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SURVEY MIRRORS AND LENSES AND THEIR REQUIRED SURFACE ACCURACY

Volume 2: Concentrator Optical Performance Software (COPS) User's Manual
Final Report for September 15, 1978—December 1, 1979

January 1980

Work Performed Under Contract No. EM-78-C-04-5348

Honeywell Inc.
Technology Strategy Center
Minneapolis, Minnesota

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Solar Energy

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SURVEY MIRRORS AND LENSES AND THEIR REQUIRED SURFACE ACCURACY

VOLUME II
CONCENTRATOR OPTICAL PERFORMANCE SOFTWARE (COPS) USER'S MANUAL

CONTRACT NO. DE-AC04-78CS35348

JANUARY 1980

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THROUGH
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PREPARED FOR

U.S. DEPARTMENT OF ENERGY
ALBUQUERQUE OPERATIONS OFFICE

PREPARED BY

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FOREWORD

Readers of this report and users of the Concentrator Optical Performance Software (COPS) program should be cautioned that although the program has been used and appears to be relatively error-free, some "bugs" may well remain and have yet to show up in our trial cases. Further, since some changes and updates occurred in developing the model, some usused variables may remain. Needless to say, the authors cannot take responsibility for any version of the program which does not correspond exactly to the program listing in this report.

This work has been supported by the Solar Heating and Cooling Research and Development Branch, Office of Conservation and Solar Applications, U.S. Department of Energy.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (CONCLUDED)

LIST OF TABLES

SECTION 1
INTRODUCTION

The Concentrator Optical Performance Software (COPS) program was developed as a portion of the project "Survey Mirrors and Lenses and Their Required Surface Accuracy," Contract Number DE-AC04-78CS35348 for the U.S. Department of Energy, Albuquerque Operations Office. This User's Manual for the COPS program documents the mathematical modeling of 11 different concentrating collectors and gives the instructions for use of the computer code. The 11 concentrators modeled are:

- Faceted Mirror Concentrator.
- Fixed Mirror, Two-Axis Tracking Receiver.
- Parabolic Trough.
- Linear Fresnel.
- Incremental Reflector (by Honeywell).
- Inflated Cylindrical Concentrator.
- CPC--Involute Reflector with Evacuated Receiver.
- CPC--Parabolic/Involute Reflector.
- Vee Trough (by JPL).

- Imaging Collapsing Concentrator (by SET, Inc.).

- Paraboloid of Revolution Dish.

The COPS program is a FØRTRAN code which simulates the optical performance of each of these concentrators using a Monte Carlo ray trace technique. This technique computes an optical efficiency defined as the fraction of available direct insolation that reaches the outer surface of a receiver for each concentrator. The program can also create a map of power density on the receiver surface. These computations are performed for a point in time as specificed by the user.

Users of the program are cautioned that it is quite possible to obtain misleading results for optical efficiency by an inappropriate choice of surface, material errors, or by selecting too few rays to be traced for the desired answers. However, experience in using the program often leads quickly to the avoidance of these difficulties. Potential users are urged to get a "feel" for the program before batch processing large numbers of ray traces.

The basic ray trace technique for the optical model computer software follows a Monte Carlo ray trace approach. Honeywell has been using this approach since it began making studies of parabolic trough collectors 6 years ago.

The code was initially developed because of Honeywell's concern with the effect of mirror surface accuracy and tracking errors on the performance of the solar collectors. The ray trace Monte Carlo approach was selected because in most cases these errors are known only statistically. Furthermore, the ray trace approach allows the investigation of different optical elements such as mirrors and lenses. In most cases, the introduction of a single equation describing the optical surface (mirror or lens) in the ray path is sufficient for the simulation of a wide range of concentrator types.

SECTION 2
MONTE CARLO METHOD

BASIC FORMULATION

Given a position of a mirror/lens surface relative to the receiver, the amount of energy carried from any point on the sun's surface monochromatically at any given instant depends on the exact path of the ray through the optical interfaces of the system. The angle made by any ray with respect to each surface is a function only of the angular position on the solar disk from which the ray came and the impact point on the particular surface. Thus, for any wavelength and perfect optics, the energy carried from the sun to the receiver surface can be found by specifying the four coordinates of the ray, independent of the number of optical elements in the optics train.

If the sun's disk coordinates are δ_1 and δ_2 and the surface impact point coordinates are X_1 and X_2, then the total thermal power absorbed in a wavelength interval $d\lambda$ is:

$$E_{d\lambda} = \int_{X_1} \int_{X_2} \int_{\delta_1} \int_{\delta_2} E(X_1, X_2, \delta_1, \delta_2)\, dX_1 dX_2 d\delta_1 d\delta_2$$

where X_1 and X_2 are bounded by the actual surface extent of the mirror/lens system. To obtain the energy from the entire solar spectrum, integration over all wavelengths is required. This yields:

$$E_p = \underbrace{\int_{\lambda}}_{\text{Total Spectrum}} \overbrace{\int_{X_1} \int_{X_2}}^{\substack{\text{Mirror} \\ \text{Surface}}} \overbrace{\int_{\delta_1} \int_{\delta_2}}^{\substack{\text{Sun} \\ \text{Disk}}} E(X_1, X_2, \delta_1, \delta_2, \lambda) dX_1 dX_2 \, d\delta_1 d\delta_2 d\lambda$$

Introducing finite quality optics into the model introduces uncertainty in tracking accuracy and mirror quality.

There can be four uncertain optical parameters that are known only statistically. The first two parameters are uncertainties in the angular position of two possible gimbaled tracking drives (θ_1, θ_2). The second two parameters are the angular uncertainties in the mirror/lens surface normal at any point on the mirror/lens surface (ϕ_1, ϕ_2). We assume that each of these four parameters is statistically independent of each other or any other design parameter. For example, a given error in a mirror normal is equally likely anywhere on the mirror surface. The mirror is not known as a continuous surface with smooth waves or ripples but rather as a probability distribution of mirror normals perturbed from the mathematically correct shape by an assumed probability distribution. For each statistically known variable, the distribution is understood to be a "normal" or "standard error" distribution. Tracking errors can be treated as a discrete error when single-time point optical characteristics are desired.

Now consider a random variable, Z, defined by the normalized probability distribution P(Z). If we wished to calculate the mean value of Z (= $\overline{Z}$) or its expected value, we would form the integral of the product of $P_Z(Z)$ times Z over all allowed values of Z, i.e.,

$$\bar{Z} = \int_{-\infty}^{\infty} P_Z(Z) Z dZ$$

To simulate a specific error set (θ_1, θ_2, ϕ_1, ϕ_2), one would have to evaluate:

$$E_p(\theta_1,\theta_2,\phi_1,\phi_2) = \int_\lambda \int_{X_1} \int_{X_2} \int_{\delta_1} \int_{\delta_2} E(X_1,X_2,\delta_1,\delta_2,\lambda,\theta_1,\theta_2,\phi_1,\phi_2) dX_1 dX_2 d\delta_1 d\delta_2 d\lambda$$

Then the expected value of the termal power absorbed ($\bar{E}_p$) is given by:

$$\bar{E}_p = \int_{\theta_1} \int_{\theta_2} \int_{\phi_1} \int_{\phi_2} P_{\theta_1}(\theta_1) P_{\theta_2}(\theta_2) P_{\phi_1}(\phi_1) P_{\phi_2}(\phi_2) E_p(\theta_1, \theta_2, \phi_1, \phi_2) d\theta_1 d\theta_2 d\phi_1 d\phi_2$$

because each distribution may be statistically independent. The above expression is:

$$\bar{E}_p = \underbrace{\int_{\theta_1} \int_{\theta_2}}_{\text{Tracking Imputs}} \underbrace{\int_{\phi_1} \int_{\phi_2}}_{\text{Mirror Imper- fections}} P_{\theta_1} P_{\theta_2} P_{\phi_1} P_{\phi_2} \underbrace{\int_\lambda}_{\text{Total Spectrum}} \underbrace{\int_{X_1} \int_{X_2}}_{\text{Mirror Area}} \underbrace{\int_{\delta_1} \int_{\delta_2}}_{\text{Sun Disk}} E d\delta_2 d\delta_1 dX_2 dX_1 d\lambda d\phi_2 d\phi_1 d\theta_2 d\theta_1$$

The stochastic nature of four of the independent variables in this equation and the prime objective of performing a parametric study of the performance of the system led to the decision that the experimental Monte Carlo approach was suitable.

Basically, the premise of the method used to solve the multiple integral is a Monte Carlo technique. Any Monte Carlo computation that yields quantitative results may be considered as estimating the value of a multiple integral.

The simplest Monte Carlo approach is to observe random numbers, selected in such a way that they directly simulate the physical random processes of the problem at hand, and to deduce the required solution from the behavior of these numbers. In this project, that process involves the incident flux on the receiver over the direct solar flux on the mirror/lens aperture being equal to the convergent ratio of randomly drawn rays that reach the receiver divided by the total number of rays drawn uniformly over the concentrator aperture. Appropriate scaling of each ray value for reflectance and absorptance losses, tracking and reflective surface errors, etc., is included in the Monte Carlo simulation.

APPROACH

Figure 2-1 indicates the general program flow for any concentrator design. Input parameters include the following user options:

- Concentrator type.
- Receiver geometry.
- Reflective or lensing material.
- Error distribution.
- Time integration or time point run.
- Number of rays to trace.
- Concentrator/receiver dimensions.

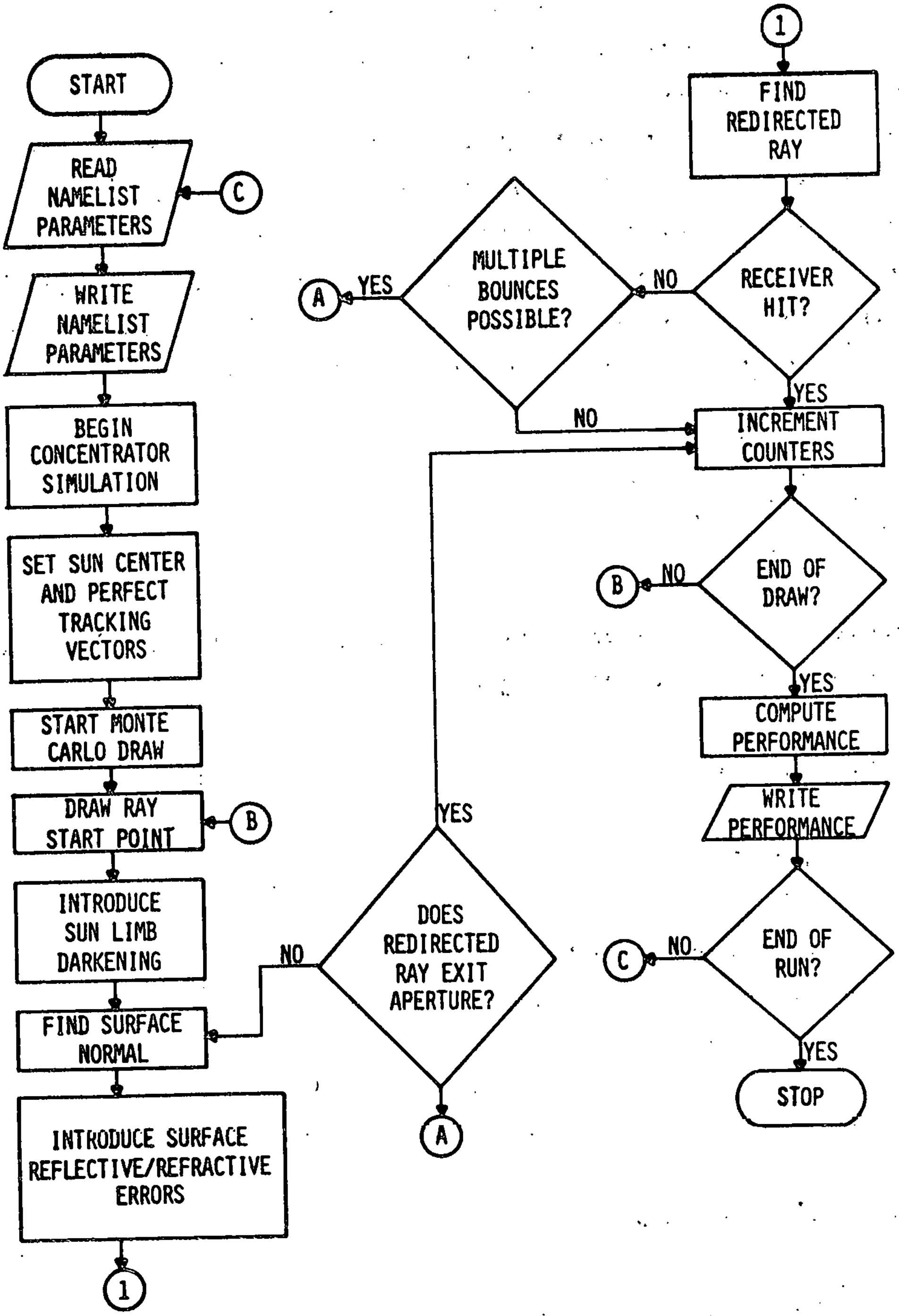


Figure 2-1. Generalized Computer Software Flowchart

For each concentrator/reflector that is being simulated, the Monte Carlo draw is made over the surface. The simulation is accomplished by randomly selecting a sufficient number of sun rays to statistically represent the sun's intensity pattern as seen from the earth's surface. Solar limb darkening and atmospheric losses are taken into account. These same rays are allowed to impinge randomly upon the mirror/lens aperture and are reflected toward the receiver. The drawn rays must represent the sun's power at that time, so each ray is given a relative weighted value as a function of the time and the number of rays drawn.

Each time a ray is drawn at some point on the concentration surface, the surface normal at that point is calculated. The surface error is a perturbation of the surface normal drawn at random over a normal distribution. This distribution has a mean and standard deviation based on the properties of the backing material and reflective/lensing materials being examined.

The ray trace technique uses vector algebra to track each ray along its optical path. The following section describes the needed concentrator specific vector derivations, as well as some basic modeling philosophy.

SECTION 3
RAY TRACE METHODOLOGY

This section describes the vector algebra derivations used in the Monte Carlo ray trace technique. The subsections are arranged to:

- Show the basic vectors and nomenclature required for all concentrator types modeled.
- Derive those general purpose steps such as reflections and refractions.
- Show the detailed mathematical modeling of all concentrator surfaces and all possible receivers.

A list of variable definitions used in the mathematical descriptions is contained in Table 3-1.

BASE VECTORS

To determine the optical efficiency for any concentrator design, we will trace the sun's ray as it is redirected to the receiver by the concentrator. To determine the reflected/refracted ray, the sun ray's direction and the surface normal must be defined. The concentrator position and sun position will be represented relative to a local unit vector triad (see Figure 3-1) with $\overrightarrow{ULV}$ being local vertical; $\overrightarrow{ULE}$, local east; and $\overrightarrow{ULS}$, local south. The unit vector to the center of the sun at any particular time is:

$$\overrightarrow{USUN} = \sin(\alpha)\cos(\varepsilon)\,\overrightarrow{ULE} + \cos(\alpha)\cos(\varepsilon)\,\overrightarrow{ULS} + \sin(\varepsilon)\,\overrightarrow{ULV}$$

Table 3-1. Variable Definitions for Mathematical Models

VARIABLES	DEFINITION
$\overrightarrow{ULS}$, $\overrightarrow{ULE}$, $\overrightarrow{ULV}$	LOCAL UNIT VECTOR TRIAD $\overrightarrow{ULS}$ - SOUTH $\overrightarrow{ULE}$ - EAST $\overrightarrow{ULV}$ - LOCAL VERTICAL
$\overrightarrow{UCA}$, $\overrightarrow{UCN}$, $\overrightarrow{UCP}$	COLLECTOR UNIT VECTOR TRIAD $\overrightarrow{UCN}$ - NORMAL TO APERTURE $\overrightarrow{UCP}$ - UNIT VECTOR ALONG WIDTH OF CONCENTRATOR $\overrightarrow{UCA}$ - UNIT VECTOR ALONG LENGTH OF CONCENTRATOR
x, y, z	DISTANCES IN THE $\overrightarrow{UCA}$, $\overrightarrow{UCP}$, $\overrightarrow{UCN}$ DIRECTIONS, RESPECTIVELY
x_o, y_o, z_o	COORDINATES OF SUN RAY HIT POINT ON SURFACE
$\overrightarrow{USUN}$ or $\overrightarrow{US}$	UNIT VECTOR IN DIRECTION OF SUN POSITION
$\overrightarrow{UN}$	UNIT NORMAL TO CONCENTRATOR SURFACE
$\overrightarrow{UR}$	UNIT VECTOR IN DIRECTION OF RE-FLECTED RAY OR REFRACTED RAY
α	SUN'S AZIMUTH ANGLE
ε	SUN'S ELEVATION ANGLE
n_1	INDEX OF REFRACTION FOR AIR
n_2	INDEX OF REFRACTION FOR LENS
RL	RECEIVER LENGTH
RW	RECEIVER WIDTH
r_{abs}	RECEIVER RADIUS (CYLINDRICAL)

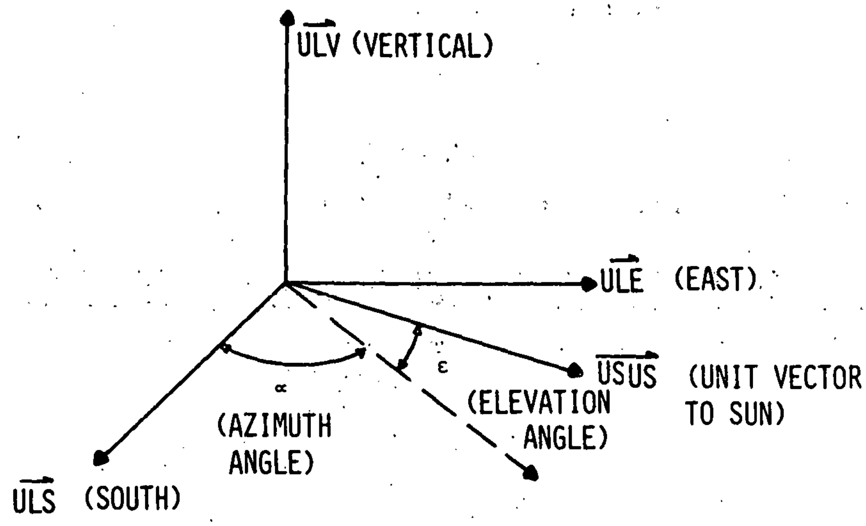


Figure 3-1. Base Vector Definitions

The sun vector in combination with the surface unit normal will be used later to calculate the redirected ray.

Before proceeding to other general-purpose vector derivations, a vector triad will be defined that is fixed with respect to the concentrator position. For all concentrators discussed, $\overrightarrow{UCN}$ is the vector normal to the concentrator aperture, $\overrightarrow{UCA}$ is the vector along the concentrator axis (length) and $\overrightarrow{UCP}$ is the vector along the concentrator width. These vectors will change depending on whether the concentrator is two-axis tracking, one-axis tracking, or stationary. However, a general formulation for the tracking vector triad can be made. The vector $\overrightarrow{UCA}$ (see Figure 3-2) can be expressed as:

$$\overrightarrow{UCA} = \cos(AX)\ \overrightarrow{ULE} + \sin(AX)\ \overrightarrow{ULS}$$

where AX is the angle between the tracking axis vector $\overrightarrow{UCA}$ and local east direction (east is zero, south is positive). The vector along the concentrator width is:

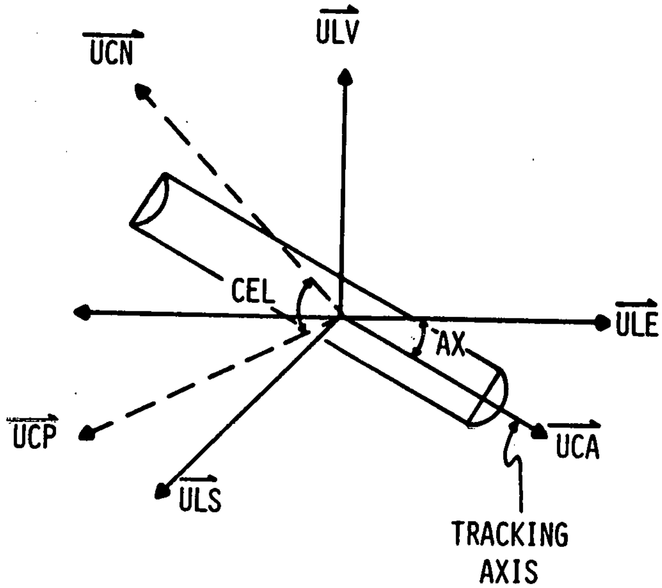


Figure 3-2. Tracking Vector Geometry

$$\overrightarrow{UCP} = -\sin(AX)\ \sin(CEL)\ \overrightarrow{ULE} + \cos(AX)\ \sin(CEL)\ \overrightarrow{ULS} - \cos(CEL)\ \overrightarrow{ULV}$$

where CEL is the collector elevation angle (angle between the collector normal and a horizontal plane).

The vector $\overrightarrow{UCN}$ is then:

$$\overrightarrow{UCN} = -\cos(CEL)\ \sin(AX)\ \overrightarrow{ULE} + \cos(CEL)\ \cos(AX)\ \overrightarrow{ULS} + \sin(CEL)\ \overrightarrow{ULV}$$

These three equations apply to all concentrator orientations and tracking types. By varying the values of AX and CEL, we can define the concentrator triad for any tracking mode.

For a two-axis tracking concentrator, the angles AX and CEL follow the sun's movement and are changing with time. Thus, the vector triad is as given in the above equations: for perfect tracking, $AX = -\alpha$. If the azimuth, α, and elevation, ε, are known, CEL can be determined using the off-axis angle (the angle between $\overrightarrow{US}$ and $\overrightarrow{UCN}$). Perfect two-axis tracking occurs when the dot product of $\overrightarrow{UCN}$ and $\overrightarrow{US}$ is a maximum. This maximum is calculated by setting the partial derivative of $\overrightarrow{UCN}$ and $\overrightarrow{US}$ with respect to CEL to zero. This results in the solution:

$$CEL = \tan^{-1}\left[\frac{\tan\ \varepsilon}{\cos\ (\alpha + AX)}\right]$$

This equation also applies for all concentrators discussed.

For a single-axis tracking concentrator, the angle AX will be a constant and CEL will vary with time as just described. For example, when the concentrator tracks north-south, AX = 90° and:

$$\overrightarrow{UCA} = \overrightarrow{ULS}$$

$$\overrightarrow{UCP} = -\sin(CEL)\ \overrightarrow{ULE} - \cos(CEL)\ \overrightarrow{ULV}$$

$$\overrightarrow{UCN} = -\cos(CEL)\ \overrightarrow{ULE} + \sin(CEL)\ \overrightarrow{ULV}$$

When the concentrator is non-tracking, both AX and CEL will be constant. CEL in this case would be the collector angle tilt toward south (usually the latitude of the location). AX would be 0° in most cases.

This vector triad ($\overrightarrow{UCA}$, $\overrightarrow{UCP}$, $\overrightarrow{UCN}$) is referred to as the collector or tracking vector triad. When ray draws on the collector aperture are made, or when receiver hit points (ray intersections) are found, this collector triad is used as the reference coordinate system. An x, y, z coordinate frame is always defined such that x is positive in the $\overrightarrow{UCA}$ direction, y along $\overrightarrow{UCP}$ and z along $\overrightarrow{UCN}$.

GENERAL PURPOSE DERIVATIONS

In addition to the sun center and tracking vectors just described, there are several other steps in logic which are common to many of the concentrator mathematical models.

Reflection

The reflection of a ray from a surface is a straightforward relationship as given below:

$$\overrightarrow{UR} = 2\ (\overrightarrow{UN}\cdot\overrightarrow{UI})\ \overrightarrow{UN}-\overrightarrow{UI}$$

where:

$\overrightarrow{UR}$ = Reflected ray vector (unit)

$\overrightarrow{UN}$ = Reflecting surface normal (unit)

$\overrightarrow{UI}$ = Incoming ray vector (unit)

Figure 3-3 describes the geometry for this reflection equation.

Surface Normal Perturbation

For either a reflecting or refracting surface normal, an error is introduced by rotating the normal vector through two angles defining the surface slope error. For a normal distribution, the angles would consist of δ_1, drawn with a normal distribution having a specified mean and variance and δ_2, drawn uniformly from 0 to 360 degrees. The sketch of the perturbation of the unit normal is shown in Figure 3-4. The fully perturbed vector is given by:

$$\overrightarrow{UNP} = \cos\ \delta UN + \sin\ \delta_1\ (\cos\ \delta_2\ \overrightarrow{UT}_1 + \sin\ \delta_2\ \overrightarrow{UT}_2)$$

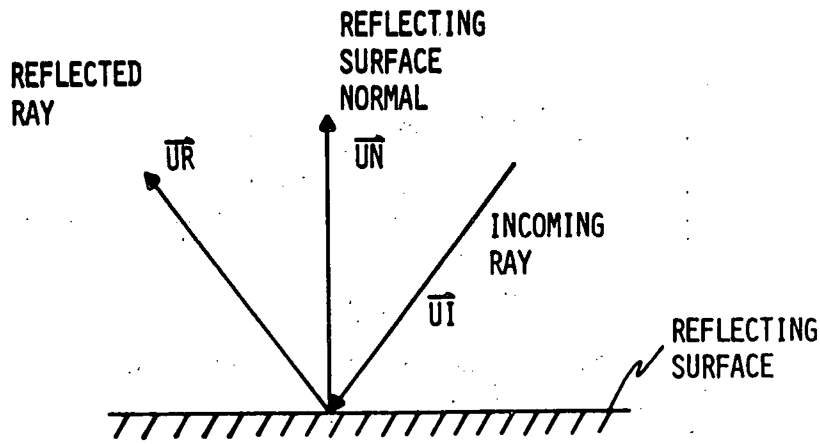


Figure 3-3. Reflection Vectors

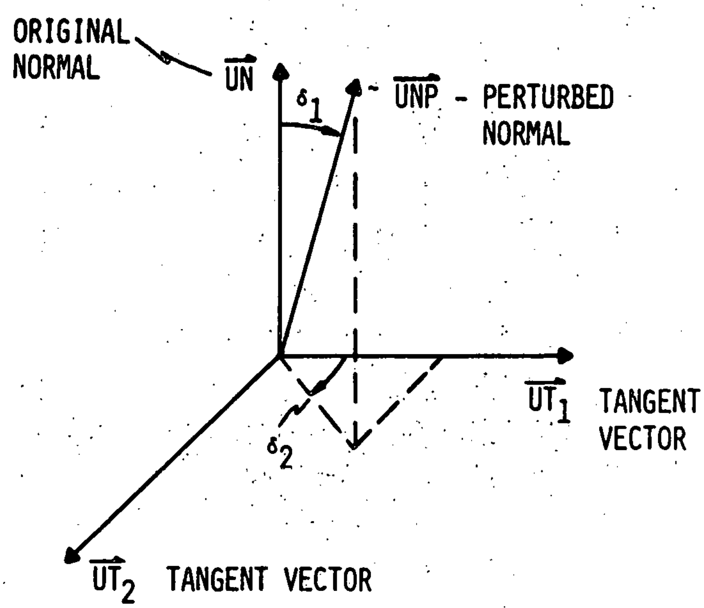


Figure 3-4. Surface Normal Error Perturbation

Refraction

The general derivation of the vector representation of a refraction is carried out here. Figure 3-5 shows the vectors and angles involved in the refraction. The incoming ray vector, $\overrightarrow{UIN}$, is assumed to point away from the interface of materials for the derivation. The angle between the incoming ray and the normal to the refractive material is:

$$\phi_1 = \cos^{-1} (\overrightarrow{UIN} \cdot \overrightarrow{ULN})$$

The Law of Refraction gives the angle between the normal and the refracted ray as:

$$\sin \phi_2 = (N_1/N_2) \sin \phi_1$$

For the case depicted in Figure 3-5, Material Number 2 has a higher index of refraction than Material Number 1 ($N_2 > N_1$) and therefore the refracted ray is

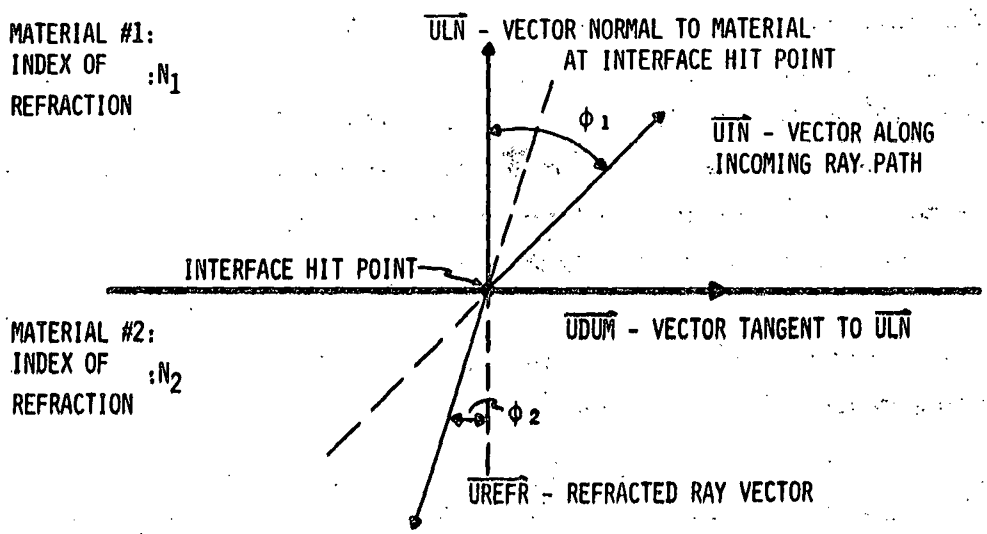


Figure 3-5. Refraction of Incoming Ray

bent toward the normal ($\phi_2<\phi_1$). In any case, the refracted ray must lie in a plane defined by $\overrightarrow{ULN}$ and $\overrightarrow{UIN}$ with angle ϕ_2 between $\overrightarrow{ULN}$ and the refracted ray, $\overrightarrow{UREFR}$. To construct this ray we need to define a vector tangent to $\overrightarrow{ULN}$ and in the plane of $\overrightarrow{ULN}$ and $\overrightarrow{UIN}$. This vector is shown as $\overrightarrow{UDUM}$ in Figure 3-5 and can be computed from the relationship:

$$\overrightarrow{UDUM} = \frac{1}{\sin\phi_1}\ \overrightarrow{UIN} - \frac{\cos\phi_1}{\sin\phi_1}\ \overrightarrow{ULN}$$

The refracted ray is then simply:

$$\overrightarrow{UREFR} = -\cos\phi_2\ \overrightarrow{ULN} - \sin\phi_2\ \overrightarrow{UDUM}$$

SURFACE NORMALS AND HIT TESTS

Using the concentrator base vectors and concentrator geometry, we can define a unit normal vector on the concentrator surface at the surface hit point. Knowing the unit normal $\overrightarrow{UN}$ and the sun vector $\overrightarrow{US}$, the redirected sun's ray can be determined. We can now examine the surface geometry for the concentrator designs being modeled and formulate the equation for the reflected/refracted ray. In addition, a distance vector $\vec{D}$ from the concentrator surface hit point to a known point on the receiver is defined for use in the receiver hit tests. (The receiver models are described later in this section.)

In some cases, the normal to the concentrator surface will be defined using the following general formulation:

$$\vec{N} = \frac{\partial F_s}{\partial x}\ \overrightarrow{UCA} + \frac{\partial F_s}{\partial y}\ \overrightarrow{UCP} + \frac{\partial F_s}{\partial z}\ \overrightarrow{UCN}$$

where:

$\vec{N}$ = Normal to concentrator surface

F_s = Surface equation as a function of x, y, z

X, Y, Z = Variable name in $\overrightarrow{UCA}$, $\overrightarrow{UCP}$, $\overrightarrow{UCN}$ directions, respectively.

Some of the designs will not be formulated in this manner, since their geometry is more easily defined using different methods.

Paraboloid of Revolution (Dish)

The paraboloid-of-revolution (dish) concentrator tracks the sun in two axes. The reflective concentrating surface is defined in Figure 3-6a. The focal length of the dish is:

$$F = a^2/4$$

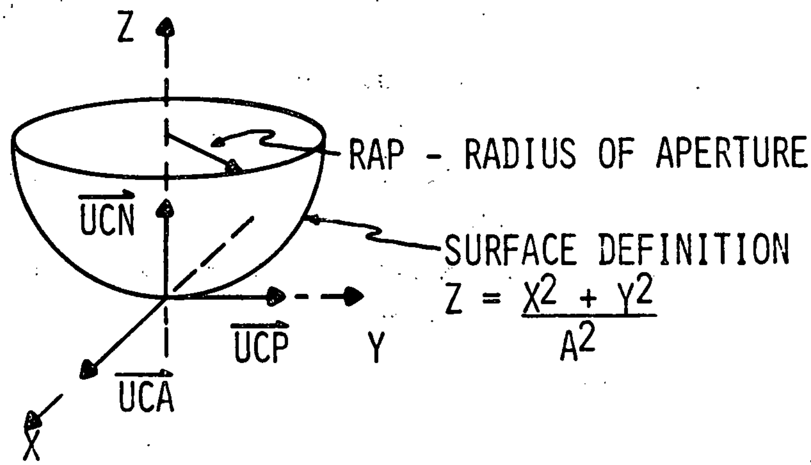
where F is defined from the origin (x = y = z = 0) to the height along the z-axis where on-axis rays focus. The entire concentrator geometry is therefore specified by F and R_{ap}, the aperture radius.

The ray trace begins with a Monte Carlo draw over the aperture of the dish. Since the aperture is circular, the draw is an equal-area draw when the square of the draw radius is randomly selected from zero to the square of the aperture radius, or:

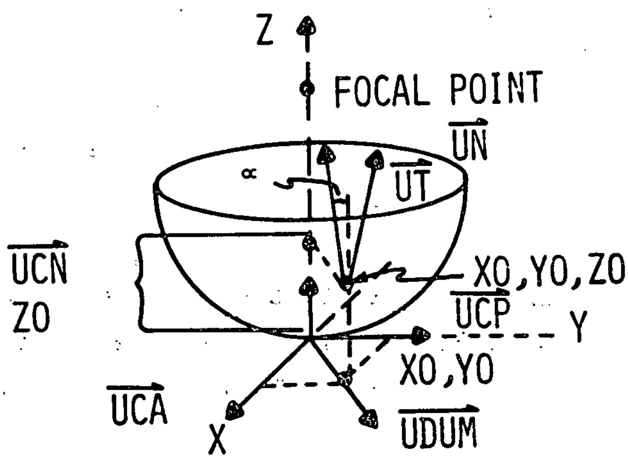
$$R^2_{draw} = R_{ap}^2 \cdot RN$$

where RN is a random number from 0 to 1. A uniform draw over angle θ completes the Monte Carlo selection of a ray starting point:

$$\theta_{draw} = 2\pi \cdot RN$$



a. Geometry



b. Vector Definitions

Figure 3-6. Paraboloid of Revolution

The starting point of the ray can be expressed in x, y, z coordinates as:

$$x_o = R_{draw} \cos \theta_{draw}$$

$$y_o = R_{draw} \sin \theta_{draw}$$

$$z_o = (x_o^2 + y_o^2)/4F$$

Given this point, the unit normal and tangent vectors are derived by referring to Figure 3-6b. A vector, $\overrightarrow{UDUM}$, in the x,y plane and also in the plane of $\overrightarrow{UN}$ and $\overrightarrow{UT}$ is:

$$\overrightarrow{UDUM} = (x_o \overrightarrow{UCA} + y_o \overrightarrow{UCP})/\sqrt{x_o^2 + y_o^2}$$

The angle α between the unit surface normal, $\overrightarrow{UN}$, and the dish collector normal, $\overrightarrow{UCN}$, is:

$$\tan \alpha = \frac{dz}{dr} = \frac{r}{2F}$$

and r is defined as $r^2 = x^2 + y^2$. Using this slope, α, the collector normal and tangent vectors are:

$$\overrightarrow{UN} = \cos \alpha \overrightarrow{UCN} - \sin \alpha \overrightarrow{UDUM}$$

$$\overrightarrow{UT} = \cos \alpha \overrightarrow{UDUM} + \sin \alpha \overrightarrow{UCN}$$

The vector from the ray start point to the center of a receiver (at the focal point) is:

$$\overrightarrow{D} = -x_o\overrightarrow{UCA} - y_o\overrightarrow{UCP} + (F-z_o) \overrightarrow{UCN}$$

RPI Concentrator

The RPI two-axis tracking, segmented concentrator configuration is defined in Figure 3-7. The nomenclature to accompany this figure is given in Table 3-2. The base configuration has four mirror banks each containing N_{col} column axes. The column axes are tilted with respect to a plane perpendicular to the collector normal vector, $\overrightarrow{UCN}$. All column axes are tilted at separate angles (γ varies along a mirror bank) to focus perfectly when the sun vector is parallel to the collector normal vector. Each column axis contains a given number of mirror facets and all columns rotate through the same angle, $\Delta\alpha$, when tracking solar elevation changes. The rotation angle is equal to one-half the angular difference between the solar elevation and the collector tilt angle from horizontal.

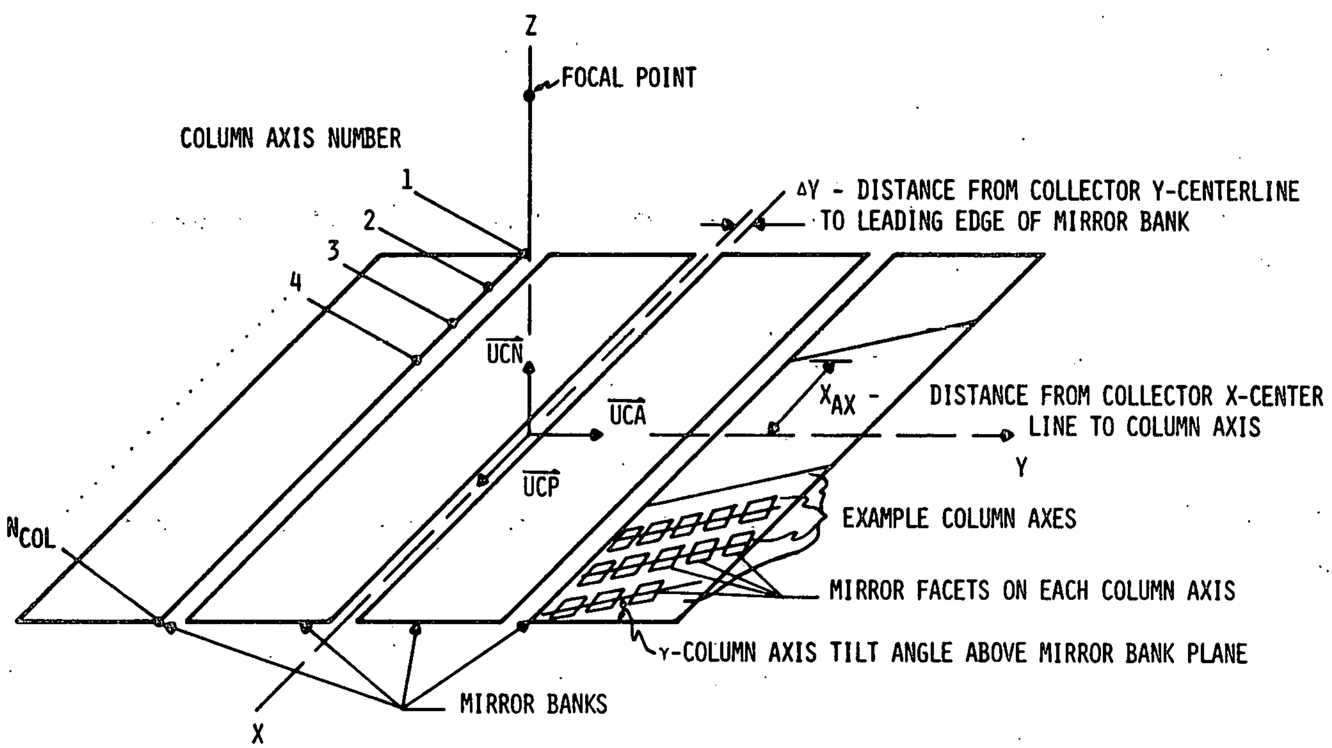


Figure 3-7. RPI Faceted-Mirror Concentrator Geometry

Table 3-2. Nomenclature for the RPI Concentrator

SYMBOL	DEFINITION
F	FOCAL DISTANCE (HEIGHT ABOVE MIRROR BANKS TO FOCAL POINT)
X_{ax}	DISTANCE FROM COLLECTOR X-CENTERLINE TO A COLUMN AXIS
Y	DISTANCE FROM COLLECTOR Y-CENTERLINE TO A MIRROR BANK
l	COLUMN AXIS LENGTH
γ	COLUMN AXIS TILT ANGLE FROM THE MIRROR BANK PLANE
α	COLUMN AXIS ROTATION ANGLE FROM MIRROR FACETS ALIGNED UP
$\overrightarrow{UCN}$, $\overrightarrow{UCA}$, $\overrightarrow{UCP}$	COLLECTOR ORTHONORMAL VECTOR TRIAD ($\overrightarrow{UCN}$ IS NORMAL TO MIRROR BANKS AND $\overrightarrow{UCA}$, $\overrightarrow{UCP}$ ARE IN PLANE OF MIRROR BANKS)
A_{len}	COLUMN AXIS LENGTH
F_{len}	MIRROR FACET LENGTH
F_{wid}	MIRROR FACET WIDTH

The RPI collector uses two-axis tracking to point focus. The method of tracking does not follow our standard two-axis definition in terms of the base collector vector triad, $\overrightarrow{UCN}$, $\overrightarrow{UCA}$, $\overrightarrow{UCP}$. These are derived as though the collector tracks in one axis and has a tilt angle from horizontal called θ_{tilt}. Figure 3-8 shows the angles and vectors of interest. The RPI collector tracks about a vectical axis to keep the mirror banks aligned parallel to the solar radiation along the $\overrightarrow{UCP}$ direction. That is, the collector tracks to keep the sun perpendicular to an imaginary column axis with zero axis tilt.

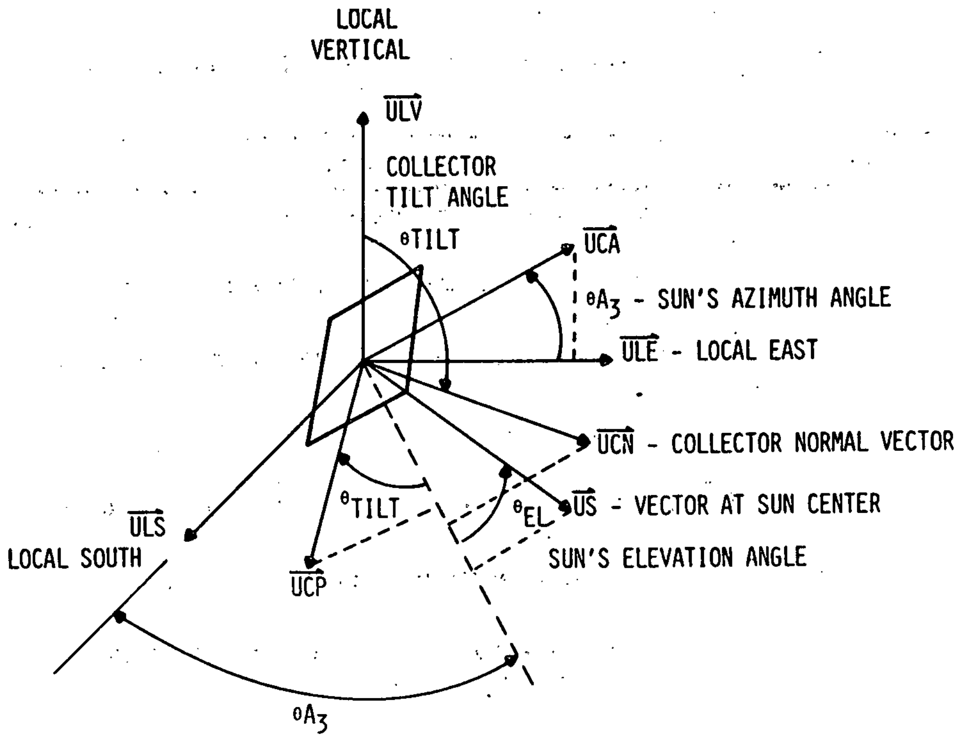


Figure 3-8. RPI Tracking Vectors

To ensure proper orientation, the collector must rotate to position the vectors $\overrightarrow{UCN}$ and $\overrightarrow{UCP}$ to be in a plane defined by the solar position $(\overrightarrow{US})$ and local vertical $(\overrightarrow{ULV})$. Thus, the collector position vectors become:

$$\overrightarrow{UCN} = \cos\theta_{tilt}\,\overrightarrow{ULV} + \sin\theta_{tilt}\,(\cos\theta_{az}\,\overrightarrow{ULS} + \sin\theta_{az}\,\overrightarrow{ULE})$$

$$\overrightarrow{UCP} = \cos\theta_{tilt}\,(\cos\theta_{az}\,\overrightarrow{ULS} + \sin\theta_{az}\,\overrightarrow{ULE}) - \sin\theta_{tilt}\,\overrightarrow{ULV}$$

$$\overrightarrow{UCA} = \cos\theta_{az}\,\overrightarrow{ULE} - \sin\theta_{az}\,\overrightarrow{ULS}$$

The first problem to solve, before beginning the actual ray trace procedure, is the determination of the column axis tilt angles. Figure 3-9 shows a single column axis and all other parameters necessary to derive the relationship defining the axis tilt angles. The RPI collector is assumed to be adjusted such that the center of the column axis focuses perfectly for the case when $\overrightarrow{US} = \overrightarrow{UCN}$ (i.e., the sun is on-axis). Actually, the analysis which follows can easily be adapted to focus perfectly for any solar elevation.

The derivation begins by defining all vectors depicted in Figure 3-9. The column axis center mirror-facet normal is $\overrightarrow{UMN}$. $\overrightarrow{UMN}$ is derived from the axis being tilted angle γ in the $\overrightarrow{UCA}$, $\overrightarrow{UCN}$ plane (a rotation about $\overrightarrow{UCP}$) and rotated angle α about a vector along the axis. This leads to:

$$\overrightarrow{UMN} = \sin\alpha\ \overrightarrow{UCP} - \cos\alpha(\sin\gamma\ \overrightarrow{UCA} - \cos\gamma\ \overrightarrow{UCN})$$

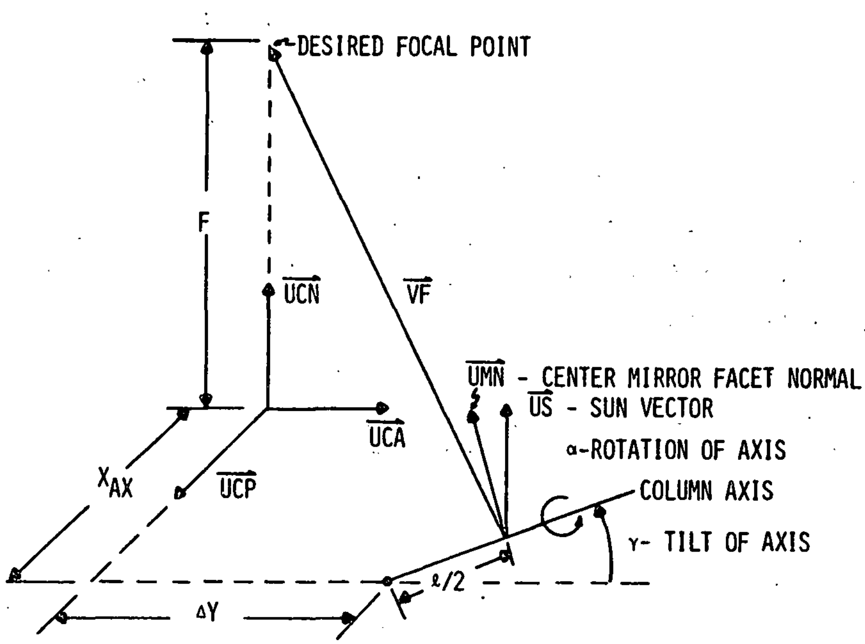


Figure 3-9. RPI Mirror Normal Definition

The vector from the column axis center to the desired focal point is:

$$\overrightarrow{VF} = -X_{ax}\overrightarrow{UCP} - (\Delta y + \frac{1}{2}\,\ell \cos \gamma)\overrightarrow{UCA} + (F - \frac{1}{2}\,\ell \sin \gamma)\overrightarrow{UCN}$$

For the case of the sun on-axis, the sun vector is simply:

$$\overrightarrow{US} = \overrightarrow{UCN}$$

Given these vectors we can now establish a relationship for the tilt angle by applying the Law of Reflection and noting that $\overrightarrow{VF}$ must be identical in direction to the perfect focus reflected ray. Given $\overrightarrow{UMN}$ and $\overrightarrow{US}$ the reflected ray is:

$$\overrightarrow{UR} = 2\,(\overrightarrow{US} \cdot \overrightarrow{UMN})\,\overrightarrow{UMN} - \overrightarrow{US}$$

Therefore, to focus perfectly we have:

$$\overrightarrow{UR} = \overrightarrow{VF} \div |\overrightarrow{VF}|$$

Using the vector component identities of this expression we can isolate the tilt angle, γ, as a function of known parameters. The algebra to do so is not presented here because it is cumbersome but not particularly difficult. The resulting equation for γ is:

$$\frac{\Delta y + \frac{1}{2}\,\ell \cos \gamma}{\sin \gamma} = \frac{F - \frac{1}{2}\,\ell \sin \gamma + |\overrightarrow{VF}|}{\cos \gamma}$$

where:

$$|\overrightarrow{VF}|^2 = X_{ax}^2 + \Delta y^2 + \frac{1}{4}\,\ell^2 + F^2 - \ell(F \sin \gamma - \Delta y \cos \gamma)$$

Because there is no simple algebraic solution for γ, Newton's method is applied to find the column axis tilt angles. Because of the symmetry of the collector, the angles need be determined in only one quadrant and can be applied to column axis in any other quadrant.

Armed with the column axis tilt angles as given, we are now ready to proceed with the ray trace for the RPI collector. Using the Monte Carlo method, a ray position is selected on some column axis and some mirror facet. The sun position $(\theta_{el}, \theta_{az})$ is known such that a column axis rotation, $\Delta\alpha$, from the perfect focus position is known:

$$\Delta\alpha = (\pi/2 - \theta_{tilt} - \theta_{el})/2$$

It remains to find the mirror-faced normal so that Snell's Law may be applied and the reflected ray hit on the receiver plane can be determined.

We begin by defining unit vectors along and normal to the column axis. Figure 3-10 shows the relevent geometry to obtain the required expressions:

$$\hat{\imath} = \cos\gamma\ \overrightarrow{UCA} + \sin\gamma\ \overrightarrow{UCN}$$

$$\hat{\jmath} = \cos\gamma\ \overrightarrow{UCN} - \sin\gamma\ \overrightarrow{UCA}$$

Similar to our previous derivation of $\overrightarrow{VF}$, a vector from the center of the mirror facet of interest to the focal point is:

$$\overrightarrow{VF}_F = -\ell_F\hat{\imath} - \Delta y\ \overrightarrow{UCA} - X_{ax}\ \overrightarrow{UCP} + F\ \overrightarrow{UCN}$$

Given the vector to the focal point, the unrotated sun on-axis mirror-facet normal vector can be computed:

$$\overrightarrow{MN} = \overrightarrow{UCN} + \overrightarrow{VF}_F \div |\overrightarrow{VF}_F|$$

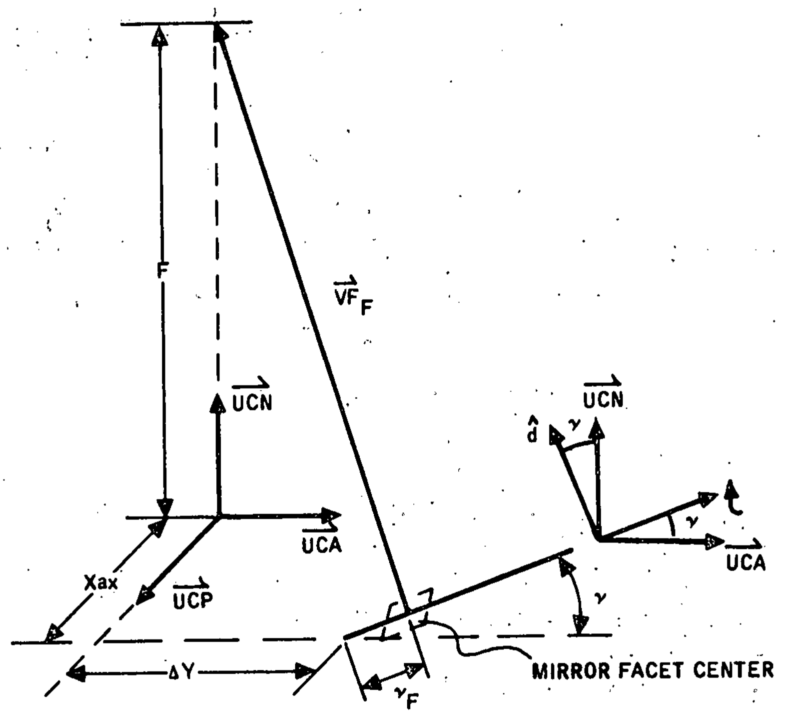


Figure 3-10. RPI Mirror-Facet Center Focus Vector Definition

By dividing $\overrightarrow{MN}$ by the magnitude of $\overrightarrow{MN}$, the mirror normal takes on unit magnitude and we call this vector:

$$\overrightarrow{UMN} = \overrightarrow{MN} \div |\overrightarrow{MN}|$$

This mirror-facet normal is an accurate representation of some of RPI's early versions of their concentrator. Later versions use a curved column axis which would alter this derivation slightly.

Now to provide elevation tracking we simply rotate $\overrightarrow{UMN}$ through angle $\Delta\alpha$ about the $\hat{\imath}$ axis. This rotation is accomplished by the following:

$$\begin{aligned}\overrightarrow{UMN}_F = \; & (\overrightarrow{UMN} \cdot \hat{\imath})\hat{\imath} \\ & + (\overrightarrow{UMN} \cdot \hat{\jmath})\ (\cos \Delta\alpha\ \hat{\jmath} + \sin \Delta\alpha\ \overrightarrow{UCP}) \\ & + (\overrightarrow{UMN} \cdot \overrightarrow{UCP})\ (\cos \Delta\alpha\ \overrightarrow{UCP} - \sin \Delta\alpha\ \hat{\jmath})\end{aligned}$$

Now $\overrightarrow{UMN}_F$ is the mirror-facet unit normal vector and it may be perturbed for surface errors. Then Snell's Law is applied to create a reflected ray. The receiver is assumed to have a planar aperture opening into a cavity absorber. The ray trace for optical performance stops at the aperture. A circular opening is assumed and flux mapping is available on the aperture.

Fixed-Mirror, Two-Axis Tracking Receiver--This concentrator is a fixed spherical dish reflector with a receiver that tracks in two axes (see Figure 3-11).

The surface of the dish is described by:

$$F_s = r_{conc}^2 - X^2 - y^2 - Z^2$$

where:

$$0 \leq (X^2 + y^2)^{1/2} \leq r_{conc}^2 \sin^2 \theta_{rim}$$

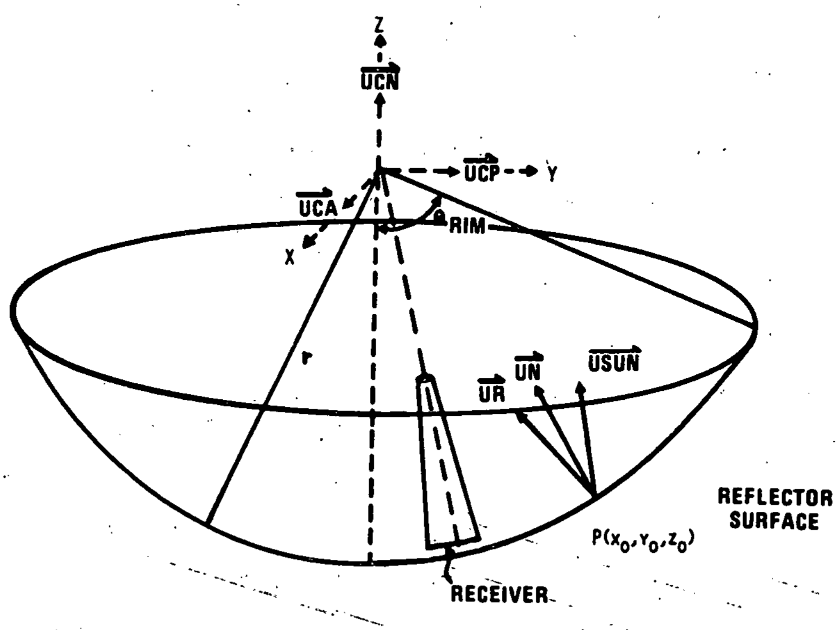


Figure 3-11. Fixed-Mirror Tracking Receiver Surface Geometry

The rim angle θ_{rim} is defined, as shown in Figure 3-11, as the angle between the line from the center to the edge of the concentrator and the normal axis of the concentrator.

A Monte Carlo draw over the aperture is done for an equal area in a fashion identical to the draw for the paraboloid-of-revolution dish. A surface hit point (X_o, Y_o, Z_o) results.

The receiver tracks so that the axis of symmetry lies on the line determined by the center of the sun and the center of the sphere.

The unit normal ($\overrightarrow{UN}$) to the surface at hit point X_o, Y_o, Z_o is determined by differentiating the equation for the surface ($F_s = \ldots$); we obtain:

$$\vec{N} = -2x_o \ \overrightarrow{UCA} - 2y_o \ \overrightarrow{UCP} - 2z_o \ \overrightarrow{UCN}$$

and the unit normal is:

$$\overrightarrow{UN} = \frac{-x_o}{r_{conc}} \ \overrightarrow{UCP} - \frac{y_o}{r_{conc}} \ \overrightarrow{UCA} - \frac{z_o}{r_{conc}} \ \overrightarrow{UCN}$$

The sign of $\overrightarrow{UN}$ is such that it points toward the center of the concentrator. The reflected ray is determined from Snell's Law:

$$\overrightarrow{UR} = 2 \ (\overrightarrow{UN} \cdot \overrightarrow{USUN}) \ \overrightarrow{UN} - \overrightarrow{US}$$

After $\overrightarrow{UR}$ is calculated, the ray can then be traced to the receiver to determine whether the ray impinges on its surface. For this concentrator design, a conical receiver has been used as the optimal receiver configuration, although a planar or cylindrical receiver could be employed. A vector $\vec{D}$ will be defined from the reflector surface hit point to a known point on the receiver. The receiver lies along a line between the sun's center and sphere center so the receiver will be positioned along a radial vector with the same direction as $\overrightarrow{US}$. The distance vector then is:

$$\overrightarrow{D} = r\ \overrightarrow{UN} - (r - RL)\ \overrightarrow{US}$$

where RL is the receiver length.

Parabolic Trough Concentrator--This line concentrator consists of a parabolic surface that usually tracks the sun in one axis and redirects the sun's energy to a receiver at the focal line overhead (see Figure 3-12).

A Monte Carlo draw for the trough simply draws uniformly in the aperture plane.

