An End-to-End Model of the
Earth Radiation Budget Experiment (ERBE)
Earth-Viewing Nonscanning Radiometric Channels

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(ABSTRACT)

The Earth Radiation Budget Experiment (ERBE) active-cavity radiometers are used to measure the incoming solar, reflected solar, and emitted longwave radiation from the Earth and its atmosphere. The radiometers are carried by the National Aeronautics and Space Administration's Earth Radiation Budget Satellite (ERBS) and the National Oceanic and Atmospheric Administration's NOAA-9 and NOAA-10 spacecraft. Four Earth-viewing nonscanning active-cavity radiometers are carried by each platform. Two of the radiometers are sensitive to radiation in the spectral range from 0.2 to 50 μm, while the other two radiometers are sensitive to radiation in the spectral range from 0.2 to 5.0 μm. Each set of radiometers comes in a wide-field-of-view (WFOV) and a medium-field-of-view (MFOV) configuration. The cavities of the shortwave (visible) radiometers are covered with a Suprasil® hemispherical dome to filter out the incoming longwave radiation.

Knowledge of the optical and physical properties of the radiometers allows
their responses to be predicted using a low-order physical model. A high-level, dynamic electrothermal end-to-end model which accurately predicts the radiometers dynamic output has also been completed. This latter model is used to numerically simulate the calibration procedures of the actual instruments. With calibration of the end-to-end model complete, a simulation of a phenomena referred to as the "solar blip" is conducted to investigate the instruments' responses to steep transient events. The solar blip event occurs when direct solar radiation is briefly incident to the active-cavity radiometric channels as the spacecraft passes into and out of the Earth's shadow.
Acknowledgments

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To my wife Anne I want to say thank you for your unwavering support, patience and understanding over the course of this research. Finally, to my family, thank you for the values and ideals which you have presented me, allowing me to go as far as I have.
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Nomenclature

A  Surface area (m²)
A_F  Coefficient associated with the field-of-view limiter temperature (W/m²K)
A_R  Coefficient associated with the reference cavity heater voltage (W/m²V²)
A_V  Coefficient associated with the active cavity heater voltage (W/m²V²)
B  Offset term which calibrates the instruments by means of internal calibration sources (W/m²)
C₁  Constant used in Planck's radiation distribution function (5.9544 x 10⁸ W-μm⁴/m²)
C₂  Constant used in Planck's radiation distribution function (1.4338 x 10⁴ µm-K)
Dₖ  Monochromatic radiation distribution factor (-)
E  Irradiance at satellite altitude (W/m²)
e  Emissive power (W)
F  Radiation view factor (-)
G  Volumetric heat generation (W/m³)
$N_{ik}$  Number of energy bundles emitted by element i, in wavelength interval k (-)

$N_{jk}$  Number of energy bundles emitted by element i which are absorbed by element j, in wavelength interval k (-)

$n$  Index of refraction for a participating medium (-); time step (-)

$Q$  Heat input (W)

$R$  Electrical resistance (Ω); Radius (m); Random number (-); Reflectivity ratio (-)

$T, \Delta T$  Temperature, temperature drop between the active and reference resistance temperature detectors (K)

$t, \Delta t$  Time, time increment (s)

$U$  Unit vector (-)

$V$  Electrical potential (V)

$V_b$  Bias voltage (V)

$V_0$  Bridge supply voltage (V)

$V_1$  Bridge output voltage (V)

$V_2$  Voltage across the heater wire (V)

$x, y, z$  Cartesian coordinates (m)

**Greek**

$\alpha$  Absorptivity (-); linear temperature coefficient of resistance (1/K)

$\delta$  Material thickness (m)

$\varepsilon$  Emissivity (-)
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta$</td>
<td>Zenith angle (rad); Cone angle (rad); Brewster angle (rad)</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>Monochromatic absorption coefficient (1/m)</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Wavelength ($\mu$m)</td>
</tr>
<tr>
<td>$\rho^d$</td>
<td>Diffuse component of reflectivity (-)</td>
</tr>
<tr>
<td>$\rho^s$</td>
<td>Specular component of reflectivity (-)</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>Stefan-Boltzmann constant ($5.6696 \times 10^{-8}$ W/m²K)</td>
</tr>
<tr>
<td>$\tau$</td>
<td>Transmissivity (-)</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Azimuthal angle (rad)</td>
</tr>
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</table>
1.0 Introduction

1.1 The Earth Radiation Budget

The ability of man to influence his surroundings on a global scale is a phenomenon unique to the twentieth century. With the advent of industrialization has come the consequence of releasing vast quantities of pollutants into the atmosphere. As a result, atmospheric composition has become dynamic, with climatic consequences that are not yet well understood. Measurement of the radiative exchange between the planet Earth and its space environment represents one of the fundamental activities for understanding the driving mechanisms of our planet's weather and climate.

The Earth radiation budget, or the energy balance of the Earth-atmosphere-ocean system, is defined as the difference between the absorbed solar radiation
and the radiation emitted from the Earth and its atmosphere. Determination of the Earth's radiation budget allows scientists to better understand the dynamic behavior of our planet's climatic system [1,2]. Contributions to the Earth's radiation budget are shown in Figure 1.

1.2 Earth Radiation Budget Measurements

The following historical overview has been obtained from Hunt et al. [3,4].

The first serious attempts at estimating the Earth radiation budget components on the basis of measurements were not made until well into the nineteenth century. Pouillet obtained an estimate of the solar constant of 1211 W/m² in 1837. However, it was not until the first decade of the twentieth century that the initial attempt to determine the components of the Earth radiation budget, on the basis of observational data, were made. These early efforts suffered from severe limitations in geographical sampling of climatic observations.

Simpson was the first to recognize, during the 1920's, the importance of the spectral distribution of water vapor absorption and to calculate the distribution of incoming and outgoing radiation as a function of latitude and season, making use of observed cloud distributions.

The 1940's and 50's marked a time of significant developments in atmospheric physics that led to increased knowledge of the Earth radiation budget.
Aircraft studies during this period provided much needed data on cloud physics.

With the onset of the 60's, man was about to enter the space-age, and with it the era of satellite meteorology. The first satellite dedicated to the determination of the Earth radiation budget was Explorer 7, launched on October 13, 1959. The radiometers on Explorer 7 consisted of black and white hemispheres containing thermistor bolometers attached to rectangular mirrors on the equator of the spacecraft. The reflected image of each hemisphere in the mirrors made the radiometers appear as "spheres" in space.

The first imaging system to be carried into space was launched on April 1, 1960, on board the TIROS-1 satellite, the first in a series of seven satellites. The Television Infrared Observation Satellites (TIROS) missions provided four years of Earth radiation budget data and included the first such satellite to provide a continuous record of data for one year, TIROS 7.

The most successful of the early observational systems were the Nimbus-6 and Nimbus-7 satellites. These satellites were launched in 1975 and 1978, respectively, and together provided more than a decade of continuous Earth radiation budget data [4].

Advancements which have influenced the evolution of Earth radiation budget instrumentation may be broken down into four broad categories: (1) spacecraft power budgets, on-board data storage, satellite stabilization, and attitude control; (2) viewing angles of nonscanning medium field-of-view and wide field-of-view
radiometers and scanning medium and high-resolution radiometers; (3) spectral isolation of the shortwave and longwave components; and (4) on-board calibration standards for both longwave and shortwave detectors.

The current Earth Radiation Budget Experiment (ERBE) is the first program to incorporate all of these advancements.

1.3 The Earth Radiation Budget Experiment

The Earth Radiation Budget Experiment (ERBE) was begun by the National Aeronautics and Space Administration (NASA) in 1979 in order to quantify the radiative interaction between the Earth and its space environment. The radiation from the sun which is absorbed by the Earth and eventually re-emitted is the energy source which drives the motions of the Earth's atmosphere and oceans and which determines our weather and climate. The goal of ERBE is to monitor this interaction over a long time scale and over specific geographical regions [5].

