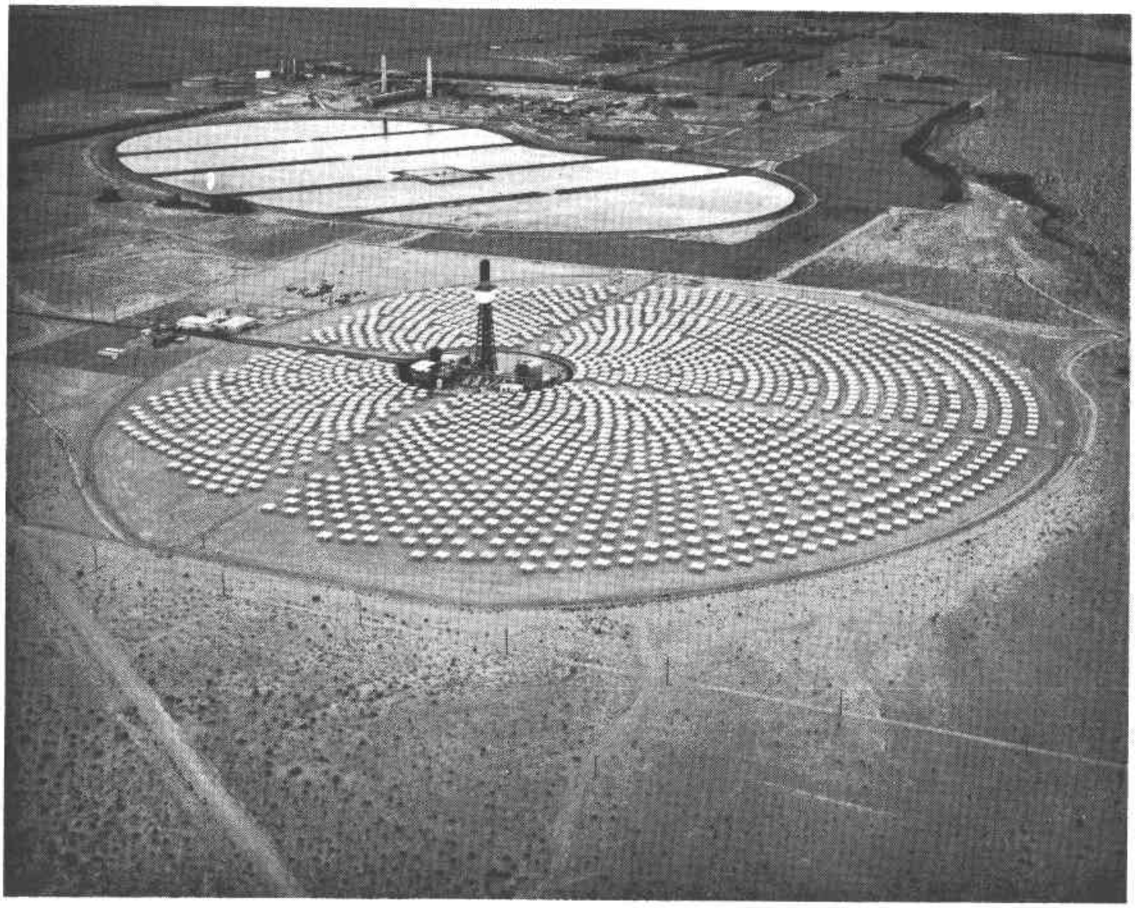

Figure 1.-1 Photograph of **Solar One**, the U.S. solar central receiver pilot plant in Barstow, CA. The plant generates 10 MW of electrical power, enough for the needs of a community of ~6,000 people. The 1818 heliostats are continuously aimed by the master-control subsystem to reflect direct sunlight onto an external cylindrical receiver atop the tower. The receiver is 7 m in diameter and 14 m in length, and its centerline is 76 m above the plane of the heliostats. Each 7 m x 7 m heliostat has 39.3 m^2 of reflective area. Total reflective area is 0.071 km^2. The heliostat field and plant structures occupy a ground area of ~0.3 km^2 (75acres). Water is pumped up and through the receiver where it is heated to steam by the concentrated sunlight. At design-point, 14.1kg/s of steam at 510°C and 101 atm is returned to ground level where it drives a Rankine-cycle turbine. Some of the steam is diverted through a heat exchanger to obtain a maximum of 4 hrs of thermal storage in hot oil and rocks. Completed in early 1982, the construction costs for this first-of-a-kind plant were ~$140 million. (Photo courtesy Southern California Edison Co.)

1. INTRODUCTION

The University of Houston (UH) Solar Central Receiver Code System is a valuable tool for designing solar central receiver plants, such as Solar One (Figure 1.-1). It provides the capabilities to analyze and optimize the collector-receiver system and to specify the coordinates of the individual heliostats of the resulting optimized solar plant. The UH Code System consists of three programs:

(1) **NS**, the cellwise performance code.

(2) **RC**, often called RCELL , the optimizer.

(3) **IH**, the individual heliostat layout and performance program.†

The most recent version of the UH Code System is the "University of Houston Solar Central Receiver Code System 1988," which includes NS88, RC88, and IH88.

Concepts, Updates, and Start-Up Kits has three major Parts:

(I) Concepts, in which many of the fundamental principles and methods used to design the UH Code System are discussed.

(II) Updates , in which the major enhancements of and updates to the UH Code System since the 1980-1985 *User's Guides* are described.

(III) Start-Up Kits, in which you are lead through the steps required to initiate the typical runs involved in a complete study, from optimization through coordinate specification.

† A fourth program, **CAVITY-CREAM**, is a two-band model (IR and Visible) for handling the problem of thermal and visible radiation exchange in a cavity receiver (which can have an arbitrary shape so long as it is everywhere concave). **CAVITY-CREAM** is available separately, after specific request and negotiation.

You will need the following reference manuals, collectively referred to as the ***User's Guides***:

(1) *A User's Manual for the UH Computer Code RC: Cellwise Optimization.* [1]† (This is the ***RC User's Guide***.)

(2) *A User's Manual for the UH Solar Central Receiver Cellwise Performance Model: NS.* [2] (This is the ***NS User's Guide***.)

(3) *Theory of Cellwise Optimization for Solar Central Receiver Systems.* [3] (This is the ***Theory User's Guide***)

(4) *User's Manual for the UH Individual Heliostat Layout and Performance Code.* [4] (This is the ***IH User's Guide***.)

(5) *Generalized Layout for Collector Field with Broken Planes Including Modifications to the RC-Optimization, CELLAY, and IH-Performance Codes.* [5] (This is the ***Multiplane User's Guide***.)

The *User's Guides* have been archived with the National Technical Information Service (NTIS), except the *Multiplane User's Guide* which is available from UH. Although written for NS80, RC80, and IH82, the *User's Guides* still provide a thorough and reasonably up-to-date discussion of the inputs, outputs, and other important characteristics of the UH Code System.

You can also obtain additional documentation. A 40-hour videotaped course with written *Course Notes* [6] covers the physics and code development methodology of the UH Code System and is available from Sandia National Laboratories, Albuquerque (SNLA). If you require even more in-depth knowledge of the UH Code System, Appendix D contains a selected list of UH Solar Central Receiver Documents.

You should note well the relationship of *Concepts, Updates, and Start-Up Kits* to the substantial amount of documentation already available for this complex code system. The goal of this report is to provide enough information in addition to the comment lines in the code system's input modules so that an experienced engineer who is

---

† The REFERENCES section contains complete bibliographic information for the *User's Guides*. A number within brackets indicates the reference number.

knowledgeable about solar central receiver systems and who has some computer experience could operate the codes adequately (i.e., could set up the less sophisticated inputs and make most of the typical runs). However, this report is not self-contained. The *User's Guides* should be consulted, when necessary, for clarification of topics already covered adequately therein and also used as more extensive reference manuals. Therefore we assume that you have access to, and some familiarity with, the *User's Guides*.

To further delineate the relationship between this report and previous documentation, consider the three Parts of this report. Part I, Concepts, is a basic introduction and not a treatise on the Physics and Code Development Methodology [6]. Part II, Updates, assumes that you have some minimal degree of familiarity with those parts of the UH Code System that are being updated. Consult the *User's Guides* for such information. Part III, Start-Up Kits, helps you to learn how to operate the UH Code System, but it does not discuss all of the possible inputs and outputs. Consult the *User's Guides* for such information.

The start-up kits are a guide to the operation of the UH Code System. They assimilate and integrate the most frequently used pieces of the *User's Guides* into a concise, structured, and manageable form. Each start-up kit has a specific function; Figure 1.-2 shows how the start-up kits are related to each other. Section 5 covers initial procedures such as tape handling, establishment of subdirectory structures, and setting up your first set of input modules for a system study. Section 6 describes in detail (for the beginner) how to obtain your first, good, useful database; this material is summarized in Section 7.1. Section 7 outlines the steps involved in making the five most common types of runs. These most common runs are also those involved in a basic system study, which may be adequate to provide your required cellwise design (especially if the tower focal height and receiver dimensions are already well-defined); if so, proceed directly to Section 11 upon completion of 7. The start-up kit in Section 9 should be used to provide the intermediate and final designs for systems having significant peak flux constraints. The start-up kit in Section 10 (for GOPT)† should be used for systems without significant peak flux constraints and is a major advance in the design of such systems.

† GOPT (pronounced "gee-opt"), an acronym for grand optimization, is a recent update to the UH Code System. See Section 4.4.

Only one of these three start-up kits (i.e., either 7, 9, or 10) should be needed for any particular design study. The beginner will likely use Section 7 for the first study. Section 8 describes the runs for some special studies that you may wish to make. Sections 6 to 10 only discuss NS and RC runs. Section 11 is concerned with IH runs, and the associated NS and RC preparatory runs, and describes how to lay out the individual heliostats given the optimum cellwise design obtained from RC. IH generates coordinates for every heliostat, as would be required to give to the surveyor or to generate a computer image of the actual heliostat field. Of course, such detailed information is not required for all system design studies (e.g., conceptual designs).

We hope that *Concepts, Updates, and Start-up Kits* will be a valuable addition to the documentation available for the University of Houston Solar Central Receiver Code System. Many of the updates described are a direct result of a major effort to increase the user friendliness of the UH Code System, and this document is itself a part of that effort. Over the past 15 years, the UH Code System has been extensively used, developed, improved, and documented. We hope that our commitment to reliability and adaptability and our greatly increased commitment to user friendliness will result in even greater acceptance, dissemination, and use of the UH Code System by the solar community.

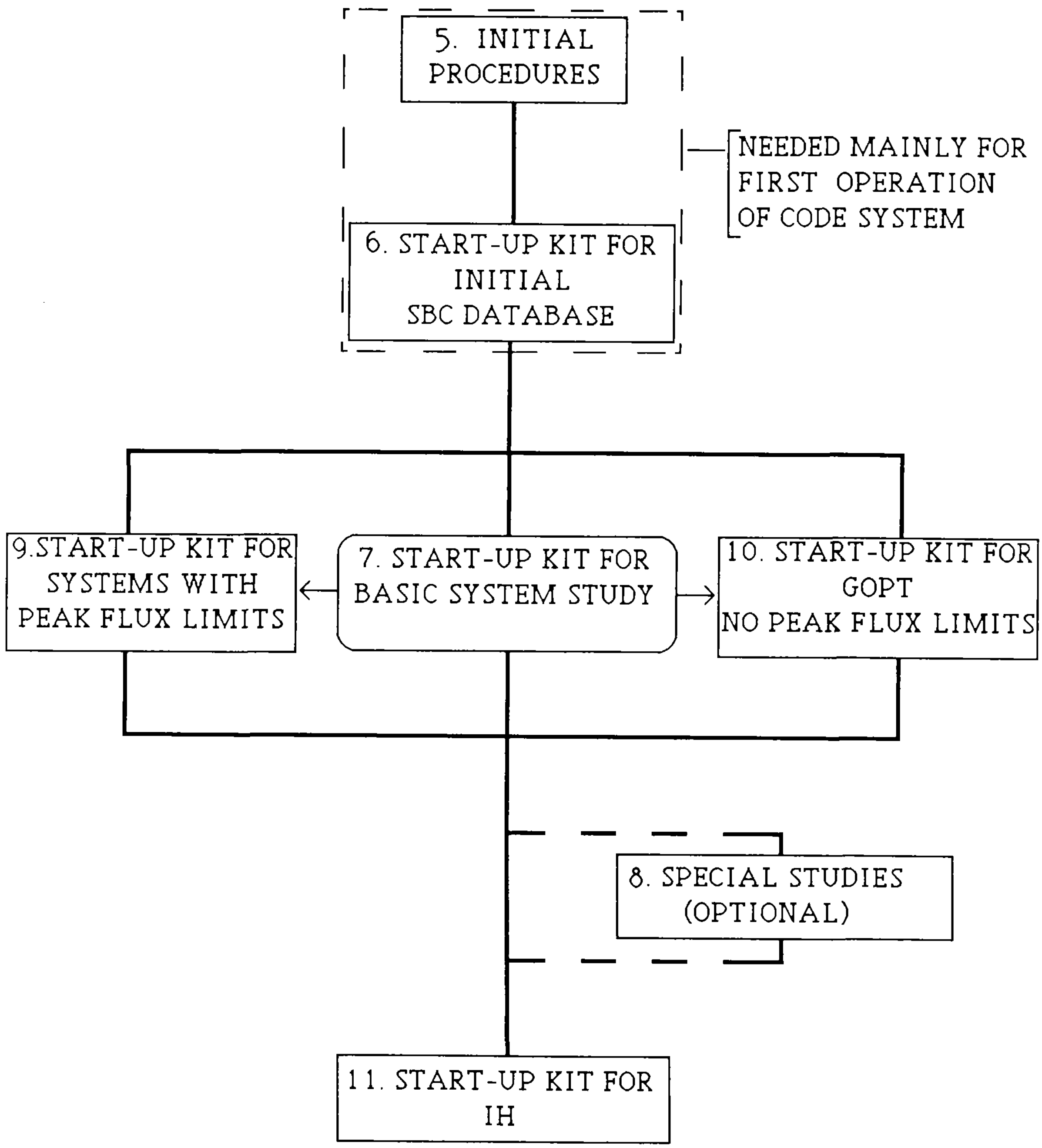

Figure 1.-2 Interrelationship of Start-Up Kits. Kit numbers refer to Section numbers in this report; e.g., the first kit is kit 5 because it is Section 5 of this report. Note that, unlike the rest of kits 5 and 6, Section 5.2 is helpful for initiating any new system study, not just the first. Dark lines show how the kits relate to each other, in terms of the order of their use in a typical system study. Start-up kits at the top of the page are generally needed before those further down. Kits 7, 9, and 10 are at the same level on the page because only one should be needed for any given study. However, the lighter arrows pointing from 7 to 9 and 10 indicate that some information flows out from 7; i.e., when using kits 9 or 10, you may need to refer back to kit 7, which provides general instructions for making some of the more common NS and RC runs.

INTRODUCTION

PART I

CONCEPTS

UH

UNIVERSITY OF HOUSTON

ENERGY LABORATORY

SOLAR THERMAL DIVISION

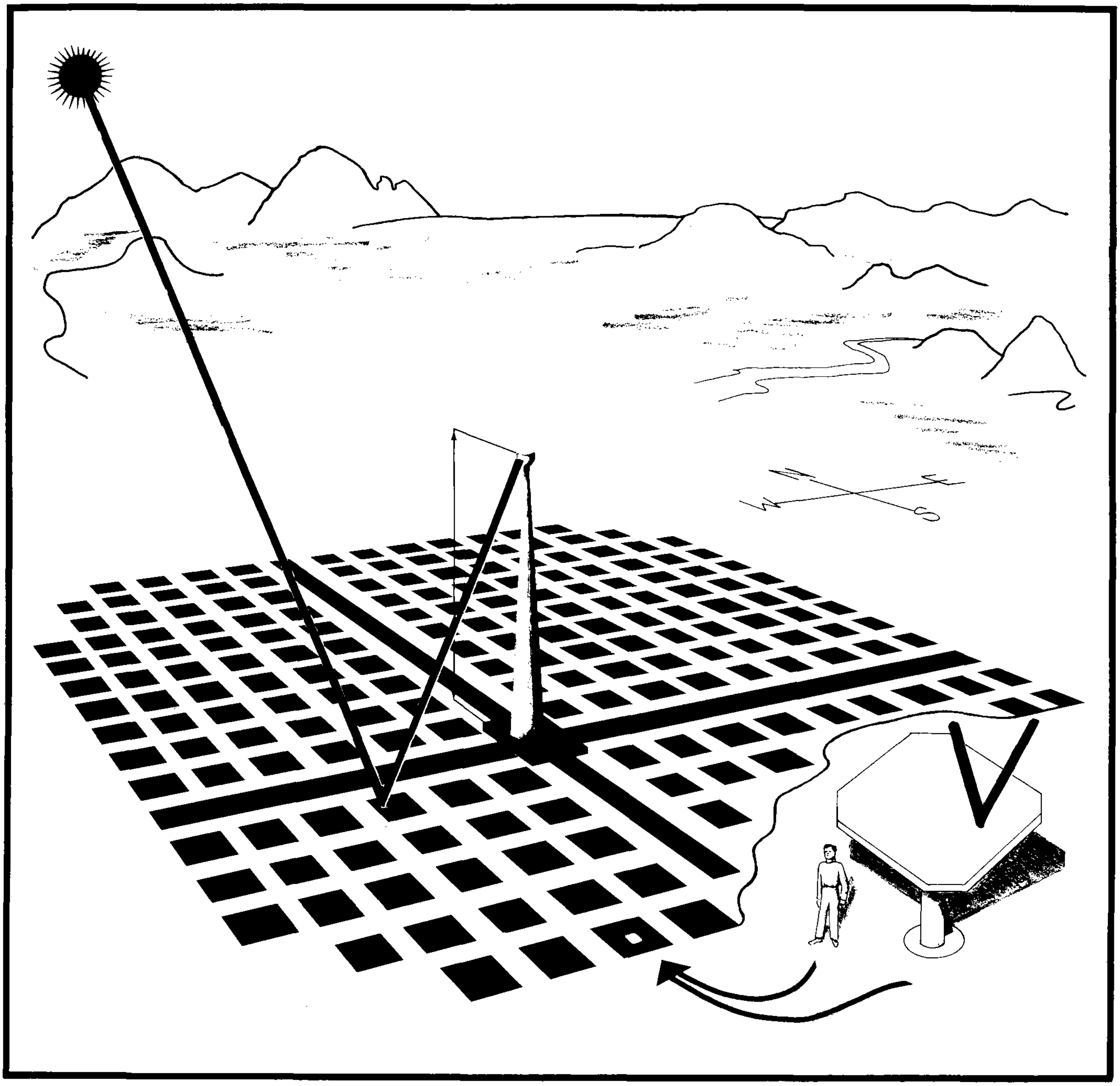

Figure 2.1-1 A schematic view of a solar central receiver system. The tower-top receiver is shown near the center of an array of squares. Each square suggests a cell of the **cell model** and, for a commercial system, would contain several dozen heliostats. The inset at the lower right shows a heliostat with a man, to suggest the scale. More modern heliostats tend to be even larger.

2. THE CELLWISE CODES NS AND RC: BASIC CONCEPTS

In Section 2 we will give a review of some basic aspects of NS and RC, including the most frequently used scaling relationships, and we will show how to scale a given system design to another power level.†

2.1 NS and RC: Some Basic Concepts

Rather than carry out a Monte Carlo analysis of the entire optical system in one step, our analysis proceeds in a step-by-step fashion through the cost and performance of each major element of a central receiver system. Beginning with the generation of diurnal solar position and intensity, the analysis continues with the definition of collector geometry, heliostat shading and blocking, image formation and degrading, receiver flux profiles, receiver thermal performance, and costs of the system components. By choosing the important variables to be angles or ratios at each step, parts of the calculations become quite general and may be stored on disk files for reuse.

The ultimate performance of a solar central receiver system is limited by: (i) the "surface" temperature of the sun (around 6000 K), (ii) solar limb darkening, (iii) the **solar limb angle** as seen from earth ($\alpha = 0.00466$ rad $\cong 0.25°$), (iv) the extra-terrestrial **solar constant** (taken as 1353 W m^{-2}, varying by about ±3.5% due to eccentricity of the earth's orbit), and (v) the earth's atmosphere, which attenuates the incoming solar beam. In the UH Code System, a diurnal motion generator computes the location of the sun, for an input site latitude and a series of input times (measured from noon on the vernal equinox), and an insolation model which uses input climate data computes the corresponding direct beam intensity. RCELL can write these "sun sample" results to a disk file called SUNSAM.

† See Appendix D for a selected list of references that provide complete details of the theory, mathematics, methods of implementation, and evolution of the UH Code System.

Over 5000 heliostats will be used in a system designed to generate 100 MW of electrical power (denoted 100 MWe). Consequently, we divide the field into a number of identical square **cells** (Figure 2.1-1) and do detailed calculations for a heliostat at the center of each cell, the **representative heliostat**. All other heliostats in that cell are assumed to behave similarly, but deviations from perfection,such as guidance errors, are taken to be statistically independent and are thus represented by an axisymmetric Gaussian degrading function. The DIMENSIONs of the array of cells is input via PARAMETER statements and, for reasonable resolution without requiring undue computer time, should be selected so that the resulting field will fill about 150 - 250 cells. A 15x17 array of cells is typical.

The cell size, in meters, must be specified. Of the many possible ways to do this, we choose to define the size of the cells in terms of the tower height. Let **DA** denote the length of a side of each cell in the field. Let **HT** denote the **tower focal height**, i.e., the vertical distance between the receiver and heliostat centerlines. We define DA by the equation DA = k • HT, where k is an arbitrary constant of proportionality. For historical reasons, we choose to assign values to k using the relationship $k = \sqrt{ORDER/4}$, where **ORDER** is an input parameter in input module FIELD. Thus, the mathematical relationship between cell size and tower focal height is

$$DA = HT \times \sqrt{\frac{ORDER}{4}} \qquad (2.1\text{-}1)$$

The location of the tower is input in terms of cells. For example, in Figure 2.1-1 the tower is in cell (11,7), counting the northwest cell as (1,1) and assuming, as implied by this particular figure, that the roads occupy a full row and a full column of cells.

From simple trigonometry, you can easily see (Figure 2.1-1) that choosing DA to be proportional to HT makes the receiver elevation angle independent of HT.† Thus, the geometrical

† If you do not see this simple fact from Euclidean geometry, then note that the receiver elevation angle θ is the angle that the line of sight to the receiver makes with the plane of the heliostats' centerlines, which is the horizontal plane in Figure 2.1-1. For a cell that is n cells south of the tower and m cells east, $\tan\theta = HT/(DA\cdot\sqrt{m^2 + n^2}) = [(m^2 + n^2)(ORDER/4)]^{-1/2}$, and so θ is independent of HT.

relationship between the receiver and the center of each cell is completely fixed once the cell array DIMENSIONs, the tower location in cells, and ORDER are specified. From simple trigonometry, the first critically important geometrical relationship has been obtained:

Geometrical Relationship 1

> If the primary field variables are chosen to be cell array DIMENSIONs, tower location in cells, and ORDER, then the system can be scaled with HT, with no effect on the fundamental field geometry.

Each heliostat normal must bisect the angle between the sun and the receiver. The sun's location is given by the diurnal motion generator, and the receiver's location is determined by the field geometry, as described above. Therefore, the instantaneous orientation of each heliostat in the field is completely defined and is independent of HT when the cell array DIMENSIONs, the tower location in cells, and the value of ORDER are specified.

Given the instantaneous orientation of each representative heliostat, the cosine of the angle of incidence (**cos i**) is computed for each. The cos i is essentially a mirror foreshortening factor and affects the instantaneous efficiency of the various portions of the heliostat field. The values of cos i are integrated over a year, after weighting them by the anticipated solar intensity, to provide the annual energy that an isolated heliostat in each cell would redirect. The associated **field matrix** (i.e., any matrix with an entry for each cell in the heliostat field) is then input to a CONTR subroutine that draws the contours of constant annual energy redirected by isolated heliostats. Such information is very useful to the field designer. For example, at about 30° N latitude the low values, ~0.6, of annual-average cos i found on the south side of the tower compared to ~0.8 on the north side indicate that the tower should be more toward the southern third of a surround field, rather than in the exact center.

Currently, the UH Code System allows you to select either split-rectangular or round heliostats. An "alt-azimuth" mounting for the heliostats is standard, but other mounting systems can be chosen. However, some, such as polar mounts, require modifications to and recompilation of the shading and blocking subroutines in RC and NS, as directed by inline comments. The reflectivity of the mirrors is also an input. Typically, the average mirror reflectivity is 91%, but this varies with the mirror washing schedule [7, 8].

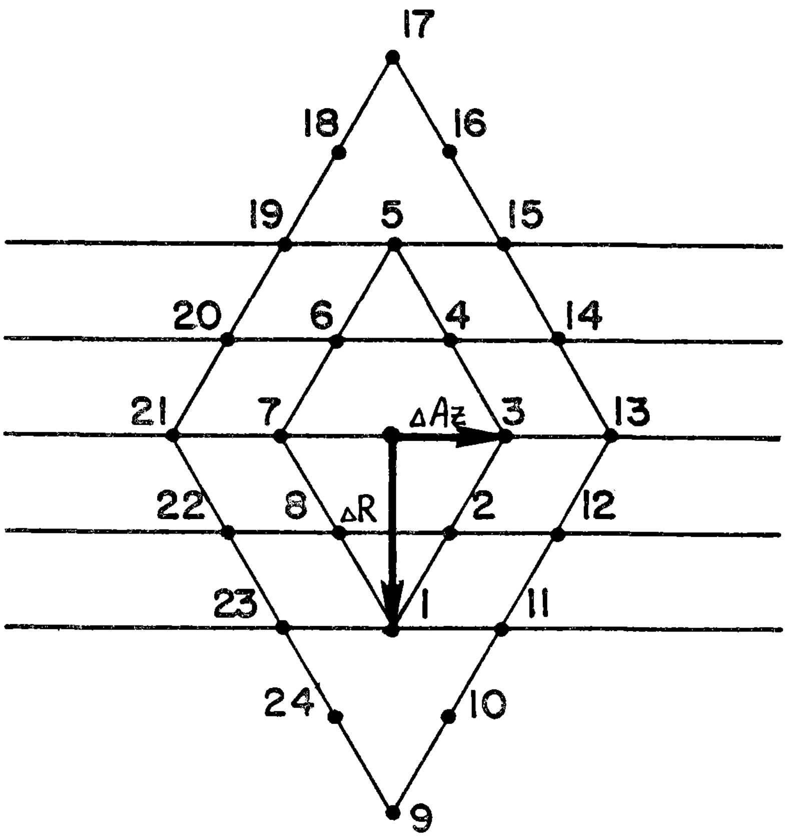

Figure 2.1-2 A radial-stagger type of heliostat neighborhood within cells in NS and RC. The representative heliostat is at the center of the figure. The definitions of the spacing parameters ΔR and ΔAz are shown. The horizontal lines represent a local straight-line approximation to tower-concentric circles. Each neighbor is numbered as in the codes. Neighbor no. 1 is toward the tower. Changing the ratio ΔR/ΔAz results in a different radial-stagger arrangement of the heliostats within a cell.

The calculation of the **shading and blocking** of heliostats by their neighbors is accomplished by examining the neighbors of each representative heliostat. The eight nearest neighbors are sufficient for most times, but for the low sun angles around sunrise or sunset as many as forty-eight neighbors must be considered.

The neighbors of each representative heliostat are arranged in a regular array by both NS and RC. The standard array is a radial stagger, although other regular arrays are available. In a **radial stagger array** (Figure 2.1-2), the neighbors are put on concentric "diamonds" surrounding the representative, with the diamonds' "major axes" pointing straight toward the tower. Alternate rows of heliostats are staggered; thus the nearest neighbor directly in front of the representative is two rows toward the tower, and the representative peeks between the two nearest neighbors on the intervening row. Note that the definitions of the spacing parameters ΔR and ΔAz are also shown in Figure 2.1-1. The arrangement of the heliostats in these local neighborhoods into exactly regular arrays is a good approximation, except for systems of less than a hundred or so heliostats, and is an important characteristic of the cellwise codes NS and RC. In contrast, the individual heliostat code, IH, uses the exact location of neighboring heliostats.

Blocking predominately occurs far from the tower and on the anti-sun side where the mirrors tend to be more nearly vertical. Although shading can occur in any portion of the heliostat field, the closer spacings near the tower, allowed by the lack of blocking, cause shading to predominate there. Shading is minimal on the sunward side where the mirrors tend to be horizontal.

The shading and blocking routines work by projecting "images" from adjacent heliostats generated by the sun (shading) and by the receiver (blocking) onto the plane of the representative heliostat. The area of the remaining, or luminous, region is computed and compared to the heliostat area to get a **fraction reflecting**. The heliostat neighbors are assumed to be exactly parallel to the representative heliostat -- a good approximation for **DMIR**† smaller than ~HT/5. The algorithm for split-rectangular heliostats is a true multiple-event processor; i.e., overlapping shading and/or blocking

† DMIR is the characteristic heliostat width. Historically, DMIR has been defined as $\sqrt{L \cdot W}$ for spilt-rectangular heliostats and as $2 \cdot (R+\delta)$ for round heliostats, where δ is the width of the non-reflecting outer ring.

events are recognized, and the overlapped area is counted only once. The algorithm for round heliostats is (like those in the DELSOL computer code) a single-event processor; i.e., overlapping events are not recognized, and the overlapped area is deducted for each separate event.†

Neither shading nor blocking depend significantly on mirror size; rather they depend primarily on the sun-heliostat-receiver positions and on the heliostat spacing measured in units of mirror width, DMIR.‡ This simple observation yields the second critically important geometrical relationship:

<u>Geometrical Relationship 2</u>

> If the spacing between mirrors is measured in units of mirror width (DMIR), then the shading and blocking calculations are essentially independent of DMIR.

The sun-heliostat-receiver positions have already been discussed; see Geometrical Relationship 1. The UH Code System takes advantage of both of these geometrical relationships, which may be combined and reexpressed as follows:

<u>Corollary</u>

> If the system variables are chosen as described by Geometrical Relationships 1 and 2, then the shading and blocking calculations are essentially independent of both DMIR and HT (for DMIR/HT less than about 1/5).

This allows the results of shading and blocking calculations to be stored on a disk file (called the shading, blocking, cos i database, or **SBC database**, for short) for use during RCELL optimization runs. An SBC database has equal validity when used with any tower focal height (HT) and any mirror diameter (DMIR), whereas a change in heliostat shape, mounting system, cell array DIMENSIONs, ORDER, tower location, or site would require a new SBC database to be computed.

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† This is true for NS and RC only. The IH shading and blocking algorithm for round heliostats has recently been enhanced and is now a multiple-event processor.

‡ Although this is a simple geometrical fact, see [2], Vol. 1, pp. 40-42 if help is needed.

At this point in the analysis, the power redirected by the heliostats in each cell of the field, after accounting for shading, blocking, and cos i losses, can be computed and integrated to obtain the annual **energy redirected** from each cell. An SBC database contains, for each field cell, the annual energy redirected from that cell for each of sixteen different heliostat spacings, measured in units of DMIR.

After redirection (and the attendant reflection loss, considered separately), the solar beam from each heliostat traverses a significant length of atmosphere, which absorbs and scatters a fraction of the beam. Depending on the clarity of the atmosphere, this effect can be quite significant, especially for the distant heliostats. The UH Code System incorporates both the DELSOL visual range model (which was developed by Vittitoe and Biggs [9]) and the more general UH **visual range model** [10,11] (which is an extension to the work of Vittitoe and Biggs). The choice of model is governed by ICORN in input module HELIOS. According to well-known physical principles, atmospheric attenuation increases exponentially with beam path-length and so it does not scale linearly with HT. Fortunately, for good solar sites, atmospheric attenuation is typically a small effect (a few percent).

If a sufficiently large receiver were used, the redirected and attenuated power could be used directly to calculate the power incident on the receiver. However, due to beam divergence from the more distant heliostats, such a receiver would be excessively large and expensive and would experience large radiation and convection losses, reducing the system efficiency. Thus the fraction of the redirected and attenuated power from each cell that actually hits a receiver of a given size must be calculated; this is called the receiver interception fraction, or **interception**, for short. Note that interception fractions are true fractions and so are independent of the effects of reflectivity, cos i, shading and blocking, atmospheric attenuation, etc.

The interception depends only on the solar limb angle, DMIR/HT, heliostat focal length/HT, the beam degrading, WCYLNT/HT, and HCYLNT/HT, where **WCYLNT** is the receiver width or diameter and **HCYLNT** is the receiver length. Thus, the interception (and, approximately, the flux density† as well) is

† Atmospheric attenuation introduces a slight non-linear dependence on HT.

independent of HT, but is dependent on ratios such as DMIR/HT. Physical intuition can help to understand this dependence; for example, consider how the flux density is not affected by shrinking every linear dimension by the same percentage. An elementary approximation of the interception [Eqs. (6.1-1) and (6.1-2)] also shows the dependence of the interception on angles and ratios. However, for relatively large values of DMIR/HT, this elementary approximation becomes less accurate because optical aberrations such as astigmatism become increasingly severe. Thus Eqs. (6.1-1) and (6.1-2) need to be modified for relatively large values of DMIR/HT, but this does not change the basic conclusion that the interception and (approximately) the receiver flux density depend on angular quantities and ratios such as DMIR/HT and not on DMIR or HT separately. These considerations lead non-trivially to Geometrical Scaling Relationship 3:

Geometrical Scaling Relationship 3

> If all linear dimensions of a central receiver system, including DMIR, heliostat focal length, WCYLNT, and HCYLNT are scaled with HT, then the interception and (approximately) the receiver flux density† are unchanged.

Unfortunately, in most design studies, DMIR is fixed and cannot be scaled with HT. Even in this case, scaling of the system with HT is a reasonable approximation for finding the starting point for further RCELL runs because the interception typically has only a small dependence upon DMIR/HT. However, the magnitude of the dependence upon DMIR/HT varies with heliostat focal length. Receiver interception from heliostats focused to **slant range** (i.e., the distance from the heliostat to the receiver) retains a small but significant dependence upon DMIR/HT due to optical aberrations. At the other focal extreme, the interception from flat heliostats has a relatively large dependence upon DMIR/HT, even though optical aberrations are nonexistent, due to the large projected image of a flat heliostat relative to the projected solar disk.

The receiver flux density calculations are quite involved, and so the results are saved on a disk file called a **node file**. For each cell in the field, a node file lists the interception fraction of each **node** (i.e., flux evaluation cell) on the receiver. Node files are intrinsically dependent upon DMIR/HT, heliostat focal length/HT,

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† Atmospheric attenuation introduces a slight non-linear dependence on HT.

WCYLNT/HT, and HCYLNT/HT, and so a new node file must be made if the value of any of these ratios is changed.

NOTE: Currently, the subroutines that control verification of node file headers will halt a run if the input values of DMIR, HT, WCYLNT, HCYLNT, or heliostat focal characteristics do not agree with the corresponding values on the node file. However, if DMIR/HT, WCYLNT/HT, HCYLNT/HT, and heliostat focal length/HT agree, then the node file is still valid and can be used by turning off the node file header verification by setting NVERI = 1 in the appropriate STD subroutine. If desired, you can easily modify the header verification routines to verify the ratios instead of the quantities themselves.

Currently, the image-generator subroutines calculate the flux density distribution reflected by each representative heliostat using a Hermite polynomial approximation, which includes a Gaussian function to simulate beam degrading due to mirror surface imperfections and random mirror aiming errors. This method is called HCOEF. However, an alternative method called FLASH is also available, which is based on an analytic evaluation of the flux density integrals. (Note that FLASH has not yet been tested in the new VAX computer environment.) Both methods provide accurate results. The approximations in HCOEF begin to break down for large heliostat images, i.e., when the size of the heliostat image cast by a "point sun" exceeds the size of the true sun's image produced by a "point mirror." Here, "the heliostat image" means the "demagnified" (i.e., minified) image produced at the receiver by a partially focused heliostat.

Once the reflected beams strike the receiver, some of the light is reflected and the remainder is absorbed. This loss is properly treated as a multiplicative loss, rather than as a subtractive loss. **Receiver absorptivity** varies with the age and type of receiver (i.e., cavity vs. external). Long-term averages for external receivers are typically estimated in design studies to be about 0.92 [7, 8].

Of the thermal energy absorbed by the receiver, only a portion is also absorbed by the working fluid, and the remainder is lost by thermal radiation and by convection. **Receiver thermal losses** are subtractive losses. In the UH Code System, the annual receiver thermal loss is the product of a thermal loss constant in kW m^{-2} (BLOSS in input module RECVER), the receiver area in m^2, and the number of hours per year that the solar central receiver system is operational. (Note that pre-heat panels can also be accommodated via inputs HLOSS and PREPAN.) Receiver thermal losses scale as the area of the receiver; this is nominally true even for convection, although, for cavity receivers, you must be quite careful to choose the proper portion of the receiver area at each stage of the calculation.

After accounting for all of the above effects, the instantaneous power absorbed by the working fluid and delivered to the base of the tower is computed.† The **annual thermal energy** delivered to the base of the tower is computed by integrating over a year. Typically, NS evaluates the instantaneous power at 7 points in time per afternoon, doubling the results, and does this for 12 days per year to perform the annual integral; RC uses 19 points in time per day, from start-up to shut-down, and 12 days per year to perform the annual integral.‡ The 12 days per year is effectively a requirement for RC, but you may readily alter the input values of the other time controls in RCDRIV and NSDRIV. Similarly, you may select to use the UH insolation model or you can input insolation data. The UH insolation model requires monthly climate data to be input via input module FIELD.

Once the annual thermal energy delivered to the base of the tower has been computed, the costs of the various components are calculated and the cost-benefit ratio (called the **figure of merit**) is determined for the solar central receiver system. The costs include both capital costs and present value (PV) of operations and maintenance (O&M) costs for the lifetime of the plant.

Heliostat costs are input on a per m^2 basis. The total cost of heliostats, which is typically 50 to 70% of the system costs considered, scales as HT^2 because the field geometry scales with HT, as discussed earlier. The total cost of land also scales as HT^2. The wiring costs scale approximately as the product of the heliostat azimuthal spacing and the number of heliostats, which in turn scale as $DMIR \times (HT^2/DMIR^2) = HT^2 / DMIR$.

The cost equations for the tower, receiver, vertical piping, and main feed pump typically vary approximately quadratically with HT or linearly with absorbed thermal power. However, more accurate

† Typically, the thermal power lost by conduction through the walls of the downcomer piping is relatively insignificant in a well-insulated downcomer.
‡ The 12 days per year is often referred to as 7 days per year. (See footnote to Table 2.1-I.)

scaling laws for these cost equations are usually available and should be used.

Miscellaneous costs, such as for fencing and permits and extra cost for land preparation around the structures in the tower exclusion region, are included via the variable CFIXD, "fixed costs."

Balance-of-plant costs, such as for turbine-generator or thermal storage, and the cost of the plant operator(s) are not currently included in the RCELL optimization process. The cost of the plant operator(s) is a particularly significant disadvantage for small systems. Balance-of-plant and operator costs may be included by inserting appropriate cost equations. However, if you insert cost equations for the turbine-generator and/or thermal storage, then you must include the efficiencies of these subsystems in the annual energy calculation as well. As the coupling between these subsystems and the collector-receiver-tower subsystem is perceived to be small, it is reasonable to allow the project's Design Integrator to perform the trade studies involving solar multiple, storage size, dispatch strategy, etc, for the integrated system. Such trade studies are usually done using Sandia's SOLERGY code [12].

Table 2.1-I
NS and RC - Typical Uses

The NS code is unconcerned with costs. It is used: (i) to generate node files; (ii) to produce receiver flux maps at off-design times; and (iii) to analyze the performance of a system on an hourly, daily, and annual basis.

The RC code is quite concerned with costs. It is used: (i) to make SBC databases; (ii) to optimize the system by reading an SBC database, solving the optimization equations and iterating the solutions as required; (iii) to print out the optimum system's heliostat-spacings in each cell, the field boundary, the delivered thermal power, the delivered annual energy, the costs, etc. [Figure 6.1-1]; (iv) to read an NS node file and produce a receiver flux map for vernal equinox noon; and (v) to compute coefficients for the heliostat-spacing polynomials (which are described in Sections 3.1 and 4.7). For systems without significant peak flux constraints, the GOPT code within RC can simultaneously optimize the receiver area and tower focal height, HT, as well (Section 4.4).

NS and RC have been extensively used, improved, and documented to a high state of reliability and adaptability. We hope that this brief introduction to NS and RC has increased your basic understanding of them, thus enabling you to use them more wisely. In Tables 2.1-I to 2.1-III and in Figure 2.1-3, you will find a summary of Section 2.1, plus a few new facts as well.

Table 2.1-II
Cellwise Codes - Summary of Basics I

Astronomical model for sun positions requires only day from vernal equinox, time from solar noon, and latitude of site.

Insolation model introduces specific climate parameters and site elevation.†

A sun-sample disk file called SUNSAM contains results of model calculations for solar position and insolation for a specific site.† SUNSAM is reused for each cell when the SBC database is computed.

The generation of an SBC database requires the specification of heliostat shape, aspect ratio, mounting system, cell array DIMENSIONs (i.e., I × J), ORDER, tower location, and SUNSAM. An SBC database is independent of tower focal height (HT) and mirror diameter (DMIR).

A trajectory file (denoted TRAJ file) is a disk file used by GOPT which contains, for each field cell, a list of representative solutions to the optimization equations. The list for each cell is parametrized by the inverse of the LAGRANGIAN PARAMETER, and GOPT interpolates each list accordingly. A TRAJ file is generated by a special subroutine (INTERG), which reads the SBC database.

† Spring and fall solar positions are about the same, but the climate parameters and the earth-sun distance change.

Table 2.1-III
Cellwise Codes - Summary of Basics II

The generation of a node file requires the specification of heliostat shape and mounting, the solar limb angle, the rms beam degrading, the relative heliostat size (DMIR/HT), the aiming strategy, the relative receiver size (WCYLNT/HT and HCYLNT/HT), and the relative heliostat focal-length characteristics (which are specified by setting the heliostat focal characteristics, particularly the slant range multiplier, SRM, in input module HELIOS). A node file is independent of heliostat spacings (i.e., of ΔR and ΔAz). Interception fractions, computed from node files, are approximately independent of time of day. Node files are also used to generate receiver flux maps and panel sums for many-heliostat densities.

An SBC database, a node file, a tower focal height (HT), and a set of cost models are required to perform a standard RCELL optimization run.†

A FINT file is used by GOPT and contains sets of receiver interception fractions for every cell in the field, one set for each element in a list of receiver sizes. A TRAJ file, a FINT file, and cost models are required for a GOPT run.† (The SBC database is currently read but not used for calculations.)

To make an ANNUAL run, you must have a design-time node file and an optimum field, specified either via a file 29 or via manual input of the IGRND matrix (for the field boundary) and COEFX and COEFY (for heliostat spacings). The NS Code then calculates diurnal sun positions, insolation, and shading and blocking fractions and generates a series of system efficiencies and clear sky powers.

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† Design-point insolation, average daily insolation per month, and annual insolation are required for this run, and these numbers are currently read from the SUNSAM disk file.

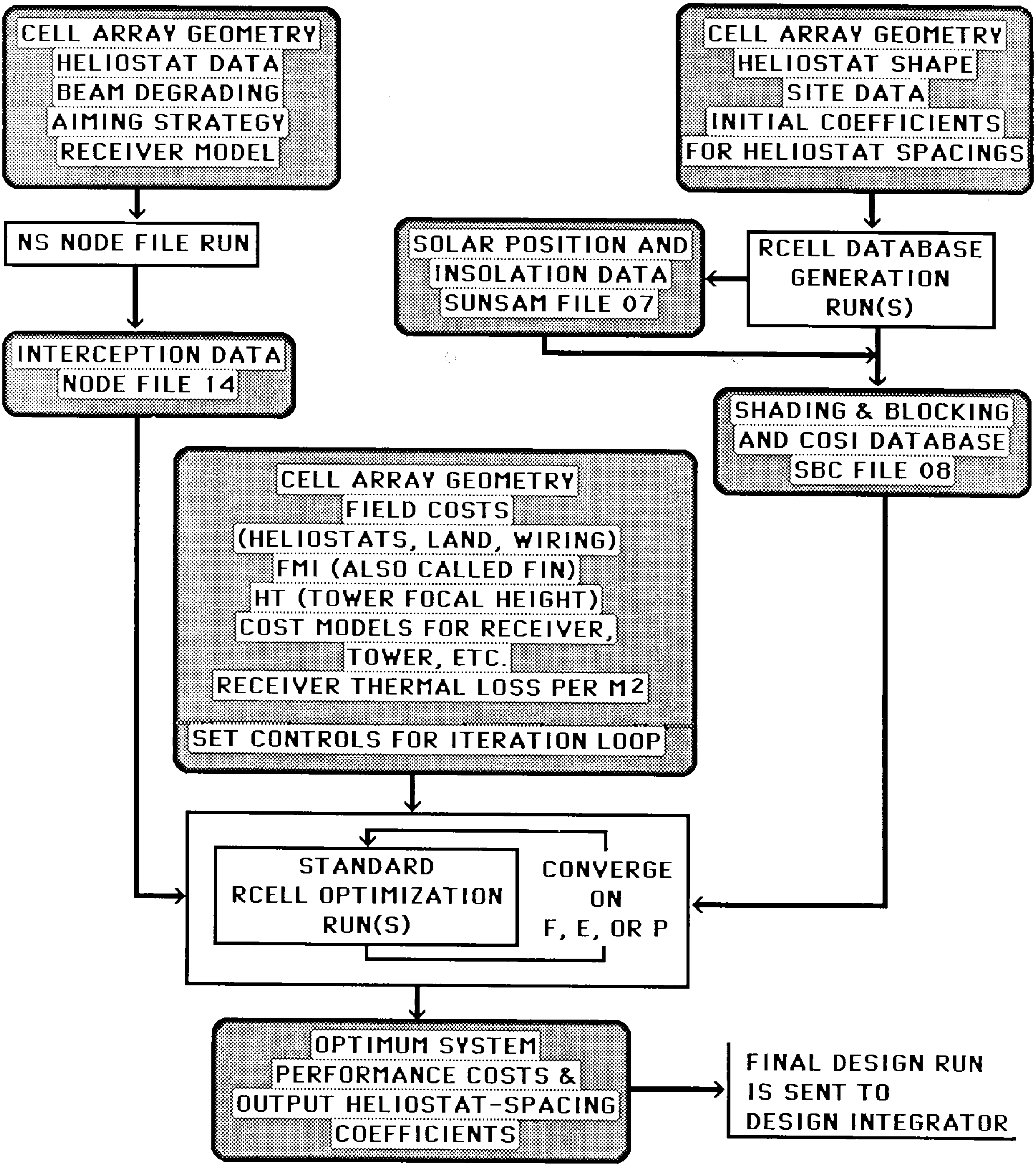

Figure 2.1-3 An Overview of the Optimization Process.

Figure 2.1-3 (facing) An Overview of the optimization process. See also Tables 2.1-I to 2.1-III. Runs are enclosed by rectangles. Both data files and manual input data are enclosed by shaded rectangles.

At the beginning of an optimization study, an NS run is made to generate a node file, which contains receiver interception data; an RCELL long run is made to generate a SUNSAM and an SBC database. A standard RCELL short run then reads the node file and the SBC database and optimizes the heliostat field; i.e., a standard RCELL optimization run finds the optimum number and spacings of heliostats in each cell of the field and computes and prints out the optimum system performance and cost. Iteration is used to converge the system to an input design-point power (P) or annual energy (E) or to the optimum power level, as determined by the system cost-effectiveness (F). Note that a recent update to standard RCELL short runs allows them to iterate automatically (see Section 4.6).

The runs shown are the minimum required for an optimization study. Other runs may also be performed, such as NS flux runs and NS annual runs. After an optimization study is completed, the final results are generally delivered to the design integrator. IH runs may then be made to lay out the individual heliostats over the optimum cellwise field (see Figure 3.4-1).

A recent update to the RC Code called GOPT (see Section 4.4) can simultaneously optimize the heliostat field, receiver area, and tower focal height, for systems without significant receiver peak flux limits. However, GOPT requires a slight modification to the process shown in Figure 2.1-3: the NS node file run is replaced by three NS Fint file runs, and the standard RCELL optimization run is replaced by a GOPT run.

2.2 Scaling Relationships

In Section 2.1, we discussed three Geometrical Scaling Relationships. Geometrical Relationships 1 and 2 are nothing more than theorems from Euclidean geometry. Geometrical Scaling Relationship 3 is based on simple principles of geometrical optics. Although easily obtained, these three scaling relationships are very important because they show that receiver interception calculations and properly constructed SBC databases are independent of the absolute size of the system. Therefore, if a given system were geometrically scaled to another size, then the new system would approximately generate a correspondingly scaled thermal power output (P).† Unfortunately, if the original system were an optimal design, you could not conclude that the geometrically scaled system would also be optimal because realistic cost models do not scale strictly geometrically (i.e., as HT^2 or as P). Thus, optimal systems have no equivalently simple scaling rules. On the other hand, the three Geometrical Scaling Relationships can sometimes be used to approximately scale an optimal design without forcing the new system too far from optimum.

The three Geometrical Scaling Relationships may be restated as follows:

(1) If the primary field variables are chosen to be cell array DIMENSIONs, tower location in cells, and ORDER, then the basic geometry of the whole system is preserved under a uniform expansion or contraction scaled by the tower focal height (HT).

(2) If, in addition to (1), the spacings between heliostats are chosen to be expressed in units of mirror diameters (DMIR), then shading and blocking are independent of both HT and DMIR (for DMIR/HT less than about 1/5).

(3) If all linear dimensions of a central receiver system (including DMIR, WCYLNT, HCYLNT, and heliostat focal length) are scaled with HT, then the interception and (approximately) the receiver flux density, as well as the shading and blocking, are unchanged.

† We can only say "approximately" because atmospheric attenuation is non-linear.

With these three geometrical scaling relationships, you can immediately write down certain quantities that depend on HT^2 and also those that are independent of HT:

<u>Quantities Scaling as HT^2</u>

Area of field, total area of mirrors, area of receiver
Total power redirected or intercepted
Total thermal power loss from receiver (approximately)
Total cost of system (approximately)

<u>Quantities Independent of HT</u>

Angular sun size and intensity
Power redirected per m^2 of mirror
Receiver flux density, $W\ m^{-2}$ (approximately)
Receiver thermal power loss per m^2 of receiver surface

These considerations lead to the following simple corollary. Suppose you are given the design specifications for an optimized solar central receiver system that produces P_1 megawatts of thermal power at design time. However, you wish to design an optimized system which produces P_2 megawatts of thermal power at design time. To first order, the tower focal height of the new system (HT_2) should be approximately given by geometric scaling:

$$HT_2 = HT_1 \times \sqrt{P_2/P_1} \ . \qquad (2.2\text{-}1)$$

All other system dimensions, including mirror diameter (DMIR), receiver length (HCYLNT), receiver width (WCYLNT), and heliostat focal lengths, should also be scaled by $\sqrt{P_2/P_1}$. The resulting system will NOT be an optimized system producing thermal power P_2, but its cost-effectiveness and performance should be relatively close to that of the optimal design producing P_2 because the "optimization valleys" tend to be fairly flat near the optimum. This is a reasonable approximation, but again it is only an approximation because of non-linear effects such as atmospheric attenuation and because of certain costs that scale other than as HT^2. Therefore, it is not reasonable to try to scale an optimal design too far (typically, no more than a factor of 1.25) from the original power P_1.

NOTE: NS allows heliostat focal characteristics to be specified as "slant range plus x%", where x is determined by the value of **SRM** in input module HELIOS. For example, setting ISR = 4 and SRM = 1.2 in HELIOS will result in each heliostat focusing to slant range plus 20%. In this way, each heliostat's focal length automatically scales with slant range and thus also with tower focal height (HT).

In practice, the size of the heliostats (DMIR) is fixed in most design studies and cannot be scaled as HT. This tends to worsen the approximation (see page 16). Even in this case, scaling all system dimensions as $\sqrt{P_2/P_1}$ can be a reasonable approximation, if done prudently, and is the best way to determine your starting point for new RCELL optimization runs to obtain the new optimal design.

2.3 Example - System Scaling

Suppose you have just finished the design of a 468 MWth solar central receiver plant. (This is approximately the thermal power a 100-MWe plant with a solar multiple of 1.8 must produce.) You have found that this plant has the following optimum system characteristics:

Mirror diameter (DMIR)	=	13.76 m
Number of round heliostats	=	5,904
Total reflective area	=	0.8776 km^2
Distance from tower to north boundary	=	1246 m
Tower focal height (HT)	=	185 m
Receiver diameter (WCYLNT)	=	16.16 m
Receiver length (HCYLNT)	=	21.03 m
Limit on peak absorbed flux	=	0.80 MW m^{-2}

Polynomial coefficients for heliostat spacings:

For ΔR (in DMIR units), COEFX =
{57.084, -0.2019, 0.01012, 1.935, -0.2082, -0.0007762}

For ΔAz (in DMIR units), COEFY =
{1.9516, -0.02239, 0.0004575, 0.1079, -0.007974, 0.0001260}

Average ΔAz (in DMIR units) = 1.71

You wish to design a new system generating twice the thermal power, i.e. 936 MWth. Utilizing the method in Section 2.2, you obtain the following estimates of system characteristics:

Mirror diameter (DMIR)	=	$\sqrt{2} \times 13.76$ m	=	19.46 m
Number of round heliostats*	=	5,904	=	5,904
Total reflective area	=	2×0.8776 km^2	=	1.7552 km^2
Tower to north boundary	=	$\sqrt{2} \times 1246$ m	=	1762 m
Tower focal height (HT)	=	$\sqrt{2} \times 185$ m	=	262 m
Receiver diameter (WCYLNT)	=	$\sqrt{2} \times 16.16$ m	=	22.85 m
Receiver length (HCYLNT)	=	$\sqrt{2} \times 21.03$ m	=	29.74 m
Limit on peak absorbed flux*	=	0.80 MW m^{-2}	=	0.80 MW m^{-2}

Polynomial coefficients for heliostat spacings:*

For ΔR (in DMIR units), COEFX = {identical to originals}

For ΔAz (in DMIR units), COEFY = {identical to originals}

Average ΔAz(in DMIR units)* = 1.71 = 1.71

*<u>Note carefully which variables are independent of the scaling.</u>

You should make one RCELL run to determine the extent to which atmospheric attenuation and costs that scale other than as HT^2 change the new system's optimum characteristics from the above estimates. You should expect a small change in the number of heliostats, and, if truly dedicated, further RCELL runs might reveal a 1-2% change in the optimal HT.

At this point, however, you realize that you can not scale every linear dimension of the system with HT because you are required to use the same size heliostats in both designs. Thus, DMIR must remain fixed at 13.76 m. You again decide to use the geometrical scaling method in Section 2.2 to obtain estimates of the new optimal system's characteristics. Of course, the additional constraint on heliostat size tends to worsen the quality of these estimates (see page 16). The estimates which you obtain are

Mirror diameter (DMIR)*	=	13.76 m	= 13.76 m
Number of round heliostats	=	$2 \times 5{,}904$	= 11,808
Total reflective area	=	same as first estimate above	
Tower to north boundary	=	same as first estimate above	
Tower focal height (HT)	=	same as first estimate above	
Receiver diameter (WCYLNT)	=	same as first estimate above	
Receiver length (HCYLNT)	=	same as first estimate above	
Limit on peak absorbed flux*	=	same as first estimate above	

Polynomial coefficients for heliostat spacings:*

For ΔR (in DMIR units), COEFX = {identical to originals}

For ΔAz (in DMIR units), COEFY = {identical to originals}

Average ΔAz(in DMIR units)* = same as first estimate above

*<u>Note carefully which variables are independent of the scaling.</u>

Using these estimates as the starting point, you must make new RCELL optimization runs in order to reoptimize the system; additional NS runs will also be required because the interception and the required aiming strategy will change (see page 16). However, as you have assumed that the heliostats for both systems focus to slant range plus 20% (an inexpensive yet reasonably good focusing quality), you do not anticipate relatively large changes in the new optimum system's characteristics from the above estimates.†

† Appendix A provides an example of an alternative, but less accurate, way to make initial estimates of tower focal height (HT), receiver width (WCYLNT), and receiver length (HCYLNT).

Finally, you decide to check with the receiver designer and the program leader because the new plant is intended to be an Nth plant, whereas your prior design was for a 1st plant. The receiver designer will allow a 20% increase in the limit on the peak absorbed flux, i.e. to 0.96 MW m^{-2}, because of increases in allowable stress for the presumably more advanced receiver. Similarly, the new receiver cost algorithm should be 80% of the old algorithm. The program leader concurs with these changes and adds that the heliostat cost should be reduced from 98.20 \$ m^{-2} to 69.84 \$ m^{-2}. Finally, only one reflector replacement will be needed for the stretched membrane heliostats instead of two, which reduces the present value of heliostat O&M from 24.23 \$ m^{-2} to 20.42 \$ m^{-2}. You make all of the necessary changes to the input modules and decide to use your most recent estimates above as your starting point for the new RCELL optimization runs. After making the required runs to reoptimize the system, you find that the effect of all of these changes, including keeping DMIR fixed and (especially) reducing heliostat costs and allowing a higher peak-flux limit, is as follows:

Mirror diameter (DMIR)	=	13.76 m
Number of round heliostats	=	12,124
Total reflective area	=	1.8020 km^2
Distance from tower to north boundary	=	1822 m
Tower focal height (HT)	=	240 m
Receiver diameter (WCYLNT)	=	21.00 m
Receiver length (HCYLNT)	=	28.35 m
Limit on peak absorbed flux	=	0.96 MW m^{-2}

Polynomial coefficients for heliostat spacings:

For ΔR (in DMIR units), COEFX =

{58.736, -0.5593, 0.02059, 6.121, -0.6874, 0.01138}

For ΔAz (in DMIR units), COEFY =

{1.8410, -0.01352, 0.0002212, 0.05687, -0.002387, 0.00003108}

Average ΔAz (in DMIR units) = 1.68

The lower-cost heliostats have allowed the field boundary to spread out while packing the heliostats more densely. As a result, the optimal HT is reduced. Conversely, the higher peak absorbed flux limit has resulted in a smaller receiver, in spite of the lower receiver cost and the relatively larger flux spillage losses from the new, more distant boundary heliostats.

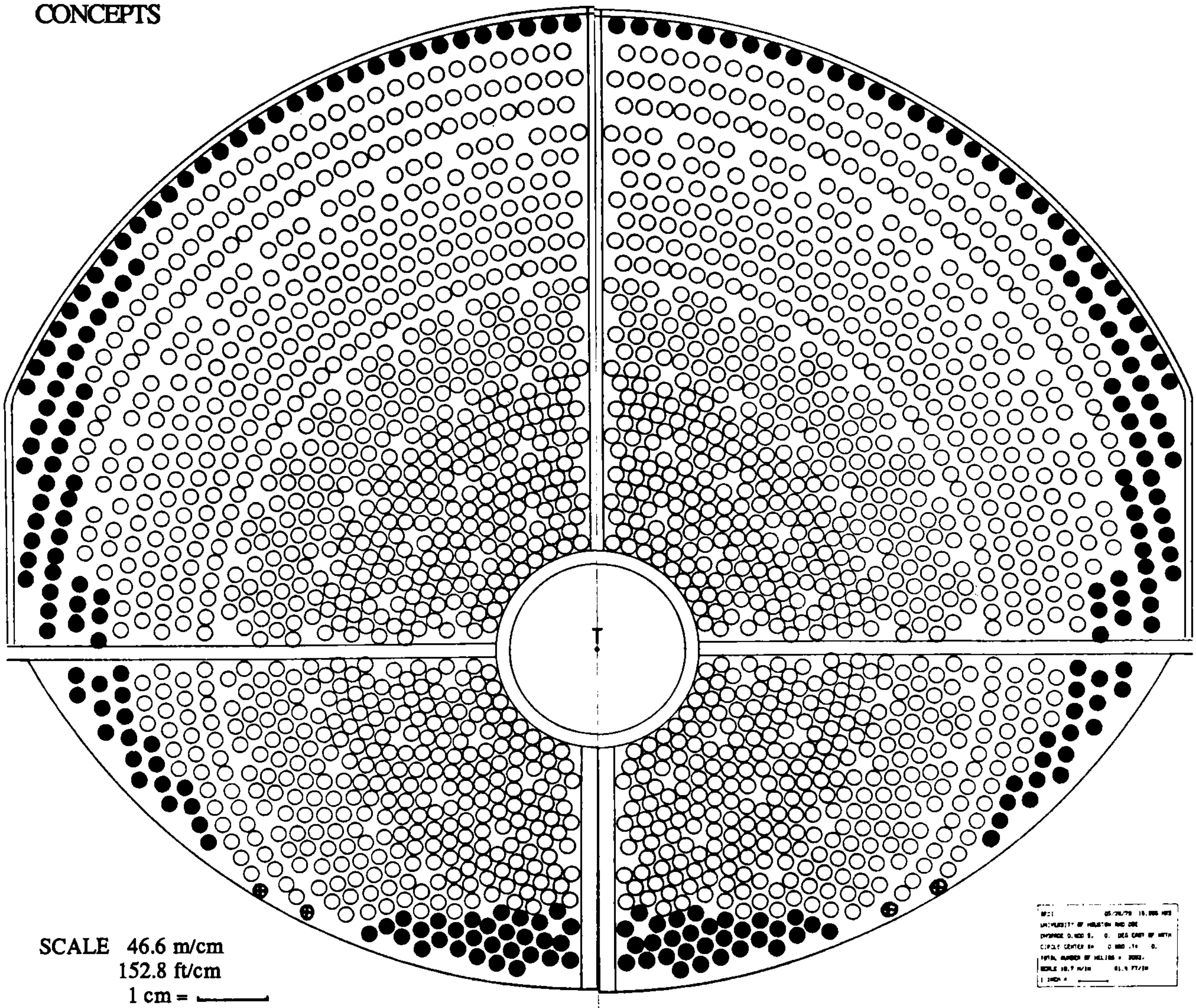

Figure 3.1-1 A scale diagram of the heliostat field layout prepared for Solar One by UH, using the IH code. Each small circle (O) represents the safety clear-out region surrounding a single heliostat. The 1818 heliostats† are strung like beads on large circles, or parts thereof, centered on the tower (T). The large circular region without any heliostats is the central exclusion zone and contains the tower, storage tanks, control buildings, turbine, etc. The general compression of the heliostats closer to the tower can easily be seen. The RCELL and NS codes were first used to determine the optimum cellwise design for a 100-MWe system. After the tower and receiver were scaled to 10 MWe, IH determined the positions of the heliostats beginning with the outermost circle and proceeding inward toward the tower. A true emulation of an optimum RCELL field is a very complex problem. Upon careful inspection, you can see several features that are characteristic of a heliostat field layout such as: (i) zones, within which the radial-stagger arrangement of the heliostats is evident; (ii) zone boundaries; i.e., the circles at which strict radial-stagger is broken; (iii) deleted and slipped heliostats, which are removed or shifted slightly, respectively, to minimize shading and blocking losses near zone boundaries; (iv) the increase in azimuthal spacing of the heliostats as you cross a zone boundary moving inward; and (v) the intricate variation of radial heliostat spacings within each zone.

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† 1818 installed heliostats (⊕ + O) + 238 empty sites (●) = 2056 defined sites in the above figure. About 72 of the original sites are empty because they were designated for potential growth; the remaining 166 are empty because of cost constraints imposed in the final design review.

3. THE INDIVIDUAL HELIOSTAT CODE IH: BASIC CONCEPTS

In the previous section we described how the cellwise codes, NS and RC, along with a considerable array of input data, can be used to define an optimized central receiver system and to estimate its performance. Following acceptance of this design and prior to construction of the system, it is necessary to define the location of each heliostat and to provide each heliostat's aim points on the receiver vs. time (i.e., as a function of image size, which is a function of solar position). The IH code provides these capabilities.

RC and NS provide the following results: (i) heliostat field boundaries; (ii) optimum heliostat spacings (Δ**R** and Δ**Az**) at the center of each cell; (iii) coefficients for polynomial fits to (ii) which yield $\Delta R(\theta,\phi)$ and $\Delta Az(\theta,\phi)$, i.e., ΔR and ΔAz as functions of receiver elevation angle θ and azimuth angle ϕ (from south);† (iv) aim points for each cell, in the form of offsets from the receiver center (or from the belt for cylindrical receivers); and (v) the fraction of the heliostats in each cell that should aim at each aim level. The field boundaries can be machine transferred to IH via a boundary vector disk file, or can be manually transferred by loading a geometrical definition of the field boundary (easily generated by plotting and curve-fitting the RC output). Detailed boundaries of roads, streams, and power line exclusions can also be input at this point. The other parameters are considerably more difficult to transfer.

3.1 The Heliostat Layout Problem

The cellwise codes, NS and RC, provide radial and azimuthal spacings (ΔR and ΔAz) for local heliostat neighborhoods at the centers of the cells. Somehow, these local heliostat spacings must be integrated to achieve a global heliostat layout that simultaneously (i) preserves the fundamental radial-stagger nature of the heliostat layout and (ii) emulates the RC optimum field. It is often surprising, especially to the newcomer, how difficult this problem can be and

† θ is the angle that the line of sight to the receiver makes with the plane of the heliostats' centerlines, as seen by an observer in the field. θ varies as the observer's location in the field varies. The polynomials used for $\Delta R(\theta,\phi)$ and $\Delta Az(\theta,\phi)$ are given by Eqs. (4.7-1) and (4.7-2), in which θ is assumed to be in degrees and ΔR and ΔAz are given in units of DMIR, the characteristic heliostat width. In particular, ΔAz is NOT in degrees or radians.

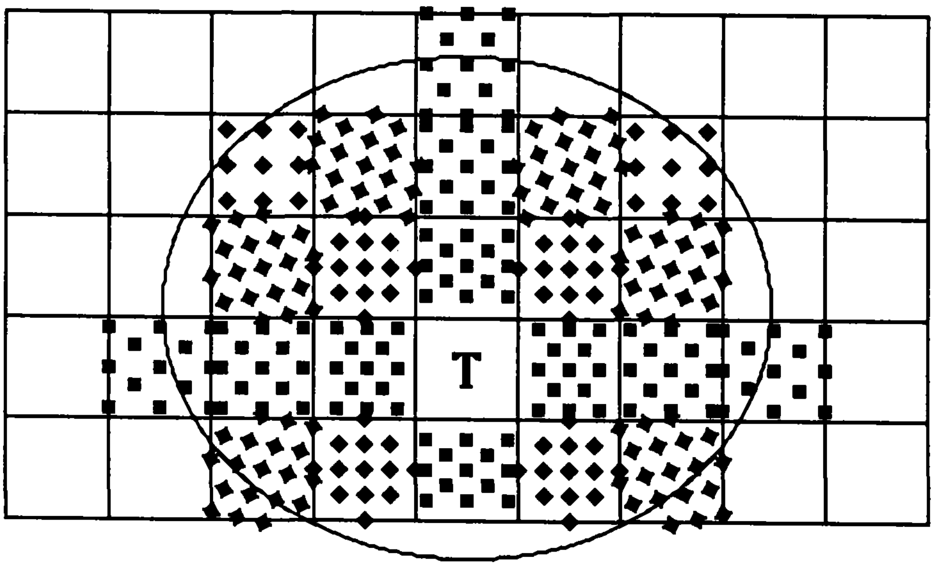

Figure 3.1-2 Chaos. The ellipse represents a heliostat field boundary, and the tower cell is marked by T. This figure depicts the sort of chaos that would occur at the boundaries of cells filled with exactly regular radial-stagger arrays of heliostats.

Even if the heliostat spacings within each cell were to vary according to fitted radial- and azimuthal-spacing functions, the heliostat locations in neighboring cells would be unrelated and the chaos would remain. The NS and RC cell structure must be abandoned when laying out the entire field of heliostats, one at a time.

Unfortunately, merely abandoning the RC and NS cell structure does not completely resolve the chaos (at least, not in any acceptable way). The true problem remains: "How do you integrate local heliostat spacings to achieve a global heliostat layout which simultaneously (i) preserves the basic radial-stagger arrangement for all heliostats and (ii) emulates well the RC optimum field?" There is no perfect solution to this problem, but the IH LAYOUT routine provides a good solution by introducing zones and other more sophisticated techniques. (See text.)

how often these two simultaneous goals are in direct conflict. Therefore, in Section 3.1 we will describe the basic problems that must be solved by a heliostat layout processor.

The first difficulty in laying out a real field of heliostats, one at a time, arises if you try to keep the RC and NS cell structure and lay out heliostats throughout each cell by using ΔR and ΔAz as defined by RC for the center of each cell. You would find that chaotic behavior occurs at the cell boundaries (Figure 3.1-2) due to the discontinuous change in ΔR and ΔAz from cell to cell.† The resulting random spatial relationship between the heliostats on either side of a cell boundary would undoubtedly lead to a loss of efficiency due to increased shading and blocking and could, in extreme cases, lead to heliostats which would be closer together than the minimum safety distance required for free-turning. Clearly, the cell structure must be abandoned when laying out a real field of heliostats.

To eliminate need for the cell structure, you would first try to develop heliostat-spacing functions, such as $\Delta R(\theta,\phi)$ and $\Delta Az(\theta,\phi)$, which would define ΔR and ΔAz at any point in the field -- not just at cell centers. (θ and ϕ are defined on p. 31.) You could do this empirically by fitting the ΔR and ΔAz data, defined by the optimizer at cell centers only, with polynomials in θ and ϕ such as Eqs. (4.7-1) and (4.7-2). Indeed, these polynomial fits have been programmed into the final stages of RCELL and should be switched-on for every RCELL run. Thus obtained, the heliostat-spacing polynomials $\Delta R(\theta,\phi)$ and $\Delta Az(\theta,\phi)$ permit you to abandon the NS and RC cell structure because they allow you to define ΔR and ΔAz at any location in the field. For simplicity of discussion, we will assume $\Delta R(\theta,\phi) = 60/\theta$ and $\Delta Az(\theta,\phi) = 2.0$ in the balance of Section 3.1.‡

Unfortunately, merely abandoning the RC and NS cell structure does not solve the fundamental problem of integrating local heliostat

† In RC and NS, this is not a problem because cell boundary effects are ignored and each cell is modelled as containing an exactly regular array of heliostats. (See Figure 2.1-2.)

‡ ΔR and ΔAz are in units of DMIR, the characteristic heliostat width. Thus, $\Delta Az(\theta,\phi)$ [in DMIR] = 2.0 is equivalent to $\Delta Az(\theta,\phi)$ [in m] = 2.0 × DMIR [in m]. Evidently, heliostats that are more distant from the receiver (θ small) must have larger ΔR to avoid excessive blocking. (See Figure 3.1-3.) On the other hand, we have found at UH that ΔAz remains nominally independent of location within a well-designed heliostat field.

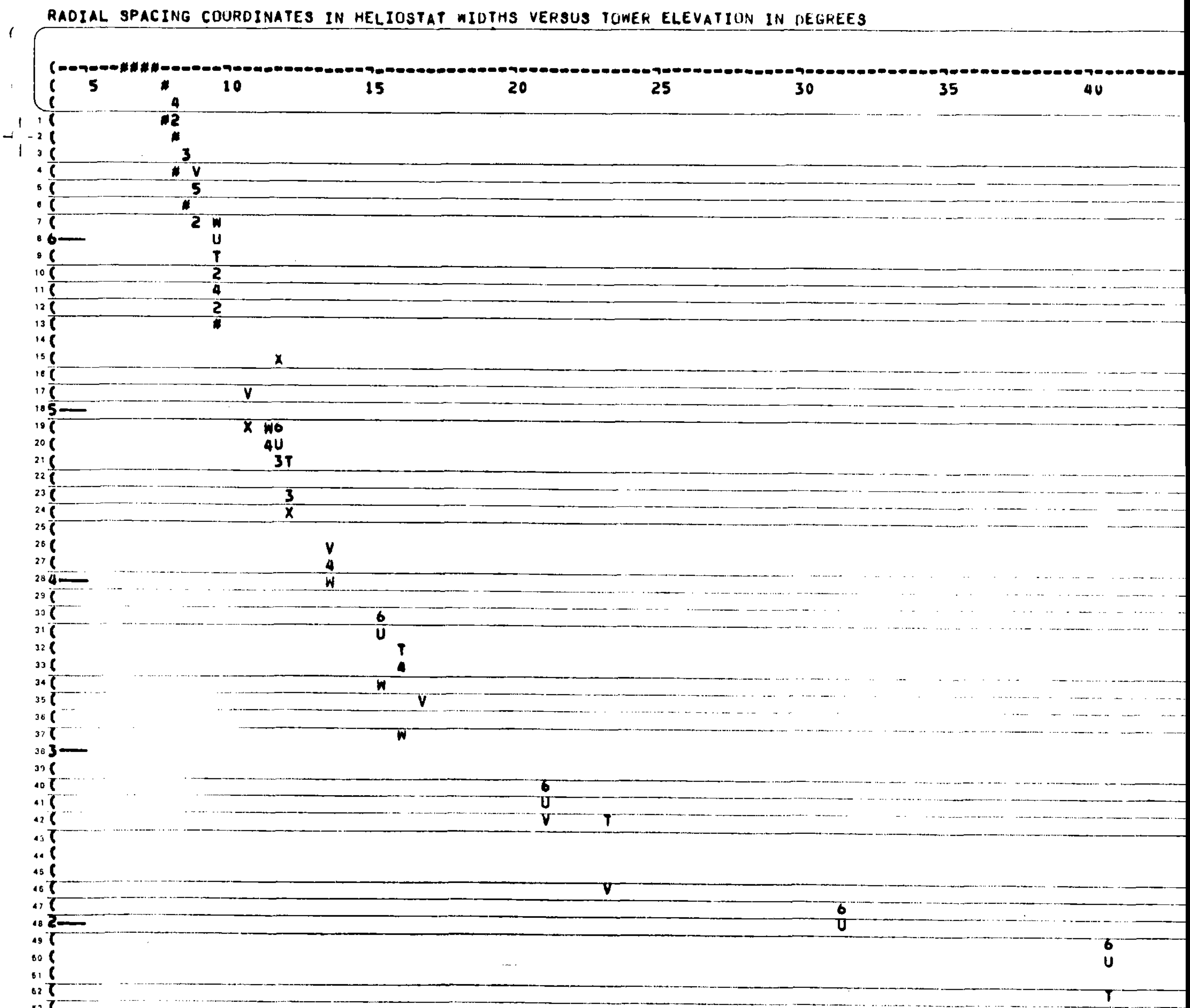

Figure 3.1-3 Example plot of radial spacing (in DMIR) vs. tower elevation angle in degrees. The horizontal axis is the tower elevation angle, and the vertical axis is radial spacing. θ is smallest for heliostats furthest from the tower. Plots such as this one are generated by subroutine PLOT2, and the letters and numbers represent data points for each cell as determined by RCELL. The data points of cells that do not contain any heliostats are marked with "#"s; thus, in this example, the data points for all cells in row 1, i.e., the northernmost row of cells, are marked with "#"s. The data points for the tower row, row 7 in this example, are marked with "T"s. Thus, in this example, the cells one row north of the tower are marked with "6"s. The cells one row south of the tower are always marked with "U"s. The other rows north and south of the tower are marked in similar fashion. PLOT2 fits these data with a polynomial [Eq. (4.7-1)] to obtain the radial-spacing function $\Delta R(\theta,\phi)$ and outputs the resulting radial-spacing coefficients. The data points marked with "#"s are not used in the fit.

spacings to obtain global heliostat positions. In other words, when laying out the heliostats one at a time as in IH, you would clearly try to use $\Delta R(\theta,\phi)$ and $\Delta Az(\theta,\phi)$ in such a way as to produce a radial-stagger heliostat layout that changes smoothly from the outer field boundary to the inner field boundary. However, you can not perfectly achieve this goal, as we will now demonstrate.