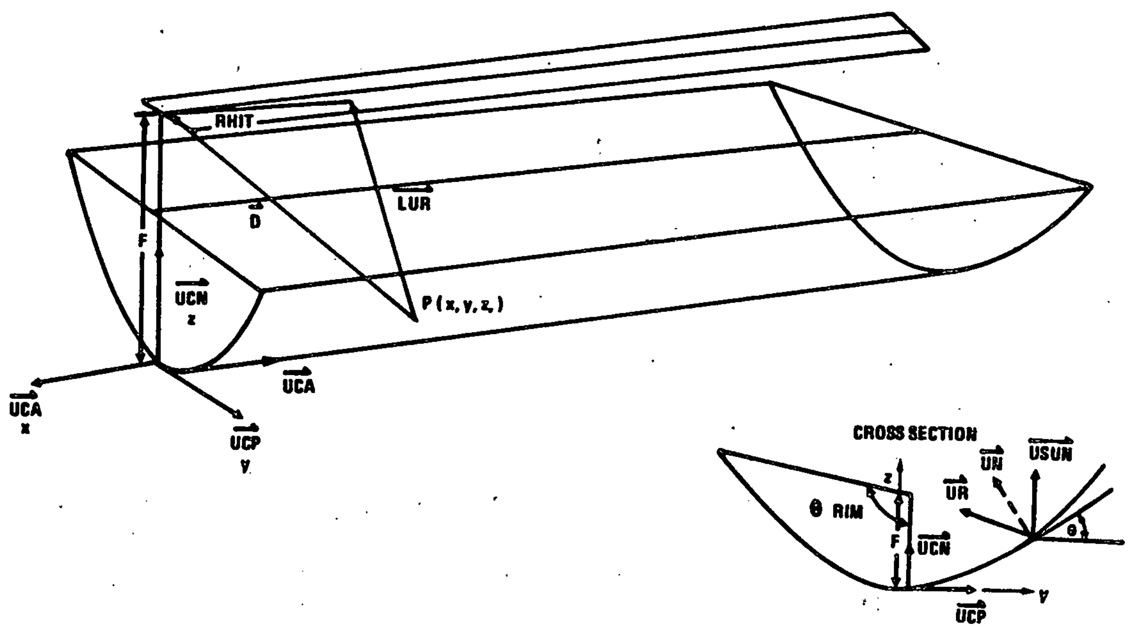


Figure 3-12. Parabolic Trough Concentrator

The surface is defined by:

$$F_s = -\frac{Y^2}{4F} + Z$$

where F is the focal length. In addition to the focal length and concentrator width, we also define a rim angle (θ_{rim}) for the parabola. The rim angle is the angle between the focal axis and the end point (edge) of the parabolic surface. Varying the rim angle for a fixed aperture will affect the optical efficiency. Optimal rim angles are usually in the range of 60 to 115^o.

The normal to the collector surface is:

$$\vec{N} = \frac{-y_o}{2F} \overrightarrow{UCP} + \overrightarrow{UCN}$$

and the unit normal is:

$$\overrightarrow{UN} = \frac{-y_o}{2F\ |\vec{N}|} \overrightarrow{UCP} + \frac{1}{|\vec{N}|} \overrightarrow{UCN}$$

where:

$$|\vec{N}| = \left(\frac{y_o^{\ 2}}{4F} + 1\right)^{1/2}$$

The reflected ray calculated from Snell's Law is the same as before:

$$\overrightarrow{UR} = 2\ (\overrightarrow{UN} \cdot \overrightarrow{USUN})\ \overrightarrow{UN} - \overrightarrow{USUN}$$

To determine if $\overrightarrow{UR}$ hits the receiver, we again define a $\overrightarrow{D}$ vector from the surface hit point to a known point on the receiver. In this case,

$$\overrightarrow{D} = -x_o \ \overrightarrow{UCA} - y_o \ \overrightarrow{UCP} + (F - Z_o) \ \overrightarrow{UCN}$$

The receiver models used with the trough would be the cylindrical or planar receivers. In the case of a cylindrical receiver, $\overrightarrow{D}$ would have its endpoint at the center of the cylinder. For the planar receiver, it would be in the middle of the receiver width.

Linear Fresnel--This concentrator type focuses the sun's energy on a linear receiver through a Fresnel lens. The Fresnel surface has "groves" such that light entering normal to the surface is focused in a line beneath the lens. The concentrator often is tracked in two axes so that the sun position is normal to the aperture. (This decreases optical losses due to off-axis aberrations.)

The Monte Carlo draw for this concentrator is again a simple uniform draw over the aperture plane.

The surface geometry at any point is defined from the focal length (F), the distance from the lens center to a Fresnel facet (y_f), and the index of refraction (n_2) for the lens material.

Figure 3-13 illustrates some of the surface geometry. If a facet center point, Y_f, is chosen along the $\overrightarrow{UCP}$ direction, the surface will be defined such that a refracted ray, $\overrightarrow{UR}$, should be directed at an angle:

$$\alpha = \tan^{-1} (F/y_f)$$

to reach the focal line. From the law of refraction (see Figure 3-13),

$$\sin \theta_2 = \sin \theta_1 \ (n_1/n_2)$$

From the diagram, we see that:

$$\theta_2 - \theta_1 = 90 - \alpha$$

By substituting and rearranging these expressions, we can solve for the Fresnel facet angle:

$$\cos \theta_1 = \left(\frac{n_1}{n_2}\right)\sqrt{\frac{F^2 + y_F^{\ 2}}{F}} - \frac{F}{y_F}$$

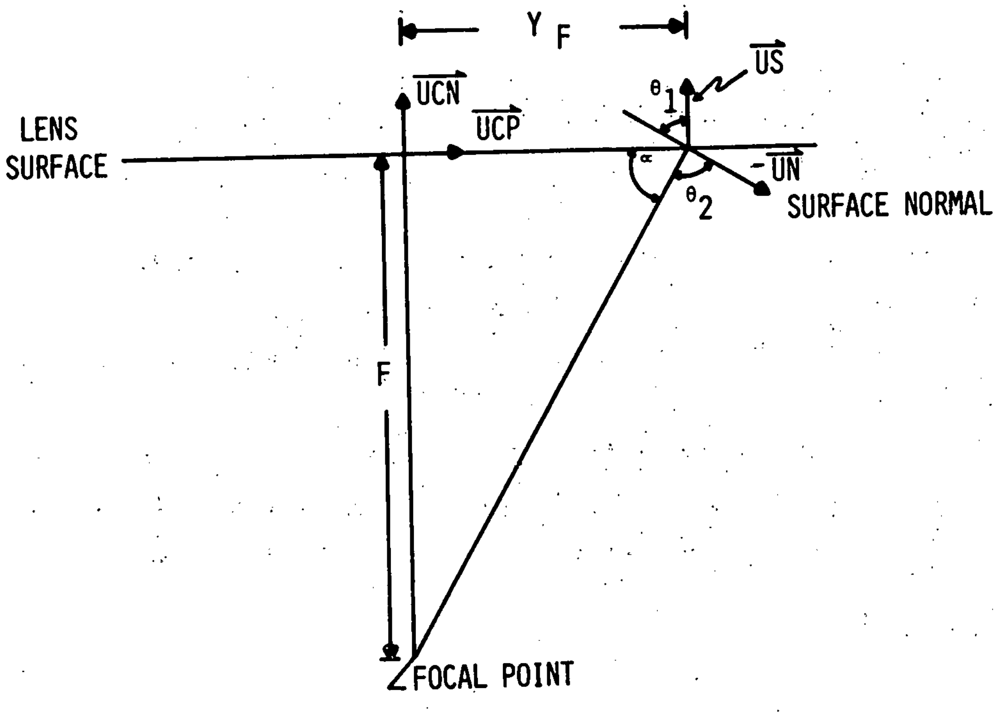


Figure 3-13. Linear Fresnel Cross Section Geometry

Rather than further manipulating this equation to find the surface equation, we can directly write the facet normal knowing θ_1:

$$\overrightarrow{UN} = \cos\theta_1 \;\overrightarrow{UCN} = \sin\theta_1 \;\overrightarrow{UCP}$$

This facet normal is used for all rays drawn within the boundaries of the Fresnel facet with center at distance y_F from the lens center. The facet boundaries are determined by a specified facet width. The refracted ray is obtained by the general refraction technique already described.

As before, we need to define the distance vector for the receiver hit test. In this case, the focal point lies beneath the concentrator surface, and for now the depth of the Fresnel facets is ignored. The distance vector is:

$$\vec{D} = -y_o \;\overrightarrow{UCP} - x_o \;\overrightarrow{UCA} - F \;\overrightarrow{UCN}$$

This and the refracted ray vector, $\overrightarrow{UR}$, are used as inputs for either the cylindrical or planar receiver hit tests.

<u>Inflated Cylindrical Concentrator</u>--The inflated cylindrical concentrator is a thin-film plastic cylinder with an aluminized reflector bonded to the lower half. The sun's rays are reflected and concentrated along the normal axis of the cylinder. Receiver positioning along the axis is dependent on the receiver diameter.

The collector is usually oriented along the east-west axis and could be actively tracking (currently LLL recommends weekly tilt adjustments).

The surface definition for this concentrator is a semicircle:

$$F_s = r_{cyl}^2 - y^2 - z^2$$

where $z \leq 0$ and r_{cyl} is the concentrator radius.

A cross section of the concentrator illustrating the vector relationships is shown in Figure 3-14.

A uniform aperture draw is utilized and incoming rays are traced to reflector surface hit points (intersections with the cylinder) by a derivation virtually identical with the hit test with a cylindrical receiver. This is presented in a later section and is not repeated here.

The surface normal is obtained by differentiating F_s to give:

$$\vec{N} = -2y_o \ \overrightarrow{UCP} - 2z_o \ \overrightarrow{UCN}$$

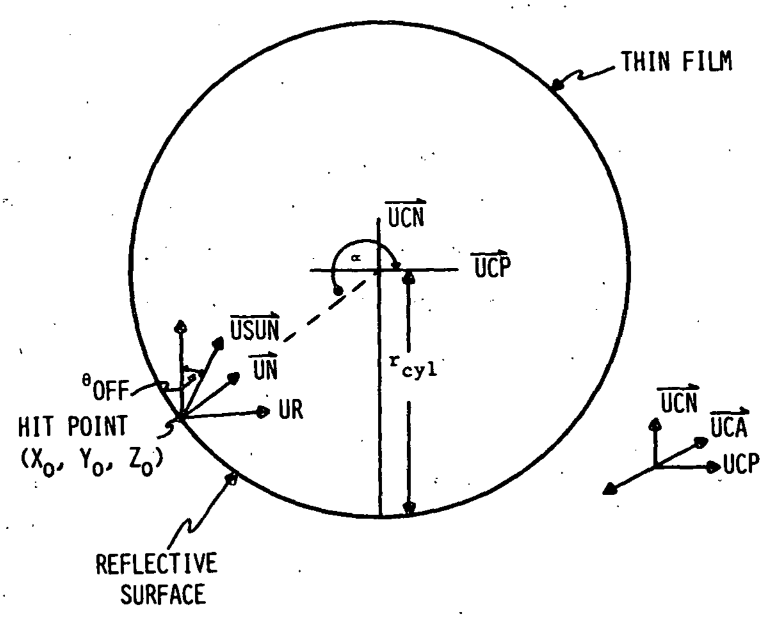


Figure 3-14. Inflated Cylindrical Concentrator Cross Section

and the unit surface normal is:

$$\overrightarrow{UN} = \frac{-y_o}{r_{cyl}} \overrightarrow{UCP} - \frac{z_o}{r_{cyl}} \overrightarrow{UCN}$$

If monthly or weekly tilt adjustments are used instead of active tracking, the local vector triad for the stationary concentrator would be used with changes in the tilt of the concentrator (θ_{tilt}).

The distance vector, $\vec{D}$, to be used in the receiver hit test has a simple formulation. For the inflated cylindrical concentrator,

$$\vec{D} = - x_o \overrightarrow{UCA} - y_o \overrightarrow{UCP} + (F + z_o) \overrightarrow{UCN}$$

where F is measured from r_{cyl} along the normal axis to the center of the receiver.

In most cases, one will want first to determine the point of ideal receiver placement, as this concentrator does not focus at one point. In this case, the distance vector is defined to the center of the cylinder in the $\overline{UCA}$, $\overline{UCP}$ plane:

$$\vec{D} = r_{cyl} \overrightarrow{UN}$$

Both the cylindrical and planar receiver models can be easily used with this design. The current receiver design is a cylindrical pipe positioned at 0.4 - 0.6 r_{cyl} along the normal axis of the concentrator.

<u>Vee Trough</u>--The Vee Trough concentrator is generally a stationary collector with several vee-shaped wings or reflectors to boost the absorber performance. One such vee-booster is shown in a cross-sectional view in Figure 3-15. The concentrator reflecting surfaces are described by the angles θ_1 and θ_2. Maxi-

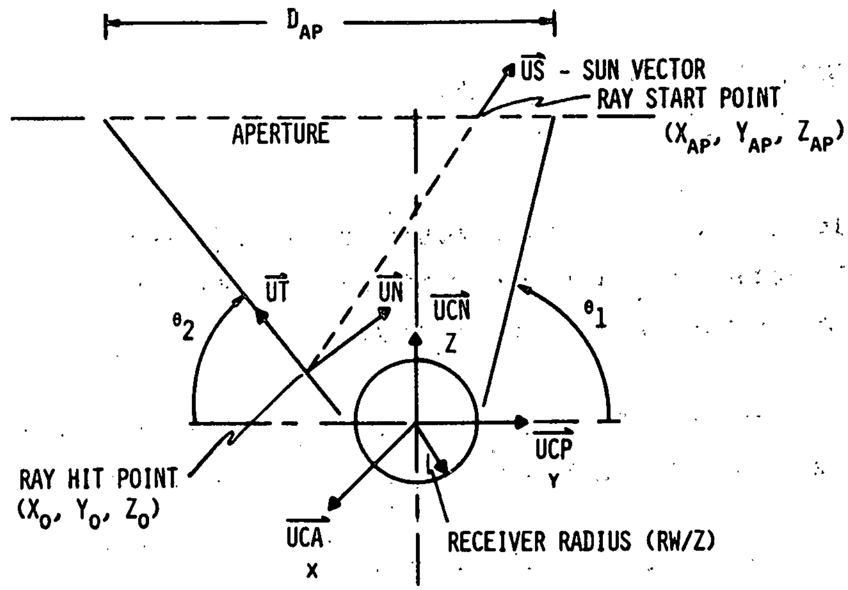


Figure 3-15. Vee Trough Concentrator Geometry

mum performance is obtained by careful selection of these angles for summer and winter; that is, the sides can be moved once during the year. Note also that the collector center position is probably best tilted toward the south with respect to a vertical axis.

The aperture plane, of width D_{ap}, is the starting point for the Monte Carlo draw. Rays are traced from the aperture to the receiver or the reflecting surfaces. For rays that intercept the reflecting surface, the hit test with a plane is constructed to find the hit point (x_o, y_o, z_o). The hit test and reflection need to define the surface normal:

$$\overrightarrow{UN} = \cos\theta_{1,2}\ \overrightarrow{UCN} \pm \sin\theta_{1,2}\ \overrightarrow{UCP}$$

and the surface tangent:

$$\overrightarrow{UT} = \pm\cos\theta_{1,2}\ \overrightarrow{UCP} + \sin\theta_{1,2}\ \overrightarrow{UCN}$$

combined with a vector, $\vec{D}$, to the center of the coordinate system:

$$\vec{D} = -x_{ap}\ \overrightarrow{UCA} - y_{ap}\ \overrightarrow{UCP} - z_{ap}\ \overrightarrow{UCN}$$

where:

$$z_{ap} = \frac{D_{ap} - RW}{\dfrac{1}{\tan\theta_1} + \dfrac{1}{\tan\theta_2}}$$

The hit point on the reflecting surface (for those rays which initially miss the absorber) is described by:

$$x_o = (-\vec{D} + L\ \overrightarrow{UI}) \cdot \overrightarrow{UCA}$$

$$y_o = (-\vec{D} + L\ \overrightarrow{UI}) \cdot \overrightarrow{UCP}$$

$$z_o = (-\vec{D} + L\ \overrightarrow{UI}) \cdot \overrightarrow{UCN}$$

where:

$$L = \frac{D \cdot UCN + 5UT \cdot UCN}{UI \cdot UCN}$$

where:

$$S\left[\frac{(\overrightarrow{UCA}\cdot\overrightarrow{UN})(\overrightarrow{UT}\cdot\overrightarrow{UCN})(\overrightarrow{UI}\cdot\overrightarrow{UCA})}{\overrightarrow{UI}\cdot\overrightarrow{UN}\cdot\overrightarrow{UI}\cdot\overrightarrow{UCN}}+\frac{(\overrightarrow{UCA}\cdot\overrightarrow{UN})(\overrightarrow{UT}\cdot\overrightarrow{UCA})}{\overrightarrow{UI}\cdot\overrightarrow{UN}}-\frac{\overrightarrow{UT}\cdot\overrightarrow{UCN}}{\overrightarrow{UI}\cdot\overrightarrow{UCN}}\right]$$

$$=\frac{\vec{D}\cdot\overrightarrow{UCN}}{\overrightarrow{UI}\cdot\overrightarrow{UCN}}-\frac{\vec{D}\cdot\overrightarrow{UN}}{\overrightarrow{UI}\cdot\overrightarrow{UN}}+\frac{-\overrightarrow{RW}(\overrightarrow{UCP}\cdot\overrightarrow{UN})}{2\,\overrightarrow{UI}\cdot\overrightarrow{UN}}-\frac{(\overrightarrow{UCA}\cdot\overrightarrow{UN})(\vec{D}\cdot\overrightarrow{UCN})(\overrightarrow{UI}\cdot\overrightarrow{UCA})}{\overrightarrow{UI}\cdot\overrightarrow{UN}\cdot\overrightarrow{UI}\cdot\overrightarrow{UCN}}+\frac{(\overrightarrow{UCA}\cdot\overrightarrow{UN})(\vec{D}\cdot\overrightarrow{UCA})}{\overrightarrow{UI}\cdot\overrightarrow{UN}}$$

Given the hit point coordinates and the reflected ray:

$$\overrightarrow{UR} = 2\,(\overrightarrow{UN}\cdot\overrightarrow{US})\,\overrightarrow{UN} - \overrightarrow{US}$$

a hit test with the receiver is done using the vector:

$$\vec{D} = -x_o\,\overrightarrow{UCA} - y_o\,\overrightarrow{UCP} - z_o\,\overrightarrow{UCN}$$

For rays which are reflected and miss the receiver, we check for aperture exists or further internal reflections up to a maximum of four.

Incremental Reflector--This concentrator utilizes flat second-surface faceted reflector panels as the concentrator surface. The facets work similar to a Fresnel lens in that they focus the sun's energy to a line (Figure 3-16). Instead of refracting the rays, the second surface is a reflective material that redirects the sun's energy to an overhead receiver. The concentrator could be made to track in one or two axes. Tilt adjustments could be made with one-axis tracking to improve performance by eliminating large off-axis sun angles.

The ray trace begins, as always, with the Monte Carlo draw over the aperture. For the present mathematical model we assume zero depth for the incremental reflector. Thus, the x, y aperture draw is assumed to be the surface hit point right through to the reflecting surface.

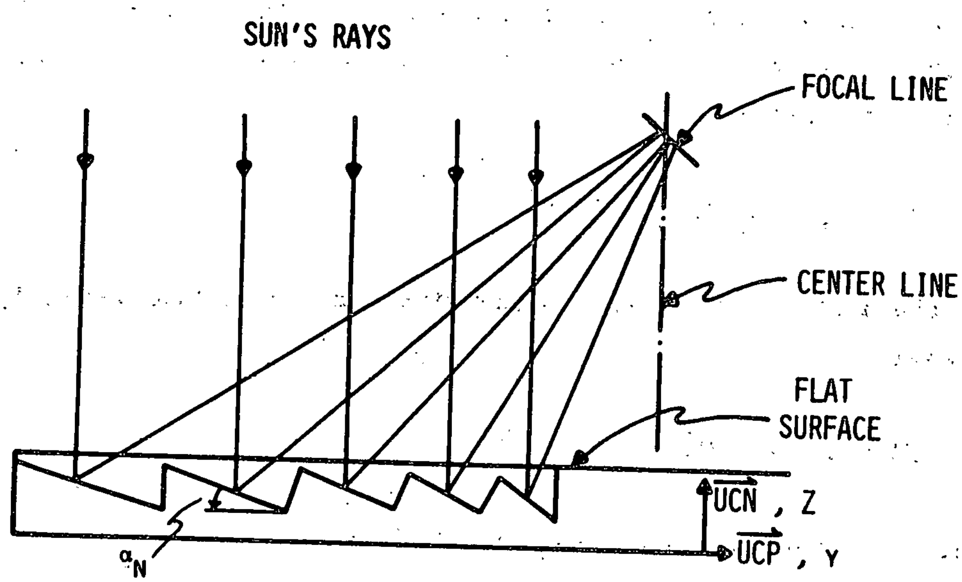


Figure 3-16. Section of Faceted Second-Surface Reflector

The ray trace proceeds with the sun's ray refraction at the top surface of the material.

This refracted sun's ray is:

$$\overrightarrow{US1} = \cos \phi_1 \ \overrightarrow{UCN} + \sin \phi_1 \ \overrightarrow{UCA}$$

where:

$$\sin \phi_1 = n_1/n_2 \sin [\cos^{-1} (\overrightarrow{US} \cdot \overrightarrow{UCN})]$$

and where:

n_2 = index of refraction for material
n_1 = index of refraction for air

The surface is defined such that direct rays (along $\overrightarrow{UCN}$) are reflected to the receiver center or focal line. The surface normal angle, α_n, shown in Figure 3-17, is found by:

$$\sin 2\alpha_n = n_1/n_2 \sin (\cot^{-1} F/y_F)$$

Again, the unit facet normal can be written directly from knowledge of the facet angle:

$$\overrightarrow{UN} = \cos \alpha_n \overrightarrow{UCN} - \sin \alpha_n \overrightarrow{UCP}$$

The reflected ray is again found from Snell's Law:

$$\overrightarrow{UR1} = 2(\overrightarrow{UN} \cdot \overrightarrow{US1}) \overrightarrow{UN} - \overrightarrow{US1}$$

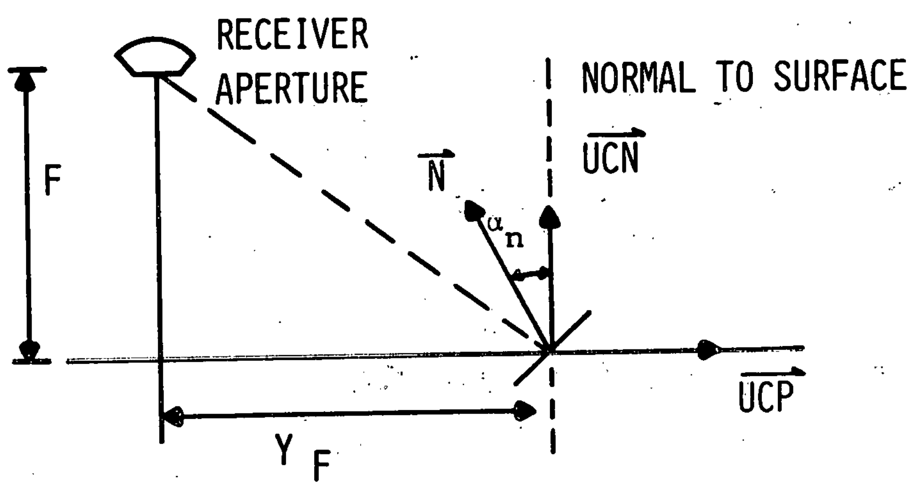


Figure 3-17. Incremental Reflector Surface Definition

Because this is a second-surface reflector, a refraction will take place as the ray exits after reflection. The refraction is shown in Figure 3-18. This refraction takes place in the plane defined by $\overrightarrow{UR1}$ and $\overrightarrow{UCN}$. A unit vector in the $\overrightarrow{UCA}$, $\overrightarrow{UCP}$ and also in the $\overrightarrow{UR1}$, $\overrightarrow{UCN}$ planes is found by:

$$UIJ = \frac{(\overrightarrow{UR1} \cdot \overrightarrow{UCP})\overrightarrow{UCP} + (\overrightarrow{UR1} \cdot \overrightarrow{UCA})\overrightarrow{UCA}}{[\,(\overrightarrow{UR1} \cdot \overrightarrow{UCP})^2 + (\overrightarrow{UR1} \cdot \overrightarrow{UCA})^2]^{1/2}}$$

The redirected ray is:

$$\overrightarrow{UR} = \cos\phi_2\,\overrightarrow{UCN} + \sin\phi_2\,\overrightarrow{UIJ}$$

where:

$$\phi_2 = \cos^{-1}(\overrightarrow{UR1} \cdot \overrightarrow{UCN})$$

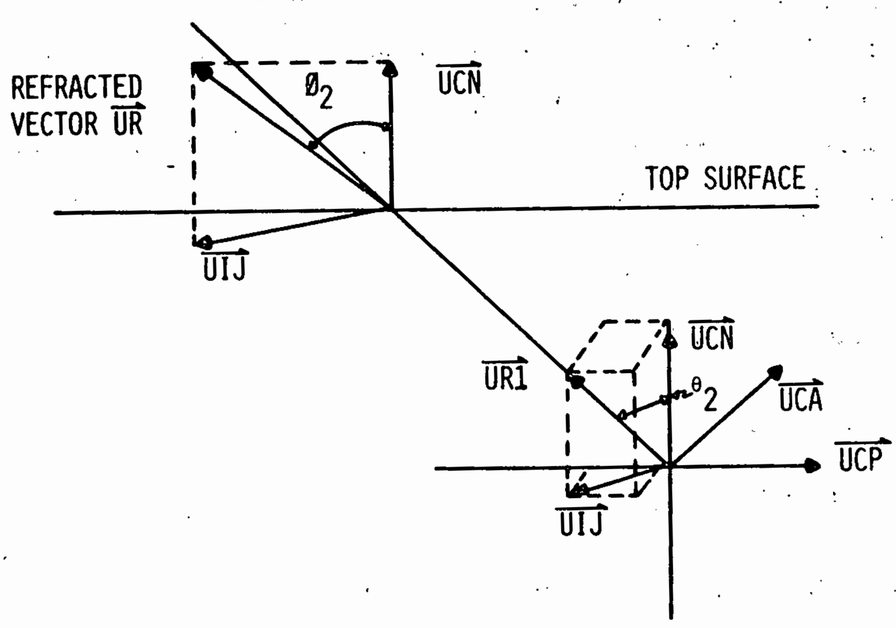


Figure 3-18. Geometry for Finding Final Redirecting Ray UR

$$\frac{\sin \phi_2}{n_1} = \frac{\sin \phi_2}{n_2}$$

The distance vector for the receiver hit test is defined as:

$$D = -y_o \ \overrightarrow{UCP} + F \ \overrightarrow{UCN} - x_o \ \overrightarrow{UCA}$$

This will be used as input with $\overrightarrow{UR}$ to one of the receiver models so the optical performance can be calculated.

<u>Compound Parabolic-Involute Reflector</u>--Although this design is usually referred to as a CPC concentrator, the geometric configuration is not parabolic. This nonimaging concentrator utilizes the involute for the reflective surface shape. The involute can be described as the curve generated by the endpoint of a taut string as it is being unwound from a circular surface.

Because the formation of this surface model has been done using polar coordinates, the equations of the surface are somewhat complicated and the derivation for the surface normal does not follow the partial differential form. One could express the surface as a function of the polar coordinates, r and θ, and follow this method. Instead, we have taken a geometric approach that will give the same result.

The involute surface can be defined as:

$$y = r \sin \theta + r\theta \cos \theta$$

$$z = r \cos \theta - r\theta \sin \theta$$

where r is the radius of the circular surface (in this case the nominal receiver pipe), and θ is the angle through which the string has been unwound (Figure 3-19). The normal to the surface for any hit point (y, z) can be

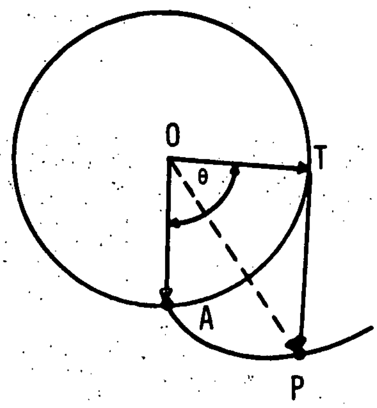


Figure 3-19. Involute Surface Definition

calculated since the surface normal is tangent to the receiver at the point defined by r and θ. Referring to Figure 3-20:

$$\overrightarrow{UN} = -\cos\theta\ \overrightarrow{UCP} + \sin\theta\ \overrightarrow{UCN}$$

where:

$$\theta = \alpha + \gamma \text{ and}$$

$$\alpha = \tan^{-1}\frac{y_o}{z_o}$$

$$\gamma = \cos^{-1}\frac{r}{\sqrt{y_o^{\,2} + z_o^{\,2}}}$$

To do the correctly-weighted draw over the surface, we again draw over the concentrator aperture plane defined by the concentrator length, width and maximum height from the center of the receiver (in this case the receiver width). To obtain the hit point, we have the following vector algebra.

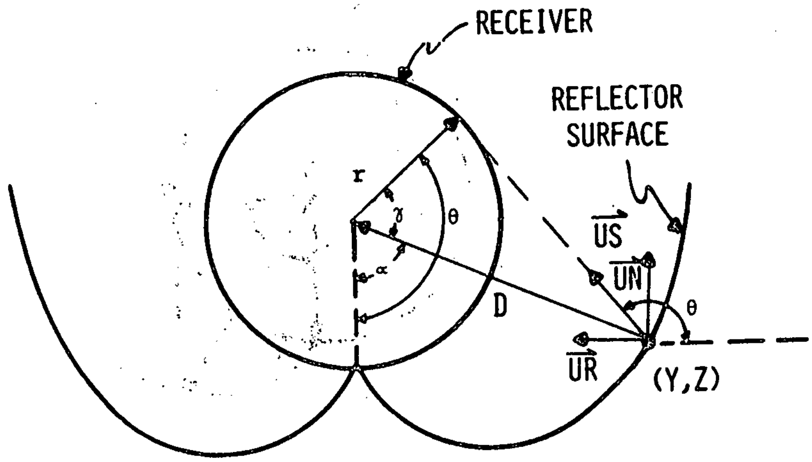


Figure 3-20. Involute Concentrator Geometry

First, we define a vector from the origin (at the center of the receiver) to the start point of the ray:

$$\overrightarrow{ORIG} = x_{ap}\ \overrightarrow{UCP} + y_{ap}\ \overrightarrow{UCA} + z_{ap}\ \overrightarrow{UCN}$$

Next we define a vector to the hit point on the involute surface:

$$\vec{D} = x_o\ \overrightarrow{UCP} + y_o\ \overrightarrow{UCA} + z_o\ \overrightarrow{UCN}$$

From Figure 3-21 we know:

$$x_o^{\ 2} + y_o^{\ 2} = r^2 + r^2\theta^2$$

and the $\vec{D}$ vector can be written in terms of θ and x_o as:

$$D = -r\theta\ \overrightarrow{UN} + \sin\theta\ UCP - r\cos\theta\ UCN + x_o\ UCA$$

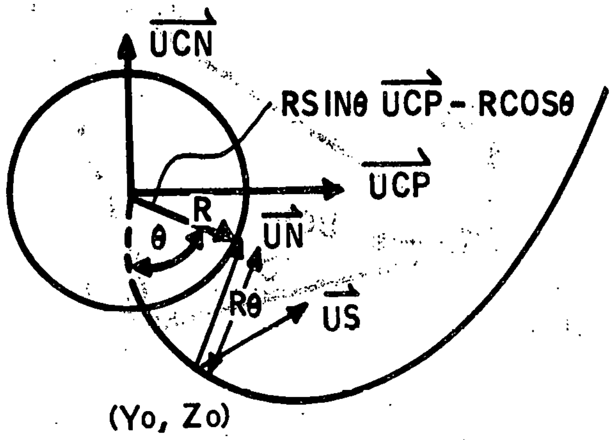


Figure 3-21. Involute Concentrator Vectors

or substituting for $\overrightarrow{UN}$ we have:

$$D = (- r\theta \cos \theta + r \sin \theta)\, \overrightarrow{UCP} + (- r\theta \sin \theta - r \cos \theta)\, \overrightarrow{UCN} + x_o\, \overrightarrow{UCA}$$

Referring to Figure 3-22, vector addition gives:

$$\ell\, \overrightarrow{US} = -\overrightarrow{ORIG} + \overrightarrow{D}$$

Also note that the vector $(-\overrightarrow{D} + z_{ap}\, \overrightarrow{UCN})$ originates from the hit point and ends at the draw planes as does $\ell\, \overrightarrow{US}$.

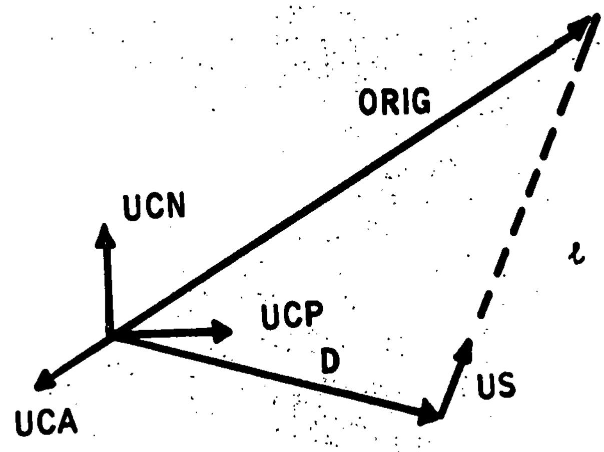


Figure 3-22. Involute Concentrator Vectors

Therefore:

$$(-\vec{D} + z_{ap}\,\overrightarrow{UCN})\cdot\overrightarrow{UCN} = \ell\,\overrightarrow{US}\cdot\overrightarrow{UCN}$$

and:

$$\ell = \frac{-(\vec{D}\cdot\overrightarrow{UCN}) + z_{ap}}{\overrightarrow{US}\cdot\overrightarrow{UCN}}$$

Letting $\overrightarrow{US}$ be written as:

$$\overrightarrow{US} = (\overrightarrow{US}\cdot\overrightarrow{UCP})\,\overrightarrow{UCP} + (\overrightarrow{US}\cdot\overrightarrow{UCA})\,\overrightarrow{UCA} + (\overrightarrow{US}\cdot\overrightarrow{UCN})\,\overrightarrow{UCN}$$

we can solve the above expressions. We have the $\overrightarrow{UCP}$ component equation:

$$(-\theta\sin\theta - \cos\theta - {}^{z_{ap}}/_{RW})\,\frac{\overrightarrow{US}\cdot\overrightarrow{UCP}}{\overrightarrow{US}\cdot\overrightarrow{UCN}} = {}^{-y_{ap}}/_{r} - \theta\cos\theta + \sin\theta$$

This equation has one unknown and can be solved iteratively for θ. The model we have implemented utilizes Newton's method to solve for θ and thus obtain the surface normal, $\overrightarrow{UN}$, and the hit point coordinates x_o, y_o, z_o.

Once the reflected ray is found, a hit test using the cylindrical receiver model will be made. The vector from the hit point to the center of the receiver is defined as follows (the center of the receiver is the point (0, 0, 0)).

$$\vec{D} = -y_o \; \overrightarrow{UCP} - z_o \; \overrightarrow{UCN} - x_o \; \overrightarrow{UCA}$$

Because multiple reflection hits are possible if the ray misses the receiver, we would repeat the above process to find a second reflected ray. The hit test would be repeated unless it is determined that the ray reflects out the concentrator aperture or more than four reflections are encountered.

Compound Parabolic Concentrator-Involute/Parabolic Reflector

This concentrator utilizes a reflector that is a combination of an involute and an ideal (parabolic) reflector. The concentration is determined from the acceptance angle, θ_a:

$$C_{ideal} = \frac{1}{\sin \theta_a}$$

The receiver may be flat (horizontal or verticle fin) or cylindrical. The mathematical definition of the surface will be somewhat different in these cases although they are derived similarly. The CPC with a cylindrical absorber will be used for this model.

The concentrator surface is defined first using polar coordinates (r, θ). Any point, P, on the reflector is characterized by its distance from the point on the absorber at which the tangent from P touches the absorber (Figure 3-23). If θ is measured from the vertical axis:

$$\rho = r\,\theta \qquad |\theta| \leq \theta_a + \frac{\pi}{2}$$

$$\rho = r\,\frac{\theta + \theta_a + (\pi/2) - \cos(\theta - \theta_a)}{1 + \sin(\theta - \theta_a)}, \quad \theta_a + \frac{\pi}{2} \leq |\theta| \leq \frac{3\pi}{2} - \theta_a$$

Knowing the values of θ and r, we can determine the y and z coordinates of the point P. Referring to Figure 3-23:

$$y_o = \sqrt{(\rho^2 + r^2)}\,\cos(\beta)$$

$$z_o = \sqrt{(\rho^2 + r^2)}\,\sin(\beta)$$

$$\text{or } z_o = y_o \tan\beta$$

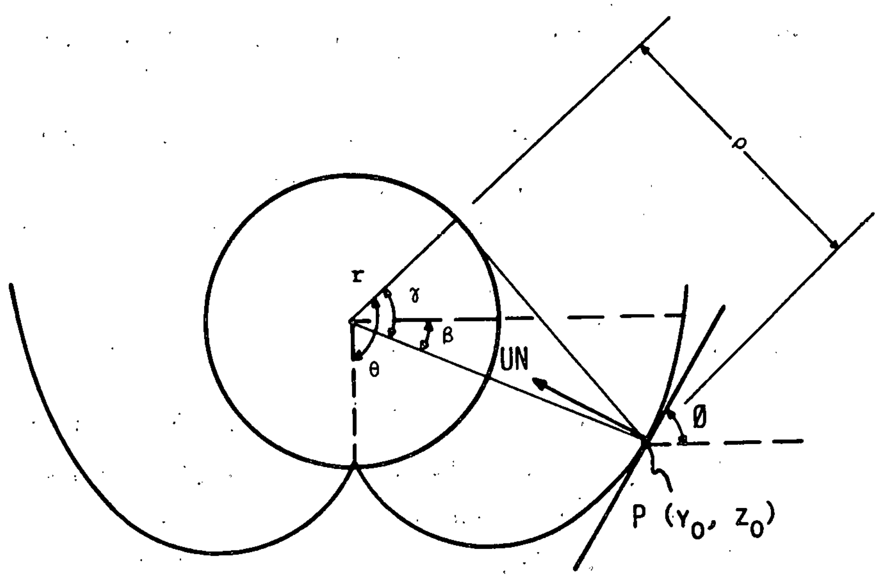


Figure 3-23. CPC Surface Geometry

where:

$$B = 90 - \theta + \gamma$$

$$\gamma = \tan^{-1} \rho/r$$

The surface normal using the partial derivative form is:

$$\vec{N} = - \tan \beta \ \overrightarrow{UCP} + \overrightarrow{UCN}$$

Dividing $|\vec{N}| = (1 + \tan^2 \beta)^{1/2} = \sec \beta,$

we have the surface normal:

$$\overrightarrow{UN} = - \sin \beta \ \overrightarrow{UCP} + \cos \beta \ \overrightarrow{UCN}$$

The hit point and angles are found in a manner nearly identical to the involute CPC case and hence it is not repeated here.

Once the reflected ray $\overrightarrow{UR}$ is determined using Snell's Law, the $\vec{D}$ vector is calculated. In this case:

$$\vec{D} = -y_o \ \overrightarrow{UCP} - x_o \ \overrightarrow{UCA} + z_o \ \overrightarrow{UCN}$$

Note that y_o and z_o in this case are measured locally using the center of one receiver tube as the origin.

This surface is compatible with the cylindrical receiver model. Slight variations in the surface definition would need to be made for a planar receiver.

SET Concentrator

The SET concentrator is a nontracking collector that uses a unique wide-angle lens and image collapsing subreflector surface to focus onto a flat shelf absorber. The lens is a two-point corrected cylindrical stepped Prism Lens. The design of the lens involves a new design method developed at SET, Inc. and produces the two-point corrected prism elements. As an approximation, the inner surface can be constructed as a circular arc. Figure 3-24 shows how we have defined the lens surface. The outer lens surface is assumed to be made of straight line segments, each defined by an angle, γ, with respect to horizontal or to a $\overrightarrow{UCA}$, $\overrightarrow{UCP}$ plane.

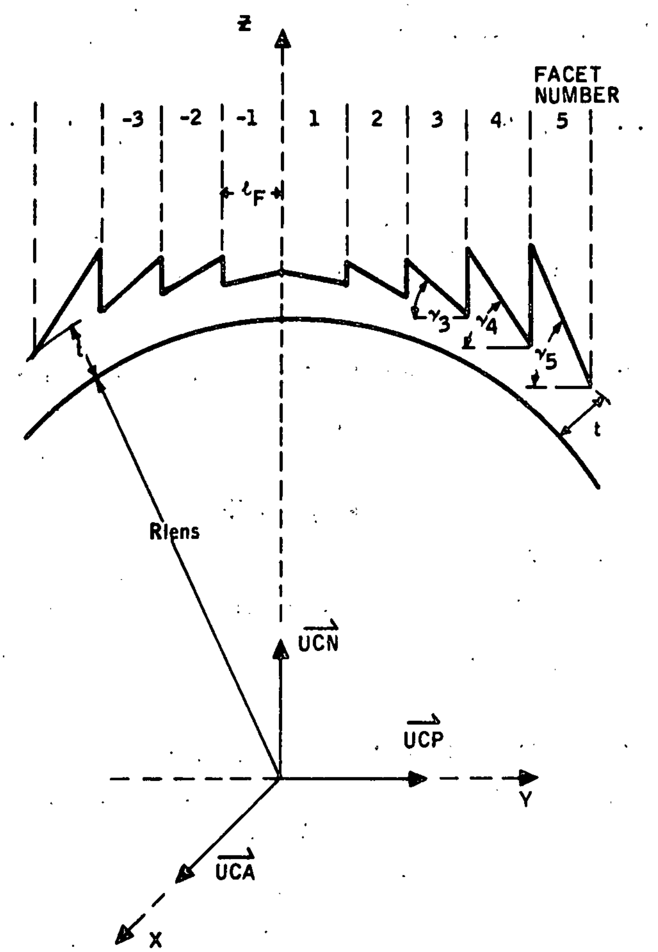


Figure 3-24. SET Concentrator Lens Geometry

The lens can have any number of specified facets (NFAC), each of width ℓ_F projected in the horizontal plane. The inner lens diameter is defined as R_{lens} and facets are numbered from the lens center outward. Figure 3-24 also shows the collector tracking vectors ($\overrightarrow{UCA}$, $\overrightarrow{UCP}$, $\overrightarrow{UCN}$) which are computed as described earlier. The definition of the subreflector follows the lens mathematical model.

Figure 3-25 shows an enlargement of one small section of the lens. An incoming ray start point is selected by a random draw in x and y in the plane defined by $\overrightarrow{UCA}$ and $\overrightarrow{UCP}$. This draw is then transferred to a lens ray start point (x_o, y_o, z_o). The sun vector, $\overrightarrow{US}$, is defined to point away from the upper lens surfaces. Before tracing the ray through the lens we first ensure that this start point does not lie in the shadow of a neighboring lens facet.

The lens normal vector is defined by:

$$\text{Facet number, } i_F = \text{integer}\left({}^{y}o/\ell_F\right) + 1$$

$$\overrightarrow{UN}_{lens} = \cos\gamma_{i_F}\ \overrightarrow{UCN} - \sin\gamma_{iF}\ \overrightarrow{UCP}$$

From the standard refraction ray trace technique we then get the first refracted ray $\overrightarrow{UR}$. This ray can then be traced to the inner lens surface.

Before tracing $\overrightarrow{UR}$ to the hit point on the inner lens surface, we check for a possible hit on a neighboring facet vertical face. Any hit on a vertical segment of the lens element will disrupt the optical path and we assume the ray is lost. This hit test with a vertical face is accomplished by creating a $\vec{D}$ vector to the center of the coordinate frame at x=y=z=0. This point is at the center of the circular arc of the lens:

$$\vec{D} = -\left[y_o - \ell_F(i_F - 1)\right]\ \overrightarrow{UCP} + \left[y_o - \ell_F(i_F - 1)\right]\ \tan\gamma_{iF}\ \overrightarrow{UCN}$$

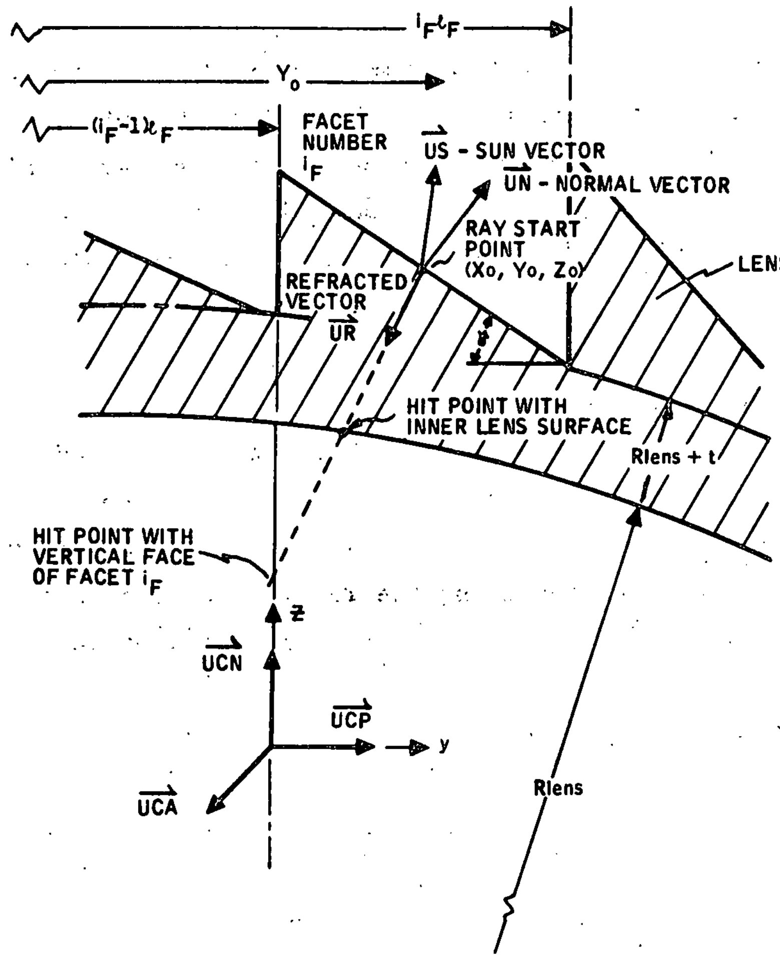


Figure 3-25. SET Concentrator Vector Definitions

Then the height above the coordinate system center of the refracted ray intersection with the neighboring vertical face is:

$$z_{hit} = \vec{D}\cdot\overrightarrow{UCN} - \frac{\vec{D}\cdot\overrightarrow{UCP}}{UR\cdot UCP}\left(\overrightarrow{UR}\cdot\overrightarrow{UCN}\right)$$

The corresponding height to the lowest point on the neighboring vertical face is:

$$z_{face} = \ell_F \tan \gamma_{iF} - \left[\sqrt{(R_{lens} + t)^2 - \ell_F^2 (i_F - 1)^2} - \sqrt{(R_{lens} + t)^2 - \ell_F^2 i_F^2}\right]$$

where t is the lens minimum thickness along a radial vector. The refracted ray $\overrightarrow{UR}$ is lost if the hit height (z_{hit}) is above the lowest height, z_{face}. If it is below we also check the other neighboring face before finding the hit point on the inner lens surface.

Since the inner lens surface is modeled as a circular arc, the inner lens hit point is found by doing a hit test with a circular cylinder. This is identical to the hit test for cylindrical receivers. A $\vec{D}$ vector is constructed to the circle center:

$$\vec{D} = -x_o\, \overrightarrow{UCA} - y_o\, \overrightarrow{UCP} - z_o\, \overrightarrow{UCN}$$

and a vector form the circle center to the hit point on the lens is:

$$\vec{R} = -\vec{D} + L\, \overrightarrow{UR}$$

where L is the length, along the $\overrightarrow{UR}$, from the x_o, y_o, z_o ray start point to the hit point on the inner lens surface. The vector $\vec{R}$ can also be represented as the sum of the two vectors, one in the plane of $\overrightarrow{UCP}$, $\overrightarrow{UCN}$ and on vector along $\overrightarrow{UCA}$:

$$\vec{R} = \overrightarrow{RHIT} + q_{hit}\, \overrightarrow{UCA}$$

Using the fact that $\overrightarrow{RHIT}$ has a known magnitude of R_{lens}, the above expressions reduce to a quadratic in length L:

$$L^2\,[1 - (\overrightarrow{UR} \cdot \overrightarrow{UCA})^2]$$

$$+\,[2\,(\overrightarrow{UR} \cdot \overrightarrow{UCA})\,(\vec{D} \cdot \overrightarrow{UCA}) - 2(\vec{D} \cdot \overrightarrow{UR})]$$

$$+\,[(\vec{D} \cdot \vec{D}) - (\vec{D} \cdot \overrightarrow{UCA})^2 - R_{lens}{}^2] = 0$$

With this information, the $\overrightarrow{RHIT}$ vector is:

$$\overrightarrow{RHIT} = -\vec{D} + L\,\overrightarrow{UR} + [\vec{D} \cdot \overrightarrow{UCA} - L\,(\overrightarrow{UR} \cdot \overrightarrow{UCA})]\,\overrightarrow{UCA}$$

The normal vector at the hit point is simply this radial hit vector. It is made into a unit vector by dividing through by R_{lens}. The refraction then occurs at the inner lens surface hit point and the refracted vector is called UR2. This vector then is reflected by the subreflector surface.

Figure 3-26 shows the geometry and nomenclature used for the subreflector and absorber shelf hit tests. The subreflector is defined by a polynominal of order N in a subreflector y, z coordinate system that is height Δz above the lens coordinate system center. The hit test with the subreflector surface is derived from the vector identity below:

$$L\,\overrightarrow{UR2} = -\overrightarrow{RHIT} + \Delta Z\,\overrightarrow{UCN} + x_h\,\overrightarrow{UCA} + y_h\,\overrightarrow{UCP} + z_h\,\overrightarrow{UCN}$$

where L is the unknown magnitude of the vector from the refracted ray origin on the inner lens surface to the hit point (x_h, y_h, z_h) on the subreflector surface. The hit point is defined by the following:

$$x_h = (L\,\overrightarrow{UR2} + \overrightarrow{RHIT} - \Delta z\,\overrightarrow{UCN}) \cdot \overrightarrow{UCA}$$

$$y_h = (L\,\overrightarrow{UR2} + \overrightarrow{RHIT} - \Delta z\,\overrightarrow{UCN}) \cdot \overrightarrow{UCP}$$

$$z_h = (L\,\overrightarrow{UR2} + \overrightarrow{RHIT} - \Delta z\,\overrightarrow{UCN}) \cdot \overrightarrow{UCN}$$

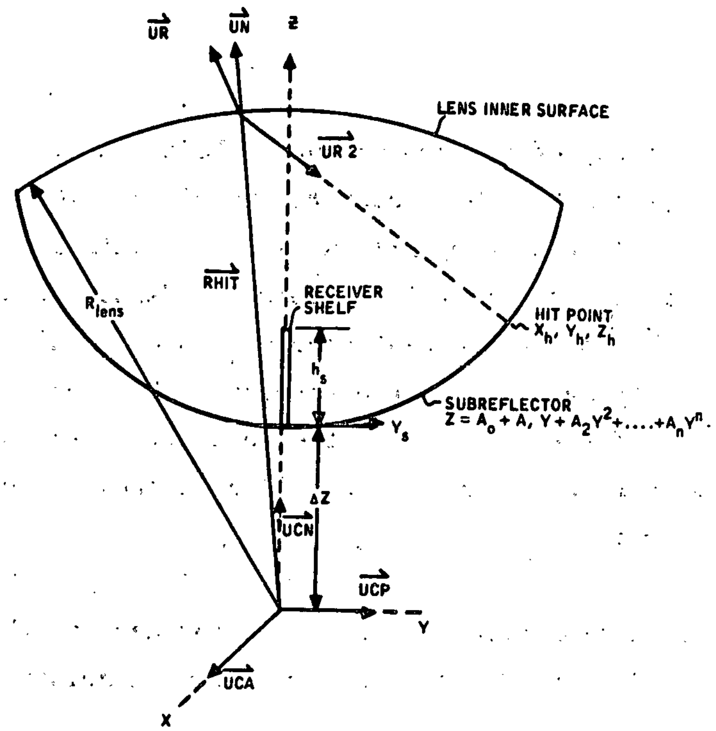


Figure 3-26. Subreflector Geometry

These expressions are combined with the vector identity to form one equation with one unknown, the length L. Newton's method is used to solve the equation and hence to find the hit point on the subreflector. The surface normal is defined by:

$$\vec{N} = -\frac{\partial z}{\partial y}\ \overrightarrow{UCP} + \overrightarrow{UCN}$$

where: $Z = A_o + A_1 y + \ldots + A_n\ y^n$

describes the subreflector surface. Once the hit point and the surface normal are found, a reflected ray is created and a hit test with the absorber shelf is completed. The hit test is that for a planar receiver as described below.

RECEIVER MODELS

The optical efficiency of the concentrators being examined is determined from the number of rays per run that reach the receiver. Three receiver types have been modeled for this program: a plane, a cylinder and a cone. For each redirected ray, a hit test is performed. Using a distance vector, $\vec{D}$, and the vector $\overrightarrow{UR}$ from the concentrator models as inputs, one can determine whether or not a ray has reached the receiver. For some of the concentrators it may be possible for rays to reach the receiver after multiple bounces on the concentrator surface. These rays will be tested through a number of reflections before being considered lost.

The following discussion details the models for each of the receivers. Although the geometries are different, the same methodology is used for each receiver type.

Planar Receiver

The planar receiver is characterized by a receiver length and width, RL and RW respectively. To determine whether a reflected ray will impinge on this receiver, we will define a vector, $\overrightarrow{RHIT}$, from the known point to which the $\vec{D}$ vector is drawn to the hit point on the receiver. For all planar receiver hit tests, the $\vec{D}$ vector ends at the center of the width and at the end of the receiver length.

If we define L as the distance along the reflected/refracted ray $\overrightarrow{UR}$ from the surface hit point to the receiver hit point, then:

$$\overrightarrow{RHIT} = -\vec{D} + L\,\overrightarrow{UR}$$

This geometry is illustrated in Figure 3-27 for the parabolic trough with a planar receiver. Because the vectors $\vec{D}$ and L $\overrightarrow{UR}$ are directed from the same

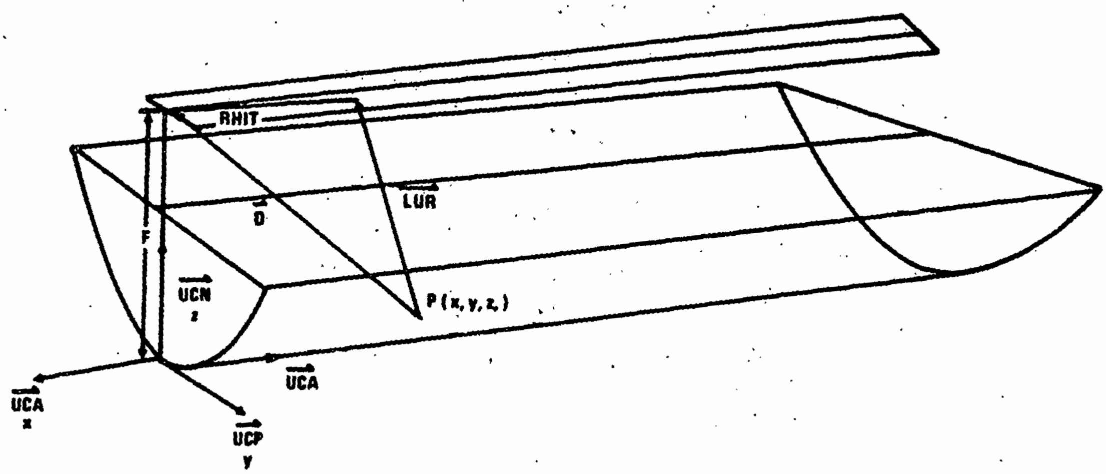


Figure 3-27. Parabolic Trough Concentrator

point along the z-direction and have the same end point (i.e., Z = F for the trough, Z = -F for the linear Fresnel), we can write:

$$L(\overrightarrow{UR} \cdot \overrightarrow{UCN}) = \overrightarrow{D} \cdot \overrightarrow{UCN}$$

Solving for L and substituting in the expression for $\overrightarrow{RHIT}$, we obtain:

$$\overrightarrow{RHIT} = \left[\frac{\overrightarrow{D} \cdot \overrightarrow{UCN}}{\overrightarrow{UR} \cdot \overrightarrow{UCN}}\right]\overrightarrow{UR} - \overrightarrow{D}$$

If the ray hits the receiver plane, then:

$$\left|\overrightarrow{RHIT} \cdot \overrightarrow{UCP}\right| \leq \frac{RW}{2}$$

$$0 < \overrightarrow{RHIT} \cdot \overrightarrow{UCA} < RL$$

It is also possible knowing the coordinates of $\overrightarrow{RHIT}$ to determine the energy distribution over the receiver plane. This is easily accomplished by dividing the receiver into zones along its width and length and calculating which zone the ray hits using the $\overrightarrow{RHIT}$ coordinates.

Cylindrical Receiver

To perform a receiver hit test for the cylindrical receiver, we again define L as the distance from the concentrator surface hit point to the receiver hit point in the direction of $\overrightarrow{UR}$. Referring to Figure 3-28, we define $\overrightarrow{RHIT}$ as a radial vector to the hit point from the center of the receiver at a distance q_{hit} from the end of the receiver along the collector axis $(\overrightarrow{UCA})$. Thus, we have:

$$\overrightarrow{RHIT} = -q_{hit}\ \overrightarrow{UCA} - \vec{D} + L\ \overrightarrow{UR}$$

where the $\vec{D}$ vector is at the cylinder center at the end of the receiver. We know from the geometry that:

$$q_{hit}(\overrightarrow{UCA} \cdot \overrightarrow{UCA}) = (-\vec{D} + L\ \overrightarrow{UR}) \cdot (\overrightarrow{UCA})$$

$$q_{hit} = (-\vec{D} \cdot \overrightarrow{UCA}) + L\ (\overrightarrow{UR} \cdot \overrightarrow{UCA})$$

If the ray hits the receiver, then $\overrightarrow{RHIT} \cdot \overrightarrow{RHIT} = r_{abs}^{\ 2}$ and

$$\begin{aligned}\overrightarrow{RHIT} \cdot \overrightarrow{RHIT} = {} & L^2\ [1 - (\overrightarrow{UR} \cdot \overrightarrow{UCA})^2] \\ & + L\ [2(\overrightarrow{UR} \cdot \overrightarrow{UCA})\ (\vec{D} \cdot \overrightarrow{UCA}) - 2(\vec{D} \cdot \overrightarrow{UR})] \\ & + [\vec{D} \cdot \vec{D} - (\vec{D} \cdot \overrightarrow{UCA})^2]\end{aligned}$$

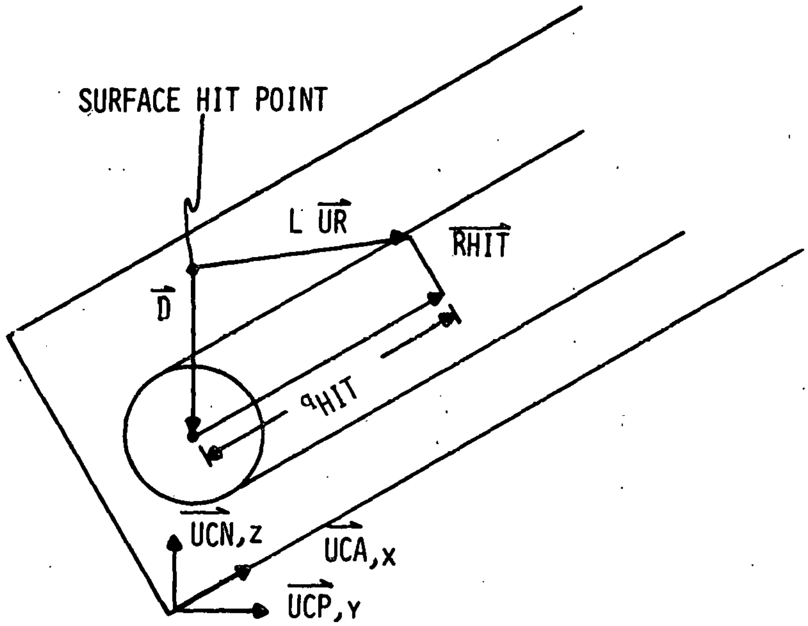


Figure 3-28. Cylindrical Receiver Hit Test Geometry

This quadratic can be solved for L. Real roots indicate a receiver hit; imaginary roots indicate a receiver miss. When real roots are found, one represents the ray entry point, and the other represents the exit point.