The ERBE mission consists of a three-satellite platform. The first ERBE instruments were launched on October 5, 1984, aboard the National Aeronautics and Space Administration's Earth Radiation Budget Satellite (ERBS). The remaining radiometric instruments were launched on December 5, 1984, and September 17, 1986, aboard the National Oceanic and Atmospheric Administration's NOAA-9 and NOAA-10 satellites. Each radiometric package
contains four Earth-viewing nonscanning active-cavity radiometers, three scanning thermistor bolometer radiometers, and a solar monitor. Inflight stability of all radiometric channels is monitored by internal calibration sources. Combined, these radiometers can quantitatively describe the spectral and spatial distribution of the Earth's radiative field.

The Earth-viewing nonscanning active cavity radiometers are described in detail in Chapter 2. The scanning thermistor bolometer radiometers and solar monitors are described elsewhere [6,7].

ERBE has established the benchmark by which the success of future Earth radiation budget measurement missions will be judged. Definitive answers to several important scientific questions have been obtained throughout the mission. Two such questions answered by ERBE have been the net cooling effect which clouds and volcanic activity produce on our climate system [8-11] and the correlation of solar activity to global-average atmospheric temperature change [12,13].

1.4 The Thermal Radiation Group

Under the direction of Professor J. R. Mahan, graduate students have been studying the dynamic electrothermal properties of instruments designed to measure the Earth radiation budget since the early 1970's. The Thermal Radiation Group
originally studied the theoretical radiative characteristics of spherical balloon-type detectors [14-16]. However, with the development of more powerful computers in the early eighties the group turned their focus towards applied numerical modelling of more complex radiative enclosures. Eskin [17] was the first student in the group to utilize a Monte-Carlo-based ray-trace technique. Eskin's work modeled the radiative exchange inside a conical cavity such as those on the ERBE mission. Gardiner [18] studied the operation of ERBE-type active cavity radiometers at cryogenic temperatures. Tira [19] was the first to utilize the Monte-Carlo ray-trace technique in conjunction with a finite-element model of an active-cavity radiometer to determine the electrical response of the detector to varying radiative inputs.

Thus began the current focus of the Thermal Radiation Group: completion of end-to-end models for space-based radiometric channels. These models usually begin with a radiative and optical analysis of the instrument in question using a Monte-Carlo ray-trace technique. The results from the ray trace are then implemented into either a finite-element or finite-difference heat conduction code which characterizes the electrothermal behavior of the instrument to various radiative inputs. Once validated by successfully processing actual data product, these models may be used to investigate the sources of any anomalous behavior of the actual instruments.

Research concluded so far includes the work of Fanney [14], Rasnic [15], Passwaters [16], Eskin [17], Gardiner [18], Tira [19-22], Kowsary [23], Meekins
[24], Haeffelin [25-28], Bongiovi [29], Chapman [30], Villeneuve [31], and the current author.

1.5 Motivation and Goals

This thesis presents the effort involved in the development of a complete end-to-end model of the Earth-viewing nonscanning active-cavity radiometric channels developed for the Earth Radiation Budget Experiment. The first step toward completion of this goal was the work completed by Eskin [17] in which he characterized the transient thermal behavior of the ERBE active cavity. Tira [19,22] advanced Eskin’s work by incorporating a two-dimensional finite-element description of the electrothermal response of the active cavity. Haeffelin [26,28] characterized the optical front end of these channels, completing a transient model of heat conduction in the hemispherical filter dome.

The goal of the current effort is to integrate the optical and radiative front end model created by Haeffelin with the electrothermal model of the active cavity created by Tira. This goal is met by adding the active cavity geometry to the radiative model of the front end completed by Haeffelin. This results in a complete description of the radiative exchange within the instrument. This description can be used as input for radiative boundary conditions in both the finite-difference heat conduction code of the hemispherical filter dome completed by Haeffelin and the
finite-element electrothermal characterization of the active cavity completed by Tira. The resulting high-level dynamic electrothermal model would then be formulated at a level which would permit the assessment of changes in the geometry, surface temperature distributions, or other thermophysical properties on the response of the instrument.

In order to demonstrate the accuracy of the resulting high-level end-to-end model it is calibrated numerically with procedures identical to those for the actual instrument. This simulated calibration will allow the model's response to a given radiative scene to be characterized in such a way that the performance of the actual radiometers may be assessed.

In addition, a low-order physical model of the radiometers is used to estimate the uncertainty in the instrument data product. This low-order physical model is also used to characterize the instruments through the use of first-principle physics. Thus three types of instrument calibration are completed: ground calibration of the actual instruments, a first-principle approach using a low-order physical model, and a numerically simulated ground calibration using the end-to-end model.

Further, a numerical simulation of the so-called "solar blip" phenomenon, an event in which an instrument is rapidly subjected to an excess of energy when the sun briefly enters its field-of-view during the satellite's entry and exit from the Earth's shadow, is conducted, allowing the responses of the actual radiometers to be studied.
2.0 The Earth-Viewing, Nonscanning, Active-Cavity Radiometer

2.1 Radiometer Description and Operation

Figures 2 and 3 show a cross-section and an assembly drawing of an ERBE Earth-viewing nonscanning active-cavity radiometer. Each radiometer consists of an optical front end and two silver conical cavities, one active and one passive. The optical front end consists of a truncated hemispherical field-of-view limiter and a base plate having a precision aperture at its center. The visible channels contain a Suprasil® hemispherical filter dome to remove the longwave component of the incident flux. Both cavities communicate thermally with a common heat sink through concentric cylindrical thermal impedances.

The field-of-view limiters and substrates of all channels have specularly reflecting coatings. These surfaces are covered by a highly emissive black
coating ($\alpha = 0.95$) for the visible channels and a low emissive vacuum deposited aluminum coating ($\alpha = 0.04$) for the total channels [32]. The wide field-of-view (WFOV) channels view the entire Earth disk, while the medium field-of-view (MFOV) channels view the Earth with an Earth central angle of approximately 10 deg.

As shown in Figure 4, each cavity consists a 30-deg cone of length 14.94 mm bonded to a cylinder of diameter 8.00 mm and length 5.49 mm. The thermal impedance sleeves are cylinders 10.28 mm in diameter and 23.00 mm long. A coupling ring connects the thermal impedances to the cavities. The cavity components are constructed from 0.0635-mm (nominal) thick electrodeposited silver (99.99 percent pure).

The ends of the thermal impedances near the coupling ring are wound with platinum wire which acts as a resistance temperature detector (RTD). The windings, along with the external surface of the sleeve, are covered with an aluminized mylar insulation jacket.

The interiors of both cavities are coated with Chemglaze Z302, a specically reflecting and highly emissive ($\alpha = 0.9$) black paint [32]. This special coating and the conical shape of the cavities assure a spectrally flat response over the 0.2 to 50 $\mu$m range.

The reference cavity views only a closed environment maintained at the heat sink temperature. During normal Earth viewing the reference cavity heater is turned
off; thus, its temperature tracks that of the heat sink very closely. The active cavity views the scene (i.e., the Earth) and is maintained at a temperature of approximately 0.78°C [19] above that of the reference cavity by electrical substitution heating. The constant temperature difference is maintained via closed-loop feedback control of the active heater using inputs from the active and reference resistance temperature detectors. This thermal control is accomplished by balancing a resistance bridge circuit. The temperature differential is the result of a bias resistor selected for each detector to produce an imbalance in the bridge in the zero heater power condition. To maintain a balanced bridge the voltage to the active heater is varied such that its squared value varies inversely with the radiative power absorbed by the cavity. The channel output is a 13-bit digitized direct measurement of the active heater voltage, sampled every 0.8 s, ranging from 0 to 10 V. A block diagram and a simplified version of the circuit which implements this feedback function are shown, respectively, in Figures 5(a) and 5(b).