If you were to try to lay out a radial-stagger field using $\Delta R(\theta,\phi)$ and $\Delta Az(\theta,\phi)$, you would be immediately blocked. The first (outermost) circle would be easy: set the circle's radius (R_1) equal to the radial distance from the tower to just inside the outer field boundary, and space heliostats like beads along the circle, using $\Delta Az_1 = 2.0$. Then $\Delta R(\theta,\phi)$ would provide the radial step to circle 3 (see Figure 3.1-4), which should contain the same number of heliostats as circle 1. However, you would have <u>two</u> requirements for the azimuthal separation on circle 3: RCELL would require $\Delta Az_3 = 2.0$, whereas the radial-stagger arrangement would require

$$\Delta Az_3 = \left(\frac{R_3}{R_1}\right)\Delta Az_1 = \left(\frac{R_1 - \Delta R}{R_1}\right)\Delta Az_1 = \left(1 - \frac{\Delta R}{R_1}\right) 2.0. \qquad (3.1\text{-}1)$$

In order for all heliostats on circle 3 to retain the radial-stagger relationship, Eq. (3.1-1) must prevail; i.e., the "beads" on circle 3 must be compressed to fit, and likewise for additional circles. Along with the compression comes increased shading and blocking, driving the performance of the heliostats off the theoretical RCELL optimum.

3.2 The Heliostat Layout Solution

The transition from RC to IH implements several modifications to overcome the deleterious aspects of the "compression effect."

(1) Start with an azimuthal spacing that exceeds the optimum by about 20% (say, $\Delta Az = 2.4$) and proceed, maintaining the radial-stagger relationship and compressing the heliostats azimuthally (see Figure 3.1-4), until the spacing is about 20% less than optimum (say, $\Delta Az = 1.6$). Note: Each of these circles will contain the same number of heliostats.

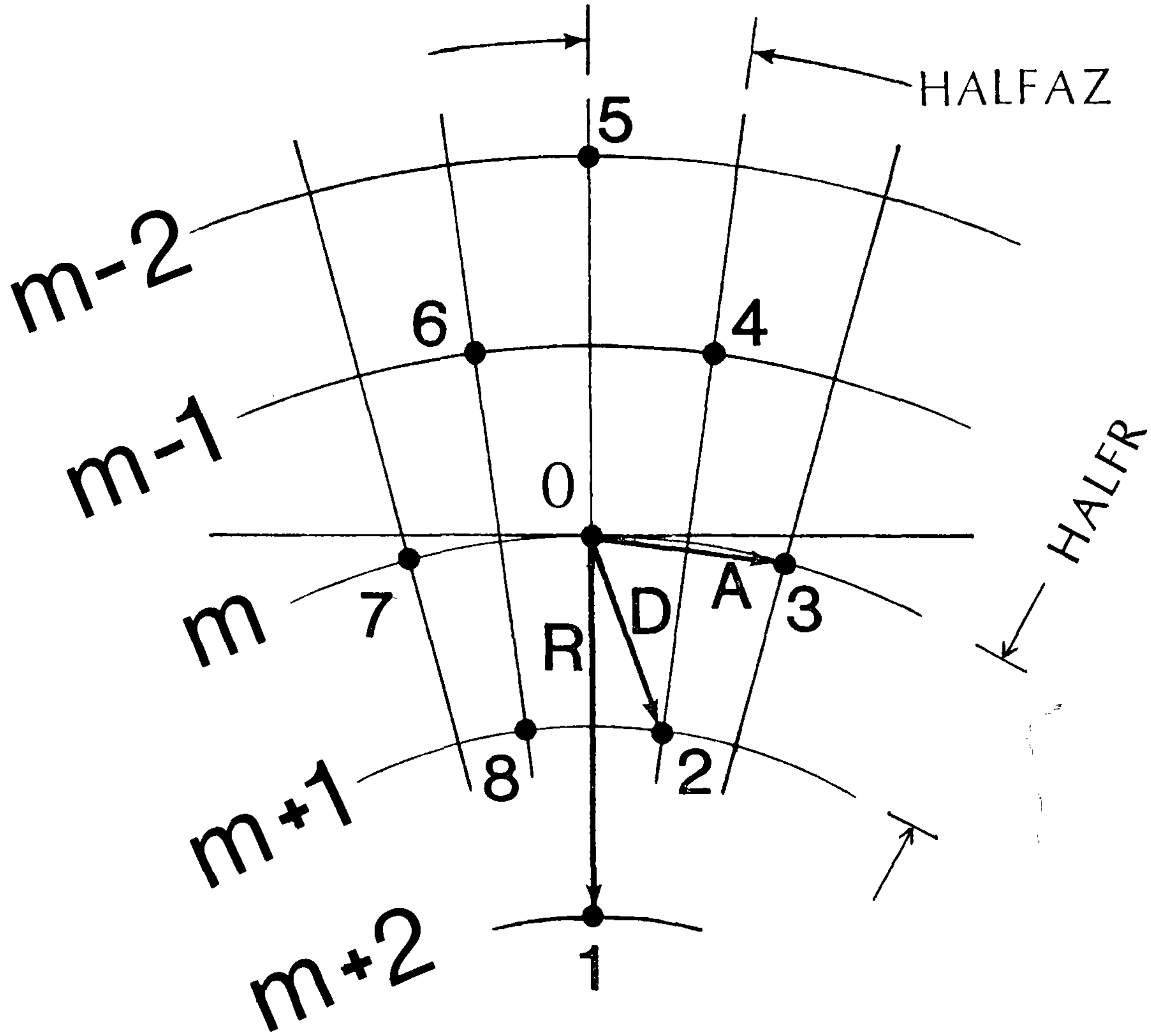

Figure 3.1-4 A radial-stagger type of heliostat neighborhood within the IH code.† The exactly regular, rectangular neighborhoods of the cellwise codes NS and RC (see Figure 2.1-2) are bent into concentric circles and radii by IH LAYOUT. The heliostat population on the inner circles is compressed. The labels indicate: A, an azimuthal neighbor; D, a diagonal neighbor; and R, a radial neighbor. Thus, the lengths of the A and R arrows represent ΔAz and ΔR, respectively. The heliostat labelled 1 is toward the tower and would be on circle m+2 if the circle containing heliostat 0 is circle m. In order to emphasize the stagger nature of the heliostat layout, HALFAZ and HALFR are also shown. However, HALFAZ is defined to be the half angle for azimuthal spacing (which is constant within a zone), whereas ΔAz is the azimuthal distance between heliostats (which decreases as you move inward within a zone).

† In the vicinity of a zone boundary or near the intersection of two field planes, IH neighborhoods are more complicated than the simple one shown here.

(2) A "**slip plane**" is then introduced; i.e., the number of heliostats on the next circle is reduced to N/(N+1) of the previous value (where N = 6, ..., 2, or 1). The process in item (1) is then repeated. Minor adjustments are made to even out the azimuthal spacings in successive circles near the slip plane. When the compression of the heliostats again reaches the lower limit (i.e., ΔAz about 20% less than optimum), another slip plane is introduced, and so on, until the inner boundary of the field is reached. Notes:
(i) The strict radial-stagger pattern is "broken" at a slip plane.
(ii) The annular region between any two slip planes is called a **zone**.
(iii) When a slip plane is introduced, ΔAz for the first circle in the new (inner) zone is always greater than ΔAz for the last circle in the old (outer) zone.

(3) Within each zone as defined above, the azimuthal spacing, ground coverage, and redirected energy will vary significantly from the smooth functions defined by fits to the RC optimizer data, while the radial spacing will match the optimum radial-spacing function's values. Intuitively, it makes more sense to hold the redirected energy (i.e., the performance) at its optimum values, rather than holding the radial spacing at the optimum values corresponding to the optimum azimuthal spacing. In other words, when ΔAz is larger than optimum (as in the outer part of a zone), ΔR should be smaller than optimum, and vice versa. Therefore, the above procedures have been modified to do this, while still maintaining strict radial-stagger within each zone. To implement this, the matrices of redirected-energy data within the RCELL SBC database are used.† A special program called CELLAY is required. For each of four values of ΔAz (i.e., for $0.85\Delta Az_0$, $0.95\Delta Az_0$, $1.05\Delta Az_0$, $1.15\Delta Az_0$), CELLAY finds the value of ΔR for each cell that would provide the required redirected energy from that cell. Four sets of data result, one set for each value of ΔAz, and each data set is then fit with a polynomial as in Eq. (4.7-1).‡ Thus, four functions result which give ΔR as a function of θ, one function for each of the four defined values of ΔAz. The four sets of

† Each matrix of redirected-energy data is called the TOTAL ENERGY matrix on the RCELL solution maps. (See Figure E.-1.) There is one TOTAL ENERGY matrix per cell, and it is a 4x4 matrix with one entry for each possible combination of four values of ΔR and four values of ΔAz.
‡ Only the first three terms of Eq. (4.7-1) are currently used by CELLAY. Adding a ϕ-dependence to the heliostat layout requires some changes to IH which are planned for the near future.

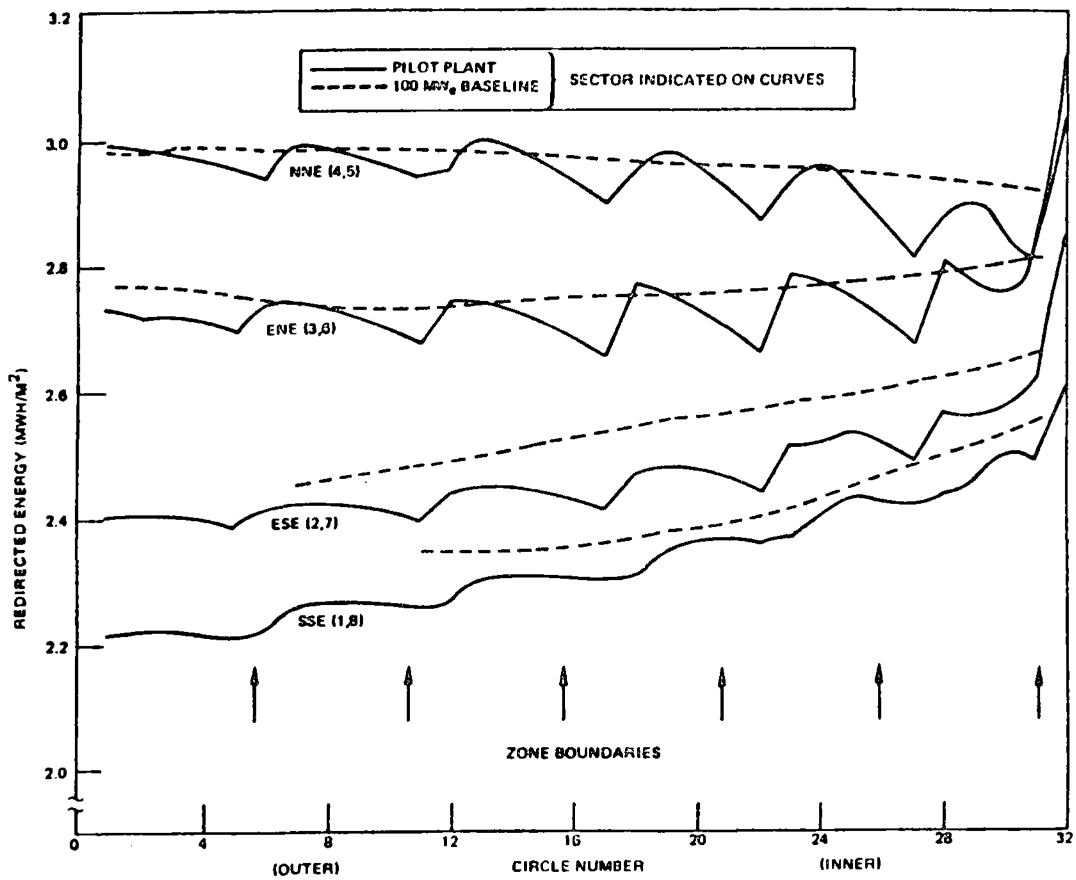

Figure 3.2-1 Redirected energy vs. circle number. The dashed curves represent a 100-MWe baseline power plant as output by RCELL. The cellwise optimum field has no zone structure. The solid curves represent the pilot plant as output by the IH performance model for an actual layout. The pilot plant was designed to resemble the 100-MWe plant. The IH layout has six zones. The four curves represent octants in the east half-field. East-west symmetry exists. Circle 1 is always the outermost circle in the IH code.It is now clear that the emulation of the 100-MWe plant could be improved somewhat.

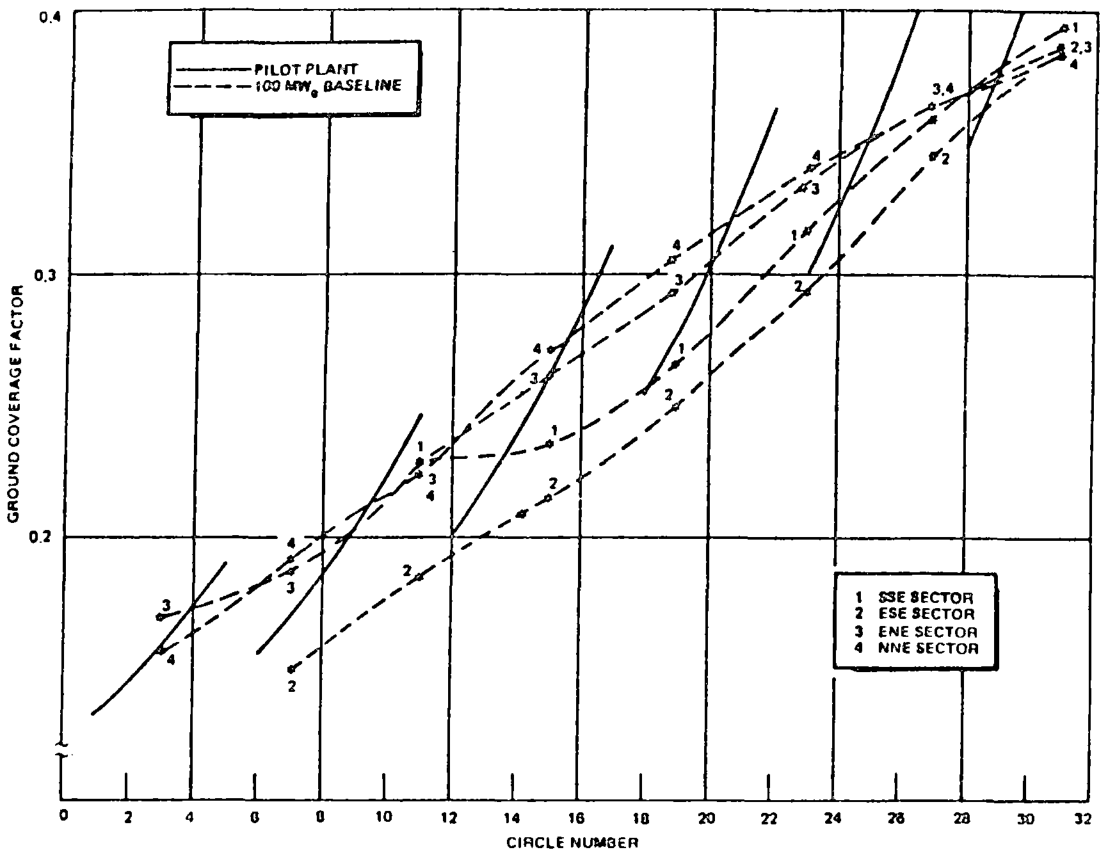

Figure 3.2-2 Ground coverage fraction vs. circle number. The solid lines represent an IH layout for a pilot plant having six zones. All octants have the same ground coverage because of the azimuthal symmetry of IH layouts. (Note: Modifications to IH to allow layouts without azimuthal symmetry are planned for the near future.) The dashed curves show output from RCELL for the corresponding 100-MWe plant. Some deviation from azimuthal symmetry can be seen, and the fact that the RCELL optimum field has no zones is demonstrated nicely. Circle 1 is always the outermost circle in the IH code.

coefficients that define these functions must be input to IH. How does IH use these functions? Within a zone, the radius of a circle of heliostats defines θ for that circle (call it circle m), but also ΔAz because of the radial-stagger layout, as discussed previously. IH interpolates the four functions to find the appropriate ΔR for these values of θ and ΔAz. This gives the radial step to circle m+2. (See Figure 3.1-4.) To find the radius of circle m+1, the process is iterated in an appropriate, although somewhat complex, fashion.

(4) Plots of the ground coverage, radial and azimuthal spacings, and redirected energy are compared to those resulting from the RCELL data, and then the control parameters, such as the ±20% mentioned in item (1) above, are adjusted to obtain the best emulation of the optimized RC result. (See Figures 3.2-1 and 3.2-2.)

3.3 Distribution of Aim Points

When an acceptable field layout is achieved (Figure 3.1-1), heliostat locations are written to a file for use by the surveyors. This file is also loaded with the aim points (Figure 3.3-1) of each heliostat; i.e., each heliostat is assigned an aim point on the receiver for each of several specified times. In order to calculate and load these aim points, the following two problems must be solved for each specified time and for each heliostat.

(1) What are the actual receiver coordinates of all the allowable aim points for this heliostat?
(2) Toward which of the allowable aim points should this heliostat be aimed?

The solution to problem (1) is easily obtained by a simple interpolation between the NS values defined in the four nearest cells. IH can overlay the heliostat layout with an NS-(and RC-)like checkerboard of cells to enable calculations such as this one, as well as facilitate comparisons of RC and IH outputs.

Problem (2) is considerably more difficult to solve. How do you convey to the IH code a method for distributing the aims of the various heliostats to the different aim levels on the receiver in such a way as to emulate the NS flux distribution? In NS and RC, the number of heliostats in each cell need not be an integer, and

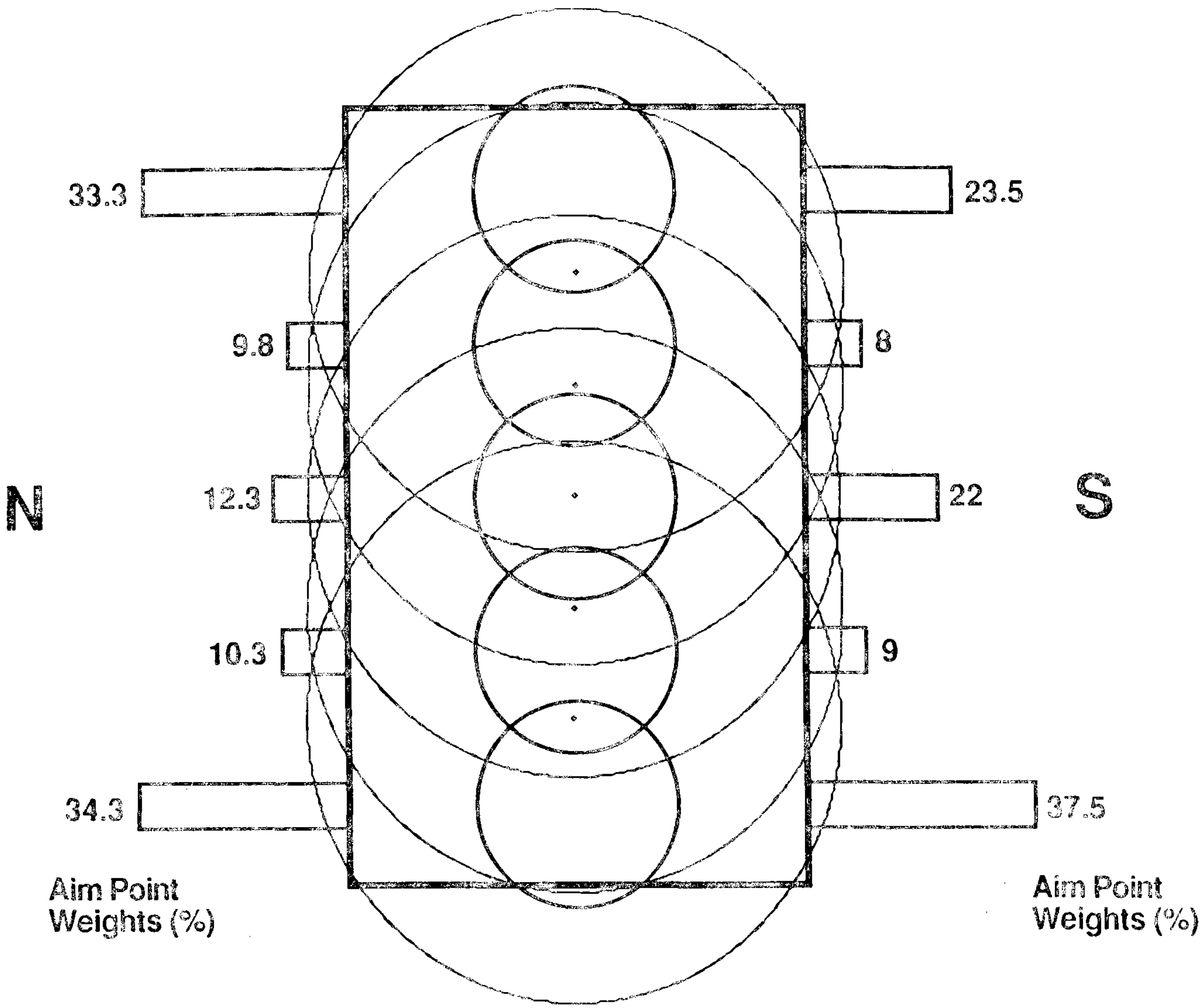

Figure 3.3-1 A five-level aiming strategy on a cylindrical receiver. The small circles are the images of well-focused heliostats in a nearby cell, and the large circles are the images of well-focused heliostats in a remote cell. The centers of the large circles are shown; these are the five aim points for the heliostats in the remote cell. Note that the five aim points for the heliostats in the nearby cell are different. Thus, the coordinates of the aim levels on the receiver vary from cell to cell, with the variation in image size; some people call this smart aims. However, there are only five aim levels per cell, hence the name "five-level" aiming strategy. The north (N) and south (S) aim point weights used by NS and RC for this particular field are also shown. IH does not use aim level weights. See discussions about aim level weights in text.

furthermore fractions of heliostats can be aimed. In contrast, IH must tell whole heliostats, one at a time, where to aim on the receiver. For example, if cell (5,4) had 13.8 heliostats in it and if a three-level aim were used with weights (0.35,0.40,0.25) for the (top,lower,center) aim levels, respectively, then NS and RC would aim 0.35 x 13.8 = 4.83 heliostats at the top aim level and similarly 5.52 and 3.45 heliostats at the lower and center aim levels. Of course, IH can not aim fractions of heliostats, and still it must distribute aim points to the heliostats in such a way as to emulate the NS distribution of aim levels in every region of the field. Thus, IH must aim the heliostats in the above example such that, if all of the heliostats in some region containing cell (5,4) were counted, then about (35%,40%,25%) would be aimed at the (top,lower,center) aim levels.

In order to match the NS distribution of aim levels in every region of the field, IH uses a sequence of aim-level identifiers. You must input this sequence to IH. To illustrate the meaning and use of such a sequence, consider the following example. Suppose that you have used NS to study the flux distribution on a cylindrical receiver. You have concluded that the best aiming strategy is a five-level aim with weights as show in the table below. For simplicity of presentation, assume also that you have assigned the following integer-identifiers to each aim level on the cylindrical receiver.

	Weight	Aim-Level Identifier
Top	.30	4
	.10	3
Center	.20	2
	.10	1
Bottom	.30	0

In NS, these weights mean that 30% of the heliostats in each cell aim at level 4, 10% aim at level 3, etc.†

A sequence of aim-level identifiers composed of 100 terms is long enough for almost any conceivable aiming strategy, but fewer terms may be sufficient if the weights are simple fractions. In this

† The coordinates of the aim levels on the receiver vary from cell to cell, with the variation in image size.

example, the weights are ratios of small whole numbers having a common denominator of 10, and so a sequence of length 10 is appropriate, as will now be demonstrated. The five aim-level identifiers (0, 1, 2, 3, 4) must be distributed appropriately throughout the sequence. Two possibilities for the sequence of aim-level identifiers are

{0,0,0,1,2,2,3,4,4,4} or {0,1,2,4,0,4,0,2,3,4}.

Note that the second is a permutation of the first. In each sequence, aim-level 0 occurs 30% of the time; aim-level 1 occurs 10% of the time, etc. This frequency of occurrence matches the required NS weights. Starting with heliostat number 1 and the first aim-level identifier in the chosen sequence, IH processes all the heliostats one after the other, assigning an aim-level identifier to each and re-cycling through the chosen sequence as many times as necessary. Of course, the objective is to distribute the aim levels to the heliostats in such a way as to emulate the NS distribution of aim levels in every region of the field. Thus, although either of the above sequences may be input to IH and will result in the field as a whole emulating the NS weights, the emulation will be better in smaller-sized regions of the field if the second sequence is used.†

3.4 From Cellwise Field To IH Field -- An Overview

Figure 3.4-1 shows the order of runs and the flow of data involved in taking a final RCELL design through CELLAY, coordinate specification, and finally IH performance runs. We hope that the brief introduction to the topic of heliostat layouts presented in Sections 3.1 to 3.3 will help you to understand the fundamental principles behind the UH layout processor and thus the reasons for the various runs shown in Figure 3.4-1. Although the procedure is rather complex, the transition from optimized spacings to heliostat coordinates is exceedingly complex if you wish to truly emulate the optimum RC design.

We now discuss Figure 3.4-1 in detail.

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† (i)User-modification of function NDRCT in IHDRIV and subroutine FCREAD in file LAYOUT is required for proper interfacing of the chosen sequence.
(ii) Matching north-side and south-side weights (see Section 4.9) will require development of a still more sophisticated technique.

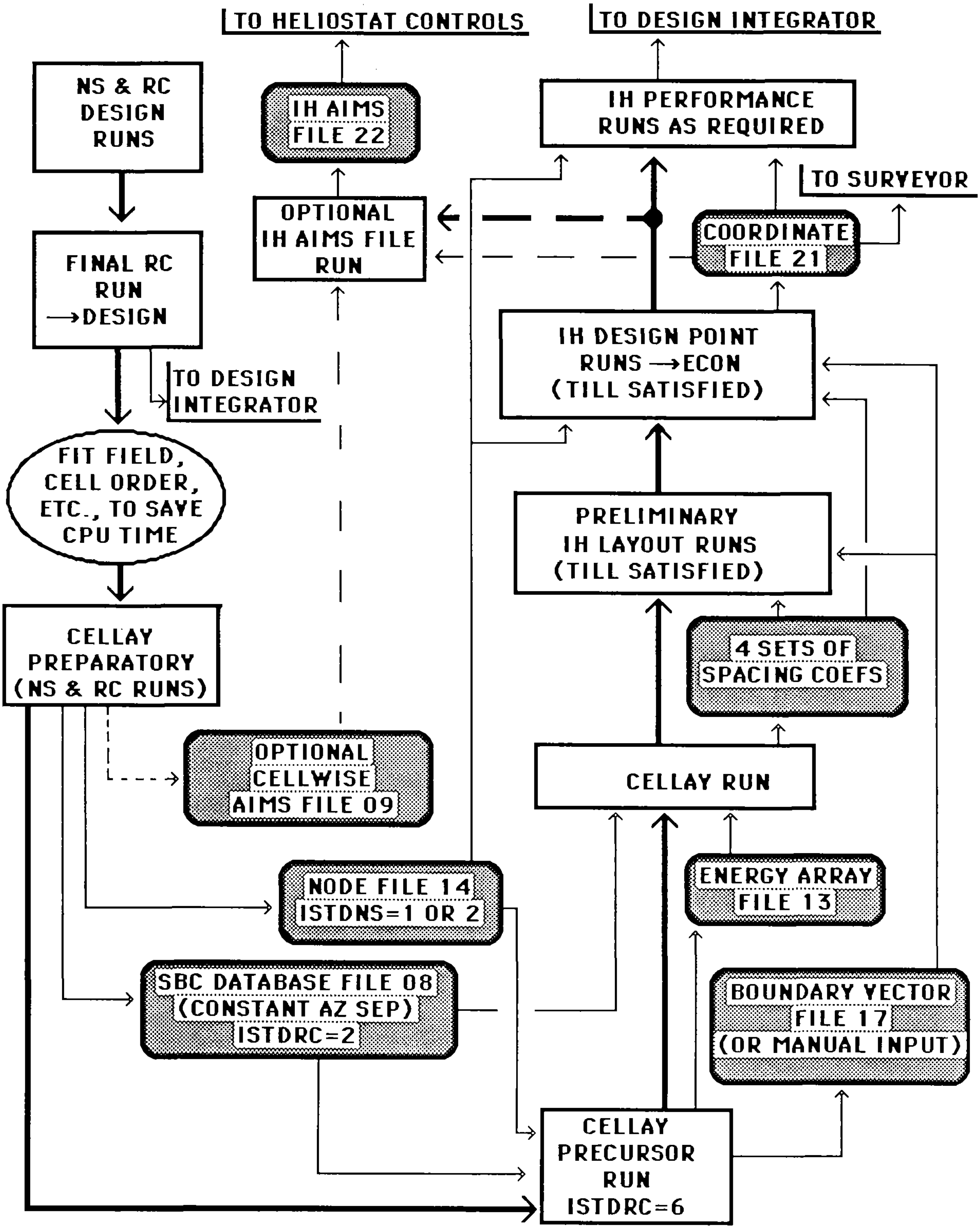

Figure 3.4-1 The RC - IH Interface.

The transition from definition of an optimized cellwise design to its realization in heliostat coordinates and system performance is diagrammed in Figure 3.4-1 (facing). Dark lines indicate the order of the required steps and runs; runs are enclosed by rectangles and the manual step is enclosed by an ellipse. Lighter lines indicate the flow of information and data; both data files and manual input data are enclosed by shaded rectangles. Dashed lines show an optional run and the data flow associated with it. Deliverables are indicated by showing to whom they are sent.

A typical system design study begins with several NS and RC runs which culminate in a final cellwise design for an optimized system; the field boundary, heliostat spacings, receiver flux maps, and annual performance of the final design are delivered to the Design Integrator, or other appropriate Program Manager. For the last few RC and NS runs, it is important to adjust the ORDER and the number of cells such that the boundary of the optimum heliostat field just fills the matrix of cells; in general this will allow use of a smaller ORDER, leading to a more definitive design run while using CPU time more efficiently by minimizing the number of unoccupied cells, i.e., cells without any heliostats.

A few NS and RC runs are required in preparation for a CELLAY run; e.g., CELLAY reads a special SBC database generated using identical input azimuthal spacings for the heliostats in every cell. CELLAY uses this special database to generate four heliostat-spacing polynomials, as described in Section 3.2. The CELLAY precursor run is a short RCELL run which generates disk file 13 containing values of the optimum redirected energy from each cell.

The four sets of heliostat-spacing coefficients generated by the CELLAY run must currently be input manually into IH. The boundary of the optimum field, taken either from the final RC design run or from the CELLAY precursor run, may be machine-transferred using disk file 17 or may be easily transferred manually by using a geometric boundary (Figure 11.1-1). One or two preliminary LAYOUT runs are made to assure that the input controls for LAYOUT have been set so as to produce a reasonable layout; e.g., all zones should have more than three circles of heliostats. Several IH design-point runs are then made, with associated further adjustments to the LAYOUT input controls, until the system produces the required design-point thermal power (ECON) and plots of ground coverage fraction (such as Figure 3.2-2) show that the optimum RCELL design is truly being emulated by the individual heliostat layout. The RCELL run using smaller ORDER cells mentioned in the second paragraph above is especially useful for these comparisons.

Once a satisfactory layout has been achieved, the coordinates of each heliostat are written to disk file 21 which is delivered to the surveyors. Daily and annual performance runs and start-up runs are made as necessary and the results delivered to the Design Integrator. In particular, data from the annual performance run can be used to plot the annual redirected energy, as in Figure 3.2-1, for a final check on the emulation of the optimum field. Aim points for each heliostat are computed as necessary, as described briefly in Section 3.3, and delivered to the engineers in charge of heliostat controls.

3.5 Suggestions For Further Reading

Section 9 is a start-up kit for IH. It describes the steps required to initiate all of the runs in Figure 3.4-1 except the optional aim point run, which is briefly described in Section 3.3.

You will find further details about the IH code in Section 4.11 and Appendix C. The *IH User's Guide* and the *Multiplane User's Guide* are helpful and provide complete programming details. More information about the basic concepts behind the IH code is also available. In our opinion, the best detailed discussion of heliostat-field-layout problems and solutions, including both conceptual and historical perspectives, is still *Collector Field Optimization Report (RADL Item 2-25)* [13].

PART II

UPDATES

UNIVERSITY OF HOUSTON

ENERGY LABORATORY

SOLAR THERMAL DIVISION

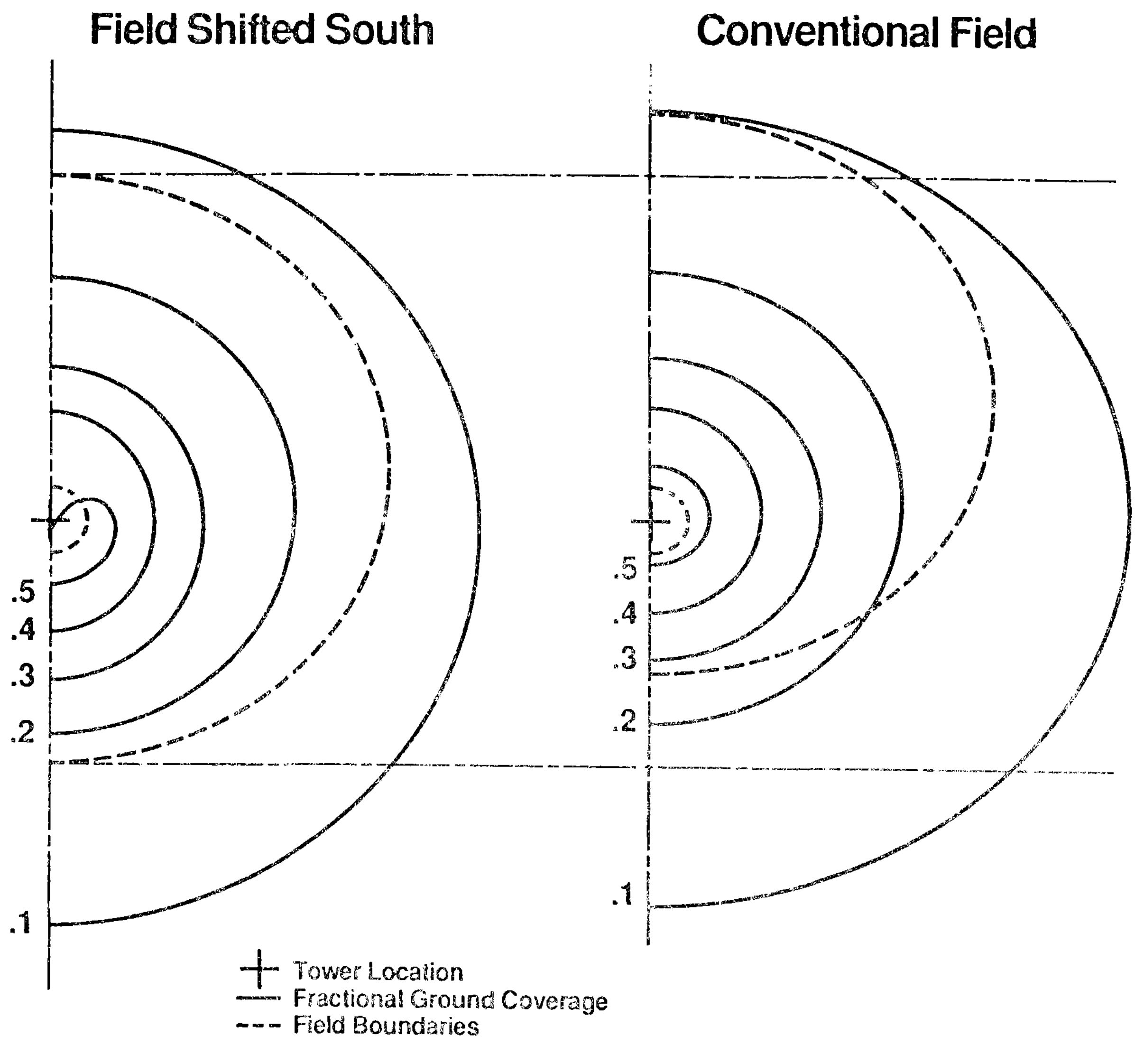

Figure 4.-1 The effect of RTRIM, a recent enhancement to the UH Code System, on collector field optimization. The collector field boundary and contours of the fraction of ground covered by reflective surface are shown for a conventional design (RTRIM = 0) and for a south-shifted design (RTRIM = 0.1). RTRIM is traded against receiver size and cost in system design studies that include significant limits on receiver peak flux, as we discuss in Section 4.8.

4. UPDATES

Since the initial release of the UH Code System and *Users Guides* in 1980-1985, significant enhancements have been made to NS, RC, and IH. In Section 4, we will bring you up-to-date on the major enhancements to the UH Code System, including user friendliness, heliostat aiming and shape, transfer of field boundaries between RC and NS, grand optimization (GOPT) , automatic iteration in RCELL, optimization under peak flux constraints (Figure 4.-1), and improvements to the field layout process.

Of all the enhancements, we hope most apparent to you will be the greatly increased emphasis on user friendliness. The input modules have been completely reorganized and many comments have been added to them. The number of standard runs has been dramatically increased, and the role of the STD subroutines has become central to the DRIVer modules. The start-up kits, found in Sections 5 to 11 of this manual, also add to user friendliness by leading you through the steps required to initiate the typical runs involved in a complete study, from optimization through to heliostat layout. Admittedly, the UH Code System is still far from being a black box with on-off switch, but we believe NS88, RC88, and IH88 to be much more user friendly.

One other major change has been completed: conversion to FORTRAN 77 and a VAX computer system. We have always been concerned about the UH Code System's availability and portability, and it has become increasingly apparent over the last few years that both availability and portability have diminished significantly and would continue to diminish were we to persist in using Honeywell's peculiar "enhanced" version of FORTRAN IV, which is incompatible with FORTRAN 77. Consequently, we have converted the entire UH Code System to standard FORTRAN 77 and have moved it from a Honeywell 66/60 computer to a VAX 11/785, which now becomes the primary computer on which the UH codes are supported. The advantages are obvious. Although we all know that, practically speaking, there is no such thing as a large, completely machine-independent FORTRAN code, the goal of portability comes very close to being achieved if standard FORTRAN 77 is used. Also, the availability of VAX computers to the average user is increasing rapidly, so transfer to VAX makes the UH Code System more widely available and decreases the number of users who must worry about any remaining portability problems.

4.1 User-Friendly Input Modules

Input to the UH Code System is by way of four **input modules**: a DRIVer module and HELIOS, RECVER, and FIELD. The DRIVer modules NSDRIV, RCDRIV, and IHDRIV are used by NS, RC, and IH, respectively, to control program execution, and each contains a large number of control switches but little specific data. The input modules HELIOS, RECVER, and FIELD are used by all three of the programs NS, RC, and IH to specify heliostat, receiver, and field input parameters. Typically, a separate HELIOS module is maintained for each heliostat design, a separate RECVER module for each type of receiver or for substantially different receiver subsystem cost or performance models, and a separate FIELD module for each site. Listings for a complete set of input modules are in Appendix F.

In the 1980 version of the UH Code System, only one DRIV module, MAIN, was used by NS, RC, and IH. This approach was found to be unacceptable as MAIN quickly increased in complexity, becoming a maze of control switches, most of which had no bearing on any one run.

The input modules are standard FORTRAN 77 routines with DATA and assignment (=) statements for data input. There is no user data input via READ statements (with rare exceptions, discussed where appropriate). The popular NAMELIST I/O, used in other solar central receiver code systems, is not standard FORTRAN 77 and so is not used in the UH Code System. However, the attractive feature of NAMELIST input (i.e., assignment of a data value by direct reference to its variable name instead of by reference to its position on the input line) has been retained. In fact, the input module approach may be thought of as our implementation of NAMELIST Input. The advantages and disadvantages of input modules are

Advantages:
(1) Allows you to change the cost model <u>equations</u> easily.
(2) Allows on-line comments that help you to set each input properly.

(3) Allows the bulk of the programs to be kept as relocatable, compiled code.

Disadvantages:

(1) Must recompile input modules and re-link program every run. However, this requires only small amounts of CPU time.

(2) A concise listing of all the important inputs on the printout has not yet been realized. However, some progress has been made. See description of VERINP below.

An outline of the data catagories in each of the input modules is as follows:

The appropriate DRIVer module contains data relating to variable DIMENSIONing, time controls, the sun, field boundaries and exclusion zones, program options, and output options.

The HELIOS module includes all inputs that relate specifically to rectangular or round heliostats. Image degradation, focusing and canting, and heliostat costs including O&M are entered in this module.

The RECVER module contains all inputs that deal with the receiver geometry, losses, and aiming levels. The tower focal height HT is now input in RECVER and is no longer input in FIELD. A control switch provides the choice of a cylindrical receiver or a flat receiver with user-specified orientation. A cavity receiver is usually represented as a flat receiver with an aperture and with unspecified interior. Sophisticated one and two-dimensional aiming strategies are available. Receiver, tower and piping costs including O&M are specified by equations in the ECOTOW portion of RECVER.

The FIELD module contains data on the collector field including site-related information and cell order. Coefficients for distribution of heliostats in the field, choices of heliostat layout patterns, and various field-related cost parameters (such as land, wiring, and washing) are also in this module. The field may be an arbitrarily inclined plane or up to five such intersecting planes. Insolation data may be input via DATA statements or calculated from long-term monthly-average climate parameters. Heliostat-to-receiver attenuation is modeled using inputs of monthly-average visual range data.

As with any solar central receiver code, there are a multitude of inputs. However, the proper setting of the numerous control switches in the DRIVer modules seems to be the most confusing aspect of the UH input modules. We have made a major effort to increase the user friendliness of the UH Code System by creating a reasonably complete set of standard runs via the STD subroutines, which are kept inside of the same disk files as the DRIVer modules. The main function of these subroutines is to set the control switches in the DRIVer modules in order to generate the desired run. In addition, we have implemented their main function in such a way as to group together just those inputs that affect the desired run. Thus, the role of the STD subroutines has become central to the function of the DRIVer modules, and this is a major change from the 1980 version of the UH Code System.

Those who have used the 1980 version of the UH Code know all too well about one of MAIN's most irritating and unfriendly aspects: the control switches in MAIN could be set exactly right for a desired run, but the printout would show that an entirely different run was actually performed because you forgot to check the appropriate STD subroutine to see how it redefined the control switch settings. The new DRIVer modules, which replace MAIN, do not have this double definition problem. All variables set in an STD subroutine are clearly marked by "**" on the left and right in the DRIVer module, and the line is commented so that these variables can no longer be set in the DRIVer modules. Indeed, most of the control switches are now set in the STD subroutines, and a goodly fraction of each DRIVer module now simply provides convenient, on-line comments about these control switches. A few control switches are still set in the DRIVer modules (but are not set in the STD subroutines), and the DIMENSIONing of the principal matrices via PARAMETER statements must still be done in the DRIVer modules.

The master switches ISTDNS, ISTDRC, ISTDLY, and ISTDIH are used by NSDRIV, RCDRIV, and the LAYOUT and IHYEAR parts of IHDRIV to tell the STDNS, STDRC, STDLY, and STDIH subroutines which standard run to set up (Appendix F.). In other words, these master switches set the programs' control switches. Before every run, you must choose the proper value of ISTD from a list of standard runs included in the DRIVer module.

The following list compiles the standard runs that are available via the ISTD master switches in RC, NS and IH. These runs are user friendly. Many other special runs are possible, but not yet in the ISTD system (see Section 4.12).

ISTDRC

1 Gives short run that reads insolation and SBC data.
2 Gives long run that generates insolation and SBC data.
3 Gives TRAJ run prior to GOPT study.
4 Gives GOPT run using three FINT files and TRAJ file.
5 Gives GOPT re-start.
6 Gives CELLAY precursor run.
7 Fixes cells in the SBC database.
8. Gives 9-variations run.
9. Gives run that reads SBC database but produces a default solution at the center of each cell's solution map.
10 Gives user-defined run.

ISTDNS

1 Makes half-field node or fint file - file 14 or 12.
2 Makes whole-field node or fint file - file 14 or 12.
3 Gives annual performance run.
4 Gives start-up study.
5 Gives cloud study (see data in cloud).
6 Gives image drift study.
7 Gives user-defined run.

ISTDLY

1 Produces field layout and stops.
2 Produces a field layout and continues to IHYEAR.
3 Reads coordinates from file 21 and continues to IHYEAR.

ISTDIH

1 Gives design-point-power test or alternative afternoon power test.
2 Gives receiver run and writes an individual heliostat node file to file 14.
3 Gives annual performance run, reading an IH node file.
4 Reads node file and outputs flux map and circle sector panel power print at set time.

The basic structure of all the STD subroutines is the same. First, every variable the STD subroutine can define is given an allowed value. The value of ISTD is then tested to assure it is within range, and the subroutine branches to a unique section of the program to set up the run specified by ISTD. For example, if ISTD is 2, then the subroutine branches to label 200 and resets only the appropriate control switches for the desired run and RETURNs. This new organization makes it much simpler for you to determine which control switches are important to a particular type of run and thus much simpler for you to modify the settings of those switches, as might be required for producing a desired run option or, in certain cases, for proper run operation. Before every run, it is good operating procedure to verify that the control switches are set properly in that unique section (of the appropriate STD subroutine) specified by ISTD. For instance, in the above example, you should verify the switch settings between label 200 and the RETURN just before label 300; any changes should be made only to this section of the program, in order to affect only the "ISTD = 2 run" and not the other standard runs. Similarly, for an "ISTD = 3 run" only the "300 section" of the STD subroutine should be changed. No changes should ever be made to the top portion of an STD subroutine where each variable is given an initial allowed value; this portion, called the "ISTD = 0 section," affects all the standard runs and is not user changeable.

As mentioned above, some progress has been made toward producing a concise printout of the important inputs. Simply copying the four input modules to the printout produces a verbose listing because of the many comments in the input modules. Thus a special subroutine, VERINP, has been written. In each run, VERINP arranges nearly all the inputs into a single record, using a standard order; this record is then written to a **diary file** (file 49). A printed report of differences between the current record and any selected previous record, such as one written by one of the standard runs, is provided by setting NRECRD. This report of differences helps you to keep track of the inputs that have been changed. The report appears near the top of the printout of each run and includes both the record number of the current record, which is always the last record of the diary file, and the record number of the selected previous record (i.e., NRECRD); this is also the only place where record numbers are printed. NRECRD is set in the section (of the appropriate STD subroutine) specified by ISTD. Thus, VERINP allows each type of run to easily refer to a previous similar type of run, revealing the specific differences in inputs between the two. NRECRD can be any integer between 1 and the maximum number of records already written to the diary file.

4.2 True Guidance for Belt Aim at Cylinders

For cylindrical receivers, a **belt aim** is a one-level aiming strategy in which each heliostat is aimed to reflect a central ray from the sun toward the axis of the cylinder, at such an elevation as to strike the cylinder's equator, or belt.† The 1980 version of NS oriented a representative heliostat at the center of a cell so that a central ray from the solar disk would be reflected to the (interior) geometric center of a cylindrical receiver, and then, after forming the reflected solar image on an image plane at the receiver center, slid the image over to the cylinder's equator, or belt. This was a good approximation, which resulted in accurate image location and receiver flux density but neglected small stereoscopic perturbations and, of course, introduced small errors in mirror orientation, which slightly affected the shading and blocking fractions. However, both the receiver flux density and the shading and blocking fractions correspond even more closely to a belt aim if each representative heliostat is oriented so that a central ray from the solar disk is properly reflected toward the cylinder's belt. This is called **true guidance** or, more simply, true aims. NS now provides true guidance for belt aims at cylindrical receivers. In Section 4.3, we will explain why true guidance was implemented.

For three-level and five-level aims for cylindrical receivers and for more complicated aiming strategies for flat receivers, receiver flux densities are calculated for each cell by generating the Hermite coefficients representing the solar image on an image plane, using the one-level aiming strategy (belt aim for cylinders and center aim for flats); then the center of the image plane is slid to each aim point on the receiver, and the flux at each receiver node is evaluated; finally, a weighted average of all the slid images is computed with the weights adjusted according to the fraction of heliostats in the cell that should be aiming at the various locations. Note that no interpolation to nodes is required at any point of this procedure. This is a good approximation, which results in accurate image locations and receiver flux densities and allows substantial savings of

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† A belt aim is also called a "one-point" aiming strategy, but this is a misnomer. In fact, the names for more complicated aiming strategies can also be misleading. A "five-level aim" or a "nine-point aim" refer to the number of aim levels or aim points per cell. The receiver coordinates of the aim levels vary from cell to cell, with the variation in image size, in order to lower the peak flux without creating unduly large spillage.

CPU time by executing the heliostat orientation and Hermite coefficient subroutines only once for each cell.

The question of when true guidance is implemented in the code also comes up for the case of FINT files. In order to use GOPT (Section 4.4), you must first make a special type of interception file called a FINT file. A FINT file contains, on a cell-by-cell basis, the fraction of beam intercepted by the receiver, for several sizes of receiver. (The fraction of beam intercepted is 1 - spillage fraction.) The total number of different receiver sizes on a FINT file is 2×INDXA + 1, where INDXA is an input in input module RECVER. The file structure is such that all of the interception fractions for the smallest receiver (no. 1) are recorded first and those for the largest receiver (no. 2×INDXA + 1) are recorded last. True guidance is implemented only for the mid-sized receiver (i.e., no. INDXA on the file), and the images for the other receivers are slid appropriately to their belts. As in the case of the multilevel aims, this is a good approximation, which allows substantial CPU time savings. (Also, due to the complex interaction of the receiver loop and the aiming strategy loop in the image generator subroutines, the most complicated multilevel aiming strategy allowed for cylindrical FINT files is a three-level aim. This is completely adequate to the needs of FINT files.)

4.3 Drift Studies

A drift study provides receiver flux density outputs for a sample of times during beam drift; i.e., the image-generation subroutines (usually HCOEF) are called, for each of several requested times, to produce a receiver flux map. Beam drift can occur actively or passively. Loss of electrical power to the heliostats leads to loss of heliostat guidance and to fixed heliostat orientation. This causes passive drift of the beam off the receiver due to the diurnal motion of the sun. Active drift of the beam occurs when the heliostats are commanded to slew in order to force the beam off the receiver quickly. NS can provide both active and passive drift studies.

Beam drift can only be modeled by allowing misguided heliostats; i.e., NS must be able to orient the heliostats so that a central ray from the sun can be reflected toward any point in the vicinity of the receiver and not just toward the aim point(s). Of course, such a capability also makes possible true guidance for belt aim at cylinders (see Section 4.2), and this is why true guidance was implemented at the time of the original drift studies (1983).

To initiate a drift study, set ISTDNS = 6 in NSDRIV. Three variables, IDRIFT, DRIFT1, and DRIFT2, have been added to COMMON group TIMEX. These variables are set in the 600 section of STDNS. IDRIFT is a control switch with the following settings :

IDRIFT =	0	for no drift study
	1	for passive drift study
	2	for active drift study

In an active drift study, DRIFT1 is the first axis (azimuthal) slew rate in deg/min and DRIFT2 is the second axis (elevation) slew rate in deg/min. DRIFT1 and DRIFT2 are only effective if IDRIFT = 2 and may be set to zero otherwise. You should also check to see if the values of NDAY1, HOUR1, HOUR2, and NHRS are appropriate for your study, as these control day of year, initial receiver flux map time, last receiver flux map time, and number of receiver flux maps, respectively. Of course, the rate at which the images drift off the receiver must be considered when setting these time controls. Finally, a disk file (unit 22) of heliostat basis vectors is written whenever a drift study is run; this file is used by the program during execution.

4.4 GOPT

GOPT (pronounced "gee-opt"), an acronym for **g r a n d** **op**timization, is a special version of RCELL which, in addition to providing optimum heliostat spacings and field boundary, provides the optimum receiver area and the optimum tower focal height when there are no peak flux constraints. In Appendix B, a reprint of a paper presented before the Solar Engineering Division of ASME, we discuss the theoretical basis for GOPT. In Section 10, a start-up kit for use with GOPT, we describe the principal runs made when doing a study.

GOPT uses a special shading, blocking, cos i (SBC) file, called a trajectory (TRAJ) file, and three special receiver interception files, called FINT files, to find the optimum heliostat spacings and field boundary for each combination of three input tower focal heights and three input receiver areas (i.e., a 3x3 grid, or 9 points). Using quadratic interpolation on this 3x3 grid, the tower focal height and receiver area that give a system with minimum cost-to-annual performance ratio are determined. A final performance pass is then made that prints out all of the optimum system characteristics, including optimum heliostat spacings and field boundary, for the system with the optimum tower focal height and receiver area. Unlike the standard version of RCELL, however, GOPT cannot produce a receiver flux map because it uses the special FINT files for computational efficiency and not the standard but much larger NODE files.

When finding the optimum receiver area and when making the three FINT files for GOPT to use for this calculation, options are provided which allow you to specify whether the receiver width, or length, or aspect ratio should remain constant. (See IRHRW in input module RECVER.) INODEF is another important control switch in RECVER with the following settings:

INODEF =	0	for standard NODE file and RCELL operation
	1	for FINT file or GOPT runs
	-1	for GOPT restart run†

There are other special inputs and switches in RECVER, which are used exclusively for GOPT runs and are described in Section 10 or in the comments in RECVER. As these inputs are not used in standard runs and are in RECVER rather than STDRC or STDNS, you must not forget to check these inputs when doing a GOPT run. Of course, there are also GOPT control switches and inputs in RCDRIV and STDRC (sections 400 and 500) when making GOPT and GOPT restart runs and in NSDRIV and STDNS (sections 100 and 200) when making FINT files. These inputs are described in Section 4.6 (control switch IGOPT) and Section 10, or in the comments in RCDRIV and NSDRIV.

GOPT can find the unconstrained optimum, but usually you have an annual thermal energy E or design-point thermal power P, which the system must be constrained to produce. This constraint is controlled by IOPTE and ECON, which are set in section 400 of STDRC (section 500 if doing a GOPT restart run).

† A GOPT restart run is used to force GOPT to repeat just its final performance pass using input values for the optimum tower focal height and receiver area. This type of run was primarily developed as a convenience for GOPT users, who would otherwise have to go back and make a standard NODE file and then a standard RCELL run to obtain essentially the same information.

IOPTE =	0	for unconstrained energy optimum
	1	for constrained energy optimum with annual thermal energy E = ECON (an input)
	-1	for constrained power optimum with design-time thermal power P = ECON (an input)
ECON	=	MWH annual absorbed energy(for IOPTE=+1)
	=	MW equinox noon power (for IOPTE=-1)

GOPT applies the annual energy constraint or equinox noon power constraint while finding the optimum heliostat spacings and field boundary for each combination of three input tower focal heights and three input receiver areas (i.e., for each point on the 3x3 grid). Thus the quadratic interpolation for optimum tower focal height and receiver area will only look at systems that produce the required annual thermal energy or design-point thermal power. This assures that the calculated optimum tower focal height and receiver area are the correct ones for a system that produces the required annual thermal energy or design-point thermal power.

GOPT can<u>not</u> handle peak flux constraints. For cavity receivers, this is not generally a significant limitation on GOPT's usefulness, but for cylindrical receivers this is a big problem. Theoretically, GOPT should apply a peak flux constraint while finding the optimum heliostat spacings and field boundary for each point in the 3x3 grid of tower focal heights and receiver areas. However, this would require that GOPT generate receiver flux maps, which the standard RCELL can do but GOPT currently cannot. Furthermore, an automatic application of a peak flux constraint is something that not even the standard version of RCELL can currently do. It would require an almost complete integration of the NS and RC codes into one unified program because RC would need the capability to generate NODE files as it searched for (if we assume a cylindrical receiver) the correct aiming strategy, correct north-south receiver peak flux ratios (by varying RTRIM), and correct receiver aspect ratio that would be needed to satisfy the peak flux constraint. The program to control this search would also need to examine the peak flux at off-design times to assure that peak flux limits were not violated. It would have to be quite sophisticated because experience shows that trading aiming strategy vs. RTRIM vs. receiver aspect ratio to finally arrive at an optimum design that satisfies the peak flux limits requires a careful analysis of the receiver flux maps and an educated prediction of the next "step" to take. Realistically, this is not only a significant programming challenge but would also result in an even more complicated set of control switches in the combined DRIVer input module. (See the discussion in Section 4.1 about MAIN, the DRIVer module in the 1980 version of the UH Code System.) Indeed, only one previous attempt has been made at only a partial unification of NS and RC. The resulting program, the Annual-Average Interception Code, was considered so complex that it was retired. This is not meant to imply that such a unification is impossible; however, a significant revision of the program control switches and a challenging programming problem is involved. The alternative of a separate stand-alone code should be considered for such an application.

The recent utility study (Phase I) [7, 8] demonstrated once again that peak flux limitations on external cylindrical receivers can place significant constraints on the system, forcing the optimum point quite far from the unconstrained or energy-constrained or power-constrained optimum. In general, GOPT cannot be used to optimize any system with a significant peak flux constraint.

Although cavity receivers have peak flux limits on the tube walls, there are no peak flux limits in the aperture plane. Experience suggests that aiming strategies are quite effective at reducing tube-wall peak fluxes for cavity receivers and can be designed so that spillage is not significantly increased. This suggests that GOPT can be used effectively to optimize systems with cavity receivers by treating the aperture plane as the receiver. Cavity receivers may be used for high temperature applications ($T > 500°$ C). Also, a direct-absorption receiver (DAR) may not have significant peak flux constraints, and so GOPT could be used for optimization of systems using a DAR.

Separate start-up kits are provided for the standard RCELL and for GOPT because the operating procedures for the two differ somewhat. Section 7 is the basic start-up kit for a simple system study using the standard RCELL. Section 9 is a start-up kit for optimizing systems with significant peak flux limits, using the standard RCELL. Section 10 is a start-up kit for optimizing systems without significant peak flux limits, using GOPT.

4.5 Round Heliostats

The 1980 version of the UH Code System included a split-rectangular heliostat as the standard heliostat model. Upon request, special subroutines that implemented a bubble-enclosed round heliostat were provided to specific users. Studies have since shown that transmission losses through the bubble make the bubble-enclosed heliostat uneconomical, and so there is no further need for this type of heliostat [14]. However, stretched-membrane round heliostats with no enclosing bubbles have been shown to be competitive with, and perhaps cheaper than, the standard split-rectangular glass-metal heliostat model. Therefore, subroutines to handle stretched-membrane round heliostats are now provided as a standard part of the UH Code System. This allows you to choose between two standard heliostat models: split-rectangular or round. A separate HELIOS input module for each type of heliostat is included on the magnetic tape containing the UH Code System (see Table 5.1-II).

A few changes have been made to HELIOS, especially to the round heliostat module. IROUND has been added to both versions of HELIOS and its switch settings are as follows:

IROUND =	0	for split-rectangular heliostats
	1	for round heliostats

IROUND is necessary because the image generation, shading and blocking (S&B), and aiming strategy subroutines have separate sections for round and split-rectangular heliostats. For a round HELIOS module, you should verify that NSEG = 1, HGLASS = ASEG = PI*RH*RH (where PI = π and RH = radius of reflective surface in meters), NGON = 0, and DMIR = 2.0*(RH + RING), where RING = width in meters of non-reflecting ring or optically distorted area on outer edge of heliostat. (DMIR is used for scaling and for S&B calculations.)

When a heliostat is shaded and/or blocked by two or more of its neighbors, each neighbor renders ineffective a certain area of the representative heliostat. If these ineffective areas do not overlap, then their sum yields the total ineffective area of the representative heliostat. However, if they do overlap, then the total ineffective area of the representative heliostat is less than the sum of the ineffective areas created by each neighbor individually. Many other solar central receiver codes make an ad-hoc assumption that there is no overlap. A set of S&B subroutines that do not allow for overlap is called a **single-event processor**. The UH S&B subroutines for split-rectangular heliostats have always assumed that overlap can occur and calculate its effect on S&B. A set of S&B subroutines that allow for overlap is called a **multiple-event processor**. In 1983, UH was asked to study the magnitude of the overlaps. (The overlap study is available from UH as Section 7 of reference [15].) The results show that the effect of the overlaps, in the case of split-rectangular heliostats, is less than 0.4% on the average S&B fraction for the entire collector field <u>if</u> that field is a reasonably well-optimized one. Therefore, a single-event processor is adequate for an optimized field. When modifications to the UH S&B subroutines were made to allow them to handle round heliostats, this conclusion permitted the installation of a single-event processor for the round heliostats. In fact, the complexity of a multiple-event processor for round heliostats has always forced us to use a single-event processor for them, even back when the bubble-enclosed round heliostats were studied.† Of course, the split-rectangular heliostats still use the more accurate multiple-event processor because that capability already existed in the 1980 version of the UH Code System.

For two round heliostats, the formula for blocking loss fraction (BLF) or shading loss fraction (SLF) is tedious but straightforward. Let a = radius of reflective area of representative heliostat = RH and b = radius of blocking area of an identical neighboring heliostat = DMIR/2. (Note that b > a.) Let H = distance (as seen in the plane of the representative heliostat) between the center of the representative heliostat and the projected center of the neighboring heliostat (which must be in front of the representative heliostat in order for there to be any shading or blocking). H differs for blocking and for shading. (For blocking, H is determined after projecting the neighboring heliostat into the plane of the representative heliostat along a direction parallel to the line joining the central aim point on the receiver with the center of the representative heliostat. For shading, the projection is along a direction parallel to the line joining the center of the sun with the center of the representative heliostat. See pages 40 - 42 of the *NS User's Guide* for more information about these projections.) The loss fraction LF is defined as the area of intersection of two circles separated by a distance H divided by the area of the reflective circle. (LF

† This is true for NS and RC only. The IH shading and blocking algorithm for round heliostats has recently been enhanced and is now a multiple-event processor. This is important in IH where the heliostat neighborhoods are not as regular as in NS and RC. The regularity in NS and RC has been used to eliminate most of the multiple events.

represents BLF if using the H appropriate for blocking or it represents SLF if using the H appropriate for shading.) If $H \geq b+a$ then LF = 0. If $H \leq b-a$ then LF = 1. Otherwise, LF is given by:

$$LF = [(\theta - \sin\theta) + (\phi - \sin\phi)] / (2 \pi)$$

where

$$\theta = 2 \arccos [(H^2 + a^2 - b^2) / (2 H a)]$$

and

$$\phi = 2 \arccos [(H^2 - a^2 + b^2) / (2 H b)] .$$

The effective fraction η_{sb} of the representative heliostat for reflection of sunlight is then simply:

$$\eta_{sb} = 1 - \Sigma (BLF + SLF)$$

where the sum is over all the nearest neighbors that are in front of the representative heliostat. (This is the no-overlap assumption.) Finally, if more than the eight nearest neighbors are considered (you may request up to 48 neighbors for start-up or shut-down studies), then those second and third rank neighbors, which are nominally at multiples of 45° from the line joining the representative heliostat to the tower (see Figure 2.1-2, neighbors 9, 11, 13, ..., 23), are eliminated from the above sum; this is because any ineffective area (on the representative heliostat) created by shading or blocking by them would overlap and be completely contained within the ineffective area created by shading or blocking by the corresponding first rank neighbors.†

To enable HCOEF to evaluate the flux distribution due to a round heliostat, subroutine ROUND was written to provide subroutine HERMIT with the necessary moments of the projected image of a round heliostat due to a point sun. Of course, HERMIT skips the calculation of the moments of split-rectangular heliostats when ROUND is CALLed and jumps to the coefficient calculation section, which did not require any program modifications. In this section, HERMIT combines the heliostat moments with the moments of the sun and the moments of the Gaussian degrading function to obtain the coefficients in the Hermite polynomial expansion of the flux distribution.

When designing subroutine ROUND, reference was often made to Appendix K, "An Optical Simulation Model for the Bubble-

† See footnote on previous page.

Enclosed Heliostat," of reference [16]. However, as there is no longer any serious interest in a bubble enclosure, there are also no losses due to bubble-transmittance, and this implies considerable simplification of the equations in the above memo. The results of this simplification are as follows: Let $\mu^M(i,j)$ denote the moments of the projected heliostat. By symmetry, all the odd moments are zero. Re-subscript the moments to take advantage of this by letting $U(n+1,m+1) = \mu^M(2n,2m)$ for n and m non-negative integers. The formula for $U(n+1,m+1)$ is straightforward:

$$U(n+1,m+1) = a^{2m} b^{2n} R^{2(n+m)} (\cos i_H)^{2m} u_{nm}$$

where

$$u_{nm} = (n+m+1)^{-1} (2n-1)¡ \, (2m-1)¡ \, / \, (2n+2m)¡$$
$$a = (q/f) - \cos i_H$$
$$b = (q/f)\cos i_H - 1$$

and

q = slant range, center of heliostat to aim point
f = focal length of heliostat
i_H = angle of incidence for a central ray from the sun striking the heliostat
R = radius of reflective area of heliostat = RH
$(2n-1)¡ = 1 \cdot 3 \cdot 5 \cdots (2n-1)$, and $-1¡ = 1$
$(2n+2m)¡ = 2 \cdot 4 \cdot 6 \cdots (2n+2m)$, and $0¡ = 1$.

The $\cos i_H$ appears in the formulae for a and b because the tangential and sagittal foci are not coincident when i_H is not zero; i.e., astigmatism is evident when the sun and receiver are not on-axis.

Multilevel aiming strategies are handled in the same way for round heliostats as for split-rectangular heliostats. Four rays are traced from the heliostat to the image plane, and an estimate of the radius of the image is made in order to determine how far the image can be slid without significantly increasing the spillage. Minor modifications were made to subroutines TRACEH, RIMEST, and TRDIAG to accommodate the new round heliostats. For example, a ray is traced from each corner of each segment of the split-rectangular heliostats. However, round heliostats have only one segment, and so the four rays traced from each round heliostat's one segment are selected to include both the foreshortened axis of the image and the corresponding perpendicular axis. This helps to maintain the accuracy of the image-size estimate when there is only one segment.

4.6 Iterative Version of RCELL

As discussed in Section 4.4, peak flux limitations make GOPT difficult to use effectively. Such limitations most often arise when designing systems with cylindrical receivers. In these cases, you must rely on the standard version of RCELL to find the optimum heliostat spacings and field boundary. Optimum tower focal height and receiver area must be found by repeated use of the standard RCELL. If you have used the 1980 version of the UH Code System, you know that this process involves making a large number of RCELL runs. However, the new version of RCELL includes a major enhancement and a big step in user friendliness: a program loop to converge FMI (an input initial guess) to FSTAR (an output) for an unconstrained optimum, or to converge design-point thermal power P (an output) to ECON (an input) for a power-constrained optimum.†

> F is called the **figure of merit** and is the objective function which is minimized by RCELL. F is the cost-effectiveness of the solar central receiver system and is defined as the total cost of the plant, including present value of operations and maintenance, divided by the annual thermal energy produced at the base of the tower.
>
> FMI, also referred to as FIN or FINPUT, is used by RCELL to determine the output heliostat spacings and field boundary. The *Theory User's Guide* shows that FMI is the parameter that provides a 1-dimensional parametrization of the solution subspace of the 2n-dimensional space of possible heliostat radial and azimuthal spacings, where n is the number of cells in the field. However, you may prefer to continue thinking of FMI as simply an initial estimate of the cost-effectiveness of the system.
>
> The concept of power-dependent cost models should not be confused with the entirely different concept of a design-point thermal power constraint. More information on FSTAR and the effect of power-dependent cost models may be found in Section 2.3 of the *Theory User's Guide*. More information on power-constrained optima may be found in Section 6 of the *Theory User's Guide*.

In the 1980 version, in order to obtain the unconstrained optimum heliostat spacings and field boundary for one given tower focal height and one given receiver area, several RCELL runs were made in which a value of FMI was input, and the output value of F

† In Appendix E, we review the optimization model.

was then fed back into the next RCELL run as the new input value of FMI, until FMI converged to F after three to five runs. Almost immediately (1981), another output (FSTAR) was added to the summary page to properly account for the effect of power-dependent cost models (often used for riser/downcomer costs and main feed pump costs) on the convergence scheme. Instead of feeding back the output values of F, the output values of FSTAR were fed back into the next RCELL run as the new input value of FMI, until FMI converged to FSTAR after three to five runs. (However, the final output value of F still represented the cost-effectiveness of the central receiver system.) Finally, to obtain (using the 1980 version) the power-constrained optimum heliostat spacings and field boundary for one given tower focal height and one given receiver area, several RCELL runs were made in which a value of FMI was input and the output value of the design-point thermal power P was visually compared to the desired value P_0. If P was too small, a larger value of FMI was input into the next RCELL run.† Similarly, if P was too large, a smaller value of FMI was input into the next RCELL run. This process was continued until P converged to P_0 after three to five runs. Clearly, to repeat any of these procedures for a few different tower focal heights and a few different receiver areas, in order to find the optimum tower focal height and receiver area, involves a large number of RCELL runs.

The latest version of RCELL has an internal convergence loop that automatically makes up to eight tries to achieve convergence. This loop should reduce the number of standard RCELL runs required for a study by a factor of 3 to 5. However, several RCELL runs will still be necessary in order to determine the optimum tower focal height, optimum cylindrical receiver area and aspect ratio, and optimum aiming strategy and RTRIM. These additional runs are discussed in Section 4.10 and Section 9.

For an unconstrained optimum, the internal loop repeats the solution of the cellwise optimization equations and the evaluation of the system figure of merit until FMI and FSTAR are within 0.01% of each other. A maximum of eight attempts are made. If convergence is achieved, the optimum field matrices are printed and the program proceeds normally to termination. If convergence is not achieved

† A higher value of FMI ($/MWH) allows less cost-effective cells to be populated with heliostats and all cells to be packed more densely. The resulting larger field provides a larger receiver design-point power.

after eight tries, it is assumed that no answer has been found; no optimum field matrices are printed; and the program could terminate with error status, if (as is usual) polynomial fits to optimum heliostat spacings are requested from subroutine PLOT2 (by setting IPLOT = 1 in RCDRIV).

For a power-constrained optimum, iteration continues until the equinox noon thermal power P and the input desired power level ECON (= P_0) are within 0.1% of each other. A maximum of seven attempts are made. If convergence is not achieved after seven tries, the value of FMI that produced the value of P closest to ECON is assumed to be the answer, and an eighth pass is made through the loop in order to send the heliostat spacings for this closest field to the polynomial fits in subroutine PLOT2. (A similar procedure has not been implemented in the unconstrained case, which is a little more complicated because the optimum value of FSTAR is not known ahead of time.)

Both GOPT and the standard version of RCELL use subroutine CACLF to estimate the value of FMI that should be used for the next iteration. You must still supply an initial value for FMI in the appropriate section of STDRC (i.e., section 100 for standard RCELL run, section 400 for GOPT run, and section 500 for GOPT restart run). For an unconstrained optimum, the value of FSTAR at the end of each iteration is simply fed back as the value of FMI to be used for the next iteration. For a power-constrained optimum, CALCF does the following to estimate FMI for the next pass through the loop:

1) After the initial time through the loop, CALCF uses a 60%-40% weighted average of (input FMI) and (P_0/P)·(input FMI), where P_0 = ECON. (Note: This "60-40" average corresponds to an educated guess based on previous experience using the RCELL and GOPT codes.)
2) After the second time through the loop, CALCF uses linear interpolation of FMI vs. P to estimate the FMI required to obtain P_0.
3) After the third and subsequent times through the loop, CALCF uses quadratic interpolation of FMI vs. P.

The controls and inputs for the new standard version of RCELL are in RCDRIV and STDRC. In order to obtain the optimum heliostat spacings and field boundary for one given tower focal height and one given receiver configuration, you must set ISTDRC = 1 in RCDRIV and make what is called a **short run**. IGOPT, set in section 100 of STDRC because you are making a short run, is an important control switch.†

IGOPT =	1	for GOPT version of RCELL. (But not for TRAJ file generation, i.e., ISTDRC=3.)
	0	for standard version of RCELL. A short run, i.e., ISTDRC=1, will iterate to convergence.
	-1	for standard version of RCELL. A short run, i.e., ISTDRC=1, will not iterate.

To be precise, the standard RCELL convergence loop is only iterated if IGOPT = 0 and NSOLN = 1 and LTAPE < +1. This assures that iteration of this particular loop does not occur:
a) during GOPT runs, wherein IGOPT = 1 and NSOLN > 1 and LTAPE = -1. (GOPT uses its own internal convergence loops.)
b) during TRAJ file generation, wherein IGOPT = 0, or -1, and NSOLN > 1 and LTAPE = -1.
c) during **long runs** for shading and blocking (SBC) database generation (i.e., an ISTDRC = 2 run), wherein IGOPT = 0, or -1, and NSOLN = 1 and LTAPE = +1.

If IGOPT is set to 0 (i.e., iteration turned on), then IOPTE and ECON must also be set.

IOPTE =	0	for unconstrained energy optimum
	1	for constrained energy optimum with annual thermal energy E = ECON (an input)
	-1	for constrained power optimum with design time thermal power P = ECON (an input)
ECON	=	MWH annual absorbed energy(for IOPTE=+1)
	=	MW equinox noon power (for IOPTE=-1)

Note that the standard RCELL convergence loop can handle annual energy constrained optima as well as the more common design-point power constrained optima. (Whenever the RCELL convergence loop is active, you should verify that IFLUX = 1, TRMI = 1.0, and TRMF = 1.0 in RCDRIV.)