Conical Receiver

Figure 3-29 indicates the geometry for the cone-shaped receiver. To completely define this receiver, the following parameters are specified:

RL = length of receiver (along axis of symmetry)

S_o = the distance from the cone vertex to the top of the receiver (negative)

θ_c = the included angle of the cone

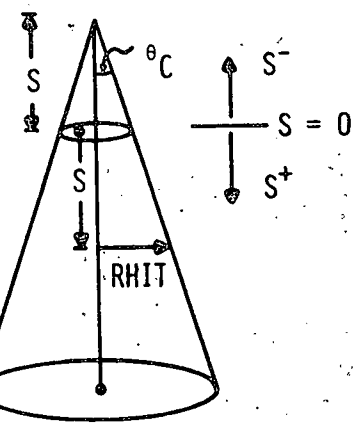


Figure 3-29. Receiver Cone Geometry

This receiver is utilized only with the fixed-mirror tracking receiver collector model in the present code version.

We again define a distance L along $\overrightarrow{UR}$ to the hit point on the receiver. We can now construct a radial vector from the cone axis to the hit point. In Figure 3-30 the two-axis tracking receiver hit vector is:

$$\overrightarrow{RHIT} = -L\ \overrightarrow{UR} + \vec{D} + S\ \overrightarrow{US}$$

where the $\vec{D}$ vector ends along the cone axis at the top of the receiver. The cone is traceked such that the axis extends through the center of the radius of curvature of the mirror and points in the direction of the sun vector $\overrightarrow{US}$.

The quantity S is the distance to the plane of $\overrightarrow{RHIT}$ along the cone axis from the receiver end point.

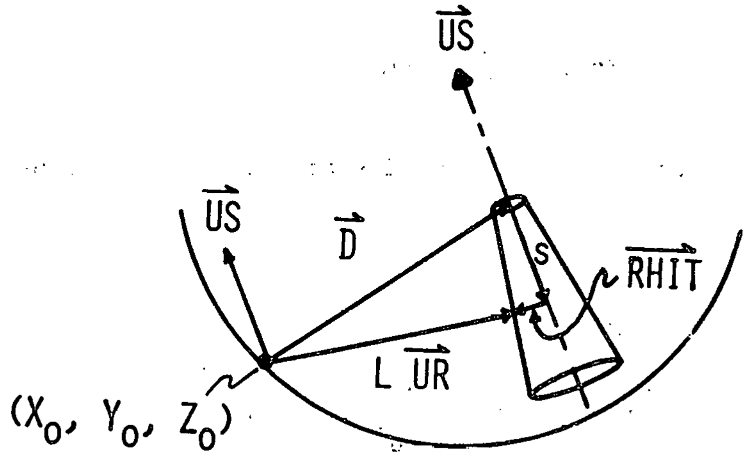


Figure 3-30. Receiver Hit Test Geometry

In order for $\overrightarrow{RHIT}$ to have its endpoint on the cylinder surface,

$$\overrightarrow{RHIT} \cdot \overrightarrow{RHIT} = |\overrightarrow{RHIT}|^2 = (S - S_o)^2 \tan^2\theta_c$$

Calculating this dot product with the previous expression for $\overrightarrow{RHIT}$,

$$\overrightarrow{RHIT} \cdot \overrightarrow{RHIT} = -2L(\vec{D} \cdot \vec{UR}) + L^2 - 2LS(\vec{UR} \cdot \vec{US}) (\vec{D} \cdot \vec{D}) +$$
$$2S(\vec{D} \cdot \vec{US}) + S^2$$

and

$$\overrightarrow{RHIT} \cdot \overrightarrow{RHIT} = (S^2 - 2SS_o + S_o^2) \tan^2\theta_c$$

This gives two unknowns (S and L) but because both L $\overrightarrow{UR}$ and $(\vec{D} + S\ \overrightarrow{USUN})$ extend from the same point in space to the surface of the hit plane with unit normal $\overrightarrow{UN}$, we can solve for L as follows:

$$L(\overrightarrow{UR} \cdot \overrightarrow{US}) = (\vec{D} + S\ \overrightarrow{US}) \cdot \overrightarrow{US}$$

Substituting the value of L in the dot product above, we obtain a quadratic in S:

$$\begin{aligned}
&S^2[1/(\overrightarrow{UR} \cdot \overrightarrow{US})^2 - \tan^2\theta_c - 1] \\
&+ S[-2\frac{\vec{D} \cdot \overrightarrow{UR}}{(\overrightarrow{UR} \cdot \overrightarrow{US})} + 2\frac{\vec{D} \cdot \overrightarrow{US}}{(\overrightarrow{UR} \cdot \overrightarrow{US})^2} + 2\ S_o \tan^2\theta_c] \\
&+ [\frac{(\vec{D} \cdot \overrightarrow{US})^2}{(\overrightarrow{UR} \cdot \overrightarrow{US})^2} + \vec{D} \cdot \vec{D} - S_o^{\ 2} \tan^2\theta_c \\
&- 2\frac{(\vec{D} \cdot \overrightarrow{US})\ (\vec{D} \cdot \overrightarrow{UR})}{\overrightarrow{UR} \cdot \overrightarrow{US}}] = 0
\end{aligned}$$

The solution of the quadratic gives the two piercing points (entry and exit) of the ray with the cone. Imaginary roots indicate that the ray failed to hit the cone.

SECTION 4
PROGRAM USE

Before running the Concentrator Optical Performance Software program the user is urged to read the previous sections, especially those portions pertaining to the concentrator type one wishes to examine. There are, naturally, limitations in the existing mathematical models which can be understood only by understanding the modeling. Many limitations, which a user can find distracting, can be eliminated by a simple change in the FØRTRAN coding. All the wants of users of the code cannot be anticipated in advance but the documentation of the models and the FØRTRAN can allow almost all user wants to be satisfied by minor code changes. In addition to the documented modeling, the code contains numerous comment cards to aid in code changes.

INPUT INSTRUCTIONS

All input to COPS is in the form of the FØRTRAN option for NAMELIST. A NAMELIST called RUN controls the type of concentrator to be simulated; type of reflective/refractive material used; day of the year; time of day; site latitude, longitude and time zone; and the ISTØP parameter to exit from program execution.

The variables in NAMELIST RUN are:

```
 NAMELIST/RUN/NDRAW,TAZ,TEL,TIME,XLAT,XLONG,TZONE,IDAY,ICONC,ISTOP,
+  NMAT,MAPS,NMATL
```

Appendix B, Glossary of NAMELIST Variables, provides a definition for each of these variables as well as all variables contained in the individual concentrator NAMELIST statements. The rules to follow in preparing the namelist input can be found in any good FØRTRAN IV reference manual. The variables that occur in the NAMELIST statements for the 11 different concentrator type are shown in Figure 4-1.

As an example of the input for the code, the following shows the input cards for simulating three cases of a paraboloid-of-revolution (dish) concentrator:

```
$RUN NDRAW=5000,IDAY=181,XLAT=35.,XLONG=90.,TZONE=6.,ICONC=11,TIME=14.,
ISTOP=0,NMAT=8,MAPS=0$
$DISHN F=1.0,RAP=1.1547,NRZ=6,SDS=0.002,DTRACRL=0.0,DTRACAZ=0.0,
IRCVR=2,NAXIS=2,RW=0.10,RL=0.10,NZONEX=5,NZONEY=5,NRZ=8,RWS=0.0,
PSM=0.0$
$RUN $
$DISHN SDS=0.004$
$RUN ISTOP=1$
$DISHN SDS=0.008$
```

The first RUN and DISHN NAMELIST statements define all the control and concentrator variables which are necessary for the run. Following NAMELIST inputs need only to define those variables which are to be changed from the previous case.

In this example, only the surface error standard deviation (SDS) is changed for the second and third runs. The RUN variables are unchanged except to set the stop flag on the last case executed.

OUTPUT DEFINITIONS

All concentrator outputs follow the same basic format. One example is given here for the inflatable cylindrical concentrator. The input is:

```
$RUN NDRAW=10000,IDAY=0,TAZ=0.0,TEL=1.50,ICONC=5,NMAT=2,MAPS=1,ISTOP=1$
$INFLATN CLENG=4.0,CWIDTH=1.0,RW=0.08,RL=4.0,SDS=0.004,NAXIS=0,
NZONEX=5,NZONEY=10,IRCVR=1,RDIST=0.306,IR=1,THETAAX=0.0,PSM=0.0,
TILTANG=0.0$
```

RPI FACETED-MIRROR CONCENTRATOR

```
NAMELIST/RPILIST/FL,TILT,DX,DY1,DY2,ALEN,FLEN,FWID,NCOL,NRZ,RMAX
◆ ,NZONEX,NZONEY,REFLTOT,RL,RW,SDS,SDR,IRCVR,PSM
```

FIXED-MIRROR TRACKING RECEIVER

```
NAMELIST/FMTRN/CWIDTH,RL,THETAC,SD,TRIM,NAXIS,NZONEX,NZONEY,
◆ TILTANG,IRCVR,THETAAX,DTRACAZ,DTRACRL,SDS,SDR,REFLTOT,PSM
```

PARABOLIC TROUGH

```
NAMELIST/TROFN/CLENG,CWIDTH,RW,RL,F,NAXIS,NZONEX,NZONEY,IRCVR
◆ ,THETAAX,DTRACRL,DTRACAZ,SDS,SDR,REFLTOT,RWS,PSM
```

LINEAR FRESNEL

```
NAMELIST/FRESN/CLENG,CWIDTH,RW,RL,F,SDS,SDR,NAXIS,FACH,
◆ FACW,NAIR,NLENS,TILTANG,NZONEX,NZONEY,IRCVR,THETAAX,DTRACRL,
◆  DTRACAZ,SDFS,TRANTOT,PSM
```

INFLATIBLE CYLINDER

```
NAMELIST/INFLATN/CLENG,CWIDTH,RW,RL,SDS,SDR,NAXIS,TILTANG,
◆ NZONEX,NZONEY,IRCVR,DEND,DTRACRL,DTRACAZ,RDIST,NZONEAX,
◆  IR,THETAAX,REFLTOT,PSM
```

INCREMENTAL REFLECTOR

```
NAMELIST/INCREFN/CLENG,CWIDTH,RW,RL,F,NAXIS,FACH,FACW,
◆  NAIR,NLENS,TILTANG,NZONEX,NZONEY,SDFS,SDS,SDR,THETAAX,
◆  DTRACRL,DTRACAZ,IRCVR,REFLTOT,RWS,PSM
```

INVOLUTE CPC

```
NAMELIST/CPCN/CLENG,CWIDTH,RW,RL,NAXIS,TILTANG,NZONEX,
◆   NZONEY,IRCVR,THETAAX,DAP,THTOL,NTOL,SDS,SDR,REFLTOT
◆ ,SRW,PSM
```

INVOLUTE/PARABOLIC CPC

```
NAMELIST/CPCN/CLENG,CWIDTH,RW,RL,NAXIS,TILTANG,NZONEX,
◆ NZONEY,IRCVR,THETAAX,DAP,THTOL,NTOL,SDS,SDR,ATHETA
◆ ,REFLTOT,SRW,PSM
```

SET IMAGE COLLAPSING CONCENTRATOR

```
NAMELIST/SETN/GAMMA,T,LF,R_ENS,AC,NFIT,NPRIS,DZ,SHITE,
◆ RW,RL,CLENG,CWIDTH,SDS,SDR,REFLTOT,TRANTOT,NAXIS,
◆ THETAAX,NZONEX,NZONEY,TILTANG,IRCVR,PSM,NLENS
```

VEE TROUGH

```
NAMELIST/VTROFN/CLENG,CWIDTH,RW,RL,NAXIS,NZONEX,NZONEY,
◆  TILTANG,IRCVR,THETAAX,THETA1,THETA2,SDS,SDR,DAP,REFLTOT
◆ ,PSM
```

PARABOLOID OF REVOLUTION (DISH)

```
NAMELIST/DISHN/F,RAP,NRZ,SDS,SDR,DTRACRL,DTRACAZ,
*IRCVR,NAXIS,RW,RL,NZONEX,NZONEY,REFLTOT,NRZ,RWS,PSM
```

Figure 4-1. Namelist Variables

The output is shown in Figure 4-2.

The first part of the output is self-explanatory. The concentrator type corresponds to ICØNC defined in Appendix B. The reflective and refractive material types are also defined in Appendix B. For this case, no refractive material is specified and the reflective material (type 5) is Kingston Kinglux™ polished aluminum. Later on in the output, this specification of reflective material type gives the values for total reflectance of 0.88 and the standard deviation for the reflective material σ_1= 0.00019 mr and σ_2= 0.00805 mr. These are the standard deviations of the material surface and thus are one-half of the reflected beam profile angular errors.

The concentrator geometry is specified in meters. In this case, the outer cylinder radius is 1.0 meter (WIDTH) and it is 4.0 meters long (LENGTH). The collector is tracking in one axis with a tracking axis oriented east-west as defined by 0.0 radian AXIS ORIENTATION. The receiver is 0.08 meter wide and 4.0 meters long. The receiver is cylindrical (RCVR. TYPE = 1) and no tilt is given to the reflecting surface relative to vertical (TILT ANGLE = 0). The receiver is positioned 0.306 meter from the cylinder center.

For the case of 10,000 rays drawn, 3903 rays missed (were wide of) the receiver. An optical efficiency of 0.556 was computed. The optical efficiency is defined by the power that reaches the receiver divided by the total possible that could reach the receiver. For this example, let us assume that the incoming solar radiation is 1 kw/m^2. The aperture area of the inflatible cylindrical concentrator is 1 m x 4 m = 4 m^2. Thus, the total possible power is 4 kW. If no rays had missed the receiver, the optical efficiency would have been:

$$\text{NOPT} = \frac{0.08 \times 4\text{kW} + 0.92 * (0.88 * \cos 4.2^{\circ}) \times 4}{4\ \text{kW}} = 0.8875$$

```
              INPUT VALUES FOR CONCENTRATOR RUN

       5  CONCENTRATOR TYPE
       2  REFL MATERIAL TYPE
       0  LENS MATERIAL TYPE
   10000  RAYS DRAWN
       1  FLUX MAP OPTION(1=YES,0=NO)


          INFLATABLE CYLINDRICAL CONC. PARAMETERS


   4.000  LENGTH
   1.000  WIDTH
       0  TRACKING AXES
   0.     AXIS ORIENTATION
   0.080  RCVR. WIDTH
   4.000  RCVR. LENGTH
       1  RCVR TYPE
   0.     TILT ANGLE
   0.306  RCVR. POSITION


          SURFACE,REFLECTANCE AND TRACKING PARAMETERS

    0.071  SUN OFF-AXIS ANGLE
    0.900  REFLECTANCE(TOTAL),
  0.00400  SURF. ERROR(ST.DEV.)
  0.00013  REFL.DISTR.1(ST.DEV.)
  0.       REFL.DISTR.2(ST.DEV.)
    0.     TRACKING ERROR-AZ.
    0.     TRACKING ERROR-ROLL



   MISSED     HIT ON    OPTICAL
     RAYS       RCVR  EFFICIENCY

     3903       6097    0.55579
```

Figure 4-2. Sample COPS Output

where 0.88 is the total reflectance and 4.1^{o} is the off-axis sun angle. The 0.08 x 4 kW accounts for the fact that some rays (8 percent) strike the receiver without directly bouncing from the reflecting surface. Since not all rays hit the receiver, the optical efficiency computed from ray trace is 0.556.

The second part of the computed output is a mapping of receiver ray hits and power (Figure 4-3). The cylinder is unrolled such that x is along the axis and y is the azimuth zones on the receiver. In this case there are ten azimuth and five length zones; therefore, each azimuth zone is 36^{o} wide and each x (length) zone is 0.8 meter long. The flux maps are in units of power per square meter of receiver area. Thus, if the incoming radiation at the concentrator aperture were 1 kW/m^2, the flux would be exactly as shown in Figure 4-3 in units of kW/m^2.

Y....   HITS IN ZONES

X
.
.

18	43	52	50	238	215	56	96	291	196
18	40	50	77	200	199	46	92	257	178
18	46	55	60	233	178	61	82	294	197
18	33	49	61	222	188	54	103	281	202
16	47	67	64	240	188	51	96	286	195

PWR/M**2 IN ZONES

0.0701	0.1675	0.2026	0.1882	0.8377	0.7540	0.1964	0.3367	1.0205	0.6877
0.0701	0.1559	0.1948	0.2911	0.7064	0.6979	0.1613	0.3226	0.9013	0.6242
0.0701	0.1792	0.2143	0.2291	0.8210	0.6242	0.2139	0.2876	1.0310	0.6908
0.0701	0.1286	0.1909	0.2295	0.7832	0.6593	0.1894	0.3612	0.9854	0.7084
0.0623	0.1831	0.2611	0.2404	0.8475	0.6593	0.1788	0.3367	1.0029	0.6838

Figure 4-3. COPS Hit and Flux Map

APPENDIX A

SUBROUTINE DESCRIPTION AND FLOWCHARTS

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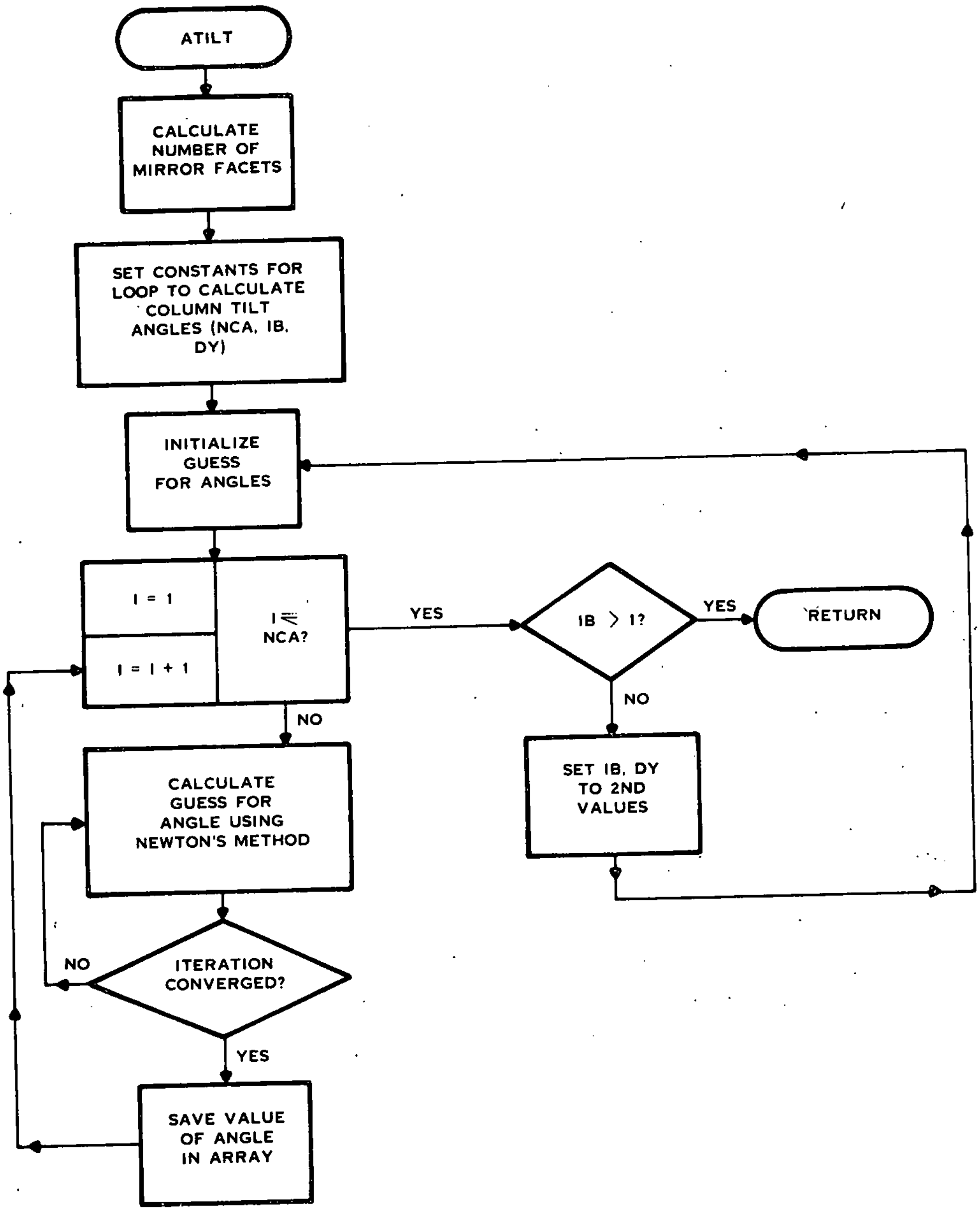
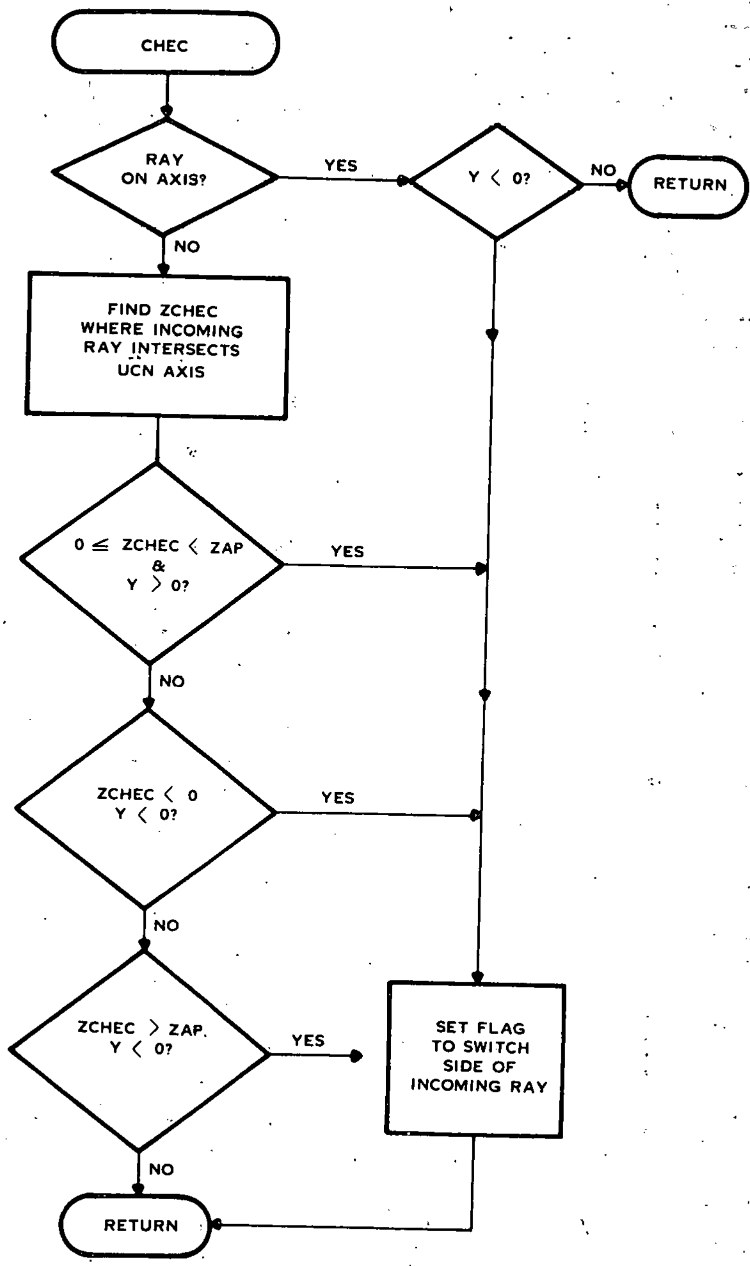
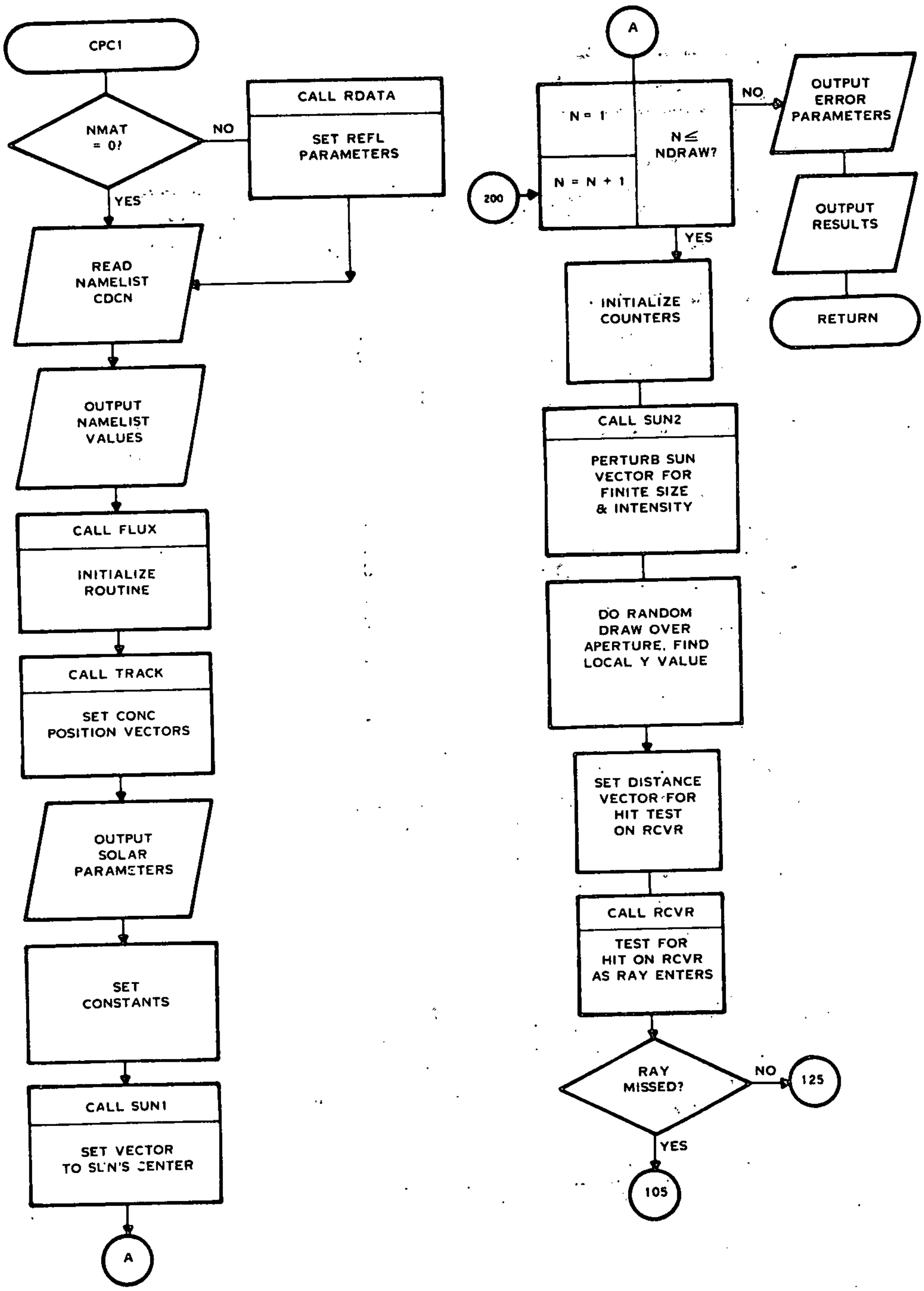
Subroutine ATILT calculates all column axis tilt angles for the RPI concentrator model. These are stored in the array CATA.

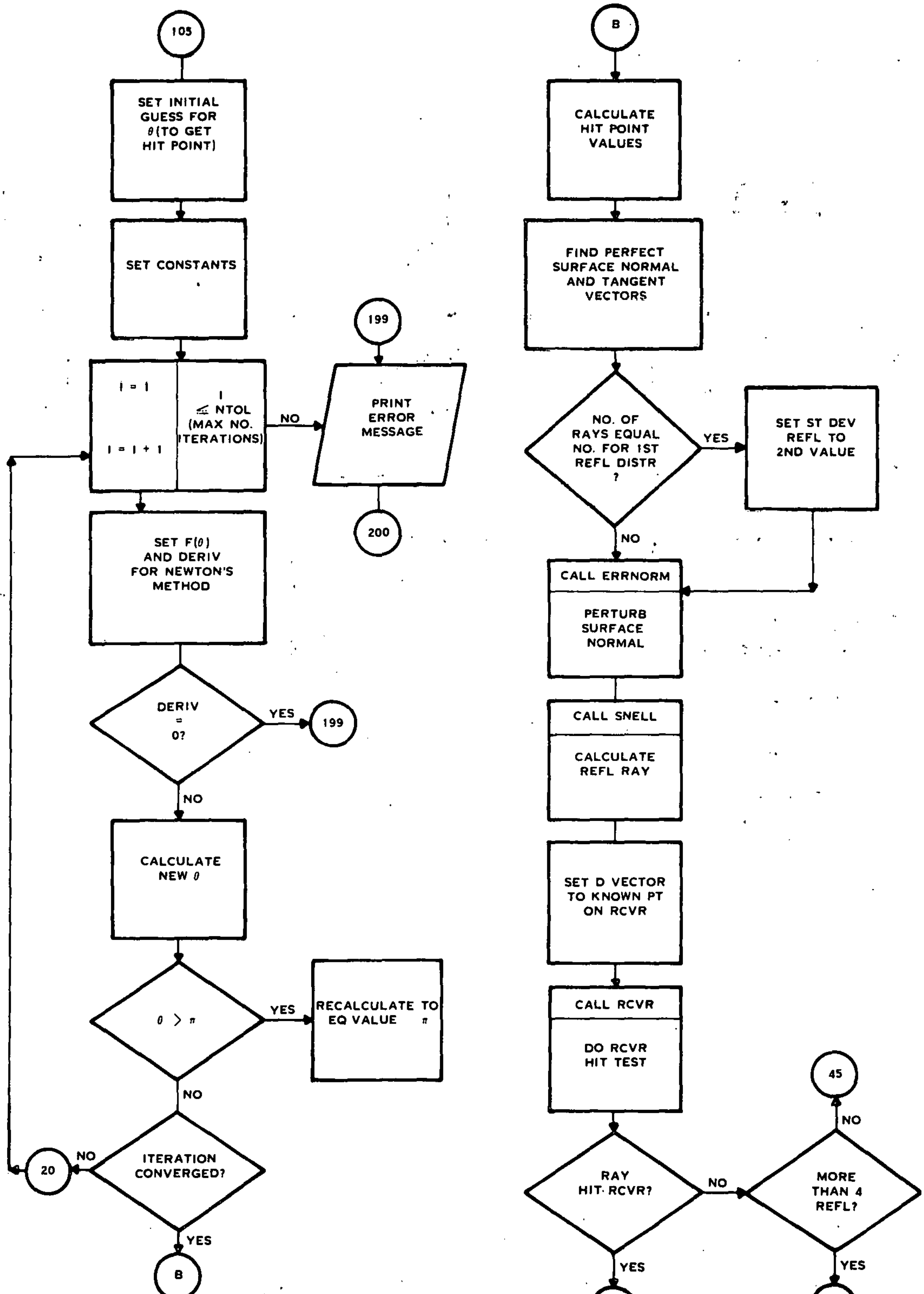


Subroutine CHEC finds the intersection of an incoming or reflected ray with the vertical axis. This information is used in CPC2 and VEEHIT to determine which side (plus or minus) of the concentrator is to be searched for the ray intersection with the reflecting surface.

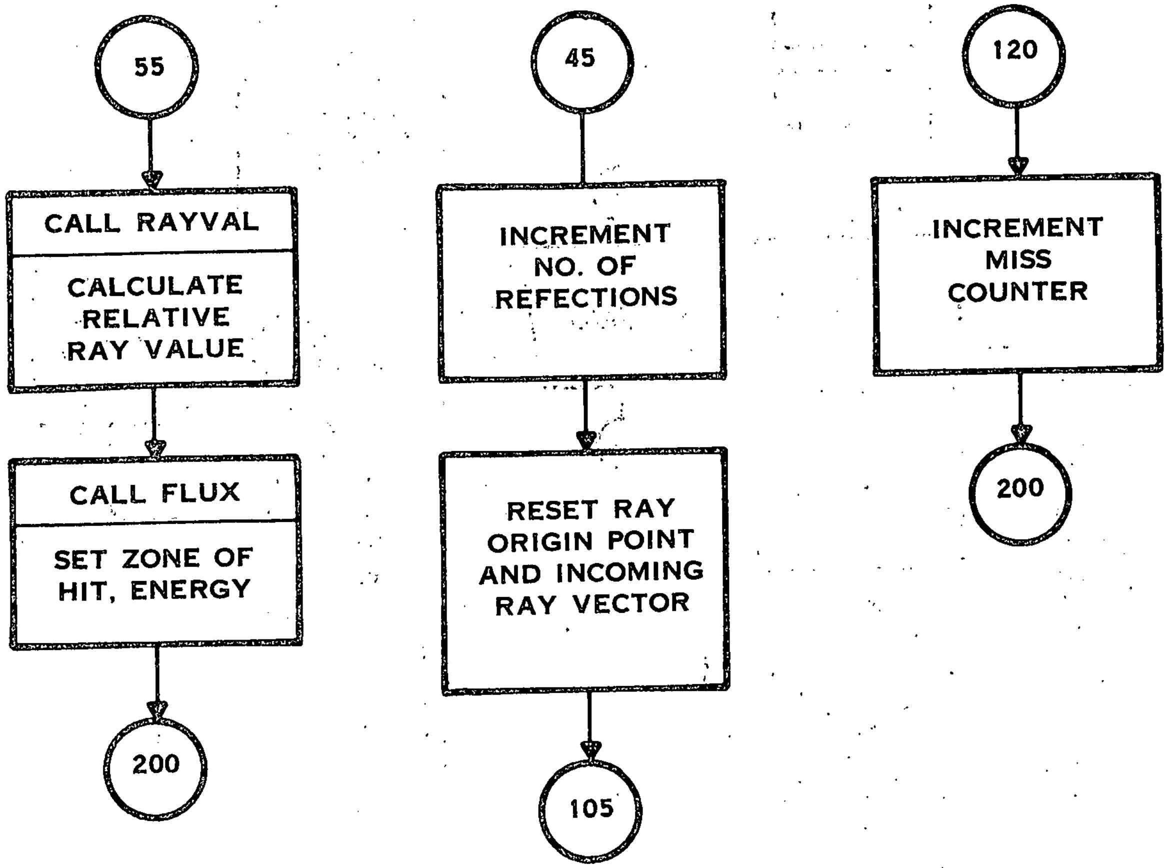


Subroutine CPC1 models an involute compound parabolic concentrator. Newton's method is used to find the intersection of the incoming ray with the CPC surface.

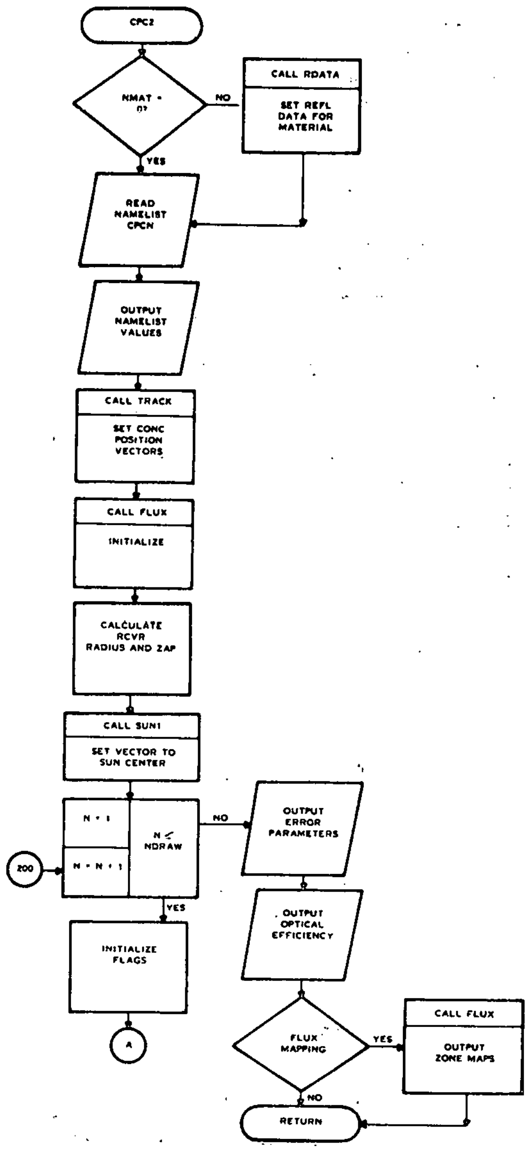



105
SET INITIAL GUESS FOR θ (TO GET HIT POINT)
SET CONSTANTS
I = 1
I = I + 1
I ≤ NTOL (MAX NO. ITERATIONS)
NO
199
PRINT ERROR MESSAGE
200
SET F(θ) AND DERIV FOR NEWTON'S METHOD
DERIV = 0?
YES
199
NO
CALCULATE NEW θ
θ > π
YES
RECALCULATE TO EQ VALUE π
NO
ITERATION CONVERGED?
NO
20
YES
B
B
CALCULATE HIT POINT VALUES
FIND PERFECT SURFACE NORMAL AND TANGENT VECTORS
NO. OF RAYS EQUAL NO. FOR 1ST REFL DISTR ?
YES
SET ST DEV REFL TO 2ND VALUE
NO
CALL ERRNORM
PERTURB SURFACE NORMAL
CALL SNELL
CALCULATE REFL RAY
SET D VECTOR TO KNOWN PT ON RCVR
CALL RCVR
DO RCVR HIT TEST
RAY HIT RCVR?
NO
MORE THAN 4 REFL?
NO
45
YES
55
YES
120

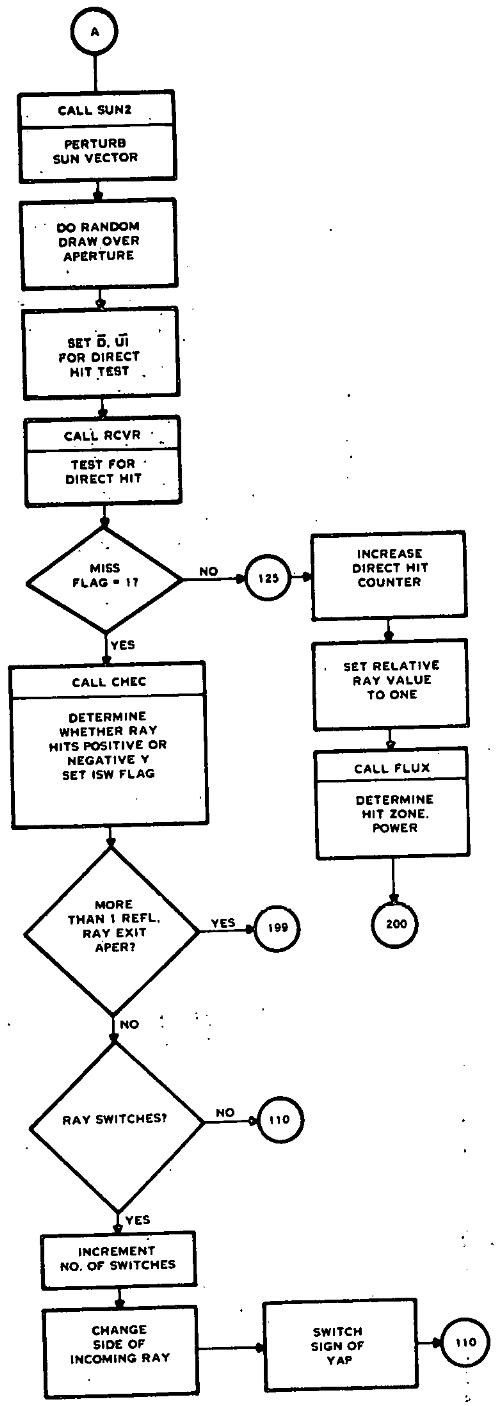
Subroutine CPC1 (concluded)



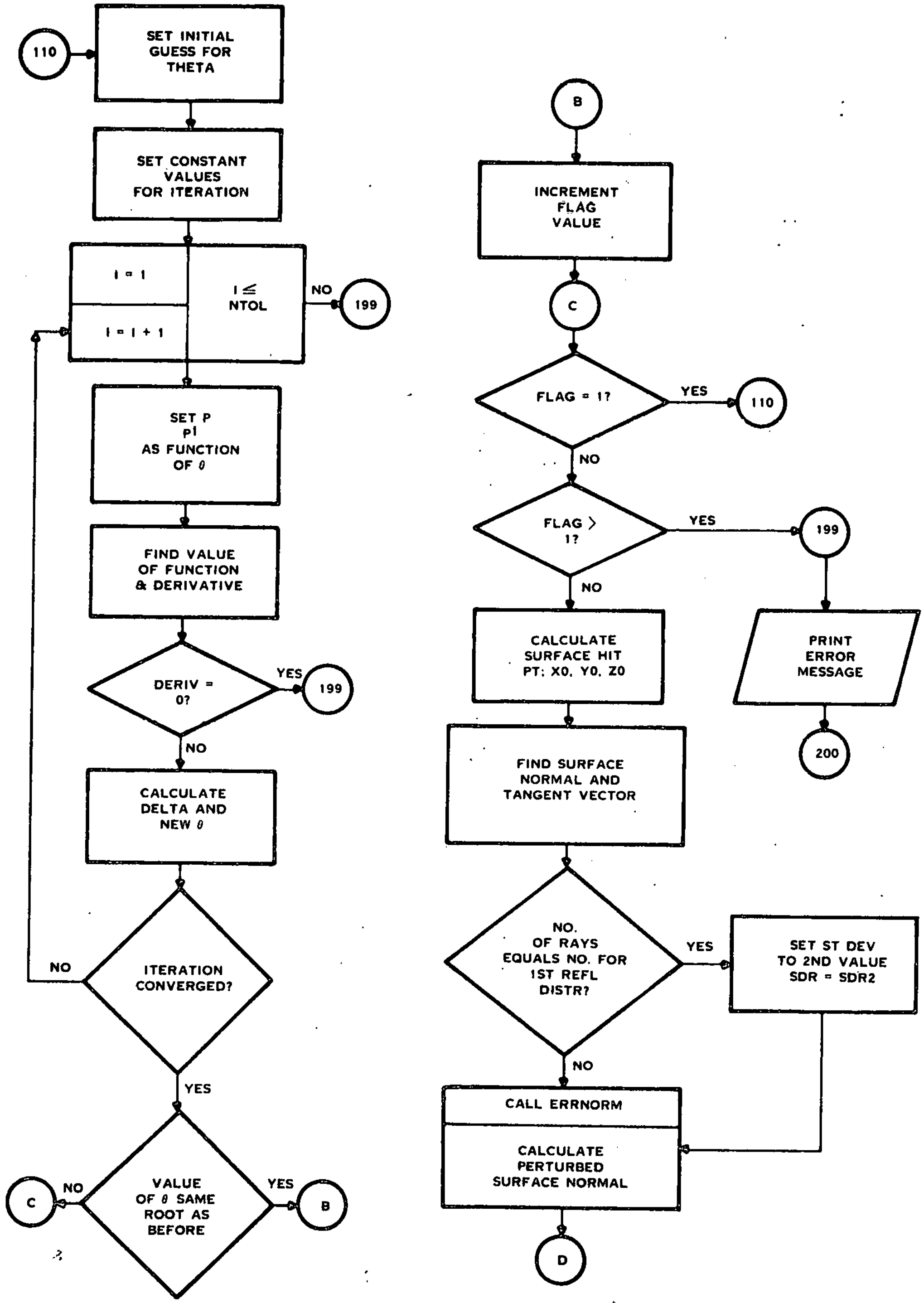
Subroutine CPC2 models a reflector absorber as defined in a paper by Rabl, "Solar Concentrators with Maximal Concentration for Cylindrical Absorbers," Applied Optics, July 1976. Newton's method is used to find ray intersections with the reflecting surface.



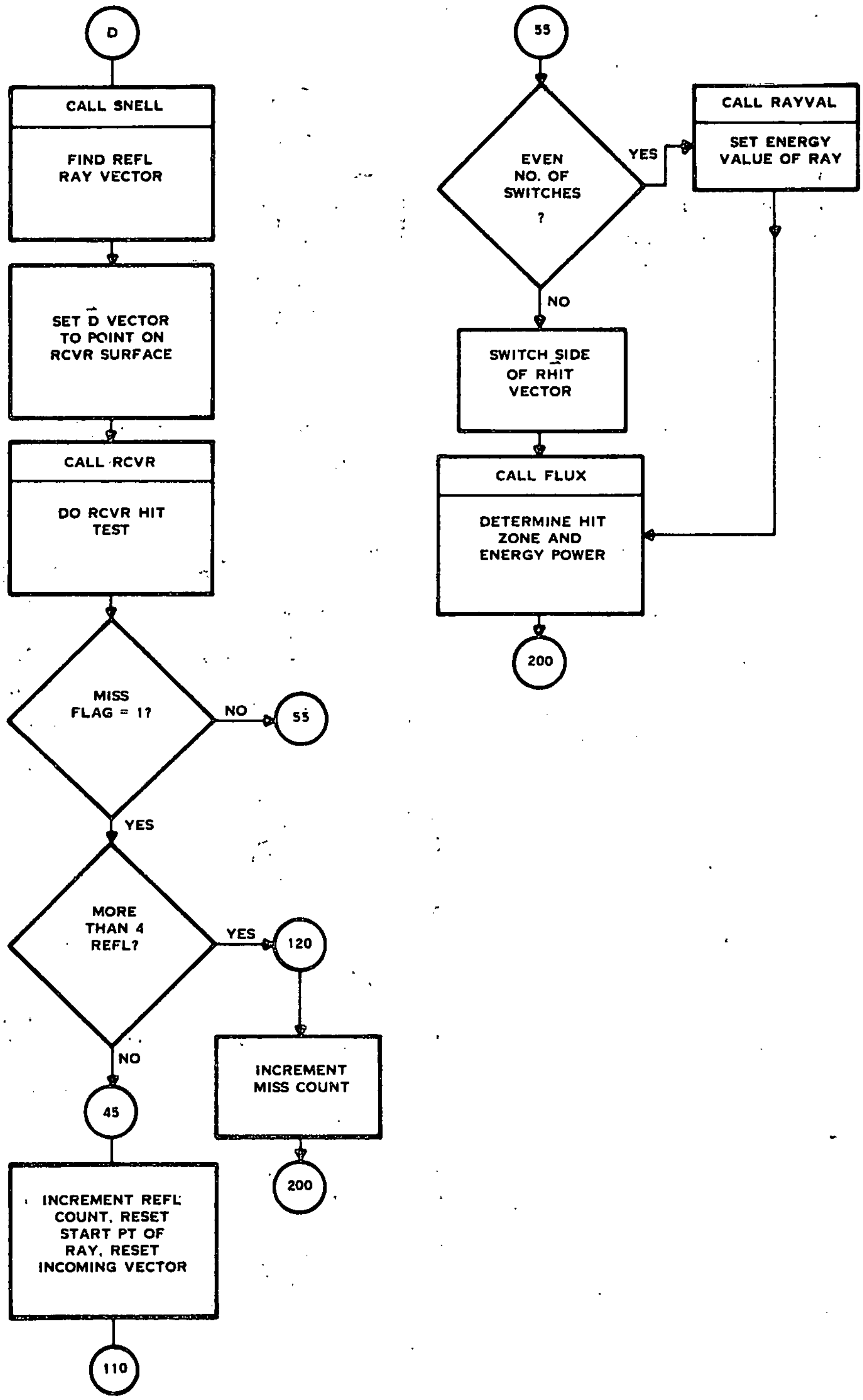
Subroutine CPC2 (continued)



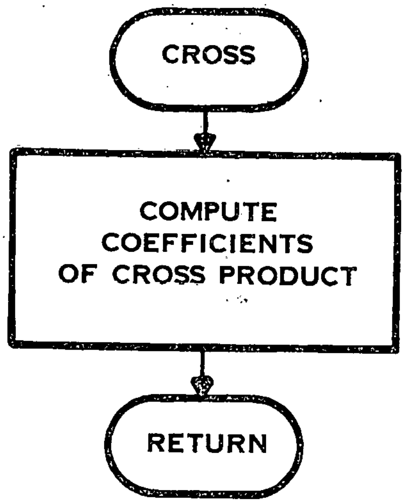
Subroutine CPC2 (continued)



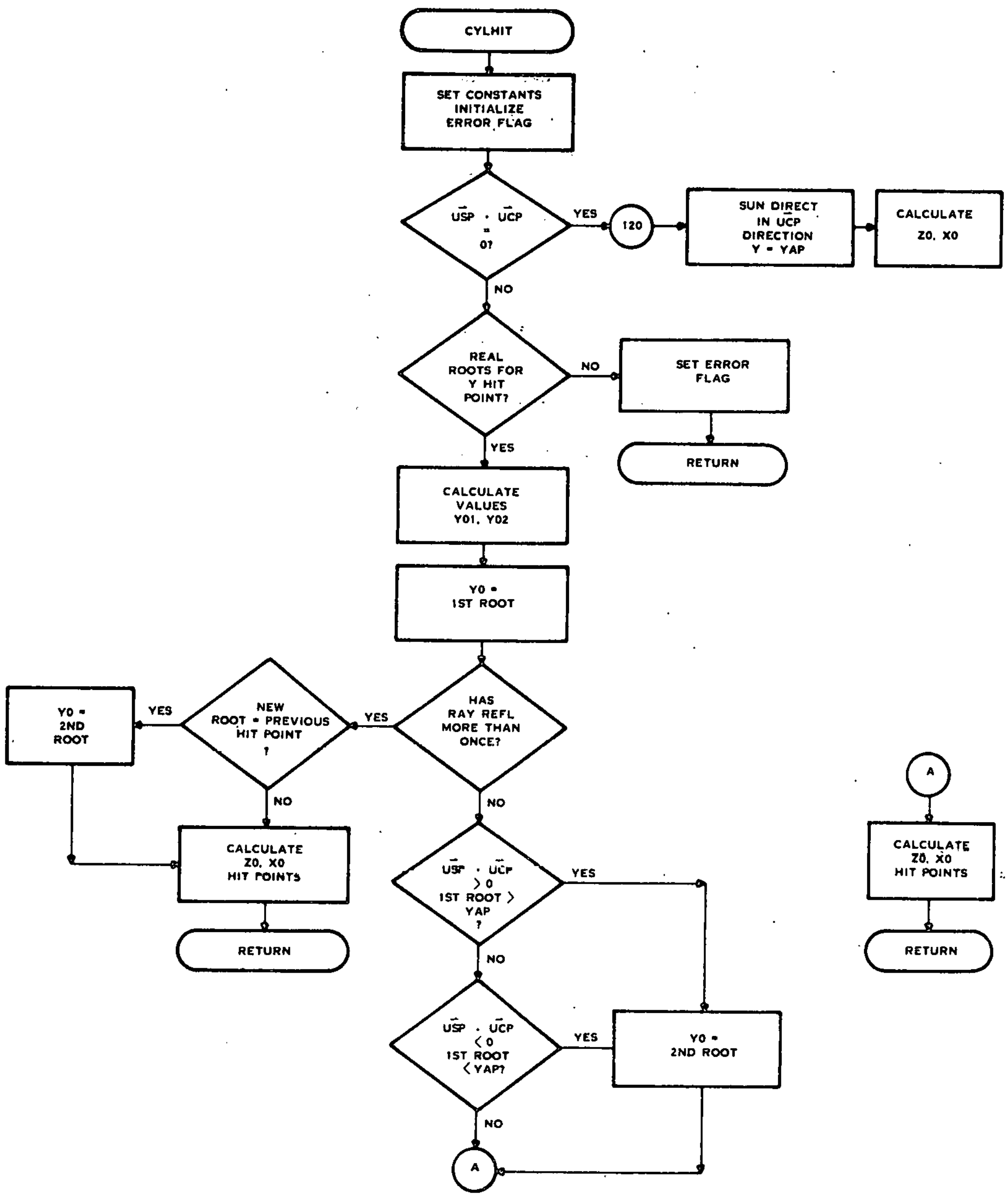
Subroutine CPC2 (concluded)



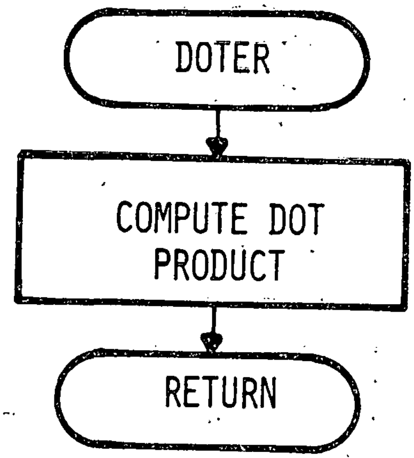
Subroutine CROSS calculates the cross product of two vectors.



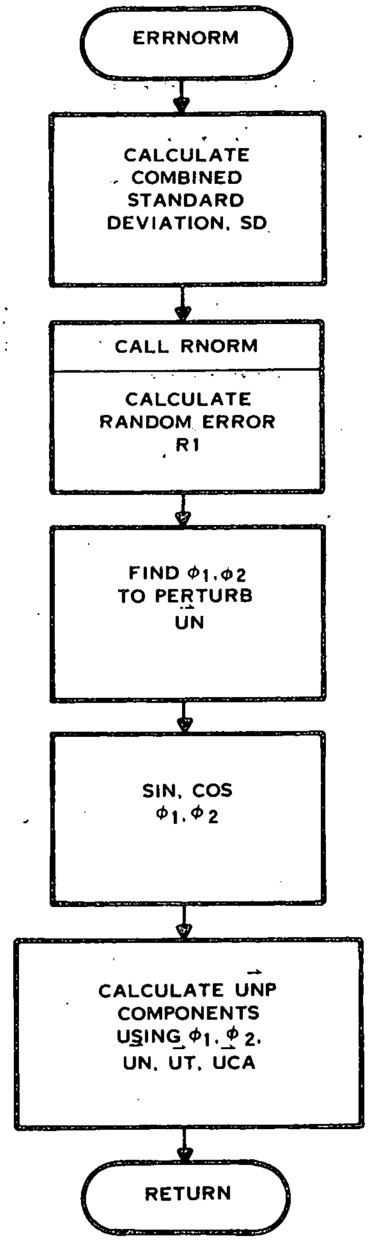
Subroutine CYLHIT finds the hit point on a cylindrical concentrator surface given an incoming ray and origin.



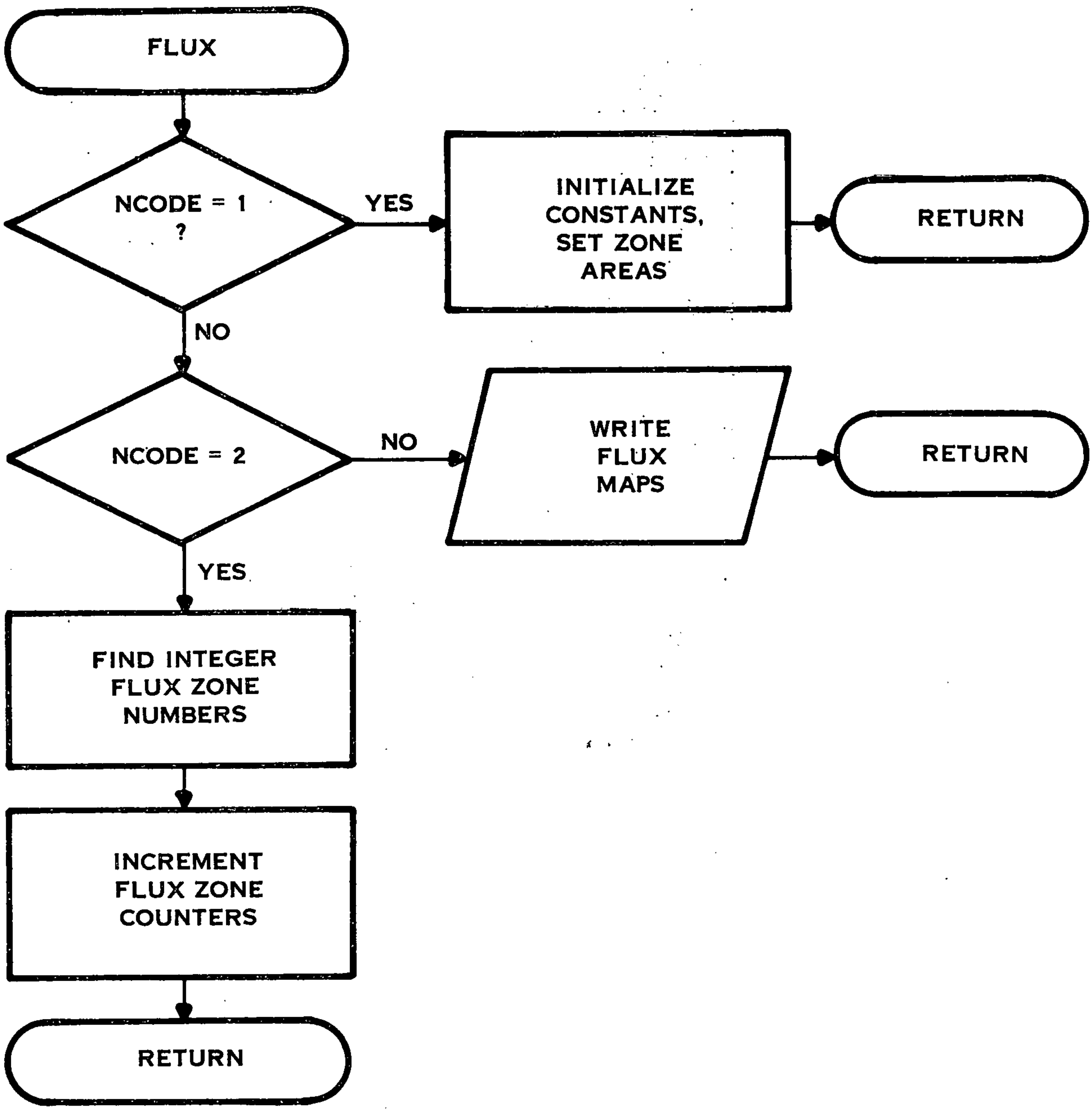
Function DOTER calculates the dot product of two vectors.