Complete dimensions and material properties for the Earth-viewing nonscanning radiometric channels are given in Tables 1 through 3.

2.2 Radiometer Characterization and Calibration

The ERBE instruments are the most completely characterized and most
accurately calibrated instruments of their type ever to be flown [32]. The equations used to characterize the total (T) and shortwave (SW) radiant energy received by the radiometers during calibration are referred to as the ground count-conversion equations. The forms of these equations have been determined [33, 34] as

\[ E_T' = A_V'V^2 + A_F'(T_F - \bar{T}_{F0}) + A_R'V_R^2 + B_T' \tag{2.1} \]

and

\[ E_{SW}' = A_V'V^2 + A_F'(T_F - \bar{T}_{F0}) + A_R'V_R^2 + A_E'E_T + B_{SW}' \tag{2.2} \]

where \( E' \) is the irradiance at the field-of-view limiter aperture (W/m\(^2\)), \( A_V' \) is a coefficient corresponding to the heater voltage term (W/m\(^2\)V\(^2\)), \( V \) is the active cavity heater voltage (V), \( A_F' \) is a coefficient corresponding to the field-of-view limiter temperature term (W/m\(^2\)K), \( T_F \) is the temperature of the field-of-view limiter (K), \( T_{F0} \) is the mean field-of-view limiter temperature during the calibration runs (K), \( A_R' \) is a coefficient corresponding to the reference cavity heater voltage (W/m\(^2\)V\(^2\)), \( V_R \) is the reference cavity heater voltage (V), \( A_E' \) is a coefficient meant to correct for the presence of the shortwave filter dome (-), and the offset terms \( B_{T,SW}' \) (W/m\(^2\)) calibrate the instruments by means of internal calibration sources. For nominal Earth scenes \( V_R \) is set equal to zero.

To perform an absolute calibration, the instruments were allowed to view
laboratory radiometric sources based on the International Practical Temperature Scale of 1968. Radiometric sources for the nonscanning channels consisted of a Master Reference Black Body (MRBB), an integrating sphere (ISP), and a solar simulator. Figure 6 shows the ERBE calibration chamber, which is an eight-foot diameter cylinder containing a Master Reference Black Body (MRBB) at one end and an integrating sphere (ISP) on the other end. The solar simulator can project a beam through a quartz window onto an instrument mounted on a carousel in the middle of the chamber. The chamber walls, chilled with liquid nitrogen, were used as a space reference source for scanner calibration.

Each radiometric source was viewed under a variety of conditions which simulated the radiative fields which the instruments would be subjected to in a space environment. Upon viewing each source, the instruments were allowed to reach a steady-state condition, at which time the voltage across the active cavity heater was recorded along with temperatures of the field-of-view limiter and various other instrument components. Additionally, the voltage in the reference cavity heater was set at one of three discrete levels while viewing the radiometric sources in order to increase the dynamic range of the instruments.

The voltage output and surface temperature data from ground calibration runs were used in a multiple regression analysis of Eqs. 2.1 and 2.2 to determine the ground count-conversion equation coefficients for each of the channels.

Inflight count-conversion equations are obtained by multiplying the ground
count-conversion equations with an appropriate configuration factor $F$, which relates the radiative flux incident to the primary aperture to that at the field-of-view limiter aperture. These configuration factors are listed in Table 4. The resulting count conversion equations are

$$E_T = A_V V^2 + A_F T_F + A_R V_R^2 + B_T$$  \hspace{1cm} (2.3)

and

$$E_{SW} = A_V V^2 + A_F T_F + A_R V_R^2 + A_E E_T + B_{SW},$$  \hspace{1cm} (2.4)

where

$$E_T = F E_T'$$,  \hspace{1cm} (2.5)

$$E_{SW} = F E_{SW}'$$,  \hspace{1cm} (2.6)

$$A_V = F A_V'$$,  \hspace{1cm} (2.7)

$$A_F = F A_F'$$,  \hspace{1cm} (2.8)
\[ A_E = F A_E', \quad (2.9) \]

and

\[ B_{T,SW} = F(B_{T,SW}' - A_F' \bar{T}_{F0}). \quad (2.10) \]

### 2.3 A Low-Order Physical Model of the Active-Cavity Radiometers

By employing a low-order physical model, theoretical values for the \( A_V \) and \( A_F \) coefficients can be represented by [35,36]

\[ A_V = \frac{-1}{\tau_{sw} A_A R \alpha} \quad (2.11) \]

and

\[ A_F = \frac{4 \sigma \epsilon F_{CF} \tau_{LW} T_F^3}{F_{CS} \tau_{SW}}, \quad (2.12) \]

where \( \sigma \) is the Stefan-Boltzman constant \((5.670 \times 10^{-8} \text{ W/m}^2\text{K}^4)\), \( \epsilon \) is the emissivity of the field-of-view limiter, \( \tau_{LW} \) is the transmissivity of the filter dome to longwave...
radiation, \( \tau_{sw} \) is the transmissivity of the filter dome to shortwave radiation, \( T_F \) is the temperature of the field-of-view limiter (K), \( F_{cf} \) is the view factor from the cavity to the field-of-view limiter, \( F_{cs} \) is the view factor from the cavity to the source of the incident thermal radiation, \( A_A \) is the area of the primary aperture (\( m^2 \)), \( R \) is the electrical resistance of the active cavity heater element (\( \Omega \)), and \( \alpha \) is the effective absorptivity of the cavity. Equations 2.11 and 2.12 assume diffuse radiation and isothermal surfaces.

The offset terms \( B \) are updated every two weeks by rotating the radiometers to look at onboard calibration sources. Values for the offset terms are obtained by rearranging Eqs. 2.3 and 2.4 to yield

\[
B_T = F_{cs} \sigma T_{bb}^4 - A_V V_{bb}^2 - A_F T_F - A_R V_R^2 + B_{MRBB-IBB} \tag{2.13}
\]

and

\[
B_{SW} = -A_V V_{SWICS}^2 - A_F T_F - A_E E_T - A_R V_R^2 , \tag{2.14}
\]

where \( T_{bb} \) is the temperature of the blackbody (K), \( V_{bb} \) is the active cavity heater voltage while looking at a blackbody (V), \( V_{SWICS} \) is the active cavity heater voltage when looking at a tungsten lamp (V), and \( B_{MRBB-IBB} \) is the correction term which brings the internal blackbodies into agreement with the Master Reference Black Body (MRBB). Values for the \( B_{MRBB-IBB} \) terms were determined by analyzing the differences in instrument output between the initial in-flight Internal Black Body...
(IBB) calibrations with previous ground calibrations which used the Master Reference Black Body (MRBB).

A low-order mathematical relationship which describes the interaction of the shortwave filter dome with the incident radiant energy (i.e., the $A_E$ coefficient) was not determined by the ERBE Science Team; therefore, only an analysis of the $A_V$ and $A_F$ coefficients is reported for the visible channels.

Substitution of the physical and optical properties of the radiometers into Eqs. 2.11 and 2.12 results in theoretical values for the coefficients $A_F$ and $A_V$. Calculation of the offset terms $B$ requires an additional step. Inspection of Eq. 2.13 reveals that a $B_{MRBB-IBB}$ correction term is included. This correction term was developed using the values for $A_V$ and $A_F$ based on a statistical regression of calibration data and not the values used in the low-order physical model; therefore, it must be modified in order to be meaningfully introduced into the model.

The values obtained for the $A_F$ and $A_V$ coefficients using this low-order physical model appear in Table 5. Table 5 displays values for the count conversion equation coefficients for the low-order physical model of the radiometers as well as for the values the ERBE science team obtained for these coefficients through statistical regression of calibration data. Chapter 6 discusses how these coefficients were also obtained utilizing the high-level end-to-end numerical models.