The flow diagram in Figure 4.6-1 highlights the most important parts of RCELL, stressing how the new convergence loop fits into the

† IGOPT is also important for GOPT runs and GOPT restart runs, for which it is set in sections 400 and 500, respectively, of STDRC.

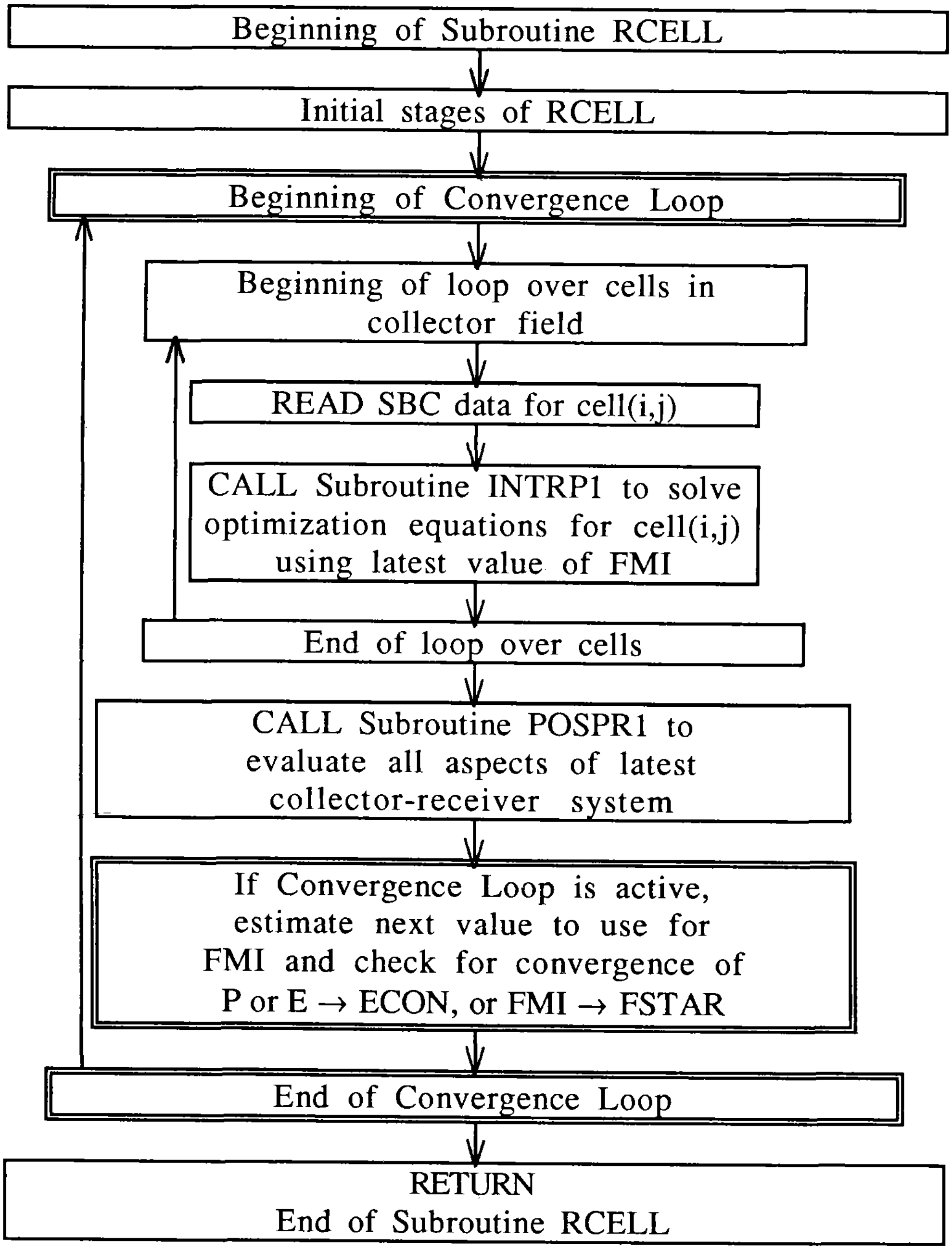


Figure 4.6-1 Major Loops in RCELL. Boxes with double borders indicate the new parts of the program required to implement the convergence loop.

overall RCELL structure. The Figure depicts a run in which the new convergence loop is active (ISTDRC=1, IGOPT=0, NSOLN=1, LTAPE=-1). However, the convergence loop is always executed at least once, regardless of the type of RC run being made. In a long run (i.e., ISTDRC = 2, generation of an SBC database), the convergence loop is only executed once, and the READ of the SBC data is replaced by a CALL to subroutine SBDATA and a subsequent WRITE. Similarly, in a TRAJ file generation run (ISTDRC = 3), the convergence loop is only executed once and the CALL to subroutine INTRP1 is replaced by a CALL to subroutine INTERP. Finally, in a GOPT run (ISTDRC = 4, or 5 for a GOPT restart), this RCELL convergence loop is only executed once and the CALL to subroutine POSPR1 is replaced by a CALL to subroutine POSTPR, which has its own internal convergence loops.

4.7 Optimum Field Specification Using File 29

How is the configuration of a heliostat field specified in the RC and NS cellwise programs? The following variables, grouped by function, are used by the cellwise programs to specify a heliostat field:

1) Heliostat spacings and field boundary
   COEFX, COEFY, ICOF, NCOEFS
   IGRND, JGRND, BGRND
2) Basic field geometry
   ID, JD in **RC** or NCELI, NCELJ in **NS**
   ORDER, XTOWI, YTOWJ
3) Number of planes (1 to 5) and ground slope
   NPLANE, EGRND, AGRND
   (If more than one plane, then also:
   IPLANE, MAXMIN, NREVSD, XSURVY, YSURVY, ZSURVY)
4) Type of local neighborhood, mechanical limits, and maximum spacing in tower cell
   KORY, LRAY
   DMECH, COORL
5) Scaling
   HT, DMIR

All of these variables are described in the *NS* and *RC User's Guides* and in the comments in the input modules. The variables in groups 2 to 5 are generally well-defined and constant throughout any given study. However, the variables COEFX, COEFY, IGRND, and BGRND in group 1 and the variable HT in group 5 are frequently not well-defined in advance and RC must be used to find their optimum values. In Section 4.7, we describe the group 1 variables and discuss new methods for dealing with them.

Heliostat spacings are specified by polynomials in θ and $\cos\phi$. For a radial-stagger type of local heliostat neighborhood, the radial spacing (ΔR) and azimuthal spacing (ΔAz) between heliostats are given (in DMIR units) by:

$$\Delta R = \frac{C_1}{\theta} + C_2 + C_3\theta + \left(\frac{C_4}{\theta} + C_5 + C_6\theta\right)\cos\phi \qquad (4.7\text{-}1)$$

$$\Delta Az = C_1 + C_2\theta + C_3\theta^2 + (C_4 + C_5\theta + C_6\theta^2)\cos\phi \qquad (4.7\text{-}2)$$

where θ and ϕ are measured in degrees, and
θ = elevation angle of receiver as seen by "observer" in field
ϕ = azimuth of "observer" as seen from receiver (south=0).
(The "observer" is located at the evaluation point, i.e., the point in the field where the heliostat spacings are to be evaluated.)

The coefficients C_i in Eq. (4.7-1) are denoted in the UH Code System by the array COEFX. Similarly, the coefficients in Eq. (4.7-2) are denoted by COEFY. NCOEFS is the number of sets of coefficients and must be less than or equal to NPLANE, the number of sloped planes comprising the field. (The field can be formed from one plane or from as many as five intersecting planes.) Usually, both NPLANE and NCOEFS are 1. ICOF is a control switch that governs the number of coefficients actually used when Eqs. (4.7-1) and (4.7-2) are evaluated. If ICOF = 1, then only C_1, C_2, and C_3 are used. This choice is often referred to as "2x3 field coefficients" and would be appropriate for a field in which the radial and azimuthal spacings of the heliostats are independent of the azimuthal angle ϕ. (A solar central receiver system at the equator or at the poles would be expected to have such azimuthal symmetry.) If ICOF = 2, then all six of the C_i are used in both equations. This choice is often referred to as "2x6 field coefficients" and is appropriate for most fields because most fields are east-west symmetric -- i.e., the radial and azimuthal spacings of the heliostats in the east half-field are a mirror image of those in the west half-field. (An example of a field having east-west symmetry but not azimuthal symmetry is a field in which the east half-field is a mirror image of the west half-field, but the heliostat spacings in the south half-field are significantly different from those in the north half-field.)

If a field is intrinsically east-west asymmetric, perhaps because of an east-west slope, then ICOF = 3 uses only C_1, C_2, and C_3 for ΔR, but for ΔAz :

$$\Delta Az = (C_1 + C_2\theta) + (C_3 + C_4\theta)\cos\phi + (C_5 + C_6\theta)\sin\phi \qquad (4.7\text{-}3)$$

WARNING: Do not use ICOF = 3 for east-west symmetric fields when running the half-field version of RCELL (i.e., when IPROG = 1 in RCDRIV). If ICOF = 3 were to be used in such a case, RCELL would compute non-zero C_5 and C_6 as the system would not know about the symmetry. Hence, ICOF = 3 must not be used for east-west symmetric systems. For more information on the design of asymmetric fields, see the *Multi-Plane User's Guide*. Such advanced designs require some care.

The remaining group 1 variables are IGRND, JGRND, and BGRND. The field boundary is input using IGRND or BGRND in NS and JGRND in RC. IGRND and BGRND are also used for the output field in RC. A typical IGRND matrix for a 15 x 17 field would be input into NSDRIV as follows:

```
DATA ((IGRND(I,J), J=1,NCELJ), I=NCELI)
 &/0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
 & 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
 & 0,0,0,0,0,0,0,1,2,1,0,0,0,0,0,0,0,
 & 0,0,0,0,0,2,4,4,4,4,4,2,0,0,0,0,0,
 & 0,0,0,0,3,4,4,4,4,4,4,4,3,0,0,0,0,
 & 0,0,0,1,4,4,4,4,4,4,4,4,4,1,0,0,0,
 & 0,0,0,3,4,4,4,4,3,4,4,4,4,3,0,0,0,
 & 0,0,0,3,4,4,4,4,4,4,4,4,4,3,0,0,0,
 & 0,0,0,3,4,4,3,4,0,4,3,4,4,3,0,0,0,
 & 0,0,0,2,4,4,4,4,4,4,4,4,4,2,0,0,0,
 & 0,0,0,0,3,4,4,4,3,4,4,4,3,0,0,0,0,
 & 0,0,0,0,0,3,4,4,4,4,4,3,0,0,0,0,0,
 & 0,0,0,0,0,0,1,2,2,2,1,0,0,0,0,0,0,
 & 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
 & 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0/
```

The numbers indicate the maximum number of quarters of a cell that are allowed to have heliostats within them. For example, a 3 appearing in a cell means that 3/4, or 75%, of the land in that cell may have heliostats on it, whereas the other 1/4 of the land may have no heliostats. Both the inner and outer field boundaries are specified by the above matrix. In this case, the inner field boundary is the central exclusion zone, which neatly covers only one cell, cell

(9,9) when counting the upper left-hand corner as (1,1). Other land constraints can also be seen in the above matrix. Cells (7,9), (9,7), (9,11), and (11,9) have 3s instead of 4s in order to simulate the fraction of the north, south, east, and west "rows" that are covered by roads. Land constraints, such as roads, exclusion zones, fences, lakes, etc., are the only reason for not loading JGRND, the input field matrix for RC, with all 4s. Unlike NS which inputs the optimum field boundary, RC outputs the optimum field boundary via the IGRND matrix. Therefore, JGRND in RCDRIV should be loaded with 4s in all cells except those where there are land constraints.

The current version of .the UH Code System, like its predecessors, supports all of the above inputs and outputs. However, the current version also supports one other method for specifying the field boundary: BGRND. The principal difference between the matrices BGRND and IGRND is that each element of BGRND is a real number between 0 and 1. Thus, in the example from the preceding paragraph, a 3 entered in a cell of IGRND would instead be entered as 0.750000 in the same cell of BGRND. In this way, any fraction of a cell (e.g., 0.345743) may be specified. This has the effect of smoothing out the field boundaries, which leads to its nickname "continuous boundaries." In fact, the current version of RC computes the optimum BGRND and IGRND matrices and then uses BGRND for all of its subsequent calculations; IGRND is only used for printouts. The methods that RCELL uses to compute BGRND and IGRND are discussed at the end of Section 4.7.

After making a series of RCELL optimization runs, it is often necessary to make one or more NS flux runs using the field obtained from RCELL in order to check the peak flux at off-design times. Of course, this means that the optimum field specified by RCELL must be input into NS via COEFX, COEFY, and either IGRND or BGRND. This involves typing into FIELD about 100 digits ($\approx$8x2x6) for the coefficients and into NSDRIV about 100 - 200 integers for a typical IGRND matrix. Furthermore, typing the matrix BGRND into NSDRIV instead of IGRND is clearly not a very pleasant prospect. In order to reduce the amount of user effort and to make the use of BGRND practical, a method to automatically transfer the optimum field specifications from RC to NS has been devised. RC WRITES a disk file (file 29) containing the following data in the order shown:

1) ((IGRND(I,J), J=1,KC), I=1,ID) using FORMAT(1X, 30I1)
2) ((BGRND(I,J), J=1,KC), I=1,ID) using FORMAT(1X, 13F9.6)

3) (I, COEFX(1,I), I=1,6) using FORMAT(2X, I2, 1P D20.12)
4) (I, COEFX(1,I), I=1,3) using FORMAT(2X, I2, 1P D20.12)
5) (I, COEFY(1,I), I=1,6) using FORMAT(2X, I2, 1P D20.12)
6) (I, COEFY(1,I), I=1,3) using FORMAT(2X, I2, 1P D20.12)

Although derived from the same data, the coefficients in 4 differ from those in 3 (and similarly those in 6 differ from those in 5) because the polynomial fitting routines in PLOT2 use different numbers of coefficients to fit the data in these two cases. Although BGRND provides better boundaries, IGRND is also included for printout purposes. Note that file 29 is not a binary file; i.e., it is written in a text-like format, which allows it to be edited with any standard text editor. NS CALLs subroutine RDFLD to READ file 29. RDFLD inputs IGRND directly but places BGRND into temporary storage in the matrix ENHEL to conserve memory. RDFLD inputs only the 2x6 coefficients and skips the 2x3 coefficients. RDFLD will not currently READ multi-plane fields properly. However, trivial modifications to this subroutine will allow it to input the 2x3 coefficients or to READ multi-plane fields.

In RC, ITRIM controls the writing of file 29; ITRIM is set in STDRC. In NS, JTRIM controls the reading of file 29; JTRIM is set in NSDRIV. The switch settings for ITRIM and JTRIM are:

ITRIM =	-2	Same as -1 except for all TRMI to TRMF
	-1	Writes optimum IGRND & COEFX,COEFY to file 29
	0	No write to file 11, 17, or 29
	1	Writes trim data to file 17 for IH Layout
	2	Writes ENHEL to file 11 (Rarely used)

JTRIM =	0	Use IGRND from DATA statement and COEFX,COEFY from Input Module FIELD
>	0	Read IGRND,BGRND,COEFX,&COEFY from file 29

The field matrix input to RC has not yet been modified, and so the matrix JGRND must still be used to input land constraints into RCELL in quarters of a cell.

Finally, we will summarize the method that RCELL uses to compute IGRND and BGRND. According to the *Theory User's Guide*, the optimum field boundary occurs where the **trim ratio** is 1.0. RCELL evaluates the trim ratio at the center of each cell and stores the results in the matrix RGRND. The *Theory User's Guide* shows that, if RGRND(I,J) > 1.0, then the center of cell(I,J) is within the field boundary; similarly, if RGRND(I,J) < 1.0, then the center of cell(I,J) is outside the field boundary. For most of the cells, this is an adequate test to determine whether the entire cell is inside or outside of the field boundary, but what about those cells that contain a part of the field boundary? What fraction of such a cell is within the field boundary? This fraction can be estimated by comparing RGRND(I,J) to 1. If the field boundary passes through the exact center of cell (I,J), then RGRND(I,J) will be exactly 1.0, and on the average about 50% of the cell will be within the field boundary. If RGRND(I,J) is slightly greater than 1.0, then the center of cell(I,J) is just inside the field boundary, and more than 50% of the cell is inside the field boundary. If RGRND(I,J) is slightly less than 1.0, then the center of cell(I,J) is just outside the field boundary, and less than 50% of the cell is within the field boundary. Thus, both IGRND(I,J) and BGRND(I,J) can be estimated by comparing RGRND(I,J) to 1. The functions used to quantify these comparisons are given in Figure 4.7-1. By their natures, IGRND(I,J) is a step function and BGRND(I,J) is a continuous, or ramp, function of RGRND(I,J).

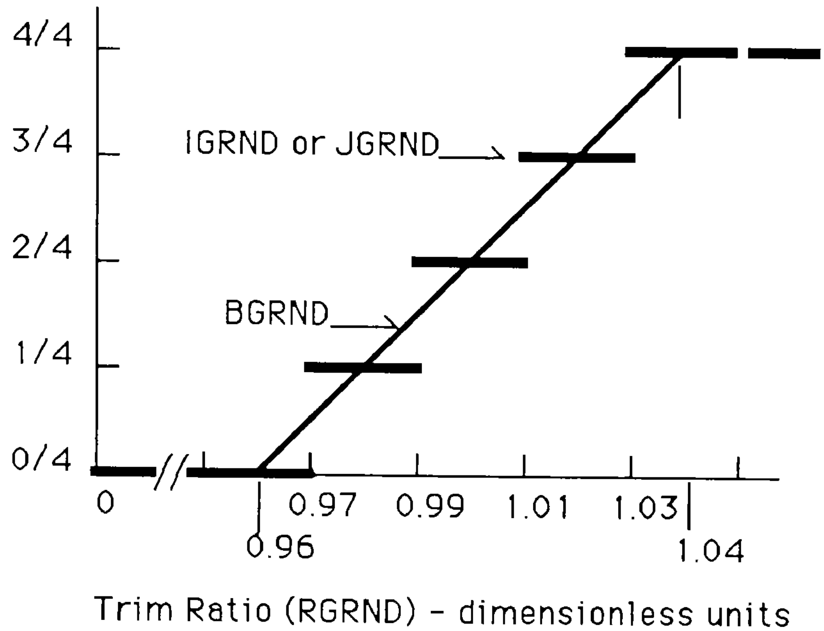


Figure 4.7-1 Step Function vs. Ramp Function for Field Boundary.

The variable DTRIM, which is in input module FIELD, is used to alter the functions shown in Figure 4.7-1. The six numbers shown on the horizontal axis in Figure 4.7-1 correspond to a value of DTRIM of 0.06. Smaller values of DTRIM make the ramp steeper and the field boundary more sharply defined. For example, a value of 0.03 for DTRIM would cause the horizontal axis in Figure 4.7-1 to be re-labeled with the six numbers 0.98, 0.985, 0.995, 1.005, 1.015, and 1.02. Similarly, larger values of DTRIM make the ramp less steep and the field boundary less sharply defined. A value of 0.06 is most often used for DTRIM. The value used is not critical, but it should not be changed frequently during a study. Of course, DTRIM should not be set to zero because this would imply an infinitely steep ramp. Additionally, if the IGRND matrix output by an RCELL run has, along several radial lines from the tower, more than one cell near the boundary that is less than 4, then the field boundary is not being sharply defined enough (see example below); in such a case, DTRIM is too large and should be reduced.

```
DATA ((IGRND(I,J), J=1,NCELJ), I=NCELI)
 &/0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
 & 0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,
 & 0,0,0,0,0,1,1,1,1,1,1,0,0,0,0,0,
 & 0,0,0,0,1,2,3,3,3,3,3,2,1,0,0,0,0,
 & 0,0,0,1,2,3,4,4,4,4,4,3,2,1,0,0,0,
 & 0,0,1,2,3,4,4,4,4,4,4,4,3,2,1,0,0,
 & 0,0,1,3,4,4,4,4,4,4,4,4,4,3,1,0,0,
 & 0,0,1,3,4,4,4,4,4,4,4,4,4,3,1,0,0,
 & 0,0,1,3,4,4,4,4,0,4,4,4,4,3,1,0,0,
 & 0,0,1,2,3,4,4,4,4,4,4,4,3,2,1,0,0,
 & 0,0,0,1,2,3,4,4,4,4,4,3,2,1,0,0,0,
 & 0,0,0,0,1,2,3,4,4,4,3,2,1,0,0,0,0,
 & 0,0,0,0,0,1,1,1,2,1,1,1,0,0,0,0,0,
 & 0,0,0,0,0,0,0,1,1,1,0,0,0,0,0,0,0,
 & 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0/
```

4.8 RTRIM†

The design of central receiver systems with cylindrical receivers is complicated by peak flux limits. Often, you may find that the optimum field determined by RCELL for a given receiver size produces the desired total absorbed power but does so by means of a flux distribution that exceeds the noon-time peak flux limit on the north panel(s). In the 1980 version of the UH Code System, there are

† RTRIM and DTRIM are unrelated.

only four ways to correct this problem : (i) change WTFLUX, which controls the relative number of heliostats that aim at the different aim points, or try a more complex aiming strategy (by changing IAIMS in RECVER) if one is available; or (ii) increase WCYLNT, the diameter of the cylindrical receiver; or (iii) increase HCYLNT, the height of the cylindrical receiver; or (iv) introduce a land constraint (via JGRND) which limits the number of heliostats that RCELL will allow in the north field. Method (i) should always be tried, but it may not provide enough of a reduction in the peak flux. Methods (ii) and (iii) are expensive, and so you will naturally wish to keep any receiver size increases to the minimum necessary. Method (iv) is undesirable as it is a very inelegant way of putting a constraint on the optimizer.

The most recent version of the UH Code System provides a fifth way to correct the above problem: (v) by changing RTRIM (in RCDRIV), some of the north heliostat field may be shifted to the south. When used in conjunction with an appropriate aiming strategy (see Section 4.9) and an appropriately sized receiver, adjusting RTRIM provides an elegant way of imposing receiver peak flux constraints on the optimum heliostat field. [Note: Methods (iv) and (v) are similar in that they both put constraints on the optimizer, but (iv) is a relatively clumsy way of doing this whereas (v) is a more balanced approach, compatible with the optimization theory and providing smoother and finer control.]

Fundamentally, the flux distribution problem on a multi-pass cylindrical receiver arises from the azimuthal asymmetry of the flux distribution itself, due to the typically greater number of heliostats in the north field, and of the imposed peak flux limits. For example, a molten salt receiver often has a multiple-pass flow path for the salt, which initially enters at the bottom of the north panel(s) and finally exits at the top of the south panel(s). As the salt temperature increases along its flow path, the amount of thermal energy it can absorb without exceeding its decomposition temperature at the tube interface decreases. Thus the peak flux limits on the south side of such a receiver are lower than those on the north side. Therefore, some method of altering the optimization equations is needed that includes an additional azimuthal dependence. A straightforward method of accomplishing this is to slightly alter the value of FMI on a cell-by-cell basis, instead of using exactly the same value of FMI for every cell as is done in the "no-peak-flux-limit" theory. Note that this affects both the optimum heliostat spacings and the field boundary. Thus, before RCELL solves the optimization equations for a cell, an "effective value of FMI" is computed for the cell by multiplying the input value of FMI by the factor $(1 + R \cos \phi)$, where ϕ is the azimuth angle of the cell as seen from the tower. (South = 0.) R denotes the input constant RTRIM, which is a real number between -1 and +1. It is best to input only small values for RTRIM; for example, RTRIM less than about 0.2 is reasonable.

If RTRIM = 0, then the effective value of FMI for all cells is just the input value of FMI. This is the standard, or "no-peak-flux-limit", mode of optimization. If RTRIM = +0.1, then cells in the south will have an effective value of FMI slightly greater than the input value of FMI, and similarly cells in the north will have an effective value of FMI slightly less than the input value of FMI; cells in the east and west rows will be unaffected. This is equivalent to telling RCELL that southerly cells are inherently more cost-effective than RCELL would have otherwise calculated, and similarly northerly cells are inherently less cost-effective. This is, in fact, true because reducing the north field, by moving heliostats to the south field, reduces the peak flux and allows use of a smaller, less costly receiver. However, there is a second-order increase in the cost of the less-efficient heliostat field that must be traded against the receiver savings. The net result of RTRIM=+0.1 is a smooth, partial shift of the "RTRIM=0 north field" toward the south field. Likewise, small negative values of RTRIM will result in a smooth, partial shift of the "RTRIM=0 south field" toward the north field. Of course, such a northward shift is generally undesirable.

In the actual RCELL code, the concept of an "effective value of FMI" is implemented by dividing the variable ELPR, the LAGRANGIAN PARAMETER, by the factor $(1 + R \cos \phi)$. Also, RTRIM is available and effective only with the most recent standard version of RCELL. The value of RTRIM does not affect GOPT runs or TRAJ file runs, although RTRIM=0.0 is recommended for such runs. As we discussed in Section 4.4, GOPT can not be used effectively with systems that have significant peak flux limits.

4.9 Separate North and South Weights for Aims

The methods of Section 4.8 can be used to decrease the peak flux on the north panel(s) of a cylindrical receiver. However, sometimes the peak-flux limits are violated on the south panel(s) in the early morning or late afternoon, instead of or in addition to the noontime violations on the north panels. The basic problem in these cases is that a single set of weights for the heliostat aiming strategy is incapable of effectively reducing the peak flux from both the north and south fields. Therefore, the most recent version of NS allows you to specify different weights for the aiming strategies in the north and south fields. (Note: The discussion here, in Section 4.9, is useful only for cylindrical receivers with surround fields and is of no consequence for flat panel receivers with north fields.)

In the 1980 version, only a single set of weights was allowed, and it was input via WTFLUX in input module RECVER. For example, a typical five-level aiming strategy for a cylindrical receiver might have used the following input:†

```
DATA WTFLUX / 0.33, 0.35, 0.135, 0.09, 0.095, 4*0.0 /
               1     2      3     4      5
```

The above weights would have resulted in 33% of the heliostats in each cell aiming at the uppermost of the "five" aim points, 35% aiming at the lowermost of the "five" aim points, and so on as depicted below.

33.0%	1
9.0%	4
13.5%	3
9.5%	5
35.0%	2

In the most recent version of NS, this scheme is expanded to allow you to specify different weights for the aiming strategies for

† Five levels is the most complex allowed by NS for cylindrical receivers. For a five-level aim, the first five numbers must add exactly to 1.0, and the last four of the nine possible WTFLUX entries must be 0. For each cell, NS computes the optimum five aim points for that cell -- hence the name "five-level aiming strategy" instead of "five-point aiming strategy" because the "five" aim points are different for each cell. However, even "five-level" can be confusing because there are five levels per cell. (See footnote to page 55.)

the north and south fields via WTFLXN and WTFLXS. To carry the above example a step further, you might find that the following inputs would satisfy all of the receiver peak-flux limits while the above single set of weights might not.

```
DATA WTFLXN / 0.333, 0.343, 0.123, 0.098, 0.103, 4*0.0 /
DATA WTFLXS / 0.235, 0.375, 0.220, 0.080, 0.090, 4*0.0 /
                 1      2      3      4      5
```

These weights would result in the following percentages of heliostats in the cells due north and due south of the tower being aimed as shown below.

North		South
33.3%	1	23.5%
9.8%	4	8.0%
12.3%	3	22.0%
10.3%	5	9.0%
34.3%	2	37.5%

For the other cells, which are neither due north nor due south, a combination of WTFLXN and WTFLXS depending on the azimuth of the cell is used. For each cell, let ϕ = azimuth of the cell as seen from tower. (West = $-\pi/2$, South = 0, East = $\pi/2$, and North = π.). Let w_i = WTFLUX(I) = i<u>th</u> weight to be used for the cell, where i = 1, 2, ... , 5 for a five-level aim. Let s_i = WTFLXS(I) and n_i = WTFLXN(I). Let κ = a real constant ≥ 1. If $|\phi| > \pi/\kappa$, then $w_i = n_i$. Otherwise, the formula for w_i is as follows:

$$w_i = \left(\frac{s_i + n_i}{2}\right) + \left(\frac{s_i - n_i}{2}\right)\cos(\kappa\phi) . \qquad (4.9\text{-}1)$$

Currently, κ = 2.0 and so the entire north field uses the weights in WTFLXN. The blending of WTFLXN and WTFLXS begins with the due east and due west heliostats, for which the blend yields the weights in WTFLXN, and continues around to the due south heliostats, for which the blend yields the weights in WTFLXS. You should verify that these statements are consistent with Eq. (4.9-1) when κ = 2.0.

In the actual NS code, κ is represented by the variable ALIM, which occurs under ENTRY point CYLN2 in SUBROUTINE CYLN in disk file FINTX.FOR. If desired, the value of ALIM may be changed and the set of subroutines in FINTX recompiled.† For example, ALIM = 3.0 would begin the blending of WTFLXN and WTFLXS at $\pm\pi/3$ from south and ALIM = 1.5 would begin the blending at $\pm 2\pi/3$ from south.

If you require only one set of weights for the entire heliostat field, then these weights should be identically entered into both WTFLXN and WTFLXS. Alternatively, the weights may be entered into WTFLXN only, and all of the weights in WTFLXS set to 0.0, which signals the program to copy the weights from WTFLXN into WTFLXS.

The COMMON region CAIM has been expanded. In the 1980 version, this COMMON region was defined by:

```
COMMON /CAIM/ WTFLUX(9)
```

In the most recent version of NS, this COMMON region is defined instead as:

```
COMMON /CAIM/ WTFLXN(9), WTFLXS(9), WTFLUX(9)
```

You should verify that the COMMON region definition in your input module RECVER is identical to the new expanded version shown above. Furthermore, input of the weights into WTFLXN and WTFLXS, using DATA statements, is the correct procedure for the most recent version of NS; do NOT attempt to input weights by loading values into WTFLUX.

† The easiest way to find ALIM is to use any standard text editor to search for "ALIM◊=", where "◊" denotes one blank space.

4.10 Trade Studies Under Peak Flux Constraints

GOPT finds the optimum tower focal height and optimum receiver area, in addition to optimum heliostat spacings and field boundary, when there are no peak flux constraints. However, the standard version of RCELL must be used to optimize systems with significant peak flux constraints. In this section, we discuss the design process in the presence of peak flux limits, including the concepts involved. For easy reference, we summarize the major steps in the start-up kit in section 9.

0) Make initial estimates of receiver length (HCYLNT) and width (WCYLNT) and tower focal height (HT).

   Estimate the receiver area needed to absorb the required design-point thermal power (ECON) without exceeding the peak flux limits established by the receiver designer. Using an appropriate aspect ratio (L/D of about 1.25 ± 0.15), estimate HCYLNT and WCYLNT. Estimate the total reflective area and associated total land area and the value of HT needed to deliver ECON. Sections 2.2 and 2.3 discuss system scaling, which is the recommended method of obtaining these initial estimates. Alternatively, a less accurate method is given in Appendix A. Another good reference for such estimates is Section 4.2 of *A Handbook For Solar Central Receiver Design* [12].

1) Find optimum field and associated aiming strategy for selected HT, HCYLNT, and WCYLNT.

   Use RCELL to determine optimum heliostat spacings and field boundary. Make NS flux runs if necessary to find a set of weights for the aims (WTFLXN and WTFLXS) that yield a reasonably uniform receiver flux distribution.

   A reasonable first estimate for RTRIM must be used in this RCELL run. Unless prior experience with the particular system to be studied suggests otherwise, try:

   $$RTRIM = 0.1 + 0.02(x_1+x_2)$$

   where:

x_1 = -1 for inexpensive heliostats (like 75 $/m²)
+1 for expensive heliostats (like 150 $/m²)
x_2 = -1 for multipass receivers with north inlet & south outlet
+1 for single pass receivers, such as sodium receivers

2) Adjust HCYLNT and RTRIM to obtain a peak flux close to the design limit.

Be sure that WCYLNT is consistent with receiver panel width. Panel width is determined from receiver tube diameter and number of tubes per panel, which are estimated by the receiver designer. Be sure that active receiver length (HCYLN) does not exceed the maximum tube fabrication length, currently quoted as 30.48 m (100 ft). Change HCYLNT and make NS flux runs until a peak flux close to, but not exceeding, the design limit is obtained. Peak fluxes that are ±1% or ±0.01 MW/m^2 from the design limits are usually acceptable, but the "+" is allowed only if the peak flux limits furnished by the receiver designer include a 5-10% safety margin. Adjust WTFLXN and WTFLXS (see Section 4.9) if necessary to maintain a fairly uniform flux distribution on the receiver. Make off-design-time runs (e.g., 8 a.m. on summer solstice) to be sure that peak fluxes at off-design times on the south and side panels are within design limits. Note that reduced flow at reduced power levels may require a revision of the design flux limit for these off-design-time runs.

Run RCELL again with the new HCYLNT to obtain a new figure of merit (F) and new optimum heliostat spacings and field boundary.

Review design-point and off-design-point flux maps and select an improved value of RTRIM. If the first estimate was grossly off, repeat step (2) with this new value.

3) Find optimum HT.

Use RCELL with between two and four other values of HT, starting with 90%HT or 110%HT. Make sure that the peak flux remains close to design limits without exceeding them. This may require new WTFLXN and WTFLXS in each case, or in rare cases a change of HCYLNT. Plot figure of merit (F) vs. HT for each HT used, including the case from (2) above. The graph should be roughly parabolic and cover a range of F of about 1%. Interpolate to find the value of HT that gives lowest F.

4) Find optimum WCYLNT, HCYLNT, and RTRIM.

For selected WCYLNT, trade HCYLNT vs. RTRIM. Increasing RTRIM shifts the field more toward the south, which decreases the peak flux on the north and thus allows a smaller HCYLNT, saving money on the receiver. However, the south field heliostats are generally poorer performers than the north field heliostats, mainly due to larger cosine of incidence losses, because the sun is in the southern sky in the northern hemisphere. Therefore, heliostats must be added to the field to bring the system back to the required ECON, increasing the cost of the heliostat field. Trading HCYLNT against RTRIM will result in a cost-effective balance.

Both RCELL runs and NS flux runs are required for this trade. You must make sure that the systems you compare have peak fluxes close to the design limits but do not exceed those limits. This constraint will likely require new WTFLXN and WTFLXS in each case tried. In particular, peak flux at off-design times on the side and south panels as well as peak flux at the design time on the north panels should be monitored to assure that peak flux limits are not violated. Monitoring of the south and side panels becomes more important as RTRIM is increased because of the increased amount of flux shifted southward. The new capability to use different weights for WTFLXS than those for WTFLXN (Section 4.9) is very helpful for maintaining the peak fluxes close to the design limits without exceeding those limits.

After the optimum HCYLNT has been determined for the selected WCYLNT, increase (and/or decrease) WCYLNT by about 5%, but in a way consistent with panel width; decrease (and/or increase) HCYLNT by the same percentage; and repeat the trade of HCYLNT against RTRIM. This step decreases (increases) receiver spillage and increases (decreases) receiver cost by about 2% prior to the trade of RTRIM vs. HCYLNT.

Step (4) thus yields two or three alternative systems. Note that a multitude of sophisticated trades are taking place simultaneously in this process. You should not be surprised by wrong guesses and should be prepared to take advantage of understanding them in order to recalibrate your understanding of the system. While the several systems should be compared on the basis of cost-effectiveness (i.e., figure of merit F), the system with lowest F should be chosen only if it meets all design goals, in particular the design flux limit.

5) Make any necessary refinements to WTFLXN and WTFLXS and then make several NS flux runs at various times and days as specified by the receiver designer. Make an NṠ annual run to obtain daily and annual statistics for the optimum system.

   Give receiver flux maps to receiver designer for detailed receiver design. Give cost summaries and daily and annual statistics for optimum system to the project's Design Integrator for analysis and use in SOLERGY studies.

The above steps yield a preliminary design. Steps (1) to (5) are usually repeated at least once in order to achieve a final system design, after the receiver designer has made a detailed design and performance evaluation of the field-receiver system supplied in step (5) and suggested any changes to the receiver. These changes are usually made necessary because the design exceeds, or does not come close enough to, the peak flux limit on some panel(s) or at some time(s). Of course, more attention to details and more runs are made for the final system design than are made for the preliminary design. In fact, some of the more time-consuming parts of step 4 may be omitted for the preliminary design.

4.11 Decompression Ratios in IH

The LAYOUT portion of IH is responsible for generating individual heliostat locations. Heliostats are laid out on concentric circles, or parts thereof, about the tower and in a manner consistent with a radial stagger configuration. (See Figure 3.1-4.) LAYOUT first puts heliostats along the outermost circle of the field and proceeds inward toward the tower.†

The layout process gives rise to zones within the collector field. A **zone** is a region where all heliostats have the same angular azimuthal separation as seen from the tower. Therefore, within a zone, the azimuthal separation of heliostats in meters decreases as you walk toward the tower. When the azimuthal separation in meters reaches the allowed minimum, the angular separation of the heliostats must be increased; i.e., the number of heliostats within a fixed angle of azimuth must be reduced in order to prevent azimuthal overcrowding. When this is done, a **slip "plane"** is introduced; i.e., at this radial distance from the tower, the regular array of radial stagger must be broken and a new zone must be started. Thus, a slip plane is also called a **zone boundary**. A slip plane is defined to lie midway between two neighboring circles of heliostats.

Near a zone boundary, **deletes** and **slips** occur; i.e., some of the heliostats are deleted and others are slightly shifted azimuthally. The shifting is done to smooth the boundary transition and to relieve the shading and blocking losses across the zone boundary. **Nose blocking** refers to the blocking of a heliostat's reflected light by a neighbor directly in front of it (i.e., lying on a radial line connecting the blocked heliostat to the tower). The deleted heliostats are removed from the field because they would have suffered about 50% nose blocking had they been left in.

The question of how many heliostats to delete near a slip plane is a complex one, and so only some basic concepts about deletes will be reviewed here. It is obviously unsatisfactory to delete an entire circle of heliostats. Thus, IH deletes only some of the heliostats from

† Proceeding from the outside inward is the natural order for laying out the heliostats. The basic reason for this is that a heliostat is blocked by heliostats in front of it, i.e., toward the tower. The heliostat-spacing polynomials computed by RCELL incorporate this effect implicitly.

the circle just outside of the slip plane. The easiest way to describe how many heliostats are deleted from this circle is to cite the **decompression ratio** (N+1)/N, where N is the number of heliostats between two deleted heliostats on the circle. This is equivalent to stating how many heliostats are within some angle of azimuth on a circle just outside of the slip plane, divided by how many heliostats are within the same angle of azimuth on a circle just inside of the slip plane.

When the University of Houston used IH to lay out the heliostat field for the Solar One Pilot Plant in Barstow, California, a decompression ratio of 4/3 was used at each slip plane. [13,17] Thus, the number of heliostats per circle was reduced by 25% each time IH created a new zone. The experience gained by the University of Houston in laying out the Barstow field was used to improve the LAYOUT routines in IH. In particular, it became clear that the layout of commercial-size fields (perhaps 5-10 times the size of the Barstow plant) would require decompression ratios smaller than 4/3 in the outermost zones, and today's larger heliostats require larger decompression ratios in the innermost zones. The basic reason is that, as the radial-stagger layout proceeds inward toward the tower, the azimuthal compression of heliostats occurs more and more rapidly because associated radial lines converge at zero radius. Consequently, the appropriate decompression ratio increases as the layout proceeds inward toward the tower. Thus, whereas a Barstow-size field may be able to use an "average" decompression ratio for the entire field, a commercial-size field will require a range of decompression ratios. Decompression ratios around 1 are appropriate for the outer zones, and ratios around 2 are appropriate for the inner zones. IH can now provide decompression ratios of :

7/6; 6/5; 5/4; 4/3; 3/2; and 2/1.

For more about IH, see Sections 3 and 11 and Appendix C. For detailed information about LAYOUT, including decompression ratios, slips, and circle radii, see the *IH User's Guide*; in particular, the discussion of slips and deletes is in Section 2.5.

4.12 Available Special Studies

The UH Code System was developed over a 15-year period. During most of this time, we were involved with many engineering firms in the development of a range of system designs. Consequently a considerable range of special studies were performed using the codes. The capability of repeating many of these studies has been retained, because we felt the studies were likely to have future use. We briefly describe these special studies here.

Although standard runs have not been defined for each study, a few have, and others can be in case of need. Not all of these runs have been checked out in the VAX environment, but no unusual difficulty is foreseen in making any of them operational. All of these runs work for level fields, and nominally they will also work for arbitrarily sloped fields and for fields with up to five intersecting planes, although some care may be required.

4.12.1 Receiver Flux Map: Cavity Interior

In conjunction with a geometry file from the UH code CAVITY-CREAM, the NS code can produce accurate flux maps on the interior nodes of the cavity. Aperturing effects are fully accommodated and fractional cell visibilities at each node are evaluated to reduce numerical ratchet-like effects.

Special aims respecting both interior and aperture boundaries can be defined.

The CAVITY-CREAM code provides visible and IR flux redistribution and provides equilibrium node temperatures on both tube walls and adiabatic surfaces.

4.12.2 Receiver Flux Map: Flats, Aperture Plane, or Cylinder

For a defined field, an NS node file run will produce a flux map, either with or without shading and blocking effects included.

RCELL runs can produce flux maps in association with each final summary page. A multiple trim run can produce multiple flux maps.

A multitude of aim strategies are available.

4.12.3 Panel Temperatures

NS or RC flux maps for a specific day and time are summed along the flow path and the fluid temperature at the outlet of each panel estimated.

If an algorithm for allowed flux vs. temperature is provided, the allowed flux is also printed. This routine is not user friendly.

4.12.4 Node Temperature and Excess Flux

An extension of the above routines estimates the fluid temperature at each node of each panel and compares the incident flux with the allowable. A matrix of the difference is output. This routine is not user friendly.

4.12.5 Flux Distribution at a Defined Time

In first approximation, the equinoon node file is representative of all times. Therefore, it can be used with a defined field and NS year to generate an approximate flux map for any time. File 29 can transfer the definition of an RC-optimized field for the purpose.

An accurate flux map results from making a node file for the specific time, using file 29 and enabling shading and blocking. This very useful run is defined via ISTDNS = 7 and benefits further if the node temperature and excess flux routines are available.

4.12.6 Flux Distribution vs. Time

An excess of data results from generating a full flux map for a multitude of times. Consequently a summary giving the power to each panel at each time in question is output.

Panel-to-panel gradients are generated and output in the same format. These are useful for estimating transverse temperature gradients and developing flow-control strategies.

Specific runs are defined; namely, annual, start-up (morning), start-up (midday), cloud passage, drift (power outage), and drift (slew).

Some of these runs can also produce full flux maps vs. time, but all can be tuned to output a large amount of field performance information.

4.12.7 Annual Run (Cellwise)

The standard annual run outputs system power and efficiency for 7 (alternatively, 3 to 10) equal time steps on the afternoons of 7 (or 12) days spaced ~ 30 days apart.

Many useful parameters are printed in summary and integrated form, and if desired, cellwise performance factors can also be output for each instant.

Panel-power summaries are available.

4.12.8 Annual Run (IH)

The same basic features are available as for the cellwise version.

Rather than an IH node file (immense), the NS cellwise node file is used. It is interpolated to the individual heliostat at an appropriate level of accuracy. Thus, for a flux map, linear interpolation is used; for panel powers, quadratic interpolation is used; for interception factors, bicubic spline interpolation is used.

Thousands of pages of output are available, so resources and needs must be balanced carefully in setting the IH control switches.

4.12.9 Start-Up (Morning) (Cellwise)

During the relatively short time period covered by a start-up study, the sun's position does not change greatly, and so a single time-centered node file is adequate to minimize errors in flux distribution due to optical aberrations. Of course, the solar elevation and hence insolation and local values of cos i and S&B are changing rapidly, although not "greatly", during the short period of a morning start-up run.

Three or four additional ranks of neighbors are considered in the shading calculation. The event processor handles overlapping shadows accurately for rectangular heliostats, but for round heliostats the distant aligned neighbors must be, and are, excluded from the list to be sampled, minimizing the overlap problem.

Five to ten times are sampled for a user-selected range of solar elevations; e.g., 5° to 15°, or 0.01° to 10°.

Both receiver power and panel powers are usually of interest. A series of receiver flux maps can be generated also, but this involves more runs.

All heliostats are assumed to be active.

4.12.10 Start-Up (Morning) (IH)

This is an individual heliostat version of the start-up study; see Section 5.4 of *SFDI Collector Field Optimization Report (RADL Item 2-25)* [13], hereafter referred to as ***SFDI***, for a description of the run done for Solar One.

4.12.11 Start-Up (Midday) (IH)

For this study, the sun is assumed stationary, and successive allocations of heliostats are moved from standby to track. To implement this study, each heliostat is assigned a pecking order (priority ranking). At each time step, a new rank (typically 10%) of heliostats is activated.

If an area on the receiver is underilluminated at some one of the time steps, more of the heliostats capable of illuminating that area can be assigned priority numbers that will turn them on.

4.12.12 Cloud Passage (Cellwise)

Time histories of five cloud fields passing over the Cool Water plant (near Solar One) have been incorporated into an interpolation routine by Aerospace Corp. [18, 19]. NS provides the capability to advance such a field across the cellwise array from any direction, interrogate the Aerospace database and obtain cloud transmission factors for each cell center, and thus generate receiver panel-by-panel power listings as a function of time [20].

See Section 5.5 of *SFDI* [13] for a more detailed description.

4.12.13 Defocus

Drift (collector outage).
The capability to generate a series of flux maps for stationary heliostats (loss of collector field power) as the sun appears to move across the sky is described in detail in Section 4.3. With some aim strategies (e.g., a four-point aim on a flat receiver), the peak flux may double before starting to decline.

Drift (slew).
In the other extreme, the heliostats may be driven rapidly on either or both axis in an active defocus mode (e.g., under loss of receiver coolant flow).

Change focal length.
Membrane heliostats are expected to defocus rapidly by inflating the "vacuum" plenum or whatever. Such a capability could be readily implemented but has not, awaiting definition of the proposed defocus mechanism.

4.12.14 Aim Assignments

As described in Section 3.3, IH is equipped to interpolate the cellwise aim file to determine the appropriate aim point for each heliostat, which is reported in terms of a shift, in meters, from the aim-at-belt point.

PART III

START-UP KITS

UH

UNIVERSITY OF HOUSTON

ENERGY LABORATORY

SOLAR THERMAL DIVISION

Table 5.1-I
Basic Characteristics of UH Code System

The 1988 UH Code System is available for VAX computers.

> The primary computer system on which the UH Code System is supported is the VAX 11/785 with operating system VAX/VMS version V4.5.

Codes are written in standard FORTRAN 77.

> Standard FORTRAN 77 makes the transfer of the Codes to non-VAX computer systems easier.

JCL command files (.COM) initiate, govern, and terminate runs.

> Disk files RUNRC.COM or RUNNS.COM or RUNIH.COM contain the necessary DCL commands to compile the input modules, link them with the rest of the permanently compiled code, assign disk files, and execute the program in batch mode. Use the DCL command SUBMIT "file" to initiate a RUN.

Codes are controlled through DRIVer modules.

> Disk files RCDRIV.FOR or NSDRIV.FOR or IHDRIV.FOR contain PARAMETER statements that establish array sizes and STD subroutines that set most program control switches.

Data is input through input modules.

> HELIOS = Heliostat data
> RECVER = Receiver data
> FIELD = Field data
>
> Multiple versions of each input module may be maintained, as appropriate, for different types of heliostats, different receiver configurations, and different sites.

For a specific run, you select appropriate:

> COM, DRIV, HELIOS, RECVER, and FIELD modules.

The bulk of the Code System is compiled upon initial receipt, and the resulting object files (.OBJ) are kept and are LINKed to the above modules for each run by the .COM files.

5. INITIAL PROCEDURES

The goal of the start-up kits in Sections 5 to 11 is to lead you through the steps required to initiate the typical runs involved in a complete system study, from optimization through to coordinate specification. The start-up kits are intended to complement the *User's Guides* [1,2,3,4,5], and so they do not discuss all of the possible inputs and outputs. It is assumed that you have at least a working familiarity with the basic concepts of solar central receiver system design and have access to the *User's Guides*, which should be used, when necessary, as more extensive reference manuals.

In Section 1, we briefly describe each start-up kit; Figure 1.-2 shows how the start-up kits are related to each other. In Section 2, we discuss the basic concepts behind NS and RC; in Figure 2.1-3 and in Tables 2.1-I to 2.1-III, the functions and features of NS and RC are summarized. In Section 4.1, we describe the new user-friendly input modules; on page 53, the standard runs selected by setting ISTD are listed. You may wish to review the information at this time.

In Section 5, we cover initial procedures, such as organizing files and setting up the input modules to begin a system study. We include a sample set of input modules in Appendix F for reference.

5.1 Initial Tape Handling and Compiling

Some basic characteristics of the UH Code System are listed in Table 5.1-I.

Upon receipt of the magnetic tape containing the code, you should contact your site's computer personnel for help in mounting and reading magnetic tapes on VAX. A sheet(s) will accompany the tape, listing all the commands used to write the tape.

You should establish a directory structure identical to the directory structure shown on the sheet(s) accompanying the tape. Files should be sorted into the subdirectories from which they originally came, as shown on the sheet(s). Table 5.1-II shows the standard directory structure and the disk files that are usually supplied on the magnetic tape. (The files under subdirectories DATA and INPUTS in Table 5.1-II are examples of files that you will create and are not supplied on the magnetic tape.)

Table 5.1-II
Disk Directory and File Structure

DATA subdirectory

DIARY1.DAT	SBC_STUDY1.DAT

DEFAULT_INPUTS subdirectory

FIELD_BARSTOW.FOR1	VERINP_PRTDEF_DEF.FOR0
HELIOS_RND_1ST_PLANT.FOR1	VERINP_DEF.FOR
HELIOS_SPLIT_REC.FOR1	
IHDRIV_DEF.FOR1	COMPDEF.COM0
NSDRIV_DEF.FOR	PRINTDEF.COM0
RCDRIV_DEF.FOR	RUNIH_DEF.COM1
RECVER_CYLN_DEF.FOR1	RUNNS_DEF.COM1
RECVER_FLAT_DEF.FOR1	RUNRC_DEF.COM1

IH88 subdirectory

ANNUALP.FOR	SORT.FOR
CELTUR.FOR	YEARP.FOR
CYLN5.FOR	
LAYOUT.FOR	COMPILEIH.COM
RSABP.FOR	PRINTIH.COM

INPUTS subdirectory

FIELD.FOR	RCDRIV.FOR
FIELD_STUDY1.FOR	RCDRIV_STUDY1.FOR
HELIOS.FOR	RECVER.FOR
HELIOS_STUDY1.FOR	RECVER_STUDY1.FOR
IHDRIV.FOR	
IHDRIV_STUDY1.FOR	RUNIH.COM
NSDRIV.FOR	RUNNS.COM
NSDRIV_STUDY1.FOR	RUNRC.COM

NS88 subdirectory

ANNUAL.FOR	RSTRUC.FOR
CLOUD.FOR	SETREC.FOR
FINTX.FOR	YEAR.FOR
HCOEF.FOR	
RCTEMP.FOR	COMPILENS.COM
RSABM.FOR	PRINTNS.COM

RC88 subdirectory

CELLAY.FOR	SUBRF.FOR
INTERG.FOR	SUBRG.FOR
INTERP.FOR	
PLOT2.FOR	CELLAY.COM
RCELL.FOR	COMPILERC.COM
RCFINT.FOR	PRINTRC.COM

All files with file type .COM must be edited. All occurrences of "user" (or VANTHULL or PHYS2Q) within these .COM files must be replaced with the user directory name supplied by your local computer personnel. (You may also make this change to the .COM0s and .COM1s.)

All disk files with file type .FOR under subdirectories IH88, NS88, and RC88 must be compiled. You can do this by using the DCL command files COMPILEIH.COM, COMPILENS.COM, and COMPILERC.COM. For example, under the NS88 subdirectory, issue the DCL command SUBMIT COMPILENS.COM. Similarly, PRINTIH.COM, PRINTNS.COM, and PRINTRC.COM will print the compiled source listings and delete the compiler listings (i.e., delete file types .LIS, not file types .FOR or .OBJ).

Under the DEFAULT_INPUTS subdirectory, issue the DCL command : $ FOR/CONTINUATIONS=40 VERINP_DEF.FOR to compile the subroutines in file VERINP_DEF.FOR. While still under the DEFAULT_INPUTS subdirectory, issue the DCL commands:
$ SUBMIT/NOTIFY/KEEP COMPDEF.COM0 and
$ SUBMIT PRINTDEF.COM0
if you wish a printed copy of the default input modules.

5.2 Initiation of a Study

You should now be ready to prepare your input modules.† You may only need to make a few changes to the supplied input modules before making your first run if you simply want to learn how to operate the UH Codes. However, you can not learn how to use the UH Codes unless you understand the various inputs and the ways that they affect the results of a study. If you intend to begin your own design study of an entirely different system from the one that the supplied input modules represent, then you may need to make substantial changes to cost model equations, weather and cloud factors, visual range data, heliostat geometry and/or focusing, etc. Much of this type of data usually remains fixed throughout a study, and discussing it here would make these start-up kits unduly complex. For more information, consult the on-line comments in the input modules and the *User's Guides*. If you are using the UH Code

† See Section 4.1 for more information about the new input modules. We include a sample set of input modules in Appendix F for reference.

System for the very first time, we highly recommend that you take the time now to review the comments in the input modules thoroughly (Appendix F), even if you intend to make only the least number of changes possible to the inputs. (Review of the IHDRIV module may be delayed until you begin IH runs in Section 11.)

COPY the three DRIV modules and an appropriate HELIOS module, RECVER module, and FIELD module from subdirectory DEFAULT_INPUTS into STUDYn modules under subdirectory INPUTS.

For example, COPY the disk file
["user".DEFAULT_INPUTS]FIELD_BARSTOW.FOR1
into the disk file
["user".INPUTS]FIELD_STUDY1.FOR
where "user" stands for your user directory name supplied by your local computer personnel.

Also COPY the three _DEF.COM1 files under subdirectory DEFAULT_INPUTS into files RUNIH.COM, RUNNS.COM, and RUNRC.COM under subdirectory INPUTS. You will make changes to the STUDYn modules to create a set of inputs appropriate to the system that you wish to study. You will also make working copies of the STUDYn modules, as described later in this section. Any changes to the input modules or the .COM files should be made to the STUDYn modules, their working copies, or the .COM files under subdirectory INPUTS. Never change any of the disk files under subdirectory DEFAULT_INPUTS.

The cellwise programs NS and RC are used during most of a study. The Individual Heliostat program IH is not needed until after the optimum field and receiver are defined on a cellwise basis. You begin the cellwise optimization by specifying the collector field geometry in terms of cells, as discussed in Section 2. To accomplish this, select (i) the DIMENSIONs of the cell array, in terms of NCELI, NCELJ in NS and ID, JD, KC in RC,† (ii) the ORDER of cells, and (iii) the tower location, in terms of XTOWI and YTOWJ, so that your heliostat field will fill about 150-250 cells and the smallest receiver elevation angle θ will be about 6° (i.e., 5-10°). A generous set of cells is 15 cells high (N-S) and 17 cells wide (E-W), with a cell ORDER = 6.0 and the tower in cell (9,9), one cell south of center. For ease of presentation, a cylindrical receiver and associated surround field are

† See the appropriate comment lines in NSDRIV and RCDRIV in Appendix F.

assumed in the above statement and in the rest of Sections 5 and 6. (For a flat or cavity receiver, the number of N-S cells may be reduced by 1/3 and the tower is usually put in the middle of the southernmost row of cells, or just to the south thereof.) The ORDER of cells is discussed in Section 2.1; it is used in the definition of cell size in Eq. 2.1-1, which is equivalent to the FORTRAN formula:

```
DA = HT * SQRT(ORDER/4.0)                    (5.2-1)
```

where DA is the length of a cell side, and HT is the tower focal height.

You must also make initial estimates of HT and the receiver dimensions WCYLNT and HCYLNT. Simple scaling algorithms, discussed in Sections 2.2 and 2.3, can be used to make initial estimates of these parameters.† When estimating the receiver dimensions, be sure to take into account any imposed peak flux limits. When estimating HT, note that, for a surround field, an HT of about 140 m may be appropriate to provide 340 MW of thermal power to the tower base at noon on the vernal equinox. (For a cavity receiver and a north field, an HT of about 200 m may be required to provide 340 MW_{th}.) Similarly, for a surround field, an HT of about 185 m may be correct to provide 470 MW_{th} at Equinox noon, and an HT of about 250 m may be needed to provide 940 MW_{th}. These values are intended to be suggestive only; they are not functionally related to each other, nor do they necessarily scale very well between themselves, because of different design conditions such as peak flux constraints, heliostat costs, etc. You should make your own initial estimates as in Section 2.3, or as appropriate; and you will determine the optimum values of HT and the receiver dimensions during your study, as discussed in Sections 9 or 10, the appropriate section depending on whether your receiver has a peak flux constraint.

Review all PARAMETER statements in NSDRIV and RCDRIV to be sure that they match the requirements of your defined geometry. In particular, check the values of NCELI, NCELJ, IGREC, JGREC, and KGREC in NSDRIV and the values of IPROG, ID, JD, KC, IGREC, and JGREC in RCDRIV. For the above example, NCELI = 15, NCELJ = 17, IPROG = 1, ID = 15, JD = 9, and KC = 17 is appropriate, assuming east-

† Appendix A gives an example of an <u>alternative</u> method for making initial estimates. A second alternative method for initial estimates is in Section 4.2 of *A Handbook for Solar Central Receiver Design* by P. K. Falcone of SNLL [12].

west symmetry. IGREC, JGREC, and KGREC control the number of **nodes** on the receiver, i.e., the number of "cells" into which the receiver surface is divided for flux evaluation. The values of INODE1, INODE2, JNODE1, and JNODE2 in RECVER control the number of active nodes and must be consistent with the values of IGREC, JGREC, and KGREC.† The number of nodes must be large enough to allow the size of a node to be substantially smaller than the smallest heliostat image; otherwise, some receiver spillage fractions could become negative. On the other hand, the number of nodes must not be made unduly large because node files (defined below) would become impractically large. The total number of receiver nodes is usually between 200 and 800.

Once you have reviewed all of the inputs and determined that the _STUDYn.FOR modules are ready, copy each one into its corresponding working copy under subdirectory INPUTS. Table 5.1-II shows that the names of the working copies are NSDRIV.FOR, RCDRIV.FOR, HELIOS.FOR, RECVER.FOR, and FIELD.FOR. These names for the working copies are <u>mandatory</u> in order to assure correct interfacing with the command files RUNRC.COM and RUNNS.COM. Until you become familiar with the UH Code System, it is recommended that you copy the STUDYn modules into their corresponding working copies each time you are preparing to make a new run and then make the changes required for that run only to the working copies. You can write a simple command file (i.e., .COM file) that will issue the five COPY commands involved. The start-up kits generally assume that you are following this procedure. The main reason for this seemingly extra copying is so you will not have to remember to undo the changes you made for the previous run before making the changes for the new run. Of course, definitive and permanent changes should be made to the STUDYn modules so that you need not make these before each new run. When you have become familiar with the UH Codes, you may be able to skip this "extra" copying step and make and undo changes, as they become necessary, to the working copies only. Even after you have reached this level, however, you will still want to keep the final version of your working copies as a unique set of STUDYn modules for each

† See the appropriate comment lines in Appendix F.2, including the definitions of HCYLN and WCYLN. Allowed values are as follows: INODE1 > 0, JNODE1 > 0, INODE2 ≤ IGREC, and JNODE2 ≤ JGREC. However, for cylindrical receivers, JNODE1 = 1 and JNODE2 = JGREC are mandatory.

study that you complete. The STUDYn modules are also helpful if you are doing more than one system study at a time.

Before describing the actual runs, it is useful to define a few terms first. Both **database** and **SBC database** always refer to a disk file of shading and blocking (S&B) and cos i data. Cos i is the cosine of the angle of incidence of sunlight upon a heliostat. For each cell in the field, annual insolation-weighted average values of cos i and S&B loss fractions for each of a 4x4 array of heliostat-neighbor-separations is written to a database, file 08. (See Section 2.1.) A database is not large, typically 10-100 Kbytes. However, a relatively large amount of CPU time is required to generate a database, typically 5 - 10 minutes on a VAX 11/785, and so a database can be relatively expensive. Fortunately, only a few databases at most need be generated for any given study. Section 6 covers database generation in detail and also the characteristics of a "good" database.

Node file refers to a file which, for each cell in the field, lists the fraction of energy intercepted by each of 200 to 800 **nodes** on the receiver. Node files are big, typically 0.1 - 1.0 Mbytes, and reading a node file requires a significant fraction of the total program CPU time. A node file is needed to generate a receiver flux map in either NS or RCELL.

A **FINT file** (Fraction INTercepted) would result from a node file if, for each cell in the field, the entries for that cell were summed over those nodes that are on the active surface of the receiver. A FINT file contains one entry for each cell in the field for each allowed receiver size. Most often, a FINT file is created for use with GOPT and thus contains the fraction intercepted for a list of receiver sizes. For the first receiver size, the fraction intercepted is tabulated for each cell in the field; then, for the second receiver size on the list, the fraction intercepted is tabulated for each cell in the field, and so forth. FINT files are much smaller than node files and take much less time to read. However, receiver flux maps can not be generated from them. Thus, GOPT cannot produce receiver flux maps.

```
AIGX=  2.584  6.075  4.446  3.307  2.180  0.740       AIGF= 19.331
AIGY=  1.000  0.603  1.294  1.876  2.383  3.020  2.696  3.220  2.292  1.531  0.416

NGON =    0  ; MAX. NUMBER OF HELIOS./CELL=   306.8    ; HGLASS/DMIR**2 =  0.7683    ; TOTAL GLASS = 0.88160E+06

                           5930.9 HELIOS    AHELI= 148.6449    ASEG= 148.6449    ; TOTAL LAND  = 0.35366E+07



F-LIMIT       OPTIMUM       ALLOWED       M-LIMIT       PLANES


   44444344444     00000000000     00000000000     000000     111111
   44444444444     00123432100     00123432100     000000     111111
   44444444444     01444444410     01444444410     000000     111111
   44444444444     14444444441     14444444441     000000     111111
   44444344444     24444444442     24444344442     000000     111111
   44444444444     34444444443     34444444443     000000     111111
   44434043444     34444444443     34434043443     000000     111111
   44444444444     24444444442     24444444442     000000     111111
   44444344444     03444444430     03444344430     000000     111111
   44444444444     01344444310     01344444310     000000     111111
   44444444444     00012321000     00012321000     000000     111111
                              X=X=X=X=X=   TRIM = TRIM * (1 + (    0.1350) * COS(AZ)) OPTION ACTIVE   **********
* * * * * * * * * * * * * * NUMBER OF HELIOSTATS PER CELL ; HT =  185.0 FOCAL HEIGHT ; AND APERTURE=1067.65 M2
                        CYLINDER LENGTH =  21.03 M; DIA. =  16.16 M
                        REDUCED  LENGTH =  21.03 M; DIA. =  16.16 M

   0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
   0.0    0.0    7.0   25.9   38.1   42.9   38.1   25.9    7.0    0.0    0.0
   0.0   13.8   43.9   52.9   58.0   59.7   58.0   52.9   43.9   13.8    0.0
   6.2   44.7   56.5   66.3   74.8   78.4   74.8   66.3   56.5   44.7    6.2
  22.5   53.2   65.9   82.9  101.0   80.1  101.0   82.9   65.9   53.2   22.5
  32.1   57.2   73.4   98.9  132.4  138.7  132.4   98.9   73.4   57.2   32.1
  30.3   59.6   78.5   81.9  163.4    0.0  163.4   81.9   78.5   59.6   30.3
  20.5   58.1   75.7  102.8  147.9  177.8  147.9  102.8   75.7   58.1   20.5
   1.9   41.9   66.1   85.5  109.6   93.2  109.6   85.5   66.1   41.9    1.9
   0.0    6.1   40.2   67.6   79.4   83.3   79.4   67.6   40.2    6.1    0.0
   0.0    0.0    0.0   17.3   27.2   38.5   27.2   17.3    0.0    0.0    0.0
BLOSS =     29.310 KW/M2

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

     EQNOON POWER      =   422.376   467.879 IN MW - (SCALED TO  950.0W/M2)
     ANNUAL ENERGY     =   980.7288 IN GWH  PARAS.=  11.6072 HELIOS  20.6660 FPUMPS
     FIXED COSTS       =     2.7754 IN $M
     TOTAL TOWER COST=    32.6457; TOW  4.6182; REC 21.5041; V P  4.4536; PUMP  2.0699 IN $M FOR  950.0 EQUINOON POWER
     SUM PV O&M COSTS=     7.6708;        0.1206;        5.6169;        0.5816;         1.3516; PV OF O&M COSTS IN $M
     LAND COST         =     2.8784 IN $M;  PV OF O&M COST =   0.000 IN $M
     WIRING COST       =     1.5991 IN $M;  PV OF O&M COST =   0.589 IN $M
     HELIOSTAT COST    =    86.5732 IN $M;  PV OF O&M COST =  21.255 IN $M
     CAPITAL COST TOT=   126.4719 IN $M;  PV O&M COST TOT=  29.515 IN $M; PV OF PARA COST=   8.127 IN $M
     GRAND COST TOTAL=   164.1136 IN $M
     FIGURE OF MERIT =   167.338 IN $/MWH , FOR FINPUT= 119.846 ,AND FSTAR= 155.516

       DC(P)/DP= 1.40233E+04 $/MW , EINC/PINC= 2152.13 HOURS AND DC(E)/DE=    5.31 $/MWH
```

Figure 6.1-1 A typical RCELL summary page. (See text, Sections 6.1 and 6.2.)

6. START-UP KIT FOR INITIAL SBC DATABASE

Section 6 provides a detailed description of how to obtain your first database. After you have some experience making a database, you will probably wish to refer to the summary of Section 6 that is provided in Section 7.1, instead of always referring back to the somewhat detailed discussion here in Section 6.

It is assumed that you have previously set up: (i) the receiver cost model equations for your system in RECVER; (ii) the heliostat cost per m^2 for your system in HELIOS; (iii) your field and wiring costs in FIELD; and (iv) the site data (latitude, elevation, ground slope, etc.) and appropriate inputs for the insolation and visual range models in FIELD. At this point, reasonable approximations are adequate for items (i) - (iii), but item (iv) should be final. Consult the *RC User's Guide* if you need help setting up these inputs.

6.1 First Run: Make an SBC Database

(1) Load a reasonable tower focal height (HT), receiver length (HCYLNT), and diameter (WCYLNT) in RECVER.

(2) In file RCDRIV.FOR, set ISTDRC = 2 to generate a database. (This type of run is often referred to as a **long run**.) Follow the instructions in section 4.10 to set RTRIM properly (unless you are studying a system with a north field only, in which case set RTRIM = 0.0). Set IFINT = 0 as you will use KTAPE = 0. Review all PARAMETER statements in RCDRIV and ORDER, XTOWI, YTOWJ in FIELD to be sure that they match the requirements of your field geometry, as discussed in section 5.2 and step (1) of section 7.3.

(3) Following the RCDRIV part of file RCDRIV.FOR, find subroutine STDRC and find that part of STDRC between statements 200 and 300. This part is called "section 200" of STDRC, and it contains the most important control switches for the ISTDRC = 2 run.

(4) Add the following line of code to section 200 of STDRC:

```
KTAPE = 0
```

This avoids the need for a node file at this early stage of the study by using entry point FINTU (User-defined INTerception Fractions) in input module RECVER. Let η denote interception fraction for a cell. (The interception fraction is 1 - spillage fraction.) In the codes, η is called FINT. The remarkably good default formula for η in FINTU is:

$$\eta = 1 - \exp[-(LD/4) (\cos R) / (2 K^2 \Sigma^2 S_r^2)] , \qquad (6.1\text{-}1)$$

where

$$\Sigma^2 = \left(\frac{\alpha}{2}\right)^2 + \sigma_B{}^2 + \left[\frac{1}{2}\left(\frac{0.5\ D_m}{S_r}\right)\left(\frac{f - S_r}{f}\right)\right]^2 , \qquad (6.1\text{-}2)$$

and

L is HCYLNT, in meters.
D is WCYLNT, in m.
cos R is cosine of incident angle on receiver.
K, denoted by KS in the code and nominally 1, is an adjustment on the spot radius. (Larger K gives more spillage.)
S_r is the slant range between heliostat and receiver.
α is the half angle of the sun = 0.00466 radians.
σ_B is the beam error in radians due to all heliostat effects (combined in quadrature).
D_m is the nominal heliostat diameter = DMIR, in m.
f is the nominal focal length of heliostat, typically 1.1 S_r or 1.2 S_r.

(5) Load heliostat-spacing coefficients into COEFX (for ΔR) and COEFY (for ΔAz) in input module FIELD, and verify that ICOF is set appropriately. (Remember that the values of ΔR and ΔAz that will result from the polynomials using these coefficients will be in DMIR units. See Section 4.7). If you have previously studied a system similar to the one you are about to study, then use the output coefficients from the previous study as your first guess for the input coefficients for your current study. Otherwise, try:

$$\Delta R = 60/\theta - 0.5 + \theta/60 \qquad (6.1\text{-}3)$$

$$\Delta Az = 2.1 \text{ (with rectangular heliostats)} \qquad (6.1\text{-}4)$$
$$= 1.7 \text{ (with round heliostats)}$$

where θ is the elevation angle (in degrees) of the receiver as seen by an observer in the field and, again, ΔR and ΔAz are in DMIR units.

This corresponds to: COEFX(1,1) = 60.0; COEFX(1,2) = -0.5; COEFX(1,3) = 1.666667E-2; and COEFY(1,1) = 2.1 or 1.7; <u>and</u> all the others zero; and ICOF = 1. These coefficients will usually give a reasonable first database.

(6) Load a reasonable value of FMI in section 200 of STDRC. Typically, CHL + CHOM is a reasonable 0th-order estimate. CHL and CHOM are both input in module HELIOS. CHL is installed heliostat cost, and CHOM is the present value of heliostat O & M (PV of O&M) for the design lifetime. (At 6.5% real interest and a 30-year lifetime, CHOM = Annual O&M × 13.06, but if interest equals inflation (i.e., 0% real interest) the multiplier is 30.)

Review the other control switches and the comments in section 200 of STDRC. The comments will often remind you of things that you forgot to do. <u>Before every run, it is good operating procedure to verify that the control switches are set properly and to review the comments in that unique section (of the appropriate STD subroutine) specified by ISTD.</u>

(7) In RUNRC.COM, use the appropriate ASSIGN/USER command to assign a reasonable name (such as SBC_STUDY1.DAT) to the SBC database (file 08) that will be produced by this run.

(8) Submit run using the command SN RUNRC, after you first define SN to the VAX operating system by issuing:
SN:== SUBMIT/NOTIFY/KEEP/NOPRINT
(This definition may be put into your LOGIN.COM file, if you have one, and then you will not need to retype it every time that you LOGIN.) Thus the command SN RUNRC will tell the operating system to process the DCL commands in file RUNRC.COM; notify you when it has finished executing all of

them; keep the printout in file RUNRC.LOG; and not to print the printout on the system printer.

(9) Examine the printout. You can either use a text editor (such as EDIT) to view file RUNRC.LOG, or you can send your printout to the system printer with the command PRINT RUNRC.LOG.

A typical RCELL **summary page** is shown in Figure 6.1-1 (on the facing page to the introduction to section 6).

The *RC User's Guide* describes all RCELL printouts including the summary page (see reference [1], Section 6).

Review the solution map in each cell carefully. Appendix E discusses the RCELL solution maps, including some remarks about distinguishing good and bad solutions. (There is a rumor that some people in the Far West call these solution maps "tea leaves.") There should be "good" solutions for all **occupied cells** (i.e., cells that contain some heliostats), and there should be promising behavior for those cells just outside the field boundary. Solutions around the map centers are typically more reliable than solutions near the edges of the maps.

Examine the output matrix entitled "INTERCEPTION FACTORS FROM USER CURVE FIT INCLUDING ATMOSPHERIC LOSSES." Typically, several cells in each corner of the field have interception fractions less than about 0.6. However, if more than about 1/3 of all cells have interception fractions less than about 0.6, then you should consider whether your receiver is too small for the field array you are using. Alternatively, if all cells have interception fractions approaching unity, then you should consider whether the converse may be true (unless you are operating under a severe peak flux constraint, or using a large value of RTRIM, or etc.).

6.2 Second Set of Runs: Short RC Runs for Database Checkout

The second set of runs should be **short runs** (ISTDRC = 1) that read the database (file 08), generate optimized fields, and print new summary pages and heliostat-spacing coefficients. The object of this second set of runs is to evaluate the database over a range of field sizes (i.e., for fields containing small and large numbers of occupied cells).

(1) In RCDRIV, set ISTDRC = 1. Set RTRIM to an appropriate value for your study, as in step (2) of Section 6.1. Review all PARAMETERs in RCDRIV to be sure that they match the values used when you made your database.

(2) In section 100 of subroutine STDRC, set IGOPT =-1, IPLONG = 1, and ITRIM = 0. Verify that LTAPE =-1. Add the line KTAPE = 0 if you are using FINTU for the interception fractions, as in Section 6.1 (First Run) above.

NOTE: Setting IPLONG to 1 will produce a **long print** which shows solution maps for every cell (i.e., like the printout you obtained in Run 1). However, do not confuse a long print with a long run, which is a run (such as in Section 6.1) that generates a new SBC database (file 08). The runs described here in section 6.2 will only read an existing SBC database because LTAPE = -1.

(3) Examine the summary page on the printout of your database run and find the EQNOON POWER. A typical RCELL summary page is shown in Figure 6.1-1. There are two values given for the equinox noon thermal power delivered to the base of the tower. The first value is calculated for noon on the autumnal equinox, and the second is calculated for noon on the vernal equinox but scaled to an insolation value of SOLARX, an input in module RECVER. The second value is the design-point power. For comparison purposes only (for now), note the relationship between the EQNOON POWER (second value) and your desired design-point power.

Above the EQNOON POWER is the matrix giving the number of heliostats per cell, which is obtained from the BGRND matrix (see Section 4.7). Above that, there are five compact matrices: F-LIMIT, the input land-constraint matrix (JGRND); OPTIMUM, the optimum field without land constraints; ALLOWED optimum, the output IGRND matrix, which includes the land constraints; M-LIMIT, showing a code for the type of heliostat mechanical limits, if any; and PLANES, showing in which plane (1 - 5) each field cell lies.