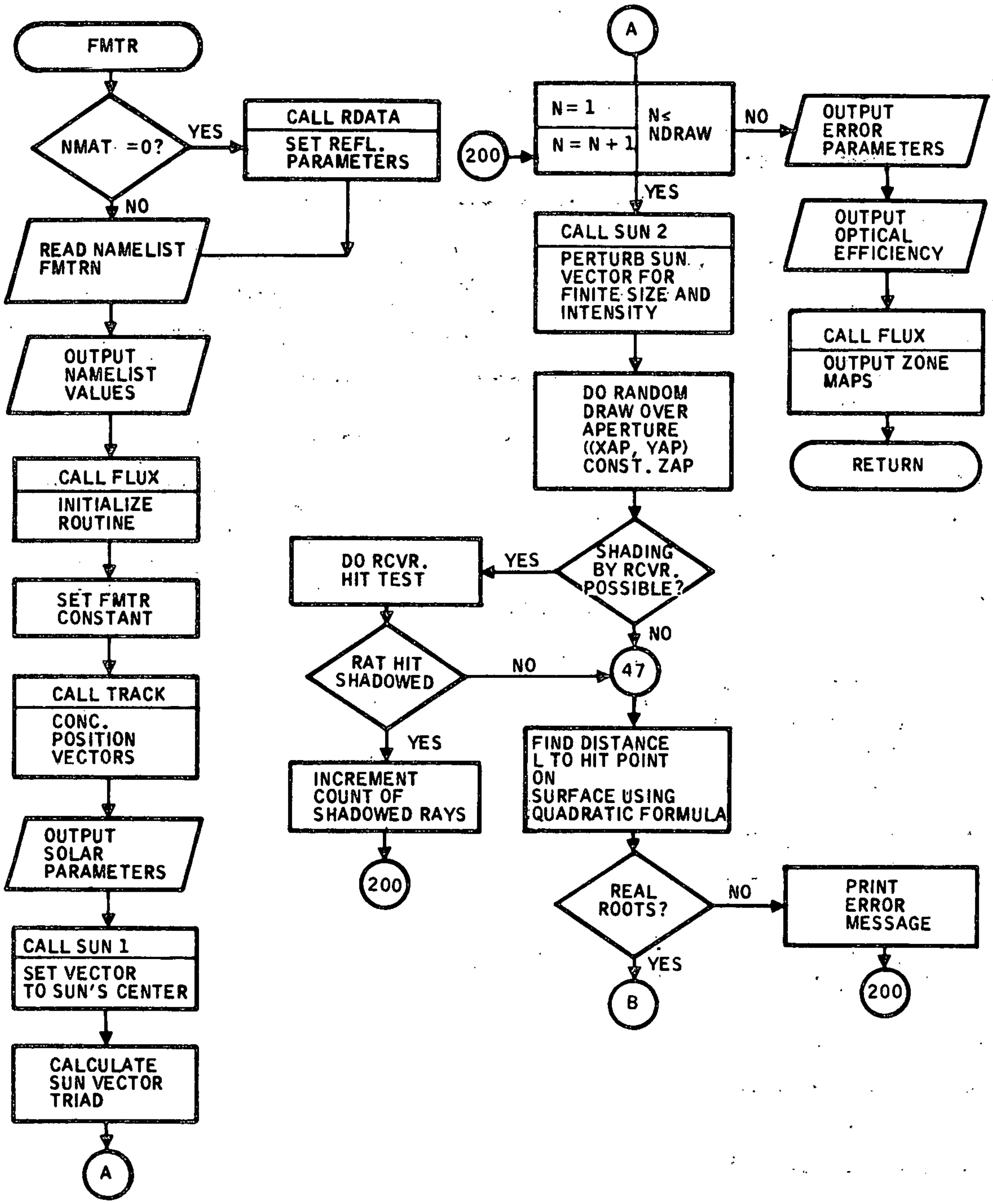
Subroutine ERRNORM perturbs a surface normal vector for surface errors and the reflectance distribution. Subroutine RNORM is called from ERRNORM to determine the first angle of rotation. The second angle is determined by an evenly distributed random rotation using the random number generator.



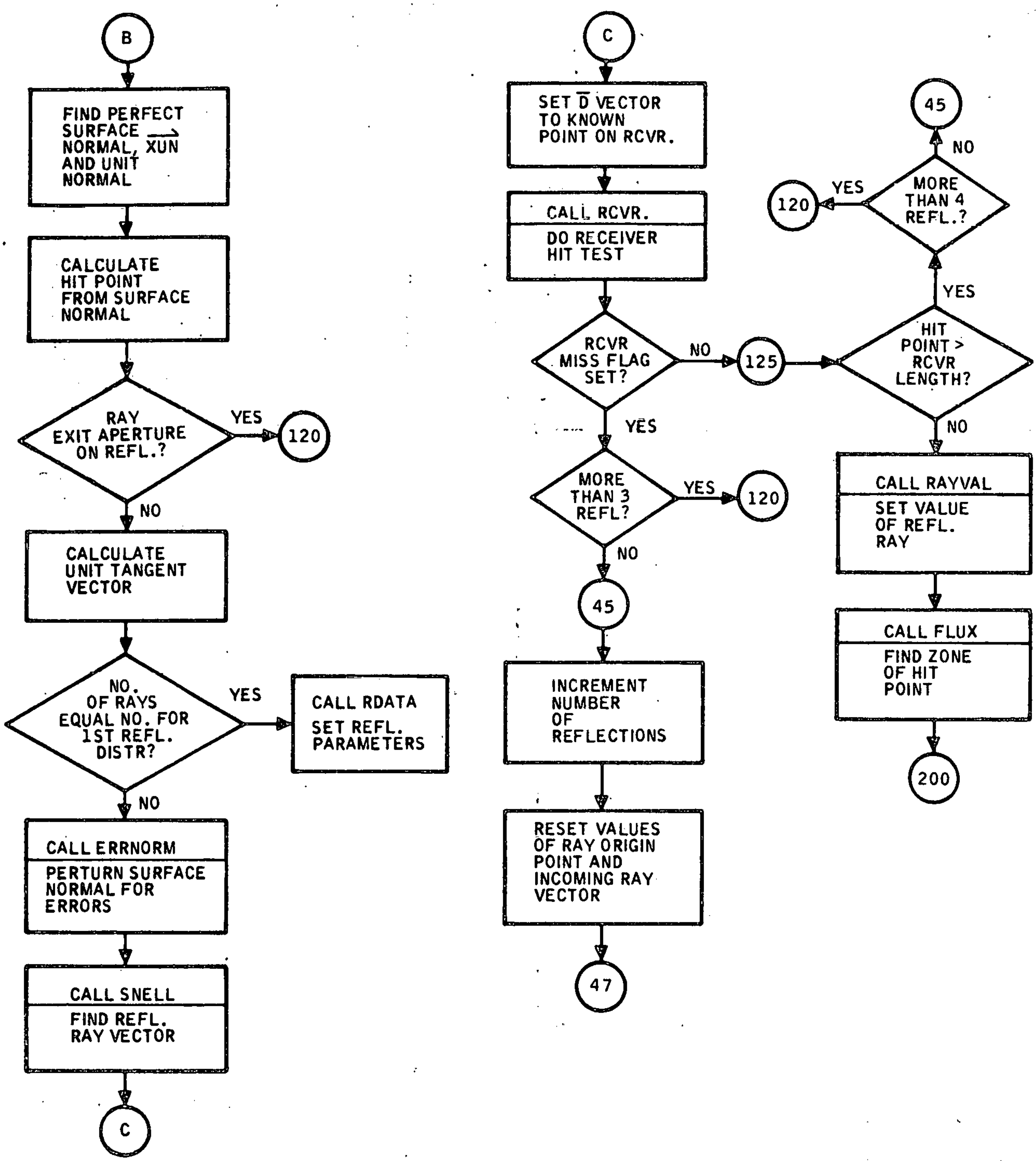
Subroutine FLUX sums up ray hits on receivers into zones on the receiver to output a flux map.



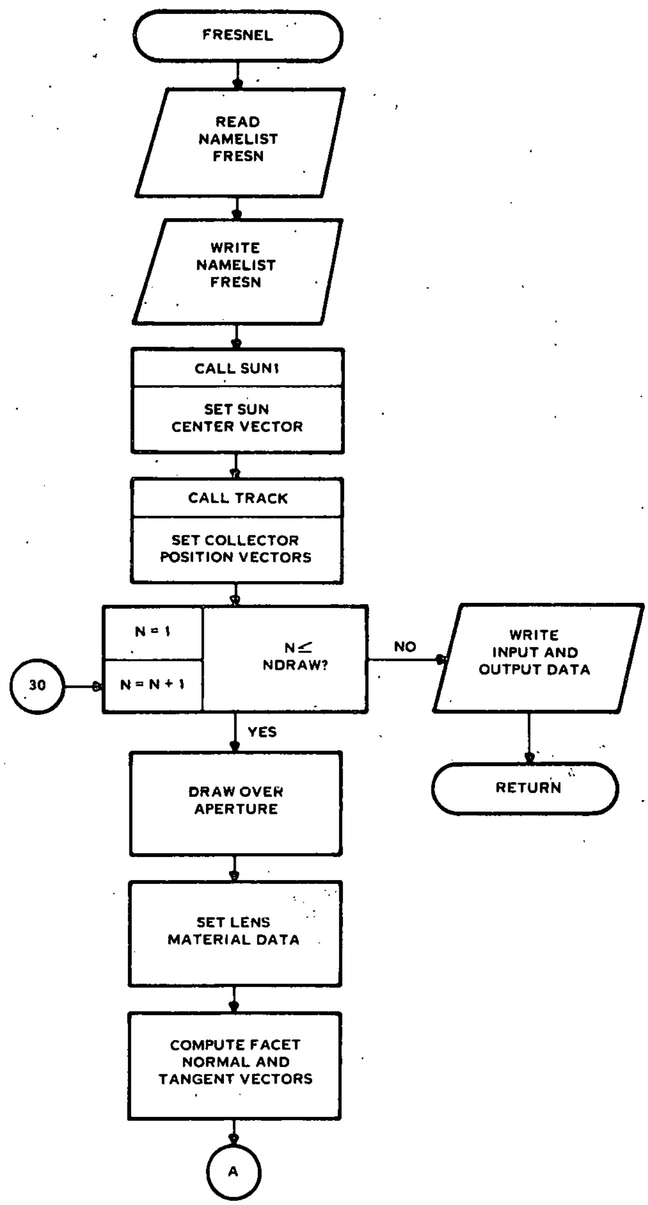
Subroutine FMTR models the fixed-mirror tracking receiver concentrator with a conical two-axis tracking absorber.



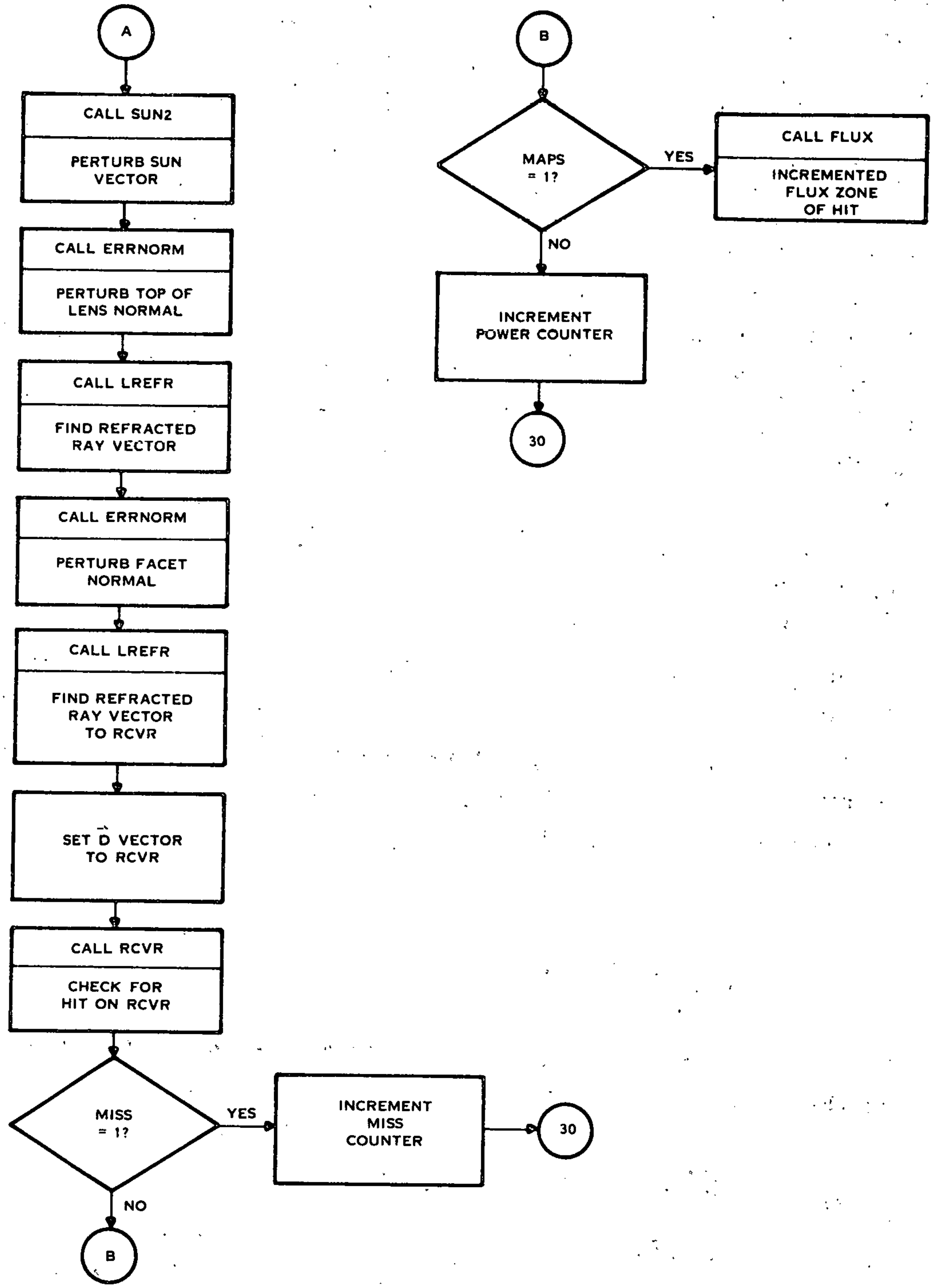
Subroutine FMTR (concluded)



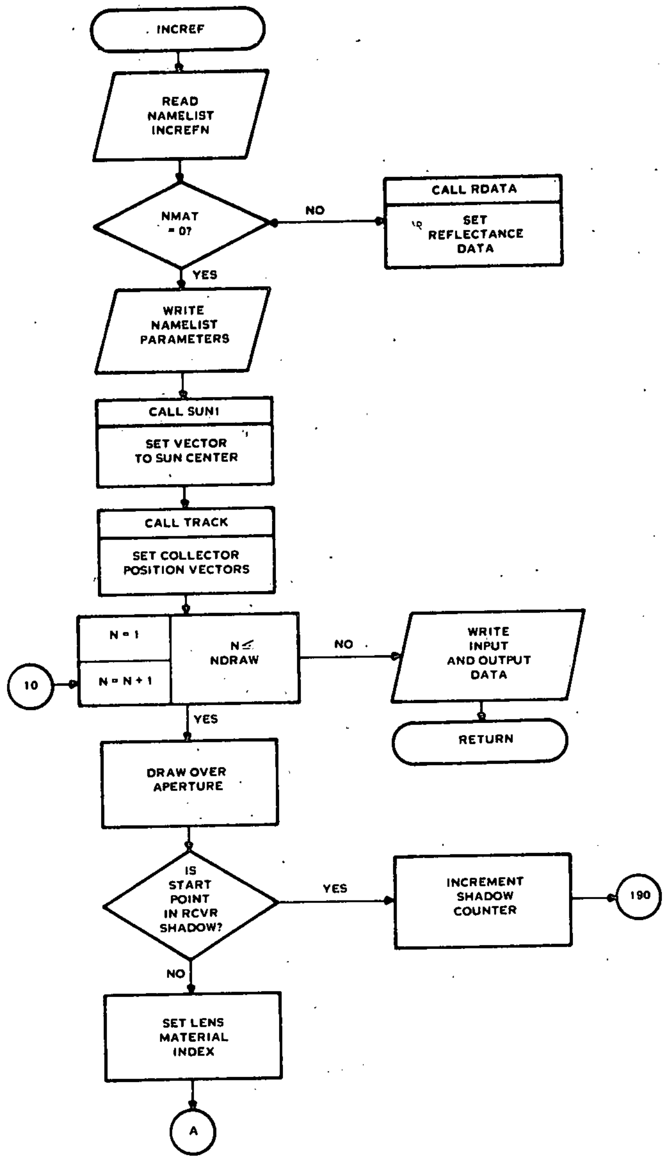
Subroutine FRESNEL models a Fresnel lens (linear) with user-specified facet width. Either a planar or cylindrical absorber can be used.



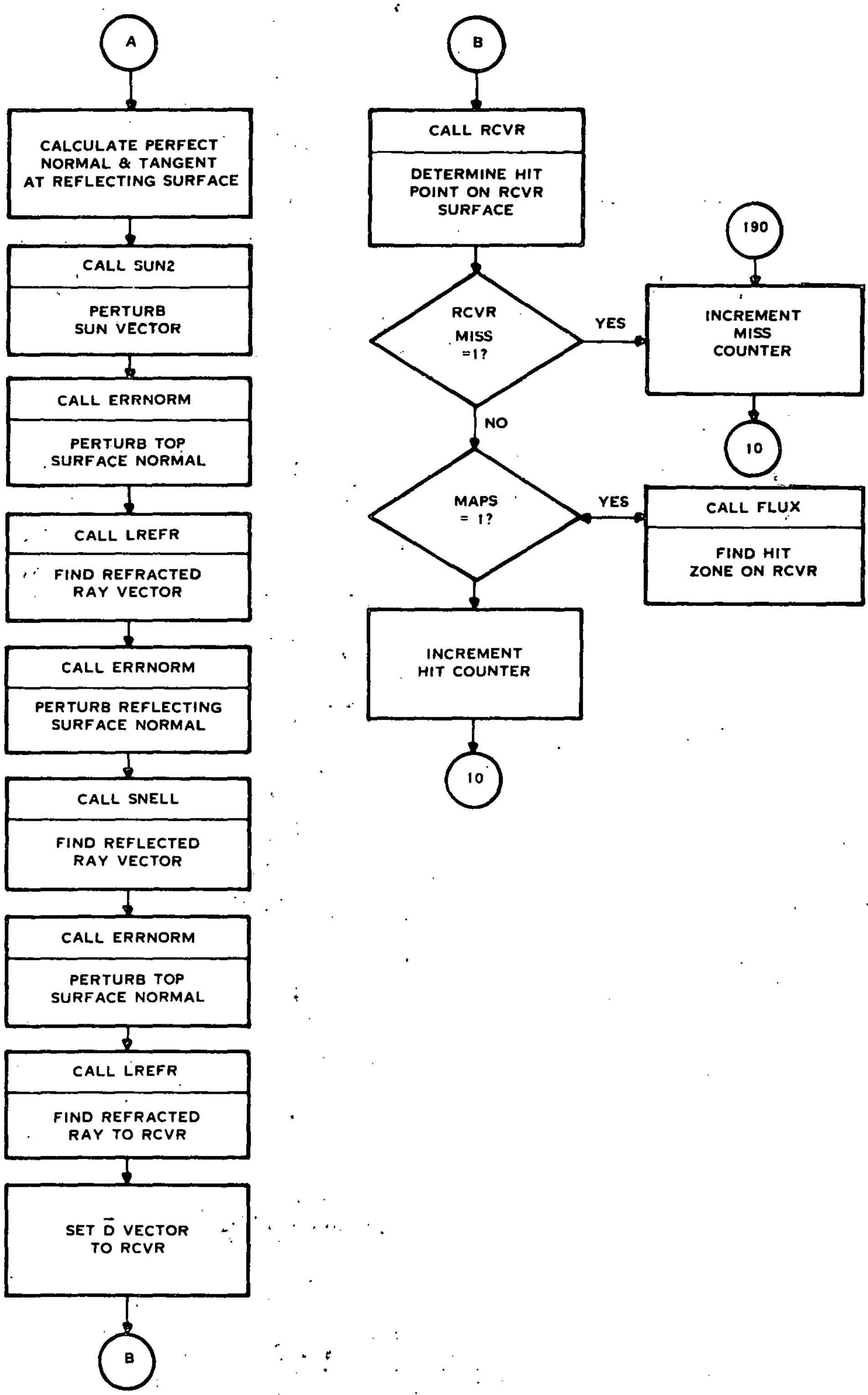
Subroutine FRESNEL (concluded)



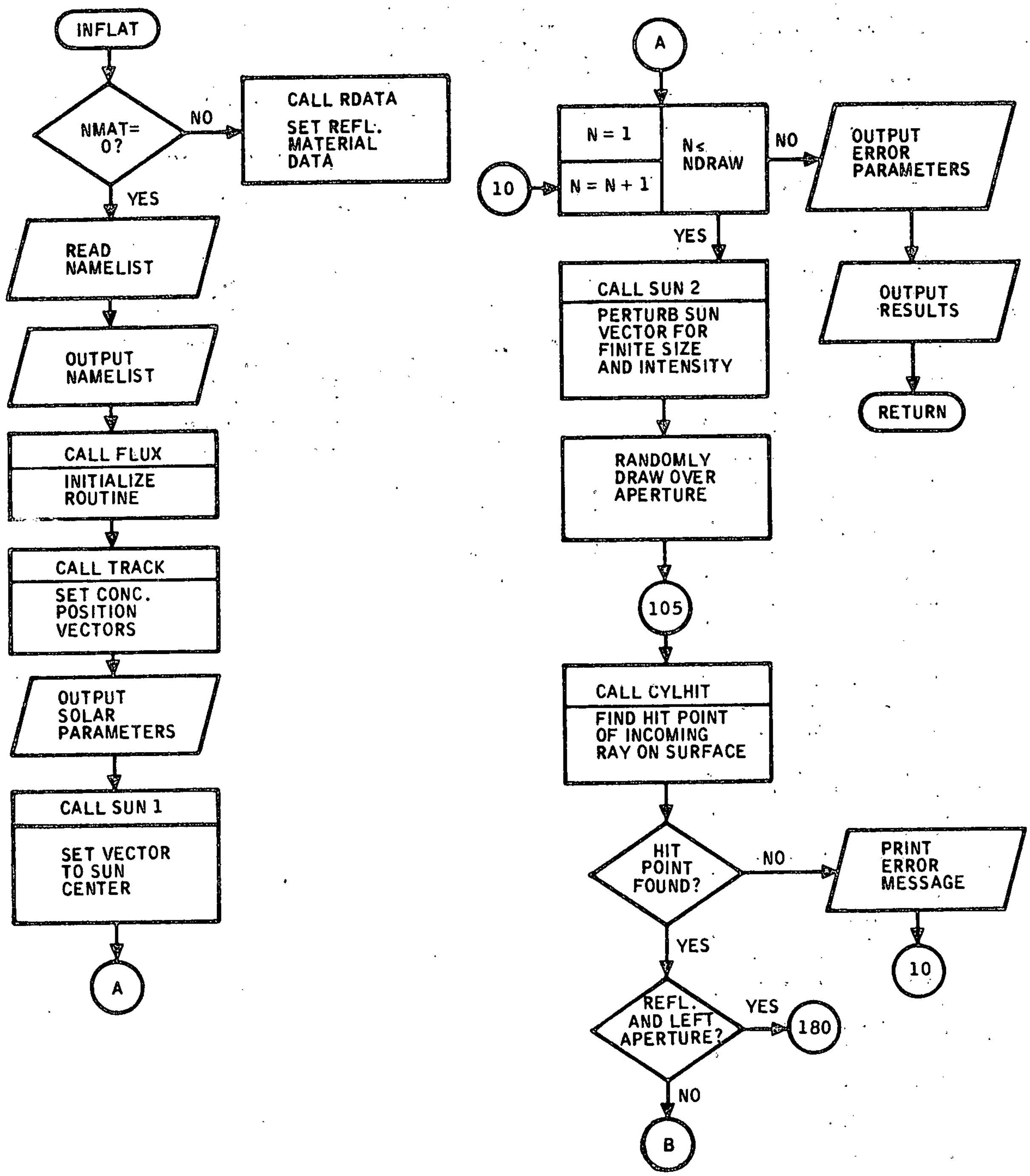
Subroutine INCREF models an incremental reflector type of concentrating collector.



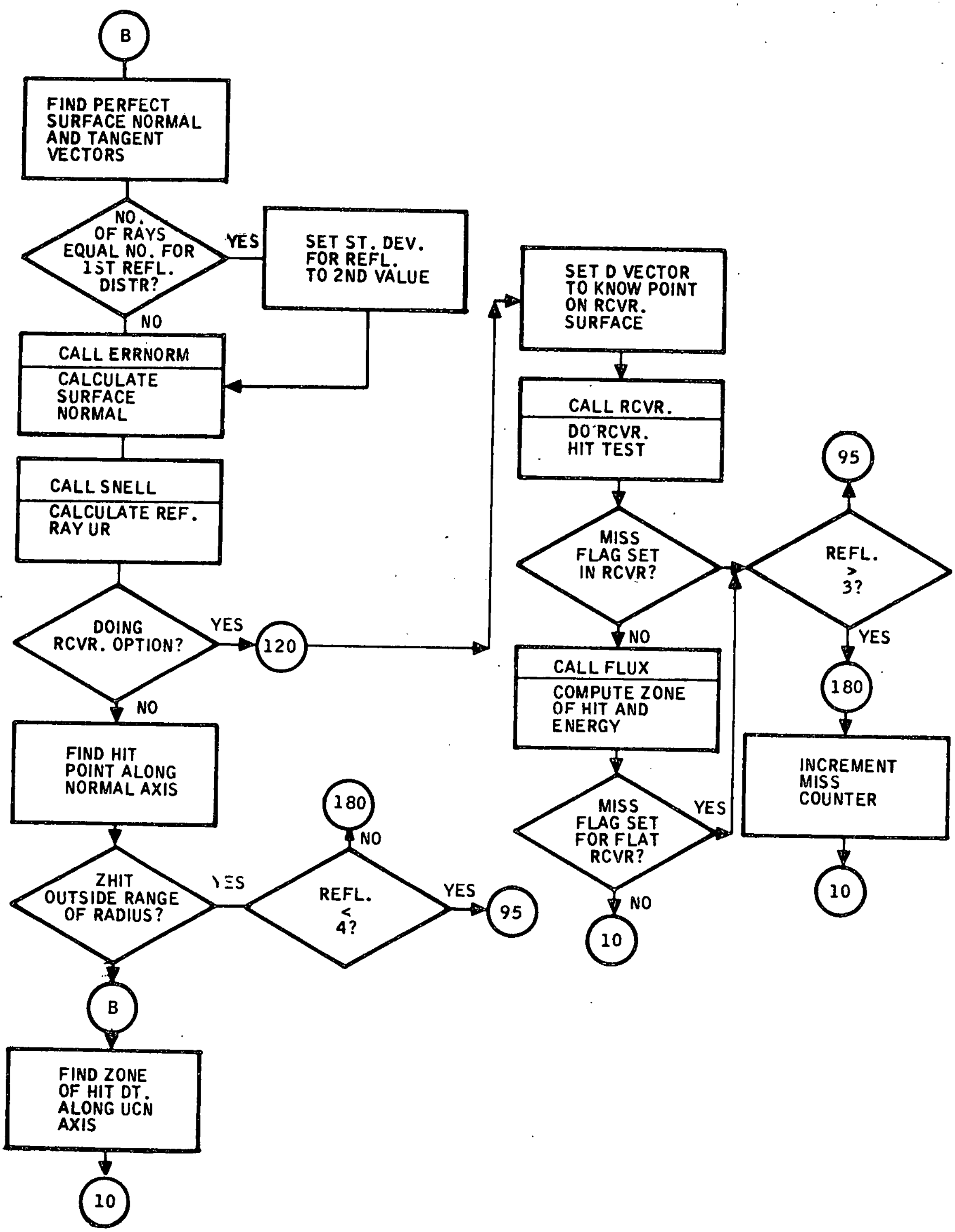
Subroutine INCREF (concluded)



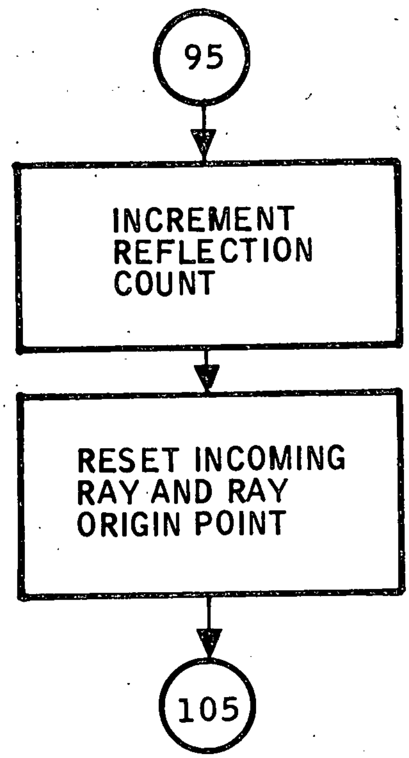
Subroutine INFLAT models the one-axis tracking inflatable concentrating collector using a cylindrical absorber.



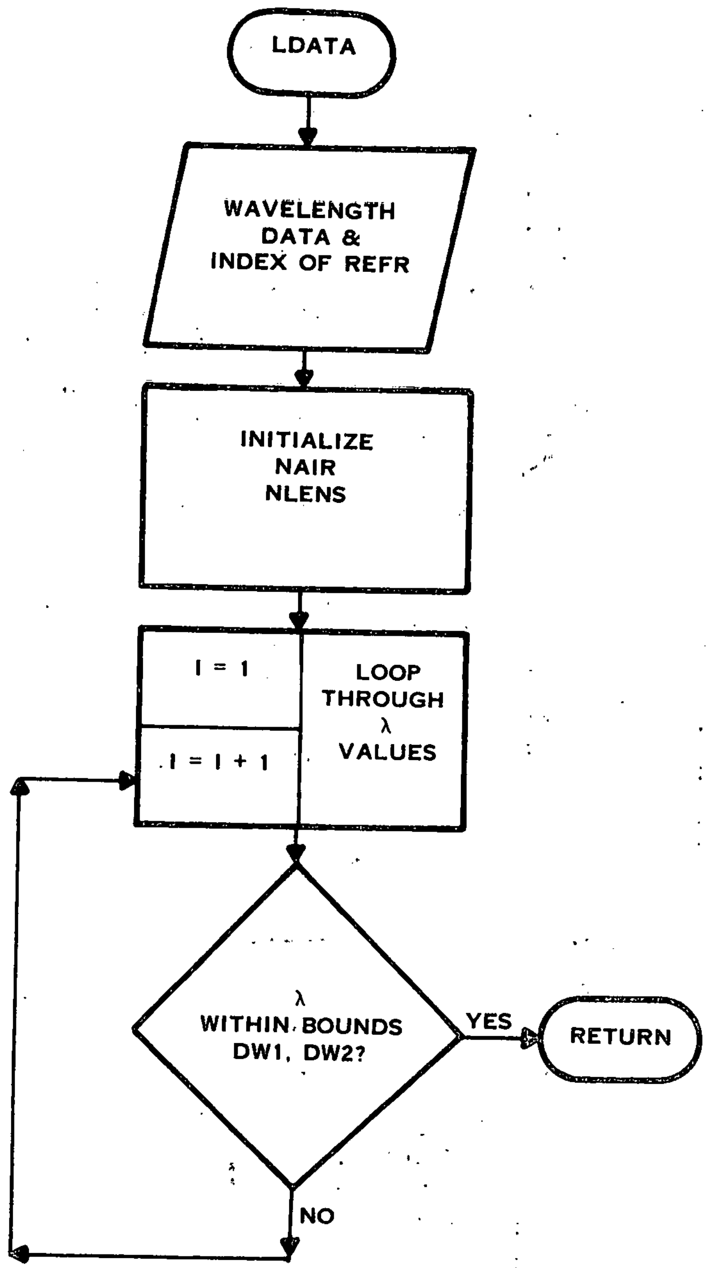
Subroutine INFLAT (continued)



Subroutine INFLAT (concluded)

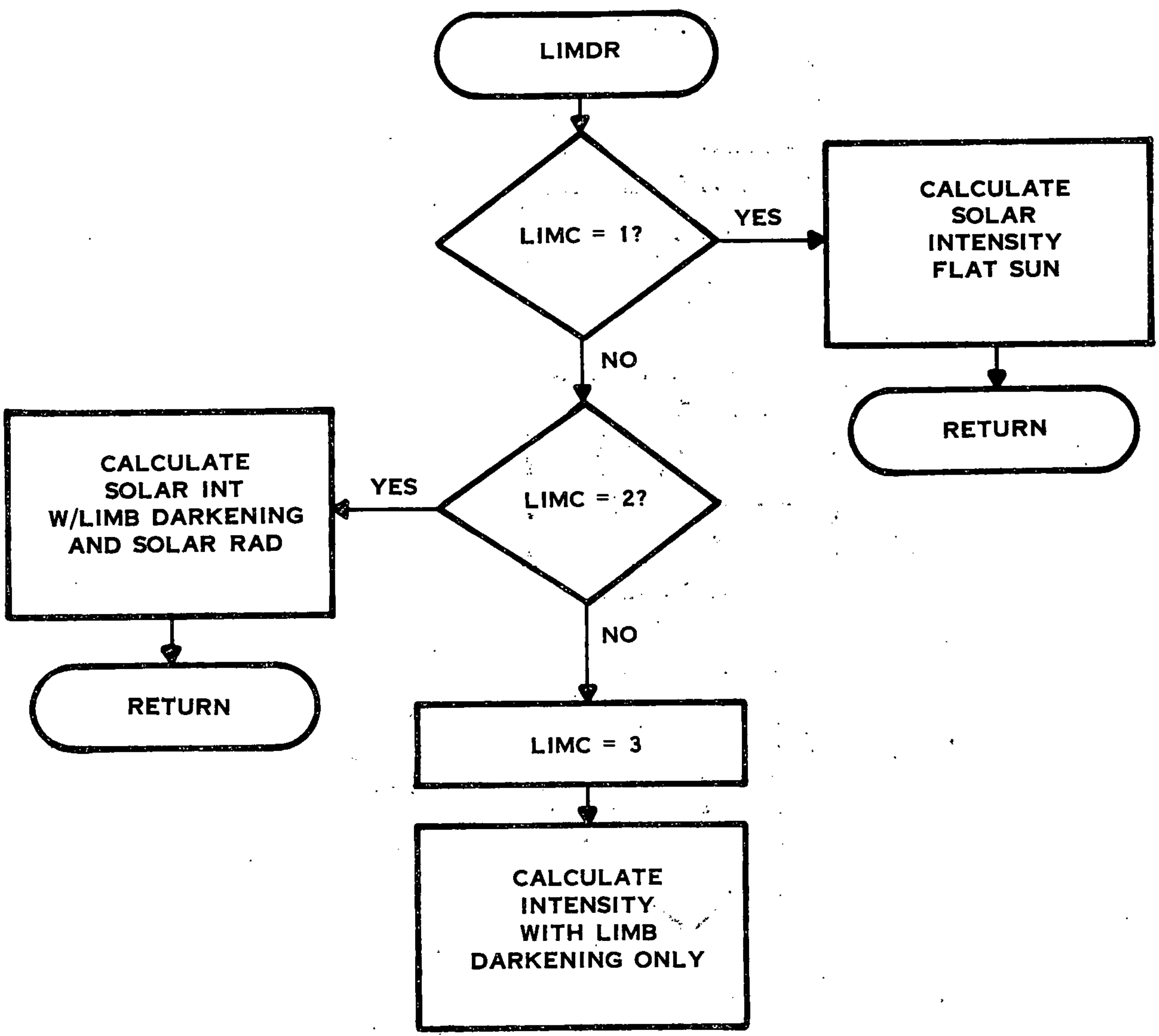


Subroutine LDATA contains the refractive index data for an acrylic lens, 10 mm thick. The refraction index is a function of the wavelength of the sun's ray.

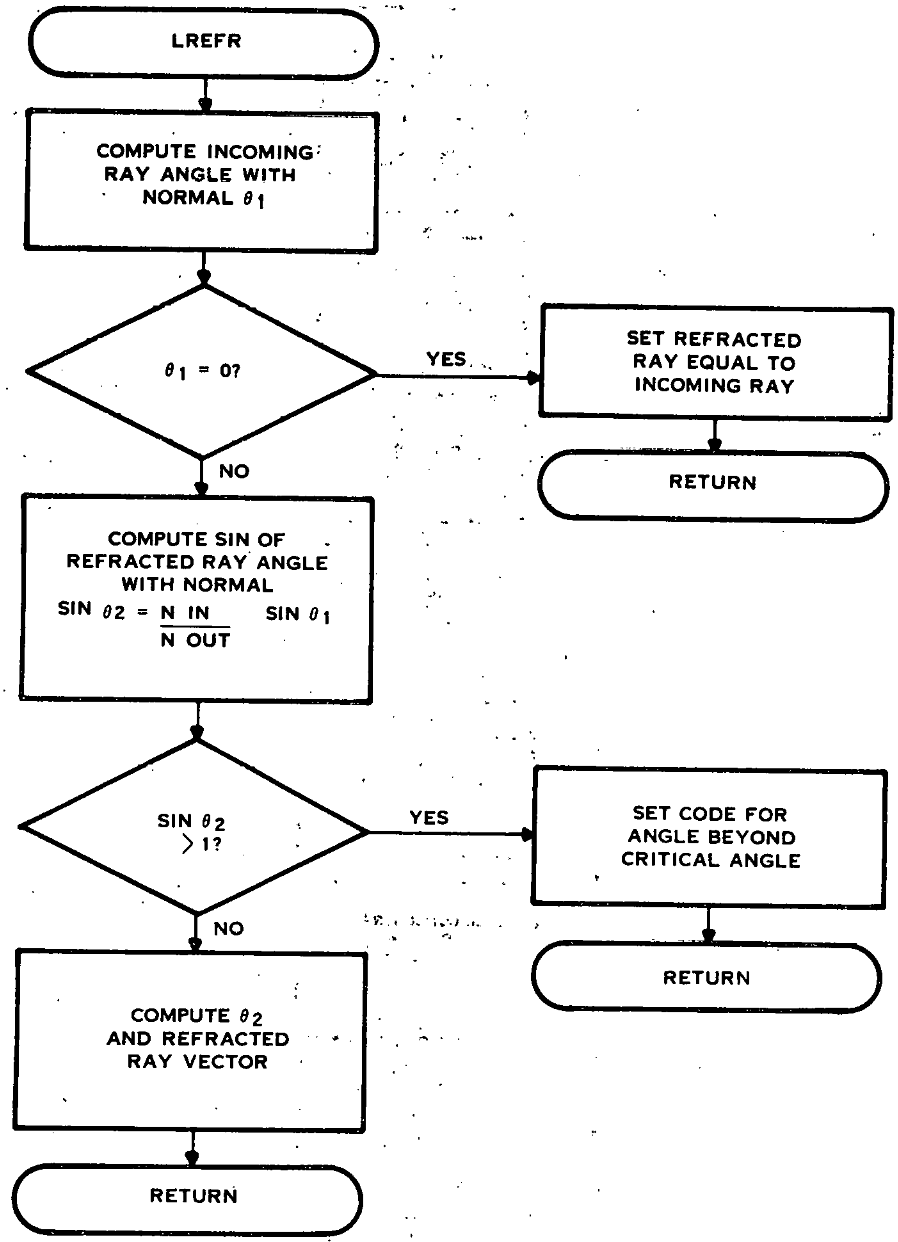


Subroutine LIMDR models the intensity distribution of energy across the surface of the sun. Three different modes are possible:

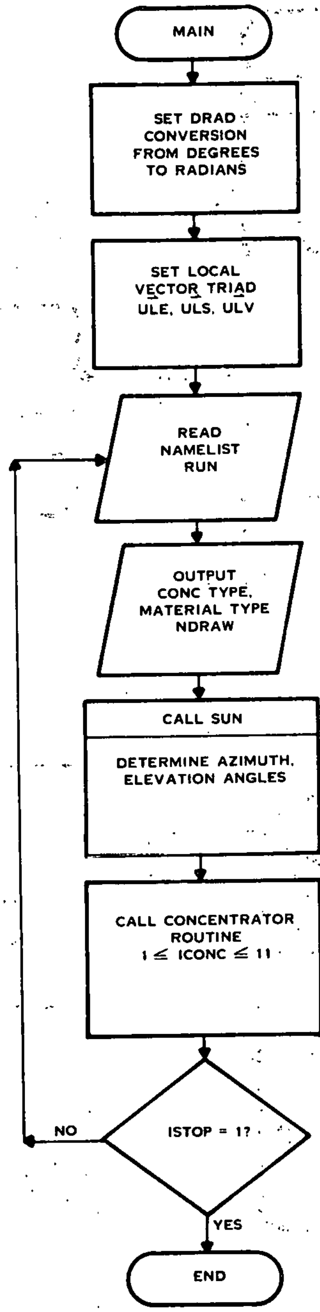
- LIMC = 1 assumes a flat sun.
- LIMC = 2 assumes a sun with limb darkening and solar radiation.
- LIMC = 3 assumes a sun with limb darkening only.



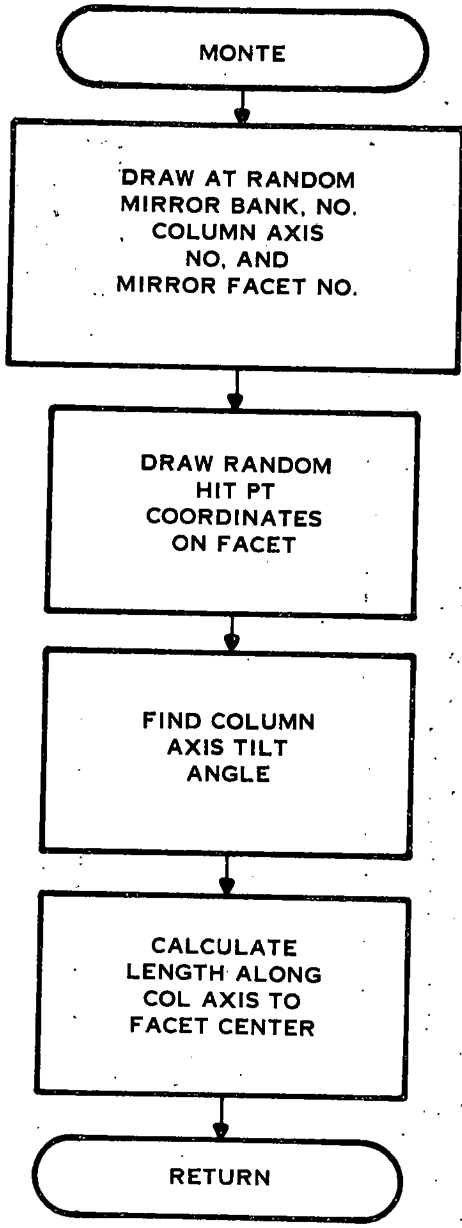
Subroutine LREFR computes the refracted ray vector using the law of sines.



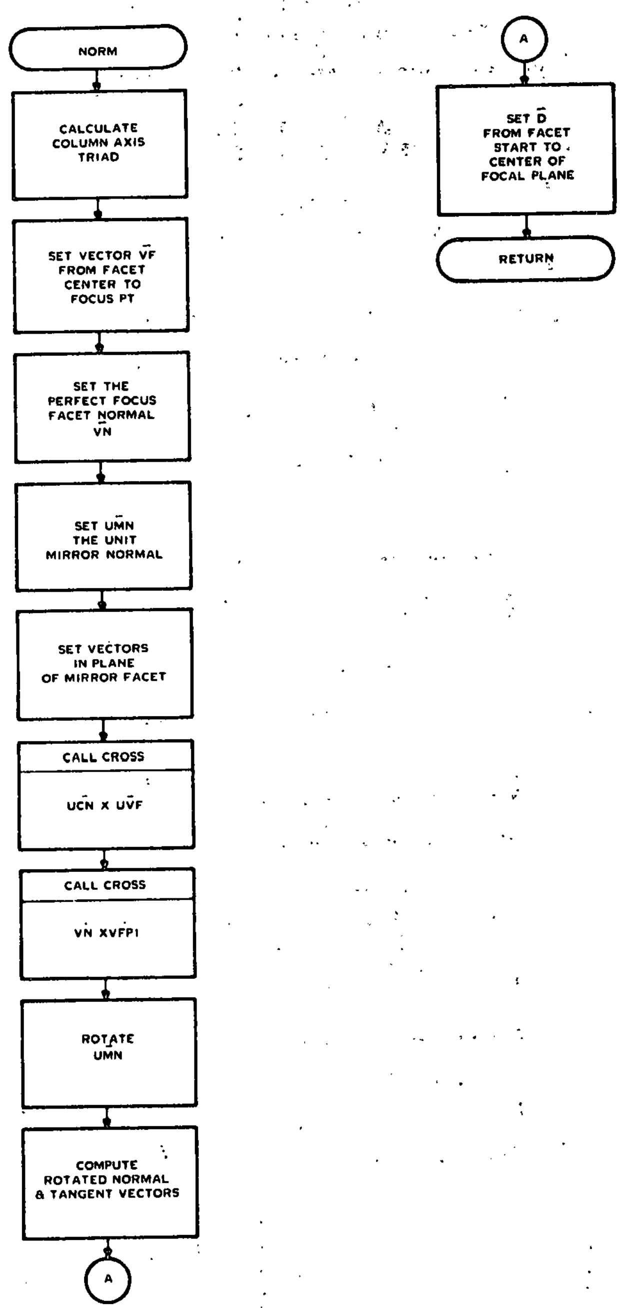
MAIN is the driver for the Monte Carlo ray trace.



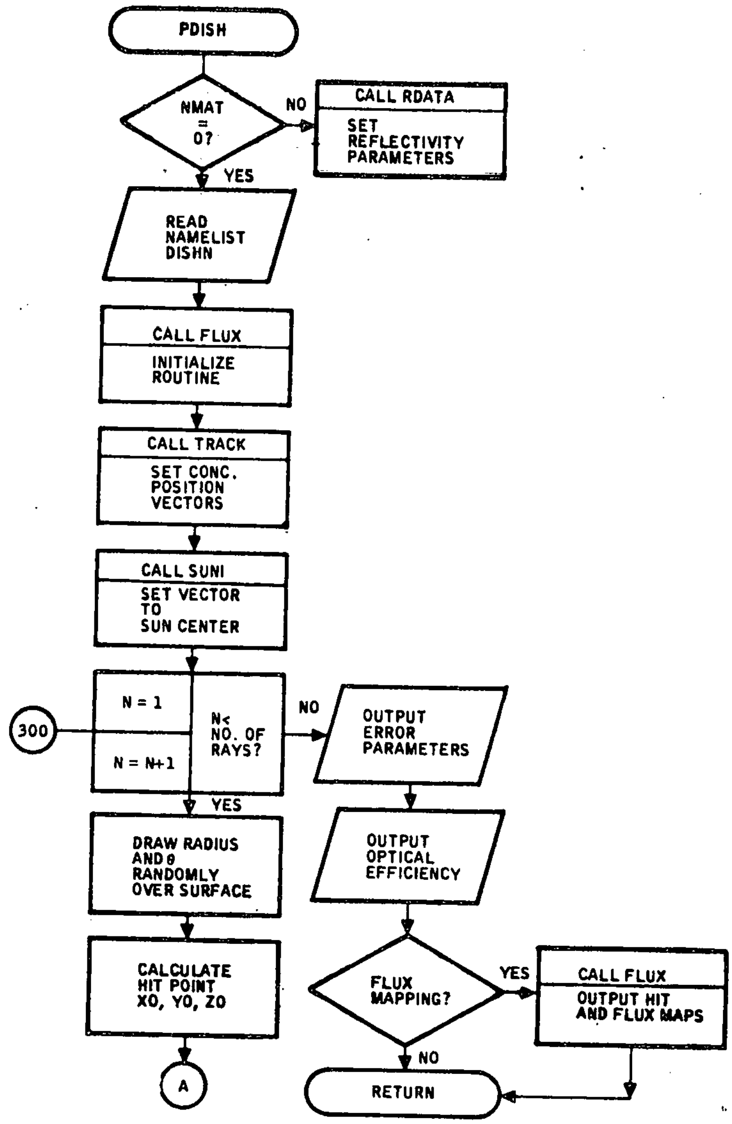
Subroutine MONTE does the Monte Carlo draw over the RPI faceted-mirror solar concentrator surface.



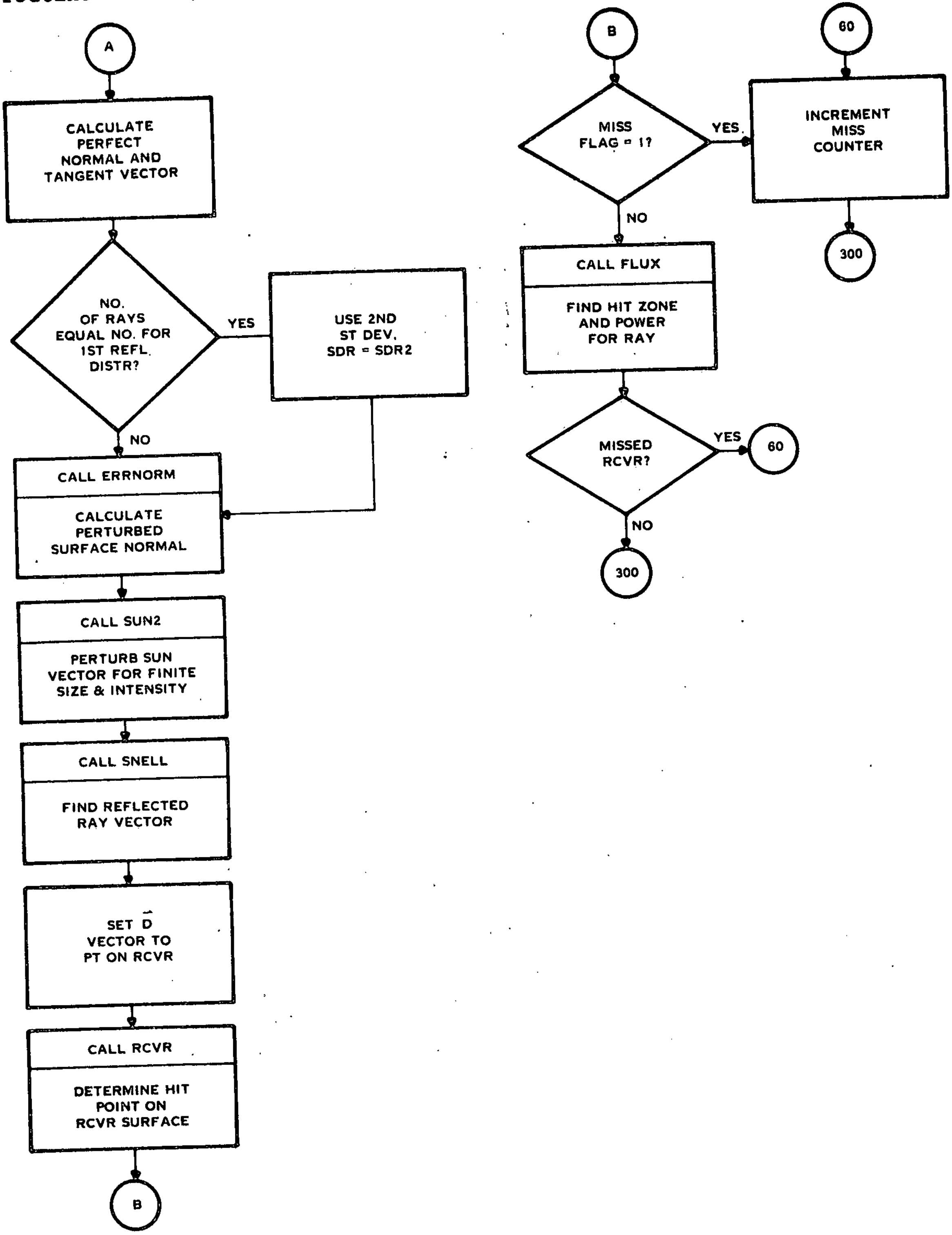
NORM calculates the surface normal and $\vec{D}$ vector to the known point on the receiver surface for each draw with the RPI concentrator model.



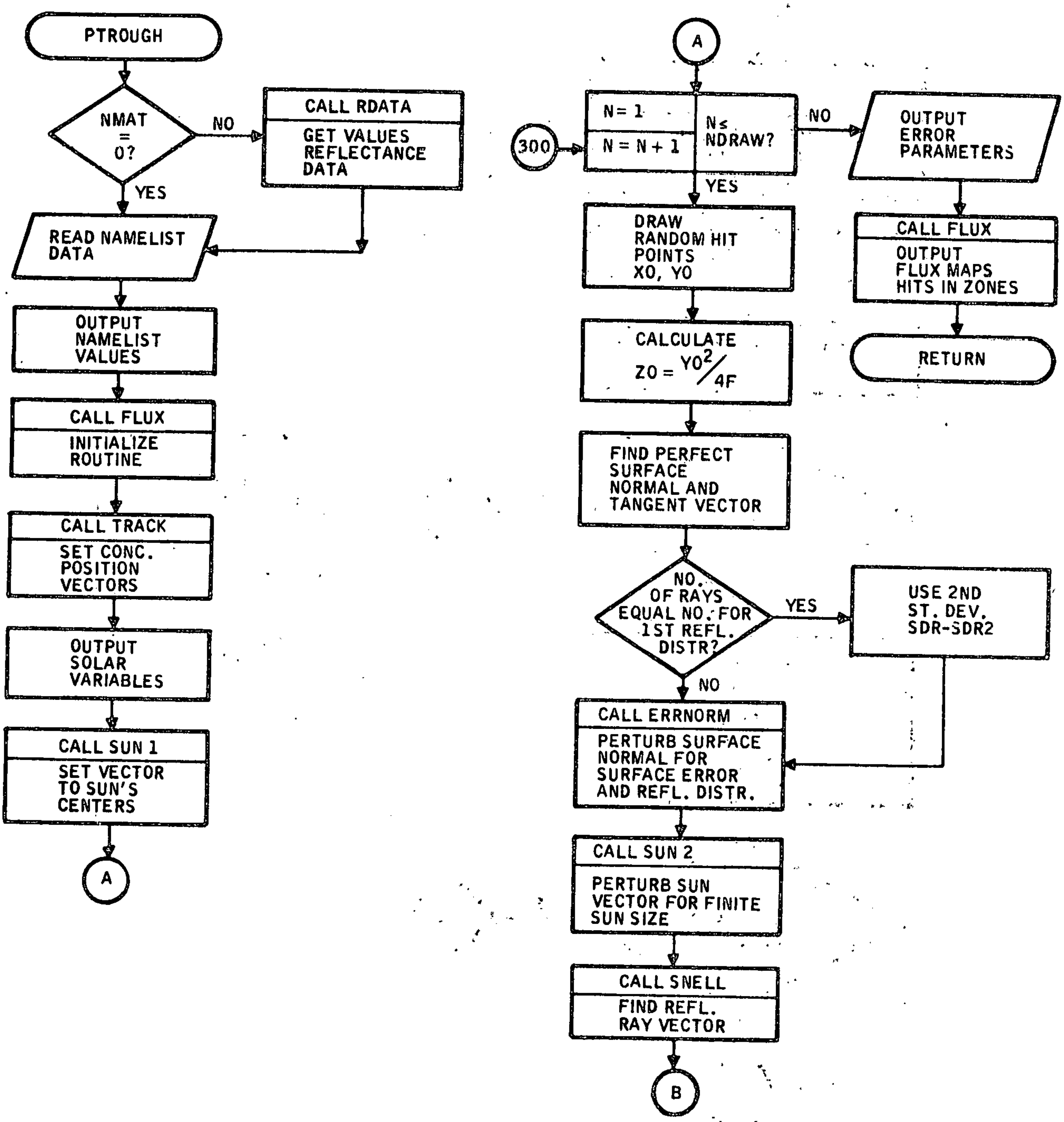
Subroutine PDISH models the paraboloid-of-revolution (dish) concentrator.



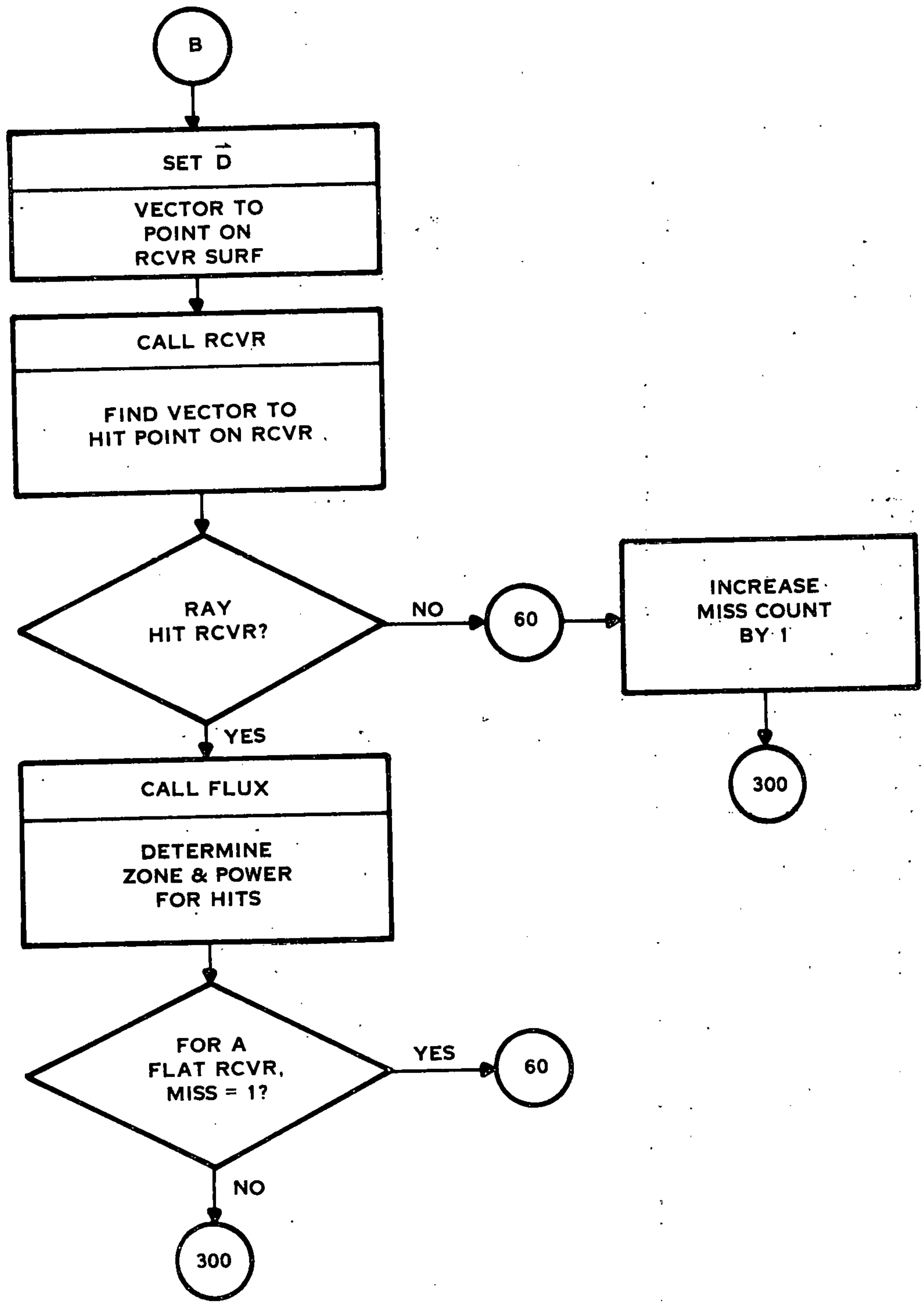
Subroutine PDISH (concluded)



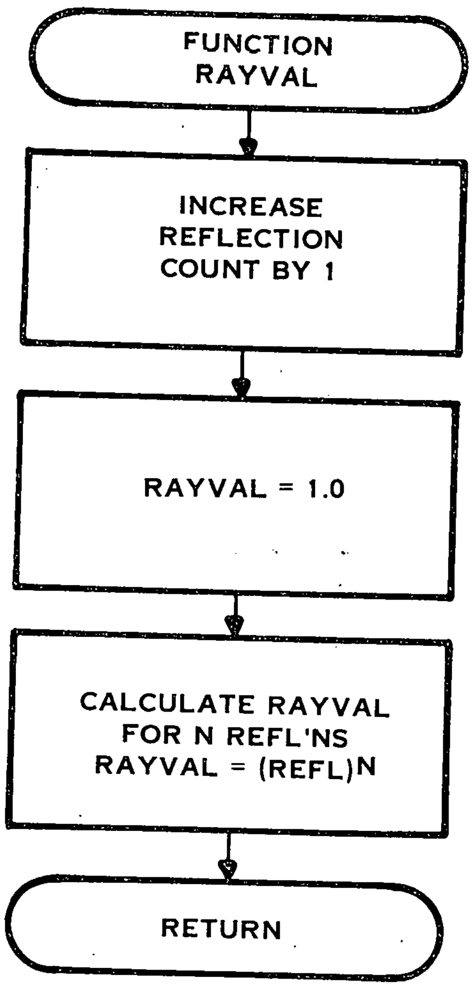
Subroutine PTROUGH models the parabolic trough concentrator surface and determines the optical efficiency for this configuration.