The differences in flux obtained using the two sets of coefficients in Table 5
in the count conversion equation are shown in Figures 7 and 8 for the Earth Radiation Budget Satellite (ERBS) wide field-of-view total (WFOVT) and medium field-of-view total (MFOVT) channels, respectively. The fluxes correspond to data from approximately three orbits on April 17, 1985.

Figures 7 and 8 illustrate that the fluxes obtained with the low-order physical model are slightly lower than those corresponding to the statistical regression of ground calibration data. However, the fluxes based on the two sets of coefficients agree well for both channels. Differences of less than 0.5 percent for the wide field-of-view total channel and less than 1.25 percent for the medium field-of-view total channel result. These differences are based on nominal average total irradiances of 310 (W/m²) for the wide field-of-view total channel and 150 (W/m²) for the medium field-of-view total channel.
3.0 An Uncertainty Analysis for an ERBE Active-Cavity Radiometer

3.1 Uncertainty Analysis Methodology

A benefit of performing an uncertainty analysis is that it allows the experimenter to determine the individual contributions each independent variable makes to the total uncertainty in the system. Description of uncertainties in single-sample experiments is discussed by Kline and McClintock [37]. This statistically based methodology requires that the experimenter know, to the same stated probability, the uncertainty associated with each variable. Under this restriction if $R(p_1, p_2, ..., p_n)$ is a linear function of $n$ independent variables $p_i$, the uncertainty of each of which is normally distributed, then the uncertainty in the result, $\Delta R$, is...
related to the uncertainty in each of the variables, $\Delta p_i$, according to

$$
\Delta R = \left[ \left( \frac{\partial R}{\partial p_1} \Delta p_1 \right)^2 + \left( \frac{\partial R}{\partial p_2} \Delta p_2 \right)^2 + \ldots + \left( \frac{\partial R}{\partial p_n} \Delta p_n \right)^2 \right]^{1/2} .
$$

(3.1)

It is emphasized that this result holds strictly only as long as $\Delta p_1$, $\Delta p_2$, ..., and $\Delta p_n$ are all known to the same probability.

3.2 Application of Uncertainty Analysis Methodology

From Eq. 2.12 it is apparent that the coefficient $A_F$ is a function of six independent variables,

$$
A_F = A_F \left( F_{CF}, \tau_{LW}, \epsilon, T_F, F_{CS}, \tau_{SW} \right) .
$$

(3.2)

Applying the Kline and McClintock uncertainty analysis methodology to $A_F$ yields

$$
\frac{\partial A_F}{\partial F_{CF}} \Delta F_{CF} = \frac{4 \sigma \epsilon \tau_{LW} T_F^3}{F_{CS} \tau_{SW}} \Delta F_{CF} ,
$$

(3.3)

$$
\frac{\partial A_F}{\partial \tau_{LW}} \Delta \tau_{LW} = \frac{4 \sigma \epsilon F_{CF} T_F^3}{F_{CS} \tau_{SW}} \Delta \tau_{LW} ,
$$

(3.4)
\[
\frac{\partial A_F}{\partial \Delta \epsilon} = \frac{4\sigma F_{CF} \tau_{LW} T_F^3}{F_{CS} \tau_{SW}} \Delta \epsilon ,
\]
(3.5)

\[
\frac{\partial A_F}{\partial \Delta T_F} = \frac{12\sigma \epsilon F_{CF} \tau_{LW} T_F^2}{F_{CS} \tau_{SW}} \Delta T_F ,
\]
(3.6)

\[
\frac{\partial A_F}{\partial \Delta F_{CS}} = -\frac{4\sigma \epsilon F_{CF} \tau_{LW} T_F^3}{F_{CS}^2 \tau_{SW}} \Delta F_{CS} ,
\]
(3.7)

and

\[
\frac{\partial A_F}{\partial \Delta \tau_{SW}} = -\frac{4\sigma \epsilon F_{CF} \tau_{LW} T_F^3}{F_{CS} \tau_{SW}^2} \Delta \tau_{SW} .
\]
(3.8)

For the total channels \( A_F \) is a function of only four independent variables because both transmissivity terms have a value of unity in the absence of a filter dome.

Similarly, from Eq. 2.11 it is apparent that \( A_v \) is a function of four independent variables,

\[
A_v = A_v (\tau_{SW}, A_A, R, \alpha) .
\]
(3.9)
Applying the Kline and McClintock uncertainty analysis methodology to the $A_v$ term yields

\[
\frac{\partial A_v}{\partial \tau_{SW}} \Delta \tau_{SW} = -\frac{1}{(\tau_{SW} A_A R\alpha)^2} A_A R\alpha \Delta \tau_{SW},
\]

(3.10)

\[
\frac{\partial A_v}{\partial A_A} \Delta A_A = -\frac{1}{(\tau_{SW} A_A R\alpha)^2} \tau_{SW} R\alpha \Delta A_A,
\]

(3.11)

\[
\frac{\partial A_v}{\partial R} \Delta R = -\frac{1}{(\tau_{SW} A_A R\alpha)^2} \tau_{SW} A_A \alpha \Delta R,
\]

(3.12)

and

\[
\frac{\partial A_v}{\partial \alpha} \Delta \alpha = -\frac{1}{(\tau_{SW} A_A R\alpha)^2} \tau_{SW} A_A R \Delta \alpha.
\]

(3.13)

For the total channels $A_v$ is a function of only three independent variables because the transmissivity has a value of unity in the absence of a filter dome.

Likewise, from Eq. 2.13 it is apparent that the total channel offset term, $B_T$, is
a function of six independent variables,

\[ B_T = B_T \left( F_{CS}, T_{bb}, A_V, V_{bb}, A_F, T_F \right). \]

(3.14)

Applying the Kline and McClintock uncertainty analysis methodology to this term yields

\[ \frac{\partial B_T}{\partial F_{CS}} \Delta F_{CS} = \sigma T_{bb}^4 \Delta F_{CS}, \]

(3.15)

\[ \frac{\partial B_T}{\partial T_{bb}} \Delta T_{bb} = 4 F_{CS} \sigma T_{bb}^3 \Delta T_{bb}, \]

(3.16)

\[ \frac{\partial B_T}{\partial A_V} = V_{bb}^2 \Delta A_V, \]

(3.17)

\[ \frac{\partial B_T}{\partial V_{bb}} \Delta V_{bb} = 2 A_V V_{bb} \Delta V_{bb}, \]

(3.18)
\[ \frac{\partial B_T}{\partial A_F} \Delta A_F = T_F \Delta A_F, \quad (3.19) \]

and

\[ \frac{\partial B_T}{\partial T_F} \Delta T_F = A_F \Delta T_F. \quad (3.20) \]

The visible channel offset term, \( B_{SW} \), is not treated here because a physical model of the \( A_e \) term is not available.

The uncertainties associated with the above coefficients and offset terms are obtained upon substituting the terms based on Eqs. 3.3 through 3.8, 3.10 through 3.13, and 3.15 through 3.20 into equations of the form of Eq. 3.1. Table 6 displays the uncertainties of the count conversion equation coefficients for each of the four ERBS nonscanning radiometric channels.

A benefit of the Kline and McClintock methodology of uncertainty analysis is that it allows the experimenter to determine the individual contributions each variable makes to the total uncertainty in the result, \( \Delta R \). Tables 7 and 8 display the contributions to the total uncertainties in \( A_F \) and \( A_v \) made by each independent variable in the theoretical (low-order model) relations, Eqs. 2.11 and 2.12, representing \( A_F \) and \( A_v \), respectively. Results are displayed for each channel. Table 9 displays the contributions to uncertainty in \( B_T \) by each independent

An Uncertainty Analysis for an ERBE Active-Cavity Radiometer
variable in Eq. 3.14. Discussion of the results in these tables is deferred until Chapter 6, where they are discussed in detail.
4.0 High-Order Radiative Analysis of the ERBE Nonscanning Channels

4.1 The Monochromatic Distribution Factor, $D_{ijk}$

The monochromatic distribution factor $D_{ijk}$ is defined as the fraction of energy emitted from surface or volume element $i$ in wavelength interval $k$ which is absorbed by surface or volume element $j$. The distribution factor includes direct radiation from $i$ to $j$ as well as all possible diffuse and specular reflections and refraction through the filter dome.