From the ALLOWED optimum matrix or the number of heliostats per cell matrix, note the size of the occupied field relative to the entire matrix of cells. The largest acceptable field corresponds to a "circle" of occupied cells inscribed in the rectangular matrix of cells; i.e, about 80% of all the cells are occupied. For larger numbers of occupied cells, the field begins to cover the corners of the rectangular matrix, and you can envision the field spilling over to cells outside of the IGRND matrix. Significant **field spill** is an obvious problem for which you must always be watchful. Similarly, if the field contains too few cells, i.e., less than about 20% of the cells are occupied, then resolution problems will be encountered. Either too few or too many occupied cells can invalidate the results given on the summary page of an RCELL run, but neither can affect the validity of your database itself.

(4) From your examination of the summary page of your database printout, determine whether you need a larger or smaller number of occupied cells in order to just fill the IGRND matrix with the largest acceptable field. If you need a larger field, then set the value of FMI in section 100 of subroutine STDRC to about 110% (or whatever percent seems reasonable) of the value you used in section 200. Similarly, decrease FMI in section 100 by about 10% (or other appropriate amount) if you need a smaller field because your previous field spilled over.

(5) Submit run and examine the resulting summary page. Continue changing FMI appropriately and submitting short runs like this until you obtain a largest acceptable field; i.e., one that nicely fills the ALLOWED optimum matrix without significant spilling. Once this field is obtained, review the solution map in each cell of this field carefully. The object of step (5) is to evaluate the database for a large field; i.e., one that has a large number of occupied cells. Every occupied cell should have an acceptable solution. If a large number of occupied cells do not have acceptable solutions, then your database will need to be refined (see third and fourth runs).

> NOTE: If you have set up your field geometry wisely, as described in Section 5.2, then the smallest receiver elevation angle θ in this largest acceptable field will automatically be about 6° (i.e., 5-10°).

(6) Examine the summary page of your last run in step (5) for the EQNOON POWER (design point). Divide this power level by 2 and load ECON in section 100 of STDRC with the result. Set

IGOPT to 0 in order to make an iterated RCELL run (Section 4.6) and set the other switches as in steps (1) and (2) above. Submit run and examine the last of the summary pages. There will be more than one summary page because you have made an iterated RCELL run. The EQNOON POWER should be 1/2 of the value from step (5).

NOTES: (i) If the power is far off, then the convergence scheme encountered problems somewhere. If this happens, try a slightly different input value for ECON. (ii) If your run terminates abnormally, try setting FMI in section 100 of STDRC to a larger initial value.

The number of occupied cells should be about 30-40% of the total number of cells. The object of step (6) is to evaluate the database for a small field; i.e., one that has a small number of occupied cells. Once this field is obtained, review the solution map in each cell carefully. Every occupied cell should have an acceptable solution. If a large number of occupied cells do not have acceptable solutions, then your database will need to be refined (see third and fourth runs).

6.3 Third Set of Runs: Refine an SBC Database

Unless your database gives good solutions when the field contains both large and small numbers of occupied cells, as discussed in Section 6.2 on database evaluation, then a new database should be made. If only a few cells do not have good solutions, probably a few near the tower, then you can "fix" just these cells by making a cell fix run as described in Section 6.4, and you may not need to make a completely new database. However, if you made your first database using the input coefficients given by Eqs. (6.1-3) and (6.1-4), then a completely new database is recommended.

(1) First you should make a run to obtain heliostat-spacing coefficients that are appropriate for a field with a medium number of occupied cells. Examine the last summary page from your last run in step (6) of Section 6.2. From the line that begins "FIGURE OF MERIT =", find the value listed for FINPUT. This is the value that RCELL used for FMI on its last iteration of your "**small-field**" run. Denote this value by FIN1.† Similarly, examine the summary page from your last run in step (5) of

† FMI, FINPUT, and FIN are all equivalent names for FMI.

Section 6.2 and find the value of FMI that you input for your "**largest-acceptable-field**" run. Denote this value by FIN2. Find the average of the two values and load into FMI under section 100 of subroutine STDRC. This value of FMI should produce a field with roughly 60% of the cells occupied, i.e., a "**medium-field run**." Set the other switches in section 100 as described in steps (1) and (2) of Section 6.2 and submit run. Examine the summary pages, the solution maps of the occupied cells, and the plots of the heliostat spacings vs. receiver elevation angle, which are generated by PLOT2 and are at the end of your RCELL printout. Hopefully, the solution map of each occupied cell will show a good solution, and the plots of the spacings, especially the radial spacings, will show definite trends in the data. (See Figure 3.1-3.) If so, then you should use the heliostat-spacing coefficients generated by PLOT2 for this medium-field run as input for your new database, which you will make in step (2) below. However, if a review of the plots and the solution maps shows substantial deviation from a good solution in many occupied cells, then you should choose the coefficients from either your "small-field" run, "medium-field" run, or "largest-acceptable-field" run (whichever has better solutions) for input to your new database run in step (2) below. In any case, these coefficients should be taken from the polynomial fits generated by PLOT2 which appear near the end of every RCELL printout.

(2) In input module FIELD, load into COEFX and COEFY the 6 radial coefficients and 6 azimuthal coefficients which you selected in step (1) above. Verify that ICOF is set appropriately. In section 200 of STDRC, load the corresponding value of FMI (i.e., it should come from the same RCELL run as the coefficients). Add the line KTAPE = 0 to section 200 if you are still using FINTU to calculate the interception fractions. At the top of RCDRIV, set ISTDRC = 2 to generate a database and set RTRIM to an appropriate value for your study, as in step (2) of Section 6.1. Review all PARAMETER statements in RCDRIV and ORDER, XTOWI, YTOWJ in FIELD to be sure that they match the requirements of your field geometry, as discussed in section 5.2 and in step (1) of Section 7.3. In RUNRC.COM, change the name of the file that you ASSIGN to be FOR008; otherwise, the new database will be written over the old database. Submit the run. Review carefully the summary page, the solution maps of each cell, and the plots of the heliostat-spacing

coefficients. By all measures, this new database should be better than the old database. If for some reason it is not, then you should seek advice from a knowledgeable user of the UH Code System to find out what you are doing wrong. Note that, if unacceptable solutions occur in only a few cells, then these cells can be "fixed" as discussed in the next section.

6.4 Fourth Run: Cell Fix Run

There may be only a few cells, probably a few near the tower, that do not have acceptable solutions. Unacceptable solutions may include those cells that print way off the trend line in the plots generated by PLOT2, near the end of your RCELL printouts, and those cells that have totally different solutions from their neighbors, which sometimes occurs near the tower. Such cells may be "fixed" by selecting a preferred solution map center for each of them.

(1) Execute an ISTDRC = 7 run to read the previous database, fix the recalcitrant cell(s), and save the new database, which is written to file 09. You will need to add an appropriate ASSIGN/USER command to RUNRC.COM for file 09.

In RCDRIV, set ISTDRC = 7 and set RTRIM to an appropriate value for your study, as in step (2) of Section 6.1. Review all PARAMETERs in RCDRIV to be sure that they match the values used when you made your database.

In section 700 of subroutine STDRC, you will need to add the line KTAPE = 0 if you will again be using FINTU for the interception fractions. Load FMI with the value that you used to define your largest acceptable field in step (5) of Section 6.2.

(2) Follow the instructions given near line 200 of RCDRIV (i.e., 11-17 lines after IROW=...) to prepare the required input data lines, one line per cell to be fixed. Each line of data identifies, via FICEL, FJCEL, a cell to be fixed and specifies, via COORX, COORY, what the heliostat spacings should be at the center of the cell's solution map, in DMIR units.

NOTE: The optimizer cannot examine an infinite range of possible heliostat spacings, and so it only looks at a patch that is 85-115% of the spacings at the center of the cell's solution map.

These data lines are one of the rare unit 05 inputs used by the UH Code System. You can put them in a disk file (e.g., INPUT1.DAT) and then add an ASSIGN/USER command in RUNRC.COM to establish the correspondence between your file and unit 05. For example:

ASSIGN/USER INPUT1.DAT FOR005

However, it is easier to add these data lines directly to RUNRC.COM, inserting them immediately after the line $ RUN/NODEBUG RCDRIV. In either case, the very last line of your data lines must be a blank line.

(3) Submit the run. The printout will be a shortened version including only the headers from most of the cell solution maps. However, full solution maps will be printed for each of the cells that you requested RCELL to fix. There may also be a few other solution maps if any cells are in the mechanical limits regime. Review the solutions in each of the fixed cells for acceptability. If some are still unacceptable, change the input data lines appropriately [step (2)] and repeat the run [step (3)], as often as necessary.

(4) Once you have obtained a satisfactory new database, remember to remove the ASSIGN command of the old database from file RUNRC.COM and to change the FOR009 on the ASSIGN command for the new database to FOR008 in order to use the new database in all subsequent runs.

6.5 Fifth Run: Obtain Desired Power Level

Once you have made a good database, you need to establish its usefulness for your system design study. Most often, you will have a design-point thermal power P_0 that the system is required to produce. You can use the new iterative version of RCELL (described in Section 4.6) to force RCELL to converge the system to this design-point power.

NOTE: If you are truly serious about using your database for a system design study, you should make a node file (see Section 7.2) before executing step (2) below, and use it in the evaluation of the usefulness of your database.)

(1) Review the summary pages of your "small-field," "medium-field," and "largest-acceptable-field" runs. You made these runs in step (6) of Section 6.2, step (1) of Section 6.3, and step (5) of Section 6.2, respectively. In each run, the second value listed for the EQNOON POWER is the design-point thermal power for that system determined by RCELL, as discussed in step (3) of Section 6.2. Does your desired design-point power P_0 lie within the range of power levels spanned by these three previous runs? If it does, then you may proceed with the run in step (2) below. If it does not, then you will need to change your tower focal height HT as follows. Denote your "medium-field" values of HT and P by H_m and P_m. Using geometric scaling, as described in Sections 2.2 and 2.3, estimate the input value that you should use for HT in order to achieve your power level P_0:

$$HT = H_m \sqrt{P_0/P_m} \,. \qquad (6.5\text{-}1)$$

If this new value of HT is reasonable, then you may now proceed with the run in step (2). On the other hand, if you are convinced that this new value of HT is incorrect for the system that you wish to study, then you are either mistaken or you must have inadvertently made a mistake somewhere else. For example, you might have input 90 (from 90%) instead of 0.90 for reflectivity. Another of many possibilities is that the receiver interception is incorrect and must be modified by changing HCYLNT and/or WCYLNT. You must identify the mistake and correct it before proceeding to step (2). To this end, you should reexamine your RCELL printouts, especially the details of the summary page of each and the other primary outputs. You might also wish to make an additional short run(s). If you can not find the mistake, then you should consult with a knowledgeable user of the UH Code System.

NOTE: There are a multitude of things that could be wrong. For example, if your heliostats are extraordinarily cheap or expensive, it may be necessary to redefine the collector field geometry in order to give a more appropriate rim angle. Unfortunately, you will have to make a new database if this is your problem.

(2) Now you are ready to make a short RCELL run that will iterate to your desired power level P_0. In RCDRIV, set ISTDRC = 1 to make a short run. Set RTRIM to an appropriate value for your

study, as in step (2) of Section 6.1. Review all PARAMETERs in RCDRIV to be sure that they match the values used when you made your database and your node file.

NOTE: If you are truly serious about using your database for a system design study, you should make a node file (see Section 7.2), and use it here in step (2) for evaluating the usefulness of your database.

In section 100 of subroutine STDRC, verify that KTAPE is set appropriately for the type of node file that you will be using. Be sure that IGOPT = 0 and IOPTE = -1. Set IPLONG = 1 to obtain a long print.

NOTE: You will probably take only one more long print in this system study. Henceforth, do not take long prints every time you make a short run. Use IPLONG = 0 for a short print. Long prints are CPU time-consuming as well as paper-eating and should be made only occasionally, i.e., when a substantial change in a critical input is made, or prior to a final-design run, or after 10-15 short runs.

Load your desired design-point thermal power P_0 into ECON. Leave ITRIM = -1 to produce a file 29, as described in Section 4.7. In RUNRC.COM, add an appropriate ASSIGN command for the new file 29. Submit run and examine the last of the summary pages carefully. There should not be significant field spill. The EQNOON POWER should be equal to the value you loaded into ECON.

Examine the solution maps for the occupied cells. There should be good solutions in all occupied cells; solutions around the map centers are more reliable than those near the map edges. Examine the plots of the heliostat spacings generated by PLOT2. There should be definite trends in the data, especially for the radial spacings (Figure 3.1-3). Close to each plot, examine the matrices which compare the heliostat-spacing data with the generated polynomial fits. There should be good agreement, although some cells near the tower may be difficult to fit and may be fixed as in Section 6.4. More than 50% of all cells should be occupied; otherwise, you are wasting a lot of computer power in the overhead associated with the unoccupied cells. Furthermore, if less than 25% of all cells are occupied, then you may encounter resolution problems. If you discover any major problems associated with the database, you may need to refine your database once more, as in Section 6.3.

At this point, you have obtained your first system generating your desired design-point power; you have a good, useful database; and hopefully you have achieved some understanding of the process. You should now proceed to Section 7.1.6, as the rest of Section 7.1 is an abbreviated recapitulation of Section 6.

7. START-UP KIT FOR BASIC SYSTEM STUDY

Considered individually, Sections 7.1 to 7.5 give instructions for performing the five most common types of runs. Considered as a set, these runs constitute the necessary runs involved in a simple study, which may be adequate to provide your required design if you do not have any peak flux constraints and if you know about what tower focal height (HT) and receiver dimensions (HCYLNT and WCYLNT) your system will use. If you can achieve a satisfactory design with only a basic system study, then you may proceed directly to Section 11 after finishing Section 7. In any case, you will probably refer to the individual Sections 7.1 to 7.5 quite regularly as these are the five most common types of runs.

<u>In Appendix F, we provide a sample set of input modules. Please refer to them, as necessary.</u>

7.1 SBC Database Generation

Section 6 provides a detailed description of how to obtain your first-ever SBC database. After you have some experience making a database, you will probably wish to refer to the summary of Section 6 which is provided here in Section 7.1.

It is assumed that you have previously set up: (i) the receiver cost model equations for your system in RECVER; (ii) the heliostat cost per m^2 for your system in HELIOS; (iii) your field and wiring costs in FIELD; and (iv) the site data (latitude, elevation, ground slope, etc.) and appropriate inputs for the insolation and visual range models in FIELD. At this point, reasonable approximations are adequate for items (i) - (iii), but item (iv) should be final. Consult the *RC User's Guide* if you need help setting up these inputs.

7.1.1 Run A = Make an SBC Database

Note that this run is made for a fixed value of FMI and thus does not iterate to a design-point power level, or to an annual thermal energy requirement, or to a converged FMI. (See Section 4.6). Be alert to this fact when examining the printout in step (7).

1. Load a reasonable tower focal height (HT), receiver length (HCYLNT), and diameter (WCYLNT) in RECVER.

2. In file RCDRIV.FOR, set ISTDRC = 2 to generate a database. (This type of run is often referred to as a **long run**.) Follow the instructions in step (1) of Section 4.10 to select a preliminary value for RTRIM (unless you are studying a system with a north field only or a system with no peak-flux constraint, in which case set RTRIM = 0.0). Review all PARAMETERs in RCDRIV and XTOWI, YTOWJ, ORDER in FIELD to be sure that they match the requirements of your field geometry, as discussed in Section 5.2 and in step (1) of Section 7.3.

3. If you already have an appropriate node file, use KTAPE = 1 or 2 in section 200 of STDRC and use the appropriate ASSIGN statement for file 14 in RUNRC.COM. Otherwise, add the following line of code to section 200 of STDRC:

   KTAPE = 0.

   This avoids the need for a node file at this early stage of the study by using entry point FINTU in input module RECVER.

4. Load appropriate heliostat-spacing coefficients into COEFX (for ΔR) and COEFY (for ΔAz) in input module FIELD. Verify that ICOF is set appropriately.

5. Load a reasonable value for FMI in section 200 of STDRC.

6. In RUNRC.COM, use the appropriate ASSIGN command to assign a reasonable name to the SBC database (file 08) produced by this run.

7. Submit run and examine the printout.

7.1.2 Database Evaluation--General Considerations

You must evaluate the quality and usefulness of your database.

The cell solution maps of those cells which contain heliostats (called **occupied** cells) should show good solutions. What makes a solution "good"? Appendix E contains a brief review of this topic, along with a description of some of the general features of the RCELL solution maps.

You will need to make a few Runs B (see below) for various power levels in order to evaluate your database. The solution maps of all occupied cells should show good solutions both when there are small and large numbers of occupied cells. If only a few cells do not have good solutions (probably a few near the tower), then these cells can be "fixed" with a cell fix run, as described under Run D below. If a large number of occupied cells do not have good solutions, then a completely new database must be made.

Similarly, the cell solution maps of occupied cells should show good solutions when the output design-point thermal power (EQNOON POWER) is equal to that which you require from your system (i.e., P_0). In order to evaluate the quality of your database under this condition, you will need to make at least one Run B (see below) which converges to P_0. If necessary, quadratic scaling as in equation 6.5-1 may be used to re-estimate the tower focal height (HT) needed to produce your desired power P_0 using your current database. (Recall that an SBC database is independent of HT, and thus can be used with a wide range of values of HT.) Alternatively, or in combination with changes to HT, you might need to rescale the receiver dimensions in order to find a system producing P_0 which can be studied using your database. Make as many Runs B which converge to P_0 as are necessary to adequately evaluate your database. If a large number of occupied cells do not have good solutions after changing HT and/or the receiver dimensions appropriately, then a completely new database must be made.

7.1.3 Runs B = Database Evaluation Runs

In order to evaluate your SBC database (keeping in mind the General Considerations above), you will need to make some RCELL short runs (ISTDRC = 1) for various power levels and perhaps for another HT or other receiver dimensions.

1. Follow the instructions in Section 7.3 for making RCELL runs which converge to a desired power level, but set IPLONG to 1 in section 100 of subroutine STDRC because you will want a long print to evaluate your database.

2. Be on guard against field spill, i.e., output fields that spill over to cells outside of the IGRND matrix. On the other hand, remember too that it is desirable for a system that produces your desired power P_0 to have a field matrix in which more than 50% of all cells are occupied; otherwise, you are wasting a lot of computer power in the overhead associated with the unoccupied cells. Furthermore, if less than 25% of all cells are occupied, then you may encounter resolution problems; i.e., you may not have enough occupied cells to provide accurate answers.

3. You should examine the plots of heliostat spacings generated by PLOT2, which appear near the end of every RCELL printout (provided that IPLOT was properly set to 1 for the run). There should be definite trends in the data, especially for the radial spacings. (See Figure 3.1-3.)

4. At an appropriate point (probably after the first couple of database evaluation runs, but certainly by the final-database-evaluation stage), it will become important to evaluate the quality of the cell solutions under the condition that the system <u>accurately</u> produce your required design-point power P_0. At such time, you should make a node file (see Section 7.2) and use it in all further database evaluation runs. This is because a node file provides accurate receiver interception fractions, whereas FINTU only provides interception estimates.

5. If you discover any major problems with the database, you will need to make a new database.

6. When you are finished making database evaluation runs, set IPLONG back to 0 in section 100 of subroutine STDRC to avoid excessive printout.

7.1.4 Run C = Make a New SBC Database if Required

If you need to make a completely new database, proceed as follows.

1. Examine your printouts from your database evaluation runs, keeping in mind the General Considerations above, and

determine which converged run comes closest to producing both the largest number of cells with good solutions and your desired power level P_0.

2. From the run that you select, locate the coefficients from the polynomial fits generated by PLOT2. Also find the value of FINPUT (i.e., FMI) used by RCELL on its last iteration; this is given on the last summary page of your selected RCELL printout.

3. In input module FIELD, load into COEFX and COEFY these 6 radial and 6 azimuthal coefficients.

4. In section 200 of subroutine STDRC, load the corresponding value of FMI.

5. If your heliostats are extraordinarily cheap or expensive, it may be necessary to redefine the collector field geometry in order to give a more appropriate rim angle.

6. Follow the other instructions for making Run A above.

7. In order to evaluate your new database, you need to make at least one database evaluation run (Run B) which converges to P_0. If only a few cells need to be fixed, then see Run D below. (If your new database seems to have a major problem, evaluate it more thoroughly and make another new database if required.)

7.1.5 Run D = Cell Fix Run

There may be only a few cells (probably a few near the tower) that do not have acceptable solutions. Such cells may be "fixed" by selecting a preferred solution-map center for each of them.

1. Execute an ISTDRC = 7 run to read the previous database, "fix" the recalcitrant cell(s), and save the "fixed" database which is written to file 09. You will need to add an appropriate ASSIGN/USER command to RUNRC.COM for file 09.

In RCDRIV, set ISTDRC = 7. Set RTRIM to an appropriate value for your study, as in step (2) of Run A above. Review all PARAMETERs in RCDRIV to be sure that they match the values used when you made your database (i.e., file 08).

In section 700 of subroutine STDRC, you will need to add the line KTAPE = 0 if you will be using FINTU for the interception fractions; otherwise, be sure that KTAPE is set appropriately to match your node file. Load FMI with a reasonable value.

2. Follow the instructions given near line 200 of RCDRIV (i.e., lines 11 - 17 after IROW=...) to prepare the required input data lines, one line per cell to be "fixed". Each line of data identifies (via FICEL, FJCEL) a cell to be "fixed" and specifies (via COORX, COORY) what the heliostat spacings should be at the center of the cell's solution map (in DMIR units). Add these data lines directly to RUNRC.COM, inserting them immediately after the line $ RUN/NODEBUG RCDRIV. The very last line of these data lines must be a blank line.

3. Submit the run and review the solutions in each of the "fixed" cells for acceptability. If any are still unacceptable, you may change the solution-map center-spacings on the appropriate input data lines and repeat the run. If you find an acceptable solution in essentially every occupied cell, you have obtained a good database. (Occasionally, acceptable solutions may not be found for a few cells near the tower. These may need to be "fixed" such that their cell centers are similar to those of their nearest neighbors.)

4. Once you have obtained a satisfactory "fixed" database, remember to remove the ASSIGN command of the old database from file RUNRC.COM and to change the FOR009 on the ASSIGN command for the new database to FOR008 in order to use the new database in all subsequent runs. Good databases should be archived for possible use in similar future studies.

7.1.6 What Next?

At this point, you have obtained your first system generating your desired design-point power; you have a good, useful database; and hopefully you have achieved some understanding of the process.

There are many possibilities for your next step. You should have already made a node file, but if you have not then you must proceed to Section 7.2 and do so now (unless you intend to go directly to Section 10). If you have been using an appropriate node file, then proceed to Section 7.3. If all of your costs, cost equations, receiver dimensions, HT, etc. are appropriate for your system study, then you may be able to make your final-design run on your first-pass through Section 7.3 and then you may proceed to Section 7.4 or 7.5 or Section 8 or 11, as suits your needs, or you may be finished. If your system has significant peak flux limits, then you may proceed directly to Section 9, but you will need to refer back to Sections 7.3 and 7.4. If your system has no significant peak flux limits but you need to optimize HT and/or the receiver dimensions, then you may proceed directly to Section 10, which will also refer you back to Section 7. (Note: Figure 1.-2 shows the interrelationship of the start-up kits.) Choose the appropriate next step for your study and go to it.

7.2 Node File Generation

1. In NSDRIV, set IGREC and JGREC to correspond to the number of vertical and horizontal (or circumferential) nodes, respectively, on the receiver. Verify that KGREC is set according to inline comments. NCELI and NCELJ are the number of N-S and E-W cells, respectively, into which the heliostat field is divided. These values should correspond to those which will be used in future RCELL runs, if any, and must match any SBC database with which you intend to use the resulting node file. It is recommended that NCELJ be odd rather than even.

   Set ISTDNS to 1 or 2, depending on whether you are making a half-field or whole-field node file, respectively.

   If you have a file 29 from a previous RCELL run and it has the correct number of field cells, ORDER, and tower location, then you can set JTRIM = 1 and the matrix IGRND and the heliostat-spacing coefficients, COEFX and COEFY, will be read from this file. Otherwise, set JTRIM = 0 to use the data in NSDRIV and FIELD to initialize IGRND, COEFX, and COEFY. (Note that the heliostat-spacing polynomials (equations 4.7-1 and 4.7-2), with coefficients COEFX and COEFY, do not depend on the cell structure of the field, HT, or DMIR. Consequently, they can be used with any run, provided that the coefficients are appropriate for the particular system and site being studied.)

The design-point thermal power and the printed flux map output by this run will be incorrect unless you input the appropriate IGRND matrix and heliostat spacing coefficients COEFX and COEFY, but this does not affect the validity of the node file.

In section 100 of subroutine STDNS (section 200 if using ISTDNS = 2), set NDAY1 and HOUR0 to the correct day and time. For example, NDAY1 = 0 and HOUR0 = 0.0 will produce a node file for Vernal equinox noon, which is the standard design point used by RCELL.

2. In input module FIELD, verify that XTOWI and YTOWJ correspond to the desired location of the tower, in cells. The ORDER of the cells should also correspond to that which will be used in future RCELL runs, if any. In particular, the values of XTOWI, YTOWJ, and ORDER must be identical with those used to make your SBC database.

   See the comments about COEFX and COEFY under 1 above.

   The multiplier on HT in the definition of FCELL can be adjusted, if necessary, to change the balance between accuracy vs. amount of computation. (Note that the value of FMIN in input module HELIOS can also be adjusted, if necessary, to change the maximum allowable mirror curvature. See Appendix F.)

3. In input module RECVER, check that ICYLN is positive. Verify that INODE1, INODE2, JNODE1, and JNODE2 are set in a manner consistent with the values of IGREC and JGREC in NSDRIV and with the type of receiver. Set the tower focal height (HT), the receiver length (HCYLNT), and the receiver width or diameter (WCYLNT). Set the aiming strategy (IAIMS, WTFLXN, WTFLXS); see Section 4.9. If you are using a RECVER module for a flat receiver (either to represent an external flat receiver or a cavity aperture), then check IAPER, APERHT, and APERWD. Verify that INODEF = 0.

4. In RUNNS.COM, use an appropriate ASSIGN statement for the node file (file 14) produced by this run. If using a file 29, include the correct ASSIGN statement for it as well.

5. Submit run and examine printout. In particular, check the matrix "Fraction of Beam Intercepted by Receiver/Cell", which appears near the end of the printout. All entries in this matrix should be reasonable; for example, no entry should be greater than 1.0.

7.3 RCELL Optimization

It is assumed that you have previously set up: (i) the receiver cost model equations for your system in RECVER; (ii) the heliostat cost per m^2 for your system in HELIOS; and (iii) your field and wiring costs in FIELD; and (iv) the site, insolation, and visual range data in FIELD. Previous RC runs, in Section 7.1, also assumed that these equations and costs were set up, but it is now important that all of these models be appropriate for the system which you will be designing. Consult the *RC User's Guide* and reference [21] if you need help in setting up these inputs.

1. In RCDRIV, set IPROG to 1 for half-field RCELL mode, which is most commonly used because most fields have an intrinsic E-W symmetry, or set IPROG to 2 for full-field RCELL mode, if your field has an intrinsic E-W asymmetry. Note that a land constraint is not an intrinsic E-W asymmetry, but an E-W slope is.

   Verify that IPLOT is 1.

   Set IGREC and JGREC to correspond to the number of vertical and horizontal (or circumferential) nodes, respectively, on the receiver. ID is the number of N-S rows into which the heliostat field is divided. JD and KC are the number of E-W columns into which the heliostat field is divided. <u>These values must correspond to those used when you made your SBC database and to the values of NCELI and NCELJ which were used in a previous node file run</u>, if any. For full-field RCELL mode, JD and KC should have identical values. However, for the more common half-field RCELL mode, JD should be half of KC, or (KC+1)/2 if KC is odd.

Set ISTDRC to 1. Land constraints, e.g., a sub-tower exclusion region, should be input via the JGRND matrix.

Set RTRIM to an appropriate value for your study. Note that RTRIM was discussed in Sections 4.8 and 4.10. (If you are studying a system with only a north field, then set RTRIM to 0.)

Set IFINT to 2 if you wish an equinox noon receiver flux map. This requires you to use a node file. Otherwise, set IFINT to 0.

In section 100 of subroutine STDRC, verify that IGOPT is 0 and set ECON to your desired output thermal power level in MW. (Alternatively, RCELL can converge on annual thermal energy or figure of merit; consult the comments in RCDRIV about IOPTE and ECON.) If you prefer, you can disable the RCELL iteration loop by setting IGOPT to -1 and FMI to an appropriate value. Check that ITRIM is set to -1 and that IPLONG is set to 0. If you wish to use a whole-field node file instead of the assumed half-field node file, then you must add the statement KTAPE = 1 to section 100. (If for some reason you do not have a node file and you wish to use FINTU, then you must add KTAPE = 0. Remember that FINTU provides only a Gaussian approximation to receiver interception fractions and it can not provide flux maps.)

2. In input module FIELD, verify that XTOWI, YTOWJ, and ORDER are consistent with your node file (file 14) and SBC database (file 08).

3. In input module RECVER, check that ICYLN is positive. Verify that INODE1, INODE2, JNODE1, and JNODE2 are set in a manner consistent with the values of IGREC and JGREC in RCDRIV, with the type of receiver, and with your node file. Verify that the tower focal height (HT), the receiver length (HCYLNT), the receiver width or diameter (WCYLNT), and the aiming strategy (IAIMS) agree with the node file values. Verify that INODEF = 0.

Set BLOSS to an appropriate value. If you are using pre-heat panels, then set PREPAN and HLOSS as described by the inline comments in RECVER.

4. In RUNRC.COM, use appropriate ASSIGN statements for the SBC database (file 08), for the sun sample file (file 07), and for the node file (file 14). If a file 29 will be written (i.e., ITRIM = -1), include the correct ASSIGN statement for it as well.

5. Submit run and examine printout. Be sure that your output field does not spill over to cells outside of the IGRND matrix. Do not fail to examine the cell solutions occasionally; e.g., set IPLONG to 1 on every tenth run or so.

   If your run terminates abnormally (particularly, if a run-time error occurs on the first pass through the iteration loop), then try setting FMI in section 100 of STDRC to a larger initial value.

7.4 NS Flux Run

NS Flux runs are used to provide receiver flux maps on days and at times other than the design point. (Note that RCELL will provide a design-point (i.e., equinox noon) flux map if IFINT is set to 2 in RCDRIV and if you use a node file.)

An NS Flux run is very similar to a node file generation run. Thus, the instructions given in Section 7.2 apply here as well, with the following exceptions and comments.

7.4.1 Type A Flux Run

1. Set ISTDNS = 7 to generate a node file. In Section 700 of subroutine STDNS, set NDAY1 to desired day and HOUR0 to desired time. Verify that IPSAB is 0 or 1. Set JDISK to +1 to generate a whole-field node file.

   NOTE: JDISK = -1 forces the NS code to assume that the field matrix ENHEL and the receiver flux matrix FLREC have east-west (E-W) symmetry. Thus, JDISK = -1 can be used for <u>noon</u> flux maps if the field has E-W symmetry.

If you are going to use a time that has very low sun angles, then you need to set NBOR to 24 or 48.

2. If you have a file 29 from your last RCELL run, set JTRIM = 1 in NSDRIV and use a corresponding ASSIGN statement in RUNNS.COM.

   If you do not have an appropriate file 29 for your field, then set JTRIM = 0; load the output IGRND matrix from last RCELL run into NSDRIV; and load output COEFX and COEFY from last RCELL run into FIELD.

3. Verify that INODEF = 0 in RECVER. Also set IAIMS, WTFLXN, and WTFLXS as appropriate (see Section 4.9). Use appropriate ASSIGN in RUNNS.COM for the node file 14. (In particular, change the name of the file on the ASSIGN command even if you do not wish to save the new node file, for otherwise the new file will overwrite an old file which you may wish to save.)

4. Submit run and examine printout. Verify that there are no Interception Fractions greater than 1.0 and that the desired thermal power is attained. If so, then examine flux map on printout.

7.4.2 Type B Flux Run

The flux map generated by the Type A Flux Run has aim points which are adjusted for the exact time t of the run, as specified by the inputs NDAY1 and HOUR0. In current practice, the aim points not continuously updated. Solar One, for example, limits the possible aim points to a fixed collection of five standard sets of aim points, each set corresponding to one of the times t_1, t_2, ... , t_5.

In order to produce an NS Flux map for any time t, using the aim points for some standard time t′ (i.e., a standard date and hour), an aim point file (file 09) is required. Such an NS Flux run allows you to rigorously evaluate the effect of aberrations, etc., on the flux distribution and the receiver spillage at time t, using the standard set of aim points for time t′.

1. Make a node file for the standard time t′, following the instructions in Section 7.2, except that you must set ITAIM to 3 in RECVER and use the appropriate ASSIGN command for file 09 in RUNNS.COM.

2. Make an NS Flux run for the time t, following the instructions above for the Type A Flux Run, except that you must set ITAIM to 2 in RECVER. The run will then read in the aim points from file 09 rather than computing them.

7.4.3 Type C Flux Run

A subroutine, RCTEMP, is available which provides temperature estimates at each receiver node for a restricted set of cylindrical receivers. A Type C Flux Run prints these temperature estimates, in addition to the regular outputs generated by a Type A Flux Run, and is made in essentially the same way that a Type A Flux Run is made, except that: (i) the CALLs to subroutine RCTEMP must be "uncommented" in the NS and RC codes; (ii) a special switch (NDAYA) is used in RECVER; and (iii) the inputs in RCTEMP must be carefully set to match the receiver being studied. Unfortunately, RCTEMP is not currently user-friendly.

7.5 NS Annual Run

1. Make an equinox noon node file as described in Section 7.2. If you will need panel power summaries along with your annual run, then you must make a whole-field node file. (See NOTE in Section 7.4.1.) Be sure to use the same ASSIGN statement in RUNNS.COM when you make the annual run.

2. In NSDRIV, check that JGRECP is JGREC + 1. Set ISTDNS = 3. If you have a file 29 from your last RCELL run, set JTRIM = 1 in NSDRIV and use corresponding ASSIGN statement in RUNNS.COM.

   If you do not have an appropriate file 29 for your field, then set JTRIM = 0; load the output IGRND matrix from last RCELL run into NSDRIV; and load output COEFX and COEFY from last RCELL run into FIELD.

In section 300 of subroutine STDNS, check that ISUMS and KDISK are both 1. Set JDISK to -1 if you made a half-field node file in step 1; for a full-field node file, set JDISK to +1. If you do not need panel power summaries, then set KANNU to 0. If you do need panel power summaries, then you must use a whole-field node file with this run, and KANNU must be 1 or 2.

3. In input module FIELD, verify that MONTH is set appropriately. MONTH = +1 is most commonly used. If you use MONTH = -1, then be sure to load the matrix ASDIN with insolation data for 12 days; with only the 7 days currently loaded, you will get a semi-annual run.

4. Submit run and examine printout.

8. SPECIAL STUDIES

Among the available special studies described in Section 4.12 are NS Drift studies, NS Start-up studies, and NS Cloud studies. Start-up kits for these studies are given now.

8.1 NS Drift Studies

Drift studies were discussed in Section 4.3 and described briefly in Section 4.12.13. To make a drift study:

1. Set ISTDNS = 6 in NSDRIV. Verify all PARAMETERs in NSDRIV and ORDER, XTOWI, YTOWJ in FIELD, as discussed in Section 5.2 and in step (1) of Section 7.2.

2. In section 600 of subroutine STDNS, set IDRIFT to 1 for a passive drift study (i.e., heliostats do not move; sun moves), or to 2 for an active drift study (i.e., heliostats move; sun does not move).

3. Set DRIFT1 and DRIFT2 (azimuth and elevation slew rates) if IDRIFT = 2.

4. Set the time controls NDAY1, HOUR1, HOUR2, and NHRS.

5. If you have a file 29 from your last RCELL run, set JTRIM = 1 in NSDRIV and use corresponding ASSIGN statement in RUNNS.COM. NCELI and NCELJ must match the values used to make your file 29.

   If you do not have an appropriate file 29 for your field, then set JTRIM = 0; load the IGRND matrix from last RCELL run into NSDRIV; and load COEFX and COEFY from last RCELL run into FIELD.

6. Verify that INODEF = 0 and that IAIMS, WTFLXN, and WTFLXS are set appropriately in RECVER.

7. Submit run and examine output.

8.2 NS Start-up Studies

Cellwise start-up studies were described in Section 4.12.9. To make an NS start-up study:

1. Set ISTDNS = 2 to generate a whole field node file. In section 200 of subroutine STDNS, set NDAY1 to desired day and HOUR0 to approximately the center of the time interval that you will examine in your start-up study. (Remember that the principal effect in an NS start-up study is the change in shading, blocking, and cos i, and so you will want to choose either an early morning or late afternoon time interval for your study.) Verify that INODEF = 0 and that IAIMS, WTFLXN, and WTFLXS are set appropriately in RECVER. Use appropriate ASSIGN in RUNNS.COM for the node file 14.

2. If you have a file 29 from your last RCELL run, set JTRIM = 1 in NSDRIV and use corresponding ASSIGN statement in RUNNS.COM.

   If you do not have an appropriate file 29 for your field, then set JTRIM = 0; load the IGRND matrix from last RCELL run into NSDRIV; and load COEFX and COEFY from last RCELL run into FIELD.

   Verify all PARAMETERs in NSDRIV and XTOWI, YTOWJ, and ORDER in FIELD, as discussed in Section 5.2 and in step (1) of Section 7.2. NCELI and NCELJ must match the values used to make your file 29.

3. Submit run and examine printout to verify that there are no Interception Fractions greater than 1.0.

4. Set ISTDNS = 4 in NSDRIV.

5. In section 400 of subroutine STDNS, set NDAY1 for desired day of start-up study.

6. Set IHORS, ESUN0, DHOUR, and NHRS appropriately. IHORS = -1 for morning study, or = -2 for afternoon (shut-down) study.

   To use the alternative method of time controls for this study, follow the instructions about the numbered lines in section

400; i.e., verify that IHORS = 1 and set HOUR1, HOUR2, and NHRS appropriately.

7. Your field should defined as in step (2) above.

8. Use the same ASSIGN command in RUNNS.COM that you used for file 14 in step (1).

9. Submit run and examine output.

8.3 NS Cloud Study

Cellwise cloud studies were described in Section 4.12.12. To make an NS cloud study:

1. You must study the subroutines in file CLOUD.FOR under subdirectory NS88. See also references [18,19,20] and Section 5.5 of reference [13]. Adjust PARAMETERS, etc., in these subroutines, as necessary. Select cloud model in subroutine CLDM.

2. Make a whole-field node file and input your field as in steps (1) to (3) of Section 8.2. HOUR0 should correspond to the center of the time interval to be examined by your cloud study.

3. Set ISTDNS = 5 in NSDRIV. In section 500 of subroutine STDNS, set the time controls (NDAY1, IHORS, HOUR0, HOUR1, and HOUR2) appropriately. Verify that JDISK is set to +1.

4. In RUNNS.COM, use the same ASSIGN command for the node file 14 that you used in step (2).

5. Your field should be defined as in step (2).

6. Submit run and examine printout.

(NOTES: (i) The cloud study has not yet been checked out in the VAX environment, but no unusual difficulty is foreseen in making it operational. (ii) The current cloud models are as wide as the Barstow field. New models (or wise trickery) will have to be employed for wider fields.)

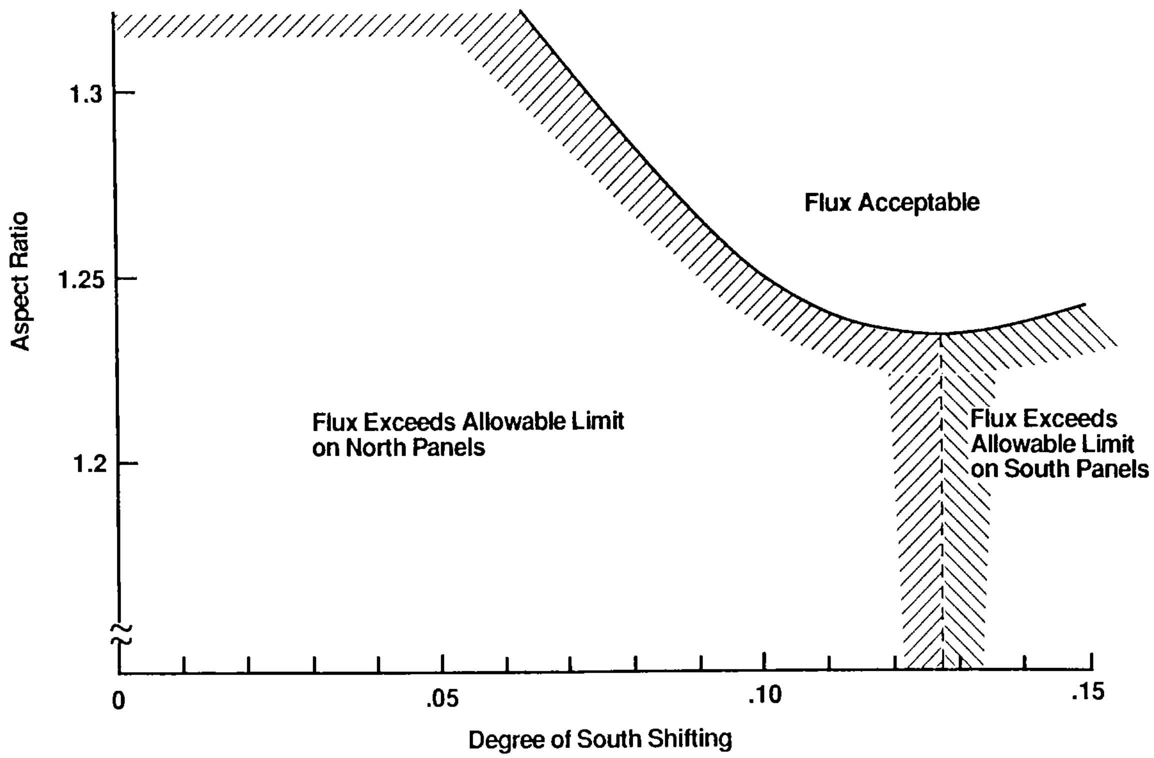


Figure 9.-1 Example plot of region of acceptable flux for a given receiver diameter and for a specific molten salt receiver design: i.e., salt flow path, tube diameter, and Allowed Absorbed Flux Constraint (AAFC) vs. salt temperature [8]. As the field is shifted to the south by increasing RTRIM, the receiver can be shortened without exceeding AAFC. A cost trade ensues, which we discuss in Section 9 and Section 4.10..

9. START-UP KIT FOR SYSTEMS WITH PEAK FLUX LIMITS

The standard version of RCELL must be used to optimize systems with significant peak flux constraints. Section 9 is a start-up kit for designing systems with peak flux constraints. A detailed discussion of the design process in the presence of peak flux constraints, including a discussion of the concepts involved, is given in Section 4.10.

0. Make zero-order estimates of the tower focal height (HT) and receiver dimensions (WCYLNT and HCYLNT) needed to deliver your design-point thermal power (ECON) without exceeding your peak flux limit.

1. Find optimum field and associated aiming strategy for selected tower focal height and receiver dimensions.

   Select a reasonable first estimate for RTRIM as discussed in Section 4.10.

   Use RCELL to determine optimum heliostat spacings and field boundary.

   Make NS flux runs if necessary to find a set of weights for the aims which yield a reasonably uniform receiver flux distribution.

2. Adjust receiver length and RTRIM to obtain a peak flux close to the design limit.

   Adjust receiver length and, if necessary, weights for aims to maintain a fairly uniform flux distribution on the receiver. Make NS flux runs as necessary to check that peak fluxes at off-design times on the south and side panels are within design limits.

   Adjust RTRIM and make another RCELL run and NS flux run(s) if necessary to obtain peak fluxes at off-design times on the south and side panels that are within design limits.

   Iterate if necessary.

3. Via several RCELL runs, find the optimum tower focal height HT.

   Plot figure of merit (F) vs HT for each HT used, including the case from (2) above. Take care that each point satisfies the peak flux constraint equally well. The graph should be roughly parabolic. Interpolate to find the value of HT which gives lowest F.

4. Find optimum receiver dimensions and RTRIM.

   For selected receiver diameter, trade receiver length vs RTRIM (Figure 9.-1). Both RCELL runs and NS flux runs are required for this trade.

   In particular, peak flux at off-design times on the side and south panels as well as peak flux at the design time on the north panels should be monitored to assure that peak flux limits are not violated.

   Review step (4) of Section 4.10.

   After the optimum receiver length has been determined, repeat the trade for a couple of different receiver diameters and select the most cost-effective design (lowest F) <u>which best satisfies all of the constraints</u>.

10. START-UP KIT FOR GOPT

10.1 Oversized SBC Database

1. You begin by making an SBC database, following the procedures in Section 7.1. However, for GOPT (which stands for Grand OPTimization and is pronounced "gee-opt") there are some important additional considerations, as follows.

   GOPT will likely be asked to evaluate systems with extreme combinations of tower focal height (HT) and receiver size (WCYLNT, HCYLNT, AELI, and BELI). Good estimation of the range of receiver sizes and range of HT is important. Therefore, your cell structure (i.e., ID, JD, and ORDER) should be generous. If your collector array is too small (e.g., if the minimum tower elevation angle is greater than 10°), then your fields may "spill over" the field matrices for (small HT, large receiver size) combinations. On the other hand, if the ORDER of your cells is too large, then you will encounter resolution problems for large HT. Careful estimation of the cell structure which comes closest to satisfying these competing ends is important.

2. Evaluate the usefulness of your database for GOPT.

   You can use an iterated RCELL run, with HT and receiver dimensions near the middle of their ranges and ECON set to your desired design-point power, to help you evaluate your database. (At this stage, you can use KTAPE = 0 to call subroutine FINTU for preliminary interceptions.) Iterated RCELL runs are described in Sections 4.6 and 7.3.

   It is very desirable to have solutions near the centers of the solution maps in all occupied cells before doing a TRAJ run.

10.2 TRAJ Run

1. When the database is in reasonable shape, you should prepare for a Grand OPTimization run (GOPT). This requires a trajectory (TRAJ) file. Set ISTDRC = 3 in RCDRIV.

2. If this run is done using FINTU as we propose, you must also set KTAPE = 0. (Add a line in section 300.)

3. ASSIGN reasonable name for TRAJ file (file 25) in RUNRC.COM. Submit run. Inspect result to see that few cells have unsmooth trajectories (see Figure 10.2-1 on p. 139).

   Cells without good solution trajectories may need to be fixed using a cell fix run (see Section 7.1.5). Repeat the trajectory run if you make a cell fix run.

10.3 FINT File Runs

1. FINT files are required for 3 tower heights. Each contains interception files for 7 (or so) receiver sizes.

2. Study algorithm in RECVER (starting with line "INODEF= ..." and continuing to line "ENTRY ECOTOW ...", approximately lines 280-400).

3. Set INDEXH (defines tower focal height) and AZERO (defines set of receiver areas) in RECVER to (hopefully) provide an optimum solution for your required design-point power (probably at Equinox noon).

4. Set INODEF = 1 in RECVER.

5. Just below INODEF in RECVER, set IRHRW appropriately to keep either (1) receiver aspect ratio (L/D) constant, or (2) receiver width constant, or (3) receiver length constant as the receiver area is varied over the 7 receiver sizes. (Whichever option is selected, a maximum receiver length of 30.48 m (100 ft) is imposed due to current tube-length fabrication and transportation constraints.)

6. Set ISTDNS = 1 or 2 in NSDRIV, depending on whether you want a whole field or half field FINT file. Verify the settings and read the comments in the corresponding section of subroutine STDNS.

7. Reduce INDEXH by 1 to make an "HT$^-$" run.

Set file name of the disk file that you will be using to store the HT^- FINT file with an ASSIGN in file RUNNS.COM. Instead of FOR014, use FOR012 in the ASSIGN command because a FINT file is always written to file 12.

Submit HT^- run and inspect output for reasonableness of the FINT file, etc.

8. Increase INDEXH by 1 to make an "HT^0" run.

   In the ASSIGN command in file RUNNS.COM, change the file name that you will be using to store the HT^0 FINT file (but do not change FOR012, as a FINT file is always written to file 12). Submit HT^0 run and inspect output; etc.

9. Increase INDEXH by 1 to make an HT^+ run.

   Change file name; submit run; inspect output; etc.

10.4 GOPT Run

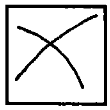
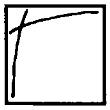
Reads 3 FINT files (14, 15, 16) from Section 10.3. (See (3) below.)
Reads TRAJ file (25) from Section 10.2.
Reads SBC file (08) from Section 10.1, although it is only used for printout purposes.

1. Set ISTDRC = 4. Load ECON in section 400 of STDRC. (ECON = desired design-point power = a constraint on the optimization of receiver Area, HT, Spacings, Trim). Load IAPA according to instructions in section 400 also. (Unlike the HT series, the receiver area series begins with 1 for the smallest of the seven receiver sizes centered at AZERO.) Verify the other inputs in section 400.

2. In RECVER, set INODEF = 1 and IRHRW as in Section 10.3.

3. Examine JCL file RUNRC.COM for appropriate ASSIGNment of files. In particular, file 14 must be your HT^- FINT file; file 15 your HT^0 FINT file; and file 16 your HT^+ FINT file.

4. Submit run - examine.

"Optimum locator" print wants to have  and FTILD  for a "good" solution.  or  are marginal to bad.

The last performance summary (no. 10) is for the optimum design.

10.5 GOPT Restart Run

If necessary, you can perform a GOPT restart run using any values of receiver area A and tower focal height HT within the range allowed by your FINT files. The results will be a nominal RCELL optimized system constrained to ECON, APAI(4) and your selected HT.

1. You will need ISTDRC = 5 in RCDRIV.

2. Set IAPA under section 500 = whatever you used before under section 400 of STDRC.

3. In RECVER, set INODEF = 1 and IRHRW as in Section 10.3.

4. Set APAI(4) and HT in RECVER to the A and HT values you select.

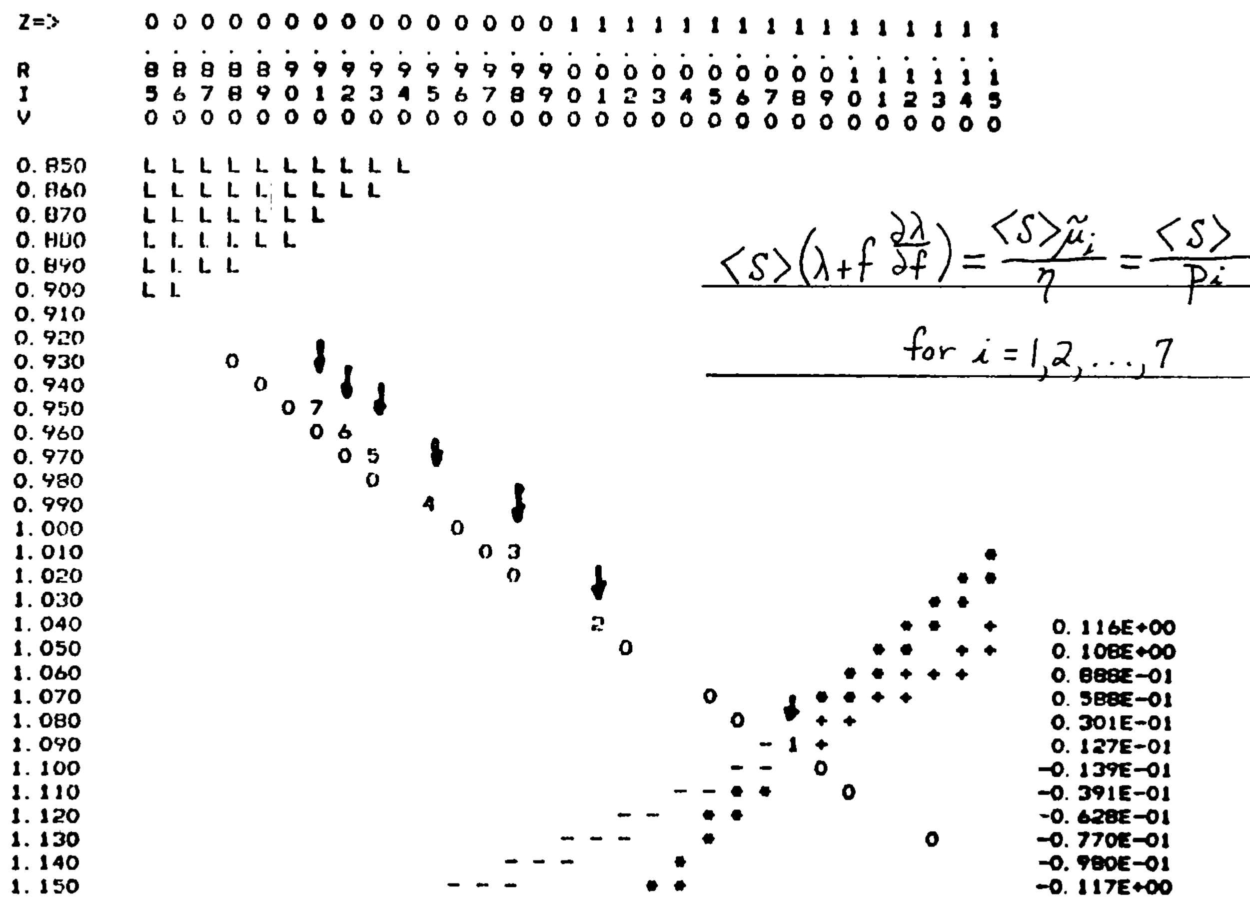
5. Submit run.

```
LOSSES/YR IN MWH/M2 VERSUS DISPLACEMENT FOR CELL (  -2   0 )  OF PLANE < 1 >   HAVING ELEV=  22.21  AND AZIM= 180.00
OPTIONS FOR RADIAL ORIENTATION AND STAGER ARRAY      LIMITS= 0     ACCURACY=  0.1E-02     LAGRANGIAN PARAMETER=  0.501
INPUTS( 2.585 1.995 ) , OUTPUTS( 2.455 1.811 ) IN DMIR , AND OPTIMUM VARIATIONS( 0.950 0.908 )

DAILY KWH/M2 AND ANNUAL MWH/M2 PERFORMANCE ( NO S&B )               * * * * * * * * UNIVERSITY OF HOUSTON
  6.378  6.189  6.096  5.646  5.147  4.451  3.882  1.98
```

COORD	LOSS FRACTION	TOTAL ENERGY	COORD	LAGRANGIAN ENERGY	TRANSVERSE ENERGY
0.850	0.286 0.221 0.181 0.171	1.418 1.546 1.625 1.646	0.900	0.356 0.666 0.969	0.0116 0.0510 0.1001
0.950	0.216 0.150 0.111 0.098	1.557 1.687 1.765 1.790	1.000	0.607 0.970 1.307	-0.0223 0.0082 0.0486
1.050	0.168 0.106 0.069 0.056	1.652 1.774 1.849 1.874	1.100	0.872 1.251 1.604	-0.0530-0.0331-0.0015
1.150	0.144 0.090 0.057 0.044	1.699 1.806 1.872 1.897	1.200	0.000 0.000 0.000	0.0000 0.0000 0.0000

******** OPTIMUM LOCATOR ********* : L FOR MECHANICAL LIMITS : 0 FOR T EQUATION : * FOR F EQUATION : X FOR OPTIMUM



$$\langle S\rangle\left(\lambda + f\frac{\partial\lambda}{\partial f}\right) = \frac{\langle S\rangle\tilde{\mu}_i}{\eta} = \frac{\langle S\rangle}{p_i}$$

for $i = 1, 2, \ldots, 7$

Figure 10.2-1 Example of a GOPT cell trajectory map. You should compare with Figure E.-1, which is an example of a standard RCELL solution map. The primary difference is that the GOPT map shows seven solutions instead of one, which allows this cell's solution trajectory to be interpolated for any value of the parameter p_i, where p_i = <S>/Lagrangian Parameter$_i$. (See Eq. E-1 and also Section B.3). Note that the solution trajectory for this cell lies quite close to the curve of "0"s, which does not shift much with changes in the Lagrangian Parameter. The curve of "*"s is shown only for solution no. 1, but there is a similar curve of "*"s through each of solutions 2 to 7. The seven solutions are found for seven evenly-spaced values of p_i within the range indicated by the line drawn over the Lagrangian Energy matrix. Note that the value shown for the Lagrangian Parameter corresponds to that for solution 7.

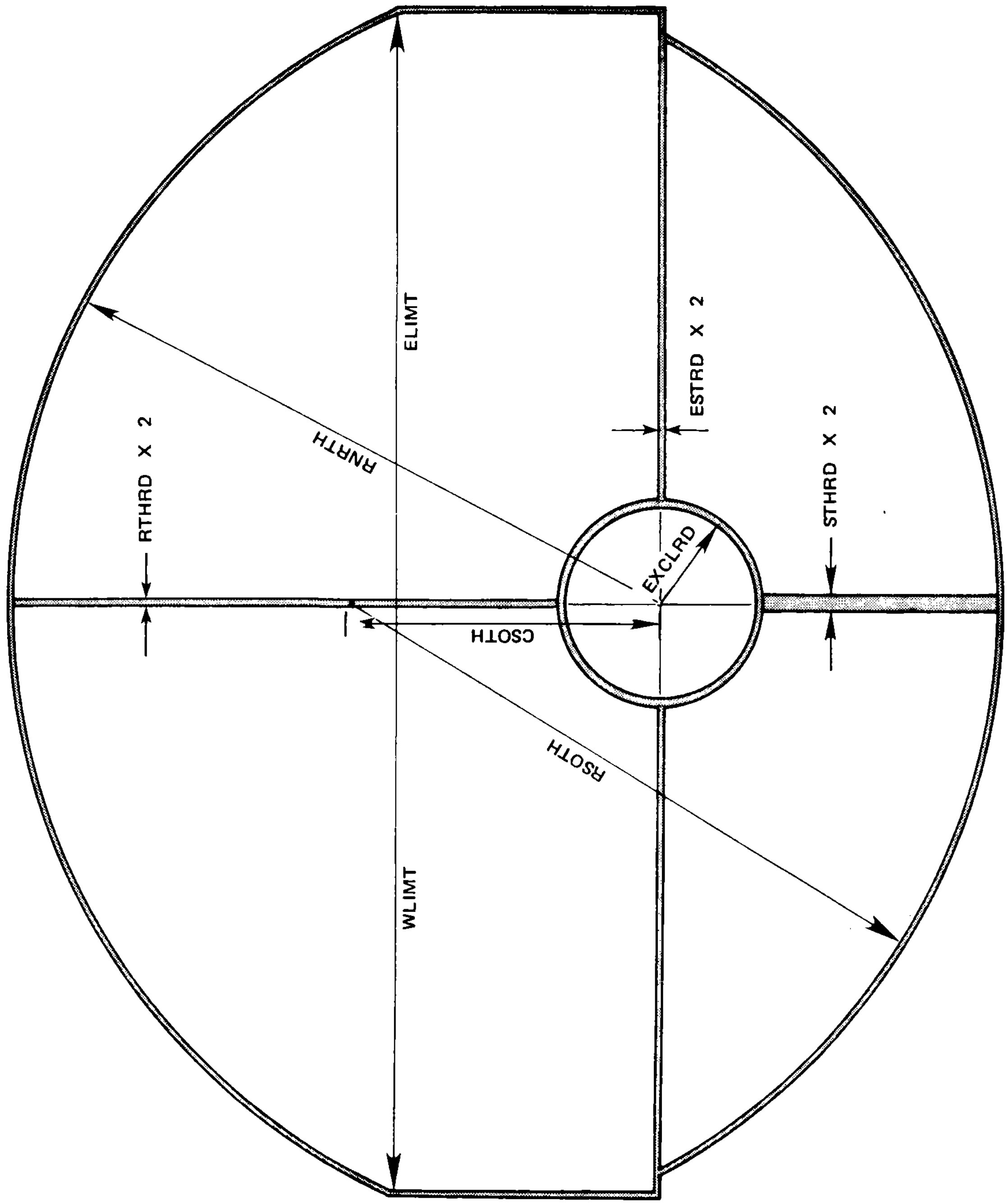


Figure 11.1-1 Geometric-boundary inputs for IH. (Used when ITRIM is set to -1 in STDLY of IHDRIV.)

11. START-UP KIT FOR IH

Before beginning with the Individual Heliostat Code (IH), review the printout from your RCELL final-design run. Examine the IGRND matrix from the summary page and check that the field does not spill over the matrix. (The 0 contour on the page of "TRIM RATIO FOR OPTIMUM SPACINGS", a few pages before the summary page, gives more resolution for making this check.) The field should also be reasonably full (percentage of cells occupied > 50%); otherwise, resolution may suffer. There should be good solutions in all cells within the field boundary, and the polynomial fits generated by PLOT2 should be fitting the heliostat spacings adequately. By all measures, you should have achieved a "good" system using the cellwise codes RC and NS. Once you are satisfied with the quality of your cellwise design, you can proceed to translate your cellwise design into an individual-heliostat design.

We highly recommended that you review Section 3.4 now.

11.1 Prepare for a CELLAY run

1. Obtain HT, WCYLNT, HCYLNT, FMI, and field boundary from RCELL final-design run.

The field boundary may be transmitted to IH by:

a. File 17 (discussed in step (5) below);
   or
b. Geometrically (Figure 11.1-1). Plot the cell boundary (from the BGRND matrix in file 29 or from the IGRND matrix on the summary page) and fit with RNRTH, RSOTH, CSOTH, ELIMT, WLIMT, and EXCLRD.

RNRTH = radius of a northern circle centered at the tower.
RSOTH = radius of a southern circle centered at a point due north of the tower a distance **CSOTH**.
ELIMT = distance to eastern boundary from tower.
WLIMT = distance to western boundary from tower.
EXCLRD = radius of tower exclusion zone.

(The *IH User's Guide* also discusses other ways to transfer the field boundary to IH.)

You must also transfer heliostat spacing information to IH. This is done via CELLAY, which reads a special file (file 13) created by RCELL.

2. Change cell structure
   Select a cell ORDER and array size (NCELI, NCELJ, ID, JD) which nicely fits the field defined in step (1) above, with a margin of +0.0 to +0.5 cells between the field boundary and the array limits. This is done for resolution and efficiency, i.e., so that you do not have too many or too few cells.

3. Node file for new cell structure
   Perform an NS node file run (ISTDNS = 1 or 2) for the field and geometry defined in step (2).

   Set JTRIM = 0 in NSDRIV. You will not be able to use file 29 since you are changing the cell structure. Modify DATA statement in IGRND matrix to be consistent with new NCELI and NCELJ. (The design-point thermal power and the printed flux map output by this run will be incorrect unless you input the appropriate IGRND matrix and spacing coefficients COEFX and COEFY, but this does not affect the validity of the node file.)

4. Make a new SBC database with all ΔAz = <ΔAz>.
   Set ISTDRC = 2. In section 200 of STDRC, set FMI to the value obtained in step (1).

   In FIELD, set ICOF = 1 to select 2x3 field coefficients.

   Look at 3-coefficient polynomial FIT ON THETA X RADIAL COEFFICIENT VS ELEVATION produced by PLOT2 in last RCELL run (examined in step (1)). Load C_1, C_2, C_3, 0., 0., 0. into COEFX (in FIELD) for radial coefficients.

   Find the matrix entitled "Y=SECOND SPACING PARAMETER IN UNITS OF DMIR" on the printout of your RCELL final-design run. (Note that there are two occurrences of this matrix on an RCELL printout. You are looking for the second and final occurrence, which comes just before the last summary page.) Copy down the value listed for AVER; this is the field-averaged value (denoted <ΔAz>) of the azimuthal-spacing coefficients. (Alternatively, look at the plot of ΔAz generated by PLOT2 in your RCELL final-design run and choose a mean value, <ΔAz>, by inspection.) Load <ΔAz>, 0., 0., 0., 0., 0. into COEFY for azimuthal coefficients. Also load <ΔAZ> into COORL.

In RUNRC.COM, ASSIGN an appropriate file name for the new files 07 and 08 that will be made.

You are making a special SBC database that is needed for the CELLAY run in Section 11.2 but that will also be used for the CELLAY precursor run in step (5) below.

If you find that you must make a cell fix run (ISTDRC = 7) in order to fix a few cells, such as a few cells near the tower, then see Section 7.1.5, but do not change the azimuthal spacing in any cell.

5. Make a CELLAY precursor run (ISTDRC = 6) to obtain file 13 (ENRGY and ENHEL matrices) and optional file 17 (field boundary via "0" contour of trim-ratio matrix).

   In section 600 of STDRC, set FMI to value found in step (1) and verify that ITRIM is set appropriately. ASSIGN file names for files 13 and 17 in RUNRC.COM.

   You will need the node file from step (3) and the SBC database from step (4). Use appropriate ASSIGN commands in RUNRC.COM.

   Submit run and review printout. There should be good solutions in all occupied cells.

11.2 CELLAY run

Perform a CELLAY run using CELLAY.COM under the RC88 subdirectory.

1. Use appropriate ASSIGN commands for the special SBC database from step (4) of Section 11.1, for the corresponding node file, and for the corresponding file 13.

2. Set the PARAMETERS in CELLAY.FOR to correspond to ID and JD from your last CELLAY precursor run. (CELLAY.FOR will be recompiled automatically by CELLAY.COM.)

3. CELLAY calls IMSL subroutine ZPOLR which, because of copyright restrictions, can not be provided on the magnetic tape containing the UH Code System. There are two ways to cope with this problem, depending on whether your company subscribes to IMSL or not.

   (i) If your company subscribes to IMSL, then obtain the appropriate information from your site's computer personnel so that you can access the on-site IMSL library and LINK in the subroutine ZPOLR. Specifically, the LINK/NOMAP command in disk file CELLAY.COM must be edited, and the argument UH_LIBRARY:IMSLSP/LIBRARY must be replaced with the appropriate argument obtained from your site's computer personnel. You may then proceed to step (4) below.

   (ii) If your company does not subscribe to IMSL, then you should seek the help of your site's computer personnel. Take the following information with you:

   You must obtain a subroutine which can compute the complex roots of a cubic polynomial with real coefficients. Subroutine RSTEP of program CELLAY invokes such a subroutine:

   ```
   CALL ZPOLR(Q, 3, Z, IER)
   ```

   where

   Q is a real vector of length four (i.e., DIMENSION Q(4)) which contains the coefficients of the cubic polynomial to be solved. Q is the input to subroutine ZPOLR. The order of the coefficients in Q is:

   ```
   Y = Q(1)*Z**3 + Q(2)*Z**2 + Q(3)*Z + Q(4)
   ```

   "3" informs ZPOLR that the polynomial is a cubic.

   Z is a complex vector of length three (i.e., COMPLEX Z(3)) which will contain the roots of the cubic polynomial. Z is the output of subroutine ZPOLR.

   IER is an error parameter which is output by ZPOLR. IER is not used by subroutine RSTEP or by the rest of the CELLAY program.

   Once you have obtained a subroutine as described above, you must edit the LINK/NOMAP command in disk file CELLAY.COM and replace the argument UH_LIBRARY:IMSLSP/LIBRARY with the appropriate argument so that the new subroutine will be LINKed in. Your site's computer personnel should help you make any necessary programming changes (such as subroutine name and argument changes) as well as with the compiling and LINKing commands in the CELLAY.COM file.

4. Submit run. This run reads the ENRGY and ENHEL matrices from file 13 and uses the special SBC database to generate four sets of fitting coefficients for ΔR, one set for each ΔAz = (0.85, 0.95, 1.05, 1.15) $\times$ $\langle \Delta Az \rangle$. These four sets of coefficients will allow IH to assign ΔAz values that vary slightly from the optimum and then compensate by varying ΔR appropriately. (See Section 3; for details, see the *IH User's Guide*.)

5. On the resulting printout, examine the plots for each of the four ΔAz. The fitting coefficients are derived from these data, and each point (i.e., letter) on the plot is a "solution" in one of the cells. Solutions may not be obtained in some cells for some ΔAz; i.e., there may be no ΔR which gives the required energy (as given by the ENRGY matrix on file 13) for one or more of the four ΔAz. This can be monitored by examining the four sets of output pages for the number of solutions that are 0.0; plotting the four curves defined by the coefficients, over a range of tower elevation angles (θ) from 5° to 60° (or 90°), may also be helpful; serious crossing of the four curves is very undesirable. If these problems are too severe and appear unbalanced, select a new $\langle \Delta Az \rangle$ that will give more satisfactory solutions and go back to step (4) of Section 11.1 to make a new SBC database.

11.3 Prepare IHDRIV and other input modules

NOTE: Appendix F.6 contains a sample IHDRIV module for reference.

1. Load coefficients from CELLAY into function RSFC in file IHDRIV.FOR.

   Load the four sets of coefficients for ΔR, from the CELLAY run, into CELAYC. Load the four values of ΔAz into AZ. (If your field has more than one plane, you will need to load the four sets of coefficients for ΔR and the four values of ΔAz for each plane.)

2. Check PARAMETERs in IHDRIV.

   Estimate the number of heliostats, circles, etc. that are required for your system and set PARAMETERs accordingly.

   It is important to limit the array sizes to reasonable values for your system because IH can use a large amount of memory when these PARAMETERs are set indiscriminately large.

3. Set field boundary in IHDRIV.

   Set ITRIM = 2 to read the field boundary from file 17.
   <u>or</u>
   Set ITRIM = -1 for direct input of geometric boundary and load RNRTH, RSOTH, CSOTH, ELIMT, WLIMT, and EXCLRD.

   ITRIM should be set appropriately in sections 10, 20, and 30 of "subroutine" STDLY.

4. Review the rest of the LAYOUT portion of IHDRIV thoroughly.

   You should verify the settings of all the inputs. In particular, verify AZMQ, RADQ, RSYMIN, RSYMAX, and EXCLRD as these inputs, along with the field boundary, greatly affect the resulting heliostat layout. Also check NCIRCA and ZRATIO.

   The heliostat model to be used by LAYOUT has some special options which must be set in IHDRIV; see the comments in IHDRIV to help you set these.

   Check the setting of IHALF in sections 10, 20, and 30 of "subroutine" STDLY. (Note that STDLY is not actually a subroutine, but its structure is parallel to that of the other STD subroutines.)

   The *IH User's Guide* and the comments in IHDRIV are necessary references for setting the inputs in IHDRIV properly. Also see Appendix C.

5. Verify that the inputs in modules HELIOS, RECVER, and FIELD are all correct for your system. (In FIELD, review EGRND and AGRND. Occasionally, a field with a northerly upward slope

may present a problem to IH. Consult with a knowledgeable user or with UH if serious problems of this nature are encountered.)

11.4 First LAYOUT Runs

1. Set ISTDLY = 1 in IHDRIV. In section 10 of "subroutine" STDLY, verify that IPRNT = 0 and that IFILE =0.

2. Submit run and examine printout.

   Verify that a reasonable layout is achieved and assigned resources are adequate. Adjust PARAMETERs and inputs and repeat this run as necessary to achieve these ends. Section 2.8, "Outputs from LAYOUT," of the *IH User's Guide* will help you interpret the printout.

11.5 Combined LAYOUT and Design-point Power Runs

1. Set SLIPAG = 1.0 in RECVER.

2. Set ISTDLY = 2 in IHDRIV to layout the heliostat field and continue on to the performance part of IH, i.e., IHYEAR. In section 20 of "subroutine" STDLY, verify that IPRNT = 0 and IFILE = 0; also check that ITRIM is set appropriately.

3. Set ISTDIH = 1 to obtain a design-point power run.

4. Review the other inputs in the IHYEAR part of IHDRIV and in section 100 of subroutine STDIH thoroughly. Verify that the heliostat area formula corresponds to the correct shape of heliostat; the code must be adjusted for this in both the LAYOUT and IHYEAR parts of IHDRIV.

   Check the output switches, LPCS, LPXY, IPSC, and ICTR, and make any changes to them in section 100 of STDIH. You will probably want to turn off most of the outputs at this point.

   Verify that IFIELD = 0. (IFIELD = 1 is useful for the studies that you may do in Section 11.6 but is not appropriate for this stage of your study.)

5. Set KDISK = 1 and JDISK appropriately to read your last node file from Section 11.1. Use the proper ASSIGN command in RUNIH.COM to assign your node file as file 14.

6. Submit run and examine printout. Your goal is to obtain a heliostat layout that produces your desired design-point power and matches the performance of the heliostat field of your RCELL final-design run. You will likely need to adjust EXCLRD (or other parts of the field boundary), RSYMIN, RSYMAX, NCIRCA, and/or ZRATIO and repeat this run until you obtain a pleasing heliostat field layout that produces the required design-point power. This should only take a few iterations. (In one of these runs, setting IPRNT = 1 in section 20 of STDLY may help you evaluate the layout in detail.) You may wish to plot the output fraction of ground covered and/or the redirected energy vs circle number or distance from tower and compare these IH outputs with the corresponding RCELL outputs from your RC final-design run. (For example, see figures 3.2-1 and 3.2-2.) As you adjust EXCLRD, RSYMIN, etc., to obtain a satisfactory layout, plots such as these will help you to simultaneously match the performance of the IH and RCELL fields.

7. After you have achieved a pleasing heliostat layout that produces your desired design-point power and truly emulates the optimum cellwise design, set IFILE = 1 and IPRNT = 1 in section 20 of "subroutine" STDLY; use an appropriate ASSIGN command for file 21 in RUNIH.COM; and repeat your last run. This will generate a heliostat coordinate file 21 and list the heliostat coordinates on the printout. (Additionally, you may wish to set IDATA = 1 to obtain file 12 containing heliostat coordinate data in a plotter-type format. However, be sure to inspect file 12 for FORMAT compatibility with your computer's plotting subroutines.)