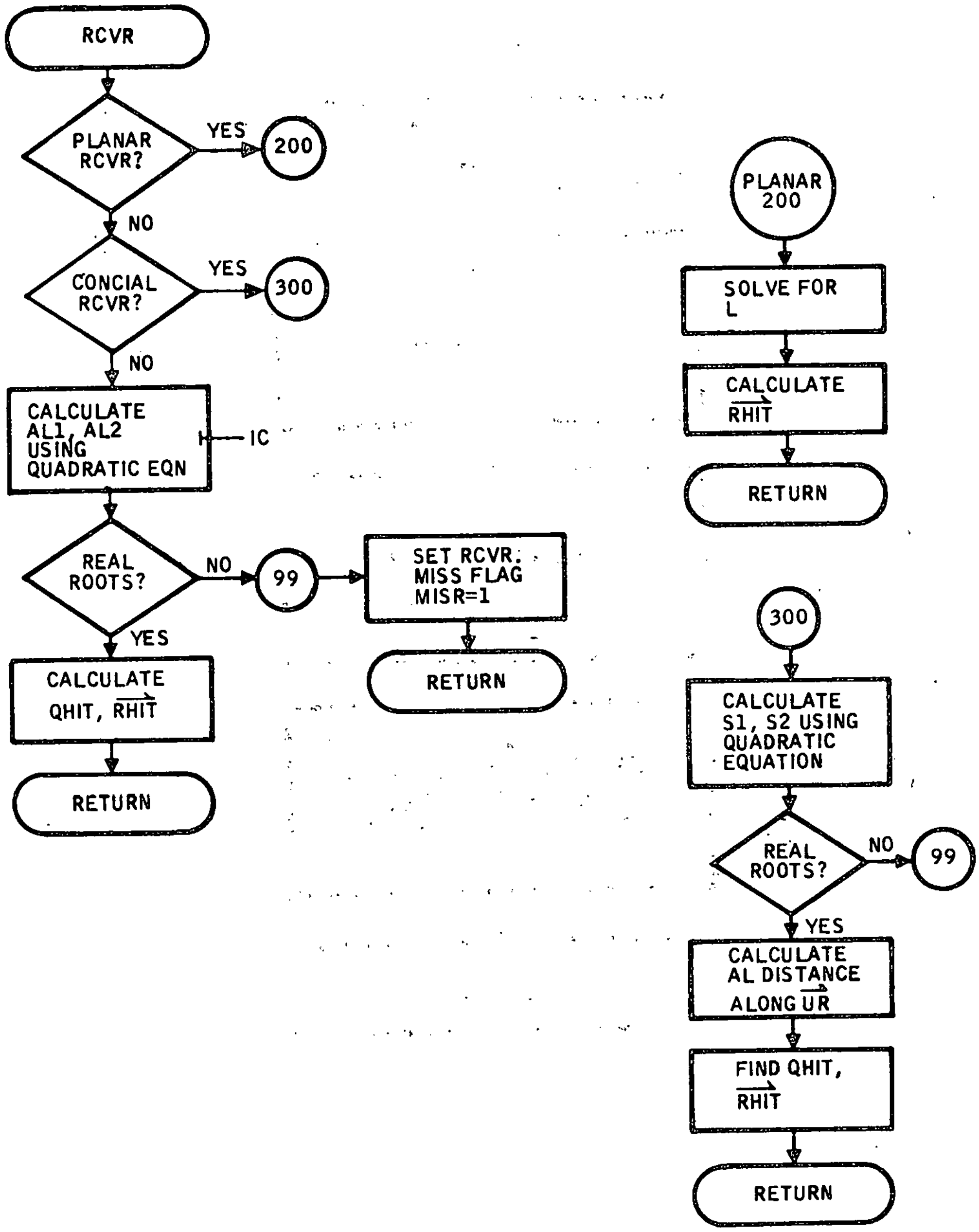
Subroutine PTROUGH (concluded)



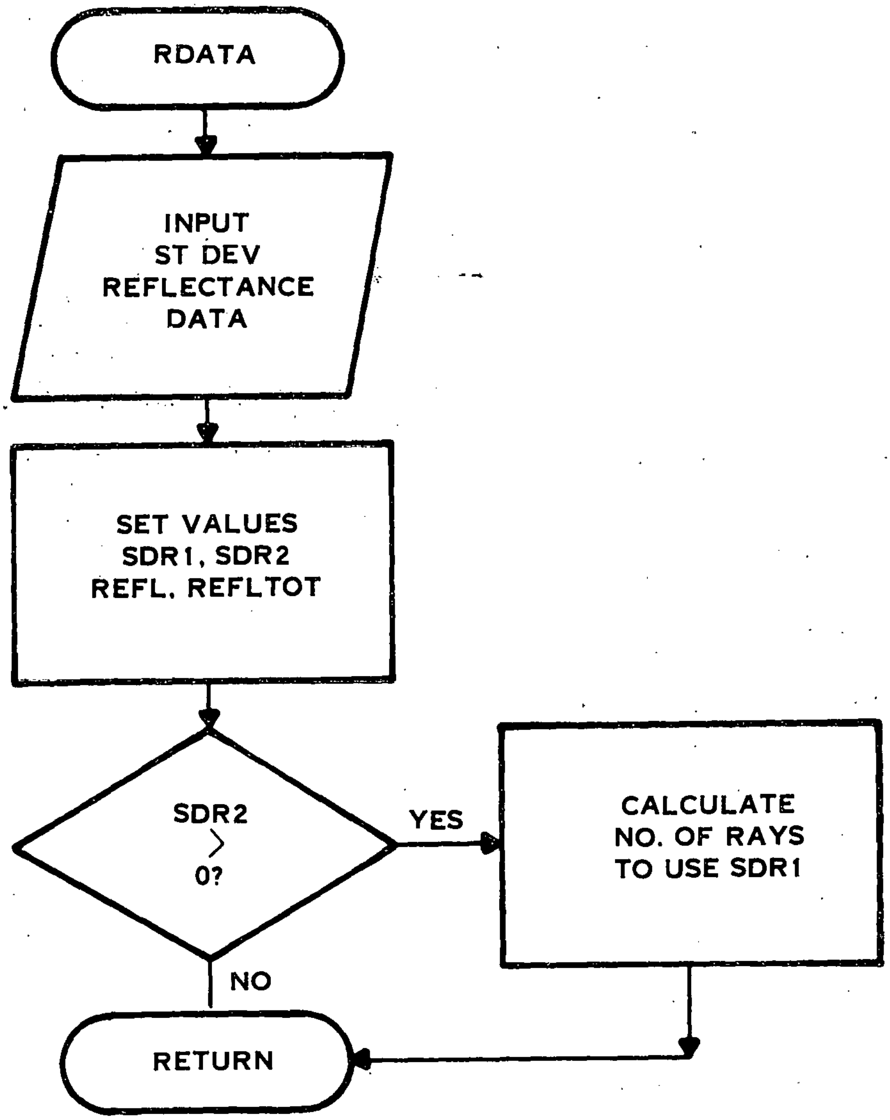
Function RAYVAL determines the relative power of a reflected ray based on the total reflectance and the number of reflections from the concentrator surface before reaching the receiver.



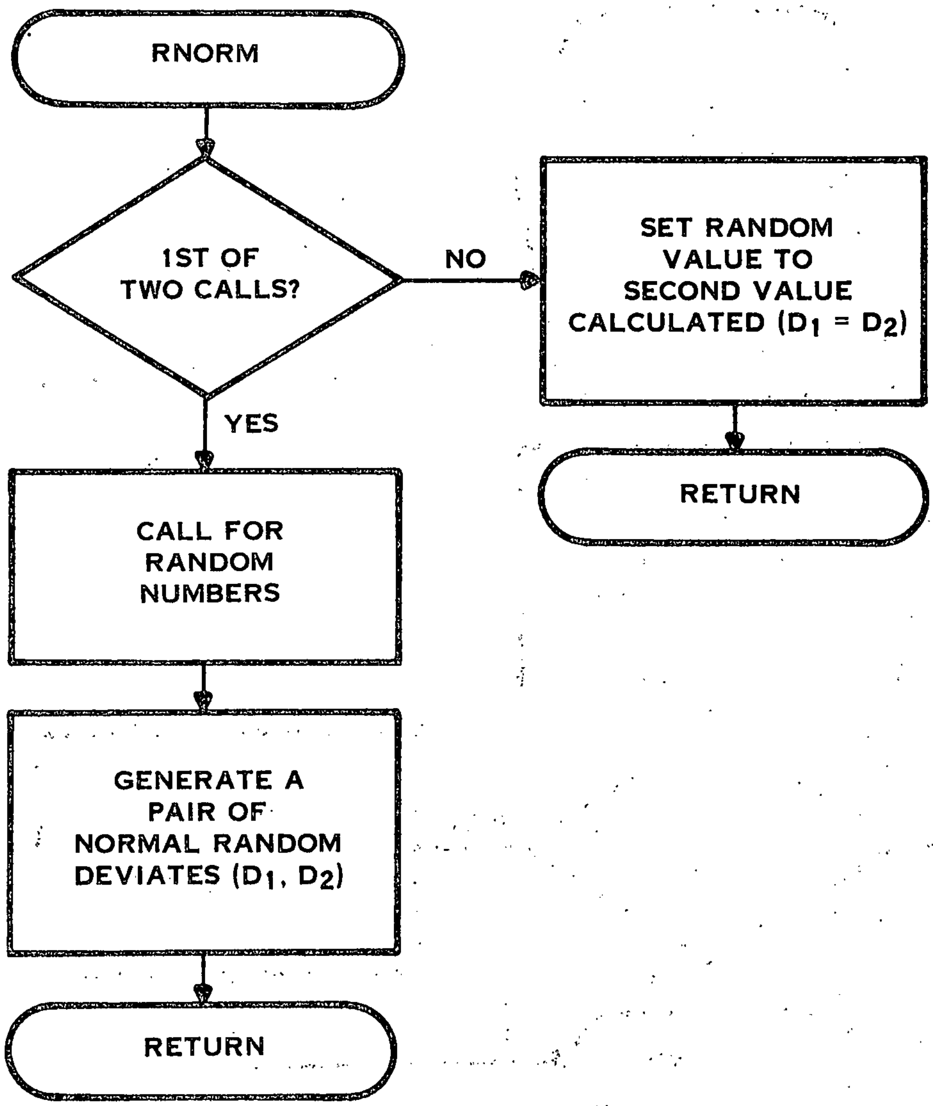
Subroutine RCVR models the receiver types and tests for a hit on the receiver for each ray of the Monte Carlo draw. Three receiver types are modeled: planar, cylindrical and conical.



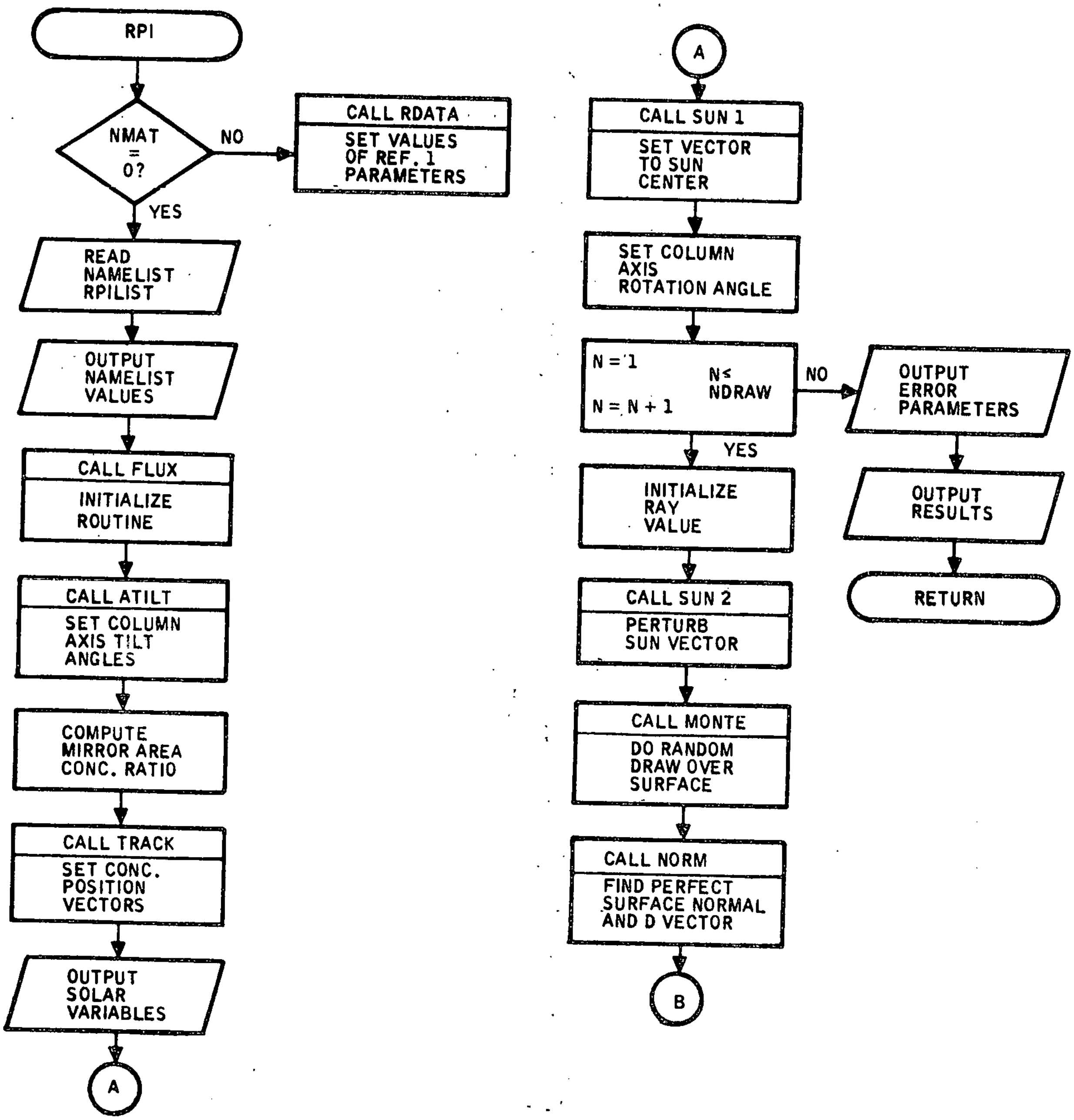
Subroutine RDATA contains reflective materials data based on Petit and Butler's measurements using bidirectional reflectometry. The data includes one or two reflectance values and their associated standard deviations, which characterize the reflected beam profile of the material as a normal or sum of two normal distributions. The standard deviations are used in conjunction with the surface error to perturb the surface normal for surface errors and the reflectance distribution.



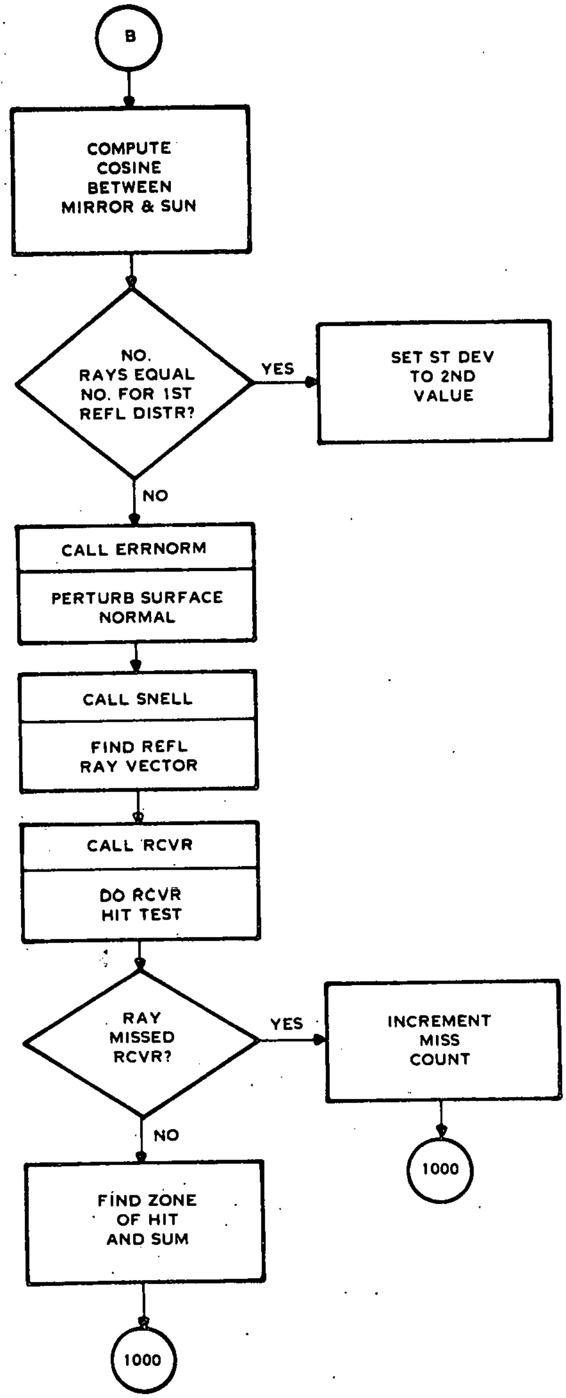
Subroutine RNORM generates pairs of independent, normally distributed random deviates (mean = 0, standard deviation = 1). They are distributed over the interval (-∞ to +∞). Input to the routine is the uniform random number generator (FLAT (X)). The function FLAT (X) returns a random number evenly distributed on (0,1).



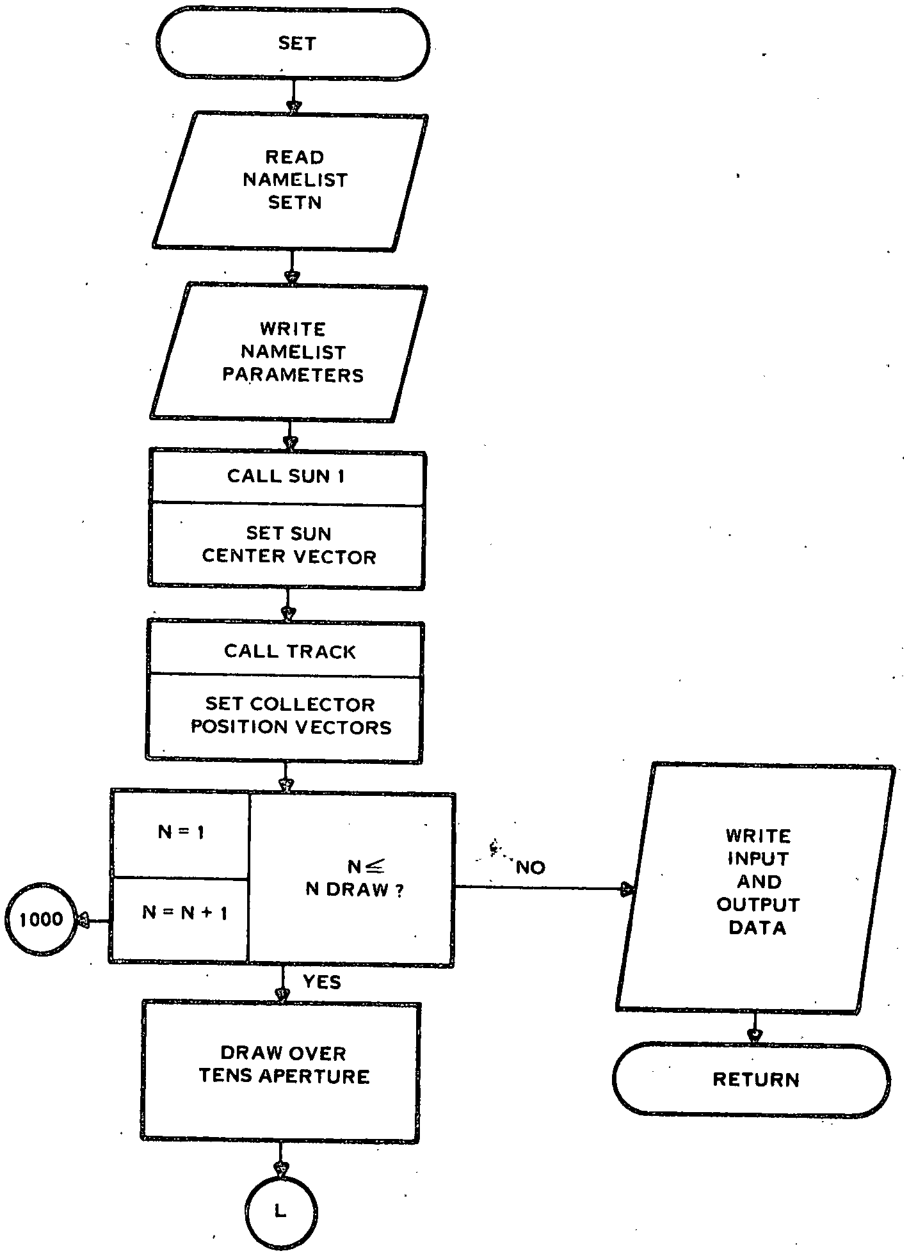
Subroutine RPI models the Rensselaer Polytechnic Institute faceted-mirror solar concentrator surface, performs all hit tests on the receiver and outputs the optical efficiency results for the concentrator.



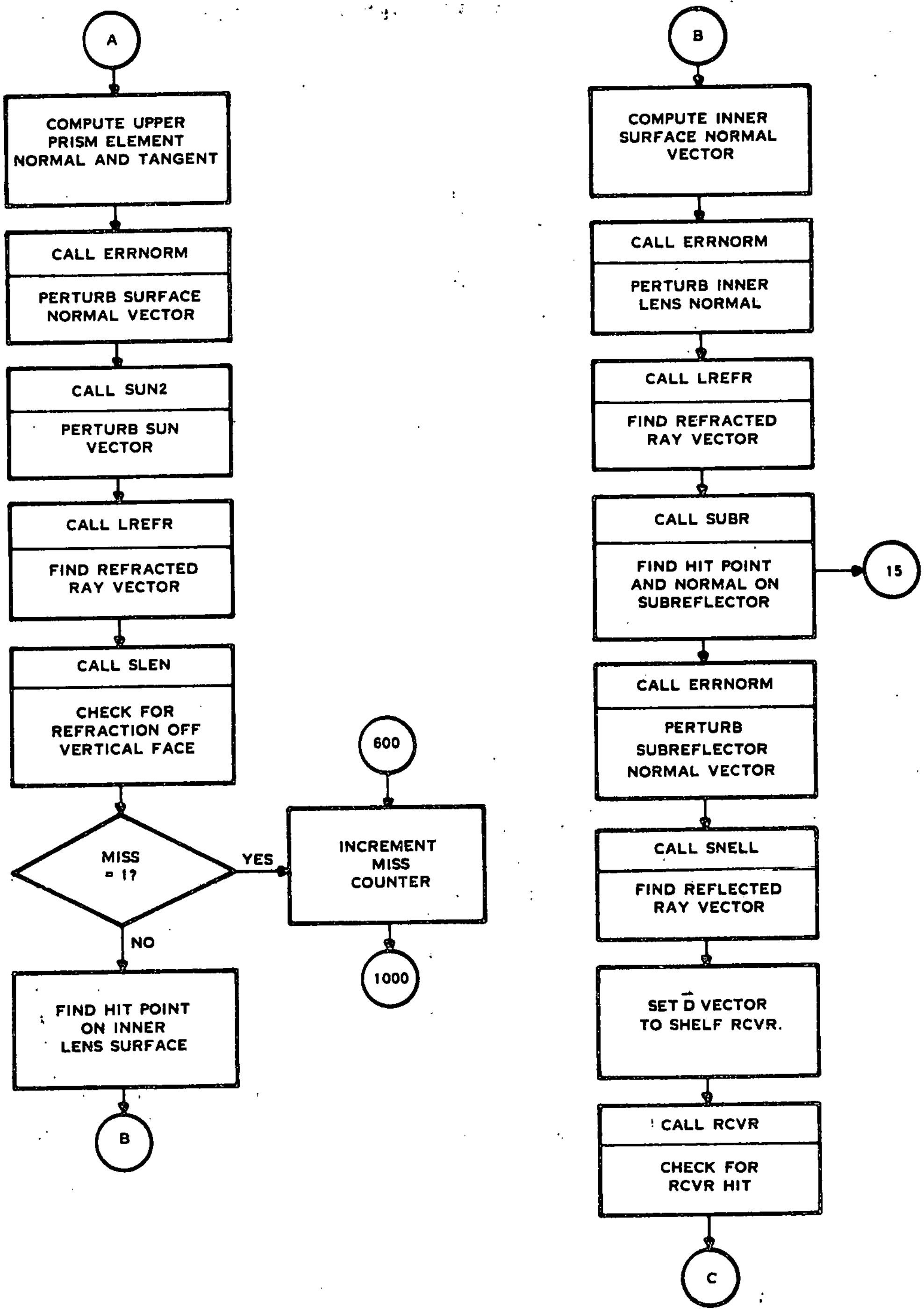
Subroutine RPI (concluded)



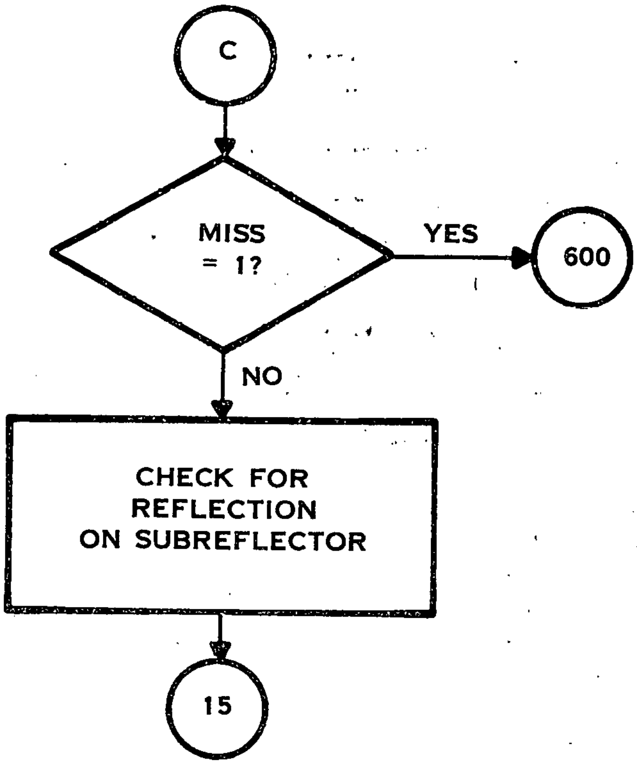
Subroutine SET models the imaging collapsing concentrator as defined by solar energy technology.



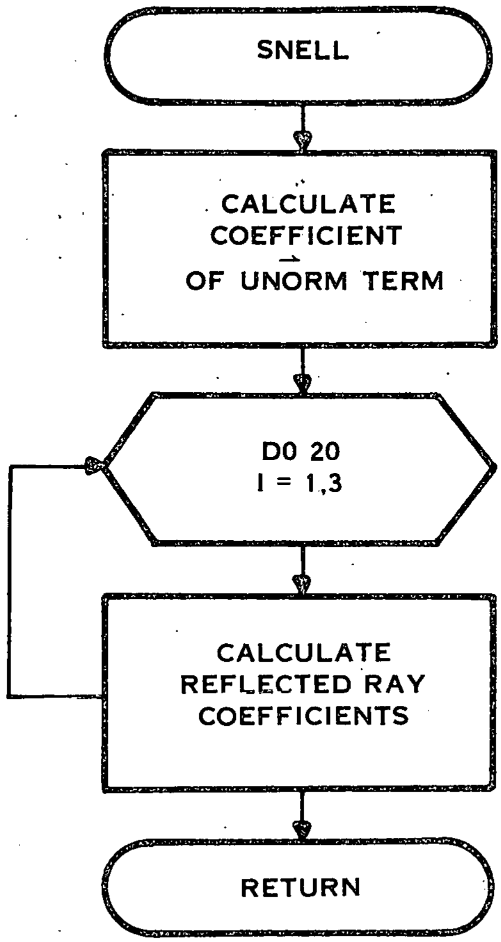
Subroutine SET (continued)



Subroutine SET (concluded)

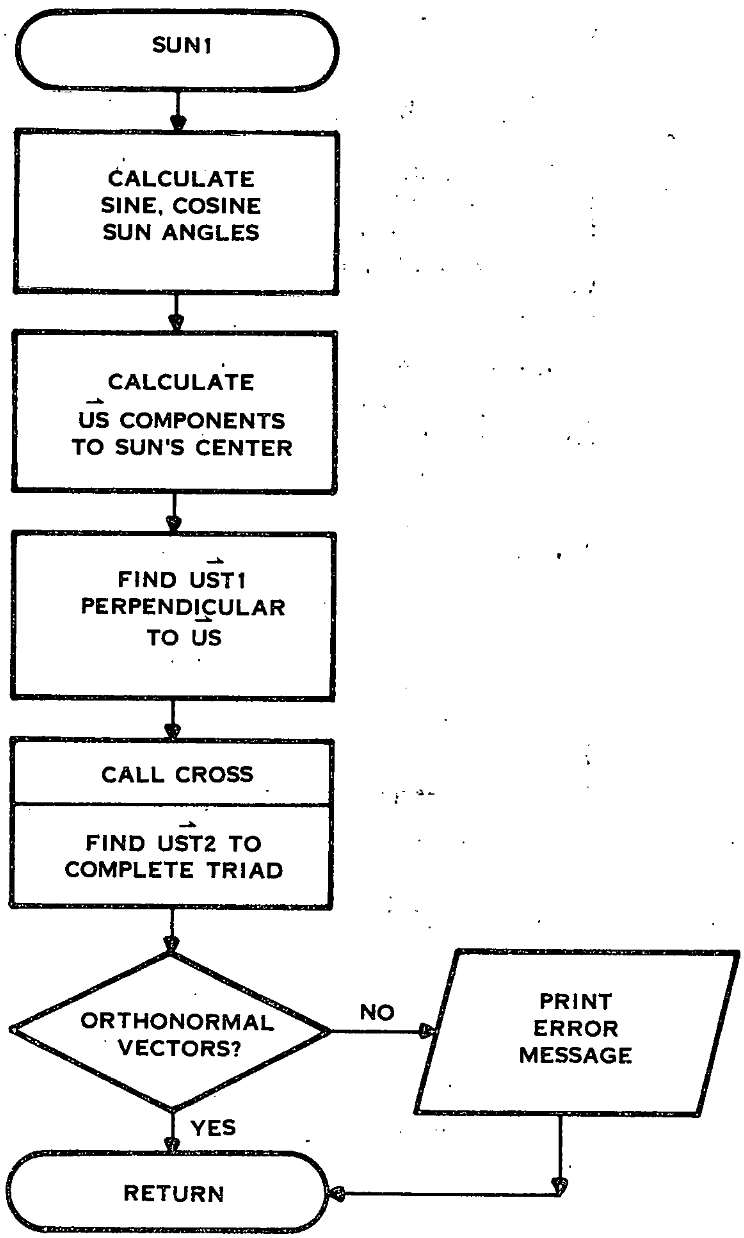


Subroutine SNELL computes the reflected ray vector.

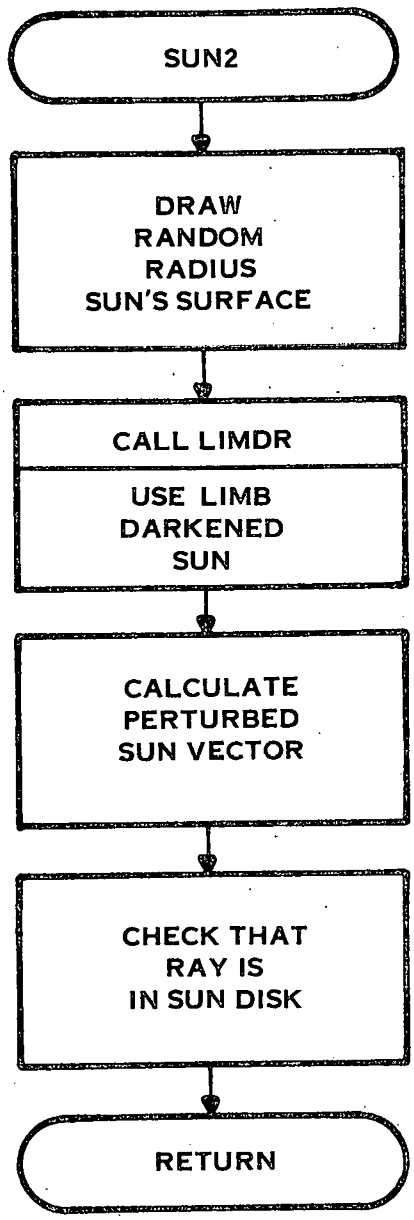


Subroutine SUN1 calculates the coefficients for the sun center vector $\overrightarrow{US}$ based on the azimuth and elevation angles calculated in Subroutine SUN.

In addition, the vectors $\overrightarrow{UST1}$ and $\overrightarrow{UST2}$, which form a vector triad on the sun face, are calculated to be used in perturbing the sun vector for the finite in SUN2.

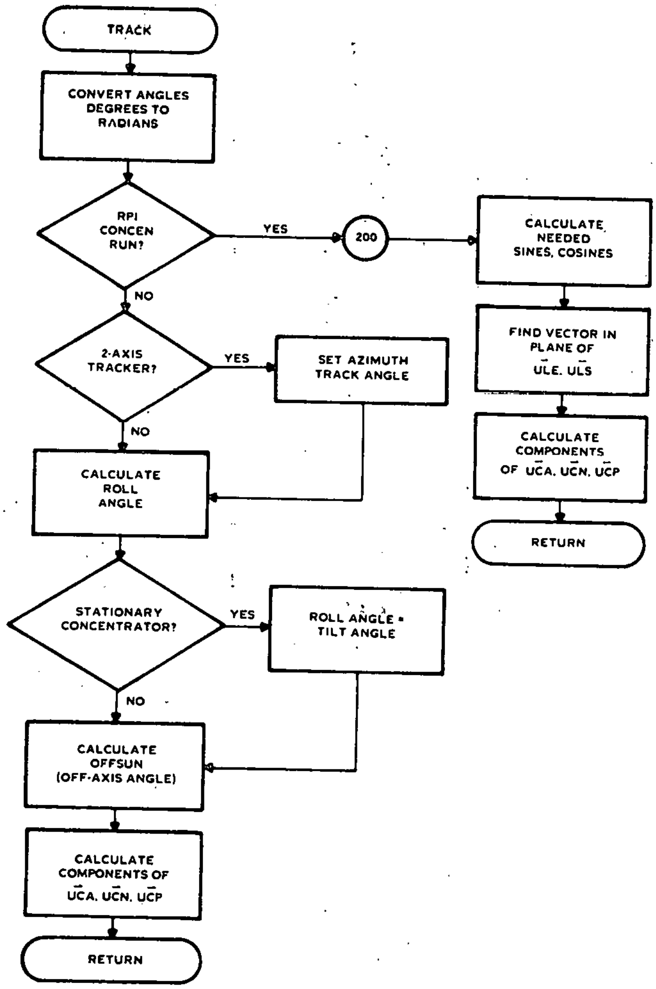


Subroutine SUN2 calculates a perturbed sun ray to account for the finite size and intensity. LIMDR, the routine that calculates the intensity distribution across the surface of the sun, is called from SUN2. We have used this routine for a limb darkened sun only.

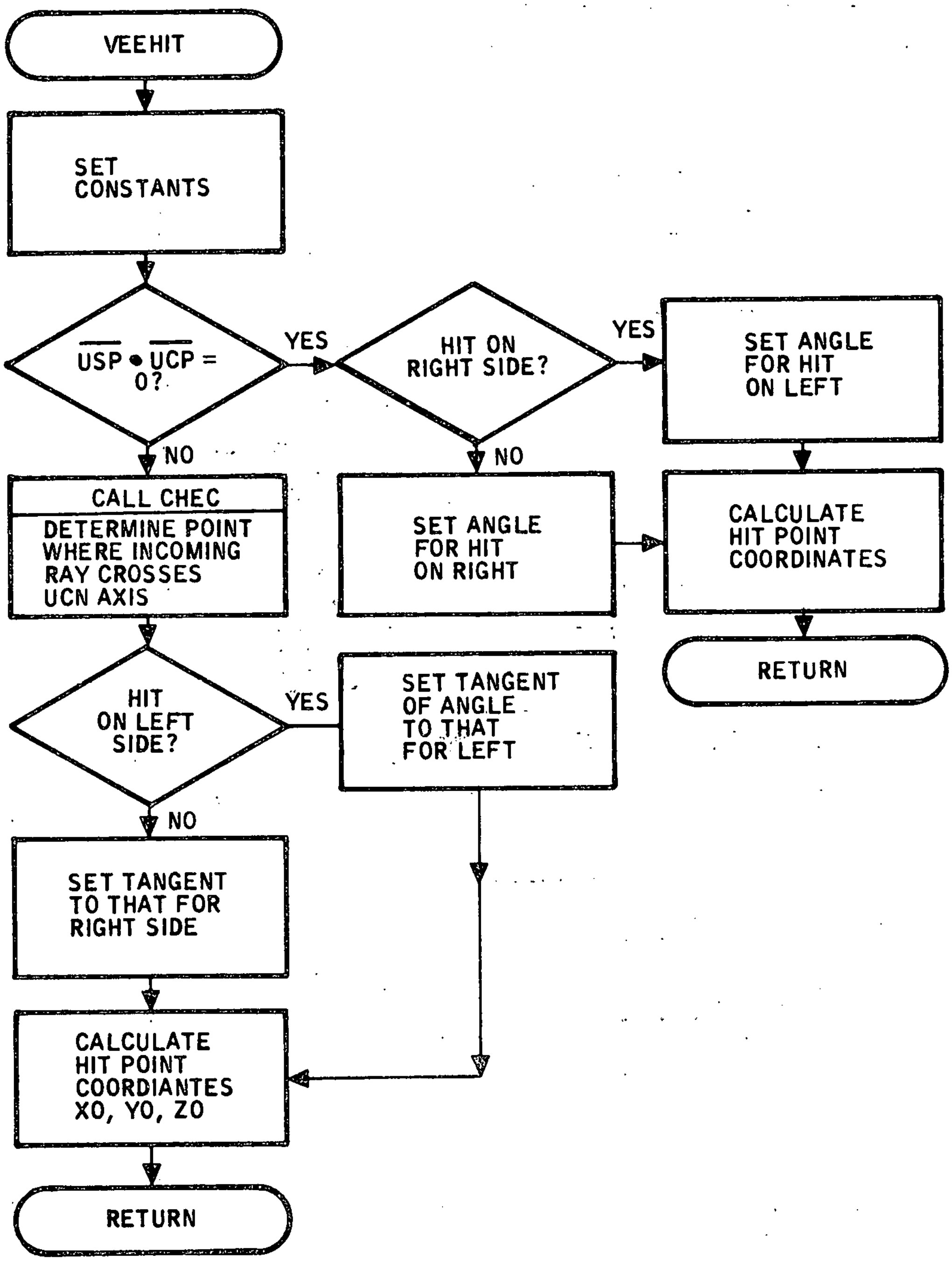


Subroutine TRACK sets the collector position vector triad $\overrightarrow{UCA}$, $\overrightarrow{UCN}$, $\overrightarrow{UCP}$ for all concentrators using the sun's position. Tracking errors are taken into consideration by input of a specific value for each concentrator run.

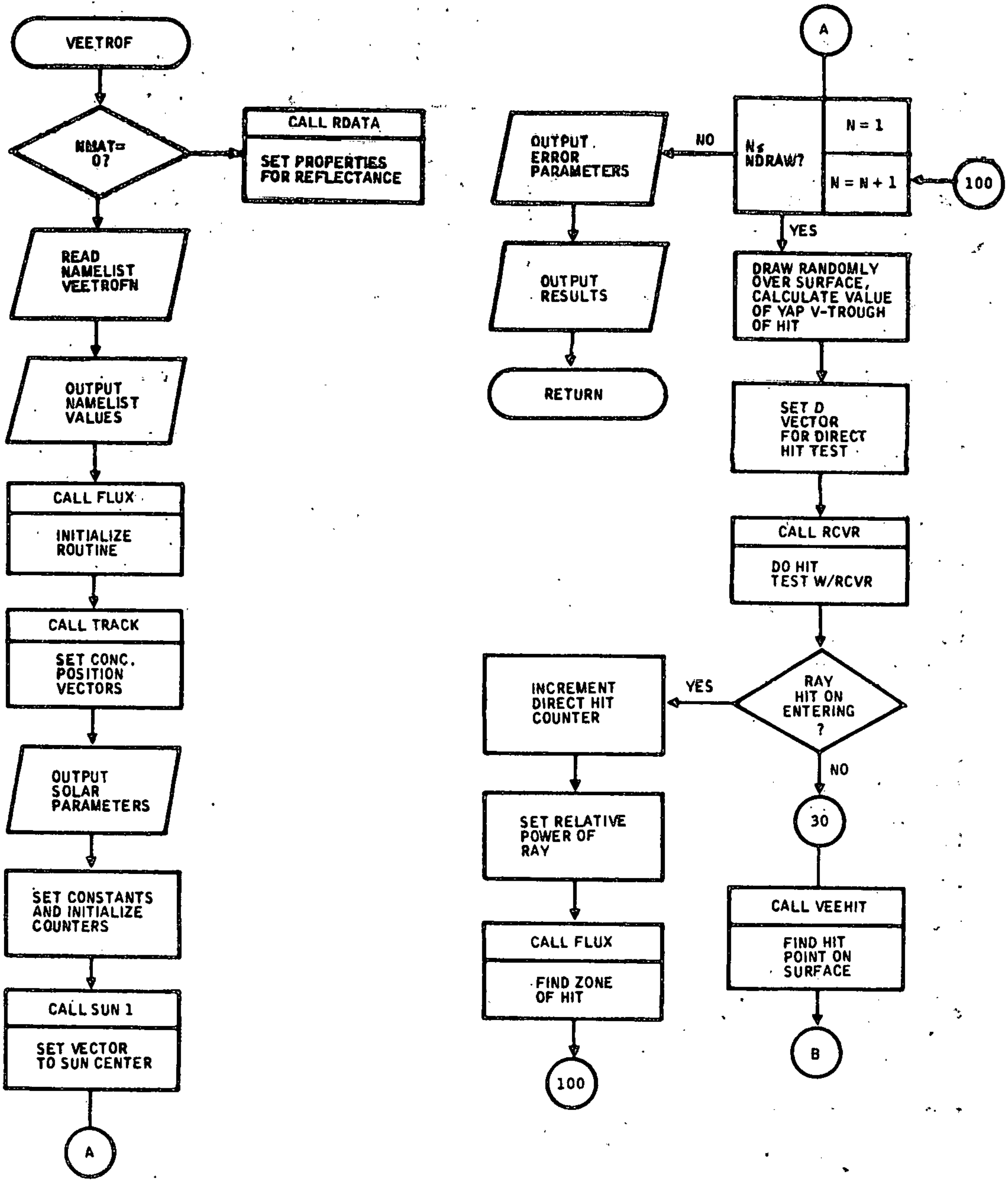
For each concentrator, the origin of this vector triad varies. For example, the origin for the parabolic trough is at the center of the concentrator at the bottom of the trough arc and at one end of the length. For the fixed-mirror tracking receiver, the origin is at the center of curvature of that sphere that contains the concentrator.



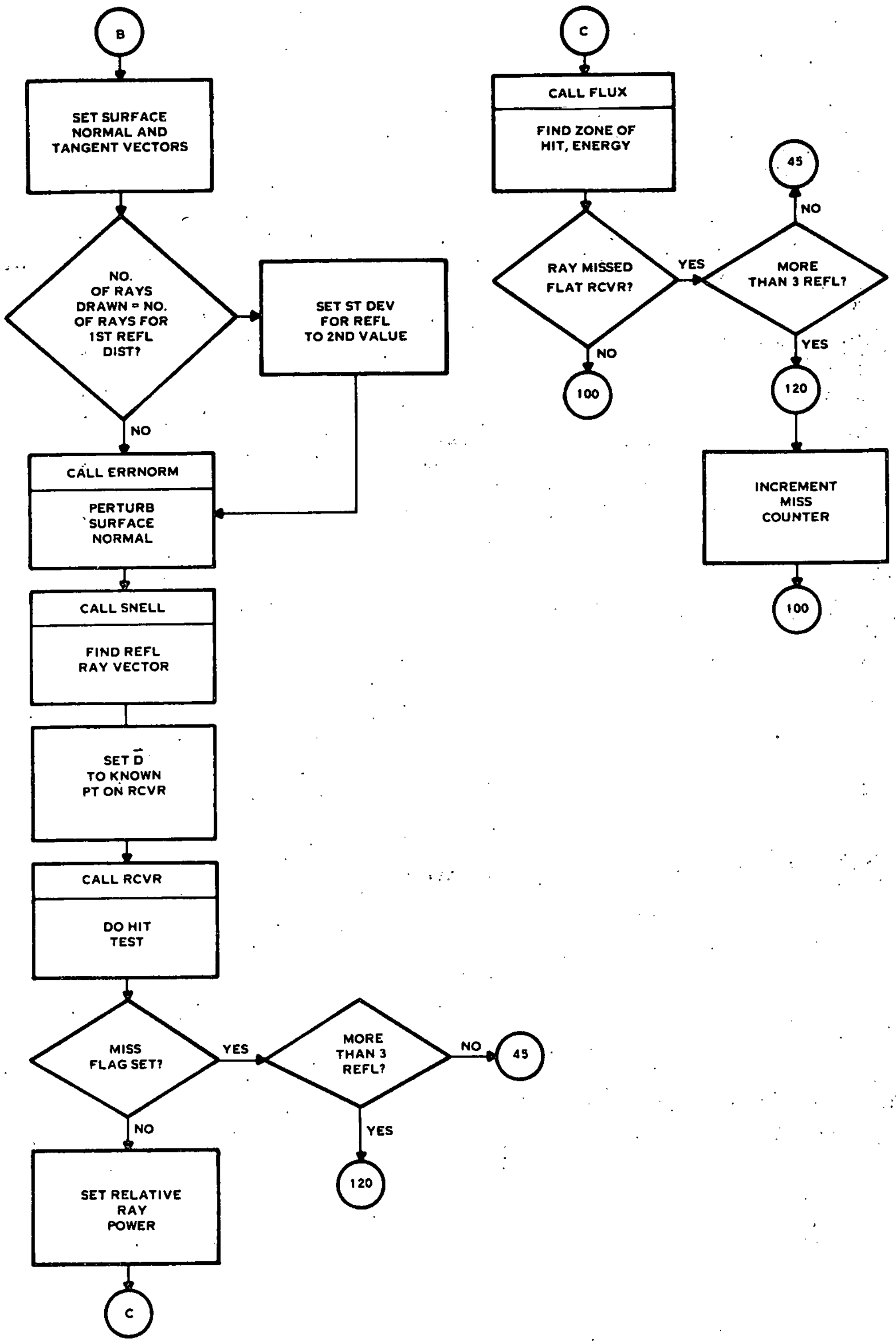
Subroutine VEEHIT finds the hit point on the vee trough surface given an incoming ray and an origin point (X_{ap}, Y_{ap}, Z_{ap}). The routine checks to see which side of the vee should be tested and uses the correct slope to find the hit point X_o, Y_o, Z_o.



Subroutine VEETROF models the variable reflector side angle vee trough collectors.



Subroutine VEETROF (concluded)



APPENDIX B

GLOSSARY OF NAMELIST VARIABLES

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VARIABLE	DESCRIPTION	NAMELIST(S)
AC	ARRAY OF COEFFICIENTS FOR SUB-REFLECTOR CURVEFIT	SETN
ALEN	LENGTH OF COLUMN AXIS (METERS) FOR THE RPI FACETED-MIRROR SOLAR CONCENTRATOR	RPI LIST
ATHETA	ACCEPTANCE ANGLE (DEGREES) FOR THE CPC-PARABOLIC INVOLUTE MODEL	CPCN (CPC2 ONLY)
CLENG	CONCENTRATOR LENGTH (METERS)	CPCN FRESN INCREFN INFLATN TROFN VTROFN SETN
CWIDTH	CONCENTRATOR WIDTH (METERS)	CPCN FMTRN FRESN INCREFN INFLATN TROFN VTROFN SETN
DAP	WIDTH OF ONE CPC OR VEE TROUGH MODULE (METERS)	CPCN VTROFN
DX	COLUMN AXIS SPACING (METERS)	RPI LIST
DZ	VERTICAL DISTANCE BETWEEN LENS AND SUBREFLECTOR COORDINATE SYSTEM CENTERS	SETN

VARIABLE	DESCRIPTION	NAMELIST(S)
DTRACAZ	ASIMUTH TRACKING ERROR ANGLE FOR THE TWO AXIS TRACKING RECEIVER	CPCN FMTRN FRESN INCREFN INFLATN DISHN TROFN RPI LIST VTROFN
DTRACRL	TRACKING ERROR ANGLE (ROLL) FOR THE ONE- AND TWO-AXIS TRACKING RECEIVERS	CPCN FMTRN FRESN INCREFN INFLATN DISHN TROFN RPI LIST VTROFN
DY1	DISTANCE FROM CONCENTRATOR CENTOR TO START OF FIRST COLUMN AXIS ROW	RPI LIST
DY2	DISTANCE FROM CONCENTRATOR CENTER TO START OF SECOND COLUMN AXIS ROW	RPI LIST
FACH	OPTIONAL INPUT OF FACET THICKNESS (IF CONSTANT) FOR FRESNEL AND INCREMENTAL REFLECTOR (METERS)	FRESN INCREFN
FACW	OPTIONAL INPUT OF FACET WIDTH (METERS), (IF CONSTANT) FOR FRESNEL AND INCREMENTAL REFLECTOR	FRESN INCREFN
F	FOCAL LENGTH (METERS) FOR LINEAR FRESNEL AND ALSO FOR: • INCREMENTAL REFLECTOR • PARABOLIC TROUGH • PARABOLOID OF REVOLUTION (DISH)	FRESN INCREFN TROFN DISHN

VARIABLE	DESCRIPTION	NAMELIST(S)
FL	FOCAL LENGTH (METERS) FOR FACETED MIRROR SOLAR CONCENTRATION	RPI LIST
FLEN	LENGTH OF INDIVIDUAL MIRROR FACET ON COLUMN AXIS (METERS)	RPI LIST
FWID	WIDTH OF INDIVIDUAL MIRROR FACET ON COLUMN AXIS (METERS)	RPI LIST
GAMMA	ARRAY OF PRISM ANGLES FOR TOP OF LENS ELEMENTS	SETN
ICONC	CONCENTRATOR TYPE: 1 = RPI FACETED-MIRROR SOLAR CONCENTRATOR 2 = FIXED-MIRROR TRACKING RECEIVER 3 = PARABOLIC TROUGH 4 = LINEAR FRESNEL 5 = INFLATABLE CYLINDRICAL CONCENTRATOR 6 = INCREMENTAL REFLECTOR 7 = INVOLUTE COMPOUND PARABOLIC CONCENTRATOR 8 = INVOLUTE/PARABOLIC COMPOUND PARABOLIC CONCENTRATOR 9 = IMAGING COLLAPSING CONCENTRATOR (SET) 10 = VEE TROUGH CONCENTRATOR 11 = PARABOLOID OF REVOLUTION (DISH)	RUN
IDAY	DAY OF YEAR (1 = JANUARY 1) NOTE: MAY BE ELIMINATED WITH USER INPUT OF TAZ, TEL.	RUN
IR	FLAG FOR RECEIVER RUN: IR = 0: HITS ALONG $\overrightarrow{UCN}$ AXIS CALCULATED (TO DETERMINE OPTIMAL RECEIVER PLACEMENT) IR = 1: RUN WITH NORMAL RECEIVER HIT TEST	INFLATN

VARIABLE	DESCRIPTION	NAMELIST(S)
IRCVR	RECEIVER TYPE: 1 = CYLINDRICAL 2 = PLANAR 3 = CONICAL NOTE: ALL RECEIVERS ARE NOT COMPATIBLE WITH ALL CONCENTRATORS. SEE DOCUMENTATION FOR ALLOWABLE COMBINATIONS	ALL NAMELISTS
ISTOP	STOP FLAG: 0 = CONTINUE FOR ANOTHER CONCENTRATOR RUN. 1 = EXECUTION COMPLETE.	RUN
NAIR	INDEX OF REFRACTION FOR AIR (REAL)	FRESN INCREFN
NFIT	ORDER OF POLYNOMIAL CURVE FIT FOR SUBREFLECTOR SURFACE	SETN
NLENS	INDEX OF REFRACTION FOR LENS (REAL) NOTE: MAY BE SET BY SUBROUTINE LDATA AS A FUNCTION OF WAVELENGTH (SEE DOCUMENTATION).	FRESN INCREFN SETN
NMAT	MATERIAL IDENTIFIER: 0 = USER WILL INPUT REFLECTANCE DATA (SDR, STANDARD DEVIATION REFLECTANCE REFLTOT: TOTAL REFLECTANCE) 1 = ALCOA ALZAK TYPE I SPECULAR; ORIENTED PARALLEL TO ROLLING MARKS 2 = BOEING FRONT SURFACE ALUMINIZED MYLAR 3 = CORNING 0317 GLASS (1.5 mm THICK), EVAPORATED SILVER COATING 4 = GARDNER LAMINATED LOW-IRON SHEET GLASS (3.35 mm THICK), SILVERED 5 = KINGSTON KINGLUX NO. C4 POLISHED ALUMINUM, ORIENTED PERPENDICULAR	RUN

VARIABLE	DESCRIPTION	NAMELIST(S)
	6 = METAL FABRICATIONS TYPE 3002 HIGH PURITY ALUMINUM 7 = 3M SCOTCHCAL-5400 8 = 3M FEK-163 9 = SHELDAHL ALUMINIZED 2 MIL FED TEFLON (G405600) 10 = SHELDAHL SILVERED 2 MIL FED TEFLON (G400300) 11 = ACRYLIC LENS MATERIAL	
NPRIS	NUMBER OF PRISM (FACET) ELEMENTS ON ONE SIDE OF SET LENS	SETN
NRZ	NUMBER OF RADIAL ZONE (BULLSEYE HIT TEST)	RPI LIST DISHN
LF	LENGTH OF PRISM (FACET) ELEMENT FOR SET LENS	SETN
NTOL	MAXIMUM NUMBER OF ITERATIONS FOR NEWTON'S METHOD USED TO DETERMINE HIT POINT ON CPC SURFACES	CPCN
NZONEAX	NUMBER OF ZONES FOR ZONING HIT POINTS ON $\overrightarrow{UCN}$ AXIS FOR THE INFLATABLE CYLINDRICAL CONCENTRATOR (I.E., WHEN IR = 0)	INFLATN
NZONEX	NUMBER OF ZONES ALONG RECEIVER LENGTH FOR FLUX AND HIT MAPS	ALL NAMELISTS
NZONEY	NUMBER OF ZONES ALONG RECEIVER WIDTH (OR CIRCUMFERENCE) FOR HIT AND FLUX MAPS	ALL NAMELISTS
PSM	MEAN OF SURFACE ERROR NORMAL DISTRIBUTION	ALL NAMELISTS

VARIABLE	DESCRIPTION	NAMELIST(S)
RAP	APERATURE RADIUS (METERS) PARABOLOID OF REVOLUTION (DISH)	DISHN
RDIST	DISTANCE FROM CONCENTRATOR CENTER TO RECEIVER CENTER ALONG $\overrightarrow{UCN}$ AXIS (METERS) FOR THE INFLATABLE CYLINDRICAL CONCENTRATOR	INFLATN
REFLTOT	TOTAL REFLECTANCE (OPTIONAL INPUT USED WHEN NMAT = 0)	CPCN FMTRN INCREFN INFLATN DISHN TROFN RPI LIST VTROFN SETN
RL	RECEIVER LENGTH (METERS)	CPCN FMTRN FRESN INCREFN INFLATN DISHN TROFN VTROFN SETN
RLENS	RADIUS OF INNER LENS SURFACE	SETN
RMAX	MAXIMUM RADIUS OF RECVR PLANE (METERS)	RPI LIST
RW	RECEIVER WIDTH (METERS) ACTUAL	CPCN FRESN INCREFN INFLATN DISHN TROFN VTROFN
RWS	RECEIVER WIDTH FOR SHADOWING OF INCOMING RADIATION	TROFN DISHN INCREFN

VARIABLE	DESCRIPTION	NAMELIST(S)
SDFS	STANDARD DEVIATION FOR FIRST SURFACE ERROR (RUD), FRESNEL, INCREMENTAL REFLECTOR	FRESN INCREFN
SDR	STANDARD DEVIATION OF REFLECTANCE DISTRIBUTION (OPTIONAL INPUT USED WHEN NMAT = 0, USER INPUT OF REFLECTANCE DATA)	CPCN FMTRN INCREFN INFLATN DISHN TROFN RPI LIST VTROFN SETN
SDS	STANDARD DEVIATION OF SURFACE ERROR (INNER LENS SURFACE FOR FRESNEL)	CPCN FMTRN FRESN INCREFN INFLATN DISHN TROFN RPI LIST VTROFN SETN
SHITE	HEIGHT OF ABSORBER (RECEIVER) SHELF	SETN
SO	DISTANCE FROM CONE VERTEX TO TOP OF CONICAL RECEIVER ALONG $\vec{US}$ (ASSUMES CONE VERTEX AT CENTER OF SPHERE, NORMALLY NEGATIVE)	FMTRN
SRW	RECEIVER WIDTH FOR SURFACE DEFINITION	CPCN
T	MINIMUM LENS THICKNESS	SETN

VARIABLE	DESCRIPTION	NAMELIST(S)
TAZ	SUN'S AZIMUTH ANGLE (RAD) OPTIONAL INPUT, CALCULATED BY SUBROUTINE SUN	RUN
TEL	SUN'S ELEVATION ANGLE (RAD) OPTIONAL USER INPUT, CALCULATED BY SUBROUTINE SUN	RUN
THETAAX	ORIENTATION OF CONCENTRATOR AXIS ALONG LENGTH (DEGREES) (0° = EAST, SOUTH POSITIVE)	CPCN FMTRN FRESN INCREFN INFLATN TROFN VTROFN SETN
THETA1	ANGLE BETWEEN SLOPE OF RIGHT SIDE OF VEE TROUGH AND + $\overrightarrow{UPC}$ AXIS (DEGREES)	VTROFN
THETA2	ANGLE BETWEEN SLOPE OF LEFT SIDE OF VEE TROUGH AND + $\overrightarrow{UPC}$ AXIS (DEGREES) NOTE: THETA2 WILL NORMALLY BE LARGER THAN 90°.	VTROFN
THETAC	INCLUDED HALF ANGLE OF CONICAL RECEIVER	FMTRN
THTOL	TOLERANCE FOR CONVERGENCE OF θ IN NEWTON'S METHOD FOR CPCs	CPCN
TILT	COLLECTOR TILT FROM HORIZONTAL	RPI LIST

VARIABLE	DESCRIPTION	NAMELIST(S)
TILTANG	TILT OF CONCENTRATOR TOWARD SOUTH (DEGREES)	CPCN FMTRN FRESN INCREFN INFLATN VTROFN SETN
TIME	TIME OF DAY (FRACTIONAL HOURS PAST MIDNIGHT) NOTE: MAY BE ELIMINATED WITH USER INPUT OF TAZ, TEL.	RUN
TRANTOT	TOTAL TRANSMITTANCE OF LENS	FRESN INCREFN SETN
TRIM	RIM ANGLE OF CONCENTRATOR	FMTRN
TZONE	TIME ZONE NUMBER: ZONE — STANDARD TIME — DAYLIGHT SAVINGS TIME ATLANTIC — 4 — 3 EASTERN — 5 — 4 CENTRAL — 6 — 5 MOUNTAIN — 7 — 6 PACIFIC — 8 — 7 NOTE: MAY BE ELIMINATED WITH USER INPUT OF TAZ, TEL.	RUN
XLAT	LATITUDE OF LOCATION (DEGREES) NOTE: MAY BE ELIMINATED WITH USER INPUT OF TAZ, TEL.	RUN
XLONG	LONGTITUDE OF LOCATION (DEGREES) NOTE: MAY BE ELIMINATED WITH USER INPUT OF TAZ, TEL.	RUN