Following this definition, the power absorbed by surface or volume element $j$, due to emission from surface element $i$, in the wavelength interval $k$, is given simply by

$$Q_{ijk} = \epsilon_i A_i e_{b,\Delta \lambda_k}(\Delta \lambda_{kr} T_i) D_{ijk},$$  

(4.1)
where $\varepsilon_i$, $A_i$, and $T_i$ are the emissivity, surface area and temperature of element $i$, and $e_{b,\Delta\lambda}$ is the emissive power of element $i$ in wavelength interval $k$.

Similarly, the power absorbed by surface or volume element $j$, due to diffuse emission from volume element $i$, in the wavelength interval $k$, is given as

$$Q_{ijkl} = 4\kappa_{\Delta\lambda_k} V_i e_{b,\Delta\lambda_k}(\Delta\lambda_k, T_i) D_{ijkl},$$

(4.2)

where $V_i$ and $T_i$ are the volume and temperature of element $i$, $\kappa_{\Delta\lambda_k}$ is the monochromatic absorption coefficient in wavelength interval $k$ of element $i$, and $e_{b,\Delta\lambda}$ is the emissive power of volume element $i$ in wavelength interval $k$. Equation 4.2 is independent of the element's optical depth, because this has already been considered in computing $D_{ijkl}$.

The emissive power $e_{b,\Delta\lambda}$ of an element in a given wavelength interval is found by integrating Planck's blackbody radiation distribution function over the wavelength band of interest,

$$e_{b,\Delta\lambda_k} = \int_{\lambda_1}^{\lambda_2} \frac{2\pi C_1}{\lambda^5 (e^{C_2/\lambda T} - 1)} d\lambda,$$

(4.3)

where $C_1$ and $C_2$ are physical constants and $T$ is the temperature of the element.

Finally, the total power absorbed by surface or volume element $j$ due to
emission from surface or volume element $i$ is given by

$$Q_{ij} = \sum_k Q_{ijk}, \quad (4.4)$$

where the summation is over the wavelength bands of interest. Note that the analysis implies the need for a separate monochromatic distribution factor matrix for each wavelength interval $k$.

Three simple properties of monochromatic distribution factors exist which may be used to reduce the time and effort required for their calculation. They are

$$\sum_{i=1}^{n} D_{ijk} = 1.0, \quad j = 1,2,...n, \quad (4.5)$$

$$\epsilon_i A_i D_{ijk} = \epsilon_j A_j D_{ijk}, \quad i = 1,2,...n, \quad j = 1,2,...n, \quad (4.6)$$

and

$$\sum_{i=1}^{n} \epsilon_i A_i D_{ijk} = \epsilon_j A_j, \quad j = 1,2,...n. \quad (4.7)$$

Equation 4.5 is a statement of conservation of energy, while Eq. 4.6 expresses a
reciprocity relationship. Equation 4.7 is a combination of Eqs. 4.5 and 4.6 obtained by summing Eq. 4.5 over i and applying Eq. 4.6 to the result. Equation 4.7 may be rearranged to represent the error in the distribution factors between each surface of the enclosure,

\[
\text{percent error} = \left[ 1 - \frac{\sum_{i=1}^{n} \varepsilon_i A_i D_{ijk}}{\varepsilon_j A_j} \right] \times 100, \quad j = 1,2,...n. \tag{4.8}
\]

As the number of energy bundles emitted from each surface increases, the monochromatic distribution factors converge to their proper values, and the right hand side of Eq. 4.8 approaches zero.

### 4.2 Determination of Monochromatic Distribution Factors

The Monte-Carlo ray-trace method is used to compute the distribution of monochromatic radiation within the radiometer enclosure. The basic assumptions allowing the use of this method are that thermal radiation transport between two elements may be assumed to occur in discreet energy bundles, and that the laws of chance may be used to determine the disposition of each energy bundle as it
interacts with an element.

The enclosure specified by the field-of-view limiter aperture and walls, the substrate, and the cavity (i.e., cone and cylinder) is subdivided into surface elements whose absorptivities, specularities, and temperatures are specified. In addition, the filter dome is subdivided into volume elements with known temperatures and transmissivities. Millions of energy bundles are then allowed to enter the enclosure through the field-of-view limiter aperture with directional and spatial distribution dependent upon the nature of the source field being simulated. Millions of energy bundles are also diffusely emitted from the field-of-view limiter walls, the substrate, the primary aperture, the cavity, and from the volume elements describing the filter dome. The path of each bundle is traced through the radiometer as it is reflected from, and transmitted through, the various surface and volume elements until it is eventually absorbed or exits through the field-of-view limiter aperture.

The procedure for determining the monochromatic distribution factors for axially symmetric enclosures is outlined below.

**Step 1. Location and Direction of Emission**

For diffuse emission, emission locations must be uniformly distributed over an element's surface or throughout its volume. For a hemispherical surface element, such as on the field-of-view limiter, the distribution of emission points
along the z-direction is found from

\[ z = r \left( 1 - \sqrt{R_g} \right) , \]  

(4.9)

where \( z \) is measured from the origin of the hemisphere, \( r \) is the radius of the hemisphere and \( R_g \) is a random number uniformly distributed between zero and one. For cylindrical surface elements, such as on the cylinder portion of the cavity, the z-coordinate of emission is found from

\[ z = z_0 + R_z \Delta z , \]  

(4.10)

where \( z_0 \) is the z-coordinate of the lowest edge of the element, \( \Delta z \) is the element height, and \( R_z \) is a random number uniformly distributed between zero and one. For an element of a horizontal disk, such as on the primary aperture and substrate, the z-coordinate is a constant value determined by the geometry. In this case uniform distribution of emission locations is a function of radius. The emission radius is found from

\[ r = r_0 + \sqrt{R_r} \Delta r , \]  

(4.11)

where \( r_0 \) is the inner radius of the element, \( R_r \) is a uniformly distributed random number between zero and one, and \( \Delta r \) is the difference between the inner and outer radii of the element. For elements of a conical surface, such as on the
cavity, uniform distribution of emission points is also a function of radius, and the radial location of emission is found using Eq. 4.11. Once this radius is determined, the z-coordinate, measured from the vertex of the cone is determined by

$$z = \frac{\tan \theta}{r},$$  \hspace{1cm} (4.12)

where $\theta$ is the cone angle and $r$ is the radius determined by Eq. 4.11. For hemispherical volume elements such as those in the filter dome, the radial emission location must first be determined using Eq. 4.11. The z-coordinate is then determined using Eq. 4.9.

Having found either the z-coordinate or radius, the azimuthal location of emission is found from

$$\phi = II R_\phi,$$  \hspace{1cm} (4.13)

where $II$ is the included azimuthal angle of the element in question, and $R_\phi$ is a uniformly distributed random number between zero and one.

Once the emission location has been determined, the emission direction is found. The direction is determined by the equations

$$\theta = \sin^{-1} \sqrt{R_\theta}$$  \hspace{1cm} (4.14)

and
\[ \phi = 2\pi R_\phi, \]

where \( R_\theta \) and \( R_\phi \) are uniformly distributed random numbers between zero and one, \( \theta \) is the angle between the local surface normal and the emission direction, and \( \phi \) is the angle between the local surface tangent and the emission direction. These two angles \((\theta, \phi)\) are then used to find the emission direction cosines. For volume elements an additional random number is used to determine into which of the two hemispheres the energy bundle is emitted.