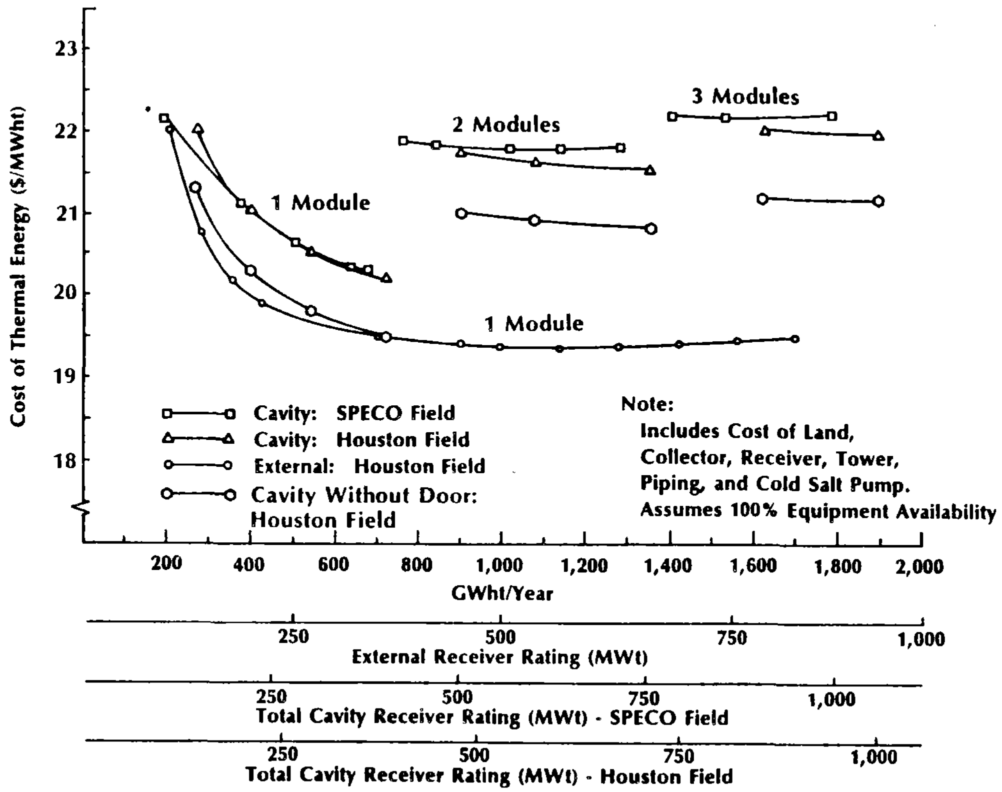
11.6 Performance runs

1. Set ISTDLY = 3 in IHDRIV and use the appropriate ASSIGN command in RUNIH.COM to read your heliostat coordinate file 21. Verify the inputs in section 30 of "subroutine" STDLY.

2. Set ISTDIH as appropriate to obtain whichever available performance run you may require.

3. Verify the inputs in the corresponding section of subroutine STDIH. Check the output switches, LPCS, LPXY, IPSC, and ICTR, and make any changes to them required to turn on the outputs you need. The subfield option (IFIELD = 1) may be useful. If IFIELD is set to 1, then calculations will be made for only a portion of the entire field as specified by ANG1, ANG2, IROW1, and IROW2. (Alternatively, IZSE can be used to force the printing of only one sector of the field, but calculations will still be done for all sectors.)

4. WARNING: Extremely long CPU times and/or extremely long printouts can be easily generated by incautious choices of number of time steps, types of outputs, and quantities of output. An annual run for Solar One with multiple outputs ran several hours and wrote several thousand pages. The Utility Study [7, 8] has 3.5 to 7 times more heliostats. Computers are faster today, but the printout may still be difficult to deal with.



COST OF THERMAL ENERGY VS.
ANNUAL THERMAL ENERGY —
RECEIVER COST SENSITIVITY
FIGURE 5-5

Figure 12.-1 The RCELL Code and the SOLERGY Code were used in the recent Utility Study [7,8]. One of the important decisions was the selection of an external rather than a cavity configuration for the molten salt receiver. Cost estimates for comparable designs for both systems were carefully audited for consistency. RCELL was then used to optimize the heliostat field as well as the receiver elevation and size for a range of design-point power levels (designated Houston Field on the figure). The study shows that cavities without doors and external receivers are comparable from 50 to 350 MW (thermal). As larger cavity designs are not practical, larger cavity systems require modularization and so accrue a 5-10% cost penalty vs. large single external receiver systems, which were selected for utility-scale applications. Cavities with doors promise some operational advantage, but the doors add a 2-5% penalty to the system cost.

12. CONCLUSION

The University of Houston Solar Central Receiver Code System, developed over the last 15 years, is a valuable tool for use in design studies and performance assessment of central receiver heliostat fields and their interaction with the receiver. (See Figure 12.-1.)

Since the initial release of the UH Code System and *User's Guides* in 1980-1985, significant enhancements have been made to NS, RC, and IH. In Section 4, we discuss the major enhancements to the UH Code System, including user friendliness, heliostat aiming and shape, transfer of field boundaries between RC and NS, grand optimization (GOPT), automatic iteration in RCELL, optimization under peak flux constraints, and improvements to the field layout process.

In the past few years, we have put great emphasis on increasing the user friendliness of NS, RC, and IH. The input modules and DRIVer modules have been completely reorganized, and many comments have been added to them. Most important, the number of standard runs has been dramatically increased, and the role of the STD subroutines has become central to the DRIVer modules.

The start-up kits found in Sections 5 to 11 of this manual also add to the user friendliness of the UH Code System. The goal of the start-up kits is to lead you through the steps required to initiate the typical runs involved in a complete system study, from optimization through to coordinate specification. The start-up kits are intended to complement the *User's Guides* [1,2,3,4,5] that already exist for NS, RC, and IH.

One other major change to the UH Code System has been completed: conversion to FORTRAN 77 and a VAX computer system. The goal of a machine-independent computer program comes very close to being achieved when standard FORTRAN 77 is used, and the availability of VAX computers to the average user is increasing rapidly. Thus, transfer of the UH Code System to a VAX makes it more widely available and decreases the number of users who must worry about any remaining machine-dependent lines of code.

We feel that this document and the associated 1988 Code System bring the extremely powerful, versatile, and design-related

UH Solar Central Receiver Code System to the point that it can be used intelligently by a skilled solar engineer or scientist. The Codes and the central receiver systems they model are not simple, and likewise the implementation and use of the UH Code System are not simple. Although codes have been written that are easier to use, we believe that they have neither the versatility, integrity, nor the sensitivity to the designer's needs that we have implemented in the UH Code System.

APPENDICES

APPENDIX A

APPENDIX A
Example: 0th-Order Estimate of HT, WCYLNT, and HCYLNT

The scaling method of Sections 2.2 and 2.3 is recommended for estimating the starting point of a system design study. Alternatively, a good reference for starting-point estimates is *A Handbook For Solar Central Receiver Design* by P. K. Falcone [12]. However, there are less accurate (i.e., 0th-order) ways to estimate HT, WCYLNT, and HCYLNT. For example, suppose you wish to make 0th-order estimates for a solar central receiver system delivering 500 MWth and having a peak-flux limit of 0.85 MW m^{-2} at equinox noon. You might proceed as described below, but note that the following method requires you to pre-estimate numbers such as the ratio of average to peak flux, the receiver aspect ratio, the average field efficiency, the average fraction of ground covered by mirrors, the "tower offset factor", and the extreme tower elevation angle, all of which you really do not know beforehand.

> **WARNING:** The numbers used in this example are only sample numbers, and under no circumstances are these numbers to be interpreted as "typical" or "recommended".

Allowed Peak Incident Flux = (Eq. A-1)

$$\frac{\text{Safety Margin} \times \text{Allowed Peak Absorbed Flux} + \text{Thermal loss per m}^2}{\text{Receiver Absorptivity}}$$

Allowed Peak Incident Flux = $(0.9 \times 0.85 + (0.03-0.01))/0.92 \sim 0.85$

Average Incident Flux = (Eq. A-2)

Ratio of average to peak flux $\times$ Allowed Peak Incident Flux

Average Incident Flux = $0.6 \times 0.85 = 0.51$ MW m^{-2}

Incident Power = (Eq. A-3)

$$\frac{\text{Design Thermal Power + Thermal Loss}}{\text{Receiver Absorptivity}}$$

Incident Power ~ (500 + 0)/0.92 = 543.5 MW

$$\text{Receiver Area} = \frac{\text{Incident Power}}{\text{Average Incident Flux}} \quad \text{(Eq. A-4)}$$

Receiver Area ~ 543.5 MW / 0.51 MW m^{-2} = 1066 m^2

Iterate equations A-3 and A-4:
Incident Power $\cong$(500 + 0.03$\times$1066)/0.92 = 578 MW

Receiver Area $\cong$578 MW / 0.51 MW m^{-2} = 1133 m^2

Receiver Diameter (WCYLNT) = (Eq. A-5)

$$\sqrt{\frac{\text{Receiver Area}}{\pi \times \text{Aspect Ratio}}}$$

(Note: This receiver is assumed to be cylindrical.)

$\text{WCYLNT} = [\ 1133/(\pi \times 1.25)]^{0.5} = 17.0$ m

Receiver Length (HCYLNT) = Aspect Ratio $\times$ WCYLNT (Eq A-6)

HCYLNT = 1.25 $\times$ 17.0 = 21.2 m

Area of Glass = (Eq. A-7)

$$\frac{\text{Incident Power}}{\text{Average Field Efficiency} \times \text{Design Insolation}}$$

(Note: Field efficiency includes cos i, shading & blocking, mirror reflectivity, receiver interception, and atmospheric attenuation factors at design time.)

Area of Glass = $(578 \times 10^6\ \text{W})/(0.67 \times 950\ \text{W m}^{-2}) = 0.91 \times 10^6\ \text{m}^2$

Field Diameter = (Eq. A-8)

$$2 \times \sqrt{\frac{\text{Area of Glass}}{\pi \times \text{Avg. Fraction of Ground Covered}}}$$

(Note: This field is assumed to be a surround field.)

Field Diameter $= 2 \times [\ (0.91 \times 10^6)/(\pi \times 0.23)\ ]^{0.5} = 2240\ \text{m}$

Tower Focal Height (HT) = (Eq. A-9)

Tower Offset Factor × (Field Diameter/2) ×
Tangent(Extreme Tower Elevation Angle)

(Note: This field is assumed to be a surround field. The Tower Offset Factor is used to offset the tower from the center of the field, toward the south.)

HT $= 1.2 \times (2240/2) \times \tan(8°) = 189\ \text{m} \cong 190\ \text{m}$

NOTE: The heliostat diameter (DMIR) is not needed in any of these calculations.

APPENDIX A

APPENDIX B
Reprint of GOPT Paper From 1985 ASME Conference

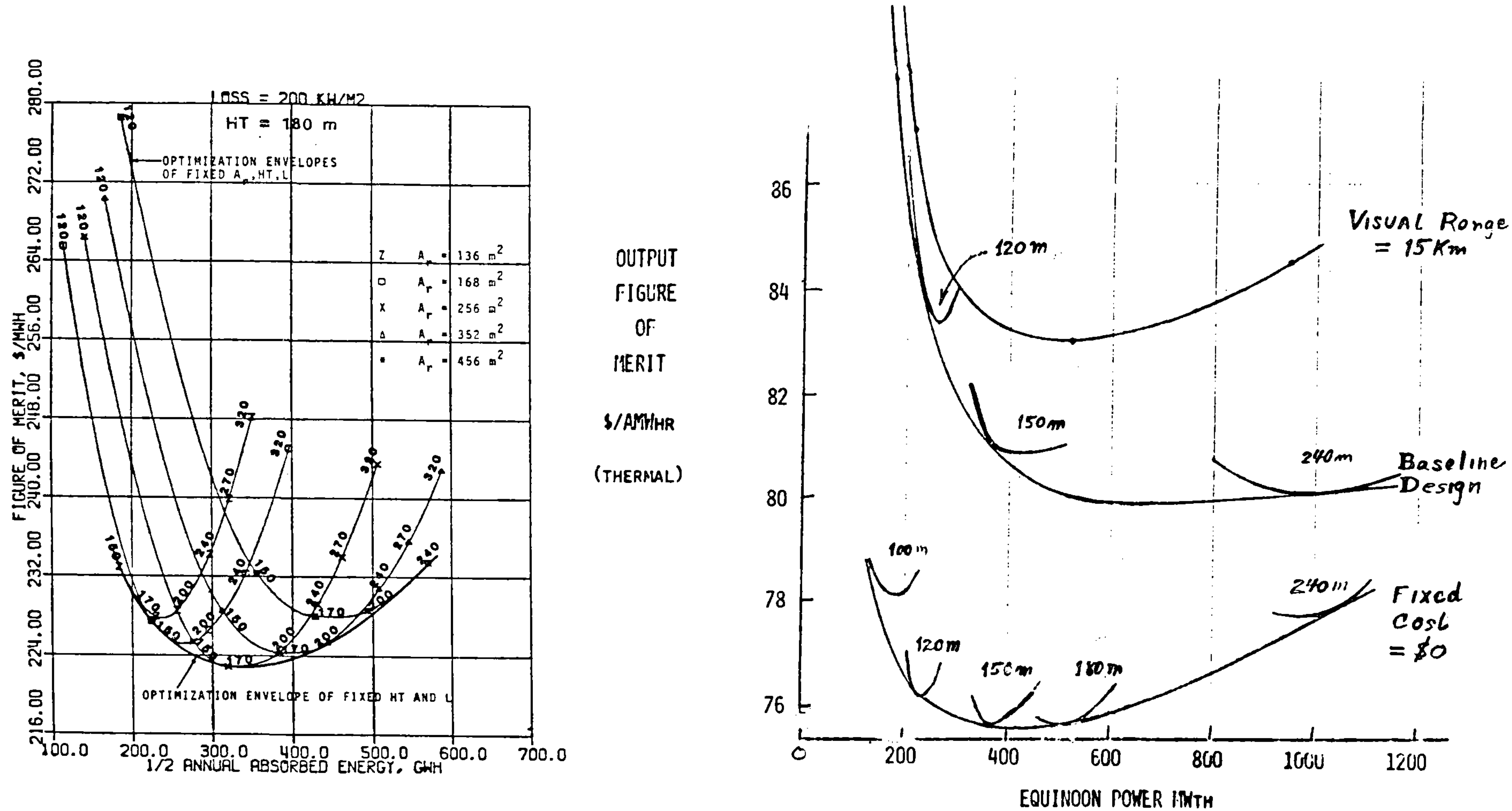


Figure B.-1 Examples of optimization envelopes, which are curves of system cost-effectiveness vs. system size, as parametrized by various program inputs. In the past, the receiver area, A_r, and the tower focal height, HT, were optimized by computing such optimization envelopes. The two figures show progressively greater degrees of system optimization. In the figure on the left, the parameter that varies along each curve is FMI, a code input, and each curve is for a different A_r. HT is 180 m, and L, the receiver thermal loss per m^2, is 200 kW/m^2. Both A_r and FMI vary along the darker, lower curve, which represents the next higher level of system optimization. In the figure on the right, which is from a separate study, each small curve is like the darker, lower curve just described, and each one is for a different value of HT. Along each of the three larger envelopes, called grand optimization envelopes, HT, A_r, and FMI all vary, and the upper and lower envelopes correspond to variation of other input parameters as shown. Over the past eight years, many enhancements to the UH Code System have made computer studies such as these much easier to perform. However, this appendix describes a different method that automatically optimizes A_r and HT in addtion to the heliostat field, for systems without significant peak flux limits.

COMBINED COLLECTOR-RECEIVER OPTIMIZATION FOR CENTRAL RECEIVER SYSTEMS USING RCELL

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ABSTRACT

A new procedure for utilization with the computer code, RCELL, is presented. This procedure based on the previous cellwise optimization for the collector, provides optimized tower height, aperture area, and collector geometry in a single execution. Two interception data files provide interpolation in a range of tower heights. The shading and blocking data is converted to a new TRAJectory file which parameterizes the optimum collector geometry and provides more efficient operation. Comparison with previous work for a high temperature cavity receiver shows good agreement, and the grand optimum system shows at least 10% improvement in the cost benefit ratio.

INTRODUCTION

Solar energy system analysis is intensely cost oriented, and cost effective optimization of the optical component of the central receiver system has been achieved by a cellwise approach to the collector field. The "RCELL" optimization procedure includes a complete cost-performance model for a fixed tower and receiver, and a variable distribution of heliostats (including a variable density of heliostats). The cost effective distribution of heliostats i- acheived by appropriately converging inpu estimates of the cost benefit ratio.

Optimized central receiver systems show a complex adjustment to changes in design parameters and costs. Tower and receiver costs are known parametrically in terms of tower height, receiver size, and design power. Hence, it is possible to consider optimization of tower height and receiver size. Note that "tower height" is a euphemism for the vertical distance from the mean reflective surface to the centerline of the receiver. Heliostat cost is known for specific models, but not parametrically in terms of heliostat size and/or guidance accuracy. Thus, although much engineering expertise has gone into heliostat design, and RCELL includes heliostat cost, we are not currently able to optimize heliostat size by solving a stationary equation. (Ref 1).

Dr. Pitman has developed a method to use RCELL output data to optimize receiver size as a function of the radiative and convective losses. (Ref 2 and 3). See Figure 1. This method of optimization is based on a separation of costs into tower-receiver and collector subsystems. Figure 2 shows the data flow for a new combined collector-receiver optimization scheme that directly outputs optimized tower heights and receiver areas, if given appropriate input data. The TRAJ data file will be explained in section 3.

In both methods, an independent receiver model must be executed to generate a file of interception data for a given tower height (H). In combined optimization of aperture area and tower height, two interception files for two tower heights are required to allow interpolation. Both methods require a preliminary execution of RCELL to generate: (1) insolation data, and (2) the shading and blocking database (SAB), which contains a 4x4 set of variations for the heliostat neighborhood geometry. The combined optimization parameterizes a subset of the SAB database and transfers it to the TRAJectory file which is more suitable for optimization.

[1] Dr. C. L. Pitman is now at Division of Chemistry and Physics, Sam Houston State University, Huntsville, Texas 77341.

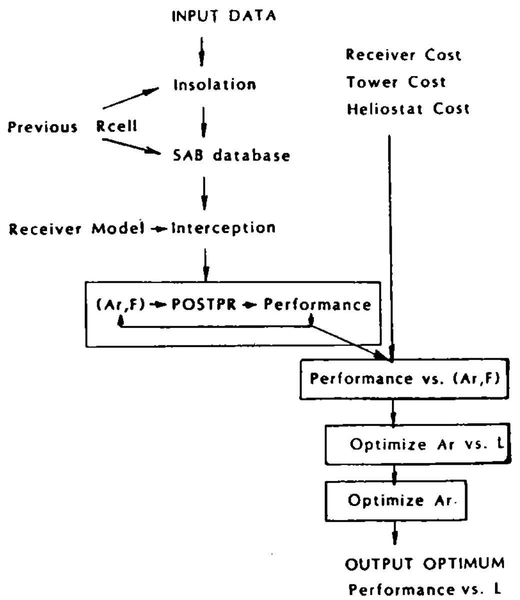

Figure 1) Data Flow for Pitman's Optimization

The SAB database is the annual average shading and blocking data for each cell in the collector field. POSTPR is the performance generating subroutine. A_R = Area of receiver, F = input cost benefit ratio, and L = loss parameter in KW/m^2. Results are output for fixed tower height (H). The collector field performance data is contained on a small file. The optimizations indicated on the right side of the figure require auxilliary computer programs and graphical analysis and thus involve much more operator effort than the new combined collector-receiver optimization procedure of Figure 2.

Standard RCELL optimization for a fixed receiver area (A_R) and tower height (H) requires that the input cost benefit ratio (F) be converged to (F*) which is shifted from the true cost benefit ratio ($\tilde{F}$) due to power dependent costs. In the current implementation of the combined collector-receiver optimization procedure, the output estimate of annual thermal energy (E) is converged to an input energy constraint (E_{CON}) for each sample in a 3x3 set of variations of A_r and H. (See E(F) → E_{CON} in box of Figure 2.) The combined collector-receiver optimum is then determined by finding that system which minimizes the cost benefit ratio ($\tilde{F}$).

2. The Cellwise Model

The cellwise optimization program requires a set of coefficients to generate the nominal heliostat radial and azimuthal spacing parameters (R_c,Z_c) in each computational cell of the collector field. This set of spacing parameters serves as a center for the 4x4 set of variations which is sent to the shading and blocking processor for each time in the annual sample. The annual average output from the SAB processor is written to the SAB database for each cell.

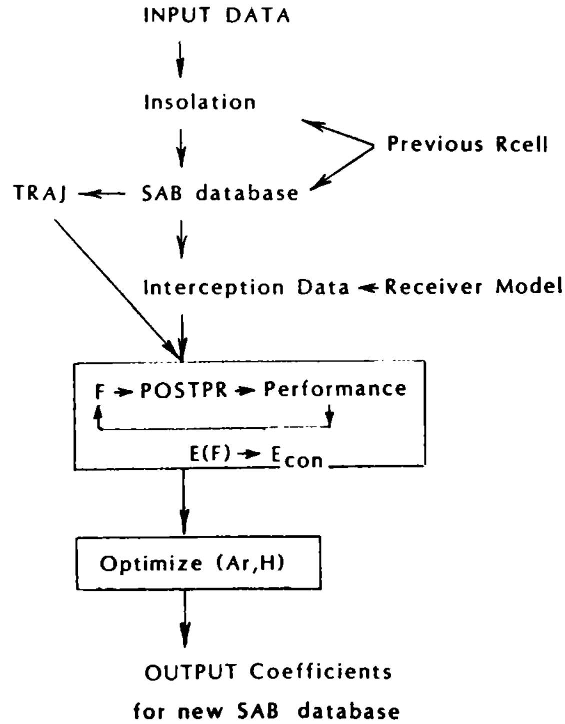

Figure 2) Data Flow for Combined Receiver-Collector Optimization

Compare to Figure 1. Input data includes the receiver cost model and receiver loss, L. The interception data now includes two "node" files for tower heights H_1 and H_2. POSTPR is heavily modified to optimize F, A_R, and H for a given L. The TRAJ data file contains all of the performance data for each cell as a function of the cell matching parameter. Each of the 9 trial values for (A_r,H) generate performance which is converged to the input value of annual thermal energy. The optimum value of (A_r,H) is obtained by interpolating the 9 converged outputs from POSTPR.

An introduction to the optimization model is appropriate. See Ref 1. Let

$$\tilde{F} = C/E$$

be the cost benefit ratio, i.e., total solar subsystem cost (C) over total thermal energy (E) produced in an average year, available at the base of the tower at temperature T. Our objective is to minimize this cost benefit ratio. The annual thermal energy (E) is given by

$$E = aA_H\tilde{S}(\sum_c \eta_c \lambda_c f_c \phi_c) - A_R L H_a$$

where a is the multiplicative loss factor including heliostat reflectivity, receiver absorptivity and fraction of heliostats operational. A_H is the area of a cell. S is the annual direct insolation at normal incidence for the site-specific average year.

$$\tilde{S} = \int_{H_a} d\tau\ \tilde{\sigma}(\tau)$$

where $\tilde{\sigma}$ is the expected instantaneous direct beam irradiance at normal incidence and H_a is the number of useful hours of insolation per year. The sum extends over all cells within the field boundary. η_c is the receiver interception factor for a representative heliostat in cell c (including effects of atmospheric absorbtion). λ_c is the annual energy redirected toward the receiver per square meter of mirror in cell c, after accounting for cosine and shading and blocking effects. $f_c\phi_c$ is the fraction of ground covered by glass in cell c, ϕ_c is the fraction of land used in cell c and is zero or one except along the field boundary. A_R is the area of the receiver, and L is the loss parameter in kW/m^2. Thus, A_RLH_a represents the annual radiative and convective losses associated with receiver operation at the temperature T.

Let E_c denote the annual total solar energy redirected by the heliostats of cell c, and let A_c denote the total area of glass in cell c. λ_c is related to E_c and A_c by the equation:

$$\lambda_c = \lambda_c(R_c, Z_c) = E_c/\tilde{S}A_c,$$

where R_c is the radial spacing parameter, and Z_c is the azimuthal spacing parameter in cell c, both in units of the heliostat width, D_m. The SAB processor returns λ_c for each of the 16 variations for (R_c, Z_c).

The collector cell geometry is congruent to tower height, so the total land area of each cell (A_H) is given by

$$A_H = b\ H^2$$

where b is a constant. The total area of glass per cell (A_c) is

$$A_c = f_c\phi_c A_H,$$

where the fraction of ground covered by glass is

$$f_c = (A_M/D_M^2\gamma_c)/R_cZ_c.$$

R_c and Z_c are in units of heliostat width (D_M). A_M is the reflective area of the heliostat, and $\gamma_c = 1/2$ for radial stagger neighborhoods.

The total solar subsystem cost C is defined to include everything necessary to produce the thermal energy (E) at the base of the tower, but to exclude thermal storage, the turbine-generator subsystems, etc. Let

$$C = C_R(E, A_R, H) + C_C(A_R, H)$$

where

$$C_C = C_hA_H\ \Sigma\phi_c\psi_c$$

and

$$\psi_c = f_c(1+\beta_1r_c + \beta_2R_c + \beta_3Z_c) + \alpha.$$

C_R is the cost of the tower and receiver subsystem. C_R depends on receiver area (A_R), tower height (H), and annual energy (E) which can be related to design-point power (P). C_C is the cost of the collector subsystem. C_h is the cost of the complete heliostat per square meter. r_c is the distance from the base of the tower to cell c. α is the relative cost of land and $\beta_{1,2,3}$ are relative cost parameters for various kinds of wiring. $C_hA_H\phi_cf_c$ is the cost of heliostats in cell c, and the other costs are compared to heliostats.

The optimum system minimizes the cost benefit ratio $(\tilde{F})$. The stationary conditions for the optimum choice of (R_c, Z_c, ϕ_c) are

$$\lambda_c + f_c\partial_f\lambda_c = (\partial_f\psi_c)\ \tilde{\mu}/\eta_c,$$

$$\partial_t\lambda_c = (\partial_t\psi_c)\ \tilde{\mu}/\eta_cf_c,$$

$$\rho_c = \eta_c\lambda_cf_c/\tilde{\mu}\psi_c,$$

with

$$\phi_c = \begin{cases}0 \text{ if } \rho_c < 1,\\ 1 \text{ if } \rho_c > 1.\end{cases}$$

$$\tilde{\mu} = C_h/(Fa\tilde{S}).$$

$\tilde{\mu}$ is the cell matching parameter for the given input cost benefit ratio (F). To minimize cell-size effects in the new optimization approach $\phi_c(\rho_c)$ has been represented as a ramp function, instead of a step function.

The stationary conditions are derived in Ref (1). The variable t is orthogonal to f_c and the array geometry can be represented by (R_cZ_c) or (f_c, t_c). See Ref (1).

3. Combined Collector-Receiver Optimization

All three stationary conditions contain the parameter

$$p_c = \eta_c/\tilde{\mu} = \eta_cFa\tilde{S}/C_h,$$

so that the optimized behavior of the collector can be represented by the functions

$$\{R_c(p_c),\ Z_c(p_c),\ \phi_c(p_c),\ \lambda_c(p_c), \text{ and } \psi_c(p_c)\}$$

which determine C_C and $\Sigma\ \eta_c\lambda_cf_c\phi_c$. Data supporting these functions constitutes the TRAJ file shown in Figure 2. Hence, given $\eta_c(A_R, H)$, we can calculate the parameter p_c, and hence C_R, C, E, and F as functions of (A_R, H). The use of the TRAJ data file greatly accelerates numerical procedures.

Attempts to solve the stationary conditions

$$\partial_H \tilde{F} = 0 = \partial_{A_R} \tilde{F}$$

failed because of difficulties with the gradient terms. Instead we developed a procedure based on interpolation within a 3x3 sample of the (A_R,H) plane to find the minimum $\hat{F}$ and the associated combined collector-receiver optimum. In this procedure, each of the nine (A_R,H) sample points is converged to an input annual energy constraint (E_{CON}). Consequently, F and $\hat{F}$ are determined as functions of (E_{CON},A_R,H). Therefore, the combined collector-receiver optimum (i.e., the optimum values of A_r, H, and $\hat{F}$ which defines the heliostat spacings and their number) is a function of E_{CON}. Curves of $\hat{F}$, A_r, H, etc., plotted vs. E_{CON} provide a definition of optimal systems for a range of constrained energies.

The grand optimum, i.e., the point of absolute-minimum cost benefit ratio ($\hat{F}$), can be determined graphically by inspecting the curve of $\hat{F}(E_{CON})$. In the present case, the grand optimum energy is close to the largest energy which could be reached within the limits of validity for the tower cost model. The curve of $\hat{F}(E_{CON})$ also provides data for a further optimization of the total solar central receiver system, including storage and balance of plant costs.

It should be noted that many system studies produced comparisons of optimized solar towers of different height. See for example Refs (4,5). Ref (4) shows the grand optimum over a wide range of tower heights, but this required extensive operator interaction and provided relatively crude receiver optimization. The current process is orders of magnitude faster and involves much less operator effort.

4. High Temperature Cavity Receiver Applications

The dual-cavity, air-cooled receiver system described by C. L. Pitman (Ref 2) was selected for a trial application of the combined collector-receiver optimization procedure. See Figure 4. Whereas Pitman's procedure generated optima for loss parameter (L) and for two tower heights (H), the new procedure was applied for fixed loss paramter (L) of 100 and 500 kW/m^2 and optimum tower height and aperture area were determined.

Design Assumptions

McDonnell-Douglas second-generation heliostats having fourteen 1.2 m x 3.3 m segments (56.84 m^2 of total reflective area) were assumed. The heliostat segments were canted on both axes and focused in the long axis. (Focusing on the short axis as well would not significantly improve performance.) In order to simulate a heliostat field composed of a few bands of fixed focal length heliostats (where the focal length varies from band to band), the heliostat cant and focal lengths were assumed to be slant range (heliostat to aperture distance) plus 20% (where the 20% defocusing approximates the effect of the bands). The receiver contained two elliptical apertures. The normal to each aperture was angled 20 degrees below the horizontal. One aperture was oriented to face 60 degrees west of due north and the other 60 degrees east of due north. All of the heliostats in the west-half field were aimed at the center of the west-facing aperture, and the east-half field was similarly aimed at the east-facing aperture. Beam degrading (due to mirror surface imperfections, aiming errors, etc.) was assumed to be Gaussian in character with an rms of 2.83 milliradians (about 1/6 degree). The site location was Albuquerque, NM, which has favorable weather and direct beam insolation.

The receiver working fluid was assumed to be air, since it has the least technological risk in terms of materials degradation at very high temperatures. However, air is a poor heat transfer medium, and large volumes must be pumped in order to absorb the required thermal energy (E), which in turn implies a large annual electrical energy requirement to drive the compressor. This is particularly serious for small temperature rises, explaining the upward trend in F for low losses (i.e., low temperature rise) seen in Figure 4. In addition, the receiver was sized to provide an average flux below 100 KW/m^2.

All dollar values were expressed in terms of 1980 dollars, and N-th plant costs were assumed. N-th plant costs are those which are anticipated with a mature solar central receiver industry (which might come about as early as the 1990's), so these costs are lower than current costs in order to estimate the effects of component price declines which will occur with large scale mass production. Both capital costs and present value of operations and maintenance costs were included. For example, installed heliostat costs were assumed to be 82 \$ m^{-2}, and the inclusion of appropriate present value of operations and maintenance costs increased this to 126 \$ m^{-2}. Land cost, including site preparation, was set at 2.028 \$ m^{-2} (8200 \$/acre).

Since the compressor electrical energy requirement is large, the diameter and cost per unit length of the downcomer were scaled to keep the working fluid (air) pressure drop constant in the downcomer.

5. Results

A comparison of the two methods (i.e., Pitman's work and the combined collector-receiver optimization procedure) shows satisfactory agreement. Prior to initiation of a study such as this, careful inspection is important to verify that both the original shading and blocking database and the TRAJectory file have good data for all cells and suitable values of cell matching

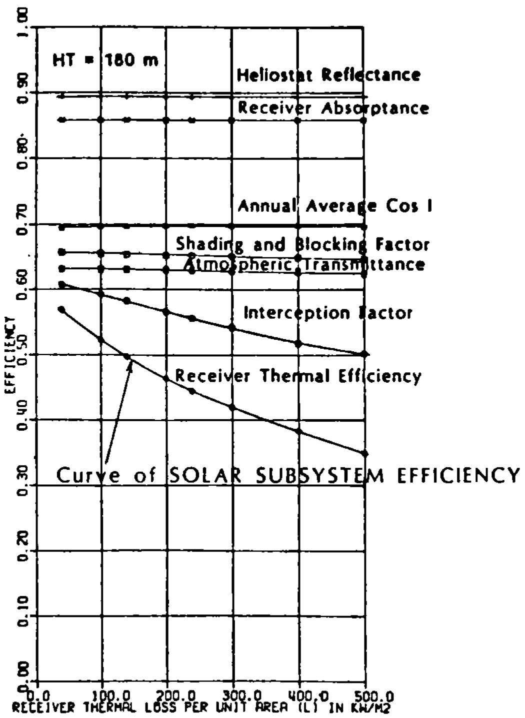

Figure 3) Water-fall of Efficiencies versus Receiver Loss Parameter

Each curve shows the cumulative effect of the efficiencies listed above it. The lowest curve is the solar subsystem efficiency, which is the net efficiency of the combined collector-receiver system.

parameters.

Figure 3 (from Ref 2) shows a water-fall of efficiencies for the high temperature air receiver system being studied as a function of the loss parameter (L), for convective and radiative losses in kW/m^2. These results are for fixed tower height (H) and optimum receiver size (A_R). Each curve in Figure 3 is the product of all the efficiencies shown above it. The curve of solar subsystem efficiency, is the net efficiency of the combined collector-receiver system. In the notation of section 2, the solar subsystem efficiency (η_s) is the ratio of the annual thermal energy (E) produced at the tower base to the product of the annual insolation ($\tilde{S}$) and the total reflective area of the heliostat field (ΣA_c):

$$\eta_s = E/\tilde{S}(\Sigma_c A_c).$$

Figure 4 shows a comparison of Pitman's optimization and the combined optimization procedure. The comparison occurs where the curves intersect in Figure 4. The numbers shown at intersections are optimum tower heights (interpolated from the new procedure) which are comparable to the two values for the sloping curves from Pitman's procedure. The combined optimization procedure indicates that systems optimized for a given receiver loss parameter (L) have a solar subsystem efficiency (η_s) which is approximately independent of H and hence of E as well. This exceedingly interesting result is not fully understood at this time!

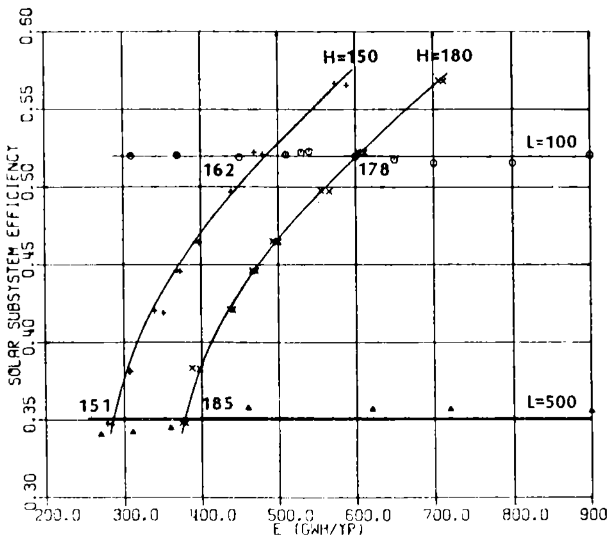

Figure 4) Comparison of Optimization Methods using Solar Subsystem Efficiency versus Annual Thermal Energy

Pitman's procedure provides the curves for H = 150 m and H = 180 m, whereas the combined optimization procedure provides the curves for L = 100 kW/m^2 and L = 500 kW/m^2. Circles and triangles mark combined optimization outputs, whereas, + and x mark Pitman's outputs.

Figure 5 shows peak flux density versus annual thermal energy (E) produced at the tower base, as predicted by the combined optimization procedure. These fluxes occur at the center of the aperture and are not limited by heat transfer considerations, directly, although the cavity expansion ratio must be adequate. Notice that higher loss parameter (L) requires higher fluxes for fixed energy constraint. The case marked "perfect focus" shows the results for a system with L of 500 kW/m^2 in which the heliostats were focused and canted to slant range, instead of the standard "slant range plus twenty percent." The relatively small increase in peak flux over the standard focus case (for L of 500) shows the the finite sun size and beam dominate heliostat size effects for nominally focused heliostats.

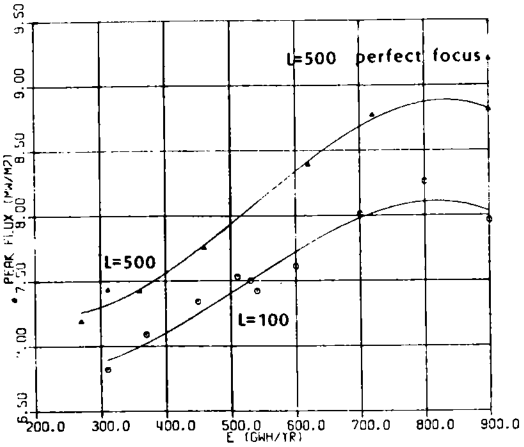

Figure 5) Peak Flux Density in Aperture versus Annual Thermal Energy

Circles represent L = 100 kW/m^2 and triangles represent L = 500 kW/m^2. There is no clear cut reason for a peak in the flux density at 800 GWH/yr, and the scatter of data points suggests that we ignore this feature of the computer generated fit to the data points. However, an extension of the study to higher energies would show a limiting flux density.

Figure 6 shows optimum receiver area (A_R) and optimum tower height (H) versus the annual thermal energy (E) in GWH/yr. Higher loss parameter (L) causes smaller apertures and higher towers for fixed energy. Higher L causes the aperture to shrink in order to compensate for the greater thermal loss. This increases the average flux concentration as well. Reduced interception causes the field to shrink, thus reducing the annual energy produced (E). A taller tower and proportionatly larger field is required to compensate for the relatively smaller rim angle of the field. The reduced system efficiency also results in a higher $\bar{F}$ which increases heliostat density in the field.

The curves in Figure 6 increase as expected but the tower height curve for L of 100 kW/m^2 shows the effect of a step in the tower cost model. The unresolved step probably accounts for the shoulder in the plot for 500 kW/m^2. The solid curves in Figure 7 show the cost of the tower and the tower-heliostat cost ratio as a function of the annual thermal energy. The dashed curves show smoothed behavior as it might be expected. The tower cost model behaves erratically in the 500 to 700 GWH/yr range due to branching related to various over-turning moments. The concrete tower cost model is described in Ref 5. The data basis for the cost model (Stearns-Roger) imposes limits on receiver weight and tower height,

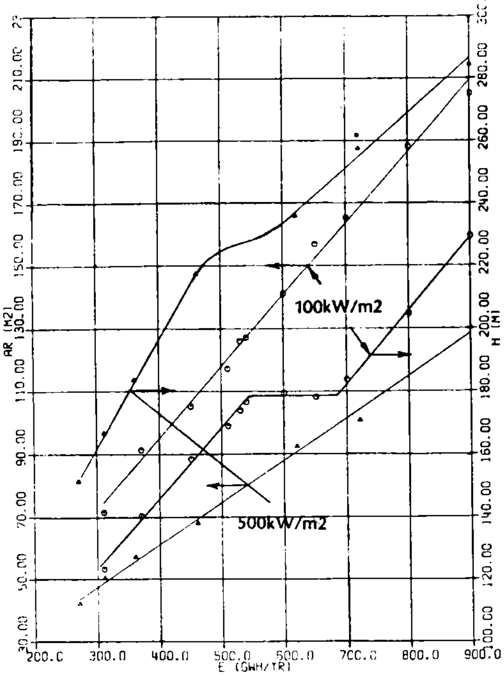

Figure 6) Optimum (A_r,H) versus Annual Thermal Energy for L = 100 and 500 kW/m^2

A_r is the receiver aperture area and H is the tower height. Δ gives L = 500 and 0 gives L = 100 kW/m^2. The tower heights for L = 100 show the effect of a step in tower cost. See discussion.

which hinder optimization. See Figure 1 of Ref (6).

Figure 8 shows the cost benefit ratio F versus annual thermal energy in GWH/yr. We have a satisfactory comparison between Pitman's results (where the loss L varies for fixed H), and the combined optimization (where the optimum H is found for fixed L). Notice the encircled data occuring near the intersections. Figure 8 also shows the grand optimum near or beyond E = 900 GWH/yr for both L = 100 and 500 kW/m^2. The 10% improvement shown in $\bar{F}$ versus E justifies the computational effort and indicates the desirability of large systems. The inclusion of the storage subsystem and balance of plant costs would alter the size of the grand optimium system, probably toward still larger sizes. This is another important reason for displaying the results as a function of annual thermal energy. The (approximate) grand optimum for L = 500 kW/m^2 requires 19,818 heliostats and gives 538 MW at equinox noon. The grand optimum for L = 100 kW/m^2 requires 13,542 heliostats and gives 488 MW at equinox noon. More heliostats and higher towers are required to give the same power at higher losses.

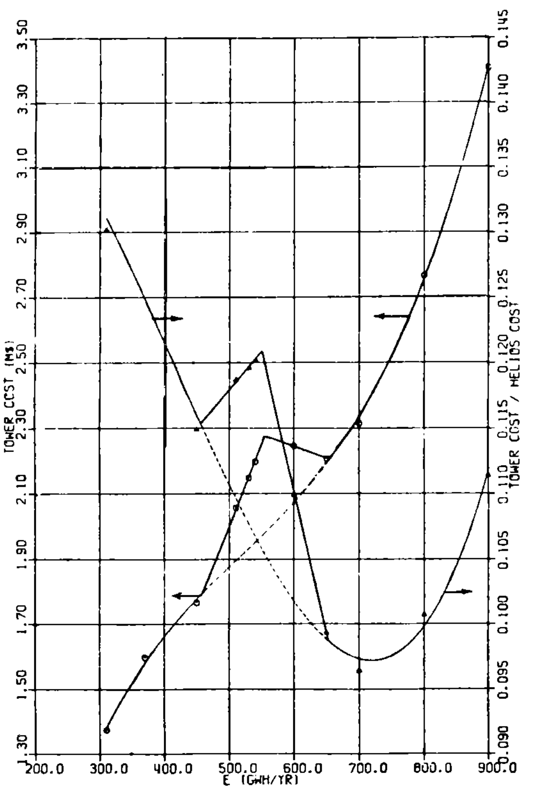

Figure 7) Tower Cost versus Annual Thermal Energy for L = 100 kW/m^2

Δ gives the ratio of tower cost to heliostat cost on left side, and O gives tower cost on right. The tower cost model branches in the energy range 450 to 650 GWH/yr. See discussion.

6. Conclusions

Combined collector-receiver optimization was achieved using the RCELL approach and the UH receiver interception data. In addition to heliostat spacings and field boundary, the receiver aperture area and tower height are optimized in a single execution for a constrained annual thermal energy and a fixed receiver loss parameter. Other attributes of the receiver such as tilt angle and ratio of semi-major to semi-minor axes are fixed wisely but not optimized. It is difficult to increase the parameter set which is being optimized. Each additional parameter increases the number of variations required by a factor of 3 or 4, and the complexity of the cost benefit function F increases, making it difficult to find the optima.

A special run with perfectly focused heliostats showed negligible improvement compared to the baseline (focal length equal 120% of ideal).

The cavity views are 60° east and west of north because of the twin cavity scheme. However, an inspection of cosine of incidence angle behavior for the heliostats in useful cells indicates that annual average interception will not differ significantly from the equinox noon data which is ordinarily used for optimization studies. (Grazing incidence on the heliostats would cause large abberations which worsen the annual average performance relative to the noon performance.) Therefore, the more involved annual average interception calculations which may be required for surround fields such as those associated with cylindrical receivers, are not required in the present case.

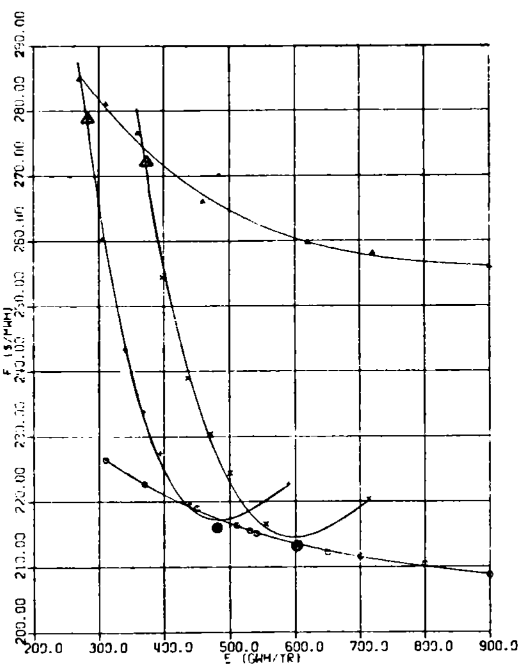

Figure 8) Cost Benefit Ratio versus Annual Thermal Energy for L = 100 and 500 kW/m^2

Δ and O represent the current study, using fixed loss parameter and constrained annual energy. + and x represent Pitman's study using fixed tower heights and variable loss parameters. Circle enclosed + and x represent the L = 100 cases and lie close to the current results for L = 100. Similarly, triangle enclosed + and x represent the L = 500 cases, and lie close to the current results for L = 500. The Δ and O curves tend to flaten out at E = 900, indicating that the grand optimina occur near or beyond E = 900.

The combined optimization procedure vastly simplifies the operator role, especially if relatively few values of receiver loss parameter (L) are needed and if, as is usual, the tower height range is relatively well known, a priori. The new TRAJectory data file is the key element in this realization of combined collector-receiver optimization. The TRAJectory file is characterized by a parameter which is proportional to the input cost benefit ratio and cell interception.

The TRAJectory data reduces the CPU time required per heliostat field optimization by a significant amount. An execution of the combined optimization program makes roughly 50 passages through the TRAJ file (i.e., heliostat field optimizations) and (because of the TRAJ file approach) takes only about 6/100 hour-CPU on the Honeywell 66/60. By comparison, a single execution of RCELL for given receiver area and tower height requires about 4/100 hour. Therefore, following the generation of the TRAJ file the combined collector-receiver optimization procedure requires 20 to 50 times less CPU than the repeated executions required in previous RCELL studies. Operator effort is also greatly reduced.

The cost benefit ratio ($\tilde{F}$) can be significantly improved by seeking the grand optimum system. Our results show 10% improvement over optimizations for a fixed tower focal height.

Results may be limited by the range of validity of the tower (and/or other) cost models. The optimum tower height shows unexpected behavior which is attributed to a peculiarity of the SANDIA tower cost model.

The optimization procedure can be extended to cylindrical receivers, but a change in the interception data treatment is required to deal with the variable radius of the cylinder. A fixed ratio of cylinder radius to height would be assumed, just as a fixed ratio of semi-major to semi-minor axes is assumed for the cavity aperture.

The constraint to annual thermal energy can (easily) be converted to a design-time power constraint.

ACKNOWLEDGEMENTS

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APPENDIX C

9. Big Field Layout Multi-Plane Collector Study

9.1 Introduction

The original Barstow version of individual heliostat code has been modified to include:

1) a range of zone ratios;
2) East/West asymmetry;
3) multi-plane layout capability, and
4) the receiver model.

However, prior to this study, no serious application of these mods existed. The east-west symmetry of the original code required an even number of A circles, a restriction which is maintained by SLPTST in the IH82 version even though the symmetry is not required. The range of zone ratios (i.e., 7/6 --- 3/2, 2/1) was not tested adequately. The multi-plane capabilities greatly complicated the IH82 version and many aspects remained uncertain.

After this study, the multi-plane capability becomes deliverable as the IH83 version. All zone ratios work, and no restriction on the number of A circles occurs. However, the east-west asymmetry is not yet implemented for daily and annual performance average outputs.

Note concerning the mulit-plane collector mods The Barstow experience suggests that full scale commercial collector fields may need several planes to approximate the available terrain.

The multi-plane mod was first developed for the optimization code, then the incomplete IH82 version was issued. We now have complete a multi-plane capability in this NS82D version, which provides appropriate interception data (i.e., node files) and the now complete IH83 version. However, the developmental test runs are not to be considered as practical examples of commercial scale collector fields. Further development of a practical example is needed to guarantee that the coefficient fitting schemes are entirely suitable.

9.2 Code Development of IH83 Version

This version is designed to handle a 12,000 heliostat field (or east half field). It utilizes all zone ratios as required, and provides shading and blocking output for an RCELL optimum trim. SAB output requires 136K words of core, but annual output will require more core.

The IH83 code mods go into the source files, MAIN, LAYOUT, YEARP, and FIELD. The following subprograms have mods for IH83: MAIN, HELIOS, LAYOUT, ZONE, MECHLM, COORDS, ROW, CIRCA, CIRCB, CIRCC, CIRCD, TRIM, ROADS, FCREAD, FSLIP, YEARP, CELTUR, CIRSEC, SECTOR, SECPRT, ASKPRT, SUBFLD, and SECTR2. The purposes of these mods will be described, but a user will be expected to receive a fresh code delivery of the IH-code system.

In order to lower the core requirements for a system of 12,000 heliostats, we have developed a half-field LAYOUT capability, and systematically commented dimension statements relating to annual performance vectors in MAIN and YEARP. We have also increased the capabilities of the SUBFIELD option to deal with the IH82 version by delaying the heliostat sort operation until after the call to SUBFIELD. The SORT operation makes the code compatible with multi-planes.

A special output of slipage† fractions was developed to verify the multi-zone ratio layouts. This output calls SECTOR from the MAIN program module after the call to LAYOUT and before the call to YEAR (which gives performance).

The layout process is improved in several ways. An input list of zone ratios is automaticaly replaced by higher ratios as required. The requirements for a sucessful zone now include an input "NCIRCA" for the minimum number of A-circles. (A circles have no slips or deletes). The number of A-circles is now allowed to be odd. If an odd number of A-circles occur in a zone, the deletes must fall between the heliostats of the previous delete circle, hence, the deletes can not stack up on a radius in this case. This type of displacement spoils the east-west symmetry and is not allowed in the previous versions which required such symmetry. The current version no longer includes the SLPTST subroutine which was used to maintain an even number of A-circles.

The user must be aware that not all vectors are sized by parametric input at the top of MAIN. Internally dimensioned vectors limit the number of rows (i.e., circles) to 130. The maximum number of zones is 30 for ZRATIO and 20 for IDEL and

† Slipage refers to the fractional displacement of heliostats surrounding a delete to take advantage of the added space and minimize the effects of the zone boundary.

ADEL. The maximum number of deletes per circle is 50 and the maximum number of heliostats per circles is 300. Most of these quantities are guarded in appropriate ways, to avoid faulting in execution. IH83 is relatively fault proof in comparison to the previous version.

9.3 Input Mods

The common group PLDATA and associated inputs was deleted from LAYOUT. These inputs can be used by SCPLOT and PCOORD if called by SECTR2. However, we are not now providing a SECTR2 output, and the inputs are not currently being provided. SECTR2 output is a special output for multi-planes which require considerable CORE in its present version.

The common group ZONE3 has a new variable NCIRCA which is input from MAIN to control the minimum number of A-circles allowed per zone. All zones are the same.

The common group GPLANE now appears in the MAIN module in order to input the Q-point (i.e., cue-point) variables. There are five Q-points for a maximum of five planes in a multi-plane layout. Each Q-point is the location of the first heliostat in the outer circle of its plane. The outer radius of plane (1) = RADQ(1), and the azimuth of the first heliostat in plane (1) = AZMQ(1). In this study we used

AZMQ(1) = 3.141592 (radians)

RADQ(1) = 1400.0 (meters).

Azimuths are measured positively to the east of south, so that our input gives of first heliostat just east of north (i.e., north but in the east half plane). Each circle has two special points:

1) Q-point of first heliostat location

2) P-point dividing heliostats which are spaced irrationally, i.e., where the circle of heliostats closes.

In this study all circles are split by the south road but in principle another input is needed for P-points.

The common group BOUNDX has a new variable IHALF which goes to ROADS where it controls the new half plane layout option.

IHALF = 0 gives whole field layout
1 gives east half field layout
-1 gives west half field layout

The MAIN module contains two new SECTOR outputs which occur just after the call to LAYOUT. The first SECTOR output gives heliostat identification numbers, see figure 1. The second SECTOR output gives heliostat slipage fractions for diagnostic purposes. The user may wish to comment these calls. The slipage fraction output gives the difference of slipage fractions for consecutive heliostats and is not very easy to interpret.

The IH83 version is designed to reduce the CORE requirement for 12,000 heliostats and it does not provide annual performance unless the YEARP subprogram is recompiled with comments removed from statements involving the annual quantities. These comments contain the key word CORE. One other comment occurs in the SECTOR program because of the half field layout option which conflicts with the half field output option (See line 67 involving the JHALF variable).

9.4 Output Examples

The following Zone Summary represents the big field layout which was developed for this study. There are 4487 heliostats in the east half field which is not exactly symmetric to the west half.

ZONAL SUMARY ******** NUMBER OF ZONES = 10

NUMBER OF CIRCLES/ZONES

8	5	5	5	6	7	9	11	12	1

NUMBER OF HELIOSTATS/ZONES

3175.	1701.	1458.	1215.	1215.	1134.	1094.	891.	486.	20.

DECOMPRESSION RATIO/ZONE

1.3158	1.1667	1.1667	1.2000	1.2000	1.2500	1.3333	1.5000	2.0000	2.0000

The last circle is unacceptable and should be eliminated since complete zones are desirable. The first decompression ratio listed is RSYMAX/RSYMIN which is larger than most zone ratios. The zone ratios are

$$(7/6)^2, (6/5)^2, (5/4), (4/3), (3/2), (2/1)^2.$$

The number of zones is one greater than the number of zone ratios.

There are several outputs relating to circles which were described previously.

The heliostat identification number output by SECTOR deserves notice. See figure 1. Heliostat number one is given ID = 1001 where the first 1 is the row number (i.e., for circle #1) and the 001 is number one in circle 1. Hence ID = 22002 is number 2 in circle 22. The sector output divides the field into 24 pie shaped sectors which are numbered clockwise from 6 o'clock (i.e., south). The first 12 sectors do not print because we have excluded the west half field. Sector 13 is just east of north. The circle numbers are given at the left side with letters B, C, or D designating circles B, C, or D having deletes and slips. A-circles are undesignated and have only equi-spaced heliostats. Circle 1 is trimed after heliostat #12. The radial stagger configuration shows very clearly. Horizontal spacing in the print line corresponds to azimuth angle as closely as possible. Hence, the large spacing in the 40th circle corresponds to large azimuthal spacing but not large physical separations on the inner circle. The average spacings in a zone should be nearly the same for all zones.

The **** represent deletes and must occur on C-circles. Each **** output shows a heliostat directly in front of it on the D-circle. The number of heliostats between **** output is the denominator of the zone ratio.

The heliostat slipage fraction output is also provided by SECTOR. This output is given by

FSLIP = -(AZ(IJ) - AZ(IJ-1) + DAZM)/DAZM where

DAZM = average azimuthal spacing in circle, ane

AZ(IJ) = azimuth of heliostat IJ

Several exceptions occur. The first output per circle is invalid because IJ-1 goes to the previous circle (due to half field layout). The first output after **** is constructed by a special formula which uses the location of the delete. However, FSLIP combines the slipage of heliostats IJ and IJ-1. Plus outputs mean expanded separation and minus mean contracted. A-circles have all zeros. This output requires careful study and is used as a diagonistic tool for developing layout strategy.

The heliostat shading and blocking output (i.e., FMIRR) is given for design time (i.e., noon of day 0). This output confirms the general expectations for the layout and if the subfield option was turned off so that the whole field was utilized the total power at design time could be used to confirm system specifications. In this case we have set

IFIELD = 1 to call <u>subfield</u>, and

ANG1 = 1.0,

ANG2 = 0.9,

to limit the calculations to sector having

$$.9\pi < AZ < \pi$$

which covers sectors 13 and part of 14. See figure 2.

SECTOR 13

D 1	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012					
2	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
3	3001	3002	3003	3004	3005	3006	3007	3008	3009	3010	3011	3012	3013	3014	3015	3016	3017
4	4001	4002	4003	4004	4005	4006	4007	4008	4009	4010	4011	4012	4013	4014	4015	4016	4017
5	5001	5002	5003	5004	5005	5006	5007	5008	5009	5010	5011	5012	5013	5014	5015	5016	5017
6	6001	6002	6003	6004	6005	6006	6007	6008	6009	6010	6011	6012	6013	6014	6015	6016	6017
B 7	7001	7002	7003	7004	7005	7006	7007	7008	7009	7010	7011	7012	7013	7014	7015	7016	7017
C 8	****	8001	8002	8003	8004	8005	8006	****	8007	8008	8009	8010	8011	8012	****	8013	8014
D 9	9001	9002	9003	9004	9005	9006	9007	9008	9009	9010	9011	9012	9013	9014			
10	10001	10002	10003	10004	10005	10006	10007	10008	10009	10010	10011	10012	10013	10014			
11	11001	11002	11003	11004	11005	11006	11007	11008	11009	11010	11011	11012	11013	11014			
B12	12001	12002	12003	12004	12005	12006	12007	12008	12009	12010	12011	12012	12013	12014			
C13	****	13001	13002	13003	13004	13005	13006	****	13007	13008	13009	13010	13011	13012			
D14	14001	14002	14003	14004	14005	14006	14007	14008	14009	14010	14011	14012					
15	15001	15002	15003	15004	15005	15006	15007	15008	15009	15010	15011	15012					
16	16001	16002	16003	16004	16005	16006	16007	16008	16009	16010	16011	16012					
B17	17001	17002	17003	17004	17005	17006	17007	17008	17009	17010	17011	17012					
C18	****	18001	18002	18003	18004	18005	****	18006	18007	18008	18009	18010					
D19	19001	19002	19003	19004	19005	19006	19007	19008	19009	19010							
20	20001	20002	20003	20004	20005	20006	20007	20008	20009	20010							
21	21001	21002	21003	21004	21005	21006	21007	21008	21009	21010							
B22	22001	22002	22003	22004	22005	22006	22007	22008	22009	22010							
C23	****	23001	23002	23003	23004	23005	****	23006	23007	23008							
D24	24001	24002	24003	24004	24005	24006	24007	24008	24009								
25	25001	25002	25003	25004	25005	25006	25007	25008									
26	26001	26002	26003	26004	26005	26006	26007	26008	26009								
27	27001	27002	27003	27004	27005	27006	27007	27008									
B28	28001	28002	28003	28004	28005	28006	28007	28008	28009								
C29	29001	29002	29003	29004	****	29005	29006	29007									
D30	30001	30002	30003	30004	30005	30006	30007										
31	31001	31002	31003	31004	31005	31006	31007										
32	32001	32002	32003	32004	32005	32006											
33	33001	33002	33003	33004	33005	33006	33007										
34	34001	34002	34003	34004	34005	34006											
B35	35001	35002	35003	35004	35005	35006	35007										
C36	36001	36002	36003	****	36004	36005											
D37	37001	37002	37003	37004	37005												
38	38001	38002	38003	38004	38005												
39	39001	39002	39003	39004	39005												
40	40001	40002	40003	40004	40005												
41	41001	41002	41003	41004	41005												
42	42001	42002	42003	42004	42005												
43	43001	43002	43003	43004	43005												
B44	44001	44002	44003	44004	44005												
C45	45001	45002	****	45003	45004												
D46	46001	46002	46003														
47	47001	47002	47003														

Figure 9.1 Heliostat Identifiation Numbers

Only one plane occurs. Sectors 1 to 12 are deleted for layouts of east helf field. The circle numbers occur at the left with B, C, D labels. Deletes are indicated by **** when this occur (alwyas in circle C). The first heliostat ID = 1001 (for circle 1 heliostat 001).

SECTOR 12

FMIRR

SECTOR 13

D 1	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000						
2	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
3	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	0999	0999	
4	0982	0982	0982	0983	0983	0983	0983	0983	0984	0984	0984	0984	0985	0985	0984	0984	0984	
5	0977	0954	0955	0955	0955	0955	0955	0955	0955	0956	0956	0956	0957	0957	0957	0958	0958	
6	0841	0950	0947	0932	0932	0947	0954	0842	0947	0943	0933	0933	0949	0958	0844	0945	0951	
B 7	1000	0839	0925	0924	0888	0924	0929	0892	0886	0922	0926	0890	0926	0933	0897	0884	0920	
C 8	****	0880	0914	0916	0916	0917	0883	****	0877	0911	0913	0917	0922	0837	****	0875	0909	
D 9	0985	0872	0903	0972	0907	0875	0972	0869	0901	0973	0911	0879	0975	0867				
10	0945	0945	0945	0945	0945	0945	0945	0946	0946	0946	0947	0947	0948	0948				
11	0917	0946	0938	0923	0924	0933	0950	0936	0943	0940	0925	0926	0940	0954				
B12	0833	0919	0912	0876	0912	0923	0837	0830	0915	0914	0878	0914	0928	0892				
C13	****	0875	0908	0904	0904	0912	0879	****	0872	0905	0907	0905	0917	0884				
D14	0979	0868	0899	0952	0903	0872	0960	0865	0896	0962	0908	0876						
15	0933	0934	0934	0934	0934	0934	0935	0935	0936	0936	0937	0937						
16	0922	0925	0937	0914	0937	0925	0846	0928	0939	0916	0938	0926						
B17	0884	0882	0911	0911	0883	0890	0860	0884	0913	0915	0887	0895						
C18	****	0877	0879	0923	0873	0881	****	0874	0882	0994	0879	0885						
D19	0985	0868	0971	0972	0871	0972	0865	0973	0974	0876								
20	0943	0943	0943	0944	0944	0944	0945	0945	0946	0947								
21	0920	0932	0945	0919	0945	0931	0843	0929	0948	0922								
B22	0887	0886	0915	0916	0887	0874	0883	0883	0911	0920								
C23	****	0873	0881	0985	0882	0882	****	0868	0872	0986								
D24	0994	0870	0982	0990	0875	0989	0868	0987	0986									
25	0959	0952	0959	0960	0960	0961	0962	0962										
26	0965	0931	0931	0932	0932	0933	0933	0934	0935									
27	0932	0903	0908	0932	0861	0934	0910	0911										
B28	0903	0890	0838	0890	0902	0892	0892	0841	0895									
C29	0874	0889	0890	0881	****	0869	0885	0894										
D30	0858	0974	0864	0975	0854	0976	0872											
31	0985	0978	0978	0979	0980	0979	0978											
32	0954	0954	0954	0955	0956	0957												
33	0962	0926	0926	0926	0927	0928	0929											
34	0945	0900	0944	0913	0945	0903												
B35	0879	0891	0896	0875	0864	0887	0903											
C36	0934	0889	0943	****	0927	0892												
D37	0912	0918	0960	0907	0927													
38	0965	0965	0965	0966	0966													
39	0976	0976	0976	0974	0973													
40	0981	0972	0972	0973	0975													
41	0947	0947	0948	0949	0951													

Figure 9.2 Individual Heliostat FMIRR for Design Time

Design time is vernal equinox noon. This output and the slipage output which is not reproduced here verify that the big field layout is working with a wide range of zone ratios.

APPENDIX D

Selected List of University of Houston Solar Central Receiver Documents

* - Items with an asterisk support code delivery

A. REPORTS

* A.18 The University of Houston Solar Central Receiver Code System: Concepts, Updates, and Start-up Kits, C.L. Pitman and L.L. Vant-Hull, Aug., 1988, SAND 88-7029 (SNLA).

* A.17 Course Notes for The University of Houston Solar Central Receiver Codes: Physics and Code Development Methodology, C.L. Pitman and L.L. Vant-Hull, Aug., 1986 (SNLA, Div. 6226, Gregory J. Kolb).

* A.16 Theory of Cellwise Optimization for Solar Central Receiver Systems, F.W. Lipps, May, 1985, SAND 85-8177 (SNLL).

A.15 Receiver Loss Study: Optics of High Temperature Solar Central Receiver Systems, C.L. Pitman and L.L. Vant-Hull, March, 1985, SAND 85-8176 (SNLL).

* A.14 User's Manual for the University of Houston Individual Heliostat Layout and Performance Code, C.L. Laurence and F.W. Lipps, Dec., 1984, SAND 84-8187 (SNLL).

A.13 Atmospheric Transmittance Model for a Solar Beam Propagating Between a Heliostat and a Receiver, C.L. Pitman and L.L. Vant-Hull, Feb., 1984, SAND 83-8177 (SNLL, NTIS).

A.12 Letter Report on Plastic Enclosed Heliostat Study, L. L. Vant-Hull, April 15, 1983 (UH Energy Lab). (Also is section 10 of B.3 below.)

* A.11 Generalized Layout for Collector Field with Broken Planes Including Modifications to the RC-Optimization, CELLAY, and IH-Performance Codes, F.W. Lipps and L.L. Vant-Hull, Dec. 1982, SANDIA Procurement 84-1637 (UH Energy Laboratory).

A.10 Bulletins #1, #2, and #3, Solar Central Receiver Code Documentation Project: Errors and Revisions for 1980 Archive Version of RC and NS Codes, L.L. Vant-Hull, et al., Summer, 1981 (UH Energy Lab).

* A.9 Solar Energy Systems Simulation and Analysis: 5th Quarterly Progress Report on Contract AC03-79-SF10769, L.L. Vant-Hull, January 10, 1981, DOE/SF/10763-T10. DOE/TIC Accession No. DE81026975 (NTIS, DOE/TIC).

* A.8 A User's Manual for the University of Houston Solar Central Receiver - Cellwise Performance Model: NS (Vols. 1 and 2), F.W. Lipps and L.L. Vant-Hull, Dec. 1980, DOE/SF/10763-T9; SAN/0763-4 (NTIS).

* A.7 A User's Manual for the University of Houston Computer Code -RC: Cellwise Optimization, C.L. Laurence and F.W. Lipps, Dec.1980, DOE/SF/10763-T7; SAN/0763-3 (NTIS).

* A.6 A Programmer's Manual for the University of Houston Computer Code, RCELL, F.W. Lipps and L.L. Vant-Hull, Sept., 1980, DOE/SF/10763-T5; SAN/0763-1 (NTIS).

* A.5 A Description of the Capabilities of the Individual Heliostat Code, M.D. Walzel, July, 1980, DOE/SF/10763-T4; SAN/0763-2 (NTIS).

* A.4 Collector Field Optimization Report (RADL item 2-25): Solar Facilities Design Integration, 10 MWe Solar Thermal Central Receiver Pilot Plant, L.L. Vant-Hull, et al., Oct., 1979, revised Jan., 1981. SAN/0499-22 or MDC G8214 (NTIS).

A.3 Solar Energy System Simulation and Analysis: Final Report for the Period May 1, 1978 through April 30, 1979, Task 4.0, L. L. Vant-Hull and F.W. Lipps, April, 1979, DOE Contract EG-77-C-04-3974 (UH Energy Lab).

* A.2 Notes on Collector Field Optimization - Extensions of the Basic Theory, F.W. Lipps, and L.L. Vant-Hull, Nov., 1978, DOE/SF/10763-T6; SAN/0763-5 (NTIS).

A.1 Liquid Metal Cooled Solar Central Receiver Feasibility Study and Heliostat Field Analysis: Final Report - Part II, L.L. Vant-Hull, et al., May, 1978, ORO 5178-78-2 (NTIS).

B. SOLAR THERMAL ADVANCED RESEARCH CENTER REPORTS

B.4 STARC Annual Technical Progress Reports, 1982, 1983, ...,1988, University of Houston Energy Laboratory, Subcontract no. XX-4-04006-7, XX-6-06006-1, and XX-7-07028-1 (SERI, NTIS).

* B.3 System Design Studies for Central Receiver Application 1983: Optical Code Development and Power Tower Studies: Topical Report, F.W. Lipps and L.L. Vant-Hull, Jan, 1984, DOE Contract no. DE-AC03-81SF11557 (UH Energy Lab).

* B.2 Computer Simulation of Shading and Blocking, Discussion of Accuracy and Recommendations, F.W. Lipps, Dec. 1, 1983, DOE Contract no. DE-AC03-81SF11557 (UH Energy Lab).

* B.1 Cavity Design Capability and Incident Flux Density Code for Solar Central Receiver Applications, F.W. Lipps and L. L. Vant-Hull, March, 1983, DOE Contract no. DE-AC03-81SF11557 (UH Energy Lab).

(Includes Appendix: Programmer's Manual for CREAM: Cavity Radiation Exchange Analysis Model, F.W. Lipps, Feb., 1981)

C. CONFERENCE PROCEEDINGS EDITED BY UNIVERSITY OF HOUSTON

C.2 Proc. of Systems Studies for Central Solar Thermal Electric, 1978 DOE Workshop, CONF-780383 (UH Energy Lab, NTIS).

C.1 Proc. of ERDA Solar Workshop on Methods for Optical Analysis of Central Receiver Systems, Aug., 1977, CONF-770850 (UH Energy Lab, NTIS).

D. SYSTEM STUDIES IN WHICH UH PARTICIPATED AND THE UH CODE SYSTEM WAS USED AND DEVELOPED

D.16 Arizona Public Service: Utility Solar Central Receiver Study, Vols. 1 & 2, Arizona Public Service (APS), Black & Veatch Engineers-Architects (BV), Babcock & Wilcox (B&W), Pitt-Des Moines, Inc. (PDM), Solar Power Engineering Co. (SPECO), and University of Houston (UH), Nov. 1988, DOE Report No. DOE/AL/38741-1 (NTIS).

D.15 Alternate Utility Team: Utility Solar Central Receiver Study, Vols. 1 & 2, APS, BV, CBI Industries (CBI), Foster Wheeler Solar Development Corp. (FW), Olin Corp. (Olin), Precision Controls and Instrumentation (PCI), and UH, Sept. 1988, DOE Report No. DOE/AL/38741-2 (NTIS).

D.14 Solar Central Receiver Technology Advancement For Electric Utility Applications: Phase I Topical Report, Vols. 1 & 2, Pacific Gas and Electric Company (PG&E) and Bechtel National, Inc., ed. by P. De Laquil III, B. D. Kelly, & J. C. Egan, prepared for DOE under Cooperative Agreement DE-FC04-86AL38740 and for the Electric Power Research Institute (EPRI) under RP 1978-1, Aug. 1988, PG&E Report No. GM 633022-9 (San Ramon, CA). Equivalently, Bechtel Report No. 007.2-88.2 (San Francisco, CA). Presumably, this report will also be released as DOE Report No. DOE/AL/38741-3 (NTIS).

D.13 Fort Hood Solar Cogeneration Facility Conceptual Design Study, Final Technical Report, R. Dawson, MDAC, Aug. 1981, DOE contract no. DE-AC03-81SF11495. (NTIS, or MDC G9716).

D.12 Solar Repowering System for Texas Electric Service Company Permian Basin Steam Electric Station Unit No. 5, Final Report, Rockwell International (Energy Systems Group), July, 1980, DOE/SF/10607-1 (NTIS).

D.11 Solar Central Receiver Reformer System for Ammonia Plants, Final Report, T. Rozenman, PFR Engineering, July, 1980, DOE/SF/10735-1 (NTIS).

D.10 Solar Central Receiver Hybrid Power Systems Sodium-Cooled Receiver Concept, Final Report (3 vols.), Rockwell International (Energy Systems Group), Jan. 1980, DOE/ET/20567-1 (NTIS).

D.9 Conceptual Design of Advanced Central Receiver Power Systems, Final Technical Report (5 vols.), A. Brower, et al., General Electric Co., June 29, 1979, DOE SAN-20500-1 (NTIS).

D.8 Conceptual Design of Advanced Central Receiver Power Systems Sodium-Cooled Receiver Concept, Final Report (4 vols.), Rockwell International(Energy Systems Group),March 1979, DOE SAN/1483-1.

D.7 Liquid Metal Cooled Solar Central Receiver Feasibility Study and Heliostat Field Analysis: Final Report - Part I, MDAC, et al., Oct., 1977, ORO 5178-78-1 (NTIS).

D.6 Central Receiver Solar Thermal Power System Phase 1: CDRL Item 2, Pilot Plant Preliminary Design Report (7 vols.), R. Hallett and R. Gervais, MDAC, Oct. 1977, DOE SAN/1108-8 (NTIS).

D.5 Solar Thermal Power Systems Based on Optical Transmission, (a feasibility study), Final Report, L.L. Vant-Hull and C.R. Easton Oct. 21, 1975, NSF/RANN/SE/GI-39456/FR/75/3 (NTIS Accession No. PB 253 167/AS).

D.4 Solar Thermal Power Systems Based on Optical Transmission, Technical Report No. 2: Design, Fabrication, and Test of a Heliostat for a Central Receiver Solar Thermal Power Plant, L.L. Vant-Hull and C.R. Easton, Sept., 1975, NSF/RANN/SE/GI-39456/TR/75/2 (NTIS Accession no. PB 252 667/LL).

D.3 Solar Thermal Power Systems Based on Optical Transmission, Technical Report No. 1: Solar Tower Receiver Study, L.L. Vant-Hull and C.R. Easton, Dec., 1974, NSF/RANN/SE/GI-39456/TR/75/2 (NTIS Accession no. PB 253 166/AS).

D.2 Solar Thermal Power Systems Based on Optical Transmission, Progress Report No. 2, L.L. Vant-Hull and C.R. Easton, Dec., 1974, NSF/RANN/SE/GI-39456/PR/74/2 (NTIS Accession no. PB 244 436/AS).

D.1 Solar Thermal Power Systems Based on Optical Transmission, Progress Report No. 1, L.L. Vant-Hull and C.R. Easton, Feb., 1974, NSF/RANN/SE/GI-39456/PR/73/4 (NTIS Accession no. PB 237 005).

E. JOURNAL ARTICLES

E.14 "Performance of Optimized Solar Central Receiver Systems as a Function of Receiver Thermal Loss Per Unit Area," C.L. Pitman and L.L. Vant-Hull, Solar Energy 37, no. 6, pp. 457-468 (1986).

E.13 "Solar Thermal Power", A.F. Hildebrandt, et al., Natural Resources Journal 25, pp. 1095-1157 (Univ. of New Mexico School of Law, Oct., 1985).

E.12 "Instantaneous Flux Distribution on a Solar Central Receiver", L.L. Vant-Hull, J. Solar Energy Engineering 106, pp. 39-43 (ASME, Feb., 1984).

* E.11 "Geometric Configuration Factors for Polygonal Zones Using Nusselt's Unit Sphere", F.W. Lipps, Solar Energy 30, no. 5, pp. 413-419 (1983).

E.10 "A Numerical Approach to the Flux Density Integral for Reflected Sunlight", F.W. Lipps, Solar Energy 24, no. 5, pp. 461-469 (1980).

E.9 "An Analysis of the Terminal Concentrator Concept for Solar Central Receiver Systems", K. Athavaley, F.W. Lipps and L.L. Vant-Hull, Solar Energy 22, no. 6, pp. 493-504 (1979).

* E.8 "An Analytic Evaluation of the Flux Density Due to Sunlight Reflected from a Flat Mirror Having a Polygonal Boundary", F.W. Lipps and M.D. Walzel, Solar Energy 21, no. 2, pp. 113-121 (1978).

E.7 "A Cellwise Method for the Optimization of Large Central Receiver Systems", F.W. Lipps and L.L. Vant-Hull, Solar Energy 20, no. 6, pp. 505-516 (1978).

* E.6 "A Solar Flux Density Calculation for a Solar Tower Concentrator Using a Two-Dimensional Hermite Function Expansion", M.D. Walzel, F.W. Lipps and L.L. Vant-Hull, Solar Energy 19, no. 3, pp. 239-253 (1977).