APPENDIX C

LISTING OF COPS PROGRAM

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      NAMELIST/RUN/NDRAW,TAZ,TEL,TIME,XLAT,XLONG,TZONE,IDAY,ICONC,ISTOP
     +  NMAT,MAPS,NMATL
      COMMON/RUNC/NDRAW,TAZ,TEL,TIME,IDAY,XLAT,XLONG,ICONC,
     + NMAT,DRAD,MISR,TZONE,MAPS,RPWR,AMIR,NMATL
      COMMON/VECTOR/ULE(3),ULV(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
      DRAD=0.0174532925
C
C   SET LOCAL DIRECTION VECTORS, ULE,ULS,ULV
C
      DO 15 I=1,3
      ULE(I)=0.0
      ULS(I)=0.0
      ULV(I)=0.0
   15 CONTINUE
      ULS(1)=1.0
      ULE(2)=1.0
      ULV(3)=1.0
C    INITIALIZE RUN NAMELIST
      NDRAW=10
C  SUN AZIMUTH AND ELEVATION IN RADIANS
      TAZ=0.0
      TEL=1.5
       TIME=12.
C  LONGITUDE AND LATITUDE IN DEGREES
      XLAT=33.
      XLONG=90.
      TZONE=6.
      IDAY=0
      ICONC=3
      ISTOP=1
      NMAT=0
      MAPS=1
C
C   READ INPUT LIST
C
    5 READ(5,RUN)
      WRITE(6,1000) ICONC,NMAT,NMATL,NDRAW,MAPS
 1000 FORMAT(1H1,20X,33HINPUT VALUES FOR CONCENTRATOR RUN,///,
     +   10X,I10,2X,17HCONCENTRATOR TYPE,/,
     +   10X,I10,2X,18HREFL MATERIAL TYPE,/,
     + 10X,I10,2X,18HLENS MATERIAL TYPE,/,
     +   10X,I10,2X,10HRAYS DRAWN,/,
     + 10X,I10,2X,27HFLUX MAP OPTION(1=YES,0=NO),///)
      MISR=0
      RPWR=0.0
       IF(IDAY.NE.0) CALL SUN(IDWN)
      IF (IDWN.EQ.0) GO TO 25
      WRITE(6,111)
  111 FORMAT(//,5X,36HSUN IS BELOW HORIZON-GO TO NEXT CASE)
      GO TO 35
   25 IF(ICONC.EQ.1) CALL RPI
      IF(ICONC.EQ.2) CALL FMTR
      IF(ICONC.EQ.3) CALL PTROUGH
```

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            IF(ICONC.EQ.4) CALL FRESNEL
            IF(ICONC.EQ.5) CALL INFLAT
            IF(ICONC.EQ.6) CALL INCREFL
            IF(ICONC.EQ.7) CALL CPC1
            IF(ICONC.EQ.8) CALL CPC2
            IF(ICONC.EQ.9) CALL SET
            IF(ICONC.EQ.10) CALL VEETROF
            IF(ICONC.EQ.11) CALL PDISH
        35  IF(ISTOP.NE.1) GO TO 5
             STOP
            END

:   11-27-78 *** 14.4 ***

: (SEC)       .45          LINES/MINUTE  8370

  NO   DIAGNOSTICS IN ABOVE COMPILATION
S WERE USED FOR THIS COMPILATION
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2-18-79 08.954

```
      SUBROUTINE CPC1
C
C    THIS ROUTINE MODELS THE INVOLUTE CPC/WINSTON CONCENTRATOR.
C      THE SURFACE MODEL IS DEFINED THROUGH ITERATION AND RAYS
C      ARE TRACED FROM THE SURFACE TO THE RECEIVER. MULTIPLE
C      BOUNCE RAYS ARE FOLLOWED THROUGH 4 BOUNCES.
C

      NAMELIST/CPCN/CLENG,CWIDTH,RW,RL,NAXIS,TILTANG,NZONEX,
     +    NZONEY,IRCVR,THETAAX,DAP,THTOL,NTOL,SDS,SDR,REFLTOT
     + ,SRW,PSM
C
      COMMON/RUNC/NDRAW,TAZ,TEL,TIME,IDAY,XLAT,XLONG,ICONC,
     + NMAT,DRAD,MISR,TZONE,MAPS,RPWR,AMIR,NMATL
      COMMON/VECTOR/ULE(3),ULV(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
      COMMON/RCVRC/IRCVR,THETAC,SD,RW,RL,QHIT
      COMMON/TRAC/NAXIS,TILTANG,OFFSJN,THETAAX,DTRACRL,DTRACAZ,IRPI
      COMMON/ZONE/NZONEX,NZONEY
      DIMENSION D(3),UT(3),UR(3),UN(3),UNP(3),
     + USP(3),RHIT(3),UI(3),ORIG(3)
C
C    READ NAMELIST VALUES
C
      READ(5,CPCN)
C
C
C    OBTAIN DATA FOR REFLECTIVE MATERIAL PROPERTIES
C
      IF(NMAT.NE.0) CALL RDATA(NMAT,NDRAW,SDR1,SDR2,REFLTOT,REFL
     + ,NCHECR)
      SDR=SDR1
C
C    OUTPUT NAMELIST VALUES
C
      WRITE(6,6000) CLENG,CWIDTH,DAP,NAXIS,THETAAX,TILTANG,IRCVR,
     + RW,RL,SRW
 6000 FORMAT(20X,21HCPC1 CONC. PARAMETERS,/,
     + 10X,F10.3,2X,6HLENGTH,/,
     + 10X,F10.3,2X,5HWIDTH,/,
     + 10X,F10.3,2X,16HCPC MODULE WIDTH,/,
     + 10X,I10,2X,13HTRACKING AXES,/,
     + 10X,F10.3,2X,16HAXIS ORIENTATION,/,
     + 10X,F10.3,2X,10HTILT ANGLE,/,
     + 10X,I10,2X,10HRCVR. TYPE,/,
     + 10X,F10.3,2X,11HRCVR. WIDTH,/,
     + 10X,F10.3,2X,12HRCVR. LENGTH,/,
     + 10X,F10.3,2X,27HRCVR WIDTH FOR SURFACE DEFN,///)
      AMIR=DAP*CLENG
      NDIRECT=0
C    SET SUN VECTOR US TO SUN'S CENTER
C
      CALL SUN1(TAZ,TEL)
C
```

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```
      C   INITITALIZE FLUX ROUTINE
      C
            IF(MAPS.EQ.1) CALL FLUX(RHIT,UCN,UCA,UCP,CONVP,1)
      C
      C   SET CONCENTRATOR POSITION VECTORS
      C
          CALL TRACK(TAZ,TEL)
          WRITE(6,1010) IDAY,TIME,XLAT,XLONG,TEL,TAZ
 1010 FORMAT(15X,15HSOLAR CONSTANTS,//,
     +   10X,I10,2X,3HDAY,/,
     +   10X,F10.2,2X,4HTIME,/,
     +   10X,F10.3,2X,8HLATITUDE,/,
     +   10X,F10.3,2X,9HLONGITUDE,/,
     +   10X,F10.3,2X,9HELEVATION,/,
     +   10X,F10.3,2X,7HAZIMUTH,///)
      C
      C   SET CONSTANTS NEEDED FOR DIMENSIONS .
      C
          RW2=SRW*0.50
          DZUP=0.5*(SRW-RW)
      C
      C   SET SUN VECTOR US TO SUN'S CENTER
      C
          CALL SUN1(TAZ,TEL)
          DO 200 N=1,NDRAW
          IREFL=0
          KERR=0
          THETAO=-10.
      C
      C   PERTURB SUN VECTOR FOR FINITE SUN SIZE AND INTENSITY DISTR.
      C
          CALL SUN2(ACC,USP,DRAD)
      C
      C   DRAW OVER APERTURE
      C
          XAP=CLENG*FLAT(0.0)
          Y=CWIDTH*FLAT(0.0)
      C
      C   DETERMINE LOCAL Y VALUE OF HIT POINT
      C
          YAP=Y - DAP*(INT(Y/DAP)+0.5)
          ZAP=RW2

      C   DETERMINE WHETHER INCOMING SUN RAY , US, HITS RECEIVER ON
      C    ENTERIING.  DO RECEIVER HIT TEST USING UI=-US VECTOR
      C    AS THE INCOING RAY. D VECTOR IS DISTANCE FROM APERTURE
      C    HIT POINT  TO CENTER OF RECEIVER.
      C
          DO 10 I=1,3
          UI(I)=-USP(I)
          ORIG(I)=-XAP*UCA(I) - YAP*UCP(I) - (ZAP-DZUP)*UCN(I)
       10 CONTINUE
          CALL RCVR(ORIG,UI,RHIT,MISR1)
```

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```
      C
      C  IF THERE IS A RECEIVER HIT, INCREASE DIRECT HIT COUNTER
      C    BY 1.  IF THE RAY MISSES THE RECEIVER, FIND HIT POINT
      C    ON REFLECTOR SURFACE.
           IF(MISR1.NE.1) GO TO 125
           GO TO 105
      C
      C  IF RAY REFLECTED AND DID NOT HIT RECEIVER, FIND NEXT
      C    HIT POINT.  RESET INCOMING VECTOR TO BE THE VALUE OF
      C    UR.  SET THE ORIGINATION OF THE RAY AT THE PREVIOUS HIT
      C    POINT
      C
        45 IREFL=IREFL + 1
           XAP=XO
           YAP=YO
           ZAP=ZO
           THETAO=THETA
           DO 50 I=1,3
           USP(I)=-UR(I)
        50 UI(I)=UR(I)
      C
      C  RAY DOES NOT HIT RECEIVER DIRECTLY
      C
      C  FIND HIT POINT USING ITERATIVE METHOD
      C
       105 IF(YAP.GT.0.0) THETA=1.40
           IF(YAP.LT.0.0) THETA=-1.40
           IFLAG=1
           IF(IREFL.LT.1) GO TO 106
           THETA=ABS(THETAO)-0.5
           IF(THETA.LT.0.0) THETA=0.0001
           THETA=SIGN(THETA,YAP)
       106 VECTR=DOTER(UI,UCP)/DOTER(UI,UCN)
           DO 20 I=1,NTOL
           CT=COS(THETA)
           ST=SIN(THETA)
           IF(I.EQ.NTOL) GO TO 199
           FTH=YAP/RW2 + THETA*CT - (THETA*ST+CT+ZAP/RW2)*VECTR - ST
           FDERIV=-ST*THETA - THETA*CT*VECTR
           IF(ABS(FDERIV ).LE.0.00001) FDERIV=0.00001*SIGN(1.,FDERIV)
           DELTA=FTH/FDERIV
           IF(ABS(DELTA).GT.2.5) DELTA=2.5*SIGN(1.,DELTA)*
          + FLOAT(NTOL-I)/NTOL
           THETA=THETA-DELTA
           IF(ABS(THETA).GT.3.1415927) THETA=(THETA/3.1415927-INT(THETA/
          + 3.1415927))*3.1415927
           IF(ABS(DELTA).LT.THTOL) GO TO 100
        20 CONTINUE
       100 IF(ABS(THETA-THETAO).GT.THTOL) GO TO 73
           IFLAG=IFLAG+1
      C GUESS NEW THETA BASED ON OLD THETA
           THETA=ABS(THETA)-0.5*FLOAT(IFLAG)
           IF(THETA.LT.0.0) THETA=0.001
```

```
             THETA=SIGN(THETA,YAP)
             IF(IFLAG.GT.6) GO TO 199
             GO TO 106
       73    YO=-RW2*THETA*CT + RW2*ST
             ZO=-RW2*THETA*ST - RW2*CT
             XO=XAP + (ZO-ZAP)*(DOTER(USP,UCA)/DOTER(USP,UCN))
      C
      C    FIND PERFECT SURFACE NORMAL
      C
             IF(THETA.GE.0.0) THETA1=THETA-1.570796
             IF(THETA.LT.0.0) THETA1=THETA+1.570796
             ST1=SIN(THETA1)
             CT1=COS(THETA1)
             DO 30 I=1,3
             UN(I)=CT1*UCN(I) - ST1*UCP(I)
          30 UT(I)=CT1*UCP(I) + ST1*UCN(I)
      C
      C    CALCULATE PERTURBED SURFACE NORMAL(UNP) BASED ON
      C     REFLECTANCE PROPERTIES AND SURFACE ERROR DISTRIBUTION.
      C
             IF(N.EQ.NCHECR) SDR=SDR2
             CALL ERRNORM(SDS,SDR,UN,UT,UCA,UNP,PSM)
      C
      C    CALCULATE REFLECTED RAY UR
      C
             CALL SNELL(UR,UNP,USP)
      C
      C    DO RECEIVER HIT TEST
      C
             DO 40 I=1,3
          40 D(I)=-XO*UCA(I) - YO*UCP(I) - (ZO-DZUP)*UCN(I)
             CALL RCVR(D,UR,RHIT,MISR1)
             IF(MISR1.NE.1) GO TO 55
             IF(IREFL.GE.4) GO TO 120
      C
      C    CHECK TO SEE IF RAY EXITS OUT APERTURE
      C
             IF(DOTER(UR,UCN).LE.0.0) GO TO 45
             TCHEC=DOTER(UR,UCP)/DOTER(UR,UCN)
             YCHEC=ABS(YO-(ZO-DZUP)*TCHEC)
             IF(YCHEC.GT.DAP*0.5) GO TO 120
             GO TO 45
          55 CONVP=RAYVAL(IREFL,REFLTOT)
              IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,2)
             RPWR=RPWR+CONVP
             GO TO 200
         120 MISR=MISR + 1
             GO TO 200
         125 NDIRECT=NDIRECT + 1
             IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,1.0,2)
             RPWR=RPWR+1.0
             GO TO 200
         199 WRITE(6,1990) I
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        1990 FORMAT(5X,29HERROR, ITERATION FAILED ITER=,I5,/)
         200 CONTINUE
             WRITE(6,6020) OFFSUN,REFLTOT,SDS,SDR1,SDR2
        6020 FORMAT(20X,43HSURFACE,REFLECTANCE AND TRACKING PARAMETERS,//,
            + 10X,F10.3,2X,18HSUN OFF-AXIS ANGLE,/,
            + 10X,F10.3,2X,19HREFLECTANCE(TOTAL),/,
            + 10X,F10.5,2X,20HSURF. ERROR(ST.DEV.),/,
            + 10X,F10.5,2X,21HREFL.DISTR.1(ST.DEV.),/,
            + 10X,F10.5,2X,21HREFL.DISTR.2(ST.DEV.),///)
             WRITE(6,1112) NDIRECT
        1112 FORMAT(//,15X,21HDIRECT HITS ON RCVR=,I10)
       C  COMPUTE OPTICAL EFFICIENCY
               NHIT=NDRAW-MISR
             EOPT=RPWR*COS(OFFSUN)/NDRAW
             WRITE(6,9199) MISR,NHIT,EOPT
        9199 FORMAT(///,14X,6HMISSED,4X,6HHIT ON,3X,7HOPTICAL,/,
            +          16X,4HRAYS,6X,4HRCVR,1X,10HEFFICIENCY,//,
            +          10X,2I10,F10.5,/)
             IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,3)
             RETURN
             END

:   11-27-78 *** 14.4 ***

: (SEC)        .95          LINES/MINUTE 14580

:  NO   DIAGNOSTICS IN ABOVE COMPILATION
)S WERE USED FOR THIS COMPILATION
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?-18-79 08.953

```
      SUBROUTINE VEETROF
C
C THIS ROUTIN MODELS THE VEE - TROUGH CONCENTRATING
C    COLLECTOR TO DETERMINE THE OPTICAL PERFORMANCE.
C     THE SURFACE MODEL AND RECEIVER HIT TESTS ARE DONE FOR THIS
C       THIS CONCENTRATOR FROM THIS ROUTINE.
C
      NAMELIST/VTROFN/CLENG,CWIDTH,RW,RL,NAXIS,NZONEX,NZONEY,
     +  TILTANG,IRCVR,THETAAX,THETA1,THETA2,SDS,SDR,DAP,REFLTOT
     + ,PSM
      COMMON/RUNC/NDRAW,TAZ,TEL,TIME,IDAY,XLAT,XLONG,ICONC,
     + NMAT,DRAD,MISR,TZONE,MAPS,RPWR,AMIR,NMATL
      COMMON/VECTOR/ULE(3),ULV(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
      COMMON/RCVRC/IRCVR,THETAC,SO,RW,RL,OHIT
      COMMON/TRAC/NAXIS,TILTANG,OFFSUN,THETAAX,DTRACRL,DTRACAZ,IRPI
      COMMON/ZONE/NZONEX,NZONEY
      DIMENSION D(3),UT(3),UR(3),UN(3),UNP(3),
     + USP(3),RHIT(3),UI(3),VDUM(3)
C
C READ NAMELIST VALUES
C
      READ(5,VTROFN)
C
C OBTAIN DATA FOR REFLECTIVE MATERIAL PROPERTIES
C
      IF(NMAT.NE.0) CALL RDATA(NMAT,NDRAW,SDR1,SDR2,REFLTOT,REFL
     + ,NCHECR)
      SDR=SDR1
C
C OUTPUT NAMELIST VALUES
C
      WRITE(6,6000) CLENG,CWIDTH,THETA1,THETA2,DAP,NAXIS,TILTANG,
     + IRCVR,RW,RL
 6000 FORMAT(20X,21HVEE TROUGH PARAMETERS,//,
     + 10X,F10.3,2X,6HLENGTH,/,
     + 10X,F10.3,2X,5HWIDTH,/,
     + 10X,F10.3,2X,14HTHETA-RT. SIDE,/,
     + 10X,F10.3,2X,15HTHETA-LEFT SIDE,/,
     + 10X,F10.3,2X,9HVEE WIDTH,/,
     + 10X,I10,2X,13HTRACKING AXES,/,
     + 10X,F10.3,2X,10HTILT ANGLE,/,
     + 10X,I10,2X,10HRCVR. TYPE,/,
     + 10X,F10.3,2X,11HRCV. WIDTH,/,
     + 10X,F10.3,2X,12HRCVR. LENGTH,///)
      AMIR=DAP*CLENG
C
C INITIALIZE FLUX ROUTINE
C
      IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,1)
C
C SET SUN VECTOR US TO SUN'S CENTER
C
      CALL SUN1(TAZ,TEL)
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2-18-79 08.953

```
C
C     SET COLLECTOR POSITION VECTORS
C
      CALL TRACK(TAZ,TEL)
      WRITE(6,1010) IDAY,TIME,XLAT,XLONG,TEL,TAZ
 1010 FORMAT(15X,15HSOLAR CONSTANTS,//,
     +  10X,I10,2X,3HDAY,/,
     +  10X,F10.2,2X,4HTIME,/,
     +  10X,F10.3,2X,8HLATITUDE,/,
     +  10X,F10.3,2X,9HLONGITUDE,/,
     +  10X,F10.3,2X,9HELEVATION,/,
     +  10X,F10.3,2X,7HAZIMUTH,///)
C
C     SET PARAMETERS FOR VEE TROUGH.
C
      T1=TAN(THETA1)
      CT1=COS(THETA1)
      ST1=SIN(THETA1)
      T2=TAN(THETA2)
      CT2=COS(THETA2)
      ST2=SIN(THETA2)

      NDIRECT=0
C   COMPUTE APERTURE HEIGTH
      ZAP=(DAP-RW)/(1./T1+1./T2)
      YCEN=0.5*RW+ZAP/T1-DAP*0.5
      DO 100 N=1,NDRAW
      IREFL=0
C
C     PERTURB SUN VECTOR FOR FINITE SUN SIZE AND INTENSITY DISTR.
C
      CALL SUN2(ACC,USP,DRAD)
C
C     DRAW OVER APERTURE
C
      XAP=CLENG*FLAT(0.0)
      YAP=DAP*(-0.5+FLAT(0.0))+YCEN
      ISIDE=INT(SIGN(1.,YAP))
C
C     DETERMINE WHETHER INCOMING SUN RAY , US, HITS RECEIVER ON
C       ENTERIING.  DO RECEIVER HIT TEST USING UI=-US VECTOR
C       AS THE INCOING RAY. D VECTOR IS DISTANCE FROM APERTURE
C       HIT POINT  TO CENTER OF RECEIVER.
C
      DO 10 I=1,3
      UI(I)=-USP(I)
   10 D(I)=-XAP*UCA(I) - YAP*UCP(I)-ZAP*UCN(I)
      CALL RCVR(D,UI,RHIT,MISR1)
C
C     IF THERE IS A RECEIVER HIT, INCREASE DIRECT HIT COUNTER
C       BY 1.  IF THE RAY MISSES THE RECEIVER, FIND HIT POINT
C       ON REFLECTOR SURFACE.
      IF(MISR1.EQ.0) GO TO 125
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1-18-79 08.953

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      GO TO 30
   45 IREFL=IREFL + 1
      XAP=XO
      YAP=YO
      ZAP=ZO
      DO 25 I=1,3
25    UI(I)=UR(I)
C
C  FIND NEXT HIT POINT OF REFLECTED RAY
C
C  CHECK FOR CROSSOVER OF SIDES OR APERTURE EXIT
  30  CALL VEEHIT(UI,YAP,ZAP,RW,ISW)
      IF(ISW.EQ.0) GO TO 120
      ISIDE=ISIDE*ISW
      IF(ISIDE.EQ.-1) GO TO 50
      DO 40 I=1,3
      UN(I)=-ST1*UCP(I) + CT1*UCN(I)
   40 UT(I)=ST1*UCN(I) + CT1*UCP(I)
      GO TO 70
   50 CONTINUE
      DO 60 I=1,3
      UN(I)=ST2*UCP(I) + CT2*UCN(I)
   60 UT(I)= ST2*UCN(I) - CT2*UCP(I)
C NOW GET HIT POINT ON REFLECTOR
   70 DUCN=DOTER(D,UCN)
      UIUCN=DOTER(UI,UCN)
      DUN=DOTER(D,UN)
      UIUN=DOTER(UI,UN)
      UCPUN=DOTER(UCP,UN)
      RHS1=DUCN/UIUCN-DUN/UIUN-ISIDE*0.5*RW*UCPUN/UIUN
      UCAUN=DOTER(UCA,UN)
      UIUCA=DOTER(UI,UCA)
      DUCA=DOTER(D,UCA)
      RHS2=UCAUN*DUCA/UIUN-UCAUN*DUCN*UIUCA/(UIUN*UIUCN)
      UTUCN=DOTER(UT,UCN)
      UTUCA=DOTER(UT,UCA)
      BOT1=UCAUN*UTUCN*UIUCA/(UIUN*UIUCN)
      BOT2=UCAUN*UTUCA/UIUN-UTUCN/UIUCN
      S=(RHS1+RHS2)/(BOT1+BOT2)
      AL=(DUCN+S*UTUCN)/UIUCN
      DO 71 I=1,3
   71 VDUM(I)= -D(I)+AL*UI(I)
      XO=DOTER(VDUM,UCA)
      YO=DOTER(VDUM,UCP)
      ZO=DOTER(VDUM,UCN)
C
C   CALCULATE PERTURBED SURFACE NORMAL(UNP) BASED ON
C     REFLECTANCE PROPERTIES AND SURFACE ERROR DISTRIBUTION.
C
      IF(N.EQ.NCHECR) SDR=SDR2
      CALL ERRNORM(SDS,SDR,UN,UT,UCA,UNP,PSM)
C
C   CALCULATE REFLECTED RAY UR
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2-18-79   08.953

      C
            CALL SNELL(UR,UNP,USP)
      C
      C   DO RECEIVER HIT TEST
      C
            DO 80 I=1,3
         80 D(I)=-XO*UCA(I) - YO*UCP(I) -ZO*UCN(I)
            CALL RCVR(D,UR,RHIT,MISR1)
            IF(MISR1.NE.1) GO TO 75
            IF(IREFL.GE.4) GO TO 120
            GO TO 45
         75 CONVP=RAYVAL(IREFL,REFLTOT)
            IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,2)
            RPWR=RPWR+CONVP
            GO TO 100
        120 MISR=MISR + 1
            GO TO 100
        125 NDIRECT=NDIRECT + 1
            IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,1.0,2)
            RPWR=RPWR+1.0
        100 CONTINUE
            WRITE(6,6020) OFFSUN,REFLTOT,SDS,SDR1,SDR2
       6020 FORMAT(20X,43HSURFACE,REFLECTANCE AND TRACKING PARAMETERS,//,
           + 10X,F10.3,2X,18HSUN OFF-AXIS ANGLE,/,
           + 10X,F10.3,2X,19HREFLECTANCE(TOTAL),/,
           + 10X,F10.5,2X,20HSURF. ERROR(ST.DEV.),/,
           + 10X,F10.5,2X,21HREFL.DISTR.1(ST.DEV.),/,
           + 10X,F10.5,2X,21HREFL.DISTR.2(ST.DEV.),///)
            WRITE(6,303) NDIRECT
        303 FORMAT(///10X,20HDIRECT HITS ON RCVR=,I10)
      C  COMPUTE OPTICAL EFFICIENCY
               NHIT=NDRAW-MISR
            EOPT=RPWR*COS(OFFSUN)/NDRAW
            WRITE(6,9199) MISR,NHIT,EOPT
       9199 FORMAT(///,14X,6HMISSED,4X,6HHIT ON,8X,7HOPTICAL,/,
           +               16X,4HRAYS,6X,4HRCVR,6X,10HEFFICIENCY,//,
           +               10X,2I10,5X,F10.5,/)
            IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,3)
            RETURN
            END

  11-27-78 *** 10.4 ***

  (SEC)       .87         LINES/MINUTE 13682

  NO   DIAGNOSTICS IN ABOVE COMPILATION
 )S WERE USED FOR THIS COMPILATION
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-18-79   08.954

              SUBROUTINE VEEHIT(UI,YAP,ZAP,RW,ISW)
              DIMENSION UI(3)
              COMMON/VECTOR/ULE(3),ULV(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
       C
       C  THIS ROUTINE CHECKS FOR A SWITCH OVER IN THE SIDE OF
       C THE REFLECTED RAY -- OR A RAY EXIT OUT THE APERTURE
       C
              ISW=1
              AL=-YAP/DOTER(UI,UCP)
              IF(AL.LT.0.0) RETURN
              ZHIT=ZAP+AL*DOTER(UI,UCN)
              IF(ZHIT.GT.0.5*RW) ISW=-1
              IF(ZHIT.GT.ZAP) ISW=0
              RETURN
              END


  11-27-78 *** 14.4 ***

 (SEC)      .30         LINES/MINUTE  2986

  NO   DIAGNOSTICS IN ABOVE COMPILATION
 ) WERE USED FOR THIS COMPILATION
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```
      SUBROUTINE INFLAT
C
C
C   THIS ROUTINE DOES THE OPTICAL ANALYSIS FOR A
C     INFLATED CYLINDRICAL CONCENTRATING COLLECTOR.
C
      COMMON/RUNC/NDRAW,TAZ,TEL,TIME,IDAY,XLAT,XLONG,ICONC,
     + NMAT,DRAD,MISR,TZONE,MAPS,RPWR,AMIR,NMATL
      COMMON/VECTOR/ULE(3),ULV(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
      COMMON/RCVRC/IRCVR,THETAC,SO,RW,RL,QHIT
      COMMON/TRAC/NAXIS,TILTANG,OFFSJN,THETAAX,DTRACRL,DTRACAZ,IRPI
      COMMON/ZONE/NZONEX,NZONEY
      DIMENSION JBIN(20,20),D(3),D1(3),UT(3),UN(3),UNP(3),
     + UR(3),USP(3),RHIT(3),HIT(10)
      NAMELIST/INFLATN/CLENG,CWIDTH,RW,RL,SDS,SDR,NAXIS,TILTANG,
     + NZONEX,NZONEY,IRCVR,DEND,DTRACRL,DTRACAZ,RDIST,NZONEAX,
     +  IR,THETAAX,REFLTOT,PSM
C
C   READ NAMELIST VALUES
C
      READ(5,INFLATN)
C
C
C   OBTAIN DATA FOR REFLECTIVE MATERIAL PROPERTIES
C
      IF(NMAT.NE.0) CALL RDATA(NMAT,NDRAW,SDR1,SDR2,REFLTOT,REFL
     + ,NCHECR)
      SDR=SDR1
C   OUTPUT NAMELIST VALUES
C
      WRITE(6,6000) CLENG,CWIDTH,NAXIS,THETAAX,RW,RL
     + ,IRCVR,TILTANG
      IF(IR.EQ.1) WRITE(6,6010) RDIST
 6010 FORMAT(10X,F10.3,2X,14HRCVR. POSITION,///)
 6000 FORMAT(20X,39HINFLATABLE CYLINDRICAL CONC. PARAMETERS,///,
     + 10X,F10.3,2X,6HLENGTH,/,
     + 10X,F10.3,2X,5HWIDTH,/,
     + 10X,I10,2X,13HTRACKING AXES,/,
     + 10X,F10.3,2X,16HAXIS ORIENTATION,/,
     +  10X,F10.3,2X,11HRCVR. WIDTH,/,
     + 10X,F10.3,2X,12HRCVR. LENGTH,/
     + 10X,I10,2X,9HRCVR TYPE,/,
C
     + ,10X,F10.3,2X,10HTILT ANGLE)
C   INITIALIZE FLUX ROUTINE
C
      IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,1)
C
C   SET SUN VECTOR US TO SUN'S CENTER.
C
      CALL SUN1(TAZ,TEL)
C
C   SET COOLECTOR POSITION VECTORS
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•18-79   08.952

```
      C
            CALL TRACK(TAZ,TEL)
      C
      C   DETERMINE HIT POINT OF EACH RAY AND FOLLOW RAY PATH TO
      C     RECEIVER
      C
            RCYL=CWIDTH*0.5
            AMIR=3.141592654*RCYL*RCYL
            DO 5 I=1,NZONEAX
          5 HIT(I)=0.0
            DO 10 N=1,NDRAW
      C
      C   PERTURB SUN VECTOR FOR FINITE SUN SIZE AND INTENSITY DISTR.
      C
            CALL SUN2(ACC,USP,DRAD)
            IREFL=0
      C
      C  DRAW OVER APERTURE
      C
            XAP=FLAT(0.0)*CLENG
            YAP=-RCYL + 2.*RCYL*FLAT(0.0)
            ZAP=0.0
      C
      C  CHECK FOR DIRECT HIT ON RCVR
            DO 15 I=1,3
            D(I)=-XAP*UCA(I)-YAP*UCP(I)-(RDIST+ZAP)*UCN(I)
       15   UR(I)=-USP(I)
            CALL RCVR(D,UR,RHIT,MISR1)
            IF(MISR1.EQ.1) GO TO 105
      C   HIT RCVR
            IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,1,0,2)
            RPWR=RPWR+1.0
            GO TO 10
         95 IREFL=IREFL+1
            XAP=XO
            YAP=YO
            ZAP=ZO
            DO 65 I=1,3
         65 USP(I)=-UR(I)
        105 CALL CYLHIT(USP,XAP,YAP,ZAP,XO,YO,ZO,IREFL,KERR,RCYL)
            IF(KERR.EQ.1) GO TO 50
            IF(IREFL.GT.0.AND.ZO.GT.0.0) GO TO 180
      C
      C   FIND PERFECT SURFACE NORMAL
      C
            DO 20 I=1,3
            UN(I)=-YO/RCYL*UCP(I)-ZO/RCYL*UCN(I)
         20 UT(I)=YO/RCYL*UCN(I)-ZO/RCYL*UCP(I)
      C
      C   CALCULATE PERTURBED SURFACE NORMAL(UNP) BASED ON
      C    REFLECTANCE PROPERTIES AND SURFACE ERROR DISTRIBUTION.
      C
            IF(N.EQ.NCHECR) SDR=SDR2
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18-79 08.952

```
      CALL ERRNORM(SDS,SDR,UN,UT,UCA,UNP,PSM)
C
C
C   CALCULATE REFLECTED RAY UR
C
      CALL SNELL(UR,UNP,USP)
C
C   DO HIT TEST TO DETERMINE OPTICAL EFFICIENCY TO RCVR.
C   SET DVECTOR
C     RDIST= DISTANCE FROM CENTER OF CYLINDER TO CENTER OF RE-
C      CEIVER ALONG NORMAL AXIS
C
      DO 130 I=1,3
  130 D(I)=-XO*UCA(I) - YO*UCP(I) - (RDIST+ZO)*UCN(I)
C
C   CALL RCVR. TO DO HIT TEST ON PLANAR OR CYL. RECEIVER.
C
      CALL RCVR(D,UR,RHIT,MISR1)
      IF(MISR1.EQ.1.AND.IREFL.GT.3) GO TO 180
      IF(MISR1.EQ.1) GO TO 95
      CONVP=RAYVAL(IREFL,REFLTOT)
      IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,2)
      RPWR=RPWR+CONVP
      GO TO 10
   50 WRITE(6,1110)
 1110 FORMAT(5X,37HERROR, HIT POINT ON SURFACE NOT FOUND,/)
      GO TO 10
  180 MISR=MISR + 1
   10 CONTINUE
      WRITE(6,6020) OFFSUN,REFLTOT,SDS,SDR1,SDR2,DTRACAZ,DTRACRL
 6020 FORMAT(20X,43HSURFACE,REFLECTANCE AND TRACKING PARAMETERS,//,
     + 10X,F10.3,2X,18HSUN OFF-AXIS ANGLE,/,
     + 10X,F10.3,2X,19HREFLECTANCE(TOTAL),/,
     + 10X,F10.5,2X,20HSURF. ERROR(ST.DEV.),/,
     + 10X,F10.5,2X,21HREFL.DISTR.1(ST.DEV.),/,
     + 10X,F10.5,2X,21HREFL.DISTR.2(ST.DEV.),/,
     + 10X,F10.3,2X,18HTRACKING ERROR-AZ.,/,
     + 10X,F10.3,2X,19HTRACKING ERROR-ROLL,//)
C  COMPUTE OPTICAL EFFICIENCY
        NHIT=NDRAW-MISR
      EOPT=RPWR*COS(OFFSUN)/NDRAW
      WRITE(6,9199) MISR,NHIT,EOPT
 9199 FORMAT(///,14X,6HMISSED,4X,6HHIT ON,3X,7HOPTICAL,/,
     +          16X,4HRAYS,6X,4HRCVR,1X,10HEFFICIENCY,//,
     +          10X,2I10,F10.5,/)
      IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,3)
      RETURN
      END
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11-27-78 *** 14.4 ***

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·18-79   08.953

      SUBROUTINE CYLHIT(USP,XAP,YAP,ZAP,XO,YO,ZO,IREFL,KERR,RCYL)
C
C  THIS ROUTINE FINDS THE SURFACE HIT POINT FOR THE INFLATED
C     CYLINDRICAL CONCENTRATOR.
C  INPUTS ARE-
C            USP                THE INCOMING RAY
C            XAP,YAP,ZAP        THE POINT ON THE APERTURE(OR SURFACE)
C                   FROM WHICH THE RAY ORIGINATES
C
      DIMENSION USP(3)
      COMMON/VECTOR/ULE(3),ULN(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
      KERR=0
      SA=DOTER(USP,UCA)
      SP=DOTER(USP,UCP)
      SN=DOTER(USP,UCN)
      A=1.-SA*SA
      B=-2.*(YAP*SP+ZAP*SN)
      C=YAP*YAP+ZAP*ZAP-RCYL*RCYL
      QUAD=B*B-4.*A*C
      IF(QUAD.LT.0.0) GO TO 50
      AL1=(-B+SQRT(QUAD))/(2.*A)
      AL2=(-B-SQRT(QUAD))/(2.*A)
      AL=AL1
      IF(AL2.GT.AL1) AL=AL2
      XO=XAP-AL*SA
      YO=YAP-AL*SP
      ZO=ZAP-AL*SN
      RETURN
   50 KERR=1
      RETURN
      END

11-27-78 *** 14.4 ***

(SEC)        .35          LINES/MINUTE  5189

 NO   DIAGNOSTICS IN ABOVE COMPILATION
 WERE USED FOR THIS COMPILATION
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18-79 08.952

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      SUBROUTINE INCREFL
      REAL NAIR,NLENS
      NAMELIST/INCREFN/CLENG,CWIDTH,RW,RL,F,NAXIS,FACH,FACW,
     + NAIR,NLENS,TILTANG,NZONEX,NZONEY,SDFS,SDS,SDR,THETAAX,
     + DTRACRL,DTRACAZ,IRCVR,REFLTOT,RWS,PSM
      COMMON/RUNC/NDRAW,TAZ,TEL,TIME,IDAY,XLAT,XLONG,ICONC,
     + NMAT,DRAD,MISR,TZONE,MAPS,RPWR,AMIR,NMATL
      COMMON/VECTOR/ULE(3),ULV(3),ULB(3),UCN(3),UCA(3),UCP(3),US(3)
      COMMON/RCVRC/IRCVR,THETAC,SO,RW,RL,QHIT
      COMMON/TRAC/NAXIS,TILTANG,OFFSUN,THETAAX,DTRACRL,DTRACAZ,IRPI
      COMMON/ZONE/NZONEX,NZONEY
      DIMENSION D(3),UT(3),UN(3),UNP(3),UR(3),
     + USP(3),RHIT(3),PUS(3),UCAP(3),UCNP(3),
     + UCPP(3),US1P(3),PUR(3),UR1(3),WAVL(20)
C THE CENTER WAVELENGTHS OF 20 EQUAL ENERGY BANDS
      DATA WAVL/390.,440.,480.,510.,540.,570.,600.,630.,660.,
     + 700.,740.,780.,820.,870.,960.,1020.,1080.,1220.,1480.,1680./
C   READ NAMELIST VALUES
C
      READ(5,INCREFN)
C
C
C   OBTAIN DATA FOR REFLECTIVE MATERIAL PROPERTIES
C
      IF(NMAT.NE.0) CALL RDATA(NMAT,NDRAW,SDR1,SDR2,REFLTOT,REFL
     + ,NCHECR)
      SDR=SDR1
C   WRITE NAMELIST PARAMETERS
C
      WRITE(6,6000) CLENG,CWIDTH,F,FACW,NAXIS,RW,RL,RWS,IRCVR,THETAAX,
     + TILTANG
 6000 FORMAT(20X,32HINCREMENTAL REFLECTOR PARAMETERS,///,
     + 10X,F10.3,2X,6HLENGTH,/,
     + 10X,F10.3,2X,5HWIDTH,/,
     + 10X,F10.3,2X,12HFOCAL LENGTH,/,
     + 10X,F10.5,2X,19HFRESNEL FACET WIDTH,/,
     + 10X,I10,2X,13HTRACKING AXES,/,
     + 10X,F10.3,2X,11HRCVR. WIDTH,/,
     + 10X,F10.3,2X,12HRCVR. LENGTH,/,
     + 10X,F10.3,2X,17HRCVR SHADOW WIDTH,/,
     + 10X,I10,2X,10HRCVR. TYPE,/,
     + 10X,F10.3,2X,16HAXIS ORIENTATION,/,
     + 10X,F10.3,2X,10HTILT ANGLE,///)
      AMIR=CLENG*CWIDTH
      ISHAD=0
C
C
C   SET SUN VECTOR US TO SUN'S CENTER
C
C
      CALL SUN1(TAZ,TEL)
C   INITIALIZE FLUX ROUTINE
C
```

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•18•79  -08.952
              IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,1,1)
      C
      C    SET COLLECTOR POSITION VECTORS UCA,UCN,UCP
      C
              CALL TRACK(TAZ,TEL)
              WRITE(6,1010) IDAY,TIME,XLAT,XLONG,TEL,TAZ
       1010 FORMAT(15X,15HSOLAR CONSTANTS,//,
           +  10X,I10,2X,3HDAY,/,
           +  10X,F10.2,2X,4HTIME,/,
           +  10X,F10.3,2X,8HLATITUDE,/,
           +  10X,F10.3,2X,9HLONGITUDE,/,
           +  10X,F10.3,2X,9HELEVATION,/,
           +  10X,F10.3,2X,7HAZIMUTH,///)
              DO 10 N=1,NDRAW
              XO=FLAT(0.0)*CLENG
              YO=CWIDTH*(0.5-FLAT(0.0))
      C  CHECK FOR RECEIVER SHADOW
              IF(ABS(YO).GT.RWS*0.5) GO TO 5
              ISHAD=ISHAD+1
              GO TO 190
      C
      C  GET LENS MATERIAL DATA
          5   IF(NMATL.LT.11) GO TO 20
              JW=INT(20.*FLAT(0.0))+1
              WAVEL=WAVL(JW)
              CALL LDATA(NMATL,WAVEL,NAIR,NLENS)
         20   ZO=0.0
      C  DETERMINE FACET CENTER DISTANCE FROM ORIGIN
              XNF=INT(ABS(YO)/FACW)
              YFC=FACW*(XNF+0.5)
      C    FIND SLOPE OF FACET NORMAL AT YFC
              ALPHA= ATAN2(YFC,F)
              THETA1=ARSIN(NAIR/NLENS*SIN(ALPHA0)*0.5*SIGN(1,YO)
              CT1=COS(THETA1)
              ST1=SIN(THETA1)
              DO 40 I=1,3
              UT(I)=CT1*UCP(I) + ST1*UCN(I)
          40  UN(I)=CT1*UCN(I) - ST1*UCP(I)
      C
      C    PERTURB SUN VECTOR FOR FINITE SUN SIZE AND THE INTENSITY
      C      DISTRIBUTION.
      C
              CALL SUN2(ACC,USP,DRAD)
      C
      C    FIND SUN VECTOR AFTER FIRST SURFACE REFRACTION.
      C      USE PERTURBED SURFACE POSITION VECTORS TO ACCOUNT FOR ERRROR
      C      IN FIRST SURFACE .  THE PERTURBED VECTOR TRIAD IS
      C         UCAP, UCPP, UCNP.
      C         THE REFRACTED SUN VECTOR IS US1P.
      C         THE ST.DEVIATION FOR SURFACE ERROR IS SDFS.
      C
              CALL ERRNORM(SDFS,0.,UCN,UCP,UCA,UCNP,PSM)
      C    FIND FIRST SURFACE REFRACTED SUN VECTOR
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18-79 08.952

```
      C
            CALL LREFR(NAIR,NLENS,UCNP,USP,US1P,ICOD)
            IF(ICOD.EQ.1) GO TO 190
            DO 80 I=1,3
   80       US1P(I)=-US1P(I)
      C
      C   CALCULATE PERTURBED SURFACE NORMAL(UNP) BASED ON
      C     REFLECTANCE PROPERTIES AND SURFACE ERROR DISTRIBUTION.
      C
            IF(N.EQ.NCHECR) SDR=SDR2
            CALL ERRNORM(SDS,SDR,UN,UT,UCA,UNP,PSM)
      C
      C   CALCULATE REFLECTED RAY UR1
      C
            CALL SNELL(UR1,UNP,US1P)
      C
      C   PERTURB REFLECTED RAY VECTOR FOR REFRACTION AT FIRST SURFACE
      C     ON EXIT FROM REFLECTOR
      C
            CALL ERRNORM(SDFS,0.,UCN,UCP,UCA,UCNP,PSM)
            DO 110 I=1,3
            UR1(I)=-UR1(I)
  110       UCNP(I)=-UCNP(I)
            CALL LREFR(NLENS,NAIR,UCNP,UR1,UR,ICOD)
            IF(ICOD.EQ.1) GO TO 190
      C
      C   FIND D VECTOR TO KNOWN PPOINT ON RECEIVER SURFACE
      C
            DO 140 I=1,3
  140 D(I)=-XO*UCA(I) - YO*UCP(I) + (F-ZO)*UCN(I)
      C
      CC   DO HIT TEST ON RECEIVER SURFACE
      C
            CALL RCVR(D,UR,RHIT,MISR1)
      C
      C   DETERMINE IF RAY HITS RECEIVER
      C     FIND ZONE OF RECEIVER HITS
      C
            IF(MISR1.EQ.1) GO TO 190
            IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,REFLTOT,2)
            RPWR=RPWR+REFLTOT
            GO TO 10
  190 MISR=MISR + 1
   10 CONTINUE
            WRITE(6,6020) OFFSUN,REFLTOT,SDS,SDFS,SDR1,SDR2,DTRACAZ,DTRACRL
 6020 FORMAT(20X,43HSURFACE,REFLECTANCE AND TRACKING PARAMETERS,//,
          + 10X,F10.3,2X,18HSUN OFF-AXIS ANGLE,/,
          + 10X,F10.3,2X,19HREFLECTANCE(TOTAL),/,
          + 10X,F10.5,2X,20HSURF. ERROR(ST.DEV.),/,
          + 10X,F10.5,2X,32HSURF. ERROR(ST.DEV.)-1ST SURFACE,/,
          + 10X,F10.5,2X,21HREFL.DISTR.1(ST.DEV.),/,
          + 10X,F10.5,2X,21HREFL.DISTR.2(ST.DEV.),/,
          + 10X,F10.3,2X,18HTRACKING ERROR-AZ.,/,
```

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·18-79   08.952

             + 10X,F10.3,2X,19HTRACKING ERROR=ROLL,//)
              WRITE(6,1070) ISHAD
         1070 FORMAT(/10X,21HRAYS BLOCKED BY RCVR=,I10)
        C  COMPUTE OPTICAL EFFICIENCY
                NHIT=NDRAW-MISR
              EOPT=RPWR*COS(OFFSUN)/NDRAW
              WRITE(6,9199) MISR,NHIT,EOPT
         9199 FORMAT(///,14X,6HMISSED,4X,6HHIT ON,3X,7HOPTICAL,/,
             +             16X,4HRAYS,6X,4HRCVR,1X,10HEFFICIENCY,//,
             +             10X,2I10,F10.5,/)
              IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,3)
              RETURN
              END

 11-27-78 *** 14.4 ***

(SEC)      .74          LINES/MINUTE 13781

 NO   DIAGNOSTICS IN ABOVE COMPILATION
 WERE USED FOR THIS COMPILATION
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18=79   08.951

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      SUBROUTINE FRESNEL
      REAL NAIR,NLENS
      NAMELIST/FRESN/CLENG,CWIDTH,RW,RL,F,SDS,SDR,NAXIS,FACH,
     + FACW,NAIR,NLENS,TILTANG,NZONEX,NZONEY,IRCVR,THETAAX,DTRACRL,
     +  DTRACAZ,SDFS,TRANTOT,PSM
      COMMON/RUNC/NDRAW,TAZ,TEL,TIME,IDAY,XLAT,XLONG,ICONC,
     + NMAT,DRAD,MISR,TZONE,MAPS,RPWR,AMIR,NMATL
      COMMON/VECTOR/ULE(3),ULV(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
      COMMON/RCVRC/IRCVR,THETAC,SD,RW,RL,QHIT
      COMMON/TRAC/NAXIS,TILTANG,OFFSUN,THETAAX,DTRACRL,DTRACAZ,IRPI
      COMMON/ZONE/NZONEX,NZONEY
      DIMENSION  JBIN(20,20)
      DIMENSION  D(3),UT(3),UN(3),UNP(3),UR(3),USP(3),RHIT(3)
      DIMENSION PUS(3),UCAP(3),UCNP(3),UCPP(3),US1P(3),WAVL(20)
C  THE CENTER WAVELENGTHS OF 20 EQUAL ENERGY BANDS
C
      DATA WAVL/390.,440.,480.,510.,540.,570.,600.,630.,660.,
     + 700.,740.,780.,820.,870.,960.,1020.,1080.,1220.,1480.,1680./
C
C   READ NAMELIST VALUES
C
      READ(5,FRESN)
C
C   OUTPUT NAMELIST VALUES
C
      WRITE(6,6000) CLENG,CWIDTH,F,FACW,NAXIS,THETAAX,RW,RL,IRCVR
 6000 FORMAT(20X,25HLINEAR FRESNEL PARAMETERS,///,
     + 10X,F10.3,2X,6HLENGTH,/,
     + 10X,F10.3,2X,5HWIDTH,/,
     + 10X,F10.3,2X,12HFOCAL LENGTH,/,
     + 10X,F10.5,2X,19HFRESNEL FACET WIDTH,/,
     + 10X,I10,2X,13HTRACKING AXES,/,
     + 10X,F10.3,2X,16HAXIS ORIENTATION,/,
     + 10X,F10.3,2X,11HRCVR. WIDTH,/,
     + 10X,F10.3,2X,12HRCVR. LENGTH,/,
     + 10X,I10,2X,10HRCVR. TYPE,///)
      AMIR=CWIDTH*CLENG
C
C   INITIALZE FLUX ROUTINE
C
      IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,1)
C
C   SET SUN VECTOR US TO SUN'S CENTER
C
      CALL SUN1(TAZ,TEL)
C
C  DETERMINE COLLECTOR POSITION VECTORS UCA,UCP,UCN
C
      CALL TRACK(TAZ,TEL)
      WRITE(6,1010) IDAY,TIME,XLAT,XLONG,TEL,TAZ
 1010 FORMAT(15X,15HSOLAR CONSTANTS,//,
     +  10X,I10,2X,3HDAY,/,
     +  10X,F10.2,2X,4HTIME,/,
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     +  10X,F10.3,2X,8HLATITUDE,/,
     +  10X,F10.3,2X,9HLONGITUDE,/,
     +  10X,F10.3,2X,9HELEVATION,/,
     +  10X,F10.3,2X,7HAZIMUTH,///)
C
C    DETERMINE HIT POINTS FOR EACH RAY DRAW ON SURFACE
C
        DO 30 N=1,NDRAW
        XO=FLAT(0.0)*CLENG
        YO=CWIDTH*(0.5-FLAT(0.0))
C
C  GET LENS MATERIAL DATA
        IF(NMATL.LT.11) GO TO 20
        JW=INT(20.*FLAT(0.0))+1
        WAVEL=WAVL(JW)
C
C   OBTAIN DATA FOR LENSING MATERIAL PROPERTIES
C
        CALL LDATA(NMATL,WAVEL,NAIR,NLENS)
 20     ZO=0.0
C  DETERMINE FACET CENTER DISTANCE FROM ORIGIN
        XNF=INT(ABS(YO)/FACW)
        YFC=FACW*(XNF+0.5)
C   FIND SLOPE OF FACET NORMAL AT YFC
        ALPHA=ATAN2(F,YFC)
        ARG=COS(ALPHA)/(NLENS/NAIR-SIN(ALPHA))
        THETA1=ATAN(ARG)*SIGN(1.,YO)
        CT1=COS(THETA1)
        ST1=SIN(THETA1)
        DO 40 I=1,3
        UT(I)=CT1*UCP(I) + ST1*UCN(I)
 40     UN(I)=CT1*UCN(I) - ST1*UCP(I)
C  FACETS ARE ASSUMED TO HAVE ZERO THICKNESS
C
C   PERTURB SUN VECTOR FOR FINITE SUN SIZE AND THE INTENSITY
C      DISTRIBUTION.
C
        CALL SUN2(ACC,USP,DRAD)
C
C   FIND SUN VECTOR AFTER FIRST SURFACE REFRACTION.
C      USE PERTURBED SURFACE POSITION VECTORS TO ACCOUNT FOR ERRROR
C      IN FIRST SURFACE .  THE PERTURBED VECTOR TRIAD IS
C         UCAP, UCPP, UCNP.
C         THE REFRACTED SUN VECTOR IS US1P.
C         THE ST.DEVIATION FOR SURFACE ERROR IS SDFS.
C
C
        CALL ERRNORM(SDFS,0.,UCN,UCP,UCA,UCNP,PSM)
C   FIND FIRST SURFACE REFRACTED SUN VECTOR
C
        CALL LREFR(NAIR,NLENS,UCNP,USP,US1P,ICOD)
        IF(ICOD.EQ.1) GO TO 130
        DO 789 I=1,3
```

•18•79 08.951

```
  789 US1P(I)=-US1P(I)
C
C     CALCULATE PERTURBED SURFACE NORMAL(UNP) BASED ON
C      REFLECTANCE PROPERTIES AND SURFACE ERROR DISTRIBUTION.
C
        CALL ERRNORM(SDS,SDR,UN,UT,UCA,UNP,PSM)
C
C     CALCULATE REFRACTED RAY(UR) USING LAW OF REFRACTION
        CALL LREFR(NLENS,NAIR,UNP,US1P,UR,ICOD)
        IF(ICOD.EQ.1) GO TO 130
C
C     FIND D VECTOR TO KNOWN POINT ON RECEIVER SURFACE.
C
        DO 100 I=1,3
  100 D(I)=-XO*UCA(I) - YO*UCP(I) - (F-ZO)*UCN(I)
C
C     DO HIT TEST ON RECEIVER SURFACE
C
        CALL RCVR(D,UR,RHIT,MISR1)
C
C     DETERMINE IF RAY HITS RCVR. AND POSITION OF HIT IF IT
C      OCCURS.
C
C     FOR PLANAR RCVR.
C
        IF(MISR1.EQ.1) GO TO 130
C   MAKE POWER FN OF WAVE LENGTH (TRANSMITTANCE)
        CONVP=TRANTOT
        IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,2)
        RPWR=RPWR+TRANTOT
        GO TO 30
  130 MISR=MISR+1
   30 CONTINUE
        WRITE(6,6020) OFFSUN,SDS,SDFS,DTRACAZ,DTRACRL,
     + NAIR,NLENS
 6020 FORMAT(20X,43HSURFACE,REFLECTANCE AND TRACKING PARAMETERS,//,
     + 10X,F10.3,2X,18HSUN OFF-AXIS ANGLE,/,
     + 10X,F10.5,2X,20HSURF. ERROR(ST.DEV.),/,
     + 10X,F10.5,2X,25HOUTER SURF. ERR (ST.DEV.),/,
     + 10X,F10.3,2X,18HTRACKING ERROR-AZ.,/,
     + 10X,F10.3,2X,19HTRACKING ERROR-ROLL,/,
     + 10X,F10.3,2X,9HINDEX-AIR,/,
     + 10X,F10.3,2X,10HINDEX-LENS,///)
C COMPUTE OPTICAL EFFICIENCY
         NHIT=NDRAW-MISR
        EOPT=RPWR*COS(OFFSUN)/NDRAW
        WRITE(6,9199) MISR,NHIT,EOPT
 9199 FORMAT(///,14X,6HMISSED,4X,6HHIT ON,3X,7HOPTICAL,/,
     +           16X,4HRAYS,6X,4HRCVR,1X,10HEFFICIENCY,//,
     +           10X,2I10,F10.5,/)
        IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,3)
        RETURN
        END
```

2-18-79 08.950

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      SUBROUTINE PTROUGH
      NAMELIST/TROFN/CLENG,CWIDTH,RW,RL,F,NAXIS,NZONEX,NZONEY,IRCVR
     + ,THETAAX,DTRACRL,DTRACAZ,SDS,SDR,REFLTOT,RWS,PSM
      COMMON/RUNC/NDRAW,TAZ,TEL,TIME,IDAY,XLAT,XLONG,ICONC,
     + NMAT,DRAD,MISR,TZONE,MAPS,RPWR,AMIR,NMATL
      COMMON/VECTOR/ULE(3),ULV(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
      COMMON/RCVRC/IRCVR,THETAC,SD,RW,RL,GHIT
      COMMON/TRAC/NAXIS,TILTANG,OFFSUN,THETAAX,DTRACRL,DTRACAZ,IRPI
      COMMON/ZONE/NZONEX,NZONEY
      DIMENSION  JBIN(20,20)
      DIMENSION  D(3),UT(3),UN(3),UNP(3),UR(3),USP(3),RHIT(3)
C
C   READ NAMELIST PARAMETERS
C
      READ(5,TROFN)
C
C   OBTAIN DATA FOR REFLECTIVE MATERIAL PROPERTIES
C
      IF(NMAT.NE.0) CALL RDATA(NMAT,NDRAW,SDR1,SDR2,REFLTOT,REFL
     + ,NCHECR)
      SDR=SDR1
C
C  OUTPUT NAMELIST VALUES
C
      WRITE(6,6000) CLENG,CWIDTH,F,RW,RL,RWS,NAXIS,IRCVR,THETAAX
 6000 FORMAT(20X,27HPARABOLIC TROUGH PARAMETERS,///,
     + 10X,F10.3,2X,6HLENGTH,/,
     + 10X,F10.3,2X,5HWIDTH,/,
     + 10X,F10.3,2X,12HFOCAL LENGTH,/,
     + 10X,F10.3,2X,10HRCVR WIDTH,/,
     + 10X,F10.3,2X,11HRCVR LENGTH,/,
     + 10X,F10.3,2X,17HRCVR SHADOW WIDTH,/,
     + 10X,I10,2X,13HTRACKING AXES,/,
     + 10X,I10,2X,10HRCVR. TYPE,/,
     + 10X,F10.3,2X,16HAXIS ORIENTATION,///)
      AMIR=CLENG*CWIDTH
C
C   INITIALIZE FLUX ROUTINE
C
      IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,1)
C
C   SET VECTOR TO SUN'S CENTER
C
      CALL SUN1(TAZ,TEL)
C
C   SET CONCENTRATOR POSITION VECTORS
C
      CALL TRACK(TAZ,TEL)
      WRITE(6,1010) IDAY,TIME,XLAT,XLONG,TEL,TAZ
 1010 FORMAT(15X,15HSOLAR CONSTANTS,//,
     +  10X,I10,2X,3HDAY,/,
     +  10X,F10.2,2X,4HTIME,/,
     +  10X,F10.3,2X,8HLATITUDE,/,
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2-18-79 08.950

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     +  10X,F10.3,2X,9HLONGITUDE,/,
     +  10X,F10.3,2X,9HELEVATION,/,
     +  10X,F10.3,2X,7HAZIMUTH,///)
        ISHAD=0
        DO 300 N=1,NDRAW
C
C  DRAW RAYS OVER SURFACE
C
        XO=CLENG*FLAT(0.0)
        YO=CWIDTH*(-0.5+FLAT(0.0))
C  CHECK FOR RECEIVER SHADOW
        IF(ABS(YO).GT.RWS*0.5) GO TO 10
        ISHAD=ISHAD+1
        GO TO 60
 10     ZO=(YO*YO*0.25)/F
C    FIND THE UNPERTURBED SURFACE NORMAL UN AND
C    THE PERTURBED SURFACE NORMAL UNP
C
        PHI=ATAN(YO/(2.*F))
        CPHI=COS(PHI)
        SPHI=SIN(PHI)
        DO 30 I=1,3
        UN(I)=CPHI*UCN(I)-SPHI*UCP(I)
 30     UT(I)=CPHI*UCP(I)+SPHI*UCN(I)
C
C    DETERMINE PERTURBED NORMAL USING ST. DEV.
C    FOR REFLECTANCE AND SURFACE ERROR
C
        IF(N.EQ.NCHECR) SDR=SDR2
        CALL ERRNORM(SDS,SDR,UN,UT,UCA,UNP,PSM)
C
C    PERTURB SUN'S RAY FOR FINITE SUN SIZE
C    AND VARIATION IN SUN'S INTENSITY
C
        CALL  SUN2(ACC,USP,DRAD)
C
C    CALCULATE REFLECTED RAY USING SNELL'S LAW
C
        CALL  SNELL(UR,UNP,USP)
C
C    FIND D VECTOR TO KNOWN POINT ON RCVR.
C    SURFACE
C
        DO 50 I=1,3
 50     D(I)=-XO*UCA(I)-YO*UCP(I)+(F-ZO)*UCN(I)
C
C    CALL RCVR. HIT TEST ROUTINE; IRCVR INDICATES
C    RCVR GEOMETRY
C
        CALL RCVR(D,UR,RHIT,MISR1)
C
C    DETERMINE IF RAY HITS RCVR. FOR RCVR HITS,
C    FIND ZONE OF HIT POINT
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2-18-79   08.950