**Step 2. Determination of Intersection Points**

With known direction cosines assigned to the energy bundle, the possible intersections it makes with the mathematical surfaces of the enclosure are easily determined. The equation which describes the path of the energy bundle is

\[ \frac{x_2 - x_1}{l} = \frac{y_2 - y_1}{m} = \frac{z_2 - z_1}{n}, \]

where \((x_1, y_1, z_1)\) are the coordinates of the emission point; \(l, m\) and \(n\) are the emission direction cosines; and \((x_2, y_2, z_2)\) is the point of intersection of the energy bundle's path with another surface of the enclosure. Possible intersections are found by solving Eq. 4.16 in conjunction with the mathematical relations describing the enclosure surfaces. Several possible intersection points are obtained for each
curved surface, the number depending on the geometrical complexity of the surface. Only one possible intersection point exists for each planar surface of the enclosure. Those points which are physically impossible, either due to blockage, or due to limits of the actual geometry not reflected in the mathematical surface equations, are discarded. Of the remaining points, the nearest one to the emission location is chosen as the point of intersection.

**Step 3. Absorption, Reflection, or Transmission?**

In general, once an energy bundle intersects a surface, one of four events can occur: the bundle can be absorbed, it can be reflected specularly or diffusely, or it can be transmitted. These possible events may be seen in Figures 9 and 10. In the current work, for an intersection point not on the filter dome, the bundle will either be absorbed or reflected. In order to determine whether the bundle is absorbed, a uniformly distributed random number between zero and one is drawn and compared to the known surface absorptivity. If the random number is less than the surface absorptivity, the bundle is absorbed by the element and is recorded by a counter. At this stage the ray trace would be complete and one would return to Step 1 and emit a new bundle. If the random number is less than the known surface absorptivity, the bundle is reflected.

To determine the type of reflection, a uniformly distributed random number is obtained and compared to the reflectivity ratio, R, defined
\[ R = \frac{\rho^s}{\rho^s + \rho^d}. \quad (4.17) \]

The reflectivity ratio may be thought of as the probability that a reflection will be specular. If the random number is less than \( R \), the bundle undergoes a specular reflection as described in Step 4; otherwise a diffuse reflection occurs. Diffuse reflections are treated as diffuse emission described in Step 2.

If the intersection point occurs on the filter dome, then the possibility of transmission must also be considered. In the current effort, filtering in the dome is assumed to work by absorption; that is, reflections occur only when the angle between the incident energy bundle and the local surface normal are larger than the Brewster angle, \( \theta_b \). The Brewster angle is defined as

\[ \theta_b = \tan^{-1} \frac{n_0}{n_1}, \quad (4.18) \]

where \( n_0 \) is the index of refraction of a vacuum and \( n_1 \) is the index of refraction of the filter dome material. Bundles whose incident angles are larger than the Brewster angle are assumed to be specularly reflected as described in Step 4.

For bundles that are not reflected, refraction in the filter dome is modeled according to Snell's law,
\[
\frac{\sin(\theta_1)}{\sin(\theta_2)} = \frac{n_2}{n_1},
\]  

(4.19)

where \( \theta_1 \) and \( \theta_2 \) are the angles incident and refracted beams make with the normal to the interface between two media having refractive indices of \( n_1 \) and \( n_2 \).

When an energy bundle in wavelength interval \( k \) enters a volume element in the filter dome, a uniformly distributed random number between zero and one is drawn and set equal to

\[
P[\kappa_\lambda(\lambda) d] = 1.0 - \exp\left[-\kappa_\lambda(\lambda) d\right],
\]

(4.20)

where \( P[\kappa_\lambda(\lambda) d] \) is the probability that the ray will be absorbed after travelling a distance \( d \) through a medium whose monochromatic absorption coefficient is \( \kappa_\lambda(\lambda) \). Equation 4.20 is solved for \( d \) and this distance is compared to the path length \( l \) through the volume element that the ray would follow if it were not absorbed. If the distance \( d \) is greater than or equal to the path length \( l \), the ray passes through the volume element without being absorbed. If on the other hand \( d \) is less than \( l \), the ray will be absorbed in the dome volume element at a location determined by the value of \( d \).

**Step 4. Specular Reflection**

The direction of specular reflection is determined by two criteria. The first
states that the angles between the local surface normal and the paths of the incident and reflected energy bundle be equal. The second criteria requires that the incident path, the local surface normal, and the reflected path be planar. Mathematically these requirements may be stated as

\[ \mathbf{U}_2 = \mathbf{U}_1 - 2(\mathbf{U}_1 \cdot \mathbf{n})\mathbf{n}, \] (4.21)

where \( \mathbf{U}_1 \) is the vector representing the incident energy bundle, \( \mathbf{U}_2 \) is the vector representing the reflected energy bundle, and \( \mathbf{n} \) is the local unit normal vector. At this point, one would return to Step 2 and continue through the steps until the bundle is absorbed.

These steps are repeated until a sufficiently large number of energy bundles \( N_j \) are emitted from each surface \( i \), in each wavelength interval \( k \), to correctly characterize the radiative exchange within the enclosure. Once enough energy bundles have been emitted, the monochromatic distribution factors are calculated as

\[ D_{ijk} = \frac{N_{ijk}}{N_{ik}}, \] (4.22)

where \( N_{ijk} \) is the number of bundles emitted by element \( i \) which are absorbed by element \( j \) in wavelength interval \( k \), and \( N_{ik} \) is the number of energy bundles emitted by element \( i \), in wavelength interval \( k \).
5.0 Model Formulation

5.1 Introduction

The development of equations which govern the transient electrical and radiative heating of the active-cavity radiometer in the completed end-to-end model are described in this chapter. These developments were originally presented by Tira [19]. The geometry of the end-to-end model is significantly more complex than that used by Tira, and as a consequence, equations describing radiative heating of the active cavity are correspondingly more complex. In addition, Tira's development had the resistors in the bridge circuit shown in Table 5(b) located on the wrong legs. Fortunately, this error did not affect his analysis, however, because he assumed that the reference cavity was maintained at the heat sink temperature.
5.2 Overview

The completed end-to-end model includes a transient two-dimensional finite-element characterization of the electrothermal behavior of the active cavity for all channels, along with a three-dimensional transient finite-difference model of heat conduction in the filter dome included for the visible channels. The radiative boundary conditions for both models are obtained using a Monte-Carlo ray-trace analysis, as described in Chapter 4. An assumption which was made in the analysis was that the values specified for the surface emissivities were constant and equivalent to the surface absorptivities over all wavelength intervals. That is, all surfaces are considered to be gray. While probably a good assumption for the black surfaces, and especially those in the cavity, this is of questionable validity for the polished aluminum surfaces for visible radiation.

The current model consists of 220 surface elements describing the internal surfaces of the instrument, 100 of which describe the surfaces of the cavity which can receive incident radiation, one surface element characterizing the plane of the field-of-view limiter aperture, and 60 volume elements which characterize the filter dome. A complete characterization of the surface and volume elements is given in Table 10.

This distribution of surface and volume elements was chosen with reference to the work done by Tira [19] and Haeffelin [39]. Tira showed that 100
surface elements was the optimal number to describe the electrothermal behavior of the cavity. This configuration includes ten azimuthal divisions, six axial divisions on the cone, and four on the cylinder. Haeffelin found that eight azimuthal divisions were sufficient to accurately represent the optical front end of the instrument; however, in order to maintain geometrical continuity, ten azimuthal divisions are used throughout the model.

Both the finite-element and finite-difference implementations are described in detail elsewhere [19,20,28]. The rest of this chapter deals with the numerical description of radiative power incident to the surfaces of the active cavity.