E.5 "Power with Heliostats", A.F. Hildebrandt and L.L. Vant-Hull, Science 197, no. 4309, pp. 1139-1146 (Sept. 16, 1977).

* E.4 "Four Different Views of the Heliostat Flux Density Integral", F.W. Lipps, Solar Energy 18, no. 6, pp. 555-560 (1976).

E.3 "Contribution of the Solar Aureole to the Measurements of Pyrheliometers", T.H. Jeys and L. L. Vant-Hull, Solar Energy 18, no. 4, pp. 343-348 (1976).

E.2 "Tower-top Focus Solar Energy Collector", A.F. Hildebrandt and L.L. Vant-Hull, Mech. Eng. 96, no. 9, pp. 23-27 (Sept., 1974).

E.1 "Large-Scale Concentration and Conversion of Solar Energy," A.F. Hildebrandt, et al., Trans. Am. Geophys. Union 53, no. 7, pp. 684-692 (July 1972).

F. CONFERENCE PAPERS

F.12 "Central Receiver System Optimization Under An Allowable Flux Constraint", L.L. Vant-Hull and C. L. Pitman, Proc. 4th Int. Symp. on Research, Development and Applications of Solar Thermal Technology, Santa Fe, NM, June, 1988, pp. pending (SERI).

* F.11 "Combined Collector-Receiver Optimization For Central Receiver Systems Using RCELL", F.W. Lipps, et al., Solar Engineering - 1985, Book no. H00320, pp. 309-316 (ASME).

F.10 "Requirements and Availability of Direct Beam Solar Data for the Design and Evaluation of Concentrating Collectors", L.L. Vant-Hull, Proc. of the Fifth Conference on Atmospheric Radiation, Nov., 1983, pp. 330-336. (Boston, MA: Amer. Met. Soc.)

F.9 "Solar One - The 10 MWe Central Receiver Pilot Plant at Barstow, CA", L.L. Vant-Hull and A.F. Hildebrandt, Progress in Solar Energy 5: The Renewable Challenge, CONF-820629, June, 1982, Pt. 1, pp. 361-366 (Boulder, CO.: ASES).

F.8 "Optimization of Heliostat Fields for Solar Tower Systems," L.L. Vant-Hull, Systemes Solaires Thermodynamiques: Proc of International Symposium No. 306, Marseille, June 15-20, 1980, pp. 319-325 (Paris: Centre National de la Recherche Scientifique, ISBN 2-222-02804-3).

* F.7 "Short-term Effect of Cloud Transits on the Barstow Central Receiver Power Plant", C.L. Laurence, Proc. 1980 Annual Meeting ASES, Phoenix, AZ, Conf-800604-P2, 3.1, pp. 586-590 (Boulder, CO: ASES).

F.6 "Methods for Estimating Total Flux in the Direct Solar Beam at Any Time", L.L. Vant-Hull, Proc. 1976 Annual Meeting ASES, Winnipeg, Canada, CONF-760842-P1, pp. 369-375 (Boulder, CO: ASES).

F.5 "Reflection Coefficient for Back-surface Glass Mirror," T. Kent and L.L. Vant-Hull, Proc. 1976 Annual Meeting ASES, Winnipeg, Canada, CONF-760842-P6, pp. 316-324 (Boulder, CO: ASES).

F.4 "A New Method for Collector Field Optimization", M.S. Abdel-Monem, A.F. Hildebrandt, F.W. Lipps and L.L. Vant-Hull, Heliotechnique and Development 1, 1976, CONF-7511131, pp. 372-387 (Cambridge, MA: Development Analysis Associates).

F.3 "Central Receiver Systems for Irrigation Pumping and Cattle Feedmill Applications", F.W. Lipps and A.F. Hildebrandt, Proc. Second Southeastern Conf. on Applications to Solar Energy, Baton Route, LA, April 19-22, 1976, CONF-760423, pp. 430-435.

F.2 "An Analytical Integration of the Solar Flux Density Due to Rectangular Mirrors," F. W. Lipps, 74-WA/SOL-18 of Proc. Winter Annual Meeting ASME, Nov. 1974 (New York, NY: ASME).

F.1 "Shading and Blocking Geometry for a Solar Tower Concentrator with Rectangular Mirrors", F.W. Lipps and L.L. Vant-Hull, 74-WA/SOL-11 of Proc. Winter Annual Meeting ASME, Nov. 1974 (New York, NY: ASME).

G. THESES FROM UNIV. OF HOUSTON SOLAR THERMAL DIVISION

G.6 Effect of High Receiver Thermal Loss Per Unit Area on The Performance of Solar Central Receiver Systems Having Optimum Heliostat Fields and Optimum Receiver Aperture Areas, Charles L. Pitman, Ph.D. Dissertation, Dec., 1983.

G.5 Low-Temperature Study of a Sputtered Metal Film Gas-Supporting Electrode on Beta-Alumina Solid Electrolyte in the Sodium Heat Engine, Arthur K. Detwiler III, Ph.D. Dissertation, Dec., 1983.

G.4 Locating The Sun, Charles L. Pitman, M.S. Thesis, May, 1978.

G.3 Analysis of a Conical Terminal Concentrator, Kumud A. Athavale, M.S. Thesis, August, 1976.

G.2 Solar Power Density Calculations Using Two Dimensional Hermite Polynomials, Michael D. Walzel, M.S. Thesis, May, 1976.

G.1 The Contribution of the Solar Aureole to the Measurements of Pyrheliometers, Thomas H. Jeys, M.S. Thesis, December, 1975.

<u>Abbreviations used in above:</u>

ASES American Solar Energy Society, Boulder, CO 80302.

ASME American Society of Mechanical Engineers, New York, NY 10017.

DOE/TIC U. S. Dept. of Energy, Technical Information Center, Oak Ridge, TN 37831. (Phone: (615) 576-1155)

MDC or
MDAC McDonnell Douglas Astronautics Company, Huntington Beach, CA 92647.

NTIS National Technical Information Service, Springfield, VA 22161. (Phone: (703) 487-4780)

SERI Solar Energy Research Institute, Golden, CO 80401.

SNLA Sandia National Laboratories, Albuquerque, NM 87185.

SNLL Sandia National Laboratories, Livermore, CA 94550.

FIGURE E-1

LOSSES/YR IN MWH/M2 VERSUS DISPLACEMENT FOR CELL (-2 3) OF PLANE < 1 > HAVING ELEV= 12.76 AND AZIM= 123.69
OPTIONS FOR RADIAL ORIENTATION AND STAGER ARRAY LIMITS= 0 ACCURACY= 0.7E-03 LAGRANGIAN PARAMETER= 1.349
INPUTS(4.135 1.641) , OUTPUTS(4.259 1.708) IN DMIR , AND OPTIMUM VARIATIONS(1.030 1.041)

DAILY KWH/M2 AND ANNUAL MWH/M2 PERFORMANCE (NO S&B)
5.887 5.678 5.528 5.069 4.596 3.966 3.457 1.794

* * * * * * * * UNIVERSITY OF HOUSTON

COORD	LOSS FRACTION	TOTAL ENERGY
0.850	0.237 0.152 0.097 0.082	1.368 1.521 1.619 1.646
0.950	0.159 0.085 0.042 0.034	1.508 1.641 1.718 1.733
1.050	0.109 0.046 0.016 0.012	1.598 1.711 1.765 1.772
1.150	0.079 0.029 0.013 0.009	1.651 1.741 1.771 1.777

COORD	LAGRANGIAN ENERGY ("*"s)	TRANSVERSE ENERGY ("O"s)
0.900	0.237 0.730 1.336	-0.0067 0.0076 0.0367
1.000	0.540 1.065 1.578	-0.0153-0.0031 0.0157
1.100	0.806 1.356 1.696	-0.0193-0.0085 0.0002
1.200	0.000 0.000 0.000	0.0000 0.0000 0.0000

******** OPTIMUM LOCATOR ********* : L FOR MECHANICAL LIMITS : O FOR t EQUATION : * FOR f EQUATION : X FOR OPTIMUM

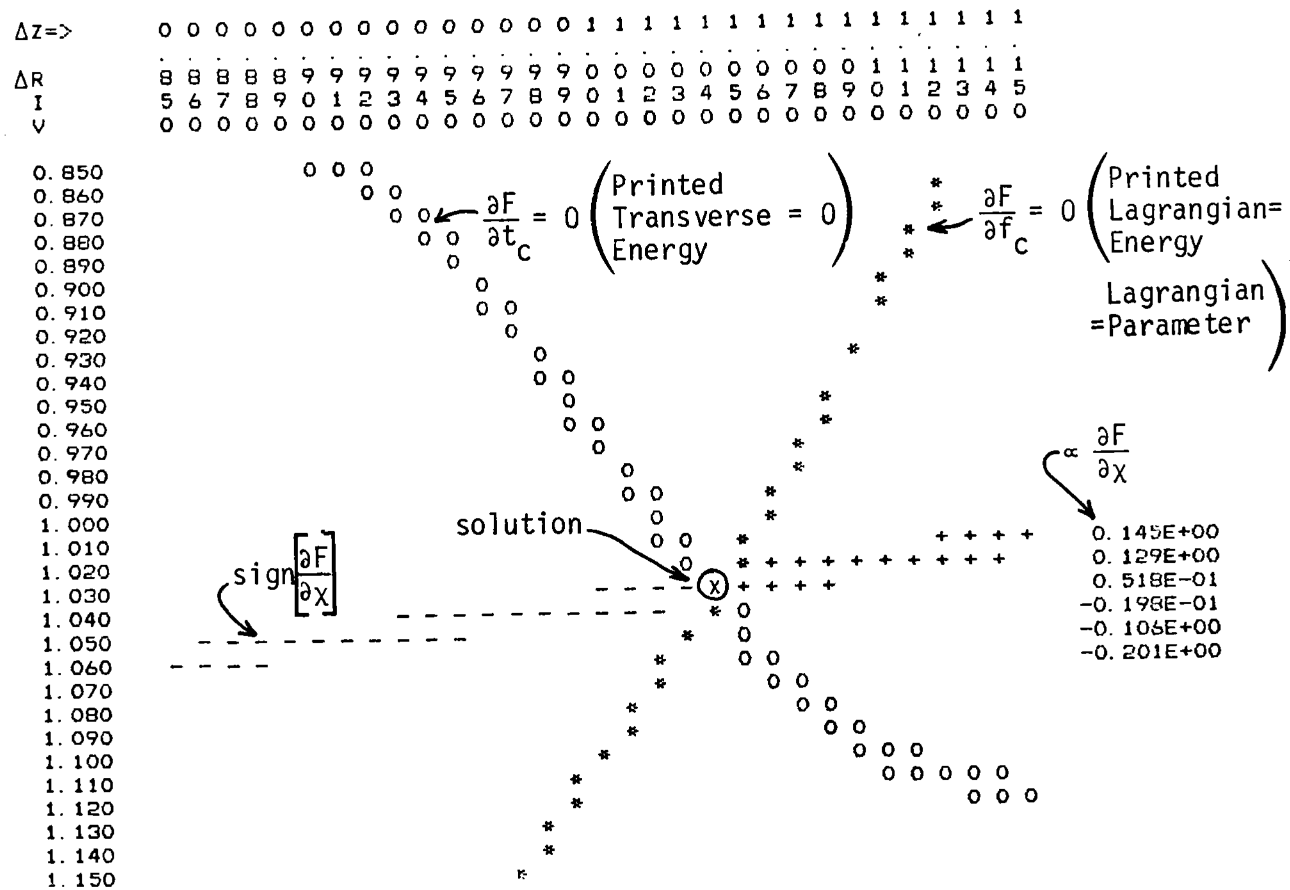

Figure E.-1 A "good" RCELL solution map. See text.

APPENDIX E
RCELL Solution Maps

Figure E.-1 shows a typical RCELL solution map.† The tower is in cell (0,0) in the numbering scheme for these maps, and so the map in Figure E.-1 is for a cell located 2 cells north and 3 cells east of the tower. Before launching into a full description of Figure E.-1, we will first give a rudimentary explanation of what an RCELL solution map is and a qualitative discussion of what its most important features are.

For each computational cell in a heliostat field, RCELL reads data for that cell from an SBC database file. These are the numbers in the top half of Figure E.-1, which display the shading and blocking losses for several variations in radial and azimuthal spacings about the nominal value. RCELL then uses this data to calculate the most cost-effective radial and azimuthal separations for a local heliostat neighborhood at the center of the cell and prints a solution map in order to show graphically the results it obtained. This is the lower half of Figure E.-1.

The solution map shows a curve of "*"s and a curve of "0"s. The meaning of these curves requires a detailed explanation. First, though, you need to get an intuitive feel for what the "*"s and "0"s mean. Two simple yet reasonably equivalent explanations of the "*"s and "0"s are:

> (i) The "*"s correspond to the various ways to obtain the optimal "energy" per m^2 of glass from the cell, based on economics and performance. In this interpretation, the "0"s then correspond to the proper number of square meters of glass to put in the cell, for various nearly-optimal arrangements of the heliostats. Thus, where the "*"s and "0"s cross is the solution; i.e., the heliostat spacings that produce the optimal energy per m^2 and accommodate the maximal glass.
>
> (ii) Alternatively, the "*"s correspond to the most cost-effective number of heliostats to put in a cell, for several radial-stagger arrangements of the heliostats (Figure 2.1-2).

† These solution maps are only printed if IPLONG is set to 1 in the appropriate section of STDRC.

> The "0"s then correspond to the optimal radial-stagger arrangements of the heliostats, for each of several constant numbers of heliostats within the cell. Thus, where the "*"s and "0"s cross is the solution; i.e., the optimal radial-stagger arrangement using the most cost-effective number of heliostats, and thus producing the most cost-effective amount of energy.

Now we give a mathematical explanation of the "*"s and "0"s. Let F denote the **cost-benefit ratio** for the system or, as we usually refer to it, the system **figure of merit.** F is defined as the total cost of the solar plant, including present value of operations and maintenance, divided by the annual thermal energy produced at the base of the tower. (See Section 2.1 for more details.) As the figure of merit will change if the heliostats are rearranged (because a rearrangement will change the amount of shading and blocking), F is a function of the radial and azimuthal spacings of the heliostats in each cell, ΔR_c and ΔZ_c. The most cost-effective radial and azimuthal spacings for the heliostats in each cell will be those for which the cost-benefit ratio (F) is a minimum. As any "well-behaved" function, F will have a local minimum (or perhaps maximum, but this will be checked later) wherever all first partial derivatives of F are zero. If we could somehow find the values of ΔR and ΔZ for each cell† at which all the first partial derivatives of F vanish, then we would have determined the optimum heliostat spacings for our solar plant. RCELL does exactly this and then prints a solution map for each cell so that you can check the solution for acceptability.

The *Theory User's Guide* derives a set of optimization equations, starting with the basic principle that all the first partial derivatives of F vanish at the optimum. For the purposes of our simplified discussion here, we need only be concerned with the results, which are shown on the solution map in Figure E.-1. f_c denotes the fraction of ground covered by reflective surface in cell no. c, (-2,3) in this case. For our present purposes, we may define t_c as a "shape" parameter for the local heliostat neighborhood in cell no. c. As the *Theory User's Guide* shows, f_c and t_c are simply and directly related to the radial and azimuthal spacings of the heliostats,

† Note that we have dropped the c subscripts from ΔR and ΔZ, but they remain implied because spacings are always computed for each of several hundred cells.

ΔR and ΔZ, and so the partial derivatives of F may be taken with respect to them instead of with respect to ΔR and ΔZ. As shown in Figure E.-1, the net results of this analysis are: (i) $\partial F/\partial t_c = 0$ wherever the values of the TRANSVERSE ENERGY matrix (printed in the top half of Figure E.-1) vanish; and (ii) $\partial F/\partial f_c = 0$ wherever the values of the LAGRANGIAN ENERGY matrix are equal to the value of the LAGRANGIAN PARAMETER. The curve of "*"s shows the combination of ΔR and ΔZ for which $\partial F/\partial f_c$ vanishes, and similarly the curve of "0"s shows the combinations of ΔR and ΔZ for which $\partial F/\partial t_c$ vanishes. The solution (marked by an X on the map) occurs at the intersection of these two curves, where both conditions hold simultaneously.

You can check the solution map by estimating the points at which the values of the printed LAGRANGIAN ENERGY matrix equal the LAGRANGIAN PARAMETER (for the curve of "*"s) and similarly the points at which the TRANSVERSE ENERGY equal 0 (for the curve of "0"s). (Note: More details about these matrices will be given later in Appendix E.) In this case, the solution $(\Delta R_s, \Delta Z_s)$ is (1.030,1.041) in the units of the solution map, or (4.259,1.708) in units of mirror "diameters"(i.e., DMIR); see OPTIMUM VARIATIONS and OUTPUTS at the top of Figure E.-1.

RCELL also plots a **circle of signs** through the solution so that you can check that the "X" is in fact a minimum and not a maximum. For a minimum, the signs must be "-" on the left side of the X and "+" on the right side, as in Figure E.-1. The signs are printed at the points of the circle $(\Delta R)^2 + (\Delta Z)^2 = (\Delta R_s)^2 + (\Delta Z_s)^2$ and are the signs of $\partial F/\partial \chi$, where $\chi = \arctan(\Delta Z/\Delta R)$. RCELL also prints scaled values of $\partial F/\partial \chi$ on the right side of the solution map in order to allow a relative estimate of how closely $\partial F/\partial \chi$ approaches zero at the X; this permits an additional check on the adequacy of the solution.

Figure E.-1 is a typical example of a "good" solution map. In general, a "good" solution map will show well-defined curves of "*"s and of "0"s, intersecting at a single point (X) and having "-"s on the left of X and "+"s on the right. OPTIMUM VARIATIONS between 0.90 and 1.10 for both ΔR and ΔZ generally lead to the best solutions because outside of this range (i.e. near the edges of the solution maps) the LAGRANGIAN ENERGY and TRANSVERSE ENERGY matrices

```
LOCATOR  ********* : L FOR MECHANICAL LIMITS : 0 FOR T EQUATION : * FOR F EQUATION

Z=>       0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
          . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
R         8 8 8 8 8 9 9 9 9 9 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1
I         5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
V         0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0.850               0 0 0 0 0 0 0 0                       * *     + +
0.860           0 0 0 0 0 0 0 0 0 0 0 0                 * *   + +
0.870         0 0 0                 0 0 0 0           * * + +
0.880     0 0 0                         0 0 0       * * + +
0.890     0 0                               0 0   * + +
0.900     0                                   0 X +
0.910                                       - - * 0
0.920                                   - - * *   0 0
0.930                               - -   * *       0 0
0.940                           - -     * * *       0 0
0.950                       - -       * * *           0 0
0.960                 - - -         * * *             0 0 0
0.970             - - -           * * *                 0 0
0.980         - -               * * *                   0 0
0.990     - -                 * * *                       0 0
1.000                       * * *                         0 0
1.010                       * * *                         0 0
1.020                     * * *                           0 0
1.030                   * * *                             0 0
1.040                 * * *                             0 0 0
1.050                 * * *                             0 0 0
1.060               * * *                             0 0 0 0
1.070             * * *                             0 0 0 0
1.080             * * *                         0 0 0 0 0
1.090           * * *                     0 0 0 0 0 0
1.100           * * *           0 0 0 0 0 0 0 0 0
1.110     0 0 * * * 0 0 0 0 0 0 0 0 0 0 0
1.120     0 0 * * * 0 0 0 0
1.130       * * *
1.140       * * *
```

Figure E.-2 Finding the Correct Solution. $(\Delta R,\Delta Z)$ coordinates are given in multiplicative form. (1.000,1.000) is the input estimate derived from the heliostat-spacing coefficients in input module FIELD. X marks the solution. 0 marks the points where the t-equation holds and * marks the points where the f-equation holds. In this case, no mechanical limits occur in the "window", but an alternative "solution" occurs in the lower left. The circle of signs is always passed through the solution point. "-" on the left of X and "+" on the right of X verifies that the solution is minimum of the figure of merit F. The "+"s and "-"s refer to the sign of $\partial F/\partial \chi$ and are placed on a circle in the $(\Delta R,\Delta Z)$ plane which is called the circle of signs. (See text.)

must be extrapolated (as opposed to being interpolated when ΔR and ΔZ are within the range 0.90 to 1.10).

RCELL uses quadratic interpolation and extrapolation, and this can lead to other "apparent solutions" at times. See Figure E.-2. Note that RCELL has put the X at the proper one of the two alternatives (in this case and usually, the higher density of reflective surface), as can be seen by examining the circle of signs. Occasionally, RCELL may not select the correct solution from two possible alternatives, and you need to be able to recognize such occurrences and respond appropriately.

If the LAGRANGIAN PARAMETER is greater than (less than) all entries in the LAGRANGIAN ENERGY matrix or if all the entries in the TRANSVERSE ENERGY matrix are positive (negative), then a proper solution cannot be found for that cell. In such cases, RCELL will generate an appropriate default "solution". For example, if the LAGRANGIAN PARAMETER had been 2.000 in Figure E.-1 (instead of 1.349), then RCELL would have returned default OPTIMUM VARIATIONS of (1.15,1.15). If the printout from one of your RCELL runs ever reveals that a significant fraction of the occupied cells (i.e., cells which will actually contain some heliostats) have default "solutions", then you should immediately recognize that this is a RED ALERT condition and that you are abusing your SBC database. In other words: (i) the value of FMI that you are using (FMI is described later in Appendix E) is too far from a "reasonable" value for your current SBC database; or (ii) the interception fractions, and thus the receiver, are too small; or (iii) the centers of the solution maps (ΔR_0,ΔZ_0) are too far away from the solutions you seek and therefore your SBC database needs to be fixed or re-made. (See Section 6.)

An additional default condition exists for cases in which the LOSS FRACTION is essentially independent of ΔR or of ΔZ. This situation occurs when the INPUT ΔR_0 or ΔZ_0 is so large that the rows or columns of heliostats no longer interact. In such a case, even though the LAGRANGIAN PARAMETER may be larger than the maximum LAGRANGIAN ENERGY so that RCELL would normally have returned OPTIMUM VARIATIONS of (1.15,1.15), there is no reason to increase the heliostat spacings. Therefore, the default processor compares the LOSS FRACTION at (ΔR,ΔZ)=(1.15,1.15) with that at (1.05,1.15). If the change is less than 0.004, the process repeats; i.e., the value at (1.05,1.15) is compared to that at (0.95,1.15), and so forth. Whenever the change is greater than 0.004, the larger radial spacing is selected and the processor moves in azimuth; e.g., the value at (1.05,1.15) is compared to that at (1.05,1.05), etc., as above. Thus, an X appearing at a grid point such as (1.05,0.95) without an accompanying curve of "*"s is probably of this default type. This feature of the default processor prevents "runaway solutions" and extreme variations in spacings across the field boundary. In fact, the default "solution" in the above example (i.e., for LAGRANGIAN PARAMETER = 2.000 in Figure E.-1) would actually be (1.05,1.05), and so the default processor would do a very nice job of "migrating" into the region where real solutions are to be found.

Now we will describe some of the details of Figure E.-1. (See Section 6.2 of the *RC User's Guide* and Section 5 of the *5th Quarterly Progress Report* [22] for further details. Of course, the *Theory User's Guide* covers all of the theoretical aspects). ELEV is the receiver elevation angle (in degrees) as seen from the center of the cell. AZIM is the azimuth angle of the cell (from south) as seen from the tower. LIMITS is a mechanical limits code, which need not concern us at present. ACCURACY is an estimate of the accuracy of the solution that RCELL found; an accuracy of less than 0.5E-03 generally indicates a good solution, whereas larger than 0.1E-02 indicates a poor solution and 0.1E13 indicates that no solution could be found. (A default "solution" is returned in the latter case.)

The LAGRANGIAN PARAMETER is the value of the LAGRANGIAN ENERGY which is required of this cell (see Sections 2.1 and 2.2 of the *Theory User's Guide*). The LAGRANGIAN PARAMETER is defined as follows:

$$\text{LAGRANGIAN PARAMETER} = \frac{\langle S \rangle \tilde{\mu}}{\eta_c} = \frac{\langle S \rangle}{\eta_c}\left(\frac{C_h}{F' a \langle S \rangle}\right) = \frac{C_h}{F' a \eta_c} \qquad \text{(E-1)}$$

where

$\langle S \rangle$ = long-term-average annual direct-normal insolation at site (MWH m^{-2}), which is the product of WCFM (from input module FIELD) and the ANNUAL TOTAL DIRECT BEAM INSOLATION, available from the SUNSAM portion of the RCELL printout (if LSUN was set to 0 or 1 in STDRC).

η_c = receiver interception fraction for cell no. c (dimensionless), available from the matrix printout INTERCEPTION FACTORS

FROM RECEIVER PROGRAM INCLUDING ATMOSPHERIC LOSSES.

$\tilde{\mu}$ = cell-matching parameter (dimensionless)μ, defined in the *Theory User's Guide* as the quantity within parentheses above.

C_h = Cost of installed heliostats per m^2, including present value of operations and maintenance (\$ m^{-2})
= CHL + CHOM (from input module HELIOS).

F′ = input estimate of figure of merit F (\$/MWH); the value of this parameter is changed appropriately on subsequent iterations when RCELL is in automatic iteration mode (see Section 4.6).
= FMI (from STDRC).

a = dimensionless product of the following: ABSOR, receiver absorptivity; REFLE, heliostat reflectivity; and three correction factors: OUTAGE, an allowance for heliostats which are out of service; SLIPAG, an allowance for differences between RC and actual IH shading and blocking at Barstow; and, if applicable, SNSHAD, an allowance for heliostat-tracking-sensor shadow.
= FRLOS (from input module RECVER).

For example, if $<S>=2.246$ MWH m^{-2}, $\eta_c=0.712$, C_h=\$94.07 m^{-2}, F′=\$113/MWH, and a=0.8667, then $\tilde{\mu}$ = 0.4276 (dimensionless) and the LAGRANGIAN PARAMETER = 1.349 MWH m^{-2}. You should understand and memorize equation (E-1).

Returning to the details of Figure E.-1, the INPUTS are the values ΔR_0 and ΔZ_0, which RCELL derived from the heliostat-spacing coefficients, COEFX and COEFY, that were input via FIELD when the SBC database was generated. ΔR_0 and ΔZ_0 are in units of DMIR, the characteristic heliostat "diameter", input via HELIOS. All spacings ΔR and ΔZ are scaled to units of ΔR_0 and ΔZ_0 before being plotted on the solution map. For example, the point $(\Delta R_0,\Delta Z_0)$ corresponds to the point (1.000,1.000) on the solution map in Figure E.-1. The solution maps may be thought of as "windows" which show ±15% variations of the input heliostat spacings.

The OUTPUTS are the values ΔR_s and ΔZ_s: the optimum heliostat spacings found for this cell by RCELL. The OPTIMUM VARIATIONS are $(\Delta R_s/\Delta R_0, \Delta Z_s/\Delta Z_0)$ and correspond to the coordinates of the X shown on the solution map.

With this much information, you can interpret the RCELL outputs and solution maps and should be able to use the RCELL code successfully. If you are more dedicated, wishing also to understand what you are doing to the code and what the code is doing to you, then you should also read and understand the remainder of this Appendix.

The next five lines of numbers are taken from the SBC database. The two lines starting with DAILY report the daily energy which an isolated heliostat could redirect, after cosine of incidence losses (but not after reflectivity losses which are factored-in elsewhere), on each day of the seven sample days input via KVEC in RCDRIV (usually days 93, 124, 155, 186, 216, 246, and 276, where day 0 is the vernal equinox) and followed by the annual energy. The annual energy after cos i losses for cell (-2,3), which we will denote S_c, is 1.794 MWH m^{-2} in Figure E.-1.

From this data, you can obtain the annual average cos i for this cell as follows:

$$\langle \cos i_c \rangle \equiv \int \sigma(\tau) \cos i_c(\tau) d\tau \ / \int \sigma(\tau) d\tau = S_c / \langle S \rangle \quad \text{(E-2)}$$

where $\sigma(\tau)$ is the direct-normal insolation at time τ. Thus, as $\langle S \rangle$ = 2.246 MWH m^{-2} for this site, $\langle \cos i_c \rangle = 1.794/2.246 = 0.7988$ (dimensionless). Values of $\langle \cos i_c \rangle$ for every cell are given in the RCELL matrix printout ANNUAL AVERAGE COS I FOR HELIOSTATS, and these values will be in agreement with the values obtained from equation (E-2).

Returning to the details of Figure E.-1, the two sets of sixteen numbers under LOSS FRACTION and under TOTAL ENERGY correspond to sixteen variations of heliostat spacings: i.e., the sixteen combinations of $\{0.85\Delta R_0, 0.95\Delta R_0, 1.05\Delta R_0, 1.15\Delta R_0\}$ and $\{0.85\Delta Z_0, 0.95\Delta Z_0, 1.05\Delta Z_0, 1.15\Delta Z_0\}$. COORD lists the variation for each row (ΔR); for reasons of space, the variations are not printed for the columns (ΔZ), but they are the same; i.e., the leftmost column of the

LOSS FRACTION matrix is 0.85 and the rightmost column is 1.15, and similarly for the TOTAL ENERGY matrix. For each of the sixteen different heliostat spacings considered, the LOSS FRACTION is the fraction of energy lost due to shading and blocking, and the TOTAL ENERGY is the annual energy redirected by this cell after shading, blocking, and cos i losses (but not after reflectivity losses which are factored-in elsewhere). In the language of mathematics, if we denote the annual-average shading, blocking and cos i efficiency for this cell by λ_c (or sometimes by $<\lambda_c>$) and the annual-average shading and blocking efficiency by $<\eta_{sb}>$, then we see that:

$$\text{LOSS FRACTION} \equiv 1 - <\eta_{sb}> \qquad \text{(E-3)}$$

$$\text{TOTAL ENERGY} \equiv \int \sigma(\tau)\eta_{sb}(\tau)\cos i_c(\tau)d\tau \equiv <S>\lambda_c \qquad \text{(E-4)}$$

where

$$<\eta_{sb}> \equiv \int \sigma(\tau)\eta_{sb}(\tau)\cos i_c(\tau)d\tau \ / \int \sigma(\tau)\cos i_c(\tau)d\tau = <S>\lambda_c/S_c \qquad \text{(E-5)}$$

For example, in Figure E.-1 the (0.85,0.85) variation of heliostat spacings gives a TOTAL ENERGY of 1.368 MWH m^{-2}. From equation (E-5), $<\eta_{sb}>$ = 1.368/1.794 = 0.7625, and from equation (E-3), LOSS FRACTION = 0.2375, in agreement with the value given in Figure E.-1. Similarly λ_c = 1.368/2.246 = 0.6091 if $<S>$ = 2.246 MWH m^{-2} (as in the example on the previous page).

When an SBC database is generated, RCELL first calculates the TOTAL ENERGY matrix and then calculates from it the LOSS FRACTION, the LAGRANGIAN ENERGY, and the TRANSVERSE ENERGY matrices. As the calculation of the LAGRANGIAN ENERGY and the TRANSVERSE ENERGY involves taking derivatives numerically, the nine numbers in each of these matrices are defined at the centers of each set of four adjacent numbers in the TOTAL ENERGY matrix, i.e., at the nine combinations of the COORD variations $\{0.90\Delta R_0, 1.00\Delta R_0, 1.10\Delta R_0\}$ and $\{0.90\Delta Z_0, 1.00\Delta Z_0, 1.10\Delta Z_0\}$. (Note: The row of 0.000s, corresponding to a COORD of 1.200, is a convenient printing tactic and has no meaning.)

The LAGRANGIAN ENERGY and TRANSVERSE ENERGY are defined as follows:

$$\text{LAGRANGIAN ENERGY} = \langle S \rangle \left(\lambda_c + f_c \frac{\partial \lambda_c}{\partial f_c} \right) \quad \text{(E-6)}$$

$$\text{TRANSVERSE ENERGY} = \langle S \rangle \frac{\partial \lambda_c}{\partial t_c} - \varepsilon_2 \left(\frac{\langle S \rangle \tilde{\mu}}{\eta_c} \right) \quad \text{(E-7)}$$

where

f_c = fraction of ground covered by reflecting surface in cell no. c.
$\propto 1/((\Delta R) \cdot (\Delta Z))$.

t_c = a "shape" parameter for the local heliostat neighborhood in cell no. c and called the ORTHOGONAL PARAMETER on the RCELL printout.
$= ((\Delta R)^2 - (\Delta Z)^2)/2$.

ε_2 = a small perturbation caused by costs of land, wire, and heliostat washing. (In Section 2.2 of the *Theory User's Guide*, ε_2 is denoted by $\partial_{t_c}\Gamma$.)

The curve of "*"s shown on the solution map in Figure E.-1 is the f-equation (i.e., $\partial F/\partial f_c = 0$) and the curve of "0"s is the t-equation (i.e., $\partial F/\partial t_c = 0$). In Section 2.2 of the *Theory User's Guide* , it is shown that these optimization equations can be written, respectively, as:

$$\eta_c \left(\lambda_c + f_c \frac{\partial \lambda_c}{\partial f_c} \right) = \tilde{\mu} (1 + \varepsilon_1) \quad \text{(E-8)}$$

$$\frac{\partial \lambda_c}{\partial t_c} = \frac{\tilde{\mu} \varepsilon_2}{\eta_c} \quad \text{(E-9)}$$

(Note: $(1+\varepsilon_1)$ is denoted by $\partial_{f_c}\Gamma$ in the *Theory User's Guide*, where ε_1, like ε_2, is a small perturbation caused by costs of land, wire, and heliostat washing).

Comparing equations (E-6) through (E-9) and using equation (E-1), we find that the optimization equations may be written as:

$$\text{LAGRANGIAN ENERGY}/(1+\varepsilon_1) = \text{LAGRANGIAN PARAMETER} \quad \text{(E-10)}$$

$$\text{TRANSVERSE ENERGY} = 0 \quad \text{(E-11)}$$

NOTE: For simplicity of presentation, the perturbation term $(1+\varepsilon_1)$, is not shown in the labelling of Figure E.-1 (but was included when RCELL plotted the curve of "*"s).

You can verify that RCELL plotted the curves of "*"s and "0"s correctly by using equations (E-10) and (E-11) to draw the curves through the LAGRANGIAN ENERGY matrix and the TRANSVERSE ENERGY matrix. (The perturbative term ε_1 is small and may be neglected for this check.) As discussed in the introduction to Appendix E, the solution for the optimum heliostat spacings occurs at the intersection of the curve of "*"s and the curve of "0"s.

Finally, we should mention, if only in the sketchiest terms, that RCELL finds the minimum of F by an iterative approach in which it examines each cell c independently; it then cycles through all the cells again, as often as necessary (either automatically or by repeated RCELL runs), until an appropriate stopping condition is met. It is this iteration, i.e. cycling, which "connects" the "solutions" in the individual cells to the solution for the entire field. The stopping condition depends on the type of optimum requested. For a constrained optimum, the stopping condition is that the system produce the required design-point thermal power P_0 or alternatively the required annual thermal energy E_0. (Note: See ECON in Section 4.6 for more details. Additional constraints such as receiver peak flux limits complicate the process. See Section 4.10.) For an unconstrained optimum, the stopping condition is that the value of FMI converge to the output value of FSTAR. (Notes: (i) For our purposes here, FMI (also called FIN) may be roughly defined as an input estimate of the figure of merit F. See the *Theory User's Guide* for more details and for the definition of FSTAR. (ii) The values of P, E, FIN, and FSTAR are given on the summary page of the RCELL printout, and so you can easily check to see that the appropriate stopping condition is met.)

APPENDIX E

More details of the RCELL solution maps can be found in Section 5 of the *Fifth Quarterly Progress Report* [22]. The *Theory User's Guide* provides an in-depth discussion and derivation of the equations upon which RCELL is built.

APPENDIX F
Default Input Modules

APPENDIX F

APPENDIX F.1
Default Input Module: HELIOS_RND_NTH_PLANT.FOR1

```
      SUBROUTINE HELIOS(HT)
C                                ****** 1600FT2 ROUND HELIOS ******
      COMMON /DUMCOP/ HTC,IRCVRC,FCANTC,FUSEGC,FVSEGC,
     &                CTOWRC,CRECVC,CVPLMC,CFPMPC,CTTOWC,TOWOMC,
     &                RECOMC,VPOMC,FPOMC,TOTOMC,FPARAC
C
      COMMON /VERTX/ BU(18),BV(18),ICORN
      COMMON /SUNX/ ALPHAL,R2,R4,R6,IROUND
C
      COMMON /HELIX/ USEG,VSEG,ASEG,NSEG,NREV,SIGMA,
     &               SUFLAT(32),SVFLAT(32)
C
CONSTANTS FOR SPLIT-RECT-HELIOSTAT SHADING AND BLOCKING GEOMETRY
      COMMON /HELI2/ UMIR,VMIR,SLOT
C
CONSTANTS FOR HELIOSTAT CHARACTERISTICS
      COMMON /HELIO/ NGON,IAXIS,RH,WH,DMIR,DMECH,HGLASS,FMIN,CHL,CHOM,
     &               FCANT,FUSEG,FVSEG,ISR,SRM,THELI
C    * * * * *  COST FACTORS * * * * *
C
      COMMON/COST/ FMI,CEI,CFIXD,CL,CLOM,CW(2),CWP(2),CWR(2),
     &             CWA(2),IMODU
C
      COMMON/PVGRP/FLIFE,PRICE,ETAEL,FPV,CHPR
C
      DATA INIT/0/
      DATA PI/3.14159265/
C
C*C==== SELECTION OF ROUND OR RECTANGULAR HELIOSTAT ============C*C
C*    COMMON /SUNX/ ALPHAL,R2,R4,R6,IROUND
      IROUND = 1
C                                  * 0 SPLIT-RECTANGULAR HELIOSTAT
C                                  * 1 FOR  ROUND  HELIOSTAT (SET
C                                            NSEG=1     AND
C                                          ASEG=HGLASS=PI*RH**2)
C*C======================================================C*C
C
      ICORN = 1
C                          * ICORN CURRENTLY NOT USED FOR:
C                            NUMBER OF VERTICES OF POLYGONAL HELIOSTAT
C                            FOR SAB. CURRENTLY, HELIO MUST BE EITHER
C                            ROUND OR SPLIT-RECTANGULAR.
C
C                      * ICORN CURRENTLY USED ONLY FOR VIS RANGE MODEL
C                        SELECTION. ICORN .GE. 0 FOR UH MODEL.
C                                   ICORN .LT. 0 FOR DELSOL MODEL.
      IF(ICORN .LT. 0) THEN
      DO 20 I = 1,18
      WRITE(6,25)
```

```
   25 FORMAT(1X,'WARNING: DELSOL VISUAL RANGE MODEL. DELSOL VISUAL',
     & ' RANGE MODEL. DELSOL VISUAL RANGE MODEL. DELSOL VISUAL',
     & ' RANGE MODEL.')
   20 CONTINUE
      END IF
C
C
C*    COMMON /HELIX/ USEG,VSEG,ASEG,NSEG,NREV,SIGMA,
C*   &               SUFLAT(32),SVFLAT(32)
C
C ******** CENTER OF SEGMENTS FOR SPLIT-RECT-HELIOSTAT
      DATA SUFLAT /32*0.0000/
      DATA SVFLAT /32*0.0000/
C
      NSEG = 1
C                              * NUMBER OF SEGMENTS.
C                                =1 FOR ROUND HELIOSTATS.
      USEG = 0.0
C                              * WIDTH OF SEGMENT IN METERS (U DIRECTION)
      VSEG = 0.0
C                              * WIDTH OF SEGMENT IN METERS (V DIRECTION)
      RH = 0.3048 * SQRT(1600.0 / PI)
C                              * RADIUS OF CIRCULAR HELIOSTAT IN METERS
      ASEG = PI * RH*RH
C                              * AREA OF ROUND HELIOSTAT IN METERS**2
      SIGMA= .00250
C                              * RMS DEGRADING CONSTANT IN RADIANS
C                            (USED FOR IMAGE GENERATION ONLY)
C
C
CONSTANTS FOR SPLIT-RECT-HELIOSTAT SHADING AND BLOCKING GEOMETRY
C*    COMMON /HELI2/ UMIR,VMIR,SLOT
      UMIR = 0.0
C                             *WIDTH OF HELIOSTAT IN U-DIRECTION
      VMIR = 0.0
C                             *WIDTH OF HELIOSTAT IN V-DIRECTION
      SLOT = 0.0
C                             *WIDTH OF SLOT FOR SPLIT HELIOSTAT
C
C
C
CONSTANTS FOR HELIOSTAT CHARACTERISTICS
C*    COMMON /HELIO/ NGON,IAXIS,RH,WH,DMIR,DMECH,HGLASS,FMIN,CHL,CHOM,
C*   &               FCANT,FUSEG,FVSEG,ISR,SRM,THELI
      NGON = 0
C                            *NUMBER OF SIDES OF HELIOSTAT FOR SAB
      IAXIS = 1
C                            *INDEX OF MOUNTING SYSTEM
C                           ( 1 GIVES ALT-AZIMUTHAL )
C                           ( 2 GIVES RADIAL PITCH-ROLL )
C                           ( 3 GIVES AZIMUTHAL PITCH-ROLL )
C                           ( 4 GIVES POLAR AXIS )
C                           ( 5 GIVES RECEIVER ORIENTED AXIS )
C
C
C
      RING = 3.0 * 0.0254
C                      * THICKNESS OF NON-REFLECTING RING ON OUTER EDGE
```

```
C                        OF HELIOSTAT
C
      DMIR = 2.0 * (RH + RING)
C  DMIR = OCCLUDING DIAMETER OF HELIOSTAT IN METERS - USED FOR SCALING
C       AND S&B.
C   ***======*** WARNING: DMIR MUST BE .GE. 2.0*RH ***======***
C
      DMECH = 1.0 + (0.3 + 4.0*0.0254)/DMIR
C                                 *MECHANICAL LIMIT IN DMIR UNITS
      HGLASS = NSEG*ASEG
C  TOTAL AREA OF REFLECTIVE SURFACE IN SQ METERS
C                                 * AREA = 148.6M2 OR 1600FT2
C
C   * * * * *  COST FACTORS * * * * *
C
C*    COMMON/COST/ FMI,CEI,CFIXD,CL,CLOM,CW(2),CWP(2),CWR(2),
C*   &             CWA(2),IMODU
      FLIFE = 13.06
C                                            * FINANCIAL LIFE IN YEARS
C                                              (PRESENT VALUE FACTOR)
C                                             6.5 % REAL INT ==> 13.06
      CHL   = (75.00 - 1.70 - 3.46)*(CEI/320.0)
C                                           * HELIO COST IN $/M2
      CHOM = (1.32*FLIFE)*(CEI/325.3)  + 3.46*(CEI/320.)
C                                           * HELIO PV OF O & M COST IN $/M2
C                                             (INCLUDES 1 REFLECTOR REPLACEMENT
C                                              AT $8.90/M2)
C
C*    COMMON/PVGRP/FLIFE,PRICE,ETAEL,FPV,CHPR
      PRICE = .05E3/316.9*CEI
C                                           * COST OF ELECT IN $/MWH
      ETAEL = 0.3819
C                                           * EFFICIENCY OF CONVERSION TO ELECT
      FPV    = FLIFE * PRICE
C                                           * PRESENT VALUE FOR ELECT. PARASITICS
      CHPR   = 200.E-6
C                                           * PARASITIC POWER PER HELIOSTAT
C                                             100 W FAN + 100 W DRIVE POWER
      CHPR   = CHPR*3737./HGLASS
C                                           * HELIOSTAT PARASITICS IN MWHE/M2
C                                             (MULTIPLY BY HOURS OF OPERATION
C                                              AND DIVIDE BY REFLECTIVE AREA OF
C                                              A HELIOSTAT)
C
C     CEI IS "COST ESCALATION INDEX". SEE SUBROUTINE FIELD.
C      218.8 = 1978, 238.7 = 1979, 261.2 = 1980
C      297.  = 1981, 314.  = 1982, 316.9 = 1983
C      322.7 = 1984, 325.3 = 1985, 320.  = 1986
C
      ISR = 4
C                                          * CANT OR FOCUS CONTROL
C
C  =0 USE GIVEN VALUES FCANT, FUSEG, FVSEG FOR WHOLE FIELD
C  =1 CANT ONLY TO SLANT RANGE(SR)
C  =2 CANT TO SR AND FOCUS U DIR OF SEGMENTS TO SR
C  =3 CANT TO SR AND FOCUS V DIR OF SEGMENTS TO SR
C  =4 CANT TO SR AND FOCUS U AND V DIR OF SEG TO SR
C  =5 FOCUS ONLY  U DIR OF SEGMENTS TO SR, CANT TO FCANT
```

```
C   =6 FOCUS ONLY  V DIR OF SEGMENTS TO SR, CANT TO FCANT
C   =7 FOCUS U AND V DIR OF SEGMENTS TO SLANT RANGE, CANT TO FCANT
C   =8 TO CALL ENTRY FOCUS
C
C   IF FCANT, FUSEG, OR FVSEG IS A MULTIPLE OF TOWER HEIGHT,
C   THEN INPUT MODULE FIELD MUST BE CALLED BEFORE HELIOS.
C   IF HELIOSTAT IS FLAT, SET FUSEG AND FVSEG = 1.0E10.
C
      FCANT = 1.0E10
C                                * CANT FOCAL DISTANCE - METERS
      FUSEG = 8.0 * HT
C                                * FOCAL LENGTH SEGEMENT HORIZ DIR
      FVSEG = FUSEG
C                                * FOCAL LENGTH SEGMENT VERT DIR
C                                (ONE ASSUMES THAT FUSEG=FVSEG FOR MEM. HEL.)
      SRM = 1.2
C                                * MULTIPLIER FOR SLANT RANGE CANT AND
C                                  FOCUS FOR CANTING/FOCUSING TO SR*SRM
      FMIN =  SRM * (2.0*HT)
C                                * MINIMUM FOCAL LENGTH FOR SLANT RANGE CANT
C                                  & FOCUS. (I.E., FOR FOCAL LENGTH=SR*SRM,
C                                  THEN ALSO FOCAL LENGTH .GE. FMIN.)
C                                  IF NO LIMIT SET TO 0.00. FMIN IS NOT ACTIVE
C                                  IF ISR=1; ALSO NOT ACTIVE IF ISR=8, UNLESS
C                                  CODED IN ENTRY FOCUS.
C
C
      RETURN
C
      ENTRY FOCUS(SRX,FCANTX,FUSEGX,FVSEGX,HT)
      HTX = HT
C
      FUSEGX = 2.000*HTX
      IF( SRX.LT.3.000*HTX ) GOTO 1000
      FUSEGX = 4.000*HTX
      IF( SRX.LT.6.000*HTX ) GOTO 1000
      FUSEGX = 7.500*HTX
      IF( SRX.LT.9.000*HTX ) GOTO 1000
      FUSEGX = 10.0*HTX
C
 1000 FCANTX = 1.0E10
      FVSEGX = FUSEGX
C
      IF(INIT .EQ. 0) GO TO 1002
      WRITE(6,1001) SRX,FCANTX,FUSEGX,FVSEGX
 1001 FORMAT(56X,'FOCUS ==> SR,FCANT,FUSEG,FVSEG=',4E10.3)
C
 1002 INIT = 1
C
      FCANTC = FCANTX
      FUSEGC = FUSEGX
      FVSEGC = FVSEGX
C
      RETURN
C
      END
```

APPENDIX F.2
Default Input Module:
RECVER_CYLN_DEF.FOR1

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CC                                                                CC
C      STANDARD INPUT MODULE FOR CYLNDRICAL RECEIVERS             CC
CC                                                                CC
      SUBROUTINE RECVER(IGREC,JGREC,HT,IRCVR)
CC                                                                CC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

      DIMENSION SR(ID,JD),COSR(ID,JD),FINT(ID,JD)
C
      COMMON /DUMCOP/ HTC,IRCVRC,FCANTC,FUSEGC,FVSEGC,
     &                CTOWRC,CRECVC,CVPLMC,CFPMPC,CTTOWC,TOWOMC,
     &                RECOMC,VPOMC,FPOMC,TOTOMC,FPARAC


CC===================================================================C
CONSTANTS FOR DEFAULT FINTS - NOT CURRENTLY USED.
CC-------------------------------------------------------------------
      COMMON /FINT/ COFNT(8)
C
      COMMON /TOWER/ ICYLN,HCYLNT,WCYLNT,HCYLN,WCYLN,OFSET,REFLT,ABSOR,
     &               FRLOS,NPANLS,INODE1,INODE2,JNODE1,JNODE2
C
      COMMON /XLOSS/ KPANL,PREPAN,BLOSS,HLOSS,BOILER,HEATER,SOLARX

CC=================================================================C
C - RECEIVER DATA FOR RECEIVER PERFORMANCE SUBROUTINE-
CC-----------------------------------------------------------------
      COMMON /CAIM/WTFLXN(9),WTFLXS(9),WTFLUX(9)
C
      COMMON /RECVR/ YUP,YDN,XLF,XRT,IAIMS,LUPSD,ITAIM,ANGREC,
     &               APERHT,APERWD,KSHAPE,IAPER,RAREA,NVERI,
     &               ALPHA,NODES,WING,AWING,JWING,NDAYA,IHORA
C
C        VARIABLES FOR APERTURE STUDY.
      COMMON/APST/AORX,AORY,DSPLAC(3),FCELLV
C
      COMMON/FDATA/HZERO,AZERO,RHOA,RHOH,INDXA,INDXH,INODEF
     &            ,RHRW,THRW,APAI(11),AELI(11),BELI(11)
C
      COMMON /SUNX/  ALPHAL,R2,R4,R6,IROUND
      COMMON /HELIX/ USEG,VSEG,ASEG,NSEG,NREV,SIGMA,
     &               SUFLAT(32),SVFLAT(32)
      COMMON /HELIO/ NGON,IAXIS,RH,WH,DMIR,DMECH,HGLASS,FMIN,CHL,CHOM,
     &               FCANT,FUSEG,FVSEG,ISR,SRM,THELI
      COMMON /COST/ FMI,CEI,CFIXD,CL,CLOM,CW(2),CWP(2),CWR(2),
     &              CWA(2),ITMODU
      COMMON/PVGRP/FLIFE PRICE,ETAEL,FPV,CHPR
CC=================================================================
```

```
      ICYLN = 1
C                          * >0 CALLS CYLN(IMAGE CODE) AND
C                          <0 CALLS FRECVR(READS NODE FILE)
C                         1 FOR CYLINDRICAL RECEIVER CALC
C                        -1 FOR CYLINDRICAL RECEIVER OUTPUT FROM NODES
C                         2 FOR FLAT PANEL RECEIVER CALC
C                        -2 FOR FLAT PANEL RECEIVER OUTPUT FROM NODES
C                         3 FOR CAVITY RECEIVER CALC - CAVITY
C                           CAVITY GEOMETRY IS READ FROM FC 10
C                        -3 FOR CAVITY RECEIVER OUTPUT FROM NODES
      IRCVR = +1
C                          (IRCVR COMMENTS NEED IMPROVEMENT)
C                         * IRCVR PERTAINS TO NS AND IH ONLY.
C                           0= NO RECEIVER CALLS
C                          -1= ANNUAL OR FRECVR OUTPUTS FOR CAVITY
C                              NODE FILE REQUIRED BUT NOT VISFACS
C                           1= YES, CALL RECEIVER SUBROUTINES
C                              VISFACTOR CALC STARTS AT ZONE=JNODE1
C                           2= WRITES ZEROES INTO VISFACTOR FILE
CC=====================================================================
CX1
      INODE1 =  1
C                           *LOOP PARAMETERS TO CONTROL RECEIVER NODES
      INODE2 =  22
C                           *IN THE VERTICAL DIRECTION - FOR RCFINT&RCFLUX
C                            (IGREC IN NS/RCDRIV MUST ACCOMODATE INODE)
      JNODE1 =  1
C                           *LOOP PARAMETERS FOR AZIMUTHAL OR HORIZONTAL
      JNODE2 =  40
C                           *DIRECTION (USUALLY JNODE2= NO. OF PANELS)
C                            (JGREC IN NS/RCDRIV MUST ACCOMODATE JNODE)
      NPANLS = JNODE2-JNODE1+1
C                                  *NUMBER PANELS (OR COLUMNS) RECEIVER
CC=====================================================================
CX2
      HT = 247.5
      HTC = HT
C                            * FOCAL HEIGHT OF RECEIVER IN METERS
CX3
      HCYLNT = 28.4
C                           * MAX HEIGHT OF RECEIVER
      HCYLN = HCYLNT*(INODE2-INODE1+1)/FLOAT(IGREC)
C                                                        *HEIGHT OF RECVR
CX4
      WCYLNT = 22.7
C                        **** WCYLNT = DIAMETER
C                           * MAX WIDTH  OF RECEIVER
      IF (IABS(ICYLN) .EQ. 1)WCYLN = WCYLNT
C
      OFSET = 0.0
C                           * OFSET SHOULD ALWAYS BE 0.0
      OUTAGE = .98
C                           *PERCENT HELIOSTATS NOT ACTIVE
CX5
      HGLASX = 148.64
C                           * NOMINAL REFLECTIVE AREA OF HELIOSTAT.
C                             (NEEDED FOR SCALING OF SLIPAG ONLY).
```

```
      SLIPAG = 1.0 - 0.03*(76./HT)*((HGLASX/47.38)**0.5)
C                              * PERFORMANCE EFFICIENCY LOST BY LAYOUT
C                              INCLUDING CORRECTION FOR ACTUAL IH S&B
C                              AT SOLAR ONE. FOR ESTIMATE, USE
C                              SLIPAG = 1.0 - 0.03*(76./HT)*((A/47.38)**0.5)
C                              WHERE HT IS TYPICAL FOR SYSTEM UNDER
C                              STUDY AND A IS REFLECTIVE AREA OF A
C                              HELIOSTAT = NSEG*ASEG. (A = 148.64)
      REFLE = .94*.968
C                              *REFLECTIVITY AND DUST = 0.91
      SNSHAD= 1.0
C                              *SENSOR SHADOW, 1.0 OR .98
      REFLT = REFLE*OUTAGE*SLIPAG*SNSHAD
      ABSOR = .92
C                                 *RECEIVER ABSORPTIVITY - NOT INCLUDING
C                               ANGULAR DEPENDANT EFFECT - SEE CYLN.
C                                          *** ESTIMATES ***
C                               .92 LIFE AVG FOR ALL EXTERNAL(.96 NEW)
C                               .97 LIFE AVG FOR A DEEP CAVITY
C                               .94 LIFE AVG FOR A SHALLOW CAVITY
      FRLOS = ABSOR*REFLT
      RAREA = HCYLN*WCYLN
C                                 *AREA OF RECEIVER IN M2
      IF(IABS(ICYLN) .EQ. 1)
     &   RAREA = 3.14159265 * RAREA * FLOAT(NPANLS) / FLOAT(JGREC)
C
C
C*    COMMON /XLOSS/ KPANL,PREPAN,BLOSS,HLOSS,BOILER,HEATER,SOLARX
      KPANL = 0
C                         * CONTROL TO LOOP OVER RCEIVER LOSSES.
C                         = 0  FOR NO LOOP. CONSULT UH IF WISH TO
C                              USE LOOP OVER LOSSES.
C
C
      PREPAN = 0.
C                              *HALF NUMBER OF PRE-HEAT PANELS
      BLOSS = 30.1
C                            *KW/M2 RAD.&CONV. LOSSES FOR BOILER PANELS
C                            OR FOR AN APERTURED FLAT
      HLOSS  = 20.00
C                         *KW/M2 RAD.&CONV. LOSSES FOR PRE-HEAT PANELS
      APAN   = RAREA / NPANLS
C                                            *AREA PER PANEL
      BOILER = BLOSS*APAN * 1000.
C                                            *W/PANEL LOSS FOR BOILER PANELS
      HEATER = HLOSS*APAN * 1000.
C                                            *W/PANEL LOSS FOR HEATER PANELS
      SOLARX =     950.
C                                            *WATTS/M2 FOR STANDARD SUN OUTPUTS
C

CC=============================================================C
C - RECEIVER DATA FOR RECEIVER PERFORMANCE SUBROUTINE-
C*    COMMON /CAIM/WTFLXN(9),WTFLXS(9),WTFLUX(9)
CC-------------------------------------------------------------
CX6
      DATA WTFLXN/0.333,0.343,0.123,0.098,0.103,4*.000/
C*C            ABOVE WEIGHTS FOR SF WU AR1.25 - NORTH FIELD
```

```
      DATA WTFLXS/0.235,0.375,0.22,0.08,0.09,4*.000/
C*C            ABOVE WEIGHTS FOR SF WU AR1.25 - SOUTH FIELD
C*C
C                        WTFLUX WEIGHT FACTORS ARE APPLIED TO FLUX.
C                        SUM OF FACTORS (FOR NO. OF AIMS) MUST BE 1.
C                        FOR 2 PT. AIM THE ORDER OF FACTORS IS UP,DOWN.
C                        FOR 3 PT. AIM THE MIDDLE WT IS LAST. FOR
C                        CYLINDERS, THE POSSIBLE AIMS ARE AS SHOWN:
C
C                                             1          1
C                                  1                     4
C                        1                    3          3
C                                  2                     5
C                                             2          2
C
C*    COMMON /RECVR/ YUP,YDN,XLF,XRT,IAIMS,LUPSD,ITAIM,ANGREC,
C*   &               APERHT,APERWD,KSHAPE,IAPER,RAREA,NVERI,
C*   &               ALPHA,NODES,WING,AWING,JWING,NDAYA,IHORA
C
C*C      SWF = WTFLUX(1)+WTFLUX(2)+WTFLUX(4)+WTFLUX(5)
C*C      WTFLUX(3) = 1.00000000 - SWF
C
      YUP   =  .9
C                           * FRACTION OF IMAGE RADIUS USED FOR (HI) HI-LO
C                             SMALLER FRACTIONS GIVE LARGER SHIFTS AND
C                             MORE SPILLAGE.
      YDN   =  .9
C                           * FRACTION OF IMAGE RADIUS USED FOR (LO) HI-LO
      XLF   =  .9
C                           * FRACTION OF IMAGE RADIUS USED FOR SHIFT LEFT
      XRT   =  .9
C                           * FRACTION OF IMAGE RADIUS USED FOR SHIFT RIGHT
CX7
      IAIMS = 5
C                            * NUMBER OF AIM POINTS
      LUPSD = 1
C                            * 1 TO SHIFT VERTICALLY, 0 HORIZONTALLY
C (** 0 FOR FLAT RECEIVERS ONLY.**    LUPSD EFFECTIVE IF IAIMS = 2 OR 3.)
      ITAIM = 1
C                            * 1 COMPUTES AIMS BUT DOES NOT WRITE
C                                THEM TO FILE 09
C                            * 2 READ FILE 09 FOR AIMS (SHIFTS)
C                            * 3 COMPUTE AIMS AND WRITE THEM TO FILE 09
C
C                            * -1,-2,-3, SAME AS ABOVE EXCEPT BYPASSES
C                              IMAGE GENERATORS, HERMIT OR FLASH. USE
C                              ONLY FCELL=0.0 WITH ITAIM=-1,-2,-3.(SEE
C                              INPUT MODULE FIELD FOR DEF. OF FCELL.)
      IAPER = 0
C                           * 0 FOR NO APERTURE. ANGLE OF INCIDENCE
C                             LOSSES ARE ASSUMED FOR RECEIVER.
C                             (FOR CYLINDERS, IAPER MUST BE 0.)
  600 CONTINUE
C  **600 NVERI = 4**         ** THIS SWITCH NOW SET IN STDRC AND STDNS**
C                            * HEADER VERIFICATION CONTROL
C                           =0 ALL VERIFICATION OFF
C                           =1 TURN OFF NODE FILE ONLY
C                           =2 TURN OFF SBC FILE ONLY
```

```
C                            =3 TURN OFF SUN FILE ONLY
C                            =4 TURN ON ALL HEADER VERIFICATION
C
C*     COMMON/FDATA/HZERO,AZERO,RHOA,RHOH,INDXA,INDXH,INODEF
C*    &            ,RHRW,THRW,APAI(11),AELI(11),BELI(11)
C             FDATA RELEVANT IF INODEF NOT 0

CX11
       INODEF = 0
C                           * DEFAULT IS 0 FOR NODE FILE OPERATION
C                                  IS 1 FOR FINT FILES FOR GOPT
C                                  IS -1 FOR GOPT RE-START
       IF (INODEF .EQ. 0) GOTO 300
C
       IRHRW = 2
C                             * SELECTS METHOD FOR CALC. REC. DIM'S.
C                               = 1  RHRW GIVEN
C                               = 2  WCYLNT GIVEN
C                               = 3  HCYLNT GIVEN
C
       GO TO (281,282,283), IRHRW
   281 RHRW = 2.00
       GO TO 284
   282 WCYLNT = 7.25
       WCYLN = WCYLNT
       RHRW = 0.0
       GO TO 284
   283 HCYLNT = 28.0
       HCYLN = HCYLNT
       RHRW = -1.0
C
   284 THRW = HTC / HCYLNT
C
       HZERO = 200.
C                             * CENTER OF GEOMETRIC SERIES OF TOWER HEIGHTS
CX8
       AZERO = 450.0
C                             * CENTER OF GEOMETRIC SERIES OF REC AREAS
       HCMAX = 30.5
C                             * MAX REC. HEIGHT IN M (LIMIT IS TUBE LENGTH)
       RHOA  = 2.0**(1./3.)
C                             * RATIO FOR SERIES OF AREAS
       RHOH  = 2.0**(1./5.)
C                             * RATIO FOR SERIES OF HEIGHTS
CX9
       INDXA = 3
C                             * DETERMINES LENGTH OF AREA SERIES.
C                               NO. OF AREAS = 2*INDXA + 1 .LE. 10

CC===========================================================
CX10
       INDXH = -4
C                             * SELECTS HEIGHT FROM SERIES - SCALED TO
C                               HZERO.
C HT    87.10 100.0 114.9 132.0 151.6 174.1 200.0 229.7 263.9 303.1 348.2
400.0
C INDXH  -6    -5     -4    -3    -2    -1     0     1     2     3     4
5
```

```
C
      IF(ICYLN.EQ.1 .AND. IAIMS.GT.3) STOP 'USE IAIMS.LE.3 - STOP'
      TWO = 2.000
      IF (ICYLN .EQ. 1) TWO = 1.000
      PIX = 3.1415926
      IF (ICYLN.EQ.2 .AND. KSHAPE.EQ.1) PIX = 4.000
      HT = HZERO * RHOH**INDXH
      AESTM = -40.0 + HT**2.00/114.3
C                                             * NORTH FIELDS-FLATS&CAVITIES
      IF(ICYLN .EQ. 1) AESTM = HT**2.25/235.6
C                                             * SURROUND FIELDS-CYLINDERS
C*C      XII    = ALOG(AESTM/AZERO)/ALOG(RHOA)
C*C      ACENT = AZERO * RHOA**INT(0.5 + XII)
C*C      APAI(1) = ACENT / RHOA**INDXA
C*C      ABOVE NOT YET IMPLEMENTED IN GOPT. NEEDS IAPA MOD.
C
C
      APAI(1) = AZERO / RHOA**INDXA
      GO TO (261,262,263), IRHRW
  261 AELI(1) = SQRT(APAI(1)/(PIX*RHRW))
      BELI(1) = RHRW * AELI(1)
      GO TO 264
  262 AELI(1) = WCYLNT
      BELI(1) = APAI(1) / ( PIX * AELI(1) )
      GO TO 264
  263 BELI(1) = HCYLNT
      AELI(1) = APAI(1) / ( PIX * BELI(1) )
C
C
  264 GO TO (271,272,273), IRHRW
C
  271 RRHOA = SQRT(RHOA)
      DO 290 I=1,2*INDXA
      AELI(I+1) = AELI(I)*RRHOA
      BELI(I+1) = BELI(I)*RRHOA
  290 APAI(I+1) = APAI(I)*RHOA
      GO TO 274
  272 DO 289 I=1,2*INDXA
      APAI(I+1) = APAI(I)*RHOA
      AELI(I+1) = WCYLNT
      BELI(I+1) = APAI(I+1) / ( PIX * AELI(I+1) )
  289 CONTINUE
      GO TO 274
  273 DO 288 I=1,2*INDXA
      APAI(I+1) = APAI(I)*RHOA
      BELI(I+1) = HCYLNT
      AELI(I+1) = APAI(I+1) / ( PIX * BELI(I+1) )
  288 CONTINUE
C
  274 DO 292 I = 1,2*INDXA+1
      IF(BELI(I) .GT. HCMAX) THEN
      BELI(I) = HCMAX
      AELI(I) = APAI(I) / ( PIX * BELI(I) )
      END IF
  292 CONTINUE
      RAREA = APAI(1+2*INDXA)
      THRW = HT/BELI(1+INDXA)
      IF(ICYLN .EQ. 2) THRW = THRW / 2.0
```

```
      WRITE(6,302) AESTM,AZERO
  302 FORMAT(' AESTM,AZERO=',2F10.2)
      WRITE(6,301) HT,APAI,AELI,BELI
  301 FORMAT(1H0,'   FINT FILE FOR GOPT IN USE WITH'/,
     &'   HT  =',F10.2/,'   APAI=',11F10.2/,
     &'   AELI=',11F10.2/,'   BELI=',11F10.2)
C
      IF (INODEF .EQ. -1) THEN
        HT = HTC
C===================================================================C
C   TO RE-START GOPT, LOAD OPTIMUM HT (NEAR LINE 72) AND OPTIMUM    C
C   APAI(4), OR APPROPRIATE CHOICE WITHIN RANGE SET BY IAPA, HERE.  C
C   FMI AND IAPA ARE SET IN STDRC.                                  C
C===================================================================C
        APAI(4) = 616.522
      END IF
C=C
  300 CONTINUE
      HTC = HT
      IRCVRC = IRCVR
      RETURN


CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CC                                                                    CC
      ENTRY ECOTOW(IMODU,ATPOW,EQPOW,EQPOWS,HTX,AEL,BEL,
     &CTOWR,CRECV,CVPLUM,CFPUMP,CTTOW,TOWOM,RECOM,VPOM,FPOM,TOTOM,FPARA)
CC                                                                    CC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C*    COMMON /HELIO/ NGON,IAXIS,RH,WH,DMIR,DMECH,HGLASS,FMIN,CHL,CHOM,
C*   &                FCANT,FUSEG,FVSEG,ISR,SRM,THELI
C*    COMMON /COST/ FMI,CEI,CFIXD,CL,CLOM,CW(2),CWP(2),CWR(2),
C*   &              CWA(2),ITMODU
C*    COMMON/PVGRP/FLIFE,PRICE,ETAEL,FPV,CHPR
C
C*C      FSYS = 1.0
C*C                          * FRACTION OF SYSTEM (= .5 FOR DUAL
C*C                            RECEIVERS, ETC.)
CC--------------------------------------------------------------------C
      JSALT = 1
C                          * 0 FOR SODIUM, 1 FOR SALT : 1ST PLANT COSTS
C
      THTB = HTX + DMIR/2. - BEL/2. - AEL/2.
C     (KEEP IN MIND: BEL AND AEL ARE ALREADY 1/2-WIDTHS FOR FLAT REC'S)
C
C          TOWER COST DUE TO LARRY STODDARD OF BLACK&VEATCH - 2/24/87
      CTOWR = (0.6E6 + 17.72 * THTB**2.392) * (CEI/320.)
C                                          CONCRETE TOWER COST EFFECTIVE
C
      IF( THTB .LT. 76. ) CTOWR=(0.201E6+26.5*THTB**2.44)*(CEI/320.)
C                                             STEEL TOWER COST EFFECTIVE
C
C
C       CYLINDRICAL RECIEVER COST MODEL
C
      CRECV = 2.3E6 + 15.9E6*(AEL/14.)*(BEL/19.5)**0.6
      IF(JSALT .EQ. 0) STOP 'SODIUM REC. COST EQN. NEEDED'
```

```
      CRECV = CRECV*(CEI/320.0)
C
C       PIPING COST MODEL
C
      SCALE = 1.0 + (HTX+66.0)/800.0
      SREPOW = SQRT(EQPOWS/390.)
      DH = 0.4064*SREPOW
      DC = DH
      IF(JSALT .EQ. 0) THEN
      DH = 0.6604*SQRT(EQPOWS/410.)
      DC = DH * 22./26.
      END IF
      HOT  = (1.6*HTX + 1.4*160.*SREPOW)*(11140.+2846.*DH)*DH
      COLD = (1.4*HTX + 0.9*160.*SREPOW)*(494.+6782.*DC)
      CVPLUM = HOT + COLD
      CVPLUM = CVPLUM*(CEI/320.0)
C
C       FEED PUMP COST MODEL
C
      PSIF = 300.
      FHM = PSIF / 2.711
      CFPUMP =  1.4E6*( ((HTX+FHM)/(150.+70.))*(EQPOWS/390.) )**0.85
      IF(JSALT .EQ. 0) THEN
      PSIF = 600.
      FHM = PSIF / 2.711
      CFPUMP =  1.4E6*( (FHM/150.)*(EQPOWS/390.) )**0.85
      END IF
      CFPUMP = CFPUMP*(CEI/320.0)
C
      CTTOW = CTOWR + CRECV + CVPLUM + CFPUMP
C
C
      TOWOM = 0.002*CTOWR      * FLIFE
      RECOM = 0.020*CRECV      * FLIFE
      VPOM  = 0.010 *CVPLUM    * FLIFE
      FPOM  = 0.050*CFPUMP     * FLIFE
      TOTOM = TOWOM + RECOM + VPOM + FPOM
      FPARA = 0.0292*ATPOW * (HTX + 0.75*FHM)/366.
      CTOWRC = CTOWR
      CRECVC = CRECV
      CVPLMC = CVPLUM
      CFPMPC = CFPUMP
      CTTOWC = CTTOW
      TOWOMC = TOWOM
      RECOMC = RECOM
      VPOMC = VPOM
      FPOMC = FPOM
      TOTOMC = TOTOM
      FPARAC = FPARA
      RETURN


CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C   * * * * GAUSSIAN FINTS * * FINTU * * 12/2/86 - LVH           CC
CC                                                               CC
      ENTRY FINTU(ID,JD,SR,COSR,FINT)
CC                                                               CC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
```

```
      KS = 1.0
C          * LARGER KS GIVES MORE SPILLAGE
      KS2 = KS*KS
      IF(ISR .EQ. 0) THEN
      FOC = FMIN
      IF(FCANT .GE. FMIN) FOC = FCANT
      IF(FUSEG.LT.FOC .AND. FUSEG.GE.FMIN) FOC = FUSEG
      IF(FVSEG.LT.FOC .AND. FVSEG.GE.FMIN) FOC = FVSEG
      END IF
      WDT = WCYLN
      HDT = HCYLN
      IF(INODEF.GT.0) THEN
      WDT = 2.0 * AELI(1+INDXA)
      HDT = 2.0 * BELI(1+INDXA)
         IF(IABS(ICYLN).EQ.1) THEN
         WDT = WDT / 2.0
         HDT = HDT / 2.0
         END IF
      END IF
      DO 5 I=1,ID
      DO 5 J=1,JD
      FINT(I,J) = 0.0
      IF(COSR(I,J) .LE. 0.0) GO TO 5
      SRIJ = SR(I,J)
      DDT = (0.5*DMIR / 2.0) / SRIJ
      IF(ISR .GT. 0) FOC = SRM * SRIJ
      SIG2 = (ALPHAL/2.0)**2+SIGMA**2+( DDT*(1.0-SRIJ/FOC) )**2
      XI = (HDT*WDT/4.0)*COSR(I,J)/(2.0*KS2*SIG2*SRIJ**2)
      FINT(I,J) = 1.0 - EXP(-XI)
    5 CONTINUE
C      WRITE(6,4) ALPHAL,SIGMA,HDT,WDT,FOC,SIG2,SRIJ,XI,COSR,SR
C    4 FORMAT(1X, 8 G10.3)
      RETURN
      END