      C
            IF(MISR1.EQ.1) GO TO 60
            IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,REFLTOT,2)
            RPWR=RPWR+REFLTOT
            GO TO 300
   60       MISR=MISR+1
    300 CONTINUE
            WRITE(6,6020) OFFSUN,REFLTOT,SDS,SDR1,SDR2,DTRACAZ,DTRACRL
   6020 FORMAT(20X,43HSURFACE,REFLECTANCE AND TRACKING PARAMETERS,//,
       + 10X,F10.3,2X,18HSUN OFF-AXIS ANGLE,/,
       + 10X,F10.3,2X,19HREFLECTANCE(TOTAL),/,
       + 10X,F10.5,2X,20HSURF. ERROR(ST.DEV.),/,
       + 10X,F10.5,2X,21HREFL.DISTR.1(ST.DEV.),/,
       + 10X,F10.5,2X,21HREFL.DISTR.2(ST.DEV.),/,
       + 10X,F10.3,2X,18HTRACKING ERROR-AZ.,/,
       + 10X,F10.3,2X,19HTRACKING ERROR-ROLL,//)
        WRITE(6,1070) ISHAD
   1070 FORMAT(/10X,21HRAYS BLOCKED BY RCVR=,I10)
     C  COMPUTE OPTICAL EFFICIENCY
          NHIT=NDRAW-MISR
        EOPT=RPWR*COS(OFFSUN)/NDRAW
        WRITE(6,9199) MISR,NHIT,EOPT
   9199 FORMAT(///,14X,6HMISSED,4X,6HHIT ON,3X,7HOPTICAL,/,
       +            16X,4HRAYS,6X,4HRCVR,1X,10HEFFICIENCY,//,
       +            10X,2I10,F10.5,/)
        IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,3)
        RETURN
        END


:   11-27-78 *** 14.4 ***

: (SEC)        .63          LINES/MINUTE 12729

: NO   DIAGNOSTICS IN ABOVE COMPILATION
)S WERE USED FOR THIS COMPILATION
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2-18-79 08.949

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      SUBROUTINE FMTR
C
C  THIS ROUTINE MODELS THE FIXED MIRROR TWO AXIS TRACKING
C     RECEIVER CONCENTRATOR.  THE SURFACE IS A FIXED SECTION OF
C     A SPHERE DEFINED BY THE RADIUS AND RIM ANGLE OF THE CONCENTRATOR.
C     THE RECEIVER MODEL IS THAT OF THE CONE.
C
      NAMELIST/FMTRN/CWIDTH,RL,THETAC,SO,TRIM,NAXIS,NZONEX,NZONEY,
     + TILTANG,IRCVR,THETAAX,DTRACAZ,DTRACRL,SDS,SDR,REFLTOT,PSM
      COMMON/RUNC/NDRAW,TAZ,TEL,TIME,IDAY,XLAT,XLONG,ICONC,
     + NMAT,DRAD,MISR,TZONE,MAPS,RPWR,AMIR,NMATL
      COMMON/VECTOR/ULE(3),ULV(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
      COMMON/RCVRC/IRCVR,THETAC,SO,RN,RL,QHIT
      COMMON/TRAC/NAXIS,TILTANG,OFFSUN,THETAAX,DTRACRL,DTRACAZ,IRPI
      COMMON/ZONE/NZONEX,NZONEY
      COMMON/CONECOM/ US1(3),US2(3)
      DIMENSION  XUN(3)
      DIMENSION  D(3),UT1(3),UT2(3),UN(3),UNP(3),UR(3),USP(3),
     +  RHIT(3)
C
C  READ NAMELIST VALUES
C
      READ(5,FMTRN)
C
C   READ NAMELIST VALUES
C
C
C   OBTAIN DATA FOR REFLECTIVE MATERIAL PROPERTIES
C
      IF(NMAT.NE.0) CALL RDATA(NMAT,NDRAW,SDR1,SDR2,REFLTOT,REFL
     + ,NCHECR)
      SDR=SDR1
      WRITE(6,6000) CWIDTH,TRIM,IRCVR,NAXIS,TILTANG,THETAAX,RL,
     + THETAC,SO
 6000 FORMAT(20X,34HFIXED MIRROR TRACKING RCVR, INPUTS,////,
     + 10X,F10.3,2X,5HWIDTH,/,
     + 10X,F10.3,2X,9HRIM ANGLE,/,
     + 10X,I10,2X,10HRCVR. TYPE,/,
     + 10X,I10,2X,13HTRACKING AXES,/,
     + 10X,F10.3,2X,10HTILT ANGLE,/,
     + 10X,F10.3,2X,16HAXIS ORIENTATION,/,
     + 10X,F10.3,2X,11HRCVR LENGTH,/,
     + 10X,F10.3,2X,10HCONE ANGLE,/,
     + 10X,F10.3,2X,2HSO,///)
C
C   INITIALIZE FLUX ROUTINE
C
      IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,1)

      ISHAD=0
      AMIR=3.141592654*0.25*CWIDTH*CWIDTH
      RCONC=CWIDTH*0.5/SIN(TRIM)
      CLENG=CWIDTH
```

?-18-79   08.949

```
      STHAC=SIN(THETAC)
      ZAP=-RCONC*COS(TRIM)
      ZAPO=ZAP
      WRITE(6,1010) IDAY,TIME,XLAT,XLONG,TEL,TAZ
 1010 FORMAT(15X,15HSOLAR CONSTANTS,//,
     +  10X,I10,2X,3HDAY,/,
     +  10X,F10.2,2X,4HTIME,/,
     +  10X,F10.3,2X,8HLATITUDE,/,
     +  10X,F10.3,2X,9HLONGITUDE,/,
     +  10X,F10.3,2X,9HELEVATION,/,
     +  10X,F10.3,2X,7HAZIMUTH,///)
 9911 FORMAT(5X,3HUCP,3F10.3,/,5X,3HUCN,3F10.3,/,5X,3HUCA,3F10.3,/)
C
C  SET VECTOR US TO SUN'S CENTER
C
      CALL SUN1(TAZ,TEL)
C
C   SET COLLECTOR POSITION VECTOR TRIAD
C
      CALL TRACK(TAZ,TEL)
C
C   SET POSITION VECTOR TRIAD UST1,UST2,US FOR USE IN CONICAL RE-
C     CEIVER HIT POINTS.
C
      CANGL=DOTER(US,UCN)
      SANGL=SQRT(1.-CANGL*CANGL)
      IF(ABS(SANGL) .LT.0.000001) GO TO 600
      DO 599 I=1,3
  599 US1(I)=(-UCN(I) + CANGL*US(I))/SANGL
      CALL CROSS(US1,US,US2)
      GO TO 605
  600 DO 601 I=1,3
      US1(I)=UCP(I)
  601 US2(I)=UCA(I)
  605 CONTINUE
      DO 200 N=1,NDRAW
C   PERTURB SUN'S RAY FOR FINITE SUN SIZE
C   AND VARIATION IN SUN'S INTENSITY
C
      CALL  SUN2(ACC,USP,DRAD)
      IREFL=0
C
C   DRAW OVER CONC. APERTURE
C
      ZAP=-RCONC*COS(TRIM)
      ZAPO=ZAP
      RAP=SQRT(.25*CWIDTH*CWIDTH*FLAT(0.0))
      RTH=6.2831853*FLAT(0.0)
      XAP=COS(RTH)*RAP
      YAP=SIN(RTH)*RAP
C
      DO 341 I=1,3
  341 D(I)=-XAP*UCA(I) - YAP*UCP(I) - ZAP*UCN(I)
```

1-18-79   08.949

```
      C   CHECK FOR INCOMING SUN RAY HIT ONRCVR
            DD=DOTER(D,D)
            DUS=DOTER(D,US)
            ARG=DD-DUS*DUS
            P=SQRT(ARG/(STHAC*STHAC))
            IF(P.GT.RCONC) GO TO 47
            ISHAD=ISHAD+1
      C  HITS ON FLAT TOP OF RECEIVER ARE ASSUMED LOST FOR
      C  EFFICIENCY CALCULATIONS DONE LATER
            IF(P.LT.-SO) GO TO 200
            DO 33 I=1,3
         33 RHIT(I)=-D(I)+DUS*US(I)
      C HIT WITHIN RCVR ZONES
            QHIT=P+SO
            CONVP=1.0
            IF(MAPS.EQ.1) CALL FLUX(RHIT,0.,0.,0.,CONVP,2)
            RPWR=RPWR+CONVP
            GO TO 200
         45 IREFL=IREFL + 1
            DO 90 I=1,3
         90 USP(I)=-UR(I)
            XAP=XO
            YAP=YO
            ZAP=ZO
      C  FIND HIT POINT ON SPHERICAL REFLECTOR SURFACE
         47 SA=DOTER(USP,UCA)
            SP=DOTER(USP,UCP)
            SN=DOTER(USP,UCN)
            A=1.0
            B=-2.0*(XAP*SA + YAP*SP + ZAP*SN)
            C=XAP*XAP + YAP*YAP +ZAP*ZAP - RCONC*RCONC
            QUAD=B*B - 4.*A*C
            IF(QUAD.LT.0.0) GO TO 130
            AL1=(-B+SQRT(QUAD))*0.5/A
            AL2=(-B-SQRT(QUAD))*0.5/A
        533 FORMAT(5X,3HAL1,F12.3,5X,3HAL2,F12.3,/)
            AL=AL1
      C
      C   BE SURE AL IS THE POSITIVEROOT
      C
            IF(AL.LT.0.) AL=AL2
      C
      C   CALCULATE THE PERFECT SURFACE NORMAL
      C
            DR=1./RCONC
            DO 10 I=1,3
         10 XUN(I)=AL*USP(I) - XAP*UCA(I) - YAP*UCP(I) - ZAP*UCN(I)
            XMAG=SQRT(DOTER(XUN,XUN))
            DO 105 I=1,3
        105 UN(I)=XUN(I)/XMAG
      C
      C   DETERMINE COORDINATES OF HIT POINT FROM XUN VECTOR
      C
```

2-18-79 08.949

```
              XO=-DOTER(XUN,UCA)
              YO=-DOTER(XUN,UCP)
              ZO=-DOTER(XUN,UCN)
              IF(IREFL.GT.0.AND. ZO.GE.ZAPO) GO TO 120
              XYRT=SQRT(XO*XO+YO*YO)
              X1=ZO*XO/(XYRT*RCONC)
              Y1=ZO*YO /(XYRT*RCONC)
              Z1=XYRT*DR
              DO 11 I=1,3
           11 UT1(I)=X1*UCA(I) + Y1*UCP(I) - Z1*UCN(I)
              CALL CROSS(UT1,UN,UT2)
      C
      C   DETERMINE PERTURBED NORMAL USING ST. DEV.
      C   FOR REFLECTANCE AND SURFACE ERROR
      C
              IF(N.EQ.NCHECR) SDR=SDR2
              CALL ERRNORM(SDS,SDR,UN,UT1,UT2,UNP,PSM)
      C
      C   CALCULATE REFLECTED RAY USING SNELL'S LAW
      C
              CALL  SNELL(UR,UNP,USP)
      C
      C   FIND DISTANCE VECTOR,D, TO KNOWN POINT ON RECEIVER SURFACE
      C
              DO 50 I=1,3
           50 D(I)=RCONC*UN(I) + SO*US(I)
      C
      C   DO RECEIVER HIT TEST USING CONICAL RECEIVER
      C
              CALL RCVR(D,UR,RHIT,MISR1)
      C
      C   DETERMINE IF RAY HITS RECEIVER.  MULTIPLE BOUNCES ARE POSSIBLE
      C       ; FOLLOW THROUGH THREE OR FOUR REFLECTIONS.
      C
              IF(MISR1.EQ.0) GO TO 125
              IF(IREFL.GE.4) GO TO 120
      C   IF RAY REFLECTED, RETURN TO FIND NEXT HIT POINT ON SURFACE
      C
              GO TO 45
      C
      C   SET ZONES OF RAY HITS IN TERMS OF DISTANCE S(CALCULATED IN RCVR)
      C      ALONG THE LENGTH OF THE RECEIVER(I.E.IN DIRECTION OF US)
      C
      CC   QHIT IS THAT DISTANCE.
      C
          125 CONVP=RAYVAL(IREFL,REFLTOT)
              IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,2)
              RPWR=RPWR+CONVP
              GO TO 200
          130 WRITE(6,1111)
         1111 FORMAT(5X,37HERROR, HIT POINT ON SURFACE NOT FOUND,/)
          120 MISR=MISR+1
          200 CONTINUE
```

!-18-79   08.949

```
      WRITE(6,6020) OFFSUN,REFLTOT,SDS,SDR1,SDR2
 6020 FORMAT(20X,43HSURFACE,REFLECTANCE AND TRACKING PARAMETERS,//,
     + 10X,F10.3,2X,18HSUN OFF-AXIS ANGLE,/,
     + 10X,F10.3,2X,19HREFLECTANCE(TOTAL),/,
     + 10X,F10.5,2X,20HSURF. ERROR(ST.DEV.),/,
     + 10X,F10.5,2X,21HREFL.DISTR.1(ST.DEV.),/,
     + 10X,F10.5,2X,21HREFL.DISTR.2(ST.DEV.),///)
C WRITE POWER ON RCVR,SHADING HITS AND MISSES
      WRITE(6,9999) ISHAD
 9999 FORMAT(///,15X,22HHIT RECEIVER ON WAY IN,I5,/)
C  COMPUTE OPTICAL EFFICIENCY
        NHIT=NDRAW-MISR
      EOPT=RPWR*COS(OFFSUN)/NDRAW
      WRITE(6,9199) MISR,NHIT,EOPT
 9199 FORMAT(///,14X,6HMISSED,4X,6HHIT ON,3X,7HOPTICAL,/,
     +           16X,4HRAYS,6X,4HRCVR,1X,10HEFFICIENCY,//,
     +           10X,2I10,F10.5,/)
      IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,3)
      RETURN
      END
```

: 11-27-78 *** 14.4 ***

: (SEC)   .94   LINES/MINUTE 14705

: NO   DIAGNOSTICS IN ABOVE COMPILATION
)S WERE USED FOR THIS COMPILATION

2-18-79 08.948

```
      SUBROUTINE CPC2
      NAMELIST/CPCN/CLENG,CWIDTH,RW,RL,NAXIS,TILTANG,NZONEX,
     + NZONEY,IRCVR,THETAAX,DAP,THTOL,NTOL,SDS,SDR,ATHETA
     + ,REFLTOT,SRW,PSM
C
C THIS ROUTINE IS THE SURFACE MODEL FOR THE CHAMBERLAIN
C   CPC CONCENTRATOR WHICH IS A COMBINATION OF AN INVOLUTE
C   AND COMPOUND PARABOLIC SURFACE.
C
C  INPUT VARIABLES ARE
C     COLLECTOR DIMENSIONS(E.G. RL,CLENG,CWIDTH,RW,ETC.)
C     NTOL      THE NUMBER OF ITERATIONS TO DETERMINE THE HIT POINT
C     THTOL     THE TOLERANCE ON THETA.
C RAYS ARE DRAWN OVER THE APERTURE AND THE HIT POINT ON THE SURFACE
C     IS FOUND ITERATIVELY USING NEWTON'S METHOD.
C THE CYLINDRICAL RECEIVER MODEL IS THE ONLY RECEIVER WHICH CAN
C     BE USED WITH THIS MODEL.  ANY OTHER RECEIVER WOULD REQUIRE A
C     DIFFERENT SURFACE.
C
      COMMON/RUNC/NDRAW,TAZ,TEL,TIME,IDAY,XLAT,XLONG,ICONC,
     + NMAT,DRAD,MISR,TZONE,MAPS,RPWR,AMIR,NMATL
      COMMON/VECTOR/ULE(3),ULV(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
      COMMON/RCVRC/IRCVR,THETAC,SD,RW,RL,QHIT
      COMMON/TRAC/NAXIS,TILTANG,OFFSUN,THETAAX,DTRACRL,DTRACAZ,IRPI
      COMMON/ZONE/NZONEX,NZONEY
      DIMENSION D(3),UT(3),UR(3),UN(3),UNP(3),USP(3),
     + RHIT(3),UI(3),ORIG(3)
C
C READ NAMELIST VALUES
C
      READ(5,CPCN)
C
C OBTAIN DATA FOR REFLECTIVE MATERIAL PROPERTIES
C
      IF(NMAT.NE.0) CALL RDATA(NMAT,NDRAW,SDR1,SDR2,REFLTOT,REFL
     + ,NCHECR)
      SDR=SDR1
C
C  WRITE NAMELIST PARAMETERS
C
      WRITE(6,6000) CLENG,CWIDTH,RW,RL,SRW,DAP,NAXIS,THETAAX,TILTANG,
     + IRCVR
 6000 FORMAT(20X,21HCPC2 CONC. PARAMETERS,///,
     + 10X,F10.3,2X,6HLENGTH,/,
     + 10X,F10.3,2X,5HWIDTH,/,
     + 10X,F10.3,2X,10HRCVR WIDTH,/,
     + 10X,F10.3,2X,11HRCVR LENGTH,/,
     + 10X,F10.3,2X,27HRCVR WIDTH FOR SURFACE DEFN,/,
     + 10X,F10.3,2X,16HCPC MODULE WIDTH,/,
     + 10X,I10,2X,13HTRACKING AXES,/,
     + 10X,F10.3,2X,16HAXIS ORIENTATION,/,
     + 10X,F10.3,2X,10HCONC. TILT,/,
     + 10X,I10,2X,10HRCVR. TYPE,///)
```

1-18-79 08.948

```
      C
      C
      C   SET SUN VECTOR US TO SUN'S CENTER
      C
          CALL SUN1(TAZ,TEL)
      C  SET COLLECTOR POSITION VECTORS UCA,UCN,UCP
      C
          CALL TRACK(TAZ,TEL)
          AMIR=DAP*CLENG
          WRITE(6,1010) IDAY,TIME,XLAT,XLONG,TEL,TAZ
     1010 FORMAT(15X,15HSOLAR CONSTANTS,//,
         +  10X,I10,2X,3HDAY,/,
         +  10X,F10.2,2X,4HTIME,/,
         +  10X,F10.3,2X,8HLATITUDE,/,
         +  10X,F10.3,2X,9HLONGITUDE,/,
         +  10X,F10.3,2X,9HELEVATION,/,
         +  10X,F10.3,2X,7HAZIMUTH,///)
      C
      C   INITIALIZE FLUX ROUTINE
      C
          IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,1)
      C
      C   SET CONSTANTS NEEDED FOR DIMENSIONS INSERT ELSEWHERE LATER.
      C
          RW2=SRW*0.50
          DZUP=0.5*(SRW-RW)
          ATHETA=ATHETA
      C
      C   CALCULATE Z OF APERTURE USING EQUATION FOR HEIGHTH ALONG
      C      SURFACE AT MAXIMUM ANGLE.
      C
          THETAM=4.71238898 - ATHETA
          DTH=THETAM-ATHETA
          RHO=RW2*((THETAM + ATHETA + 1.5707963 - COS(DTH))/(1.+SIN(DTH)))
          ZMAX=-RW2*COS(THETAM) - RHO*SIN(THETAM)
          DO 200 N=1,NDRAW
          KERR=0
          IFLAG=0
          IREFL=0
          THETA0=0.0
      C
      C   PERTURB SUN VECTOR FOR FINITE SUN SIZE
      C
          CALL SUN2(ACC,USP,DRAD)

      C
      C   DRAW OVER APERTURE
      C
          XAP=CLENG*FLAT(0.0)
          Y=CWIDTH*FLAT(0.0)
          YAP=Y - DAP*(INT(Y/DAP)+0.5)
          ZAP=ZMAX
```

2-18-79 08.948

```
      C
      C   DETERMINE WHETHER INCOMING RAY,US,HITS RECEIVER ON
      C     ENTERING.  DO RCVR. HIT TEST USING UI=-US VECTOR AS THE IN
      C     INCOMING RAY.  D VECTOR GOES FROM HIT POINT ON APERTURE TO
      C     CENTER OF RECEIVER.
      C
            DO 10 I=1,3
            UI(I)=-USP(I)
         10 D(I)=-XAP*UCA(I) - YAP*UCP(I) - (ZAP-DZUP)*UCN(I)
            CALL RCVR(D,UI,RHIT,MISR1)
      C
      C   IF THERE IS A RECEIVER HIT, INCREASE DIRECT HIT COUNTER BY 1.
      C      IF THE RAY MISSES THE RECEIVER, FIND HIT POINT
      C      ON REFLECTOR SURFACE.
            IF(MISR1.NE.1) GO TO 125
            GO TO 105
      C
      C   IF RAY REFLECTED AND DID NOT HIT RECEIVER, FIND NEST HIT
      C     POINR. RESET INCOMING VECTOR TO BE THE VALUE OF UR.
      C     SET THE ORIGIN OF THE RAY AT THE PREVIOUS HIT POINT.
      C
         45 IREFL=IREFL+1
            XAP=XO
            YAP=YO
            ZAP=ZO
            THETAO=THETA
            IFLAG=0
            DO 50 I=1,3
            USP(I)=-UR(I)
         50 UI(I)=UR(I)
      C   FIND HIT POINT USING ITERATIVE METHOD
      C
        105 CALL CHEC(D,UCN,UCP,USP,ISW,YAP,ZAP,ZCHEC)
            IF(IREFL.GT.0.AND.ZCHEC.GT.ZMAX) GO TO 120
            IF(ISW.EQ.0) GO TO 110
      C      IFSIDE OF COLLECTOR CHANGES(I.E.ISW=1), CHANGE REFLECTED
      C      (OR INITIAL SUM) RAY SIDE
            NSWS=NSWS+1
            DUMA=DOTER(USP,UCA)
            DUMP=DOTER(USP,UCP)
            DUMN=DOTER(USP,UCN)
            DO 109 I=1,3
        109 USP(I)=DUMA*UCA(I)-DUMP*UCP(I) + DUMN*UCN(I)
            DO 1095 I=1,3
       1095 UI(I)=-USP(I)
            YAP=-YAP
        110 THETA=2.90
            IF(IREFL.GT.0) THETA=(0.8-0.1*IFLAG)*THETAO
            VECTR=DOTER(UI,UCP)/DOTER(UI,UCN)
            DO 20 I=1,NTOL
            CT=COS(THETA)
            ST=SIN(THETA)
            RHOPR=RW2
```

2-18-79   08.948

```
      RHO=RW2*THETA
      DTH=ABS(THETA)-ATHETA
      IF(THETA.GT.(ATHETA + 1.570796327)) RHO=
     + RW2*(THETA+ATHETA+1.570796237-COS(DTH))/(1.+SIN(DTH))
      S1=1.+SIN(DTH)
      IF(THETA.GT.(ATHETA+1.570796327)) RHOPR=
     +    (-RW2*COS(DTH)*(THETA+ATHETA+1.57079627-COS(DTH)) +
     +    RW2*S1*S1)/(S1*S1)
      IF(I.EQ.NTOL) GO TO 199
      GTH=RHO*(-ST*VECTR+CT) - RW2*(CT*VECTR+ST) -
     +    ZAP*VECTR + YAP
      GDERIV=RHO*(-CT*VECTR - ST) + RHOPR*(-ST*VECTR+CT) -
     +    RW2*(-ST*VECTR+CT)
      IF(ABS(GDERIV).LE.0.00001) GDERIV=.00001*SIGN(1.,GDERIV)
      DELTA=GTH/GDERIV
      IF(ABS(DELTA).GT.1.5) DELTA=1.5*SIGN(1.,DELTA)
     + *FLOAT(NTOL-I)/NTOL
      THETA1=THETA
       THETA=THETA-DELTA
      IF(ABS(THETA).GT.THETAM) THETA=THETAM*SIGN(1.,THETA1)
     + *FLOAT(NTOL-I)/NTOL
      IF(ABS(DELTA).LT.THTOL) GO TO 100
   20 CONTINUE
  100 IF(ABS(THETA-THETAO).GT.THTOL) GO TO 103
      IFLAG=IFLAG+1
      IF(IFLAG.LT.9) GO TO 110
      GO TO 120
  103 YO=RW2*SIN(THETA) - RHO*COS(THETA)
      ZO=-RW2*COS(THETA) - RHO*SIN(THETA)
      XO=(ZO-ZAP)*DOTER(US,UCA)/DOTER(US,UCN) + XAP
C
C    FIND PERFECT SURFACE NORMAL
C
      DZ=RW2*SIN(THETA)-RHO*COS(THETA) - RHOPR*SIN(THETA)
      DY=RW2*COS(THETA) + RHO*SIN(THETA) - RHOPR*COS(THETA)
      PHIN=ATAN2(DZ,DY)
      CP=COS(PHIN)
      SP=SIN(PHIN)
      DO 30 I=1,3
      UN(I)=CP*UCN(I) - SP*UCP(I)
   30 UT(I)=CP*UCP(I) + SP*UCN(I)
C
C    CALCULATE PERTURBED SURFACE NORMAL(UNP) BASED ON
C       REFLECTANCE PROPERTIES AND SURFACE ERROR DISTRIBUTION.
C

C    PUT IN ROUTINE FOR CALCULATION OF UNIT NORMAL PERTURBATION
       IF(N.EQ.NCHECR) SDR=SDR2
       CALL ERRNORM(SDS,SDR,UN,UT,UCA,UNP,PSM)
C
C    CALCULATE REFLECTED RAY UR
C
      CALL SNELL(UR,UNP,USP)
```

2-18-79 08.948

```
C
C   DO RECEIVER HIT TEST
C
         DO 40 I=1,3
      40 D(I)=-XO*UCA(I) - YO*UCP(I) - (ZO-DZUP)*UCN(I)
         CALL RCVR(D,UR,RHIT,MISR1)
         IF(MISR1.NE.1) GO TO 55
         IF(IREFL.GE.4) GO TO 120
C
C   RAY REFLECTED AND DID NOT HIT RECEIVER, FIND NEXT HIT POINT
C
         GO TO 45
C
C   CHECK TO SEE IF RAY EXITS OUT APERTURE
C
      55 NSWS1=NSWS-2*(NSWS/2)
         IF(NSWS1.NE.1) GO TO 56
         DUM1=DOTER(RHIT,UCA)
         DUM2=DOTER(RHIT,UCP)
         DUM3=DOTER(RHIT,UCN)
         DO 115 I=1,3
     115 RHIT(I)=DUM1*UCA(I) - DUM2*UCP(I) + DUM3*UCN(I)
      56 CONVP=RAYVAL(IREFL,REFLTOT)
         IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,2)
         RPWR=RPWR+CONVP
         GO TO 200
     120 MISR=MISR+1
         GO TO 200
     199 WRITE(6,1111) I
    1111 FORMAT(5X,22HTHETA DID NOT CONVERGE,2X,2HI=,I5,/)
         GO TO 200
     125 NDIRECT=NDIRECT + 1
         CONVP=1.0
         IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,2)
         RPWR=RPWR+CONVP
     200 CONTINUE
         WRITE(6,6020) OFFSUN,REFLTOT,SDS,SDR1,SDR2
    6020 FORMAT(20X,43HSURFACE,REFLECTANCE AND TRACKING PARAMETERS,//,
       + 10X,F10.3,2X,18HSUN OFF-AXIS ANGLE,/,
       + 10X,F10.3,2X,19HREFLECTANCE(TOTAL),/,
       + 10X,F10.5,2X,20HSURF. ERROR(ST.DEV.),/,
       + 10X,F10.5,2X,21HREFL.DISTR.1(ST.DEV.),/,
       + 10X,F10.5,2X,21HREFL.DISTR.2(ST.DEV.),///)
         WRITE(6,303) NDIRECT
     303 FORMAT(///,10X,20HDIRECT HITS ON RCVR=,I10)
C   COMPUTE OPTICAL EFFICIENCY
          NHIT=NDRAW-MISR
         EOPT=RPWR*COS(OFFSUN)/NDRAW
         WRITE(6,9199) MISR,NHIT,EOPT
    9199 FORMAT(///,14X,6HMISSED,4X,6HHIT ON,3X,7HOPTICAL,/,
       +            16X,4HRAYS,6X,4HRCVR,1X,10HEFFICIENCY,//,
       +            10X,2I10,F10.5,/)
         IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,3)
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?-18-79   08.948

    266                    RETURN
    267                    END

:   11-27-78 *** 14.4 ***

: (SEC)      1.10          LINES/MINUTE 14534

:  NO   DIAGNOSTICS IN ABOVE COMPILATION
)S WERE USED FOR THIS COMPILATION
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2-18-79 08.949

```
      SUBROUTINE CHEC(D,UCN,UCP,USP,ISW,YAP,ZAP,ZCHEC)
C
C    THIS SUBROUTINE IS CALLED FORM CPC2, TO FIND POSITIVE
C     OR NEGATIVE SIDE OF HIT ON SURFACE IN UCP DIRECTION.
C     OUTPUT SETS A FLAG TO SITCH SIGN OF VECTORS SO ONLY
C     POSITIVE THETA VALUES ARE CALCULATED.
C
      DIMENSION D(3),UCN(3),UCP(3),USP(3)
      ISW=0
      D1=DOTER(D,UCN)
      D2=DOTER(D,UCP)
      D3=DOTER(USP,UCP)
      D4=DOTER(USP,UCN)
      IF(ABS(D3).LT.0.0000001) GO TO 10
      ZCHEC=-D1+D2*D4/D3
      IF(ZCHEC.GT.0.0.AND.ZCHEC.LT.ZAP.AND.YAP.GT.0.0) ISW=1
      IF(ZCHEC.LT.0.0.AND.YAP.LT.0.) ISW=1
      IF(ZCHEC.GT.ZAP.AND.YAP.LT.0.0) ISW=1
C     WRITE(6,100) ZCHEC,YAP,ISW
  100 FORMAT(5X,5HACHEC,7X,3HYAP,7X,3HISW,/,5X,2F10.3,I10)
      RETURN
   10 IF(YAP.LT.0.00) ISW=1
      WRITE(6,100) ZCHEC,YAP,ISW
      RETURN
      END
```

E 11-27-78 *** 14.4 ***

E (SEC) .32 LINES/MINUTE 4740

E NO DIAGNOSTICS IN ABOVE COMPILATION
DS WERE USED FOR THIS COMPILATION

2-18-79 08.946

```
      SUBROUTINE RPI(JBIN)
      COMMON/RPIC/FL,TILT,DX,DY1,DY2,ALEN,FLEN,FWID,NCOL,XAX,NFAC,
     1 NCA,DY,XLF,ARPI(20),RR(20),CR(20),NRZ,RMAX
      COMMON/RUNC/NDRAW,TAZ,TEL,TIME,IDAY,XLAT,XLONG,ICONC,
     + NMAT,DRAD,MISR,TZONE,MAPS,RPWR,AMIR,NMATL
      COMMON/VECTOR/ULE(3),ULV(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
      COMMON/RCVRC/IRCVR,THETAC,SP,RW,RL,QHIT
      COMMON/TRAC/NAXIS,TILTANG,OFFSUN,THETAAX,DTRACRL,DTRACAZ,IRPI
      COMMON/ZONE/NZONEX,NZONEY
      DIMENSION CATA(2,50),D(3),UV(3),UR(3),UNP(3),USP(3),RHIT(3)
     1 ,UT1(3),UT2(3),D1(3),EOPTZ(20)
C
C     DEFINITIONS FOR RPI TWO AXIS
C     TRACKING, MULTI-FACETED
C     COLLECTOR.
C     FL=FOCAL LENGTH (M)
C     TILT=COLLECTOR TILT FROM HORIZONTAL (DEG)
C     DX=COLUMN AXIS SPACING (M)
C     DY1=DISTANCE FROM COLLECTOR CENTER TO START
C         OF FIRST COLUMN AXIS ROW (M)
C     DY2=DISTANCE FROM COLLECTOR CENTER TO START
C         OF SECOND COLUMN AXIS ROW (M)
C     ALEN= LENGTH OF A COLUMN AXIS (M)
C     FLEN=LENGTH OF AN INDIVIDUAL MIRROR FACET ON A
C           COLUMN AXIS (M)
C     FWID=WIDTH OF A MIRROR FACET (M)
C     NCOL=NUMBER OF COLUMN AXIS PER
C           MIRROR BANK (MUST BE AN ODD NUMBER)
C     RMAX=MAXIMUM RADIUS OF RECEIVER PLANE
C     NRZ=NUMBER OF RADIAL ZONES ON RECEIVER
C
C NAMELIST VALUES FOR RPI COLLECTOR
C
      NAMELIST/RPILIST/FL,TILT,DX,DY1,DY2,ALEN,FLEN,FWID,NCOL,NRZ,RMAX
     + ,NZONEX,NZONEY,REFLTOT,RL,RW,SDS,SDR,IRCVR,PSM
      PI=3.14159265
      IRPI=1
      SUM=0.0
      SOFF=0.0
C
C     READ VALUES FROM NAMELIST
C
      READ(5,RPILIST)
      RMAX=RW*0.5
C
C    OBTAIN DATA FOR REFLECTIVE MATERIAL PROPERTIES
C
      IF(NMAT.NE.0)  CALL RDATA(NMAT,NDRAW,SDR1,SDR2,REFLTOT,
     + REFL,NCHECR)
      SDR=SDR1
      WRITE(6,6000) FL,TILT,ALEN,FLEN,FWID,NCOL,RMAX
 6000 FORMAT(20X,27HRPI CONCENTRATOR PARAMETERS,//,
     + 10X,F10.3,2X,12HFOCAL LENGTH,/,
```

2-18-79   08.946

```
     + 10X,F10.3,2X,10HTILT ANGLE,/,
     + 10X,F10.3,2X,13HCOLUMN LENGTH,/,
     + 10X,F10.3,2X,12HFACET LENGTH,/,
     + 10X,F10.3,2X,11HFACET WIDTH,/,
     + 10X,I10,2X,15HNO.COLUMN AXES,/,
     + 10X,F10.3,2X,15HMAX RADIUS RCVR,///)
C
C   INITIALIZE FLUX ROUTINE
C
      IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,1)
C
C     CALL ROUTINE TO SET UP COLUMN AXIS
C     TILT ANGLES
C
      CALL ATILT(CATA)
      DO 112 I=1,2
  112 WRITE(6,113) I,(CATA(I,J),J=1,NCA)
  113 FORMAT(///,28X,23HCOLUMN AXIS TILT ANGLES,/,
     + 32X,11HMIRROR BANK,I5,/,(10(1X,F7.3),/))
C  COMPUTE MIRROR AREA AND CONCENTRATION RATIO
      AMIR=FWID*FLEN*NFAC*NCOL*4
      DO 5 I=1,NRZ
      ARPI(I)=0.0
      EOPTZ(I)=0.0
      RR(I)=I*RMAX/NRZ
    5 CR(I)=AMIR/(PI*RR(I)*RR(I))
C
C     SET VECTOR TO SUN'S CENTER
      CALL SUN1(TAZ,TEL)
C
C   SET COLLECTOR POSITION VECTORS UCA,UCN,UCP
C
      CALL TRACK(TAZ,TEL)
      WRITE(6,1010) IDAY,TIME,XLAT,XLONG,TEL,TAZ
 1010 FORMAT(///,15X,15HSOLAR CONSTANTS,//,
     +  10X,I10,2X,3HDAY,/,
     +  10X,F10.2,2X,4HTIME,/,
     +  10X,F10.3,2X,8HLATITUDE,/,
     +  10X,F10.3,2X,9HLONGITUDE,/,
     +  10X,F10.3,2X,9HELEVATION,/,
     +  10X,F10.3,2X,7HAZIMUTH,///)
C
C     COLUMN AXIS ROTATION ANGLE
      DALP=(90.-TILT/DRAD-TEL/DRAD)*0.5
      CDAL=COS(DALP*DRAD)
      SDAL=SIN(DALP*DRAD)
C
C    START DRAW OVER NUMBER OF RAYS
C
      DO 1000 N=1,NDRAW
      CALL SUN2(ACC,USP,DRAD)
C     DO  MONTE CARLO DRAW OVER COLLECTOR
      CALL MONTE(CATA,CAT,TEL,XO,YO,DRAD)
```

2-18-79 08.946

```
      C      FIND SURFACE NORMAL AND DVECTOR
             CALL NORM(CAT,D,UN,UCA,UCN,UCP,CDAL,SDAL,XO,YO,UT1,UT2)
      C   COMPUTE COSINE BETWEEN MIRROR AND SUN
             COFF=DOTER(UN,US)
             SOFF=SOFF+COFF
             CONVP=REFLTOT*COFF
      C      PERTURB SURFACE NORMAL
             IF(N.EQ.NCHECR) SDR=SDR2
             CALL ERRNORM(SDS,SDR,UN,UT1,UT2,UNP,PSM)
      C      FIND REFL. RAY
             CALL SNELL(UR,UNP,USP)
      C
      C      DO RECEIVER HIT TEST
      C
             DO 20 I=1,3
          20 D1(I)=D(I)-0.5*RL*UCA(I)
             CALL RCVR(D1,UR,RHIT,MISR1)
             IF(MISR1.EQ.1) GO TO 60
      C
      C      DETERMINE HIT POINT ON FLAT RCVR.
      C
             IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,2)
      CC   TEST TO SEE IF RAY HITS RECEIVER.
      C  BULLS EYE FLUX ZONING
             DO 30 I=1,3
          30 RHIT(I)=RHIT(I)-0.5*RL*UCA(I)
             RMAG=SQRT(DOTER(RHIT,RHIT))
             IF(RMAG.GT.RMAX) GO TO 60
             I=0
          44 I=I+1
             IF(RMAG.GT.RR(I)) GO TO 44
             ARPI(I)=ARPI(I)+CONVP
             RPWR=RPWR+CONVP
             GO TO 1000
          60 MISR=MISR+1
        1000 CONTINUE
             AVGCOS=SOFF/NDRAW
             WRITE(6,6020) OFFSUN,REFLTOT,SDS,SDR1,SDR2,DTRACAZ,DTRACRL
        6020 FORMAT(1H1,///,20X,40HSURFACE,REFLECTANCE AND TRACK PARAMETERS,//
            + 10X,F10.3,2X,18HSUN OFF-AXIS ANGLE,/,
            + 10X,F10.3,2X,19HREFLECTANCE(TOTAL),/,
            + 10X,F10.5,2X,20HSURF. ERROR(ST.DEV.),/,
            + 10X,F10.5,2X,21HREFL.DISTR.1(ST.DEV.),/,
            + 10X,F10.5,2X,21HREFL.DISTR.2(ST.DEV.),/,
            + 10X,F10.3,2X,18HTRACKING ERROR-AZ.,/,
            + 10X,F10.3,2X,19HTRACKING ERROR-ROLL,//)
             DO 70 I=1,NRZ
             ARPI(I)=ARPI(I)*AMIR/NDRAW
             SUM=SUM+ARPI(I)/AMIR
          70 EOPTZ(I)=SUM
             WRITE(6,1090) (RR(I),CR(I),ARPI(I),EOPTZ(I),I=1,NRZ)
             WRITE(6,76) AVGCOS
        1090 FORMAT(//,16X,6HRADIUS,2X,10HCONC RATIO,7X,
```

2-18-79   08.946

```
                * 5HPOWER,3X,10HEFFICIENCY.,//,(10X,F12.4,F12.1,2F12.4))
        76   FORMAT(///,10X,15HAVERAGE COSINE=,F10.6)
      C  COMPUTE OPTICAL EFFICIENCY
               NHIT=NDRAW-MISR
             EOPT=RPWR/NDRAW
             WRITE(6,9199) MISR,NHIT,EOPT
       9199 FORMAT(///,14X,6HMISSED,4X,6HHIT ON,3X,7HOPTICAL,/,
           +            16X,4HRAYS,6X,4HRCVR,1X,10HEFFICIENCY,//,
           +            10X,2I10,F10.5,/)
             IRPI=0
             IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,3)
             RETURN
             END
```

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E    11-27-78 *** 14.4 ***

E (SEC)        .74          LINES/MINUTE 13907

E  NO  DIAGNOSTICS IN ABOVE COMPILATION
DS WERE USED FOR THIS COMPILATION
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2-18-79   08.947

```
              SUBROUTINE NORM(CAT,D,UN,UCA,UCN,UCP,CDAL,SDAL,XO,YO,UT1,UT2)
              COMMON/RPIC/ FL,TILT,DX,DY1,DY2,ALEN,FLEN,FWID,NCOL,XAX,NFAC,
            1 NCA,DY,XLF,ARPI(20),RR(20),CR(20),NRZ,RMAX
              DIMENSION XI(3),YJ(3),VF(3),UVF(3),VN(3),UMN(3),
            1 YJP(3),D(3),UCPP(3),UN(3),UCA(3),UCN(3),UCP(3),VFP1(3),
            1 VFP2(3),UT1(3),UT2(3)
      C       COMPUTE THE HIT FACET NORMAL
      C
      C       FIRST GET THE COLUMN AXIS VECTOR TRIAD
              CG=COS(CAT)
              SG=SIN(CAT)
              DO 50 I=1,3
              XI(I)=CG*UCA(I)+SG*UCN(I)
              YJ(I)=CG*UCN(I)-SG*UCA(I)
      C
      C       SET UP VECTOR FROM FACET CENTER
      C        TO PERFECT FOCUS POINT
      C
           50 VF(I)=-XLF*XI(I)-DY*UCA(I)-XAX*UCP(I)+FL*UCN(I)
      C       UNITIZE AND COMPUTE NORMAL VECTOR
              VMAG=SQRT(DOTER(VF,VF))
              DO 70 I=1,3
              UVF(I)=VF(I)/VMAG
           70 VN(I)=UVF(I)+UCN(I)
      C       VN IS THE PERFECT FOCUS, FACET NORMAL
              VMAG=SQRT(DOTER(VN,VN))
              DO 80 I=1,3
           80 UMN(I)=VN(I)/VMAG
      C       SET UP VECTORS IN THE PLANE
      C       OF THE MIRROR FACET
              CALL CROSS(UCN,UVF,VFP1)
              CALL CROSS(VN,VFP1,VFP2)
              V1=SQRT(DOTER(VFP1,VFP1))
              V2=SQRT(DOTER(VFP2,VFP2))
              DO 90 I=1,3
              VFP1(I)=VFP1(I)/V1
           90 VFP2(I)=VFP2(I)/V2
      CUMN,VFP1,VFP2 ARE ORTHONORMAL TRIAD FOR UN-ROTATED MIRROR FACET
      C
      C       NOW ROTATE THE UNIT MIRROR
      C       NORMAL (UMN) THROUGH A ROTATION
      C       ANGLE EQUAL TO ONE-HALF THE
      C       ANGLE BETWEEN THE SUN AND THE
      C       COLLECTOR NOTMAL
      C
      C       SET UP ROTATED COORDINATE FRAME
              DO 200 I=1,3
              YJP(I)=CDAL*YJ(I)+SDAL*UCP(I)
          200 UCPP(I)=CDAL*UCP(I)-SDAL*YJ(I)
              ADUM=DOTER(UMN,XI)
              BDUM=DOTER(UMN,YJ)
              CDUM=DOTER(UMN,UCP)
               DDUM=DOTER(VFP1,XI)
```

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2-18-79   08.947

                EDUM=DOTER(VFP1,YJ)
                FDUM=DOTER(VFP1,UCP)
                GDUM=DOTER(VFP2,XI)
                HDUM=DOTER(VFP2,YJ)
                PDUM=DOTER(VFP2,UCP)
      C         COMPUTE ROTATED NORMAL & TANGENT VECTORS
                DO 220 I=1,3
                UT1(I)=DDUM*XI(I) + EDUM*YJP(I) + FDUM*UCPP(I)
                UT2(I)=GDUM*XI(I)+HDUM*YJP(I) + PDUM*UCPP(I)
            220 UN(I)=ADUM*XI(I)+BDUM*YJP(I)+CDUM*UCPP(I)
      C         COMPUTE D VECTOR FROM FACET START
      C         POINT TO CENTER OF FOCAL PLANE
                DO 240 I=1,3
            240 D(I)=-XO*UT1(I)-YO*UT2(I)+VF(I)
                RETURN
                END


E   11-27-78 *** 14.4 ***

E (SEC)      .51         LINES/MINUTE  8088

E  NO   DIAGNOSTICS IN ABOVE COMPILATION
DS WERE USED FOR THIS COMPILATION
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2-18-79 08.948

```
                SUBROUTINE MONTE(CATA,CAT,TELL,XO,YO,DRAD)
                COMMON/RPIC/ FL,TILT,DX,DY1,DY2,ALEN,FLEN,FWID,NCOL,XAX,NFAC,
               1 NCA,DY,XLF,ARPI(20),RR(20),CR(20),NRZ,RMAX
                DIMENSION CATA(2,50)
          C
          C     MONTE CARLO DRAW FOR
          C     MIRROR BANK, COLUMN AXIS,
          C     FACET NUMBER AND HIT POINT
          C     COORDINATES
          C
          C     MIRROR BANK NUMBER
                MB=INT(FLAT(0.0)*4.0)+1
          C     COLUMN AXIS NUMBER
                NC=INT(FLAT(0.0)*NCOL)+1
          C     FACET NUMBER
                NF=INT(FLAT(0.0)*NFAC)+1
          C      HIT POINT COORDINATES ON FACET
                XO=-FLEN*0.5+FLAT(0.0)*FLEN
                YO=-FWID*0.5+FLAT(0.0)*FWID
          C     GET COLUMN AXXIS TILT ANGLE
                IB=1
                IF(MB.EQ.1.OR.MB.EQ.4) IB=2
                IF(NC.GT.NCOL/2) GO TO 70
                NA=NCOL/2-NC+2
                GO TO 75
             70 NA=NC-NCOL/2
          C     COLUMN AXIS TILT ANGLE LOOK-UP
             75 CAT=CATA(IB,NA)
          C
          C     CHANGE THE INTEGER VALUES TO X,Y,Z
          C     COORDINATE POINTS
          C
                XAX=(NC-NCOL/2-1)*DX
                DY=DY1
                IF(IB.EQ.2) DY=DY2
          C     LENGTH ALONG COLUMN AXIS TO FACET CENTER
                XLF=ALEN/FLOAT(NFAC)*(FLOAT(NF)-0.5)
                RETURN
                END
```

E 11-27-78 *** 14.4 ***

E (SEC) .36 LINES/MINUTE 6467

E NO DIAGNOSTICS IN ABOVE COMPILATION
DS WERE USED FOR THIS COMPILATION

2-18-79 , 08.947

```
      SUBROUTINE ATILT(CATA)
C     AFTER NAMELIST READ, CALCULATE
C     NUMBER OF MIRROR FACETS AND ALL
C     COLUMN AXIS TILT ANGLES
C
      COMMON/RPIC/ FL,TILT,DX,DY1,DY2,ALEN,FLEN,FWID,NCOL,XAX,NFAC,
     1 NCA,DY,XLF,ARPI(20),RR(20),CR(20),NRZ,RMAX
      DIMENSION CATA(2,50)
      NFAC=INT(ALEN/FLEN)
      DRAD=0.01745329
C     SET UP LOOP TO GET COLUMN TILT ANGLES
      NCA=NCOL/2+1
      IB=1
      DY =DY1
C     INITIAL GUESS FOR ANGLE
   10 ANG1=5.0*DRAD
      DO 400 I=1,NCA
      XAX=(I-1)*DX
   50 C=COS(ANG1)
      S=SIN(ANG1)
      A1=ALEN*ALEN*0.25
      A2=ALEN*DY
      D1=A1*(C**4/(S*S)+S*S+2.*C*C-1.)
      D2=A2*(C**3/(S*S)-FL*C*C/(S*DY))
      D3=DY*DY*C*C/(S*S)-XAX*XAX-2.*FL*DY*C/S
      F=D1+D2+D3
      P1=A1*(-4.*C*C*C/S-2.*C**5/(S*S*S)-2.*S*C)
      P2=A2*(-3.*C*C/S-2.*C**4/(S*S*S)+2*FL*C/DY
     1    +FL*C*C*C/(DY*S*S))
      P3=-2.*DY*DY*C/S-2.*DY*DY*C*C*C/(S*S*S)+
     1     2.*FL*DY/(S*S)
      FP=P1+P2+P3
      ANG2=ANG1-F/FP
      CHEC=(ANG2-ANG1)/ANG1
      IF(ABS(CHEC).LT.0.00001) GO TO 200
      ANG1=ANG2
      GO TO 50
C
C     FOUND CORRECT ANGLE
C
  200 ANG=ANG2
      CATA(IB,I)=ANG
  400 CONTINUE
      IF(IB.GT.1) GO TO 500
      IB=2
      DY=DY2
      GO TO 10
  500 RETURN
      END
```

E 11-27-78 *** 14.4 ***

1-02-80   08.852

```
      SUBROUTINE SET
C  THIS IS THE DRIVER ROUTINE FOR SOLAR ENERGY
C  TECHNOLOGY'S (SET) IMAGE
C  COLLAPSING CONCENTRATOR, ICC (ALSO CALLED SPLICS)
      REAL LF,NLENS
      NAMELIST/SETN/GAMMA,T,LF,RLENS,AC,NFIT,NPRIS,DZ,SHITE,
     + RW,RL,CLENG,CWIDTH,SDS,SDR,REFLTOT,TRANTOT,NAXIS,
     + THETAAX,NZONEX,NZONEY,TILTANG,IRCVR,PSM,NLENS,YS,ZS
      DIMENSION GAMMA(20),AC(10),UR(3),UR2(3),UN(3),UNP(3),UT(3)
     1 ,RHIT(3),USP(3),UT2(3),D(3),WAVL(20),NBNC(6)
      COMMON/RUNC/NDRAW,TAZ,TEL,TIME,IDAY,XLAT,XLONG,ICONC,
     + NMAT,DRAD,MISR,TZONE,MAPS,RPWR,AMIR,NMATL
      COMMON/VECTOR/ULE(3),ULV(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
      COMMON/RCVRC/IRCVR,THETAC,SO,RW,RL,QHIT
      COMMON/TRAC/NAXIS,TILTANG,OFFSUN,THETAAX,DTRACRL,DTRACAZ,IRPI
      COMMON/ZONE/NZONEX,NZONEY
      COMMON/ICC/T,LF,RLENS,NFIT,DZ,SHITE,IP,XO,YO,ZO,SGAM,CGAM,AYO,
     1 SGN,TEST,C2,CWID,YS(30),ZS(30)
      DATA WAVL/390.,440.,480.,510.,540.,570.,600.,630.,660.,
     + 700.,740.,780.,820.,870.,960.,1020.,1080.,1220.,1480.,1680./
C  NAMELIST PARAMETERS FOR SET COLLECTOR
C     GAMMA- ARRAY OF PRISM ANGLES FROM MIDDLE TO
C            EDGE OF LENS
C     NPRIS- NUMBER OF PRISM ELEMENTS/2
C     T- MINIMUM LENS THICKNESS
C     LF- PRISM LENGTH
C     RLENS- RADIUS OF INNER LENS SURFACE
C     AC- ARRAY OF COEFFICIENTS FOR SUBREFLECTOR CURVEFIT
C     NFIT- ORDER OF CURVEFIT FOR SUBREFLECTOR
C     DZ- DISTANCE FROM LENS CURVATURE CENTER
C         TO CENTER OF SUBREFLECTOR COORDINATE SYSTEM
C     CLEN- COLLECTOR LENGTH
C     XN- INDEX OF REFRACTION OF THE LENS MATERIAL
C      SHITE- HEIGHT OF RECEIVING SHELF
      READ(5,SETN)
C
C  OBTAIN DATA FOR REFLECTIVE MATERIAL PROPERTIES
C
      IF(NMAT.NE.0) CALL RDATA(NMAT,NDRAW,SDR1,SDR2,REFLTOT,REFL
     + ,NCHECR)
      SDR=SDR1
C  WRITE NAMELIST PARAMETERS
      WRITE(6,6000) NPRIS,T,LF,RLENS,NFIT,DZ,CLENG,CWIDTH,
     +  RL,SHITE
 6000 FORMAT(//,20X,16HSET CONCENTRATOR,//,
     +10X,I10,2X,24HNUMBER OF PRISM ELEMENTS,/,
     + 10X,F10.4,2X,22HMINIMUN LENS THICKNESS,/,
     + 10X,F10.4,2X,16HLENS FACET WIDTH,/,
     + 10X,F10.4,2X,28HRADIUS OF INNER LENS SURFACE,/,
     + 10X,I10,2X,30HORDER OF SUBREFLECTOR CURVEFIT,/,
     + 10X,F10.4,2X,42HDISTANCE BETWEEN COORDINATE SYSTEM CENTERS,
     + /,
     + 10X,F10.4,2X,16HCOLLECTOR LENGTH,/,
```

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     + 10X,F10.4,2X,15HCOLLECTER WIDTH,/,
     + 10X,F10.4,2X,15HRECEIVER LENGTH,/,
     + 10X,F10.4,2X,18HSHELF(RCVR)HEIGTH ,///)
      WRITE(6,6005) (GAMMA(I),I=1,NPRIS)
 6005 FORMAT(/,30X,20HPRISM ELEMENT ANGLES,/,
     +       (10X,7F10.5))
      WRITE(6,6008) (I,AC(I),I=1,NFIT)
 6008 FORMAT(//,15X,27HCOEFFICIENTS OF CURVEFIT    ,//,
     +          (15X,2HA(,I1,2H)=,F12.5))
C  GET SUN CENTER VECTOR
      CALL SUN1(TAZ,TEL)
C  SET COLLECTOR VECTORS
      CALL TRACK(TAZ,TEL)
C  WRITE SOLAR PARAMETERS
      WRITE(6,1010) IDAY,TIME,XLAT,XLONG,TEL,TAZ
 1010 FORMAT(15X,15HSOLAR CONSTANTS,//,
     +  10X,I10,2X,3HDAY,/,
     +  10X,F10.2,2X,4HTIME,/,
     +  10X,F10.3,2X,8HLATITUDE,/,
     +  10X,F10.3,2X,9HLONGITUDE,/,
     +  10X,F10.3,2X,9HELEVATION,/,
     +  10X,F10.3,2X,7HAZIMUTH,///)
      TEST=SQRT(RLENS*RLENS-LF*LF*NPRIS*NPRIS)
      CWID=NPRIS*2.*LF
      B1=DOTER(US,UCN)/DOTER(US,UCP)
      RW=SHITE
      CWIDTH=CWID
      NOTRECT=0
      DO 4040 JK=1,6
 4040 NBNC(JK)=0
      ISHAD=0
      IBLOC=0
C  INITIALIZE FLUX ROUTINE
      AMTR=CLENG*CWIDTH
      IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,0.,1)
C  START RAY DRAW FOR PERFORMANCE
      DO 1000 N=1,NDRAW
C  MONTE CARLO DRAW OVER APERTURE
      IREFL=0
      CONVP=TRANTOT
  415 XO=CLENG*FLAT(0.0)
      YO=CWIDTH*(-0.5 + FLAT(0.0))
      AYO=ABS(YO)
C  PRISM ELEMENT NUMBER
      IP=INT(AYO/LF) + 1
C  PRISM ANGLE W.R.T. HORIZONTAL
      GAM=GAMMA(IP)
      SGAM=SIN(GAM)
      CGAM=COS(GAM)
      SGN=YO/AYO
C  HEIGHT OF HIT POINT ON FACET
      C2=SQRT((RLENS + T)*(RLENS + T)- LF*LF*IP*IP)
      YDUM=LF*IP-AYO
```

```
            ZDUM=SGAM*YDUM/CGAM
      C  CHECK FOR START POINT IN ADJACENT FACET SHADOW
            ZUP=ZDUM+SGN*YDUM*H1
            IF(ZUP.GT.0.0) GO TO 670
            GO TO 680
      C  CHECK FOR FACET HEIGTH
        670 CNEXT=SQRT((RLENS+T)*(RLENS+T)-LF*LF*(IP+1)*(IP+1))
            ZPEAK=CNEXT+TAN(GAMMA(IP+1))*LF-C2
            IF(ZUP.GT.ZPEAK) GO TO 680
      C  HIT FACET , UP COUNTER
            ISHAD=ISHAD+1
            GO TO 415
       680  ZO=ZDUM  + C2
      C  GET LENS MATERIAL DATA
            IF(NMATL.LT.11) GO TO 72
            JW=INT(20.*FLAT(0.0))+1
            WAVEL=WAVL(JW)
            CALL LDATA(NMATL,WAVEL,NAIR,NLENS)
      C  GET SURFACE NORMAL AND TANGENT
       72   DO 10 I=1,3
            UN(I)=CGAM*UCN(I) + SGN*SGAM*UCP(I)
         10 UT(I)= -SGN*CGAM*UCP(I) + SGAM*UCN(I)
      C  FIND PERTURBED SUN & SURFACE NORMALS
      C  VECTORS HERE
            IF(N.EQ.NCHECK) SDR=SDR2
            CALL CROSS(UN,UT,UT2)
            CALL ERRNORM(SDS,SDR,UN,UT,UT2,UNP,PSM)
            CALL SUN2(ACC,USP,DRAD)
      C  GET REFRACTED RAY
            CALL LREFR(1.0,NLENS,UNP,USP,UR,ICOD)
            IF(ICOD.EQ.1) GO TO 120
      C  CHECK FOR HIT ON VERTICAL FACE
      C  OR INNER LENS SURFACE
            CALL SLEN(UR,RHIT,UN,UT,MISS)
            IF(MISS.EQ.0) GO TO 690
            IBLOC=IBLOC+1
            GO TO 120
       690  CALL CROSS (UN,UT,UT2)
      C  SLEN RETURNS CODE FOR HIT SURFACE
      C  AND NEXT LENS NORMAL AND TARGET
      C  VECTORS
      C  PERTURB NORMAL
            CALL ERRNORM(SDS,SDR,UN,UT,UT2,UNP,PSM)
            DO 48 I=1,3
         48 UR(I)=-UR(I)
      C  GET REFRACTED RAY
            CALL LREFR(NLENS,1.0,UNP,UR,UR2,ICOD)
            IF(ICOD.EQ.1) GO TO 120
      C  CHECK FOR RAY HIT ON ABSORBER SHELF
            DO 12 I=1,3
         12 D(I)=-RHIT(I)+DZ*UCN(I)-QHIT*UCA(I)
            AL=DOTER(D,UCP)/DOTER(UR2,UCP)
            ZHIT=-DOTER(D,UCN)+AL*DOTER(UR2,UCN)
```

```
      IF(ZHIT.LT.0.0.OR.ZHIT.GT.SHITE) GO TO 307
      DO 303 I=1,3
  303 UR(I)=UR2(I)
      NDIRECT=NDIRECT+1
      GO TO 61
C  NOW FIND INTERCEPT WITH SUBREFLCTOR
C  CHECH SIDE OF REFLECTION--DO HIT TEST ON PLUS Y-SIDE
  307 ISW=1
      IF(ZHIT.GT.0.0.AND.ZHIT.LT.(RLENS-D7)) ISW=-1
      SWITCH=SGN*ISW
      IF(SWITCH.GT.0.0) GO TO 309
C  CHANGE SIDES
      DR1=DOTER(RHIT,UCA)
      DR2=DOTER(RHIT,UCP)
      DR3=DOTER(RHIT,UCN)
      DU1=DOTER(UR2,UCA)
      DU2=DOTER(UR2,UCP)
      DU3=DOTER(UR2,UCN)
      DO 308 I=1,3
      RHIT(I)=DR1*UCA(I)-DR2*UCP(I)+DR3*UCN(I)
  308 UR2(I)=DU1*UCA(I)-DU2*UCP(I)+DU3*UCN(I)
  309 CALL SUBR(AC,RHIT,UR2,XH,YH,ZH,UN,UT,1,MISS)
      IF(MISS.EQ.1) GO TO 120
  15  CALL CROSS(UN,UT,UT2)
C  CALL SUBREFLECTOR SURFACE NORMAL
      CALL ERRNORM(SDS,SDR,UN,UT,UT2,UNP,PSM)
      DO 16 I=1,3
   16 UR2(I)=-UR2(I)
C  GET REFLECTED RAY
      CALL SNELL(UR,UNP,UR2)
C  CHECK FOR HIT ON SHELF
      DO 20 I=1,3
   20 D(I)= -XH*UCA(I) - YH*UCP(I) - ZH*UCN(I)
      AL=-YH/DOTER(UR,UCP)
      ZHIT= ZH +AL*DOTER(UR,UCN)
      IF(ZHIT.GT.0.0) GO TO 50
      IF(DOTER(UR,UCN).GT.0.0) GO TO 120
C  RAY HAS REFLECTED ON SAME SIDE OF SHELF
      DO 52 I=1,3
   52 RHIT(I)=DZ*UCN(I)-D(I)
      CALL SUBR(AC,RHIT,UR,XH,YH,ZH,UN,UT,2,MISS)
      IF(MISS.EQ.1) GO TO 120
      IREFL=IREFL+1
      IF(IREFL.GT.5) GO TO 120
      DO 771 I=1,3
  771 UR2(I)=UR(I)
      GO TO 15
   50 IF(ZHIT.LT.SHITE) GO TO 60
C  ASSUMES RAYS REFLECTED ABOVE SHELF ARE LOST
  120 MISR=MISR+1
      GO TO 1000
C  HIT ON SHELF,DO FLUX
C
```

1-02-80   08.852