5.3 Radiative Heating of the Active Cavity

Radiation entering the active cavity emanates from either an instrument surface or from a body external to the instrument. While the spatial distribution of radiation emitted from instrument surfaces is constant, the spatial distribution of radiation from external bodies may vary with time. This requires that a new distribution factor matrix be computed each time the directional emissive properties of the external source change.

The net radiative input for the cavity, \( Q_{\text{rad}} \), is the sum of the net radiative inputs, \( Q_{\text{rad}}^j \), for each element \( j \) in the active cavity. The net radiative input for each element \( j \), is equal to the difference between the power absorbed, \( Q_{\text{rad}}^a \), and
the power emitted, $Q_{\text{rad}_i}$, by that element, or

$$Q_{\text{rad}_i} = Q_{\text{rad}_i}^a - Q_{\text{rad}_i}^a.$$  \hspace{1cm} (5.1)

The power absorbed by element $j$, $Q_{\text{rad}_j}^a$ includes radiation emitted from all elements in the model geometry which is absorbed by element $j$. For the total channels, $Q_{\text{rad}_j}^a$ is

$$Q_{\text{rad}_j}^a = Q_{\text{scene}_j} + Q_{\text{fovl}_j} + Q_{\text{sub}_j} + Q_{\text{ring}_j} + Q_{\text{pa}_j} + Q_{\text{cav}_j},$$  \hspace{1cm} (5.2)

and for the visible channels

$$Q_{\text{rad}_j}^a = Q_{\text{scene}_j} + Q_{\text{fovl}_j} + Q_{\text{sub}_j} + Q_{\text{dome}_j} + Q_{\text{pa}_j} + Q_{\text{cav}_j},$$  \hspace{1cm} (5.3)

where, $Q_{\text{scene}_j}$ is the power absorbed from the scene, $Q_{\text{fovl}_j}$ is the power absorbed from the field-of-view limiter, $Q_{\text{sub}_j}$ is the power absorbed from the substrate, $Q_{\text{ring}_j}$ is the power absorbed from the ring which links the primary aperture to the substrate, $Q_{\text{dome}_j}$ is the power absorbed from the filter dome, $Q_{\text{pa}_j}$ is the power absorbed from the primary aperture, and $Q_{\text{cav}_j}$ is the power absorbed from all cavity elements.

These absorbed powers are calculated using
\[ Q_j = \sum_{i=1}^{n} \sum_{k=1}^{m} \varepsilon_i A_i e_{b,\Delta\lambda_k} (\Delta\lambda_k, T_i) D_{ijk} \]  \hspace{1cm} (5.4) 

for surface elements, and

\[ Q_j = \sum_{i=1}^{n} \sum_{k=1}^{m} 4\kappa_{\Delta\lambda_k} V_i e_{b,\Delta\lambda_k} (\Delta\lambda_k, T_i) D_{ijk} \]  \hspace{1cm} (5.5) 

for volume elements. In Eqs. 5.4 and 5.5 the subscript \( k \) refers to wavelength interval \( \Delta\lambda_k \), the subscript \( i \) refers to surface element \( i \), \( \varepsilon_i \) is the emissivity of surface element \( i \), \( A_i \) is the surface area of surface element \( i \), \( V_i \) is the volume of volume element \( i \), \( e_{b,\Delta\lambda_k} \) is the emissive power of volume or surface element \( i \) in wavelength interval \( k \), \( \kappa_{\Delta\lambda_k} \) is the monochromatic absorption coefficient of volume element \( i \) in wavelength interval \( k \), and \( D_{ijk} \) is the monochromatic distribution factor from element \( i \) to element \( j \) in wavelength interval \( k \).

Cavity element \( j \) emits radiation to its surroundings in wavelength interval \( \Delta\lambda_k \) according to

\[ Q_{rad}^j = \epsilon_j A_j e_{b,\Delta\lambda_k} (\Delta\lambda_k, T_j), \]  \hspace{1cm} (5.6) 

where \( \epsilon_j \) is the emissivity of surface element \( j \), \( A_j \) is the surface area of surface
element \( j \), and \( e_{b,\Delta \lambda} \) is the emissive power of element \( j \) in wavelength interval \( k \).

The volumetric generation within each cavity element \( j \), \( G_{rj} \), is obtained by substituting Eqs. 5.4, 5.5 and 5.6 into Eqs. 5.2 and 5.3 and dividing by the volume of cavity element \( j \), \( V_j = A_j \delta \), where \( \delta \) is the element thickness. These substitutions yield

\[
G_{radj} = \frac{1}{A_j \delta} \left( \sum_{i=1}^{n} \sum_{k=1}^{m} \epsilon_i A_i e_{b,\Delta \lambda_k} D_{ijk} \right)_{scene_j} + \frac{1}{A_j \delta} \left( \sum_{i=1}^{n} \sum_{k=1}^{k} \epsilon_i A_i e_{b,\Delta \lambda_k} D_{ijk} \right)_{fove_j} + \\
\frac{1}{A_j \delta} \left( \sum_{i=1}^{n} \sum_{k=1}^{m} \epsilon_i A_i e_{b,\Delta \lambda_k} D_{ijk} \right)_{sub_j} + \frac{1}{A_j \delta} \left( \sum_{i=1}^{n} \sum_{k=1}^{m} \epsilon_i A_i e_{b,\Delta \lambda_k} D_{ijk} \right)_{ring_j} + \\
\frac{1}{A_j \delta} \left( \sum_{i=1}^{n} \sum_{k=1}^{m} \epsilon_i A_i e_{b,\Delta \lambda_k} D_{ijk} \right)_{pa_j} + \frac{1}{A_j \delta} \left( \sum_{i=1}^{n} \sum_{k=1}^{m} \epsilon_i A_i e_{b,\Delta \lambda_k} D_{ijk} \right)_{cav_j} - \\
\frac{1}{A_j \delta} \left( \epsilon_i A_i e_{b,\Delta \lambda_k} \right)_{cav_j}
\]

(5.7)

for the total channels, and

\[
G_{radj} = \frac{1}{A_j \delta} \left( \sum_{i=1}^{n} \sum_{k=1}^{m} \epsilon_i A_i e_{b,\Delta \lambda_k} D_{ijk} \right)_{scene_j} + \frac{1}{A_j \delta} \left( \sum_{i=1}^{n} \sum_{k=1}^{k} \epsilon_i A_i e_{b,\Delta \lambda_k} D_{ijk} \right)_{fove_j} + \\
\frac{1}{A_j \delta} \left( \sum_{i=1}^{n} \sum_{k=1}^{m} \epsilon_i A_i e_{b,\Delta \lambda_k} D_{ijk} \right)_{sub_j} + \frac{1}{A_j \delta} \left( \sum_{i=1}^{n} \sum_{k=1}^{m} 4\kappa_{\Delta \lambda_k} V_i e_{b,\Delta \lambda_k} D_{ijk} \right)_{dome_j}
\]

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\[
\frac{1}{A_j \delta} \left( \sum_{i=1}^{n} \sum_{k=1}^{m} \epsilon_i A_i e_b \Delta \lambda_k D_{ijk} \right)_{paj} + \frac{1}{A_j \delta} \left( \sum_{i=1}^{n} \sum_{k=1}^{m} \epsilon_i A_i e_b \Delta \lambda_k D_{ijk} \right)_{cav_j} - \frac{1}{A_j \delta} \left( \epsilon_i A_i e_b \Delta \lambda_k \right)_{cav_j}
\]

(5.8)

for the visible channels.

5.4 Electrical Heating of the Active Cavity

Fine wire electrical heaters are wound around the outside surfaces of both the active and reference cavities, as shown in Figure 4. It is assumed that heat generated by these wires is transferred entirely to the cavity walls. The resistance temperature detector (RTD), also a fine wire, is wound around the thermal impedance sleeve near its junction with the coupling ring, as shown in Figure 4. Two of the four arms of the deflection bridge shown in Figure 5(a) are fixed resistors (R_3 and R_4). A third arm is the RTD associated with the reference cavity (R_2). During normal Earth viewing, the voltage in the reference cavity is set equal to zero, and thus the temperature of the reference cavity and its RTD closely follow that of the heat sink. During ground, internal, and solar calibrations the voltage in the reference cavity is set at one of three discrete levels. This nonzero voltage raises the temperature of the reference cavity, and ultimately the

Model Formulation
resistance of this arm of the bridge.