CC=================================================================
```

APPENDIX F.2

APPENDIX F.3
Default Input Module: FIELD_BARSTOW.FOR1

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CC                                            C
      SUBROUTINE FIELD(HT,NTOW)
CC                                            C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

CC===============================================================CC
CC                                                               CC
CC1   CONSTANTS FOR SITE INFORMATION **** SOLAR ONE AT BARSTOW   CC
CC                                                               CC
CC---------------------------------------------------------------CC
      COMMON /SITE/ XLAT,ILAT,MONTH,HS,XSURVY,YSURVY,ZSURVY(5),
     &         INPUTL,NPLANE,IPLANE,MAXMIN,NREVSD,EGRND(5),AGRND(5)
      COMMON /GRPLS/ASDCS(7,10),ASDIN(12,10)

CC===============================================================CC
CC                                                               CC
CC2   CONSTANTS FOR ATMOSPHERIC DATA                             CC
CC                                                               CC
CC---------------------------------------------------------------CC
      COMMON /ATMOS/WCFM,CMW,RATMOS,PATMOS,PPS(13),APW(12),
     &                ATF(12)
      COMMON /VRL/ IVRL,HSA,VR(12),VRA(12),BETA(12),WVDENS(12),
     &               ISW(12),S(12),TEC(12),C(12),A(12)

      COMMON /CELL/ORDER,DA,AC,XTOWI,YTOWJ,NBOR,KORY,LRAY,LGEO,DTRIM

      COMMON/APST/XDUM(5),FCELL

      COMMON /COEF/ COEFX(5,6),COEFY(5,6),ICOF,COORL,NCOEFS

      COMMON /COST/ FMI,CEI,CFIXD,CL,CLOM,CW(2),CWP(2),CWR(2),
     &                CWA(2),IMODU

CC===============================================================CC
CC                                                               CC
CC3  INPUT INSOLATION DATA SFDI PP STUDY 4/25/79                 CC
CC                                                               CC
CC---------------------------------------------------------------CC
CX1
      DATA ((ASDIN(NDAY,IHOR),IHOR=1,7),NDAY=1,7) /
     * 988.0,991.0,973.0,951.0,907.0,814.0,537.0,
C* 988.0 SHOULD BE FIRST ENTRY UNLESS SPECIAL VALUE REQUIRED
     & 985.0,974.0,947.0,913.0,848.0,725.0,485.0,
     & 975.0,970.0,950.0,916.0,862.0,727.0,525.0,
     & 973.0,971.0,954.0,926.0,875.0,783.0,621.0,
     & 987.0,985.0,982.0,961.0,910.0,815.0,675.0,
     & 982.0,980.0,973.0,945.0,878.0,803.0,682.0,
     & 967.0,964.0,953.0,924.0,873.0,793.0,625.0 /
```

```

CC===============================================================CC
CC                                                               CC
CC4        INSOLATION DATA CAN BE INPUT BY ASDIN ******          CC
CC                                                               CC
CC---------------------------------------------------------------CC
CX2
      MONTH  = +1
C                            *-1 FOR INPUT INSOLATION DATA (ASDIN)
C                            0 FOR NO MONTHLY WEATHER DATA,
C                             ( FIXED CMW WATER INCLUDED )
C                            1 FOR MONTHLY WEATHER DATA PPS,APW,ATF,VR
      XLAT   = 35.
C                            *LATITUDE  OF SITE
      HS     = 550.
C                            *ELEVATION OF SITE IN METERS
      INPUTL = 0
C                            * 1 TO INPUT LGRND VIA NSDRIV/RCDRIV
C                              0 NOT
      NPLANE = 1
C                            * NUMBER OF PLANES FOR COLLECTOR,.LE. 5
      IPLANE = 1
C                            * INDEX OF PLANE FOR HORIZON
      MAXMIN = 1
C                            * RELEVANT IF NPLANE > 1  AND INPUTL = 0
C                              1 GIVES PEAKED COLLECTORS
C                              0 GIVES VALLEYS
      NREVSD = 0
C                            * RELEVANT IF NREVSD > 0
C                              LAST NREVSD PLANES OPPOSE OTHERS
      XSURVY = 0.
C                            * X COORD OF SURVEYORS BENCH MARK
      YSURVY = 0.
C                            * Y COORD OF SURVEYORS BENCH MARK
      ZSURVY(1)= 0.00
C                            * Z COORD OF PLANE=1 AT BENCH MARK
      EGRND(1)  = 0.00
C                            *SLOPE   OF PLANE LEVEL IN DEGREES
      AGRND(1)  = 0.00
C                            *AZIMUTH OF DOWNWARD SLOPE IN DEGREES
C                              (ETC. FOR UP TO 5 PLANES)

CC===============================================================CC
CC                                                               CC
CC5     CONSTANTS FOR ATMOSPHERIC DATA                           CC
CC                                                               CC
CC---------------------------------------------------------------CC
C*    COMMON /ATMOS/WCFM,CMW,RATMOS,PATMOS,PPS(13),APW(12),
C*   &              ATF(12)
C*    COMMON /VRL/ IVRL,HSA,VR(12),VRA(12),BETA(12),WVDENS(12),
C*   &             ISW(12),S(12),TEC(12),C(12),A(12)
      CMW = 1.44
C                            *CENTIMETERS OF ATMOSPHERIC WATER VAPOR(DEFAULT)
      REARTH = 6370.
C                            *RADIUS OF EARTH IN KILOMETERS
      HATMOS = 8.430
C                            *HEIGHT OF ATMOSPHERE IN KILOMETERS
      PATMOS = (1.0 - .0065*HS / 288.)**5.2568
```

```
C                                                          *PRESSURE IN ATMOS
      RATMOS = REARTH/(HATMOS * PATMOS)

CC=============================================================CC
CC                                                             CC
CC6       CLOUDS    * D. WATT  CLOUD FACTOR MODIFIER           CC
CC                                                             CC
CC-------------------------------------------------------------CC
      WCFM =  .85

CC=============================================================CC
CC                                                             CC
CC                 * FRACTION POSSIBLE INSOLATION              CC
CC        (LAST NO.=FRACTION DAYS PER YR. NOT SUNLESS)         CC
CC                                                             CC
CC-------------------------------------------------------------CC
      DATA (PPS(I),I=1,13)
     & /.75,.75,.80,.85,.90,.90,.90,.92,.92,.92,.85,.75,0.80/

CC=============================================================CC
CC                                                             CC
CC7      WATER      * ATMOS PRECIPITABLE WATER                 CC
CC                                                             CC
CC-------------------------------------------------------------CC
      DATA (APW(I),I=1,12)
     & /.73,.65,.72,.87,.99,1.16,1.92,1.97,1.44,.96,.76,.83/

CC=============================================================CC
CC                                                             CC
CC8      DUST       * ATMOS TURBIDITY FACTOR                   CC
CC  MODEL 11/12/79 ATF NOW LOG10 RATHER THAN LN: NEW=OLD/LN(10) CC
CC                                                             CC
CC-------------------------------------------------------------CC
      DATA (ATF(I),I=1,12)
     & /.006,.006,.006,.006,.017,.018,.035,.034,.035,.018,.006,.006/
C    THESE ATF'S FOR BARSTOW WERE CALCULATED FROM THE T(0.5)'S BELOW.
C    DATA BELOW IS FROM RUN NO 2748T ON 9/14/79 (SFDI FINAL).
C    & /.05,.05,.05,.05,.07,.07,.10,.10,.10,.07,.05,.05/

CC=============================================================CC
CC                                                             CC
CC9       INPUTS FOR VISUAL RANGE EFFICIENCY COMPUTATIONS      CC
CC                                                             CC
CC-------------------------------------------------------------CC
      IVRL = 2
C                                    * LOAD VRL CONTROL FOR SITE
C                                 =1 USUAL MODE - VR'S AVAILABLE AT SITE
C                                    INPUT (VRF(I),I=1,12)
C                                 =2 ALTERNATE SITE VR'S AVAILABLE
C                                    INPUT HSAF AND
C                                    (VRAF(I), I=1,12).
C                                 =3 INPUT SCATTERING
C                                    COEFF'S (BETAF(I),I=1,12)
C                                    NO VR'S REQD

CC=============================================================CC
CC                                                             CC
CC   SELECT SEASONAL MODEL IN THE YEAR. ISW(I) FOR I TH MONTH  CC
```

```
CC     ISW(I)=1 MIDLATITUDE WINTER MODEL                             CC
CC     ISW(I)=2 MIDLATITUDE SUMMER MODEL                             CC
CC                                                                   CC
CC10             * SEASONAL MODEL SELECTOR                           CC
CC     LOAD SEASONAL MODEL SELECTOR FOR SITE.                        CC
CC-------------------------------------------------------------------CC
       DATA (ISW(I),I=1,12)
      & /1,1,1,1,2,2,2,2,2,1,1,1/

CC===================================================================CC
CC                                                                   CC
CC11  VISUAL RANGE DATA                                              CC
CC                                                                   CC
CC     INPUT VR(I) IF IVRL = 1.                                      CC
CC              * VISUAL RANGE AT SITE (KM)                          CC
CC     LOAD VISUAL RANGES FOR SITE.                                  CC
CC-------------------------------------------------------------------CC
       DATA (VR(I),I=1,12)
      & /12*0.0/

CC===================================================================CC
CC                                                                   CC
CC12   INPUT HSA AND VRA(I) IF IVRL = 2.                             CC
CC     * ALT SITE ALTITUDES (M)                                      CC
CC                                                                   CC
CC     LOAD ALTERNATE SITE ALTITUDE FOR SITE.                        CC
CC-------------------------------------------------------------------CC
       HSA = 0
C                                  * USED ONLY WITH VRAF(I)
C
C                                    * ALT SITE VIS RANGE (KM)
       DATA (VRA(I),I=1,12)
      & /50.,50.,50.,50.,42.,42.,35.,35.,35.,42.,50.,50./

CC===================================================================CC
CC                                                                   CC
CC13     INPUT BETA(I) IF IVRL = 3.                                  CC
CC                                                                   CC
CC      LOAD THE SCAT COEFF'S FOR SITE.                              CC
CC-------------------------------------------------------------------CC
       DATA (BETA(I),I=1,12)
C                                     * SCAT COEF (1/KM) AT SITE
      & /12*0.0/

CC===================================================================CC
CC                                                                   CC
CC14      END VIS RANGE INPUT DATA                                   CC
CC                                                                   CC
CC-------------------------------------------------------------------CC
C*     COMMON /CELL/ORDER,DA,AC,XTOWI,YTOWJ,NBOR,KORY,LRAY,LGEO,DTRIM
C      HT                    NOW INPUTS VIA RECVER
CX3
       ORDER = 6.0
C                            *ORDER OF CELL SIZE - SEE BELOW
       DA = HT*SQRT(ORDER/4.)
C                                  *SPACING BETWEEN CELL CENTERS
       AC = DA**2
C                            *TOTAL AREA OF CELL IN METERS
```

```
CX4
      XTOWI= 9.0
C                                *ROW NUMBER OF TOWER IN NS SYSTEM
CX5
      YTOWJ= 9.0
C                                *COL NUMBER OF TOWER IN NS SYSTEM
C                             (RCELL AUTOMATICALLY ADJUSTS TOWER COLUMN)
C      **NBOR = 8**    **VARIABLES** IN **'S ARE SET IN STDRC/STDNS.
C                                *NUMBER OF NEIGHBORS FOR HELIOSTAT
C
C                                *RCELL AND ANNUAL BOTH ALLOW 24 NEIGHBORS
C
C                                *     NBOR = 8 FOR FIRST RANK
C
C                                *     NBOR = 24 FOR SECOND RANK
      KORY = 1
C                                * 1 FOR RADIAL    , 2 FOR N-S ORIENTATION
      LRAY = 2
C                                * 1 FOR CORNFIELD , 2 FOR STAGGERED ARRAY
      LGEO = 10
C                        *VARIATION STEP SIZE CONTROL IN RC - 10 IS OPTIMUM
      DTRIM= .060
C                                *TRIM INTERPOLATION CONSTANT IN RC
C                             (EQUALS RMS DECREMENT OF RGRND - NONCRITICAL)
      NTOW = INT(.5+XTOWI)
C
C*    COMMON/APST/XDUM(5),FCELL
C
C      FCELL = 0.000
C      FCELL =2.1*DA
      FCELL = 3.1*HT
C                             * IF NOT O, THE SLANT RANGE AT WHICH TO
C                               INTRODUCE A FINER CELL STRUCTURE (BY 1/4)
C                               FOR PURPOSES OF FLUX CALCULATIONS.
C                                (NS NODE/FINT FILE RUN.)

CC=============================================================CC
CC                                                             CC
CC    COEFFICIENTS FOR HELIOSTAT SPACINGS                      CC
CC     - FIT ON XGRND & YGRND FROM RC PLOT2                    CC
CC15                                                           CC
CC-------------------------------------------------------------CC
C*    COMMON /COEF/ COEFX(5,6),COEFY(5,6),ICOF,COORL,NCOEFS

CC=============================================================CC
CC                                                             CC
CC   FOR RCELL DATABASE   -   NEEDED FOR WRITING FILE(08) ONLY CC
CC                                                             CC
CC16   ** NOTE (1,I) BELOW REFERS TO 1ST OF 5 POSSIBLE PLANES** CC
CC                                                             CC
CC     THESE COEFS ARE ONLY ROUGH ESTIMATES.                   CC
CC     PLOT2 SHOULD OUTPUT BETTER ONES.                        CC
CC                                                             CC
CC-------------------------------------------------------------CC
CX6
      COEFX(1,1) =  6.057747E01
C                                       * RADIAL COEF NO 1 = A/TH
      COEFX(1,2) = -8.91503E-01
```

```
C                                           * NO 2 = B
      COEFX(1,3) =  2.921589E-02
C                                           * NO 3 = C x TH
      COEFX(1,4) =  5.06326
C                                           * NO 4 = D/TH x cos(phi)
      COEFX(1,5) = -6.752955E-01
C                                           * NO 5 = E x cos(phi)
      COEFX(1,6) =  1.38761E-02
C                                           * NO 6 = FxTH x cos(phi)
      COEFY(1,1) =  1.77130
C                                           * AZIMUTHAL COEF NO 1= A'
      COEFY(1,2) = -5.24368E-03
C                                           * NO 2 = B'xTH
      COEFY(1,3) =  3.657411E-05
C                                           * NO 3 = C'xTHxTH
      COEFY(1,4) = -9.86980E-03
C                                           * NO 4 = D' x cos(phi)
      COEFY(1,5) =  2.68258E-03
C                                           * NO 5 = E'xTH x cos(phi)
      COEFY(1,6) = -9.211214E-05
C                                           * NO 6 = F'xTHxTHxcos(phi)
C
C
      ICOF = 2
C                                   * 1 FOR 2x3 FIELD COEFFS , 2 FOR 2x6 COEFFS
      COORL = 2.20
C                                   * LIMITS COORX AND COORY TO COORL
C                                  COORL=COEFY(1,1) FOR CELLAY RUNS
      NCOEFS = 1
C                                   * NUMBER OF SETS OF COEFS <= NPLANE
C
C*C      CALL RDFLD2
C*C           RDFLD2 FOR READING COEF'S FROM FILE 28 WHEN MAKING A
C*C           DATABASE RUN (RC LONG RUN).
C*C
CC=============================================================CC
CC                                                             CC
CC17     CONSTANTS RELATING TO SYSTEM COST   ( SEE TECH-MEMO )   CC
CC                                                             CC
CC-------------------------------------------------------------CC
C*    COMMON /COST/ FMI,CEI,CFIXD,CL,CLOM,CW(2),CWP(2),CWR(2),
C*   &              CWA(2),IMODU
C
C      **FMI = 248.82**    ** SET IN STDRC NOW **
C                                         * INPUT FIGURE OF MERIT
      CEI =   320.0
C                                         * COST ESCALATION INDEX FOR 1986$
      CFIXD = 2.6116 E6 + 2.5*1.6*HT*HT
C                                         * FIXED COST IN $ - 2.5=4*0.62 AND
C                                           0.62 = 0.806/1.3
      CFIXD = CFIXD*(CEI/316.9)
C
      CL    = 0.806
C                                         * 1.3*COST OF LAND IN $/M2
      CL    = CL/316.9*CEI
C
      CLOM  = 0.00
C                                         * COST OF LAND O & M IN $/M2
```

```
      CW(1) = 0.00
C                                      * WIRING EQUIPMENT  IN $/M2
      CW(1) = CW(1)/316.9*CEI
      CW(2) = 0.00
C                                      * WIRING EQUIPMENT O & M IN $/M2
      CW(2) = CW(2)/316.9*CEI
      CWP(1) = .0412*1.45
C                                      * WIRING COST CONSTANT-PRIMARY FEEDERS
      CWP(1) = CWP(1)/316.9*CEI
      CWP(2) = .0412*.01*1.45*13.06
C                                      * WIRE COST CONST - PRIM FEEDERS O&M
C                                  13.06=FLIFE AT 6.5%
      CWP(2) = CWP(2)/316.9*CEI
      CWR(1) = .4327*1.45
C                                      * WIRE COST CONSTANT-RADIAL HEADERS
      CWR(1) = CWR(1)/316.9*CEI
      CWR(2) = 0.00
C                                      * WIRE COST CONSTANT RAD HDRS O & M
      CWR(2) = CWR(2)/316.9*CEI
      CWA(1) = 5.72*1.45
C                                      * WIRE COST CONSTANT-AZIMUTHAL
      CWA(1) = CWA(1)/316.9*CEI
      CWA(2) = 0.30*13.06
C                                      * WIRE COST-AZIMUTHAL O&M
C                                        (ESTIMATED WASHING COST)
C                                        13.06 = FLIFE AT 6.5%
      CWA(2) = CWA(2)/316.9*CEI

CC=====================================================================
CC                                                                   CC
CC     APPLY INFLATION FACTOR TO COSTS AS REQUIRED                   CC
CC18                                                                 CC
CC YEAR 1975  1976  1977  1978  1979  1980  1981  1982  1983         CC
CC      182.4 192.1 204.1 218.8 238.7 261.2 297.0 314.0 316.9        CC
CC                                                                   CC
CC      1984  1985  1986                                             CC
CC      322.7 325.3 320.0                                            CC
CC                                                                   CC
CC-------------------------------------------------------------------CC
      IMODU  = 1
C                                * NUMBER OF TOWER MODULES
CC===================================================================CC
      RETURN
      END
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CC                                                                   CC
      SUBROUTINE RDFLD2
CC                                                                   CC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
      COMMON /COEF/ COEFX(5,6),COEFY(5,6),ICOF,COORL,NCOEFS
C
        PARAMETER (KC = 17)
        DIMENSION BGRND(KC)
C
      OPEN(UNIT=28,STATUS='OLD')
        IC = 15
      DO 100 I=1,IC
```

```
        READ(28,200) IGRND
100     CONTINUE
200     FORMAT(1X,I1)
C*C
          DO 997 K1 = 1,IC
          READ(28,996) (BGRND(K2),K2=1,KC)
  996     FORMAT(1X, 13F9.6)
  997     CONTINUE
C*C
        DO 300 I=1,6
        READ(28,310) J,COEFX(1,I)
300     CONTINUE
310     FORMAT(2X,I2,D20.12)
        DO 320 I=1,3
        READ(28,310) J,DUMMY
320     CONTINUE
        DO 340 I=1,6
        READ(28,310) J,COEFY(1,I)
340     CONTINUE
        CLOSE(28)
C
        PRINT *,'  ECHO PRINT COEFICIENTS AS FOLLOWS:'
        PRINT *,'  ================================'
        PRINT *,' '
        PRINT *,'COEFX:'
C
        DO 350 I=1,6
        PRINT *,COEFX(1,I)
350     CONTINUE
        PRINT *,' '
        PRINT *,'COEFY:'
        DO 360 I=1,6
        PRINT *,COEFY(1,I)
360     CONTINUE
C
        RETURN
        END
```

APPENDIX F.4
Default Driver Module:
NSDRIV_DEF.FOR1

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CC                                                                CC
      PROGRAM NSDRIV
CC                                                                CC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C             DRIVER/INPUT PROGRAM FOR NS CODE SYSTEM
C
C
C             THE NS CODE IS THE CELLWISE PERFORMANCE SYSTEM.
C               NS HAS VARIABLE DIMENSIONS FOR WHOLE FIELD OR
C               ?EAST? HALF OF SYM. FIELD.
C             SHADING AND BLOCKING SUBROUTINE IS AVAILIBLE FOR SPLIT
C                RECTANGULAR AND ROUND HELIOSTATS.
C             THE NS CODE PROVIDES FOR TIME AVERAGING.
C             NS INTEGRATES HOURS BY QUAD. APPROX. WITH EQUAL STEPS.
C                DAYS ARE INTEG. BY QUADRATIC APPROX. WITH EQUAL STEPS.
C
C
C             OUTPUT FILE CODES USED FOR NS SYSTEM
C                06 = STANDARD PRINT FILE
C                09 = AIM POINT FILE (SEE CYLN)
C                10 = CAVITY GEOMETRY DATA
C                12 = RESTRUCTURED FINT FILE
C                     (USED AS INPUT FOR GOPT RUNS)
C                14 = NODAL INTERCEPTION DATA FROM RECEIVER
C                     (TEMPORARY FILE FOR FINT RUNS)
C                18 = VISIBLITY DATA FOR CAVITY ZONES AND COLLECTOR
C                26 = ANNUAL SUMMARY OUTPUTS FORMATTED FOR UPLOT2
C                29 = OPT IGRND MATRIX AND COEFX,COEFY (FROM RC SYS)
C                30 = CARD OUTPUT FOR ANNUAL SUMARY OR CLOUD DATA
C                39 = SYSTEM CREATED FILE FOR PANELV (SEE FINTP1)
C                40 = SYSTEM CREATED FILE FOR PANSUM (SEE FINTP1)
C                49 = DIARY
CC-----------------------------------------------------------------
CC=================================================================
CX0
      PARAMETER ( IPROG = -1)
C                                  * -1 FOR NSYEAR PROGRAM


CC=============================================================
CONTROL OF VARIABLE DIMENSIONS FOR RECEIVER MODEL
CC--------------------------------------------------------------
CX1
      PARAMETER ( IGREC = 22 )
C                                  *NUMBER OF ROWS FOR FLREC
      PARAMETER ( JGREC = 40 )
```

```
C*C              FOR B&W AR1.35, JGREC = 28.
C*C              FOR B&W AR1.81, JGREC=32. FOR B&W AR1.30 AND S.F.WU AR1.305,
C*C                        JGREC=36.
C*C              FOR S.F.WU AR1.10 & AR1.11, JGREC = 40.
C                                      *NUMBER OF COLUMNS FOR FLREC
C                                      *FOR FINT FILES, USE (2*INDXA + 1)TIMES
C                                       THE VALUE USED FOR NODE FILES. (E.G.,
C                                       FOR INDXA=3, 2*INDXA + 1 = 7 AND SO
C                                       USE 7 TIMES THE VALUE USED FOR
C                                       NODE FILE RUNS.)
      PARAMETER ( NSURF =  1)
C                                      *NUMBER OF SURFACES FOR CAVITY RECEIVER
      PARAMETER ( KGREC = JGREC)
C                                         *DIMS OF GREC, AZC, AND VF
C                  KGREC = MAX(IGREC,JGREC) FOR A CYLINDRICAL RECEIVER
C                  KGREC = IGREC*JGREC FOR A FLAT RECEIVER
C                  KGREC = NUMBER OF ZONES FOR A CAVITY RECIEVER

CC=====================================================================
CONTROL OF VARIABLE DIMENSIONS FOR NS PERFORMANCE CODE
CC---------------------------------------------------------------------
CX2
      PARAMETER ( NCELI = 15)
C                                      *NUMBER OF ROWS FOR NS FIELD
C                                    (IE. STEPS NORTH TO SOUTH)
      PARAMETER ( NCELJ = 17)
C                                      *NUMBER OF COLUMNS FOR NS FIELD
C                                    (IE. STEPS WEST TO EAST - WHOLE FIELD)
      PARAMETER ( NCELJ4= 4*NCELJ)
C                                        *FOR ARRAY OF SAB EVENTS
      PARAMETER ( JGRECP=  JGREC+1)
C                                        *FOR PANELH USE JGRECP = JGREC+1
C                                         OTHERWISE, JGRECP=1 IS ACCEPTABLE


CC=======================================================================
C MORE CONTROLS OF VARIABLE DIMENSIONS FOR ARRAYS IN NS CODE
CC-----------------------------------------------------------------------
      PARAMETER ( MAXIJ = 40)
C                                     * MAX OF (IGREC,JGREC,NCELI,NCELJ)
C                                     FOR AVERAGES - IGNORE JGREC FOR CAVITY
      PARAMETER ( IC = NCELI)
C                                      *NUMBER OF ROWS FOR NS FIELD
C                                    (IE. STEPS NORTH TO SOUTH)
      PARAMETER ( JC = NCELJ)
C                                      *NUMBER OF COLUMNS FOR NS FIELD
C                                    (NS - ALWAYS WHOLE FIELD)
      PARAMETER ( KC = NCELJ)
C                                      *NUMBER OF COLUMNS FOR IGRND MATRIX
C                                    (WHOLE FIELD FOR BOTH RC AND NS CODES)
      PARAMETER (NCWTS = 20)
C                                      *USE SAME VALUE AS IN RC CODE.
C                                       (NOT IMPORTANT FOR NS CODE.)

CC========================================================================
C
C ******** END OF PARAMETER INPUT LIST ** FWL 3/20/80 * CLP 11/26/86
C
```

```
C
C VARIABLE ARRAYS OCCURING IN BOTH RC AND NS SYSTEMS
CC-----------------------------------------------------------------------
      DIMENSION ASURF(NSURF),NSF(NSURF),NST(NSURF),FLRECP(MAXIJ)
      DIMENSION AI(MAXIJ),AJ(MAXIJ),AIGX(JC),AIGY(IC)
      DIMENSION FLREC(IGREC,JGREC),FINT(IC,JC)
      DIMENSION PANEL(IGREC,JGREC)
      DIMENSION IGRND(IC,KC),JGRND(IC,KC),ENHEL(IC,KC)
      DIMENSION FCOSI(IC,JC),AIGRND(IC,JC),FGRND(IC,JC)
      DIMENSION XGRND(IC,JC),YGRND(IC,JC),XA(IC),YA(JC),LGRND(IC,JC)
      DIMENSION XC(IC,JC),YC(IC,JC),ZC(IC,JC),SR(IC,JC),TX(IC,JC)
      DIMENSION ELEV(IC,JC),COSPH(IC,JC),SINPH(IC,JC)

CC=====================================================================
C
C VARIABLE ARRAYS REQUIRED FOR NS CODE ONLY
CC----------------------------------------------------------------------
      INTEGER SB(NCELI,NCELJ4)
      DIMENSION ERGM1(NCELI,NCELJ),ERGM2(NCELI,NCELJ),FAREA(NCELI,NCELJ)
      DIMENSION FMIRR(NCELI,NCELJ),TFLUX(NCELI,NCELJ)
      DIMENSION PANELH(7,9,JGRECP),PANELV(JGRECP),CPOWR(NCELI,NCELJ)
      DIMENSION SRT(NCELI,NCELJ),SLF(NCELI,NCELJ),VIS0(NCELI,NCELJ)
      DIMENSION SUP(NCELI,NCELJ),SDN(NCELI,NCELJ),VIS1(NCELI,NCELJ)
      DIMENSION COSR(NCELI,NCELJ),FV(NCELI,NCELJ)
      DIMENSION GREC(KGREC,6),AZC(KGREC),VF(KGREC)


CC======================================================================
C COLLECTED COMMON STATEMENTS
C
C FOR INPUT PARAMETERS VERIFICATION, copies of parameters not otherwise
C stored in COMMON are stored in COMMON /LOCALS/.
CC-----------------------------------------------------------------------
      COMMON /LOCALS/ LAY,IPR,ICOFC,ISTDNS,IGOPT,ID1(NCWTS),JD1(NCWTS)


C=====================================================================C
C
CONSTANTS FOR TIME CONTROLS
C-------------------------------------------------------------------
      COMMON /TIMEY/ JDVEQ,ESUN0,ESUN1,IMAX,JMAX,NSKIP,KVEC(13)

C======================================================================C
C - TIME CONTROLS FOR ANNUAL PERFORMANCE PROGRAM
C-----------------------------------------------------------------------
      COMMON /TIMEX/IDAYS,IHORS,NDAY1,HOUR0,HOUR1,HOUR2,NHRS,DHOUR,
     &              IDRIFT,DRIFT1,DRIFT2

CC=====================================================================C
CONSTANTS FOR SUN
CC---------------------------------------------------------------------
      COMMON /SUNX/ ALPHAL,R2,R4,R6,IROUND
C                           * SOLAR LIMB ANGLE IN RADIANS
      COMMON /SUNF/ ROOTSQ, CF(4)

CC==============================================================C
C - PROGRAM CONTROL FOR ANNUAL PERFORMANCE PROGRAM
CC-------------------------------------------------------------
```

```
      COMMON /CALCX/ICOEF,ISVIS,NREC,DELR,JTRIM,
     &              ISUMS,KANNU,ICLDF,JROW,JCOL,NPANL


CC==================================================================C
C - PRINT AND I/O CONTROLS FOR ANNUAL PERFORMANCE PROGRAM
CC----------------------------------------------------------------
      COMMON/PRINTX/IPSAB,IPMIR,IPANCT,JDISK,KDISK,
     &              NFILES,RATIO,IHNODE,KUPLOT,KFLUX



CC==================================================================C
C        ***======*** COMMENCE DATA INPUT ***======***
C
C      **DATA NRECRD /1/**  **NOW SET IN STDNS**
C                               * RECORD NUMBER IN DIARY FILE TO
C                                 COMPARE WITH
CC-------------------------------------------------------------------
CX3
      DATA ISTDNS /7/
C
C                                *PROVIDES 7 SAMPLE RUNS
C                        0 NOT ALLOWED. NO DEFAULT RUN EXISTS.
C                        1 MAKES HALF- FIELD NODE/FINT FILE - FC 14/12
C                        2 MAKES WHOLE-FIELD NODE/FINT FILE - FC 14/12
C                        3 GIVES ANNUAL PERFORMANCE RUN
C                        4 GIVES STARTUP STUDY
C                        5 GIVES CLOUD STUDY (SEE DATA IN CLOUD)
C                        6 GIVES IMAGE DRIFT STUDY
C                        7 GIVES USER-DEFINED RUN
C


CC=============================================================
C - INPUT  COLLECTOR ARRAY SIZE  * * * * * * FOR NS CODE
C--------------------------------------------------------------
CX4
      DATA ((IGRND(I,J),J=1,KC),I=1,IC)
     &/0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
     & 0,0,0,0,0,1,2,2,2,2,2,1,0,0,0,0,0,
     & 0,0,0,1,4,4,4,4,3,4,4,4,4,1,0,0,0,
     & 0,0,0,4,4,4,4,4,4,4,4,4,4,4,0,0,0,
     & 0,0,3,4,4,4,4,4,3,4,4,4,4,4,3,0,0,
     & 0,0,4,4,4,4,4,4,4,4,4,4,4,4,4,0,0,
     & 0,0,4,4,4,4,4,4,3,4,4,4,4,4,4,0,0,
     & 0,0,4,4,4,4,4,4,4,4,4,4,4,4,4,0,0,
     & 0,0,4,4,4,4,4,4,3,4,4,4,4,4,4,0,0,
     & 0,0,4,4,4,4,4,4,0,4,4,4,4,4,4,0,0,
     & 0,0,2,4,4,4,4,4,3,4,4,4,4,4,2,0,0,
     & 0,0,0,2,4,4,4,4,4,4,4,4,4,2,0,0,0,
     & 0,0,0,0,0,2,3,3,3,3,3,2,0,0,0,0,0,
     & 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
     & 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0/
C
C      1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7  -  COLUMN NUMBERS
C
C=====================================================================C
```

```
      DATA KVEC/ 93,124,155,186,216,246,276,  306,336,0,31,62,  365/

C=======================================================================
C          DAY 93 IS SUMMER SOLSTICE. DAY 0 IS VERNAL EQUINOX.
C          KVEC GIVES SAMPLE DAYS - 13TH DAY UNUSED BUT AVAILIBLE
CC---------------------------------------------------------------------
      JDVEQ = 2444320
C                          *JULIAN DAY OF VERNAL EQUINOX FOR MARCH 21,1980
C       **ESUN0 =  10.0**  **VARIABLES** IN **'S ARE NOW SET IN STDNS.
C                             *ELEVATION OF SUN AT STARTUP OR SHUTDOWN
C                           FOR LEVEL PLANE IN DEGREES
      ESUN1 =  10.0
C                             *ELEVATION OF SUN AT STARTUP OR SHUTDOWN
C                           FOR IPLANE IN DEGREES
      JMAX = 7
C                             *NUMBER OF SAMPLE DAYS = 7 USUALLY
C                              (JMAX ONLY EFFECTIVE IF IDAYS=1)
      NSKIP = 30
C                             *INCREMENT OF DAYS THROUGH YEAR
C

C=====================================================================C
C (DEFINITION OF COMMONS (C*) ARE REPEATED FOR CONVENIENT REFERENCE)
C
C - TIME CONTROLS FOR ANNUAL PERFORMANCE PROGRAM
C*    COMMON /TIMEX/IDAYS,IHORS,NDAY1,HOUR0,HOUR1,HOUR2,NHRS,DHOUR,
C*   &              IDRIFT,DRIFT1,DRIFT2
C       **IDAYS = 0**
C                             *2 FOR 7 SAMPLE DAYS USING KVEC
C                           1 FOR JMAX DAYS USING NDAY1 AND NSKIP
C                           0 FOR NDAY1 ONLY
C       **IHORS = 0**
C                             *2 FOR PM HRS - NOON TO ESUN0
C                           1 FOR HOUR1 TO HOUR2 IN NHRS-1 STEPS
C                           0 HOUR0 ONLY
C                          -1 FOR AM, -2 FOR PM STARTUP AT ESUN0
C       **NDAY1 =    0**
C                             *FIRST DAY FOR CALC
C       **HOUR0 =  0.0**
C                             *SELECT HOUR FOR CALC
C       **HOUR1 =-5.33**
C                             *FIRST HOUR FOR STARTUP CALC
C       **HOUR2 =-4.68**
C                             *LAST  HOUR FOR STARTUP CALC
C       **NHRS  = 7**
C                             *NUMBER OF SAMPLE POINTS= 5,7,9 IF IHORS=2
C       **DHOUR = 0.1721**
C                          *HOURS BETWEEN CALCULATIONS FOR IHORS=-1,-2,0
C       **IDRIFT = 0**
C                             *0 FOR NO HELIOSTAT BASIS FILE 22
C                           1 FOR BASIS FILE BUT NO SLEW
C                           2 FOR BASIS FILE AND ONE OR TWO AXIS SLEW
C       **DRIFT1 = 0.000**
C                             * FIRST AXIS SLEW IN DEGREES/MIN.
C       **DRIFT2 = 0.000**
C                             * SECOND AXIS SLEW IN DEGREES/MIN.
C
C
```

```
C-------------------------------------------------------------------
      CALL RECVER(IGREC,JGREC,HT,IRCVR)
      CALL FIELD(HT,NTOW)
      CALL HELIOS(HT)

CC=================================================================C
CONSTANTS FOR SUN
C*    COMMON /SUNX/ ALPHAL,R2,R4,R6,IROUND
CC------------------------------------------------------------------------
      DATA R2/.22416740E-0/,R4/.10433392E-0/,R6/.61979628E-1/
      ALPHAL = .004660
C                          * SOLAR LIMB ANGLE IN RADIANS
C*    COMMON /SUNF/ ROOTSQ, CF(4)
C                                     *FOR FLASH ONLY
      DATA ROOTSQ /5.213986/
C                               *SUN SIZE FOR SIGMA=.003
      DATA  (CF(I),I=1,4) / .7286088,-.4695325,.1112683,-.0092093/
C THE ABOVE ARE COEFICIENTS FOR FLASH FROM A KGEN2 FIT ON LBL SUN
C WITH SIGMA = .003 RADIANS.
C
C


C=============================================================C
C - PROGRAM CONTROL FOR ANNUAL PERFORMANCE PROGRAM
C*    COMMON /CALCX/ICOEF,ISVIS,NREC,DELR,JTRIM,
C*   &              ISUMS,KANNU,ICLDF,JROW,JCOL,NPANL
CC-----------------------------------------------------------------
      ICOEF = 1
C                         *1 FOR HERMITE COEFS, 0 FOR FLASH
      ISVIS = 0
C                         *  RELEVANT TO CAVITY RECIEVER MODEL
C                        0 NODES ON APERTURE SURFACE NOT VISIBLE
C                        1 NODES ARE VISIBLE
      NREC  = 21
C                         *MAX DIMENS. OF FLUXDR FOR IMAGE PLANE OUTPUT
      DELR = 1.0
C                         *METERS BETWEEN NODES OF FLUXDR ONLY
C=S
      JTRIM = 1
C                * JTRIM > 0 --  READ IGRND & COEFS FROM FILE 29.
C                * JTRIM = 0 --  IGRND FROM DATA STATEMENT AND
C                                      COEFX,COEFY FROM INP.MOD. FIELD.
CC======================================================================
C      **ISUMS = 0**
C                         *1 FOR SUM OVER HOURS FOR ANNUAL OUPUT, 0 NOT
C      **KANNU = 0**
C                         *1 PANEL POWER SUMMARY
C                         (WRITES FILES 39,40 AND CALLS PANPOW)
C                        2 SAME AS 1 AND WRITES FILE 30 FOR PUNCH
C                        0 NO ACTION AS ABOVE
C      **ICLDF = 0**
C                         *1 FOR  CLOUD STUDY 0 NOT
C                         CLOUD STUDY WRITES FILE 40
C                         BUT DOES NOT CALL PANPOW
C----------------------------------------------------------------------
      JROW  = 0
C                         *0 GIVES ALL ROWS OTHERWISE JROW ONLY
```

```
      JCOL  = 0
C                               *0 GIVES ALL COLS OTHERWISE JCOL ONLY

CC=====================================================================
C       NPANL = 0  (NPANL USED FOR INTERFACE WITH IH CODE ONLY.)
C                               * >1 TO CREATE RANDOM FILE 38 AND TO CALL
C                                 HINT FOR PANSUM INTERPOLATION, =0 NOT
C                               1 TO CALL CSPANL FOR CIRCLE SECTOR, OR
C                               2 TO CALL FCSPAN FOR FIELD CONTROL SEGMENT
C                                 BREAKDOWN FOR INCIDENT PANEL POWER.
C                                ( NOTE FCSPAN ALWAYS WRITES CARD FILE 30 )
C
C - PRINT AND I/O CONTROLS FOR ANNUAL PERFORMANCE PROGRAM
C*     COMMON/PRINTX/IPSAB,IPMIR,IPANCT,JDISK,KDISK,
C*    &              NFILES,RATIO,IHNODE,KUPLOT,KFLUX
C       **IPSAB =-1**
C                               *2 FOR DIAGONISTIC BOUNDARY VECTOR OUTPUT
C                             1 FOR SHADING AND BLOCKING ARRAY PRINT
C                             0 FOR NO SAB OUTPUT, -1 FOR NO SAB CALC
CC---------------------------------------------------------------------
      IPMIR = 1
C                               *2 FOR IMAGE PRINT, 1 FOR HEADINGS, 0 NONE
      IPANCT= 0
C                               *2 FOR PRINT&CONTOUR, 1 FOR CONTOUR, 0 NONE
C                               (APERTURE STUDY PRINT CONTROL VIA CYLN)

CC=====================================================================
C       **JDISK = -1**
C                           *  CONTROLS WRITING OF INTERCEPTION FILES IF
C                              ICYLN>0. (SEE INPUT MODULE RECVER FOR ICYLN).
C                           = 1 TO WRITE WHOLE-FIELD NODE (OR FINT) FILE.
C                           = 0 NOT TO WRITE NODE (OR FINT) FILE 14 (12).
C                           =-1 TO WRITE A HALF-FIELD NODE (OR FINT) FILE.
C                           *  CONTROLS READING OF INTERCEPTION FILES IF
C                              KDISK=1 AND ICYLN<0.
C                           = 1 TO READ WHOLE-FIELD NODE FILE (14).
C                           =-1 TO READ HALF-FIELD  NODE FILE (14).
C                              (FINT FILES (12) CAN NOT BE READ BY NS.)
C       **KDISK = 0**
C                           * 1 TO READ(14,901) AND CALL- NSFINT
C                             0 FOR FINTS FROM USER ROUTINE FINTU
C                            -1 FOR FINTS FROM INPUT DATA
C
C
CC--------------------------------------------------------------------C
      CALL STDNS(JGRECP,NRECRD,ISTDNS)
C=S
      IF (JTRIM .GT. 0) CALL RDFLD(IGRND,ENHEL,IC,KC)

      CALL VERINP(IPROG,IPLOT,IGREC,JGREC,NSURF,KGREC,
     &            NCELI,NCELJ,NCELJ4,JGRECP,ID,JD,LTRIAD,MAXIJ,
     &            IC,JC,KC,NCWTS)
      CALL WRTINP
      CALL REDINP(NRECRD)

C=====================================================================
C  CALL VIS RANGE DATA SET UP C. LAURENCE 2/26/81
C---------------------------------------------------------------------
```

```
      CALL VRLDAT(HT)
C
      CALL NSYEAR(HT,IGRND,LGRND,AIGRND,SR,ENHEL,CPOWR,ERGM1,ERGM2,
     &FV,VF,FAREA,FCOSI,FGRND,FINT,FLREC,FLRECP,TFLUX,FMIRR,GREC,
     &MAXIJ,IGREC,JGREC,KGREC,JGRECP,NCELI,NCELJ,NCELJ4,PANEL,PANELH,
     &PANELV,SB,XA,XC,YA,YC,ZC,ELEV,COSR,COSPH,XGRND,YGRND,SRT,SLF,
     &SUP,SDN,NSURF,AZC,ASURF,NSF,NST,AI,AJ,AIGX,AIGY,VIS0,VIS1,IRCVR)
C
      CALL SAVINP
      STOP
      END
C
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CC                                                               CC
      SUBROUTINE STDNS(JGRECP,NRECRD,ISTDNS)
CC                                                               CC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C                         1 MAKES HALF- FIELD NODE/FINT FILE - FC 14/12
C                         2 MAKES WHOLE-FIELD NODE/FINT FILE - FC 14/12
C                         3 GIVES ANNUAL PERFORMANCE RUN
C                         4 GIVES STARTUP STUDY
C                         5 GIVES CLOUD STUDY (SEE DATA IN CLOUD)
C                         6 GIVES DRIFT STUDY
C                         7 GIVES USER-DEFINED RUN
C-----------------------------------------------------------------------

      COMMON /TIMEY/ JDVEQ,ESUN0,ESUN1,IMAX,JMAX,NSKIP,KVEC(13)
      COMMON /TIMEX/IDAYS,IHORS,NDAY1,HOUR0,HOUR1,HOUR2,NHRS,DHOUR
      COMMON/PRINTX/IPSAB,IPMIR,IPANCT,JDISK,KDISK,
     &              NFILES,RATIO,IHNODE,KUPLOT,KFLUX
      COMMON /CALCX/ICOEF,ISVIS,NREC,DELR,JTRIM,
     &              ISUMS,KANNU,ICLDF,JROW,JCOL
      COMMON /TOWER/ICYLN,HCYLNT,WCYLNT,HCYLN,WCYLN,OFSET,REFLT,ABSOR,
     &              FRLOS,NPANLS,INODE1,INODE2,JNODE1,JNODE2
      COMMON /CELL/ORDER,DA,AC,XTOWI,YTOWJ,NBOR,KORY,LRAY,LGEO,DTRIM
      COMMON /RECVR/XDUM(13),NVERI,YDUM(7)
C
      CHARACTER*30 MESAG0,MESAG(7)
      DATA MESAG0/'ERROR:IMPROPER VALUE OF ISTDNS'/
      DATA (MESAG(I),I=1,7)/'  HALF-FIELD NODE/FINT FILE' ,
     & '  WHOLE-FIELD NODE/FINT FILE' ,
     & '   ANNUAL RUN    ANNUAL RUN' , ' STARTUP STUDY  STARTUP STUDY',
     & '  CLOUD STUDY    CLOUD STUDY' , '  DRIFT STUDY    DRIFT STUDY',
     & '    NS USER-DEFINED RUN' /

CC=================================================================C
C
C
C*C=========<*>  ISTDNS = 0  -  PRELIMINARY SWITCH SETTINGS  <*>=====C*C
C
C
C    **============================================================**
C    **= WARNING: NO CHANGES TO ISTDNS=0 SETTINGS ARE ALLOWED BECAUSE=**
C    **=          ANY CHANGES WILL AFFECT THE OTHER ISTDNS OPTIONS.  =**
C    **============================================================**
```

```
456 C
457 C       EXPLANATIONS OF MOST SWITCH SETTINGS ARE GIVEN IN NSDRIV.
458 C                                   VARIABLE DEFINED IN NSDRIV NEAR:
459 CC-----------------------------------------------------------------------
460 CX1
461                       NRECRD =   3001
462 C                                            LINE 139
463                       ESUN0  =  10.0
464 C                                            LINE 182
465                       IDAYS  =   0
466 C                                            LINE 200
467                       IHORS  =   0
468 C                                            LINE 204
469                       NDAY1  =   0
470 C                                            LINE 209 (SEE LINE 176 FOR LIST)
471                       HOUR0  =   0.0
472 C                                            LINE 211
473                       HOUR1  =  -5.33
474 C                                            LINE 213
475                       HOUR2  =  -4.68
476 C                                            LINE 215
477                       NHRS   =   7
478 C                                            LINE 217
479                       DHOUR  =   0.1721
480 C                                            LINE 219
481                       IDRIFT =   0
482 C                                            LINE 221
483                       ISUMS  =   0
484 C                                            LINE 267
485                       KANNU  =   0
486 C                                            LINE 269
487                       ICLDF  =   0
488 C                                            LINE 274
489                       IPSAB  =  -1
490 C                                            LINE 293
491                       JDISK  =  -1
492 C                                            LINE 302
493                       KDISK  =   0
494 C                                            LINE 313
495                       NVERI  =   4
496 C                                  * EXPLANATION OF SETTINGS FOR NVERI
497 C                                    GIVEN IN INPUT MODULE RECVER, LINE 188
498                       NBOR   =   8
499 C                                  * EXPLANATION OF SETTINGS FOR NBOR
500 C                                    GIVEN IN INPUT MODULE FIELD, LINE 187
501 C
502       WRITE(6,40) ISTDNS
503    40 FORMAT(1X, 'ISTDNS=' , I3)
504 C
505       IF(ISTDNS.LT.1  .OR.  ISTDNS.GT.7) THEN
506       WRITE(6,50) ((MESAG0, J=1,4), I=1,12)
507    50 FORMAT( 1X, 'STDNS REPORT' ,//, (1X,4A30) )
508       STOP
509       END IF
510
511 CC=======================================================================
512 C
513 C*C=========<*>  END OF ISTDNS = 0 SETTINGS  <*>===================C*C
```

```
C
C
C            SET ISTDNS NEAR LINE 90 IN NSDRIV
C-----------------------------------------------------------------
      GO TO (100,200,300,400,500,600,700), ISTDNS

CC==================================================================C
C
C*C===========<*> ISTDNS = 1  -  CREATES A HALF-FIELD <*>==========C*C
C                               NODE OR FINT FILE, DEPENDING ON THE
C                               SETTING OF INODEF IN SUBR. RECVER.
C                               NODE FILE WRITTEN TO FILE CODE (FC) 14.
C                               FINT FILE WRITTEN TO FC 12.
C        (NOTE: FILE CODE (FC) DEFINITIONS FOR NS ARE IN
C               NSDRIV, NEAR LINES 17-30.)
C-------------------------------------------------------------------
CX
  100 NRECRD = 3001
      IDAYS  = 0
      IHORS  = 0
      NDAY1  = 0
      HOURO  = 0.0
      ISUMS  = 0
      IPSAB  =-1
      JDISK  =-1
C
C*** BE SURE TO SET INODEF PROPERLY IN INPUT MODULE RECVER.       ***
C      INODEF=0 FOR NODE FILE.   INODEF=1 FOR FINT FILE.
C    AIMING STRATEGIES AND RECEIVER PARAMETERS ARE ALSO IN RECVER.
C              FOR FINT FILES, RESET JGREC IN NSDRIV.
C    NDAY1(SEE LINE 176 IN NSDRIV) AND HOURO MAY BE SELECTED TO GIVE
C    ANOTHER DAY AND TIME.
C    SET NRECRD TO THE NUMBER OF THE MOST APPROPRIATE RECORD ON THE
C    DIARY FILE WITH WHICH TO COMPARE THE INPUT MODULE DATA OF THIS
C    RUN.
C***                                                              ***
      WRITE(6,50) ((MESAG(ISTDNS), J=1,4), I=1,12)
      RETURN


CC=================================================================C
C*C===========<*> ISTDNS = 2  -  CREATE WHOLE-FIELD NODE <*>=======C*C
C                                OR FINT FILE
CC-----------------------------------------------------------------
CX7
  200 NRECRD= 1
      IDAYS = 0
      IHORS = 0
      NDAY1 = 0
      HOURO = 0.0
      ISUMS = 0
      IPSAB =-1
      JDISK =+1
C
C*** REMEMBER TO SET INODEF PROPERLY IN INPUT MODULE RECVER       ***
C      INODEF=0 FOR NODE FILE.   INODEF=1 FOR FINT FILE.
C\   AIMING STRATEGIES AND RECEIVER PARAMETERS ARE ALSO IN RECVER.
C              FOR FINT FILES, RESET JGREC IN NSDRIV.
```

```
572 C    NDAY1(SEE LINE 176 IN NSDRIV) AND HOUR0 MAY BE SELECTED TO GIVE
573 C    ANOTHER DAY AND TIME.
574 C***                                                              ***
575       WRITE(6,50) ((MESAG(ISTDNS), J=1,4), I=1,12)
576       RETURN
577
578 CC==================================================================
579 C
580 C*C===========<*> ISTDNS = 3  -  ANNUAL PERFORMANCE RUN <*>========C*C
581 CC-----------------------------------------------------------------
582 CX8
583   300 NRECRD= 3550
584       IHORS = 2
585       NHRS  = 7
586       ISUMS = 1
587       ICYLN = -IABS(ICYLN)
588       JDISK =+1
589 C        SET JDISK APPROPRIATELY.
590       KDISK = 1
591   321 IDAYS = 2
592   322 KANNU = 1
593   323 IPSAB = 0
594   324 IF(JGRECP.EQ.1)STOP'***** JGRECP = 1  -  STOP'
595 C
596 C   LINES 321-324 FOR NORMAL ANNUAL RUN. LINES 341-344 FOR "AFTERNOON
597 C   ONLY" RUN (REMOVE C'S FROM 341-344 AND ADD C'S TO 321-324).
598 C
599 C  341 IDAYS = 0
600 C  342 KANNU = 0
601 C  343 IPSAB = 1
602 C  344 NDAY1 = 0
603 C        SET NDAY1 APPROPRIATELY. (SEE LINE 176 IN NSDRIV.)
604 C
605       IF(IHORS.GT.0 .AND. KANNU.GT.0 .AND. JDISK.EQ.-1) STOP'ERROR IN 300'
606       WRITE(6,50) ((MESAG(ISTDNS), J=1,4), I=1,12)
607       RETURN
608
609 CC==================================================================
610 C
611 C*C===========<*> ISTDNS = 4  -  START-UP STUDY <*>================C*C
612 CC------------------------------------------------------------------
613 CX9
614   400 NRECRD= 3400
615       NDAY1 = 186
616       IDAYS = 0
617       KANNU = 1
618       NBOR  = 48
619       IPSAB = 1
620       ICYLN = -IABS(ICYLN)
621       JDISK =+1
622       KDISK = 1
623 C
624   421 IHORS = -1
625   422 ESUN0 = 5.0
626   423 DHOUR = .100
627   424 NHRS = 9
628 C        SET NDAY1(SEE LINE 176 IN NSDRIV), ESUN0, AND DHOUR
629 C        APPROPRIATELY.
```

```
C
C   LINES 441-444 GIVE ALTERNATIVE METHOD FOR TIME CONTROLS (REMOVE
C   C'S FROM 441-444 AND ADD C'S TO 421-423).
C  441 IHORS = 1
C  442 HOUR1 =-5.33
C  443 HOUR2 =-4.68
C  444 NHRS  = 6
C
C       SET NDAY1(SEE LINE 176 IN NSDRIV), HOUR1 AND HOUR2
C       APPROPRIATELY.
      WRITE(6,50) ((MESAG(ISTDNS), J=1,4), I=1,12)
      RETURN

CC==============================================================
C
C*C===========<*> ISTDNS = 5  -  CLOUD STUDY <*>==================C*C
CC--------------------------------------------------------------
CX10
  500 NRECRD= 1
      NDAY1 = 186
      IDAYS = 0
      IHORS = 0
      HOUR0 = 3.45
      IPSAB = 1
      ICYLN = -IABS(ICYLN)
      JDISK =+1
      KDISK = 1
      ICLDF = 1
      KANNU = 1
C       SET NDAY1(SEE LINE 176 IN NSDRIV) AND HOUR0
C       APPROPRIATELY.
      WRITE(6,50) ((MESAG(ISTDNS), J=1,4), I=1,12)
      RETURN

CC==============================================================
C
C*C===========<*> ISTDNS = 6  -  DRIFT STUDY <*>==================C*C
CC--------------------------------------------------------------
CX11
  600 NRECRD= 1
      IDAYS = 0
      IHORS = 1
      NDAY1 = 0
      HOUR1 = 0.0
      HOUR2 = 100./3600.
      NHRS  = 6
      IDRIFT= 1
      DRIFT1= 0.000
      DRIFT2= 0.000
      IPSAB = 0
      JDISK = 0
      KDISK = 0
C      SET IDRIFT,DRIFT1,DRIFT2,HOUR1,HOUR2 AND NDAY1(SEE LINE 176
C      IN NSDRIV) APPROPRIATELY.
      WRITE(6,50) ((MESAG(ISTDNS), J=1,4), I=1,12)
      RETURN

CC==============================================================
```

```
C
C*C============<*> ISTDNS = 7  -  USER-DEFINED RUN <*>===============C*C
C                             USER SETS SWITCHES TO MAKE A
C                             "CUSTOMIZED" RUN. A FEW OTHER SWITCHES,
C                             NOT LISTED HERE, MAY ALSO BE SET HERE.
C                             ** SETTINGS HERE DO NOT AFFECT ANY OTHER
C                                ISTDNS RUNS.**
C   C*C=========================================================C*C
C   C*C WARNING: SOME COMBINATIONS OF SWITCH SETTINGS CAN NOT   C*C
C   C*C          PRODUCE SUCCESSFUL RUNS.                       C*C
C   C*C=========================================================C*C
CC----------------------------------------------------------------------
  700              NRECRD= 3550
                   ESUN0  =  10.0
                   IDAYS  =   0
                   IHORS  =   0
                   NDAY1  =   0
                   HOUR0  =   4.0
                   HOUR1  =  -5.33
                   HOUR2  =  -4.68
                   NHRS   =   7
                   DHOUR  =   0.1721
                   IDRIFT =   0
                   ISUMS  =   0
                   KANNU  =   0
                   ICLDF  =   0
                   IPSAB  =  +1
                   JDISK  =   0
                   KDISK  =   0
CX                   ICYLN = -IABS(ICYLN)
                   NVERI  =   4
                   NBOR   =   8
C FOR EXAMPLE, THESE SETTINGS WILL GENERATE (BUT NOT WRITE TO 14) A
C NODE FILE AND PRODUCE A FLUX MAP AT 4PM ON EQUINOX DAY, INCLUDING
C SHADING & BLOCKING EFFECTS.
C
      IF(IHORS.EQ.0 .AND. ABS(HOUR0).GT. 0. .AND. JDISK.EQ.-1)
     &    STOP'ERROR-SET JDSIK=+1'
      WRITE(6,50) ((MESAG(ISTDNS), J=1,4), I=1,12)
      RETURN
C
      END
CC=====================================================================
```

APPENDIX F.4

APPENDIX F.5
Default Driver Module: RCDRIV_DEF.FOR1

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CC                                                               CC
      PROGRAM RCDRIV
CC                                                               CC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C              DRIVER/INPUT PROGRAM FOR RC CODE SYSTEM
C
C
C             THE RC CODE IS THE CELLWISE OPTIMIZATION CODE SYSTEM
C                 RC HAS VARIABLE DIMENSIONS FOR WHOLE FIELD AND
C                 ?EAST? HALF OF SYMMETRIC FIELD.
C             SHADING AND BLOCKING SUBROUTINE IS AVAILIBLE FOR SPLIT
C                 RECTANGULAR AND ROUND HELIOSTATS.
C             THE RC CODE PROVIDES FOR TIME AVERAGING.
C                 RC INTEG. HOURS BY TRAPZD. APPROX. WITH UNEQUAL STEPS.
C                 DAYS ARE INTEG. BY QUADRATIC APPROX. WITH EQUAL STEPS.
C
C             OUTPUT FILE CODES (FC) USED FOR RC SYSTEM
C                06 = STANDARD PRINT FILE
C                07 = SUN SAMPLE FILE
C                08 = SHADING AND BLOCKING DATA FILE
C                09 = MODIFIED SHADING AND BLOCKING FILE
C                11 = OUTPUT OF ENHEL MATRIX (SEE POSTPR)
C                13 = OUTPUT FOR CELLAY PROGRAM (SEE POSTPR & RCELL)
C                14 = NODAL INTERCEPTION DATA FROM RECEIVER(RCELL)
C                14 = FINT FILE FOR HT1 (GOPT)
C                15 = FINT FILE FOR HT2 (GOPT)   *** HT1<HT2<HT3 ***
C                16 = FINT FILE FOR HT3 (GOPT)
C                17 = TRIM INDICES FOR LAYOUT PROGRAM (SEE TCONTR)
C                19 = SEQUENTIAL FINT FILE FOR HT (RCELL - NOT GOPT)
C                25 = TRAJECTORY FILE
C                49 = DIARY
C
CX0
      PARAMETER ( IPROG =  1)
C                                    * 2 FOR FULL FIELD RCELL
C                                      1 FOR HALF FIELD RCELL
      PARAMETER ( IPLOT =  1)
C                                    * 1 TO PLOT SPACING DATA FOR
C                                        NEW FIELD COEFFS
C                                      0 NOT TO PLOT OR COMPUTE FITS
C                                        FOR NEW FIELD COEFFS
C===================================================
CONTROL OF VARIABLE DIMENSIONS FOR RECEIVER MODEL
C---------------------------------------------------
CX1
      PARAMETER ( IGREC = 22)
```

```
C                                *NUMBER OF ROWS FOR FLREC
      PARAMETER ( JGREC = 40)
C*C          FOR B&W AR1.81, JGREC=32. FOR B&W AR1.30, JGREC=36.
C*C          FOR S.F.WU AR1.10 AND AR1.11, JGREC=40.
C                                *NUMBER OF COLUMNS FOR FLREC
      PARAMETER ( NSURF =  1)
C                                *NUMBER OF SURFACES FOR CAVITY
C                                 = 1 IF NO CAVITY RECEIVER

C=========================================================
CONTROL OF VARIABLE DIMENSIONS FOR RC OPTIMIZATION CODE
C---------------------------------------------------------
CX2
      PARAMETER ( ID =  15)
C                               *USE ID = NCELI FROM PREVIOUS NS RUN
      PARAMETER ( JD =   9)
C                               *USE JD=(NCELJ+1)/2 FOR HALF  FIELD RC
C                                USE JD = NCELJ     FOR WHOLE FIELD RC
C

C==================================================================
CONTROL OF VARIABLE DIMENSIONS FOR ARRAYS IN BOTH NS AND RC CODES
C------------------------------------------------------------------
      PARAMETER ( MAXIJ =  40)
C                                * MAX OF (IGREC,JGREC,ID,JD)
C                               FOR AVERAGES - IGNORE JGREC FOR CAVITY
      PARAMETER ( IC = ID)
C                                *NUMBER OF ROWS IN RC FIELD
C                                 (IE. STEPS NORTH TO SOUTH)
      PARAMETER ( JC = JD)
C                                *NUMBER OF COLUMNS IN RC FIELD
C                                 (CHANGES BETWEEN WHOLE AND HALF
C                                 FIELD MODES)
      PARAMETER ( KC = 17)
C                                *NUMBER OF COLUMNS FOR JGRND MATRIX
C                                 (WHOLE FIELD FOR BOTH RC MODES)
C                                 USE KC=NCELJ FROM PREVIOUS NS RUN
      PARAMETER ( LTRIAD = 3)
C                                * 3 FOR GOPT, 1 OTHERWISE
C
      PARAMETER (NCWTS = 20)
C                                * SEE LINE 328
C
C ******** END OF PARAMETER INPUT LIST ** FWL 3/20/80 * CLP 11/26/86
C

C=========================================================
C VARIABLE ARRAYS OCCURING IN BOTH RC AND NS SYSTEMS
C---------------------------------------------------------
      DIMENSION FINT(IC,JC,LTRIAD)
      DIMENSION ASURF(NSURF),NSF(NSURF),NST(NSURF),FLRECP(MAXIJ)
      DIMENSION AI(MAXIJ),AJ(MAXIJ),AIGX(JC),AIGY(IC)
      DIMENSION FLREC(IGREC,JGREC),PANEL(IGREC,JGREC)
      DIMENSION IGRND(IC,KC),JGRND(IC,KC),ENHEL(IC,KC)
      DIMENSION FCOSI(IC,JC),AIGRND(IC,JC),FGRND(IC,JC)
      DIMENSION XGRND(IC,JC),YGRND(IC,JC),XA(IC),YA(JC),LGRND(IC,JC)
      DIMENSION XC(IC,JC),YC(IC,JC),ZC(IC,JC),SR(IC,JC),TX(IC,JC)
      DIMENSION ELEV(IC,JC),COSPH(IC,JC),SINPH(IC,JC)
```

```

C===================================================
C VARIABLE ARRAYS REQUIRED FOR RC CODE ONLY
C---------------------------------------------------
      DIMENSION CF(IGREC,JGREC)
      DIMENSION TGRND(ID,ID),IMECH(ID,JD),CONT(ID,JD),KGRND(ID,KC)
      DIMENSION HGRND(ID,JD),THETA(ID,JD),TEST1(ID,JD)
      DIMENSION EL(ID,JD,LTRIAD),EQCOSI(ID,JD),FLOSS(ID,JD)
      DIMENSION ENRGY(ID,JD),EQERG(ID,JD),RGRND(ID,JD)
      DIMENSION BGRND(ID,KC),EQTX(ID,JD)

C======================================================
C COLLECTED COMMON STATEMENTS
C------------------------------------------------------
C
CONSTANTS FOR TIME CONTROLS
C-------------------------------------------------------
      COMMON /TIMEY/ JDVEQ,ESUN0,ESUN1,IMAX,JMAX,NSKIP,KVEC(13)

C======================================================
CONSTANTS RELATING TO PROGRAM CONTROL - FOR RC CODE ONLY
C------------------------------------------------------
      COMMON/CALC/ IROW,RTRIM,ITRIM,ISUN,LSUN,NSOLN

C=======================================================
C - PRINT AND I/O CONTROLS FOR OPTIMIZATION PROGRAM
C--------------------------------------------------------
      COMMON /PRINT/KTAPE,ITWR,IFINT,LTAPE,IPDAY,IPLONG,
     &              INERGY,IFLUX,TRMF,TRMI,IPSHOR,
     &              IOPTA,IOPTH,IOPTE,IAPA,IHTI,ECON,ECON2

C=====================================================
C - CONSTANTS FOR SUN
C-----------------------------------------------------
      COMMON /SUNX/ ALPHAL,R2,R4,R6,IROUND
C
C FOR INPUT PARAMETERS VERIFICATION, copies of parameters not otherwise
C stored in COMMON are stored in COMMON /LOCALS/.
      COMMON /LOCALS/ LAY,IPR,ICOFC,ISTDRC,IGOPT,ID1(NCWTS),JD1(NCWTS)
      DATA (ID1(I),I=1,NCWTS) /NCWTS*0/
      DATA (JD1(I),I=1,NCWTS) /NCWTS*0/
C
C=========== ***** COMMENCE DATA INPUT ***** =======================
C      **DATA NRECRD /1/**    **NOW SET IN STDRC**
C                               * RECORD NUMBER IN DIARY FILE TO
C                                 COMPARE WITH
C-------------------------------------------------------------------
CX3
      DATA ISTDRC /1/
C                               * PROVIDES 10 SAMPLE RUNS
C
C          0 NOT ALLOWED. NO DEFAULT RUN EXISTS.
C          1 GIVES SHORT RUN WHICH READS INSOLATION AND SAB DATA
C          2 GIVES LONG RUN WHICH GENERATES INSOLATION AND SAB DATA
C          3 GIVES TRAJ RUN PRIOR TO GOPT STUDY
C          4 GIVES GOPT OPTIMIZATION USING THREE FINT FILES AND TRAJ
C          5 GIVES GOPT RE-START
C          6 GIVES CELLAY PRECURSOR RUN
```

```
C            7 GIVES GIVES DATABASE CELL FIXES
C            8 GIVES 9 VARIATIONS RUN
C            9 GIVES RUN THAT READS FC08 BUT DEFAULTS PERFORMANCE TO 1,1
C           10 GIVES USER-DEFINED RUN
C

CC===============================================================
C * * FOR THE RC CODE, THE OUTPUT COLLECTOR MATRIX IS IGRND * *
C
C * * INPUT COLLECTOR MATRIX - PROVIDES LAND CONSTRAINT FOR RC CODE
C * * INCLUDES SUBTOWER EXCLUSION  * *
CC---------------------------------------------------------------
CX4
      DATA ((JGRND(I,J),J=1,KC),I=1,IC)
     &/0,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,0,
     & 4,4,4,4,4,4,4,4,3,4,4,4,4,4,4,4,4,
     & 4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,
     & 4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,
     & 4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,
     & 4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,
     & 4,4,4,4,4,4,4,4,3,4,4,4,4,4,4,4,4,
     & 4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,
     & 4,3,4,4,4,4,3,4,0,4,3,4,4,4,4,3,4,
     & 4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,
     & 4,4,4,4,4,4,4,4,3,4,4,4,4,4,4,4,4,
     & 4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,
     & 4,4,4,4,4,4,4,4,3,4,4,4,4,4,4,4,4,
     & 4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,
     & 0,4,4,4,4,4,4,4,3,4,4,4,4,4,4,4,0/
C
C       1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7  -  COLUMN NOS.
C
CC=================================================================
      DATA KVEC/ 93,124,155,186,216,246,276,  306,336,0,31,62,  365/
C      DAY 93 IS SUMMER SOLSTICE. DAY 0 IS VERNAL EQUINOX.
C
      ALPHAL = 0.004660
C                                 *SOLAR LIMB ANGLE IN RADIANS
      JDVEQ = 2444320
C                              *JULIAN DAY OF VERNAL EQUINOX: MARCH 21,1980
      ESUN0 =  10.0
C                                 *ELEVATION OF SUN AT STARTUP OR SHUTDOWN
C                               FOR LEVEL PLANE IN DEGREES
      ESUN1 =  10.0
C                                 *ELEVATION OF SUN AT STARTUP OR SHUTDOWN
C                               FOR IPLANE IN DEGREES
      IMAX = 19
C                                 *NUMBER OF SAMPLE HOURS= 3,7,11,19 ..RC ONLY
      JMAX = 7
C                                 *NUMBER OF SAMPLE DAYS = 7 REQUIRED FOR RCELL
      NSKIP = 30
C                                 *INCREMENT OF DAYS THROUGH YEAR
C
C
      CALL RECVER(IGREC,JGREC,HT,IRCVR)
      CALL FIELD(HT,NTOW)
      CALL HELIOS(HT)