```
   60 CONVP=RAYVAL(IREFL,REFLTOT)*TRANTOT
      NBNC(IREFL+1)=NBNC(IREFL+1)+1
   61 RPWR=RPWR+CONVP
C  HIT ON SHELF   SET RHIT AND POWER
      IF(MAPS.EQ.0) GO TO 1000
      DO 63 I=1,3
   63  RHIT(I)=-D(I)+AL*UR(I)
      QHIT=DOTER(RHIT,UCA)
      CALL FLUX(RHIT,UCA,UCP,UCN,CONVP,2)
 1000 CONTINUE
C  ALL RAYS DONE,PRINT ANSWERS
      WRITE(6,6020) OFFSUN,REFLTOT,SDS,SDR1,SDR2
 6020 FORMAT(20X,43HSURFACE,REFLECTANCE AND TRACKING PARAMETERS,//,
     + 10X,F10.3,2X,18HSUN OFF-AXIS ANGLE,/,
     + 10X,F10.3,2X,19HREFLECTANCE(TOTAL),/,
     + 10X,F10.5,2X,20HSURF. ERROR(ST.DEV.),/,
     + 10X,F10.5,2X,21HREFL.DISTR.1(ST.DEV.),/,
     + 10X,F10.5,2X,21HREFL.DISTR.2(ST.DEV.),///)
      WRITE(6,3015) ISHAD,IBLOC,NDIRECT
 3015 FORMAT(//,10X,43HRAYS SHADOWED BY PRISMS BEFORE HITTING LENS
     +  ,I8,/,10X,42HRAYS SHADOWED BY PRISMS AFTER HITTING LENS,
     +  I9,/,
     +  10X,23HDIRECT HITS ON ABSORBER,20X,I8,/)
C  COMPUTE OPTICAL EFFICIENCY
        NHIT=NDRAW-MISR
      EOPT=RPWR*COS(OFFSUN)/NDRAW
      WRITE(6,9199) MISR,NHIT,EOPT
 9199 FORMAT(///,14X,6HMISSED,4X,6HHIT ON,8X,7HOPTICAL,/,
     +            16X,4HRAYS,6X,4HRCVR,6X,10HEFFICIENCY,//,
     +            10X,2I10,5X,F10.5,/)
      WRITE(6,3027) (J,J=1,6),(NBNC(I),I=1,6)
 3027 FORMAT(//,6X,12HREFLECTIONS=,6I7,/,18X,6I7,/)
      IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,3)
      RETURN
      END
```

: 11-27-78 *** 14.4 ***

: (SEC)   1.18   LINES/MINUTE 12478

: NO   DIAGNOSTICS IN ABOVE COMPILATION
)S WERE USED FOR THIS COMPILATION

1-02-80   08.853

```
      SUBROUTINE SLEN(UR,RHIT,UN,UT,MISS)
      REAL LF
      DIMENSION D(3),UR(3),RHIT(3),UN(3),UT(3)
C  CHECK FOR HIT ON NEIGHBORING VERTICAL FACES
      COMMON/ICC/T,LF,RLENS,NFIT,DZ,SHITE,IP,XO,YO,ZO,SGAM,CGAM,AYO,
     1 SGN,TEST,C2,CAID,YS(30),ZS(30)
      COMMON/RUNC/NDRAW,TAZ,TEL,TIME,IDAY,XLAT,XLONG,ICONC,
     + NMAT,DRAD,MTSR,TZONE,MAPS,R2WR,AMTR,NMATL
      COMMON/VECTOR/ULE(3),ULV(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
      COMMON/RCVRC/IRCVR,THETAC,SO,RW,RL,QHIT
      COMMON/TRAC/NAXIS,TILTANG,OFFSUN,THETAAX,DTRACRL,DTRACAZ,IRPI
      COMMON/ZONE/NZONEX,NZONEY
      XL1=AYO - LF*(IP-1)
      C3=SQRT((RLENS + T)*(RLENS + T) - LF*LF*(IP - 1)*(IP - 1))
      TH7=ASIN(LF/(RLENS+T))
      C7=LF*(SGAM/CGAM+1./TAN(TH7))
C  CHECK FOR HIT ON FACE NEAREST CENTER
      DO 20 I=1,3
   20 D(I)= -XL1*SGN*UCP(I) + XL1*SGAM*UCN(I)/CGAM
      D1=DOTER(D,UCN)
      D2=DOTER(D,UCP)*DOTER(UR,UCN)
      ZHIT=D1-D2/DOTER(UR,UCP)
      DO 30 I=1,3
   30 D(I)=-XO*UCA(I)-YO*UCP(I)+(C7-ZO)*UCN(I)
      D1=DOTER(D,UCN)
      D2=DOTER(D,UCP)*DOTER(UR,UCN)
      CHIT=D1-D2/DOTER(UR,UCP)
      IF(CHIT.GT.0.0.AND.CHIT.LT.(C7-RLENS)) SGN=-SGN
      IF (IP.EQ.1) GO TO 100
      ZTEST=LF*SGAM/CGAM - C3 + C2
      IF(ZHIT.GE.ZTEST) GO TO 100
      IF(ZHIT.LT.0.0) GO TO 100
C  RAY HITS VERTICAL FACE, ASSUME LOST
      MISS=1
      RETURN
C  FIND HIT ON INNER LENS CIRCLE ARC
  100 CONTINUE
      DO 120 I=1,3
  120 D(I)=-XO*UCA(I)-YO*UCP(I)-ZO*UCN(I)
      D1=DOTER(D,UR)
      D2=DOTER(D,D)
      D3=DOTER(UR,UCA)
      A=1.-D3*D3
      B=-2.*D3*XO-D1*2.
      C=D2-XO*XO-RLENS*RLENS
      ARG=B*B-4.*A*C
      IF(ARG.GE.0.0) GO TO 130
      MISS=1
      RETURN
  130 AL=(-B+SQRT(ARG))/(2.*A)
      AL2=(-B-SQRT(ARG))/(2.*A)
      IF(AL2.LT.AL) AL=AL2
C     WRITE(6,   ) AL
```

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11-02-80    08.853

      C  FIND LENS NORMAL AND TANGENT AT THE HIT POINT
            QHIT=-DOTER(D,UCA)+AL*D3
            DO 150 I=1,3
        150 RHIT(I)= -D(I) + AL*UR(I)-QHIT*UCA(I)
            RMAG=SQRT(DOTER(RHIT,RHIT))
            DO 160 I=1,3
        160 UN(I)=RHIT(I)/RMAG
            DRC=DOTER(UN,UCN)*SGN
            DRP=DOTER(UN,UCP)*SGN
            DO 170 I=1,3
        170 UT(I)=DRC*UCP(I) - DRP*UCN(I)
            MISS=0
            RETURN
            END
```

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TE    11-27-78 *** 14.4 ***

ME (SEC)       .58          LINES/MINUTE  6889

RE  NO   DIAGNOSTICS IN ABOVE COMPILATION.
RDS WERE USED FOR THIS COMPILATION
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1-02-80 08.854

```
      SUBROUTINE SUBR(A,RHIT,UR2,XH,YH,ZH,UN,UT,IBOUN,MISS)
C  THIS ROUTINE SOLVES FOR A SUBREFLECTOR
C  HIT POINT USING NEWTONS METHOD. IT ALSO
C  RETURNS A SURFACE NORMAL AT THE
C  COMPUTED POINT.
      REAL LF
      COMMON/RUNC/NDRAW,TAZ,TEL,TIME,IDAY,XLAT,XLONG,ICONC,
     + NMAT,DRAD,MISR,TZONE,MAPS,RPWR,AMIR,NMATL
      COMMON/VECTOR/ULF(3),ULV(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
      COMMON/RCVRC/IRCVR,THETAC,SD,RN,RL,QHIT
      COMMON/TRAC/NAXIS,TILTANG,OFFSUN,THETAAX,DTRACRL,DTRACAZ,IRPI
      COMMON/ZONE/NZONEX,NZONEY
      COMMON/ICC/T,LF,RLENS,NFIT,DZ,SHITE,IP,XO,YO,ZO,SGAM,CGAM,AYO,
     1 SGN,TEST,C2,CWID,YS(30),ZS(30)
      DIMENSION A(10),VT(3),RHIT(3),UR2(3),UN(3),UT(3),D(3)
      IF(ICONC.EQ.12) GO TO 3000
      MISS=0
      NTRY=0
      C1=DOTER(UR2,UCN)
      C2=-DOTER(RHIT,UCN) + DZ
      C3=DOTER(UR2,UCP)
      C4=DOTER(RHIT,UCP)
C  MAKE INITIAL GUESS FOR LENGTH
      AL=-C2
    1 NITER=1
    5 FAL=C2 - C1*AL
      FALP= -C1
      YTEST=AL*C3+C4
      IF(YTEST.LT.0.0000001) YTEST=-NITER*0.003*C2
      AL=(YTEST-C4)/C3
C  START LOOP TO SOLVE FOR LENGTH OF
C  HIT VECTOR
      DO 10 N=1,NFIT
      FAL=FAL + A(N)*YTEST**N
   10 FALP=FALP + A(N)*N*C3*YTEST**(N-1)
      DELTA=FAL/FALP
      IF(ABS(DELTA).GT.-2.*C2) DELTA=-C2*(2.-0.03*NITER)
      ALNEW=AL - DELTA
      IF(ABS(AL-ALNEW).LT.0.0001) GO TO 100
      CHEC=(AL - ALNEW)/AL
      IF(ABS(CHEC).LT.0.0001) GO TO 100
      NITER=NITER + 1
      AL=ALNEW
      IF(NITER.LT.30) GO TO 5
  292 WRITE(6,306)
  306 FORMAT(34HITERATIONS FAILED FOR SUBREFLECTOR)
      MISS=1
      RETURN
C  LENGTH FOUND, GET NORMAL VECTOR
  100 CONTINUE
C CHECK FOR CORRECT ROOT OF EQUATION
      IF(AL.GT.0.0000001) GO TO 105
C  BAD ROOT - TRY AGAIN
```

```
            NTRY=NTRY+1
            IF(NTRY.GT.5) GO TO 292
            AL=- C2*(FLOAT(NTRY)/3.0+0.4)
            GO TO 1
      105   DO 110 I=1,3
      110 VT(I)=AL*UR2(I) + RHIT(I) - DZ*UCN(I)+QHIT*UCA(I)
C   HIT COORDINATES ON SUBREFLECTOR CONTOUR
            XH=DOTER(VT,UCA)
            YH=DOTER(VT,UCP)
            ZH=DOTER(VT,UCN)
C CHECK FOR HIT WIHTIN BOUNDARIES
            IF(ZH.GT.0.0.AND.ZH.LT.-C2) GO TO 115
            WRITE(6,112) ZH
      112   FORMAT(/,5X,33HSUBREFLECTOR HIT OUT OF BOUNDS,Z=,E12.4)
            MISS=1
            RETURN
      115 CONTINUE
            DO 120 N=1,NFIT
      120 DZDY=A(N)*N*YH**(N-1)
            VMAG=SQRT(1 + DZDY*DZDY)
            DO 130 I=1,3
            UT(I)=UCA(I)
      130 UN(I)=(-DZDY*UCP(I) + UCN(I))/VMAG
            RETURN
C    SET WITH POINT-TO-POINT SUBREFLECTOR DEFINITION
     3000 DR2N=DOTER(UR2,UCP)
            DO 3010 I=1,3
     3010 VT(I)=-RHIT(I)-QHIT*UCA(I)+DZ*UCN(I)
            IP=2
            MISS=0
C  FIND CORRECT SEGMENT OF SUBREFLECTOR
     3015 IP=IP+1
            IF(IP.GT.30) GO TO 4000
            ZI=ZS(IP)
            YI=YS(IP)
            DO 3040 I=1,3
     3040 D(I)=VT(I)+YI*UCP(I)+ZI*UCN(I)
            DMAG=SQRT(DOTER(D,D))
            CHEC=DOTER(D,UCP)/DMAG-DR2N
            IF(CHEC.LT.0.0) GO TO 3015
            IP=IP-1
C    SOLVE FOR INTERSECTION POINT
            DZ=ZI-ZS(IP)
            DY=YI-YS(IP)
            TH1=ATAN2(DZ,DY)
            CTH1=COS(TH1)
            STH1=SIN(TH1)
            DO 3070 I=1,3
     3070 VT(I)=-STH1*UCP(I)+CTH1*UCN(I)
            XLI=SQRT(DZ*DZ+DY*DY)
            DDUP=DOTER(D,VT)
            DR2UP=DOTER(UR2,VT)
            DO 3080 I=1,3
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'1-02-80    08.854

        3080 VT(I)=-D(I)+DDUP*UR2(I)/DR2UP
             XH=DOTER(VT,UCA)
             YH=DOTER(VT,UCP)
             ZH=DOTER(VT,UCN)
       C    FIND SLOPE AT HIT POINT
             FR=YH/DY
             IF(FR.GT.0.5) GO TO 3250
             DZ2=ZS(IP)-ZS(IP-1)
             DY2=YS(IP)-YS(IP-1)
             TH2=ATAN2(DZ2,DY2)
             Y1=YH+0.5*XLI*CTH1
             Z1=ZH+0.5*XLI*STH1
             Y2=YH-FR*XLI*CTH1-(0.5-FR)*XLI*COS(TH2)
             Z2=ZH-FR*XLI*STH1-(0.5-FR)*XLI*SIN(TH2)
             GO TO 3280
        3250 DZ2=ZS(IP+2)-ZS(IP+1)
             DY2=YS(IP+2)-YS(IP+1)
             TH2=ATAN2(DZ2,DY2)
             Y1=YH+(1.-FR)*XLI*CTH1+(FR-0.5)*XLI*COS(TH2)
             Z1=ZH+(1.-FR)*XLI*STH1+(FR-0.5)*XLI*SIN(TH2)
             Y2=YH-0.5*XLI*CTH1
             Z2=ZH-0.5*XLI*STH1
        3280 DZ3=Z1-Z2
             DY3=Y1-Y2
             TH3=ATAN2(DZ3,DY3)
             CTH3=COS(TH3)
             STH3=SIN(TH3)
       C    FIND NORMAL & TANGENT VECTORS
             DO 3940 I=1,3
             UT(I)=UCA(I)
        3940 UN(I)=CTH3*UCN(I)-STH3*UCP(I)
             RETURN
        4000 WRITE(6,4010)
        4010 FORMAT(/,3X,32HREFLECTED RAY ABOVE SUBREFLECTOR)
             MISS=1
             RETURN
             END

E    11-27-78 *** 14.4 ***

E (SEC)      .83         LINES/MINUTE 10313

E  NO   DIAGNOSTICS IN ABOVE COMPILATION
)S WERE USED FOR THIS COMPILATION
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2-18-79   08.944

```
      SUBROUTINE PDISH
      NAMELIST/DISHN/F,RAP,NRZ,SDS,SDR,DTRACRL,DTRACAZ,
     *IRCVR,NAXIS,RW,RL,NZONEX,NZONEY,REFLTOT,NRZ,RWS,PSM
      COMMON/RUNC/NDRAW,TAZ,TEL,TIME,IDAY,XLAT,XLONG,ICONC,
     + NMAT,DRAD,MISR,TZONE,MAPS,RPWR,AMIR,NMATL
      COMMON/VECTOR/ULE(3),ULV(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
      COMMON/RCVRC/IRCVR,THETAC,SO,RW,RL,OHIT
      COMMON/TRAC/NAXIS,TILTANG,OFFSUN,THETAAX,DTRACRL,DTRACAZ,IRPI
      COMMON/ZONE/NZONEX,NZONEY
      DIMENSION  D(3),UT(3),UN(3),UNP(3),UR(3),USP(3),RHIT(3),UDUM(3)
     + ,ARPI(20),RR(20),CR(20),EOPTZ(20),UT2(3)
      PI=3.141592654
C    READ NAMELIST PARAMETERS
C
      READ(5,DISHN)
      RMAX=RW*0.5
      SUM=0.0
      ISHAD=0
      AMIR=3.141592654*RAP*RAP
      DO 5 I=1,NRZ
      EOPTZ(I)=0.0
      ARPI(I)=0.0
      RR(I)=I*RMAX/NRZ
    5 CR(I)=AMIR/(PI*RR(I)*RR(I))
C
C    OUTPUT NAMELIST PARAMETERS
C
C
C    OBTAIN DATA FOR REFLECTIVE MATERIAL PROPERTIES
C
      IF(NMAT.NE.0) CALL RDATA(NMAT,NDRAW,SDR1,SDR2,REFLTOT,REFL
     + ,NCHECR)
      SDR=SDR1
      WRITE(6,6000) RAP,F,IRCVR,NAXIS,RMAX,RWS
 6000 FORMAT(20X,32HPARABOLOID DISH CONC. PARAMETERS,//,
     + 10X,F10.3,2X,15HAPERTURE RADIUS,/,
     + 10X,F10.3,2X,12HFOCAL LENGTH,/,
     + 10X,I10,2X,10HRCVR. TYPE,/,
     + 10X,I10,2X,13HTRACKING AXES,/,
     + 10X,F10.3,2X,24HRECEIVER APERTURE RADIUS,/,
     + 10X F10.3,2X,23HRECEIVER SHADING RADIUS,///)
C
C
C    INITIALIZE FLUX ROUTINE
C
      IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,1)
C
      CONVP=REFLTOT
C
C    SET VECTOR TO SUN'S CENTER
C
      CALL SUN1(TAZ,TEL)
C
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2-18-79   08.944

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      C    SET CONCENTRATOR POSITION VECTORS
      C
             CALL TRACK(TAZ,TEL)
             WRITE(6,1010) IDAY,TIME,XLAT,XLONG,TEL,TAZ
       1010  FORMAT(15X,15HSOLAR CONSTANTS,//,
            +  10X,I10,2X,3HDAY,/,
            +  10X,F10.2,2X,4HTIME,/,
            +  10X,F10.3,2X,8HLATITUDE,/,
            +  10X,F10.3,2X,9HLONGITUDE,/,
            +  10X,F10.3,2X,9HELEVATION,/,
            +  10X,F10.3,2X,7HAZIMUTH,///)
             DO 300 N=1,NDRAW
      C
      C   DRAW RAYS OVER SURFACE
      C
             RTH=6.2831853*FLAT(0.0)
             RD=SQRT(RAP*RAP*FLAT(0.0))
      C   CHECK FOR SHADOW OF RECEIVER
             IF(RD.GT.RWS) GO TO 15
             ISHAD=ISHAD+1
             GO TO 60
      C   CONVERT TO SURFACE POINTS
       15    XO=RD*COS(RTH)
             YO=SIN(RTH)*RD
             ZO=(XO*XO+YO*YO)*0.25/F
      C    FIND THE UNPERTURBED SURFACE NORMAL UN AND
      C    THE PERTURBED SURFACE NORMAL UNP
      C
             PHI=ATAN(RD/(2.*F))
             CPHI=COS(PHI)
             SPHI=SIN(PHI)
             DO 30 I=1,3
             UDUM(I)=(XO*UCA(I)+YO*UCP(I))/RD
             UN(I)=-SPHI*UDUM(I)+CPHI*UCN(I)
        30   UT(I)=CPHI*UDUM(I)+SPHI*UCN(I)
      C
      C    DETERMINE PERTURBED NORMAL USING ST. DEV.
      C    FOR REFLECTANCE AND SURFACE ERROR
      C
             IF(N.EQ.NCHECR) SDR=SDR2
             CALL CROSS(UN,UT,UT2)
             CALL ERRNORM(SDS,SDR,UN,UT,UT2,UNP,PSM)
      C
      C    SET SUN VECTOR US TO SUN'S CENTER
      C
      C
      C    PERTURB SUN'S RAY FOR FINITE SUN SIZE
      C    AND VARIATION IN SUN'S INTENSITY
      C
             CALL  SUN2(ACC,USP,DRAD)
      C
      C    CALCULATE REFLECTED RAY USING SNELL'S LAW
      C
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2-18-79    08.944
            CALL   SNELL(UR,UNP,USP)
      C
      C    FIND D VECTOR TO KNOWN POINT ON RCVR.
      C    SURFACE
      C
            DO 50 I=1,3
        50 D(I)=-(XO+0.5*RL)*UCA(I)-YO*UCP(I)+(F-ZO)*UCN(I)
      C
      C    CALL RCVR. HIT TEST ROUTINE; IRCVR INDICATES
      C    RCVR GEOMETRY
      C
            CALL RCVR(D,UR,RHIT,MISR1)
      C
      C    DETERMINE IF RAY HITS RCVR. FOR RCVR HITS,
      C    FIND ZONE OF HIT POINT
      C
            IF(MISR1.EQ.1) GO TO 60
            IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,REFLTOT,2)
      C  BULLS EYE FLUX ZONING
            DO 55 I=1,3
       55   RHIT(I)=RHIT(I)-0.5*RL*UCA(I)
            RMAG=SQRT(DOTER(RHIT,RHIT))
            IF(RMAG.GT.RMAX) GO TO 60
            I=0
        44 I=I+1
            IF(RMAG.GT.RR(I)) GO TO 44
            ARPI(I)=ARPI(I)+CONVP
            RPWR=RPWR+CONVP
            GO TO 300
      60    MISR=MISR+1
       300 CONTINUE
            WRITE(6,6020) OFFSUN,REFLTOT,SDS,SDR1,SDR2,DTRACAZ,DTRACRL
      6020 FORMAT(20X,43HSURFACE,REFLECTANCE AND TRACKING PARAMETERS,//,
          + 10X,F10.3,2X,18HSUN OFF-AXIS ANGLE,/,
          + 10X,F10.3,2X,19HREFLECTANCE(TOTAL),/,
          + 10X,F10.5,2X,20HSURF. ERROR(ST.DEV.),/,
          + 10X,F10.5,2X,21HREFL.DISTR.1(ST.DEV.),/,
          + 10X,F10.5,2X,21HREFL.DISTR.2(ST.DEV.),/,
          + 10X,F10.3,2X,18HTRACKING ERROR-AZ.,/,
          + 10X,F10.3,2X,19HTRACKING ERROR-ROLL,//)
            WRITE(6,1070) ISHAD
      1070 FORMAT(/10X,21HRAYS BLOCKED BY RCVR=,I10)
      C  COMPUTE OPTICAL EFFICIENCY
               NHIT=NDRAW-MISR
            EOPT=RPWR*COS(OFFSUN)/NDRAW
            WRITE(6,9199) MISR,NHIT,EOPT
            DO 70 I=1,NRZ
            ARPI(I)=ARPI(I)*AMIR/NDRAW
            SUM=SUM+ARPI(I)/AMIR
        70  EOPTZ(I)=SUM
            WRITE(6,1090) (RR(I),CR(I),ARPI(I),EOPTZ(I),I=1,NRZ)
      1090 FORMAT(//,16X,6HRADIUS,2X,10HCONC RATIO,7X,
          * 5HPOWER,3X,10HEFFICIENCY,,//,(10X,F12.4,F12.1,2F12.4))
```

```
2-18-79    08.944

      9199 FORMAT(///,14X,6HMISSED,4X,6HHIT ON,3X,7HOPTICAL,/,
     +            16X,4HRAYS,6X,4HRCVR,1X,10HEFFICIENCY,//,
     +            10X,2I10,F10.5,/)
           IF(MAPS.EQ.1) CALL FLUX(RHIT,UCA,UCN,UCP,CONVP,3)
           RETURN
           END

:    11-27-78 *** 14.4 ***

: (SEC)       .75          LINES/MINUTE 13144

:  NO   DIAGNOSTICS IN ABOVE COMPILATION
)S WERE USED FOR THIS COMPILATION
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2-18-79 08.942

```
      SUBROUTINE RCVR(D,UR,RHIT,MISR)
C
C  THIS ROUTINE PERFORMS THE RECEIVER HIT TEST FOR ALL RAYS.
C  THE RECEIVER MODEL OPTIONS ARE --
C         NRCVR=1 -- CYLINDRICAL(PIPE) RECEIVER
C         NRCVR=2 -- PLANAR(FLAT) RECEIVER
C         NRCVR=3 -- CONICAL RECEIVER
C  INPUTS FORM THE CONCENTRATOR ROUTINE ARE
C         NRCVR -- RCVR. IDENTIFICATION DESCRIBED ABOVE
C         D       -- THE DISTANCE VECTOR FROM SURFACE HIT POINT
C                    TO KNOWN POINT ON RCVR.
C         UR    -- THE REFLECTED/REFRACTED RAY VECTOR
C
C  OUTPUTS ARE--
C         RHIT    -- THE VECTOR DESCRIBING RAY HIT POINT ON RECEIVER
C         MISR1 -- INDICATOR OF RAY MISSING RCVR.
C
      COMMON/RCVRC/IRCVR,THETAC,SO,RW,RL,QHIT
      COMMON/VECTOR/ULE(3),ULV(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
      DIMENSION D(3), UR(3),RHIT(3)
      IF(IRCVR.EQ.2) GO TO 200
      IF(IRCVR.EQ.3) GO TO 300
C
C   SOLVE QUADRATIC FOR VALUE OF AL
C
      MISR=0
      RCA=DOTER(UR,UCA)
      DCA=DOTER(D,UCA)
      DR=DOTER(D,UR)
C
C   COEFFICIENTS OF QUADRATIC EQUATION
C
      A=(1.-RCA*RCA)
      B=2.*(RCA*DCA - DR)
      C=DOTER(D,D) -DCA*DCA - RW*0.25*RW
       QUAD=B*B - 4.*A*C
C
C   CHECK TO SEE IF B*B-4AC IS POSITIVE.  IF NOT,RAY MISSED RCVR.
C
      IF(QUAD.LT.0.0 ) GO TO 99
      AL1 = (-B + SQRT(QUAD))/(2.*A)
      AL2 = (-B -SQRT(QUAD))/(2.*A)
      AL=AL1
      IF(AL1.GT.AL2) AL=AL2
      QHIT= -DCA + AL*RCA
C  CHECK FOR HIT WITHIN AXIAL BOUNDARY OF RCVR
      IF(QHIT.LT.0.0.OR.QHIT.GT.RL) GO TO 99
      DO 20 I=1,3
   20 RHIT(I)= -QHIT*UCA(I) - D(I) + AL*UR(I)
      RETURN
C
  200 MISR=0
C   THIS PORTION TESTS FOR A RAY HIT ON A PLANAR RECEIVER
```

```
      C
      C
      C   FIND DISTANCE ALONG UR TO HIT POINT - AL
      C
            AL=DOTER(D,UCN)/DOTER(UR,UCN)
      C
      C  SOLVE FOR VECTOR RHIT
      C
            DO 10 I=1,3
         10 RHIT(I)=AL*UR(I) - D(I)
            QHIT=DOTER(RHIT,UCA)
            PHIT=DOTER(RHIT,UCP)+0.5*RW
            IF(PHIT.LT.0.0.OR.PHIT.GT.RW) GO TO 99
            IF(QHIT.LT.0.0.OR.QHIT.GT.RL) GO TO 99
      C
      C   RETURN TO CALLING PROGRAM VALUE OF RHIT
      C
            RETURN
        300 MISR=0
      C
      C
      C   THIS PORTION TESTS FOR A RAY HIT ON A CONICAL RECEIVER
      C
      C     FIND COEFFICIENTS OF QUADRATIC TO FIND S, THE DISTANCE RAY
      C     HITS ALONG AXIS OF CONE
      C
            TTC=SIN(THETAC)/COS(THETAC)
            RS=DOTER(UR,US)
            DR=DOTER (D,UR)
            DS=DOTER(D,US)
            A=1./(RS*RS) - TTC*TTC-1.0
            B=2.*(SO*TTC*TTC + DR/RS -DS/(RS*RS) )
            C=(DS*DS)/(RS*RS) + DOTER(D,D) - SO*SO*TTC*TTC
           +  -(2.*DS*DR)/RS
      C
      C   TEST TO SEE IF RAY HITS RCVR (NON-REAL ROOTS INDICATE MISS)
      C
            QUAD=B*B-4.*A*C
            IF(QUAD.LT.-.00000001) GO TO 99
      C
      C  POSITIVE VALUE FOR QUAD - RAYP HIT RCVR.
      C   FIND RHIT VECTOR
      C
            S1=(-B+SQRT(QUAD))/(2.*A)
            S2=(-B-SQRT(QUAD))/(2.*A)
            AL1=(DS-S1)/RS
            AL2=(DS-S2)/RS
            AL=AL1
            S=S1
            IF(AL1.GT.AL2)AL=AL2
            IF(AL1.GT.AL2) S=S2
        969 FORMAT(5X,2HS1,F12.3,5X,2HS2,F12.3,/,5X,3HAL1,
           + F12.3,5X,3HAL2,F12.3,///)
```

```
!-18-79   08.942

      C
      C    CALCULATE RHIT VECTOR
      C
             DO 60 I=1,3
          60 RHIT(I)=+AL*UR(I) - D(I) + S*US(I)
             QHIT=S
             IF(QHIT.GT.RL.OR.QHIT.LT.0.0) GO TO 99
             RETURN
          99 MISR=1
             RETURN
             END

?    11-27-78 *** 14.4 ***

: (SEC)       .58          LINES/MINUTE 12074

: NO  DIAGNOSTICS IN ABOVE COMPILATION
)S WERE USED FOR THIS COMPILATION
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?-18-79   08.936

```
      SUBROUTINE FLUX(RHIT,UCA,UCN,UCP,CONVP,NCODE)
C
C     THIS ROUTINE SUMS RAYS WHICH HIT RECEIVER
C     THE HITS ARE SUMMED BY RECEIVER ZONE
C     ACCUMULATED AND TOTAL ARE KEPT TRACK OF BY ZONE
C     POWER AND ENERGY ARE CALCULATED BY ZONE
C     ACCUMULATED POWER AND ENERGY ARE KEPT TRACK OF
C     TOTAL POWER AND ENERGY ARE CALCULATED
C
C     THE RECEIVER IS IMAGINED TO BE SLICED LONGITUDINALLY
C     FOR THE CYLINDRICAL AND CONICAL RECEIVERS, LAID
C     FLAT, AND ZONED RECTANGULARLY AND RADIALLY,
C      RESPECTFULLY.
C
      COMMON/ZONE/NZONEX,NZONEY
      COMMON/CONECOM/ US1(3),US2(3)
      COMMON/RCVRC/IRCVR,THETAC,SO,RW,RL,QHIT
      COMMON/TRAC/NAXIS,TILTANG,OFFSUN,THETAAX,DTRACRL,DTRACAZ,IRPI
      COMMON/RUNC/NDRAW,TAZ,TEL,TIME,IDAY,XLAT,XLONG,ICONC,
     * NMAT,DRAD,MISR,TZONE,MAPS,RPWR,AMIR,NMATL
      DIMENSION D(3),RHIT(3),UCA(3),UCN(3),UCP(3),NFLUX(20,20),H(20)
      DIMENSION AFLUX(20,20),AZONE(20,20),AREA(20)
      DIMENSION IFRS(10),ISNO(10)
      PI = 3.141592654
C     NCODE=1 INITIALIZE PARAMETERS
C     NCODE=2 SUM RAY HITS AND MISSES
C     NCODE=3 CALCULATE POWER AND ENERGY AND
C     PRINT ANSWERS AND FLUX MAP.
C
      IF(NCODE.EQ.2) GO TO 200
      IF(NCODE.EQ.3) GO TO 707
      PWR=0.
      CPWR=0.
C
C   SET CONSTANTS FOR RECEIVER IN QUESTION.
C
      NYZ=NZONEY
      NXZ=NZONEX
      DELY=RW/NYZ
      DELX=RL/NXZ
      YDIST=DELY
      IF(IRCVR.EQ.2) GO TO 10
      DELY=2.*PI/NYZ
      YDIST=DELY*0.5*RW
   10 CONTINUE
C      ZERO OUT ARRAYS
      DO 102 I=1,NXZ
      DO 102 J=1,NYZ
      NFLUX(I,J)=0.
  102 AFLUX(I,J)=0.
      DO 501 I=1,NXZ
      DO 501 J=1,NYZ
  501 AZONE(I,J)=DELX*YDIST
```

!-18-79 08.936

```
      IF(IRCVR.NE.3) RETURN
      RMACO=(RL-SO)*SIN(THETAC)
C     ZONAL RING AREAS
      H(1)=0.
      NZL=NXZ+1
      DO 601 I=2,NZL
      H(I)=H(I-1)+DELX
      QU1=(RMACO-H(I-1)*TAN(THETAC))**2
      QU2=(RMACO-H(I)*TAN(THETAC))**2
      AREA(I-1)=(PI*(QU1-QU2))/SIN(THETAC)
      AREAZ=AREA(I-1)/NYZ
      DO 601 J=1,NYZ
  601 AZONE(I-1,J)=AREAZ
      RETURN
  200  CONTINUE
C     IRCVR=1 CYLINDRICAL(PIPE) RECEIVER
C      IRCVR=2 PLANAR(FLAT) RECEIVER
C     IRCVR=3 CONICAL RECEIVER
C     SUM RAY HITS ON APPROPIATE RECEIVER
      GO TO (400,500,600),IRCVR
C
  400 YHIT=DOTER(RHIT,UCP)
      ZHIT=DOTER(RHIT,UCN)
      FRAC=ATAN2(ZHIT,YHIT)
      IF(FRAC.LT.0.0) FRAC=FRAC+2.0*PI
      XH=QHIT
      IX=INT(XH/DELX)+1
      IY=INT(FRAC/DELY)+1
       AFLUX(IX,IY)=AFLUX(IX,IY) + CONVP
      NFLUX(IX,IY)=NFLUX(IX,IY)+1
      RETURN
C     PLANAR(FLAT) RECEIVER
C
  500 XH =QHIT
      YH =DOTER(RHIT,UCP)
C     TRANSFORM CO-ORDINATES
C
      YH=YH+RW*0.5
C
C      COUNT HITS
      IF(ICONC.EQ.9) YH=YH-0.5*RW
      IX=INT(XH/DELX)+1
      IY=INT(YH/DELY)+1
       AFLUX(IX,IY)=AFLUX(IX,IY) + CONVP
      NFLUX(IX,IY)=NFLUX(IX,IY)+1
      RETURN
C     CONICAL RECEIVER
C
  600 YH=DOTER(RHIT,US1)
      ZH=DOTER(RHIT,US2)
      PHI=ATAN2(YH,ZH)
C NORMALIZE PHI
      IF(PHI.LT.0.) PHI=PHI+2.*PI
```

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2-18-79   08.936

      C
      C     FOR CONICAL RECEIVERS
            IY=INT( PHI/DELY)+1
            IX=INT(GHIT/DELX)+1
             AFLUX(IX,IY)=AFLUX(IX,IY) + CONVP
            NFLUX(IX,IY)=NFLUX(IX,IY)+1
            RETURN
      C     CALCULATE POWER AND ENERGY IN THE ZONE
      C     AND KEEP A RUNNING ACCUMULATIVE TOTAL
      C
      C     FLUX ON RECEIVER
        707 DO 710 I=1,NXZ
            DO 710 J=1,NYZ
       710  AFLUX(I,J)=AFLUX(I,J)*COS(OFFSUN)*AMIR/(AZONE(I,J)*NDRAW)
      C     WRITE OUTPUT
      C
            WRITE(6,7010)
            NPTS=NYZ/10+1
            DO 800 JB=1,NPTS
            IFRS(JB)=10*(JB-1)+1
        800 ISND(JB)=10*JB
            IF(ISND(NPTS).GT.NYZ) ISND(NPTS)=NYZ
            IF(IFRS(NPTS).GT.ISND(NPTS)) NPTS=NPTS-1
            DO 820 IPTS=1,NPTS
            K1=IFRS(IPTS)
            K2=ISND(IPTS)
            WRITE(6,7020)
            DO 810 NX=1,NXZ
        810 WRITE(6,7030) (NFLUX(NX,NY),NY=K1,K2)
        820 CONTINUE
            DO 840 IPTS=1,NPTS
            WRITE(6,7040)
            K1=IFRS(IPTS)
            K2=ISND(IPTS)
            DO 830 IX=1,NXZ
        830 WRITE(6,7050) (AFLUX(IX,IY),IY=K1,K2)
        840 CONTINUE
       7010 FORMAT(1H1,////,30X,17HHIT AND FLUX MAPS)
       7020 FORMAT(////,10X,5HY....,15X,13HHITS IN ZONES,
           +   /,6X,1HX,2(/,6X,1H.))
       7030 FORMAT(/,5X,10I8)
       7040 FORMAT(////,29X,17HPWR/M**2 IN ZONES)
       7050 FORMAT(/,5X,10F9.4)
            RETURN
            END

E   11-27-78 *** 14.4 ***

E (SEC)       .70          LINES/MINUTE 12935

E  NO   DIAGNOSTICS IN ABOVE COMPILATION
```

18-79 08.941

```
      SUBROUTINE RDATA(NMAT,NDRAW,SDR1,SDR2,REFLTOT,REFL,NCHECR)
C
C   THIS ROUTINE CONTAINS MATERIALS DATA(BASED ON PETIT &
C BUTLER'S MEASUREMENTS USING BI-DIRECTIONAL REFLECTOMETRY) FOR
C 10 MATERIALS.  DATA INCLUDES-
C   REFLECTANCE VALUES FOR 2 NORMAL DISTR.
C            REFL1,REFL2
C          SDRM1,SDRM2                 STANDARD DEVIATIONS O REFL. PROFILE CURV
C           FOR MATERIALS.
C         NMAT    INDEX FOR MATERIAL BEING USED IN SIMULATION
C         REFLTOT                 TOTAL REFLECTANCE VALUE FOR MATERIAL
C
C   DATA IS CONTAINED WITHIN THE  PROOGRAM FOR THE  FOLLOWING
C MATERIALS.
C         NMAT                MATERIAL
C         ----                --------
C           1                 ALCOA ALZAK TYPE 1 SPECULAR;ORIENTED
C                              PARALLEL TO ROLLING MARKS
C           2                 BOEING FRONT SURFACE ALUMINIZED MYLAR
C           3                 CORNING 0317 GLASS(1.5MM TH) - EVAPORATED
C                              SILVER COATING
C           4                 GARDNER LAMINATED LOW IRON SHEET GLASS - SILVERED
C                              (3.35MM TH)
C                             KINGSTON KINGLUX NO. C4 POLISHED ALUMINIUM
C           5                  ORIENTED PERPENDICULAR TO ROLLING MARKS
C                             METAL FABRICATIONS - TYPE 3002 HIGH PURITY
C           6                  ALUMINUM
C           7                 3M SCOTCHCAL 5400
C           8                 3M FEK-163
C           9                 SHELDAHL ALUMINIZED 2MIL FEP TEFLON(G405600)
C          10                 SHELDAHL SILVERED 2MIL FEP TEFLON(G400300)
      DIMENSION SDRM1(10),SDRM2(10),REFL1(10),REFL2(10)
      DATA SDRM1/0.00029,0.00025,0.00025,0.00005,0.00037,0.0014,
     + 0.00190,0.0009,0.0013,0.00077/
      DATA REFL1/0.62,0.90,0.95,0.92,0.65,0.44,0.86,0.86,
     + 0.80,0.77/
      DATA SDRM2/0.0071,0.0,0.0,0.,0.0161,0.0103,0.,0.,0.0309,
     + 0.0069/
      DATA REFL2/0.27,0.,0.0,0.,0.23,0.43,0.,0.,0.07,0.28/
      NCHECR=0
      SDR1=SDRM1(NMAT)*0.5
      SDR2=SDRM2(NMAT)*0.5
      REFL=REFL1(NMAT)
      REFLTOT=REFL1(NMAT) + REFL2(NMAT)
      IF(SDR2.GT.0.0) NCHECR=INT(REFL/REFLTOT*FLOAT(NDRAW))
      RETURN
      END
```

11-27-78 *** 14.4 ***

(SEC) .35 LINES/MINUTE 7862

'18-79 08.937

```
C
      SUBROUTINE SUN(IDWN)
      COMMON/RUNC/NDRAW,TAZ,TEL,TIME,IDAY,XLAT,XLONG,ICONC,
     + NMAT,DRAD,MISR,TZONE,MAPS,RPWR,AMIR,NMATL
      DIMENSION S(2)
C
C   THIS ROUTINE SOLVES FOR THE SUN AZIMUTH AND ELEVATION ANGLES(TAZ,TEL
C   FOR A SPECIFIED MON,MDAY,TIME AT LATITUDE XLAT ETC......
C
      DIMENSION A0(2) /.302,-.0002/ ,
     1A1(2) /-22.93,.4197/ ,
     2A2(2) /-.229,-3.2265/ ,
     3A3(2) /-.243,-.0903/ ,
     4B1(2) /3.851,-7.351/ ,
     5B2(2) /.002,-9.3912/ ,
     6B3(2) /-.055,-.3361/
C     XLAT= LATITUDE,DEGREES(+NORTH,-SOUTH)
C     XLONG= LONGITUDE,DEGREES(+WEST,-EAST)
C     TZONE= TIME ZONE NUMBER
C                 STANDARD  TIME          DAYLIGHT  SAVING TIME
C       ATLANTIC       4                        3
C       EASTERN        5                        4
C       CENTRAL        6                        5
C       MOUNTAIN       7                        6
C       PACIFIC        8                        7
C     IDAY= DAYS(FROM START OF YEAR)
C     TIME= HOUR AFTER MIDNIGHT
C     TEL=SOLAR ALTITUDE ANGLE, RADIANS                                 A330
C     TAZ=SOLAR AZIMUTH ANGLE, RADIANS
C     DECL=SUN DECLINATION ANGLE DELTA, RADIANS
C     EQTIME=EQUATION OF TIME ,HOURS
C     H=SOLAR HOUR ANGLE OMEGA, RADIANS
      DATA RPH/0.261799388/,RAD/.0174532925/
C     COMPUTE DECLINATION, EQUATION OF TIME
C     AND SUN RISE AND SUN SET TIMES .                              MAR16
  210 IDWN=0
      X=.017167173*FLOAT(IDAY)
      C1=COS(X)
      C2=COS(2*X)
      C3=COS(3*X)
      S1=SIN(X)
      S2=SIN(2*X)
      S3=SIN(3*X)
      DO 10 K=1,2
   10 S(K)=A0(K)+A1(K)*C1+A2(K)*C2+A3(K)*C3+B1(K)*S1+B2(K)*S2
     1+B3(K)*S3
      DECL = S(1)*RAD
      EQTIME=S(2)*.0166666667
      Y = DECL
      YY=XLAT*RAD
      HP=-TAN(Y)*TAN(YY)
C     COMPUTE DAILY CONSTANTS
      CY=COS(Y)
```

18-79   08.937

```
                  SY=SIN(Y)
                  CYY=COS(YY)
                  SYY=SIN(YY)
                  HP1 = ARCOS(HP)
                  X1=ABS(HP1)
      C     COMPUTE SOLAR HOUR ANGLE
                  H = -RPH*(TIME-12+TZONE+EQTIME) + XLONG*RAD
      C     IS THE SUN UP
                  X2=ABS(H)
                  IF (X1-X2) 130,130,20
      C     COMPUTE SOLAR DIRECTION COSINES
               20 SOLX=SYY*SY+CYY*CY*COS(H)
                  SOLY = CY*SIN(H)
                  SOLZ=-SYY*CY*COS(H)+CYY*SY
      C           COMPUTE SOLAR ALTITUDE AND AZIMUTH
               50 TEL=ARSIN(SOLX)
                  AZFAC=SOLZ/COS(TEL)
                  IF(ABS(ABS(AZFAC)-1.0).LT.2.E-7) AZFAC=SIGN(1.0,AZFAC)
                  TAZ=(3.14159265-ARCOS(AZFAC))*SIGN(1.0,H)
                  GO TO 150
              130 IDWN=1
              150 RETURN
                  END
```

11-27-78 *** 14.4 ***

(SEC)   .47   LINES/MINUTE 9597

NO DIAGNOSTICS IN ABOVE COMPILATION
WERE USED FOR THIS COMPILATION

18-79 08.937

```
      C
            SUBROUTINE SUN2(AC,USP,DRAD)
      C
      C    THIS ROUTINE PERTURBS SUN VECTOR UR TO ACCOUNT FOR THE FINITE SUN SI
      C
            COMMON/VECTOR/ULE(3),ULV(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
            COMMON/SUNC/ UST1(3),UST2(3)
            DIMENSION USP(3)
            R1=FLAT(0.0)
            R2=FLAT(0.0)
            CRN=COS(6.2831853*R1)
            SRN=SIN(6.2831853*R1)
            CALL LIMDR(R2,3,ROE)
      C
      C     USE SUN WITH LIMB DARKENING ONLY
      C
            CP=COS(ROE*DRAD)
            SP=SIN(ROE*DRAD)
            DO 30 I=1,3
         30 USP(I)=CP*US(I) + SP*CRN*UST1(I) + SP*SRN*UST2(I)
      C
      C     CHECK FOR PERTURBED RAY WITHIN LIMITS OF
      C     SUN DISK
      C     DEBUG PURPOSES
      C
      C     CHEC = DOTER(US,USP)
      C     AC=ARCOS(CHEC)/DRAD
            RETURN
            END
```

11-27-78 *** 14.4 ***

(SEC) .33 LINES/MINUTE 5185

NO DIAGNOSTICS IN ABOVE COMPILATION
WERE USED FOR THIS COMPILATION

18-79 08.937

```
      SUBROUTINE SUN1(TAZ,TEL)
C
C     SET SUN CENTER VECTOR "US"
C
      COMMON/VECTOR/ULE(3),ULV(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
      COMMON/SUNC/ UST1(3),UST2(3)
      CA = COS(TAZ)
      SA = SIN(TAZ)
      CE = COS(TEL)
      SE = SIN(TEL)
      DO 10 I=1,3
   10 US(I) = CA*CE*ULS(I) + SA*CE*ULE(I) + SE*ULV(I)
      COFF=DOTER(ULV,US)
      SOFF=SQRT(1.0 - COFF*COFF)
      DO 11 I=1,3
   11 UST1(I)=(ULV(I)-COFF*US(I))/SOF
      CALL CROSS(UST1,US,UST2)
C
C   UST1,UST2 AND US ARE TRIAD DN SUN FACE
C
C     CHECK FOR ORTHONORMAL VECTORS
      DUM=DOTER(UST1,US)
      IF(DUM .GT. 0.00001) WRITE(6,60) DUM
   60 FORMAT(//,5X,20HERRDR IN SUN TANGENT,2X,4HDUM=,F10.7)
      RETURN
      END
```

11-27-78 *** 14.4 ***

TSEC) .33 LINES/MINUTE 4694

NO DIAGNOSTICS IN ABOVE COMPILATION
WERE USED FOR THIS COMPILATION

18-79   08.938

```
      SUBROUTINE RNORM(D1,ICOUNT)
C     THIS ROUTINE GENERATES PPAIRS OF INDEPENDENT NORMAL RANDOM DEVIATES
C     MEAN=0.STANDARD DEVIATION=1
C     D1 AND D2 ARE NORMALLY DISTRIBUTED ON THE INTERV      NUMBER?
C     IT ASSUMES A FUNCTION FLAT(X) WHICH RETURNS A RANDOM NUMBER
C     EVENLY DISTRIBUTED ON (0,1)
C
      IF(ICOUNT .GT. 0) GO TO 30
   10 X=FLAT(0.0)
      Y=2.0*FLAT(0.0)-1.0
      XX=X*X
      YY=Y*Y
      S=XX+YY
      IF (S-1.0) 20,20,10
   20 XL=SQRT(-2.0*ALOG(FLAT(0.0)))/S
      D1=(XX-YY)*XL
      D2=2.0*X*Y*XL
      RETURN
   30 D1=D2
      RETURN
      END
```

11-27-78 *** 14.4 ***

(SEC)   .31   LINES/MINUTE 4046

NO DIAGNOSTICS IN ABOVE COMPILATION
WERE USED FOR THIS COMPILATION

18-79   08.938

```
      SUBROUTINE CROSS(A,B,C)
      DIMENSION A(3),B(3),C(3)
      C(1)=A(2)*B(3)-A(3)*B(2)
      C(2)=-A(1)*B(3)+A(3)*B(1)
      C(3)=A(1)*B(2)-A(2)*B(1)
      RETURN
      END
```

11-27-78 *** 14.4 ***

(SEC)   .27   LINES/MINUTE   1537

NO   DIAGNOSTICS IN ABOVE COMPILATION
WERE USED FOR THIS COMPILATION

```
18-79   08.940

      SUBROUTINE SNELL(UREFL,UNORM,USOL)
      DIMENSION UREFL(3),UNORM(3),USOL(3)
C
C    THIS SUBROUTINE SOLVES FOR A REFLECTED RAY USING SNELL'S LAW
C     INPUTS ARE --
C                            UNORM        THE NORMAL VECTOR AT THE HIT POINT
C                                         (DIRECTED OUTWARD FROM SURFACE)
C                            USOL          THE INCOMING SUN RAY VECTOR
C                                         (DIRECTION FROM SURFACE TO SUN)
C     OUTPUT IS --
C                            UREFL        THE REDIRECTED (REFL.) RAY VECTOR
C
      FACTRUN=2.0*DOTER(UNORM,USOL)
      DO 20 I=1,3
   20 UREFL(I)=FACTRUN*UNORM(I) - USOL(I)
      RETURN
      END
```

11-27-78 *** 14.4 ***

(SEC) .28   LINES/MINUTE 3590

NO DIAGNOSTICS IN ABOVE COMPILATION

WERE USED FOR THIS COMPILATION

```
18-79   08.939

              FUNCTION RAYVAL(NREFL,REFL)
              NRP1=NREFL+1
              RAYVAL=1.0
              DO 7575 I=1,NRP1
         7575 RAYVAL =RAYVAL*REFL
              RETURN
              END
```

```
11-27-78 *** 14.4 ***

(SEC)      .26          LINES/MINUTE  1556

NO   DIAGNOSTICS IN ABOVE COMPILATION
WERE USED FOR THIS COMPILATION
```

```
18-79   08.938

                SUBROUTINE LIMDR(YRN,LIMC,ROERN)
      C     THIS SUBROUTINE  GENERATES THE INTENSITY DISTRIGUTION OF ENERGY
      C     ACROSS THE SURFACE OF THE SUN.  IT HAS 3 DIFFERENT SUN MODES
      C     LIMC=1  FLAT SUN
      C     LIMC=2  SUN WITH LIMB DARKENING AND SOLAR RADIATION
      C     LIMC=3  SUN WITH  LIMB DARKENING
                GO TO (21,22,23),LIMC
         21     ROERN=.2665*SQRT(YRN)
                RETURN
         22     Y=YRN*16.98
                I=INT(Y/7.5)+1
                GO TO (31,32,33),I
         31     ROERN=0.06408*(Y**.4878)
                RETURN
         32     ROERN=0.010956*Y+0.092413
                RETURN
         33     IF (Y.GT.16.7) GO TO 34
                ROERN=0.353-0.038345*(SQRT(-193.2-Y*Y+28.28*Y))
                RETURN
         34     ROERN=0.3486*Y-5.5007
                RETURN
         23     Y=YRN*15.94
                IF(Y.GT.7.) GO TO 41
                ROERN=0.06408*(Y**.4878)
                RETURN
         41     ROERN=.010956*Y+0.092413
                RETURN
                END

11-27-78 *** 14.4 ***

(SEC)       .34          LINES/MINUTE  4901

 NO   DIAGNOSTICS IN ABOVE COMPILATION
 WERE USED FOR THIS COMPILATION
```

```
18-79   08.939

              FUNCTION DOTER(V1,V2)
              DIMENSION V1(3),V2(3)
              DOTER = 0.0
              DO 10 I = 1,3
           10 DOTER = DOTER + V1(I)*V2(I)
              RETURN
              END

11-27-78 *** 14.4 ***

(SEC)      .27          LINES/MINUTE  1502

 NO   DIAGNOSTICS IN ABOVE COMPILATION
 WERE USED FOR THIS COMPILATION
```

```
18-79   08.940

              SUBROUTINE LREFR(N1,N2,ULN,UIN,UREFR,NCHEC)
      C    THIS ROUTINE SOLVES FOR THE REFRACTED RAY VIA THE LAW OF REFRACTION.
      C       INPUTS ARE -- N1          THE INDEX OF REFRACTION FOR UIN
      C                      N2          THE INDEX OF REFRACTION FOR UREFR
      C                      ULN         UNIT LENS NORMAL VECTOR
      C                      UIN          UNIT INCOMING RAY VECTOR
      C       OUTPUT IS --
      C                       UREFR        THE REDIRECTED RAY VECTOR
      C
      C  ULN AND UIN MUST POINT IN SAME DIRECTION FROM LENS SURFACE
              REAL N1,N2
              DIMENSION ULN(3),UIN(3),UREFR(3)
              NCHEC=0
              TH1=ACOS(DOTER(ULN,UIN))
              IF(TH1.LT.0.00001) GO TO 20
              STH2=(N1/N2)*SIN(TH1)
              IF(STH2.GT.1.0) GO TO 80
              CTH2=SQRT(1.-STH2*STH2)
              STH1=SIN(TH1)
              CTH1=COS(TH1)
              DO 10 I=1,3
           10 UREFR(I)=-STH2*UIN(I)/STH1+(STH2*CTH1/STH1-CTH2)*ULN(I)
              RETURN
           20 DO 30 I=1,3
           30 UREFR(I)=-UIN(I)
              RETURN
      C  INCOMING RAY ANGLE W.R.T. SURFACE NORMAL IS BEYOND CRITICAL
           80 NCHEC=1
              RETURN
              END

 11-27-78 *** 14.4 ***

(SEC)       .34          LINES/MINUTE  5146

NO    DIAGNOSTICS IN ABOVE COMPILATION
WERE USED FOR THIS COMPILATION
```

18-79 08.941

```
      SUBROUTINE LDATA(NMAT,WAVEL,NAIR,NLENS)
      REAL NAIR,NLENS
C
C THIS ROUTINE CONTAINS DATA FOR THE REFRACIVE INDEX
C  FOR AN ACRYLIC LENS VS. WAVELENGTH.
C THE DATA COMES FROM          "NOVEL SOLAR COLLECTORS USING A LARGE
C     CIRCULAR FRESNEL LENS CONCENTRATOR"  FINAL REPORT .
C     MCDONNELL DOUGLAS COMPANY. (SAND 78-7023). MAY 1978
C VARIABLES ARE --
C        WAVEL    WAVELENGTH OF SOLAR RAY
C        NMAT     THE MATERIAL IDENTIFIER.  NMAT=11 IN THIS CASE
C        NLENS    THE INDEX OF REFRACTION FOR THE WAVELENGTH
C        NAIR     THE INDEX OF REFRACTION FOR AIR
C        DW1(I)
C        DW2(I)   THE UPPER AND LOWER BOUNDS FOR EACH
C              VALUE OF RINDX(THE INDICES OF REFRACTION)
C
      DIMENSION DW2(19),RINDX(19)
      DATA DW2/375.,425.,470.,510.,550.,590.,630.,670.,715.,765.,
     + 820.,895.,980.,1065.,1180.,1385.,1600.,1880.,2180./
      DATA RINDX /1.50661,1.50142,1.49797,1.49505,1.49261,1.49057,
     + 1.48889,1.48752,1.48616.1.48512,1.48421,1.48332,1.48282,
     + 1.48241,1.48185,1.48058,1.47992,1.47956,1.47956/
      NLENS=0.0
      NAIR=1.0
      DO 100 I=1,19
      IF(WAVEL.GE.DW2(I).AND.WAVEL.LT.DW2(I+1)) NLENS=RINDX(I)
      IF(NLENS.GT.0.) GO TO 105
  100 CONTINUE
  105 RETURN
      END
```

11-27-78 *** 14.4 ***

(SEC) .33 LINES/MINUTE 5607

NO DIAGNOSTICS IN ABOVE COMPILATION
WERE USED FOR THIS COMPILATION

18-79 08.943

```
      SUBROUTINE TRACK(TAZ,TEL)
C    THIS ROUTINE SETS THE COLLECTOR POSITION VECTOR
C     TRIAD FOR ALL CONCENTRATORS AND CALCULATES THE OFF AXIS
C    SUN ANGLE BASED UPON THE PERFECT SUN VECTOR.
C    NEEDED VARIABLES INCLUDE --
C       NAXIS = 0 -- STATIONARY CONCENTRATOR
C       NAXIS= 1 -- ONE AXIS TRACKING
C       NAXIS = 2 TWO AXIS TRACKING
C       TAZ,TEL AZIMUTH AND ELEVATION ANGLE OF THE SUN
C
      COMMON/RPIC/FL,TILT,DX,DY1,DY2,ALEN,FLEN,FWID,NCO2,XAX,NFAC,
     1 NCA,DY,XLF,JRPI(20),RR(20),CR(20),NRZ,RMAX
      COMMON/TRAC/NAXIS,TILTANG,OFFSUN,THETAAX,DTRACRL,DTRACAZ,IRPI
      COMMON/VECTOR/ULE(3),ULV(3),ULS(3),UCN(3),UCA(3),UCP(3),US(3)
      DIMENSION DUM(3)
      IF(IRPI.EQ.1) GO TO 200
      IF(NAXIS.EQ.2) THETAAX=-TAZ+DTRACAZ
      THETARL=ATAN2(COS(THETAAX+TAZ),TAN(TEL)) + DTRACRL
      IF(NAXIS.EQ.0) THETARL=TILTANG
      SAX=SIN(THETAAX)
      CAX=COS(THETAAX)
      SRL=SIN(THETARL)
      CRL=COS(THETARL)
      DO 40 I=1,3
      UCA(I)=CAX*ULE(I) + SAX*ULS(I)
      UCP(I)= -SAX*CRL*ULE(I) + CAX*CRL*ULS(I) - SRL*ULV(I)
      UCN(I)=-SRL*SAX*ULE(I) + SRL*CAX*ULS(I) + CRL*ULV(I)
   40 CONTINUE
      OFFSUN=ACOS(DOTER(UCN,US))
      OFFSUN=OFFSUN*SIGN(1.,THETAAX+TAZ)
      RETURN
  200 SA=SIN(TAZ)
      CA=COS(TAZ)
      ST=SIN(TILT)
      CT=COS(TILT)
      DO 10 I=1,3
   10 DUM(I)=CA*ULS(I) + SA*ULE(I)
      DO 20 I=1,3
      UCN(I)=CT*ULV(I) + ST*DUM(I)
      UCP(I)=CT*DUM(I) - ST*ULV(I)
   20 UCA(I)=CA*ULE(I) - SA*ULS(I)
      OFFSUN=ACOS(DOTER(UCN,US))
      RETURN
      END
```

11-27-78 *** 14.4 ***

(SEC) .42 LINES/MINUTE 6250

NO DIAGNOSTICS IN ABOVE COMPILATION
WERE USED FOR THIS COMPILATION

18-79 08.943

```
      SUBROUTINE ERRNORM(SDS,SDR,UN,UT,UCA,UNP,PSM)
      DIMENSION UN(3),UT(3),UCA(3),UNP(3)
      DATA NORCT/0/
      SD=SQRT(SDS*SDS + SDR*SDR)
      CALL RNORM(R1,NORCT)
      NORCT=NORCT+1
      IF(NORCT.EQ.2) NORCT=0
      PH1=SD*R1 + PSM
      PH2=FLAT(0.0)*6.2831853
      C1=COS(PH1)
      C2=COS(PH2)
      S1=SIN(PH1)
      S2=SIN(PH2)
      DO 90 I=1,3
   90 UNP(I)=C1*UN(I) + S1*(C2*UT(I) + S2*UCA(I))
      RETURN
      END
```

11-27-78 *** 14.4 ***

(SEC) .32 LINES/MINUTE 3157

NO DIAGNOSTICS IN ABOVE COMPILATION
WERE USED FOR THIS COMPILATION

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