```

```
CC==================================================================
C
CONSTANTS RELATING TO PROGRAM CONTROL - FOR RC CODE ONLY
C* (COMMON DEFINITIONS (C*) ARE REPEATED FOR CONVENIENT REFERENCE.)
C*     COMMON/CALC/ IROW,RTRIM,ITRIM,ISUN,LSUN,NSOLN
C       **IROW = 0**    **VARIABLES** WITH ** ARE DEFINED IN STDRC NOW.
C                          *=0 GIVES ALL ROWS
C                           >0 GIVES IROW ONLY FOR TEST PURPOSES
C                           =-1 AND LTAPE NE 1 INVOKES READ(05) FROM INTERP
C                              TO OVER-RIDE OPTIMUM FOR SELECTED CELLS
C                           =-1 AND LTAPE EQ 1 INVOKES READ(05) FROM RCELL
C                              TO OVER-RIDE COORX,COORY FOR SELECTED CELLS
C                           =-2 AND LTAPE EQ 1 INVOKES READ(05) FROM RCELL
C                           TO READ SPACING PARAMETER INPUTS AND DO CELL
C                           OPTIMIZATIONS FOR 9 VARIATIONS OF THOSE INPUTS
C
C           READ(5,997)FICEL,FJCEL,COORX,COORY
C       997 FORMAT(4F12.4)
C                            IF MORE THAN ONE CELL IS TO BE INPUT,
C         THE STACK MUST BE IN CELL ORDER, I.E., (1,1);(1,2);...(2,1);
C         (2,2);... . THE TOWER IS IN CELL (XTOWI,1.), WHERE XTOWI IS
C         DEFINED IN INPUT MODULE FIELD, NEAR LINE 178.
C         A DUMMY (I.E., BLANK) CARD IS NEEDED AS THE LAST CARD.
C------------------------------------------------------------------
      RTRIM = +0.100
C*C       RTRIM = +0.135
C=S
C * RTRIM CONTROLS TRIM = TRIM * (1+RTRIM * COS(AZ)) OPTION
C    0 GIVES STD TRIM
C   VALUES BETWEEN 0. AND 1.0 GIVE RELATIVELY MORE SOUTH FIELD
C   VALUES BETWEEN 0. AND -1.0 GIVE RELATIVETY MORE NORTH FIELD.


C      **ITRIM = 0**
C                            *-2 SAME AS -1 EXCEPT FOR ALL TRMI TO TRMF
C                            *-1 WRITES OPT JGRND & COEFX,COEFY TO FILE 29
C                            * 0 NO WRITE TO FILE 11, OR 17
C                              1 WRITES TRIM DATA TO FILE 17 FOR IH-LAYOUT
C                              2 WRITES ENHEL TO FILE 11 (RARELY USED)
      ISUN  = 1
C                              *0 FOR UNIFORM WTS , 1 FOR SINE WTS
C                              GOES TO SUNSAM TO PROBE LOW SUN
C       **LSUN  =-1**
C                              *1 TO CALC&WRITE(07,901) YEARLY SUN SAMPLE,
C                            0 TO READ&PRINT SUN SAMPLE FROM FILE 7
C                           -1 TO READ AND NOT PRINT SUN SAMPLE
C       **NSOLN = 1**
C                              * NUMBER OF SOLUTIONS FOR TRAJECTORY
C                                CALCULATIONS AND OUTPUT.
C                               1 GIVES STANDARD RCELL RUN.
C                              >1 (E.G., 7) GIVES TRAJ RUN OR GOPT RUN.
C
C - PRINT AND I/O CONTROLS FOR OPTIMIZATION PROGRAM
C*     COMMON /PRINT/KTAPE,ITWR,IFINT,LTAPE,IPDAY,IPLONG,
C*    &               INERGY,IFLUX,TRMF,TRMI,IPSHOR,
C*    &               IOPTA,IOPTH,IOPTE,IAPA,IHTI,ECON,ECON2
C       **KTAPE = 1**
C                           * 1 TO READ WHOLE FIELD NODE FILE 14
```

```
C                              2 TO READ HALF  FIELD NODE FILE 14
C                              0 FOR FINTS FROM USER ROUTINE IN RECVER
C                             -1 FOR FINTS FROM INPUT DATA IN RCDRIV
C                             -2 TO BYPASS RCFINT FOR GOPT RUNS AND
C                                CALL OPFINT TO READ 3 FINT FILES.
      ITWR = 1
C                            * 1 INCLUDES TOWER CELL IN NODE FILE 14
C                                THIS IS STD WRITE&READ PROCEDURE
C                              0 DO NOT INCLUDE TOWER CELL
C                              ( FOR READING PRE-1980 NODE FILES)
      IFINT = 2
C                            * ONLY ACTIVE WITH KTAPE = 1 OR 2
C                             -1 READS FINT FILE(19):CANNOT GIVE FLUX PRINT
C                              0 READS NODE FILE(14) AND BYPASS FLUX PRINT
C                              1 READS NODES , PRINTS FLUX, AND WRITE FINTS
C                                TO FILE 19 FOR LATER USE WITH IFINT = -1 .
C                              2 READS NODES, PRINTS FLUX, BUT NO FILE 19
C      **LTAPE = -1**
C                          * 0 READS FC 08 BUT DEFAULTS OPTIMIZATION TO 1,1
C                           -1 READS FC 08 AND OPTS PERFORMANCE
C                           +1 WRITES FC 08 AND OPTS PERFORMANCE OR
C                           +1 AND IROW < 0 COPIES SBDATA FROM FC 08
C                              TO FC 09 WITH MODS TO SELECTED CELLS AND
C                              THEN OPTIMIZES PERFORMANCE.
      IPDAY =  0
C                            * 0 FOR NO DAILY S&B PRINT , 1 FOR THREE DAYS.
C                              (1 PROVIDES A LOT OF DIAGNOSTIC OUTPUT.)
C      **IPLONG = 0**
C                            * 0 SHORTENS PRINT (NO OPT LOCATOR PRINT)
C                              1 FOR LONG PRINT (ONE PAGE PER CELL)
C                             -1 FOR NO HEADINGS FOR CELLS.
C      **IPSHOR = 0**
C                            * 0 NO ACTION
C                              1 ELIMINATE EXCESSIVE RCELL OUTPUT
C                                 FOR A PREVIOUSLY DEFINED FIELD
C      **INERGY = 0**
C                              * 1 TO WRITE(13,901)ENRGY, 0 NOT
C                                OUPUT FOR CELLAY REQ. CONST AZIMUTHAL
C                                SPACINGS PARAMETERS IN ALL CELLS.
      IFLUX = 1
C                              * NUMBER OF TRIM VALUES OUTPUT BY POSPR1
      TRMI = 1.000
C                              * INITIAL TRIM VALUE FOR POSPR1
      TRMF = 1.000
C                              * FINAL TRIM VALUE FOR POSPR1.
C                                TRIM = 1 IS NOMINAL OPTIMUM VALUE.
C
C=============================================================================C*C
C          THE NEXT GROUP OF INPUTS REFER TO GOPT, EXCEPT FOR
C          IGOPT, IOPTE, AND ECON.
C          THE PRESENT GOPT VERSION USES 3 FINT FILES AND DOES
C          NOT NEED TO INTERPOLATE INTERCEPTION DATA AT ALL
C          (EXCEPT FOR FINAL PERFORMANCE SUMMARY FOR OPTIMUM).
C
C      **IGOPT =  0**
C                        * 1 FOR G-OPT PROGRAM
C*C                        0 FOR STANDARD RCELL. A SHORT RUN, ISTDRC=1,
C*C                          WILL ITERATE TO CONVERGENCE (SEE IOPTE, ECON).
```

```
C*C                        -1 FOR STANDARD RCELL. A SHORT RUN, ISTDRC=1,
C*C                           WILL NOT ITERATE.
C        **IOPTA =  1**
C                         * 0 RE-START RUN FOR FIXED APER. AREA SOLUTION
C                           1 TO OPTIMIZE APER. AREA (REQUIRES IOPTH=1)
C        **IOPTH =  1**
C                         * 0 RE-START RUN FOR FIXED TOWER FOCAL HT SOLUTION
C                           1 TO OPTIMIZE HT (REQUIRES IOPTA = 1)
C        **IOPTE = -1**
C                            * 0 FOR UNCONSTRAINED ENERGY OPTIMUM
C                              1 FOR CONSTRAINED ENERGY OPTIMUM WITH
C                                ANNUAL ENERGY = ECON (INPUT)
C                             -1 FOR CONSTRAINED POWER OPTIMUM WITH
C                                DESIGN TIME POWER = ECON (INPUT)
C                    *** >1 NOT YET IMPLEMENTED ***
C                             >1 SAME AS 1 EXCEPT IOPTE IS THE NUMBER
C                                OF FIXED ENERGIES TO USE, FROM ECON
C                                TO ECON2 (INPUT)
C        **IAPA = 3**
C                               * INDEX OF SMALLEST AREA USED FOR SAMPLES
C        **ECON = 350.0**
C                              * MW EQUINOX NOON POWER(FOR IOPTE=-1)
C                              * MWH ANNUAL ABSORBED ENERGY(FOR IOPTE=+1)
C
C             *** ECON2 IS NOT YET IMPLEMENTED IN GOPT ***
C        ECON2 = 0.
C                              * FINAL FIXED ENERGY FOR LOOP IF IOPTE>1
C
C*C========== END OF THIS GROUP OF GOPT INPUTS ==================C*C
C
C
C
      CALL STDRC(IGOPT,NRECRD,ISTDRC)
C
C
C=============================================================C*C
C  INSERTIONS TO CONTROL CURVE FIT PROCESS
C
      LAY  = 0
C                                *0 FOR RCELL, >0 FOR CELLAY USE
      IPR  = 0
C                                *0 FOR ALL PLOTS, 10 ONLY RADIAL PLOT
      ICOFC = 1
C                                *0 FOR ALL FITS, 1 TO SKIP SINPH FITS
C                                 IF FIELD E-W SYMMETRICAL.
      ID1(1) =10
      JD1(1) = 1
C*C      ID1(2) = 14
C*C      JD1(2) = 1
C*C      ID1(3) = 14
C*C      JD1(3) = 2
C*C      ID1(4) = 14
C*C      JD1(4) = 3
C                  * ID1 AND JD1 CONTROL WHICH OCCUPIED CELLS RECEIVE
C                    ZERO WEIGHT IN PLOT2. (SEE LOOP 50 BELOW)
C=============================================================C*C
C
C
```

```
      CALL VERINP(IPROG,IPLOT,IGREC,JGREC,NSURF,KGREC,
     &             NCELI,NCELJ,NCELJ4,JGRECP,ID,JD,LTRIAD,MAXIJ,
     &             IC,JC,KC,NCWTS)
      CALL WRTINP
CCC      CALL PRTDEF(NRECRD)
      CALL REDINP(NRECRD)
C
      CALL RCELL(IPROG,IGOPT,HT,ID,JD,KC,FGRND,TGRND,XGRND,YGRND,
     &XA,YA,SR,HGRND,TEST1,FINT,EL,EQCOSI,FCOSI,FLOSS,ENRGY,
     &EQERG,RGRND,COSPH,SINPH,ELEV,IMECH,XC,YC,ZC,TX,IGRND,
     &JGRND,KGRND,LGRND,AIGRND,AIGX,AIGY,IGREC,JGREC,AI,AJ,
     &LTRIAD,FLREC,CF,PANEL,ENHEL,BGRND,EQTX)
C
C

      IF(IPLOT.NE.1) THEN
        CALL SAVINP
        WRITE(6,100)
  100   FORMAT(1X,'INPUT PARAMETERS SAVED')
        STOP
      END IF

C=S
C=S
C IF TEST1(I,J) IS SET TO 1.E+20 THE CELL IS GIVEN ZERO WEIGHT
C   IN PLOT2.
C
      DO 50 K = 1, NCWTS
        I = ID1(K)
        J = JD1(K)
        IF ( (I.EQ.0) .OR. (J.EQ.0)) GOTO 50
        TEST1(I,J) = 1.0E+20
        EQCOSI(I,J) = 0.0
   50 CONTINUE
C
C          POSTPR OVERWRITES EQLOSS SO THAT
C                            EQLOSS <== ENHEL  FOR  TRIM = 1.
C          PLOT2  ARGS SEND  EQCOSI ==> ENHEL
C                            ENHEL  ==> WEIGH (IE. WEIGHTS)
C                            FLOSS  ==> ESTIM (IE. ESTIMATES)
C
      CALL PLOT2(ID,JD,KC,NTOW,LAY,IPR,ICOFC,FGRND,TGRND,XGRND,YGRND,
     &IGRND,LGRND,EQCOSI,ELEV,COSPH,SINPH,THETA,TEST1,IMECH,ENHEL,FLOSS)
      CALL SAVINP
      WRITE(6,100)
      STOP
      END
C
C
C
      SUBROUTINE STDRC(IGOPT,NRECRD,ISTDRC)
C
C                    1 GIVES SHORT RUN TO READ SBC DATA BASES
C                    2 GIVES LONG RUN TO GENERATE  DATA BASES
C                    3 GIVES TRAJ RUN PRIOR TO GOPT STUDY
C                    4 GIVES GOPT USING THREE FINT FILES AND TRAJ
C                    5 GIVES GOPT RE-START
                     6 GIVES PRECURSOR RUN
```

```
C                        7 GIVES DATABASE CELL FIXES
C                        8 GIVES 9 VARIATIONS RUN
C                        9 GIVES RUN THAT READS FC08 BUT DEFAULTS PERF.
C                       10 GIVES USER-DEFINED RUN
C
      COMMON /CALC/ IROW,RTRIM,ITRIM,ISUN,LSUN,NSOLN
      COMMON /PRINT/KTAPE,ITWR,IFINT,LTAPE,IPDAY,IPLONG,
     &              INERGY,IFLUX,TRMF,TRMI,IPSHOR,
     &              IOPTA,IOPTH,IOPTE,IAPA,IHTI,ECON,ECON2
      COMMON /RECVR/ YUP,YDN,XLF,XRT,IAIMS,LUPSD,ITAIM,ANGREC,
     &               APERHT,APERWD,KSHAPE,IAPER,RAREA,NVERI,
     &               ALPHA,NODES,WING,AWING,JWING,NDAYA,IHORA
      COMMON /CELL/  XDUM(5),NBOR,YDUM(4)
      COMMON /COST/  FMI,CEI,CFIXD,CL,CLOM,CW(2),CWP(2),CWR(2),
     &               CWA(2),IMODU
C
      CHARACTER*30 MESAG0, MESAG(10)
      DATA MESAG0/'ERROR:IMPROPER VALUE OF ISTDRC'/
      DATA (MESAG(I),I=1,10)/  '      REGULAR RC SHORT RUN' ,
     & ' MAKE SBC DATABASE (LONG RUN)' ,' GENERATE A TRAJECTORY FILE',
     & '  GOPT RUN GOPT RUN GOPT RUN' , '        GOPT RESTART RUN' ,
     & '     CELLAY PRECURSOR RUN' , '     FIX CELLS IN DATABASE' ,
     & '    9 VARIATIONS RUN' , '          RC DEFAULT RUN' ,
     & '    RC USER-DEFINED RUN' /
C
C
C
C
C
C*C=========<*> ISTDRC = 0  -  PRELIMINARY SWITCH SETTINGS <*>======C*C
C
C
C     **=============================================================**
C     **= WARNING: NO CHANGES TO ISTDRC=0 SETTINGS ARE ALLOWED BECAUSE=**
C     **=          ANY CHANGES WILL AFFECT THE OTHER ISTDRC OPTIONS.  =**
C     **=============================================================**
C
C
C**    ** EXPLANATIONS OF MOST SWITCH SETTINGS ARE GIVEN IN RCDRIV **
C
C                          VARIABLE DEFINED IN RCDRIV NEAR:
                NRECRD =  1
C                            LINE 125
                IROW   =  0
C                            LINE 196
                ITRIM  =  0
C                            LINE 217
                LSUN   = -1
C                            LINE 224
                NSOLN  =  1
C                            LINE 228
                KTAPE  =  2
C                            LINE 238
                LTAPE  =  0
C                            LINE 257
                IPLONG =  0
C                            LINE 267
                IPSHOR =  0
```

```
C                                     LINE 271
                        INERGY =  0
C                                     LINE 275
                        IGOPT  =  0
C                                     LINE 293
                        IOPTA  =  0
C                                     LINE 295
                        IOPTH  =  0
C                                     LINE 298
                        IOPTE  = +1
C                                     LINE 301
                        NVERI  =  4
C                                      * EXPLANATION OF SETTINGS FOR NVERI
C                                        GIVEN IN INPUT MODULE RECVER,LINE 188
                        NBOR   =  8
C                                      * EXPLANATION OF SETTINGS FOR NBOR
C                                        GIVEN IN INPUT MODULE FIELD,LINE 187
                        FMI    =  151.3
C                                      * FMI=FIN=INPUT FIGURE OF MERIT.
C
      WRITE(6,40) ISTDRC
   40 FORMAT(1X,'ISTDRC=', I3)
C
      IF(ISTDRC.LT.1 .OR. ISTDRC.GT.10) THEN
      WRITE(6,50) ((MESAG0, J=1,4), I=1,12)
   50 FORMAT(1X,'STDRC REPORT',//,(1X,4A30) )
      RETURN
      END IF
C
C*C=========<*> END OF ISTDRC=0 SETTINGS <*>======================C*C
C
C
C                 SET ISTDRC NEAR LINE 82 OF RCDRIV
C
      GO TO (100,200,300,400,500,600,700,800,900,1000), ISTDRC
C
C*C========<*> ISTDRC=1  -  REGULAR RC SHORT RUN <*>==============C*C
C                              (READS FC 07,08, AND 14)
C                              (NOTE: FC DEFINITIONS FOR RC ARE IN
C                                     RCDRIV, NEAR LINES 16-30.)
  100 NRECRD =  3550
      LTAPE  = -1
      IGOPT  =  0
C*C     USE IGOPT = -1 TO DISABLE ITERATION.
      IPLONG =  0
      IPSHOR =  0
      ITRIM  = -1
      FMI    =  115.
      IOPTE  = -1
      ECON   =  936.0
C  REMEMBER TO SET IFINT=2 IF A FLUX MAP IS DESIRED.(LINE 250,RCDRIV)
C  SET FMI APPROPRIATELY. CONTROL OUTPUT VIA IPLONG & IPSHOR.
C  MAY SET LTRIAD=1 IN RCDRIV, TO CONSERVE MEMORY.
      WRITE(6,50) ((MESAG(ISTDRC), J=1,4), I=1,12)
      RETURN
C*C========<*> ISTDRC=2  -  GENERATE SBC DATABASE (LONG RUN) <*>===C*C
C                              (READS FC 14. WRITES FC 07,08.)
  200 NRECRD =  3304
```

```
      LSUN   = +1
      LTAPE  = +1
      IPLONG =  1
      INERGY =  0
      IGOPT  =  0
      FMI    =  130.563
C  SET FMI APPROPRIATELY.
      WRITE(6,50) ((MESAG(ISTDRC), J=1,4), I=1,12)
      RETURN
C*C========<*> ISTDRC=3  -  GENERATE A TRAJECTORY FILE <*>=========C*C
C                           (READS FC 07,08, AND 14. WRITES FC 25.)
  300 NRECRD =  1
      LSUN   =  0
      NSOLN  =  7
      IGOPT  =  0
      LTAPE  = -1
      IPLONG =  1
      WRITE(6,50) ((MESAG(ISTDRC), J=1,4), I=1,12)
      RETURN
C*C========<*> ISTDRC=4  -  GOPT RUN <*>===========================C*C
C                           (READS FC 07,08,14,15,16,25)
CX5
  400 NRECRD =  3080
      IGOPT  =  1
      LTAPE  = -1
      KTAPE  = -2
      NSOLN  =  7
      ECON   =  45.
      NVERI  =  0
      IOPTE  = -1
      IOPTA  =  1
      IOPTH  =  1
      IAPA   =  2
CX6
      FMI    =  450.
C *** BE SURE TO SET INODEF=1 IN RECVER. HT1, HT2, & HT3 ARE READ FROM
C     FILES 14, 15, & 16. IAPA=INDEX OF SMALLEST RECEIVER AREA TO BE
C     USED FROM FINT FILES. SET ECON TO DESIRED VALUE. BE SURE THAT
C     PARAMETER LTRIAD=3 IN RCDRIV.
C
      WRITE(6,50) ((MESAG(ISTDRC), J=1,4), I=1,12)
      RETURN
C*C========<*> ISTDRC=5  -  GOPT RESTART RUN <*>===================C*C
C                           (READS FC 07,08,14,15,16,25)
  500 NRECRD =  3004
      IGOPT  =  1
      LTAPE  = -1
      KTAPE  = -2
      NSOLN  =  7
      ECON   =  100.
      NVERI  =  0
      IOPTE  = -1
      IOPTA  =  0
      IOPTH  =  0
      IAPA   =  2
      FMI    =  150.
C*** BE SURE TO SET INODEF=-1, AND APAI(4) & HT PROPERLY IN RECVER ***
C    SET FMI APPROPRIATELY. SET ECON & LTRIAD AS IN PREVIOUS GOPT
```

```
C     RUN. APAI(4) SHOULD BE WITHIN THE RANGE OF RECEIVER AREAS
C     SELECTED BY IAPA.
C
      WRITE(6,50) ((MESAG(ISTDRC), J=1,4), I=1,12)
      RETURN
C
C*C========<*> ISTDRC=6  -  CELLAY PRECURSOR RUN <*>===============C*C
C                            (READS FC 07,08,14. WRITES FC 13 & 17.)
  600 NRECRD =  1
      ITRIM  =  1
      INERGY =  1
      IGOPT  = -1
C*C        USE IGOPT = -1 TO DISABLE ITERATION.
      LTAPE  = -1
      FMI    =  150.
C    SET FMI APPROPRIATELY.
      WRITE(6,50) ((MESAG(ISTDRC), J=1,4), I=1,12)
      RETURN
C
C*C========<*> ISTDRC=7  -  FIX SPECIFIED CELLS IN DATABASE <*>====C*C
C                            (READS FC 07,08,14. WRITES FC 09.)
  700 NRECRD =  3304
      IROW   = -1
      LTAPE  = +1
      IPLONG =  0
      IGOPT  =  0
      FMI    =  130.563
      ITRIM  = -1
C*** REMEMBER DATA CARDS - SEE COMMENTS NEAR LINE 200 (11 LINES AFTER
C     IROW) IN RCDRIV. SET FMI APPROPRIATELY.
      WRITE(6,50) ((MESAG(ISTDRC), J=1,4), I=1,12)
      RETURN
C
C*C========<*> ISTDRC=8  -  9 VARIATIONS OF CELL SPACINGS <*>======C*C
C                            FOR INPUT CELLS. (READS FC 07,08,14.)
  800 NRECRD =  1
      IROW   = -2
      LTAPE  = +1
      IPLONG =  0
      IGOPT  =  0
      FMI    =  150.
C*** REMEMBER DATA CARDS - SEE COMMENTS NEAR LINE 200 (11 LINES AFTER
C     IROW) IN RCDRIV. SET FMI APPROPRIATELY.
C
      WRITE(6,50) ((MESAG(ISTDRC), J=1,4), I=1,12)
      RETURN
C
C*C========<*> ISTDRC=9  -  DEFAULT-TO-CELL-CENTERS RUN <*>==========C*C
C                              *  (READS FC 07,08,&14)
C                                 RC SHORT RUN IN WHICH
C                                 CELL SOLUTIONS ARE INTERPOLATED TO
C                                 THE CENTERS - (1.000,1.000) - OF THE
C                                 VARIATIONS PATCHES READ FROM THE SBC
C                                 DATABASE - (FC08).
C
  900 NRECRD =  1
      LTAPE  =  0
      IGOPT  =  0
```

```
C*C      USE IGOPT = -1 TO DISABLE ITERATION.
      FMI    =  115.
      IOPTE  = -1
      ECON   =  936.0
C       SET ECON APPROPRIATELY.
C
      WRITE(6,50) ((MESAG(ISTDRC), J=1,4), I=1,12)
      RETURN
C
C*C========<*> ISTDRC=10  -  USER-DEFINED RUN <*>===================C*C
C                             USER SETS SWITCHES TO MAKE A "CUSTOMIZED"
C                             RUN. A FEW OTHER SWITCHES ,NOT LISTED HERE,
C                             MAY ALSO BE SET HERE. **NOTE THAT SETTINGS
C                             HERE DO NOT AFFECT ANY OTHER ISTDRC RUNS**
C   C*C=====================================================C*C
C   C*C WARNING: SOME COMBINATIONS OF SWITCH SETTINGS CAN NOT   C*C
C   C*C             PRODUCE SUCCESSFUL RUNS.                    C*C
C   C*C=====================================================C*C
C
 1000              NRECRD =  1
                   IROW   =  10
                   ITRIM  =  0
                   LSUN   = +1
                   NSOLN  =  1
                   KTAPE  =  0
                   LTAPE  = +1
                   IPLONG =  1
                   IPSHOR =  0
                   INERGY =  0
                   IGOPT  =  0
                   IOPTA  =  0
                   IOPTH  =  0
                   IOPTE  = +1
                   NVERI  =  4
                   FMI    =  150.
                   IFLUX  =  3
                   TRMI   =  0.8
                   TRMF   =  1.2
C
C FOR EXAMPLE, THESE SETTINGS WILL GENERATE AND PRINT A SUNSAM; USE
C FINTU TO GENERATE INTERCEPTION DATA; CREATE AN S&B DATABASE FOR
C ROW 10 ONLY; AND GIVE FULL PAGE PRINTS FOR EACH CELL IN ROW 10.
C THE USER MAY LOAD WEATHER AND SITE INFORMATION (IN INPUT MODULE
C FIELD) AND PROVIDE TRIAL SPACING COEFFICIENTS (ALSO IN FIELD).
C SUMMARY OUTPUTS (OF LITTLE VALUE HERE) ARE ALSO PROVIDED FOR 3
C TRIMS (0.8,1.0, & 1.2).
C
      WRITE(6,50) ((MESAG(ISTDRC), J=1,4), I=1,12)
      RETURN
C
      END
```

APPENDIX F.5

APPENDIX F.6
Default Driver Module: IHDRIV_DEF.FOR1

```
      PROGRAM IHDRIV
C     **************************************************************
C     *    INDIVIDUAL HELIOSTAT PERFORMANCE MODEL                  *
C     *    INCLUDING RECIEVER MODEL AND IMAGE GENERATORS           *
C     *    REVISED   8/15/81    FWL , WAH , CLL                    *
C     *    REVISED   11/14/83   FWL    FOR MULTI-PLANES            *
C     *    UPDATED   01/12/88   CLP    FOR USER-FRIENDLINESS       *
C     **************************************************************
C
C     TS - VERSION OF LAYOUT PROGRAMS             M.D.WALZEL     03/22/79
C
C     INDIVIDUAL HELIOSTAT PROGRAM                W.A.HOLLEY     03/15/78
C
C     * * * * * * SUMARY OF FILE CODES * * * * * * * *
C
C         05      SYSTEM STD READ
C         06      SYSTEM STD WRITE
C         09      AIMS   -  AIM POINTS (IFAIM)
C         10      GEOM   -  CAVITY GEOMETRY FOR CYLN
C         11      ENHEL -    CELLWISE ENHEL OUTPUT FOR COMPARISONS
C         12      PLOTER -  CIRCLE/SECTOR DATA FOR PLOTTER (IDATA)
C         14      NODE1  -  RECEIVER INTERCEPTION DATA (JDISK,KDISK)
C         17      TRIM DATA FROM RC FOR BOUNDARY (ITRIM=2 BELOW)
C         20      JCL    -  JCL FILE FOR WREAD
C         21      HELIOS -  COORDINATE DATA (ICOOR,IFILE)
C         24      NODE2  -  RECEIVER INTERCEPTION DATA (NFILES)
C         30      CARD.F -  CARDS FROM PANPOW OR FSCPAN
C         38      TEMPORARY RANDOM FILE FOR HELIOS PANEL SUMS
C         39      TEMPORARY SEQ. FILE FOR PANPOW VERSUS TIME
C         40      TEMPORARY SEQ. FILE FOR EITHER CELLWISE,
C                 OR INDIVIDUAL HELIOSTAT PANEL SUMS
C
C    * * * * * * * * * * * * * * * * * * * * * * * * *


C****************************************************************
C*********** WARNING , CONTROL OF RESOURCES IS IMPORTANT ***********
C****************************************************************


C
C     VARIABLE DIMENSIONS                         F.W.LIPPS      08/26/77
      PARAMETER ( MAXH=  3500 )
C                                           *MAX NUMBER OF HELIOSTATS PLUS 1
      PARAMETER ( MAXF=  3500 )
C                                           *MAX SIZE OF HELIOSTAT SUBFIELD
CONTROL OF VARIABLE DIMENSIONS FOR RECEIVER MODEL
      PARAMETER ( IGREC = 22 )
C                                        *NUMBER OF ROWS FOR RECEIVER
```

```
C                                                    MATRICES (FLREC, ...)
      PARAMETER ( JGREC = 36 )
C                                                   *NUMBER OF COLUMNS FOR FLREC,...
      PARAMETER ( NSURF =  1 )
C                                                    *NUMBER OF SURFACES FOR CAVITY
      PARAMETER ( KGREC = IGREC * JGREC )
C                                                       *DIMS OF FLREC AND PANEL
C               KGREC = IGREC*JGREC FOR CYLINDRICAL OR FLAT RECEIVERS.
C               KGREC = NUMBER OF ZONES FOR A CAVITY RECEIVER.
C
      PARAMETER ( NCELI = MAXH )
C                                                    *FOR CALL TO CYLN TO GENERATE A
C                                                 NODE FILE, OTHERWISE MAY BE SET TO 1
      PARAMETER ( JGRECP=JGREC+1 )
C                                                    *JGRECP = JGREC+1 FOR PANPOW(BOTH
C                                                     THE VECTOR AND THE SUBR.)
      PARAMETER ( NXD= 11,NYD=11 )
C                                                    *FOR OUTPUT CELL STRUCTURE
C                                                     (USE FULL FIELD DIMENSIONS)
      PARAMETER ( MAXIJ = 36 )
C                                                    *MAX OF (IGREC,JGREC,NXD,NYD) FOR
C                                                 AVERAGES - IGNORE JGREC FOR CAVITY
      PARAMETER ( NCR   = 60 )
C                                                    *MAX. NUMBER OF CIRCLES IN LAYOUT
C                                                 MAX NUMBER OF CIRCLES IS .LE. 130
      PARAMETER ( NS    = 16 )
C                                                    *NO. OF SECTORS AROUND COLL.FIELD
C                                                 MAX NUMBER OF SECTORS IS .LE. 16
      PARAMETER ( NSP   = NS + 1 )



      DIMENSION NH(131),NHT(131),ISECT(NCR)
      DIMENSION ENHEL(NCR,NS),FGRND(NCR,NSP),AGRND(NCR,NSP)
      DIMENSION AIMUP(NXD,NYD),AIMDN(NXD,NYD),CFINT(NXD,NYD)
      DIMENSION AIMRT(NXD,NYD),AIMLT(NXD,NYD),LGRND(NXD,NYD)
      DIMENSION XC(MAXH),YC(MAXH),ZC(MAXH),AZ(MAXH),AL(MAXH)
      DIMENSION SRT(NCELI),SLF(NCELI),SUP(NCELI),SDN(NCELI)
      DIMENSION NFCSN(MAXF),SRAZ1(MAXF),IHEL(MAXF)
      DIMENSION FINT(MAXF),FMIRR(MAXF),XBUF(MAXF)
      DIMENSION PANEL(KGREC),PANEL2(KGREC)
      DIMENSION ACELL(NXD,NYD),NCELL(NXD,NYD),AI(MAXIJ),AJ(MAXIJ)

C******IF PROPER OUTPUTS ARE TURNED OFF, MAXF MAY BE CHANGED******
C       TO 1 IN THE CORRESPONDING VARIABLES IN THE NEXT 3 LINES   **
C****** AS NECESSARY IN ORDER TO CONSERVE MEMORY. ****************

      DIMENSION FCOSI(MAXF),FAREA(MAXF)
      DIMENSION ERGM1(MAXF),ERGM2(MAXF),RTPOW(MAXF)
      DIMENSION FSAB(MAXF),ASAB(MAXF),VIS0(MAXF),VIS1(MAXF)
C
C
C  VARIABLE ARRAYS REQUIRED BY THE NS CYLN PROGRAM
      DIMENSION FLREC(KGREC),FLRECP(MAXIJ)
C     DIMENSION ASURF(NSURF),NSF(NSURF),NST(NSURF)
      DIMENSION GREC(KGREC,6),AZC(KGREC)
C     DIMENSION TFLUX(NCELI),ENHELX(NCELI)

```

```
C*********************************************************************
C        PANELH REQUIRES 7*9*JGRECP EQUIVALENT STORAGE FOR PANPOW CALL *
C          ( 7 IS MAX NO. OF DAYS PER YEAR FOR ANNUAL SUMMARY PRINT.    *
C            9 IS MAX NO. OF TIMES PER DAY FOR DAILY SUMMARY PRINT. )   *
C **** FOR A RUN WITH KANNU .GT. 0, REMOVE THE C FROM THE NEXT LINE.   *
C      DIMENSION PANELH(7,9,JGRECP),PANELV(JGRECP)
C*********************************************************************

      CHARACTER*30 MES0,MES(3)
      INTEGER ZRATIO
C
C   * * * GROUPS OF OUTPUT SWITCHES FOR FIELD VARIABLES * * *
C   * * * * * NOTE -- THESE ARE ASSUMED TO BE ZERO AT
C             THE BEGINNING OF THE RUN    * * * * *
C
      COMMON /CSOUT/LPCS(14)
      COMMON /XYOUT/LPXY(14)
      COMMON /SECOUT/IPSC(14)
      COMMON /CTROUT/ICTR(14)
C
C
CONSTANTS FOR TIME CONTROLS
C
      COMMON /TIMEY/ JDVEQ,ESUN0,ESUN1,IMAX,JMAX,NSKIP,KVEC(13)
C
C - TIME CONTROLS FOR ANNUAL PERFORMANCE PROGRAM
      COMMON /TIMEX/IDAYS,IHORS,NDAY1,HOUR0,HOUR1,HOUR2,NHRS,DHOUR,
     &              IDRIFT,DRIFT1,DRIFT2
C
      COMMON /HELIO/ NGON,IAXIS,RH,WH,DMIR,DMECH,HGLASS,FMIN,CHL,CHOM,
     &               FCANT,FUSEG,FVSEG,ISR,SRM,THELI
C
      COMMON /GRLAY/ HTD,EXCLRD,SRATIO,ZRATIO(30),BRATIO
C
      COMMON /BOUNDX/ STHRD,ESTRD,RTHRD,RSOTH,CSOTH,ELIMT,WLIMT,IHALF
C
      COMMON /DSKIP/ICIR1,ICIR2,MDEL
C                                       * SUBPROGRAM ISKIP
      COMMON /GROPT/ITRIM,IPRNT,IFILE,IFAIM,ICOOR,IDATA
C
      COMMON /ZONE3/ RSYMIN,RSYMAX,SLIP,HALFAZ,IPR,NCIRCA
      COMMON /GPLANE/NHP(5),NRP(5),NZP(5),AZMQ(5),RADQ(5)
C
      COMMON /GRPC/ RADS(131),DAZM(131),ISLIP(134),NROW,NPLANE
      COMMON /GRPB/ANG1,ANG2,IROW1,IROW2,IFIELD,IZONE,
     &             ANP1,ANP2,NCIR,AZD,IDEL(20,2),ADEL(20,50)
C
CONSTANTS FOR SUN
      COMMON /SUNX/ ALPHAL,R2,R4,R6,IROUND
C                            * SOLAR LIMB ANGLE IN RADIANS
      COMMON /SUNF/ ROOTSQ, CF(4)
C
      COMMON /HELI2/ UMIR,VMIR,SLOT
C
C - PROGRAM CONTROL FOR ANNUAL PERFORMANCE PROGRAM
      COMMON /CALCX/ICOEF,ISVIS,NREC,DELR,JTRIM,
     &             ISUMS,KANNU,ICLDF,JROW,JCOL,NPANL
C
```

```
C - PRINT AND I/O CONTROLS FOR ANNUAL PERFORMANCE PROGRAM
      COMMON/PRINTX/IPSAB,IPMIR,IPANCT,JDISK,KDISK,
     &              NFILES,RATIO,IHNODE,KUPLOT,KFLUX
C
C
C==============PRINT CONTROL FOR BOTH LAYOUT AND IHYEAR===============
C=S
      COMMON /IZZSE/ IZSE
C
C     IZSE IS USED FOR PRINTING OUT A PARTICULAR SECTOR ONLY.
C         IT AFFECTS ALL SECTOR-TYPE PRINTOUTS. IT AFFECTS ONLY
C         THE PRINTOUTS; CALCULATIONS ARE STILL DONE FOR ALL SECTORS.
C
      DATA IZSE /0/
C                 IZSE = 0        PRINT OUT ALL THE SECTORS.
C                 IZSE = 1 TO NS  PRINT OUT PARTICULAR SECTORS.
C                 IZSE = 999      PRINT NO SECTORS.
C=S
C=====================================================================





C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C*********************************************************************
C       * * * BEGINNING OF INPUT DATA FOR LAYOUT * * *

C====================================================================
      DATA ISTDLY /2/
C ISTDLY options
C     0 not allowed. No default run exists.
c     1 Layout field and stop.
C     2 Layout field and continue to ihyear.
C     3 Read helios coords from file 21 and continue to ihyear.
C====================================================================


      DATA SCALE/.30480/
C               LINEAR DIMENSIONS ARE CONVERTED FROM FEET TO METERS
C               BY SCALE. STD CONVERSION IS 2.54 CM/IN OR .3048 M/FT.


      CALL RECVER(IGREC,JGREC,HT,IRCVR)



C*********************************************************************
C*              DMIR AND HGLASS ARE SPECIALLY INPUT FOR LAYOUT      **
C*                    AND MAY BE CHANGED FOR IHYEAR (BUT            **
C*                   DMECH MAY BE VIOLATED, SO TAKE CARE.)          **
C*                                                                  **
C*      THE /HELIO/ VARIABLES MAY EITHER BE: (1)INPUT DIRECTLY HERE, **
C*           OR (2)INPUT MODULE HELIOR OR (3) INPUT MODULE HELIOS   **
C*           MAY BE CALLED.                                         **
C*                                                                  **
C*   COMMON /HELIO/ NGON,IAXIS,RH,WH,DMIR,DMECH,HGLASS,FMIN,CHL,CHOM, **
C*  &               FCANT,FUSEG,FVSEG,ISR,SRM                       **
C*********************************************************************
```

```

C *** CHOICE #1 - DIRECT INPUT ***
C      DMIR  = 23.00 * SCALE
C                                    *WIDTH OF SANDIA HELIOSTSAT IN METERS**
       EXMIR = 17.67
C                                   *EXCLUSION RADIUS FOR HELIOSTAT (FEET)**
C      DMECH = 2.*(EXMIR*SCALE) / DMIR
C                                                * MECH LIM IN DMIR     **
C      HGLASS = 612.0 * SCALE**2

C *** CHOICE #2 - CALL SPECIAL HELIO SUBROUTINE ***
C      CALL HELIOR(HT)
C
C  (IF HELIOR IS SELECTED, A SUBROUTINE NAME CHANGE TO THE APPROPRIATE**
C    HELIO INPUT-MODULE FILE, AND COMPILE AND LINK MODS TO THE        **
C    RUNIH.COM FILE MAY BE NECESSARY.)                                **

C *** CHOICE #3 - CALL REGULAR HELIO SUBROUTINE ***
       CALL HELIOS(HT)
C

C=====================>> THE USER SHOULD ALWAYS VERIFY THAT THE ABOVE**
C=====================>> LINES ARE COMMENTED OR UNCOMMENTED AS APPRO-**
C=====================>> PRIATE TO TURN ON THE SELECTED HELIO MODEL. **

C=================================================================
       AHELI = 3.14159265 * DMIR**2 / 4.
C                                 * S&B AREA OF ROUND HELIOS IN M2
C       AHELI = DMIR**2
C                                 * S&B AREA OF SQUARE HELIOS IN M2
C *** USER MUST SELECT THE APPROPRIATE FORMULA HERE AND IN IHYEAR ***
C=================================================================
C
       RHELI = HGLASS/AHELI
C

C********       END OF HELIOSTAT SPECIFICATION FOR LAYOUT    ************
C**********************************************************************


C
C*     INTEGER ZRATIO
C*     COMMON /GRLAY/ HTD,EXCLRD,SRATIO,ZRATIO(30),BRATIO
C      DATA (ZRATIO(I),I=1,30) /30*3/ ,BRATIO /3.0/
C       DATA (ZRATIO(I),I=1,30) /6,6,5,5,4,3,2,1,22*1/ ,BRATIO/6.0/
       DATA (ZRATIO(I),I=1,30) /30*6/ ,BRATIO/6.0/
C            DECOMP => ZRATIO + 1 / ZRATIO  TO DECOMPRESS NEW ZONE
C            BRATIO BIASES THE CHOICE OF NO A VERSUS 2 A CICLES IN
C                   SLPTST. THIS INPUT CAN ADJUST ZONE STUCTURE.
C
C       EXCLRD = (70.0+EXMIR)*SCALE
       EXCLRD = 128. + DMIR/2. +.3
C                                         * TOWER EXCLUSION IN METERS
       SRATIO= 2.00
C                                      *MULTIPLIER FOR AZD TO CONTROL
C                                    AZIMUTHAL ANGLES SCANNED BY SABI
C
C*     COMMON /BOUNDX/ STHRD,ESTRD,RTHRD,RSOTH,CSOTH,ELIMT,WLIMT,IHALF
```

```
      DATA (ISECT(I),I=1,NCR)
     & /115,109,103,96,93,87,79,66,60,54,43,36,29,47*19/
C       ISECT(I) GIVES LIMITING AZIMUTH FOR I-TH CIRCLE FOR ITRIM= 0
C
C*******************   BARSTOW BOUNDARYS   ************************
      STHRD = (35.0+EXMIR)*SCALE
C                                     * WIDTH/2 OF SOUTH ROAD IN METERS
      ESTRD = (10.0+EXMIR)*SCALE
C                                     * WIDTH/2 OF EAST ROAD
      RTHRD = (10.0+EXMIR)*SCALE
C                                     * WIDTH/2 OF NORTH ROAD
C     RSOTH = ((2150.-(1408.-10.)-5.-1.)+643.-EXMIR)*SCALE
C     CSOTH = (642.+1.) * SCALE
C                                                *CENTER OF SOUTH CIRCLE
C     RNRTH = (1408.-15.-EXMIR+1.00)*SCALE
C                                                *RADIUS OF NORTH CIRCLE
C     ELIMT = (1290.-EXMIR-5.0-15.0)*SCALE
C                                                *EAST FIELD LIMIT
C     WLIMT = (1290.-EXMIR-20.-15.0)*SCALE
C                                                *WEST FIELD LIMIT
C     RSYMIN  = 1.90
C                                   *MIN. AZIMUTHAL SPACING IN DMIR
C     RSYMAX  = 2.50
C                                   *START AZIMUTHAL SPACING IN DMIR
C     RADQ(1) = 1400.
C                                   *RADIUS OF FIRST HELIO IN PLANE 1
C******************************************************************
C
      RSOTH = 1246.
C                                   * FOR TEST FIELD BOUNDARY
      RNRTH = 1246.
C                                   * FOR TEST FIELD BOUNDARY
      CSOTH = 362.
C                                   * FOR TEST FIELD BOUNDARY
      ELIMT = 1178.
C                                   * FOR TEST FIELD BOUNDARY
      WLIMT = 1178.
C                                   * FOR TEST FIELD BOUNDARY
C
C     **IHALF = 0 **

C                       IHALF = 0 GIVES WHOLE FIELD LAYOUT
C                       IHALF = 1 GIVES EAST  FIELD LAYOUT
C                       IHALF =-1 GIVES WEST  FIELD LAYOUT
C
C*    COMMON /DSKIP/ICIR1,ICIR2,MDEL
      ICIR1 = 1
C                                   * CIRCLE NO. TO BEGIN DELETE TABLE
ALL
C                                   * HELIOSTATS BEFORE ICIR1 ARE DELETED.
      ICIR2 = 7
C                                   * CUT OFF FOR DELETES
      MDEL = 31
C                                   * MAXIMUM NUMBER OF DELETES PER
C                                   * CIRCLE OF HELIOSTATS; MUST AGREE
C                                   * WITH TABLE DIMENSIONS IN FUNCTION
C                                   * SUBPROGRAM ISKIP
C*    COMMON /GROPT/ITRIM,IPRNT,IFILE,IFAIM,ICOOR,IDATA
```

```
C      **ITRIM = -1 **
C                                     *2 GIVES TRIM BOUNDARY FROM FILE 17
C                                      1 GIVES TRFC BOUNDARY
C                                      0 GIVES ISECT BOUNDARY
C                                     -1 GIVES GEOMETRIC BOUNDRY
C                                     -2 GIVES GEOM BOUNDRY MINUS ISKIP LIST
C      **ICOOR = 2 **
C                              * IF ICOOR=2, YOU MUST SET IFILE = 0.
C                                        * 1 TO CALL COORDS SUBROUTINE IN LAYOUT
C                                        * 2 READS HELIOS COORDS FROM FILE 21
C      **IPRNT = 0 **
C                                        * 1 TO PRINT COORDS AND 0 NOT
C      **IFILE = 1 **
C                                        * 1 TO WRITE COORDS TO FILE 21 AND 0 NOT
C      **IDATA = 0 **
C                                        * 1 TO WRITE PLOTER (FILE 12) AND 0 NOT
C      **IFAIM = 0 **
C                                        * 0 NO READ FILE 09 BUT FLAGS FOR CYLN
C                                       1 READ NS-FILE 09 FOR 3PT CYLN AIMUP/DN
C                                        ** NO 5 PT AIMS YET **
C                                       2 READ NS-FILE 09 FOR 4PT FLAT AIMLT/RT
C                                      -1 READ IH-FILE 09 FOR 3PT CYLN SUP
C                                      -2 READ IH-FILE 09 FOR 4PT FLAT SRT
C
C         **ILYOT = 0 **                 * 1 TO STOP AFTER LAYOUT FINISHED.
C                                          0 TO CONTINUE TO IHYEAR.
C
C*     COMMON /ZONE3/ RSYMIN,RSYMAX,SLIP,HALFAZ,IPR,NCIRCA
C*     COMMON /GPLANE/NHP(5),NRP(5),NZP(5),AZMQ(5),RADQ(5)
       AZMQ(1) = 0.000
C                                       *AZMIMUTH OF FIRST HELIO IN PLANE 1
C       AZMQ(2) = 0.000
C       AZMQ(3) = 0.000
C                                    ANOTHER AZIMUTH INPUT WILL BE NEEDED
C                                    IN FUTURE FOR LINE OF DISCONTINUITY.?
       RADQ(1) = 1246. - DMIR/2.
C                                         *RADIUS   OF FIRST HELIO IN PLANE 1
C       RADQ(2) = 182.88
C       RADQ(3) = 182.88
C
       RSYMIN  = 1.71*0.9
C                                       *MIN. AZIMUTHAL SPACING IN DMIR
       RSYMAX  = 1.71*1.15
C                                       *MAX. AZIMUTHAL SPACING IN DMIR
       NCIRCA = 4
C                                      *MINIMUM NUMBER OF A-CIRCLES IN ZONE
C
C

       CALL FIELD(HT,NTOW)
C
C
C



C******************** STDLY (IMITATION) "SUBROUTINE" *************
C****************************************************************
C
```

```
C
C======================<ISTDLY = 0>==============================
      DATA MES0         /'ERROR:IMPROPER VALUE OF ISTDLY'/
      DATA   (MES(I),I=1,3)/' layout field stop.          ',
     *                      ' layout and ihyear              ',
     *                      ' read file 21 and cont    ihyear'/
C     WARNING: NO changes to ISTDLY=0 settings are allowed
c           because any changes will affect the other ISTDLY options.
        SCALE1 = 1.0
C=S                     * FILE 21 IN METERS
C
      IHALF = 0
      ITRIM = 2
      ICOOR = 1
      IPRNT = 1
      IFILE = 1
      IDATA = 0
      IFAIM = 0
      ILYOT = 0


      write(6,40) istdly
40    format(1x,' istdly=',i3)
c
      if(istdly.lt.1 .or. istdly.gt.3) then
      write(6,50) ((mes0,j=1,4),i=1,12)
50    format(1x,'stdly report',//,(1x,4a30))
      endif

      GOTO (10,20,30), ISTDLY

c=========  istdly=1 layout and stop. =========

10      IHALF = 1
      IFILE = 0
        IPRNT = 0
        ITRIM = -1
      ICOOR = 1
        SCALE1 = 1.
C=S     SCALE1 = SCALE             * FILE 21 IN FEET
C=S     SCALE1 = 1.                * FILE 21 IN METERS
        ILYOT = 1
      write(6,50) ((mes(istdly),j=1,4),i=1,12)
      GOTO 100




c=========istdly=2 layout and ihyear =========

20      ICOOR = 1
        IHALF =-1
        ITRIM = -1
        SCALE1 = 1.0
        ILYOT = 0
      IPRNT=0
        IFILE=0
      write(6,50) ((mes(istdly),j=1,4),i=1,12)
```

```
      GOTO 100

c========== istdly=3 read from file 21 and continue ihyear =========

30      ICOOR = 2
      IPRNT = 0
      IFILE = 0
      ILYOT = 0
        SCALE1 = SCALE
      write(6,50) ((mes(istdly),j=1,4),i=1,12)
100   CONTINUE
c==================<*>=========================================
C****************** END OF STDLY "SUBROUTINE" ********************

      CALL LAYOUT(MAXH,NXD,NYD,NCELI,SCALE1,HT,RHELI,NH,NHT,ISECT,
     &NCR,NS,NSP,ENHEL,FGRND,AGRND,AIMUP,AIMDN,AIMRT,AIMLT,LGRND,
     &XC,YC,ZC,AZ,AL,NFCSN,SRT,SUP,SDN)
       IF( ICOOR .EQ. 2) GOTO 356

C
C**************** OPTIONAL OUTPUT
C                 FOR LAYOUT CONTINUES DOWN
C**************** LAYOUT FINISHED
C
      DO 333 I = 1,MAXH
      XBUF(I) = FLOAT(NFCSN(I))/1000.
  333 CONTINUE
      WRITE(6,111)
  111 FORMAT(1H1,'   SECTOR OUTPUT OF HELIOSTAT IDENTIFICATION',
     & ' NUMBERS',//)
       CALL SECTOR(NS,XC,YC,AL,NH,NHT,XBUF,3,IHALF)
C       CALL SECTR2(NS,XC,YC,AZ,NH,NHT,XBUF,3,IHALF)
C
      IZONE = 0
      DO 344 I=1,NROW
      IF(ISLIP(I) .EQ. 1) IZONE = IZONE + 1
      NR = NH(I)
      IF(NR .EQ. 0) GOTO 344
      IJ0 = NHT(I) - 1
      DO 345 J=1,NR
      IJ = IJ0 + J
C=CC
      AX = AL(IJ) - AL(IJ-1)
C=S
      IF (ABS(AX) .GT. 5.0) THEN
            AX = AX - 6.28318
      ENDIF
C=SS
      IF(ISLIP(I+1).NE.1 .OR. ABS(AX).LT.1.5) GOTO 346
      NDEL = IDEL(IZONE,2)
      DO 347 JS=1,NDEL
C=CC
      AX = AL(IJ) - ADEL(IZONE,JS)
      IF(ABS(AX) .LT. 1.5) GOTO 346
```

```
  347 CONTINUE
  346 XBUF(IJ) = - ( DAZM(I) + AX ) / DAZM(I)
      IF(J .EQ. 1 .AND. ISLIP(I+1) .NE. 1) XBUF(IJ) = 0.000
  345 CONTINUE
  344 CONTINUE
C
C=S
      WRITE(6,348)
  348 FORMAT(1H1,'   SECTOR OUTPUT FOR SLIPAGE FRACTIONS'//)
       CALL SECTOR(NS,XC,YC,AL,NH,NHT,XBUF,3,IHALF)
C=SS
      DO 350 I=1,MAXH
  350 FINT(I) = 0.
C=S
356       IF( ILYOT.EQ.1 ) STOP' **** LAYOUT FINISHED ****'




C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C*************************************************
C***   BEGINNING OF INPUT DATA FOR IHYEAR   ********
C
      DATA ISTDIH /1/
C
C                                       *PROVIDES FOUR SAMPLE RUNS
C                            1 GIVES MULTI-PLANE TEST (SAB ONLY)
C                            2 GIVES RECEIVER RUN AND WRITES AN
C                              INDIVIDUAL HELIOSTAT NODE FILE TO 14
C                            3 GIVES ANNUAL PERFORMANCE RUN, READING
C                              AN IH NODE FILE.
C                            4 READS NODE FILE AND OUTPUTS FLUX MAP AND
C                              CIRCLE SECTOR PANEL POWER PRINT
C
      XGRND = HGLASS
      CALL HELIOS(HT)
      XGRND = HGLASS / XGRND
C
C                                   XGRND IS THE RATIO OF PERFORMANCE
C                                   TO LAYOUT VALUES OF HGLASS
CC    * * * OUTPUT SWITCH EXPLAINATIONS FOR YEAR * * *
C
C      LPCS CONTROLS CIRCLE SECTOR OUTPUT
C      LPXY CONTROLS XY CELL OUTPUT AND VARIABLE AVER
C      IPSC CONTROLS SECTOR AND/OR SECTR2 OUTPUT
C      ICTR CONTROLS CONTOUR OUTPUT
C
C          IN THE ABOVE GROUPS THE FIRST 6 SWITCH NAMES
C          CORRESPOND TO FIELD VARIABLES IN THIS ORDER
C
C           FINT,FMIRR,FCOSI,FAREA,FSAB,ASAB,        SUMIT,RELPOW
C             1    2     3     4    5    6
C                                     DAILY OUTPUT   7     9
C                                     ANNUAL OUTPUT  8     10
C
C      SWITCH SETTINGS
```

```
C            1) SET SWITCH TO 1 TO ACTIVATE OUTPUT (0 IS NO OUTPUT).
C            2) EXCEPT THAT AN XY CELL OUTPUT SWITCH (BEGINNING
C               MNEMONIC- LPXY) MAY BE -1 0 1 OR 2:
C                -1 TURNS OFF AVER WHICH MAY BE REQUIRED FOR CORE.
C                 1 GIVES NODE FILE CELL SPACINGS.
C                 2 GIVES SUBFIELD OPTIMUM SPACINGS.
C            3) EXCEPT FOR IPSC:
C                 1 GIVES USUAL COMPACT SECTOR OUTPUT.
C                 2 GIVES AN UNDISTORTED PRINT PLOT FOR EACH SECTOR,
C                        MAX OF 200 HELIOS/SECTOR.
C=S
C     **       LPCS(1) = 1      **
C                                  * FINT CIRCLE SECTOR OUTPUT
C     **       LPXY(1) = 1      **
C                                  * FINT XY CELL OUTPUT
C                               3 PROVIDES SPECIAL NCELL (NS-ENHEL)
C                               WRITE TO FILE 11.
C     **       ICTR(1) = 1      **
C                                  * FINT CONTOUR OUTPUT.
C     **       IPSC(1) = 1      **
C                                  * FINT SECTOR OUTPUT
C     **       LPCS(2) = 1      **
C                                  * FMIRR CIRCLE SECTOR OUTPUT.
C     **       LPXY(2) = 1      **
C                                  * FMIRR XY CELL OUTPUT
C     **       ICTR(2) = 1      **
C                                  * FMIRR CONTOUR OUTPUT
C     **       IPSC(2) = 2      **
C                                  * FMIRR SECTOR OUTPUT
C=S
C     **     IPSC(3) = 1 **
C     **     IPSC(4) = 1 **
C     **     IPSC(5) = 1 **
C     **     IPSC(6) = 1 **
C=S
C     **       LPXY(3) = 1      **
C                                  * FCOSI XY CELL OUTPUT) => NO AVER
C     **       LPXY(4) = 1      **
C                                  * FAREA XY CELL OUTPUT) => NO AVER
C     **       LPCS(7) = 1      **
C                                  * CIRCLE SEC. OUTPUT AND
C     **       LPXY(7) = 2      **
C                                  * XY CELL OUTPUT FOR SUMIT (DAILY).
C     **       IPSC(7) = 1      **
C                                  * SECTOR OUTPUT FOR SUMIT (DAILY)
C     **       LPCS(8) = 1      **
C                                  * CIRCLE SECTOR OUTPUT AND
C     **       LPXY(8) = 1      **
C                                  * XY CELL OUTPUT FOR SUMIT (ANNUAL).
C     **       IPSC(8) = 1      **
C                                  * SECTOR OUTPUT FOR SUMIT (ANNUAL)
C     **       LPCS(9) = 1      **
C                                  * DAILY CIRCLE SECTOR OUTPUT AND
C     **       LPXY(9) = 2      **
C                                  * XY CELL OUTPUT FROM RELPOW.
C     **       IPSC(9) = 1      **
C                                  * SECTOR OUTPUT FROM RELPOW
C     **       LPCS(10) = 1     **
```

```
C                                 * ANNUAL CIRCLE SECTOR OUTPUT AND
C      **      LPXY(10) = 1     **
C                                 * XY CELL OUTPUT FROM RELPOW.
C      **      IPSC(10) = 1     **
C                                 * ANNUAL SECTOR OUTPUT FROM RELPOW
C
C     *  *  *  SWITCH SETTINGS FOR RECEIVER OUTPUTS (CYLN5) *  *
C              SWITCH NAMES ENDING IN 11 - 14 CORRESPOND TO
C              RECEIVER OUTPUT VARIABLES AS FOLLOWS
C
C                 FINT, TFLUX, SUP, SRT
C                  11    12    13   14
C
C      **      LPCS(11) = 1     **
C      **      LPXY(11) = 1     **
C      **      IPSC(11) = 1     **
C      **      ICTR(11) = 1     **
C      **      LPCS(12) = 1     **
C      **      LPXY(12) = 1     **
C      **      ICTR(12) = 1     **
C
CONSTANTS FOR TIME CONTROLS
C
C*     COMMON /TIMEY/ JDVEQ,ESUN0,ESUN1,IMAX,JMAX,NSKIP,KVEC(13)
C           KVEC GIVES SAMPLE DAYS - 13TH DAY UNUSED BUT AVAILIBLE
       DATA KVEC/ 93,124,155,186,216,246,276,306,336,  0, 31, 62,365/
       JDVEQ = 2444320
C                             *JULIAN DAY OF VERNAL EQUINOX FOR MARCH 21,1980
C      **ESUN0 = 10. **
C                             *ELEVATION OF SUN AT STARTUP OR SHUTDWN
C                           FOR LEVEL PLANE IN DEGREES
C        **ESUN1 = 10.0 **
C                             *ELEVATION OF SUN AT STARTUP OR SHUTDOWN
C                              FOR THE INCILNED PLANE WHICH DEFINES THE
C                              HORIZON. (IN DEGREES) - SEE IPLANE IN
C                              INPUT MODULE FIELD.
C
C - TIME CONTROLS FOR ANNUAL PERFORMANCE PROGRAM
C*     COMMON /TIMEX/IDAYS,IHORS,NDAY1,HOUR0,HOUR1,HOUR2,NHRS,DHOUR
C      **IDAYS = 0 **
C                             *2 FOR 7 SAMPLE DAYS USING KVEC
C                           1 FOR JMAX DAYS USING NDAY1 AND NSKIP
C                           0 FOR NDAY1 ONLY
C      **NDAY1 = 186 **
C                             *DAYS AFTER VERNAL EQUINOX (IDAYS=0)
C      **JMAX  = 1 **
C                             *NUMBER OF SAMPLE DAYS (IDAYS=1)
C      **NSKIP = 30 **
C                             *NUMBER OF DAYS SKIPPED (IDAYS=1)
C      **IHORS = 3 **
C                             * 3 FOR AM+PM HOURS - STARTUP TO SHUTDWN
C                            2 FOR PM HOURS    - NOON TO SHUTDWN
C                            1 FOR HOUR1 TO HOUR2 IN NHRS-1 STEPS
C                            0 FOR HOUR0 ONLY (NO INTEGRATION)
C                           -1 FOR AM AND -2 FOR PM STARTUP AT ESUN0
C      **HOUR0 = 0. **
C                             *THE HOUR FOR IHORS =0
C      **HOUR1 = -6.650 **
```

```
C                                *THE INITIAL HOUR IF IHORS = 1
C       **HOUR2 = -5.620 **
C                                *THE FINAL HOUR IF IHORS = 1
C       **NHRS  = 5 **
C                                *NUMBER OF SAMPLE HOURS= 5,7,9 IF IHORS=2,1
C       **DHOUR = 0.1721 **
C                                *HOURS BETWEEN CALC. FOR IHORS=-2,-1
C

CONSTANTS FOR SUN
C*      COMMON /SUNX/ ALPHAL,R2,R4,R6
        DATA R2/.22416740E-0/,R4/.10433392E-0/,R6/.61979628E-1/
        ALPHAL = .004660
C                                * SOLAR LIMB ANGLE IN RADIANS
C*      COMMON /SUNF/ ROOTSQ, CF(4)
C                                        *FOR FLASH ONLY
        DATA ROOTSQ /5.213986/
C                                   *DEGRADED SUN SIZE FOR SIGMA=.003
        DATA  (CF(I),I=1,4) / .7286088,-.4695325,.1112683,-.0092093/
C THE ABOVE ARE COEFFICIENTS FOR FLASH FROM A KGEN2 FIT ON LBL SUN
C WITH SIGMA = .003 RADIANS.
C
C*      COMMON /HELI2/ UMIR,VMIR,SLOT

C=====================================================================
        AHELI = 3.14159265 * DMIR**2 / 4.
C                                  * S&B AREA OF ROUND HELIOS IN M2
C        AHELI = (UMIR-SLOT)*VMIR
C                                  * S&B AREA OF SQUARE HELIOS IN M2
C *** USER MUST SELECT THE APPROPRIATE FORMULA HERE AND IN LAYOUT ***
C=====================================================================
C
        RHELI = HGLASS/DMIR**2
        SHELI = HGLASS / AHELI
        WRITE(6,1000)  RHELI,SHELI
 1000   FORMAT(1H0,'***** HGLASS/DMIR**2 =',F7.4,'  HGLASS/AHELI =',F7.4)
C
C - PROGRAM CONTROL FOR ANNUAL PERFORMANCE PROGRAM
C*      COMMON /CALCX/ICOEF,ISVIS,NREC,DELR,JTRIM,
C*    &                 ISUMS,KANNU,ICLDF,JROW,JCOL,NPANL
C       **ICOEF = 1 **
C                              *1 FOR HERMITE COEFS, 0 FOR FLASH
C       **ISVIS = 0 **
C                              *  RELEVANT TO CAVITY RECEIVER MODEL
C                            0 NODES ON APERTURE SURFACE NOT VISIBLE
C                            1 NODES ARE VISIBLE
        NREC  = 21
C                              *  MAX DIMENS. OF FLUXDR FOR IMAGE PLANE OUTPUT
        DELR = 0.5
C                              *  METERS BETWEEN NODES OF FLUXDR ONLY
C       **ISUMS = 1 **
C                              *1 TO CALL SUMIT AND RELPOW, 0 NOT
C       **KANNU = 0 **
C                              *1 TO CALL PANPOW FOR PANEL POWER SUMMARY
C                              (WRITES FILES 39,40 AND CALLS PANPOW)
C                            2 SAME AS 1 AND WRITES FILE 30 FOR PUNCH
C                            0 NO ACTION AS ABOVE
        JROW  = 0
```

```
C                                        *0 GIVES ALL ROWS OTHERWISE JROW ONLY FOR
C                                        RC AND NS SYSTEMS
      JCOL   = 0
C                                        *0 GIVES ALL COLS OTHERWISE JROW ONLY FOR
C                                        RC AND NS SYSTEMS
C     **NPANL = 0 **
C                                       *>1 TO CREATE RANDOM FILE 38 AND TO CALL
C                                        HINT FOR PANSUM INTERPOLATION.
C                                      1 TO CALL CSPANL FOR CIRCLE SECTOR, OR
C                                      2 TO CALL FSCPAN FOR FIELD CONTROL SEGMENT
C                                        BREAKDOWN FOR INCIDENT PANEL POWER.
C                                      ( NOTE FSCPAN ALWAYS WRITES CARD FILE 30 )
C
C - PRINT AND I/O CONTROLS FOR ANNUAL PERFORMANCE PROGRAM
C*    COMMON/PRINTX/IPSAB,IPMIR,IPANCT,JDISK,KDISK,
C*   &              NFILES,RATIO,IHNODE
C     **IPSAB = 1 **
C                                        *2 FOR DIAGONISTIC BOUNDARY VECTOR OUTPUT
C                                      1 TO CALL SHADING AND BLOCKING
C                                     -1 FOR NO SAB CALC
      IPMIR = 1
C                                        *2 FOR IMAGE PRINT, 1 FOR HEADINGS, 0 NONE
      IPANCT= 0
C                                        *2 FOR PRINT&CONTOUR, 1 FOR CONTOUR, 0 NONE
C
C
C     **JDISK = 0 **
C                                        *1 INDICATES WHOLE FIELD NODE FILE
C                                     -1 INDICATES HALF FIELD (CELLWISE) NODE FILE
C                                      0 SUPRESSES WRITE TO FILE 14 IN CYLN
C     **KDISK = 0 **
C                                        *1 TO READ FILE 14 AND CALL- FINTP1.
C                                         0 TO USE FINTS GENERATED BY IFINTU IN
C                                           INPUT MODULE RECVER
C     **NFILES= 1 **
C                                        *NODE FILES TO BE READ (IF KDISK=1)
C                                        1 TO READ FILE 14
C                                        2 TO READ FILES 14 AND 24
C     **RATIO = .30 **
C                                        *FRACTION OF FIRST PANEL MATRIX IF NFILES = 2
C     **IHNODE = 0 **
C                                        * 1 TO READ OR WRITE AN INDIVIDUAL HELIOSTAT,
C                                          0 TO READ A CELLWISE NODE FILE
C
C
C   INPUTS TO DEFINE A COLLECTOR SUBFIELD FOR PROCESSING
C          ( THIS FIGURE IS NOT VERY CLEAR.)
C                                             -1.0 1 +1.0
C                                          ANG2    1    ANG1*
C                                                  1
C                                        ---------------------
C                                                  1
C                                            ANG1  1    ANG2*
C                                             0.0  1 0.0
C     **IFIELD = 0 **
C                                         *1 TO CALL SUBFLD, 0 NOT TO
      ANG1 =  -0.67
C=S                                   * ANG1 > ANG2
```

```
C                                   *FIRST AZIMUTH (PI UNITS) FOR SUBFLD
      ANG2 = -0.83
C                                      *SECND AZIMUTH (PI UNITS) FOR SUBFLD
C                                 SUBFLD SELECTS HELIOS FOR RUNSTREAM
      IROW1 = 1
C                                   *OUTER CIRCLE TO END COLLECTOR SUBFIELD
      IROW2 = NROW
C                                   *INNER CIRCLE TO END COLLECTOR SUBFIELD
      ANP1 = 0.0
C                                   *RANGE OF ANGLES FOR SECTORS TO BE
      ANP2 = 0.0
C                                   *PRINTED OUT ANP1<PHI<ANP2 (RADIANS)
C                                   AZIMUTH NEG. TO WEST POS. TO EAST
C                                   NOT ACTIVATED BY IFIELD
      NCIR  = 3
C                                   *NUMBER OF CIRCLES SCANNED BY SABI
C
C
      CALL STDIH(IRCVR,JGRECP,ISTDIH)
      CALL IHYEAR(HT,IGREC,JGREC,PANEL,PANEL2,FLREC,FLRECP,MAXH,MAXF,
     &   MAX2,FCOSI,FMIRR,FINT,FAREA,RTPOW,ERGM1,ERGM2,FSAB,ASAB,NH,
     &   NHT,XC,YC,ZC,AZ,NFCSN,NCR,NS,NSP,NXD,NYD,CFINT,MAXIJ,KGREC,
     &   NCELI,NSURF,ASURF,NSF,NST,GREC,AZC,VIS0,VIS1,ENHELX,TFLUX,
     &   SRT,SLF,SUP,SDN,ACELL,NCELL,AI,AJ,JGRECP,PANELH,PANELV,
C=S     &   LGRND,XGRND,FGRND,SRAZ1,IHEL,TIMIT,XTIME2,IRCVR)
     &   LGRND,XGRND,FGRND,SRAZ1,IHEL,TIMIT,XTIME2,IRCVR,AL)
C
      STOP
      END
C=======================================================================
C$$$$$$$$$$$$$$$$$$$==========<   end main program of ih code   >=========
C




      SUBROUTINE STDIH(IRCVR,JGRECP,ISTDIH)
C
C                             1 GIVES MULTI-PLANE TEST (SAB ONLY)
C                             2 GIVES RECEIVER RUN AND WRITES AN
C                               INDIVIDUAL HELIOSTAT NODE FILE TO 14
C                             3 GIVES ANNUAL PERFORMANCE RUN, READING
C                               AN IH NODE FILE.
C                             4 GIVES A CIRCLE SECTOR PANEL POWER PRINT AT SET
C                               TIME AND INSOLATION.
C
      COMMON /TIMEY/ JDVEQ,ESUN0,ESUN1,IMAX,JMAX,NSKIP,KVEC(13)
      COMMON /TIMEX/IDAYS,IHORS,NDAY1,HOUR0,HOUR1,HOUR2,NHRS,DHOUR
      COMMON/PRINTX/IPSAB,IPMIR,IPANCT,JDISK,KDISK,
     &              NFILES,RATIO,IHNODE
      COMMON /CALCX/ICOEF,ISVIS,NREC,DELR,JTRIM,
     &              ISUMS,KANNU,ICLDF,JROW,JCOL,NPANL
      COMMON /TOWER/ICYLN,HCYLNT,WCYLNT,HCYLN,WCYLN,OFSET,REFLT,ABSOR,
     &              FRLOS,NPANLS,INODE1,INODE2,JNODE1,JNODE2
      COMMON /GRPLS/ASDCS(7,10),ASDIN(12,10),ASDFM(7,10)
      COMMON /SITE/ XLAT,ILAT,MONTH,HS,XSURVY,YSURVY,ZSURVY(5),
     &        INPUTL,NPLANE,IPLANE,MAXMIN,NREVSD,EGRND(5),AGRND(5)
```

```
      COMMON /CELL/ORDER,DA,AC,XTOWI,YTOWJ,NBOR,KORY,LRAY,LGEO,DTRIM
      COMMON /RECVR/ XDUM1(13),NVERI,XDUM2(7)
      COMMON /XYOUT/LPXY(14)
      COMMON/CSOUT/LPCS(14)
      COMMON /SECOUT/IPSC(14)
      COMMON /CTROUT/ICTR(14)
      CHARACTER*30 MESAG0,MESAG(4)
      DATA MESAG0          /'ERROR:IMPROPER VALUE OF ISTDIH'/
      DATA (MESAG(I),I=1,4)/' DESIGN POINT POWER TEST      ',
     *                      ' RECEVER RUN WRITE TO FILE 14 ',
     *                      ' ANNUAL RUN AND READ IH NODE  ',
     *                      ' READ NODE FILE OUT FLUX MAP  '/




C========= ISTDIH = 0 =========================================
C
C     WARNING: NO changes to istdih=0 settings are allowed
c           because any changes will affect the other istdih options.
c
c     Explanations of most switch settings are given in IHDRIV.
C
c                               Variable defined in IHDRIV near:
      DO 2 I=1,14
      LPCS(I)=0
c                              lines 555-572
      LPXY(I)=0
c                              lines 555-577
      IPSC(I)=0
c                              lines 555-580
      ICTR(I)=0
c                              lines 555-572
2     CONTINUE
      LPCS(1)=1
c                              line  583
      LPXY(1)=1
c                              line  585
      LPCS(2)=1
c                              line  593
      LPXY(2)=1
c                              line  595
      IPSC(2)=1
c                              line  599
      ICTR(2)=1
c                              line  597
      ESUN0 = 10.
c                              line  658
      ESUN1 = 10.
c                              line  661
      IDAYS = 0
c                              line  669
      NDAY1 = 186
c                              line  673
      JMAX = 1
c                              line  675
      NSKIP = 30
c                              line  677
```

```
      IHORS = 0
c                                   line  679
      HOUR0 = 0.
c                                   line  685
      HOUR1 = -6.650
c                                   line  687
      HOUR2 = -5.620
c                                   line  689
      NHRS = 5
c                                   line  691
      DHOUR = 0.1721
c                                   line  693
      ICOEF = 1
c                                   line  728
      ISVIS = 0
c                                   line  730
      ISUMS = 0
c                                   line  738
      KANNU = 0
c                                   line  740
      NPANL = 0
c                                   line  751
      IPSAB = 1
c                                   line  762
      JDISK = 0
c                                   line  772
      KDISK = 1
c                                   line  776
      NFILES = 1
c                                   line  780
      RATIO = 0.30
c                                   line  784
      IHNODE = 0
c                                   line  786
      IFIELD = 0
c                                   line  800
c
        NBOR = 8
c                                   line  187
c                                              (of input module FIELD)
        NVERI = 4
c                                   line  188
c                                              (of input module RECVER)




      write(6,40) istdih
40    format(1x,' istdih=',i3)
c
      if(istdih.lt.1 .or. istdih.gt.4) then
      write(6,50) ((mesag0,j=1,4),i=1,12)
50    format(1x,'stdih report',//,(1x,4a30))
      return
      endif


c     SET ISTDIH NEAR LINE 538 OF IHDRIV.
```

```
c
      GOTO(100,200,300,400), ISTDIH
c========== istdih=1  --- DESIGN-POINT POWER TEST ==========
C
  100  continue
       IRCVR = 0
       JDISK =-1
       KDISK = 1
       NVERI = 1
       IPSC(2) = 1
       LPXY(3) = 1
       LPXY(4) = 1
       IHORS = 0
       ISUMS = 0
C         ALTERNATIVE AFTERNOON TEST
C           (REMOVE C'S FROM NEXT 8 LINES TO ACTIVATE.)
C       ISUMS = 1
C       IHORS = 3
C       DO 3 I = 3,6
C    3  IPSC(I) = 1
C       DO 4 I = 7,10
C       LPCS(I) = 1
C       LPXY(I) = 1
C    4  IPSC(I) = 1
      write(6,50) ((mesag(istdih),j=1,4),i=1,12)
      return
C
c========== istdih=2  --- receiver run and write to file 14 ==========
  200 IHNODE = 1
      write(6,50) ((mesag(istdih),j=1,4),i=1,12)
C    10 HOUR RUN ?
      RETURN
C
c========== istdih=3  --- annual run and read ih node file ==========
  300 IDAYS = 2
      IHORS = 2
      JMAX = 7
C       LONG RUN. MUCH OUTPUT.
      ISUMS = 1
      KANNU = 1
      IPSAB = 1
      IRCVR = 0
      JDISK = 0
      KDISK = 0
      IHNODE = 1
      IF(JGRECP.EQ.1)STOP'***** JGRECP = 1  -  STOP'
      write(6,50) ((mesag(istdih),j=1,4),i=1,12)
      RETURN
```

```
C



C=========  istdih=4  ---  circle sector panel power print (?)======

  400 NDAY1 = 246
      HOUR0 = 2.714
      NPANL = 1
      IPSAB = 1
      ICYLN = -2
      KDISK = 0
      LPXY(2) = 1
      IPSC(2) = 1
      LPCS(2) = 1
      ICTR(2) = 1
      MONTH = -1
      ASDIN(1,1) = 668.4
      write(6,50) ((mesag(istdih),j=1,4),i=1,12)
      RETURN
C========================< * >==============================
C
      END
C
C
      FUNCTION ISKIP(IDENT)
C
C       TABLE ENTRIES ARE IDENTIFICATION NUMBERS AS GENERATED
C       BY THE LAYOUT SUBROUTINE.
C
      DIMENSION JSKIP(20)
      DATA JSKIP
C                                                   *REMOVALS
     & /11104,20807,30604,17*0/
C
      DATA ICTR/1/
      ISKIP = 0
    1 IF(JSKIP(ICTR).EQ.0) RETURN
      IF(IDENT.LT.JSKIP(ICTR)) RETURN
      IF(IDENT.EQ.JSKIP(ICTR)) GO TO 2
      IF(ICTR.EQ.100) RETURN
      ICTR = ICTR + 1
      GO TO 1
    2 ISKIP = IDENT
      RETURN
      END
C
C
      FUNCTION RSFC(ETA,CNSAZM)
      EXTERNAL POLYNM
      DOUBLE PRECISION WKSPC(25,25)
C=S1
      DOUBLE PRECISION COFLST(25),POLYNM
C=S1     DIMENSION CELAYC(4,3,5),RS(4),AZP(4),AZ(4,5),COFLST(25)
      DIMENSION CELAYC(4,3,5),RS(4),AZP(4),AZ(4,5)
C
      COMMON /ZONE0/IROW,NHEL,NTOT,PIMATH,CORREC(10),ZFACTR,LP
      COMMON /ZONE3/ RSYMIN,RSYMAX,SLIP,HALFAZ,IPR
```

```
      DOUBLE PRECISION PIMATH
      RFUNC(C1,C2,C3,THETA) = C1/THETA+C2+C3*THETA
      DATA ((CELAYC(I,J,1),J=1,3),I=1,4)
C    &/11.029639E+01,-5.000485E+00,0.12105369E+00,
C    &  6.9032726E+01,-2.138353E+00,6.5151829E-02,
C    &  5.0959349E+01,-7.1915046E-01,3.165254E-02,
C    &  5.1593222E+01,-8.7070580E-01,3.511535E-02/
C     &/7.6256948E+01,-6.3566463E-01,2.0852482E-02,
C     & 4.9358923E+01,3.3424066E-01,7.6399559E-03,
C     & 5.2074868E+01,-1.1602792E-01,1.2732010E-02,
C     & 5.0780993E+01,3.5846674E-02,6.1396681E-03/
     &/70.275221,-.41671634,.01432542,
     & 73.88254, -1.5312818, .0375428025,
     & 60.06000, -.8780765, .026279666,
     & 57.101759, -.6658293, .01937958/
      DATA ((CELAYC(I,J,2),J=1,3),I=1,4)
     &/7.6256948E+01,-6.3566463E-01,2.0852482E-02,
     & 4.9358923E+01,3.3424066E-01,7.6399559E-03,
     & 5.2074868E+01,-1.1602792E-01,1.2732010E-02,
     & 5.0780993E+01,3.5846674E-02,6.1396681E-03/
      DATA ((CELAYC(I,J,3),J=1,3),I=1,4)
     &/7.6256948E+01,-6.3566463E-01,2.0852482E-02,
     & 4.9358923E+01,3.3424066E-01,7.6399559E-03,
     & 5.2074868E+01,-1.1602792E-01,1.2732010E-02,
     & 5.0780993E+01,3.5846674E-02,6.1396681E-03/
      DATA ((CELAYC(I,J,4),J=1,3),I=1,4)
     &/7.6256948E+01,-6.3566463E-01,2.0852482E-02,
     & 4.9358923E+01,3.3424066E-01,7.6399559E-03,
     & 5.2074868E+01,-1.1602792E-01,1.2732010E-02,
     & 5.0780993E+01,3.5846674E-02,6.1396681E-03/
      DATA ((CELAYC(I,J,5),J=1,3),I=1,4)
     &/7.6256948E+01,-6.3566463E-01,2.0852482E-02,
     & 4.9358923E+01,3.3424066E-01,7.6399559E-03,
     & 5.2074868E+01,-1.1602792E-01,1.2732010E-02,
     & 5.0780993E+01,3.5846674E-02,6.1396681E-03/
C     DATA (AZ(I,1),I=1,4) /1.8955,2.1185,2.3415,2.5645/
C      DATA (AZ(I,1),I=1,4) /1.785,1.995,2.205,2.415/
      DATA (AZ(I,1),I=1,4) /1.4535,1.6245,1.7955,1.9665/
      DATA (AZ(I,2),I=1,4) /1.785,1.995,2.205,2.415/
      DATA (AZ(I,3),I=1,4) /1.785,1.995,2.205,2.415/
      DATA (AZ(I,4),I=1,4) /1.785,1.995,2.205,2.415/
      DATA (AZ(I,5),I=1,4) /1.785,1.995,2.205,2.415/
      RAD = 180./3.1415926535
      THETA = ETA * RAD
      AITRMX = AZ(4,LP)
      AITRMN = AZ(1,LP)
C     IF(THETA .LT. 20.0) AITRMN = AZ(2,LP)
      NUMPTS = 4
      NUMCON = 3
      M = NUMCON + 1
      DO 100 IAZ = 1,4
      RS(IAZ) = RFUNC(CELAYC(IAZ,1,LP), CELAYC(IAZ,2,LP),
     & CELAYC(IAZ,3,LP), THETA)
  100 AZP(IAZ) = AZ(IAZ,LP)
C*** LSQF AND VALF COME FROM UH/SLIBB/UH
      CALL LSQF(AZP,RS,NUMPTS,M,POLYNM,COFLST,WKSPC)
      IF( CNSAZM .GT. AITRMX ) CNSAZM = AITRMX
      IF( CNSAZM .LT. AITRMN ) CNSAZM = AITRMN
```

```
      RSFC = VALF(CNSAZM,COFLST,M,POLYNM)
      RETURN
      END
C
C
      DOUBLE PRECISION FUNCTION POLYNM(X,K)
      POLYNM = X**K
      RETURN
      END
C
C
C
C
      FUNCTION TRFC(R)
      TRFC = 0.
      IF(R.LE.2.55)RETURN
      TRFC = (78.05/57.0) * SQRT((R/2.55)**2 -1)
C                                                          *COMM TRIM OPTION
      RETURN
      END
C
C
C
      FUNCTION NDRCT(IROW,JHEL)
      DIMENSION KMAG(20)
C*************************************************************
C        FOR 20 HELIOSTAT SEQUENCE FOR .35 HI&LO, .30 BELT .
C        TO BE USED WITH CYLINDRICAL RECIEVERS.
C*************************************************************
      DATA (KMAG(I),I=1,20) /1,-1,0,1,-1,0,1,-1,0,1,-1,0,
     &                       1,-1,0,1,-1,0,1,-1/
      JAIM = JHEL
      DO 100 LCOUNT = 1,20
          IF( JAIM .LT. 21 ) GO TO 101
          JAIM = JAIM - 20
  100 CONTINUE
  101 CONTINUE
      NDRCT = (-1)**(IROW+1) * KMAG(JAIM)
C
C*******************************************************
C         GIVES 4PT AIMS FOR FLAT RECIECERS ONLY.
C*******************************************************
C      DATA (KMAG(I),I=1,4)/ 1, 1,-1,-1/,NFLAG/ 1/
C      NDRCT = NFLAG * KMAG( 1 + MOD( JHEL-1 + IROW-1 , 4 ) )
C
      RETURN
      END
```

APPENDIX F.6

LH

REFERENCES

REFERENCES

REFERENCES

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   APS, BV, CBI Industries (CBI), Foster Wheeler Solar Development Corp. (FW), Olin Corp. (Olin), Precision Controls and Instrumentation (PCI), and UH, *Alternate Utility Team: Utility Solar Central Receiver Study*, Vols. 1 & 2, DOE Report No. DOE/AL/38741-2 (Springfield, VA: NTIS, Sept. 1988).†

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† The **Utility Study** (Phase 1, 1987) consisted of three parallel teams: the APS team (ref. 7), the Alternate Utility Team (ref. 7), and the PG&E team (ref. 8). Although a separate team, the AUT reported to DOE through APS, and so the two reports are grouped together in ref. 7.

8. Pacific Gas and Electric Company (PG&E) and Bechtel National, Inc., ed. by P. De Laquil III, B. D. Kelly, & J. C. Egan, *Solar Central Receiver Technology Advancement For Electric Utility Applications: Phase I Topical Report*, Vols. 1 & 2, prepared for DOE under Cooperative Agreement DE-FC04-86AL38740 and for the Electric Power Research Institute (EPRI) under RP 1978-1, PG&E Report No. GM 633022-9 (San Ramon, CA: PG&E, Aug. 1988). Equivalently, Bechtel Report No. 007.2-88.2 (San Francisco, CA: Bechtel, Aug. 1988). Presumably, this report will also be released as DOE Report No. DOE/AL/38741-3. See footnote to ref. 7.

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