The temperature of the fourth arm, which is that of the active cavity RTD \(R_1\), is not uniform around the thermal impedance since the cavity itself is not at a completely uniform temperature. However, this nonuniformity is on the order of something less than one degree kelvin. The temperature variation at the location of the RTD would be much smaller. Consequently, in the finite element analysis, the RTD is assumed to take the average temperature of the band of elements around the thermal impedance at that axial location.

The output voltage of the deflection bridge can be shown to be given by

\[
V_1 = V_0 \left[ \frac{R_1}{R_1 + R_2} - \frac{R_3}{R_3 + R_4} \right],
\]

where \(V_0\) is the bridge supply voltage, \(R_1\) is the active cavity RTD resistance, \(R_2\) is the reference cavity RTD resistance, and \(R_3\) and \(R_4\) are the two fixed resistances.

At the equilibrium condition,

\[
R_1 = R + \Delta R_1
\]

and

Model Formulation
\[ R_2 = R + \Delta R_2, \quad (5.11) \]

where \( R \) (\( = R_3 = R_4 \)) is the resistance of the active cavity RTD which would produce a zero bridge deflection. The quantity \( \Delta R_1 \) is always greater than zero because the temperature of the active RTD is controlled to be higher than that of the reference cavity RTD. When the amount of radiation incident to the active cavity changes, the cavity adopts a new temperature distribution, and the average temperature of the RTD changes accordingly. This in turn causes the value of \( \Delta R_1 \) to change. The other resistances remain constant at \( R \). Substituting Eqs. 5.10 and 5.11 into Eq. 5.9 and taking into account the small values of \( \Delta R_1 \) and \( \Delta R_2 \) which permit the result to be linearized, the expression for the output voltage becomes

\[ V_1 = \frac{V_0}{4} \left[ \frac{\Delta R_1 - \Delta R_2}{R} \right], \quad (5.12) \]

or directly in terms of \( R_1 \) and \( R_2 \),

\[ V_1 = \frac{V_0}{4} \left[ \frac{R_1 - R_2}{R} \right], \quad (5.13) \]
The resistances of the RTD's are assumed to vary linearly with temperature; therefore, they can be expressed by

\[ R_1 = R[1 + \alpha(T_1 - T_{hs})] \] \hspace{1cm} (5.14)

and

\[ R_2 = R[1 + \alpha(T_2 - T_{hs})] \] \hspace{1cm} (5.15)

where \( \alpha \) is the resistance-temperature coefficient of the RTD and \( T_1, T_2 \) and \( T_{hs} \) are the temperatures of the active and reference RTD's and the heatsink, respectively. Substitution of Eqs. 5.14 and 5.15 into Eq. 5.13 gives the output voltage in terms of the temperatures,

\[ V_1 = \frac{\alpha}{4} V_0 [T_1 - T_2] \] \hspace{1cm} (5.16)

Note that \( T_1 \) is always maintained higher than \( T_2 \), so that \( V_1 \) is never zero. The input voltage to the circuit integrator is the difference between the output voltage of the bridge \( V_1 \) and the bias voltage \( V_b \). The integrator processes this voltage difference to give an output voltage \( V_2 \), which is the energizing voltage for the electric heater wrapped around the active cavity. The output voltage of the circuit as a function of time can be expressed by the differential equation
\[
\frac{dV_2}{dt} = \frac{V_b - V_1}{\tau},
\]  

(5.17)

where \( \tau \) is the electrical time constant, \( \tau = R_cC_c \). Upon substitution for \( V_1 \) from Eq. 5.16, Eq. 5.17 becomes

\[
\frac{dV_2}{dt} = \frac{V_b}{\tau} - \frac{\alpha}{4\tau} V_0(T_1 - T_2).
\]  

(5.18)

For steady-state conditions with a specified temperature drop \( \Delta T \) between the active and reference RTD's, the right hand side of Eq. 5.18 is zero, which gives for the bias voltage

\[
V_b = \frac{\alpha}{4} V_0 \Delta T.
\]  

(5.19)

Using Eq. 5.19 to eliminate \( V_b \) from Eq. 5.18, yields

\[
\frac{dV_2}{dt} = \frac{\alpha}{4\tau} V_0 [\Delta T + (T_2 - T_1)].
\]  

(5.20)

The values of \( V_2 \) at two consecutive time steps \( n \) and \( n+1 \) can then be
estimated as

\[ V_{2}^{n+1} = V_{2}^{n} + \Delta t \frac{\alpha}{4\pi} V_{0} (\Delta T + (T_{2} - T_{1})) . \] (5.21)

The heater power input \( Q_{\text{elec}} \) is given by

\[ Q_{\text{elec}} = \frac{V_{2}^{2}}{R_{\text{hw}}} , \] (5.22)

where \( R_{\text{hw}} \) is the resistance of the heater wire.

The volumetric heat generation in each surface element \( j \) covered by the heater wire is given by

\[ G_{\text{elec}} = \frac{Q_{\text{elec}}}{A_{\text{hw}} \delta} , \] (5.23)

where \( A_{\text{hw}} \) is the total area of the cavity covered by the heater wire and \( \delta \) is the thickness of the cavity material. In terms of the heater voltage \( G_{\text{elec}} \) is expressed by

\[ G_{\text{elec}} = \frac{V_{2}^{2}}{R_{\text{hw}} A_{\text{hw}} \delta} . \] (5.24)

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An expression for the volumetric heat generation at time step \( n+1 \) may be obtained by substituting Eq. 5.21 into Eq. 5.24, giving

\[
G_{\text{elec}}^{n+1} = \frac{1}{R_{\text{hw}} A_{\text{hw}} \delta} \left( V_2^n + \Delta t \frac{\alpha}{4\tau} V_0 [\Delta T + (T_2 - T_1)] \right)^2.
\] 

(5.25)

As expected, for steady-state conditions Eq. 5.25 reduces to

\[
G_{\text{elec}} = \frac{V_2^2}{R_{\text{hw}} A_{\text{hw}} \delta}.
\] 

(5.26)
6.0 Results and Discussion

6.1 Calibration of the End-to-End Model

Calibration of the end-to-end model for the various channels was conducted by spectrally specifying radiative fluxes of sources located in the plane of the field-of-view limiter aperture. The magnitudes of these diffuse radiative source fields were specified along with their blackbody temperatures. Specification of the blackbody temperatures allows the spectral distribution of the radiative flux to be determined from Planck's blackbody radiation distribution function, as described in Chapter 4. Additionally, temperatures were specified for the field-of-view limiter, substrate, and primary aperture surface elements, and calculated for the cavity surface elements and filter dome volume elements. Knowledge of these temperatures allows the determination of both the magnitude and spectral
distribution of power emitted from all instrument surfaces. For the visible channels, temperatures of the filter dome elements were obtained from Haeffelin's [28] thermal diffusion code. Finally, the reference cavity heater voltage was set at one of three discrete levels in order to increase the dynamic range of the sensors. The temperatures and radiative fluxes used in the simulated calibrations were obtained from actual ground calibrations run conducted by TRW [35]. Values are given in Tables 11 through 14.

For each simulation, the filter dome thermal diffusion code was first allowed to reach a steady-state condition. The resulting steady-state temperatures of the filter dome volume elements were then used in the electrothermal cavity model. Once the cavity model reached a steady-state condition, the calculated voltage in the active-cavity heater wire was recorded. These voltage values were used in conjunction with the corresponding field-of-view limiter temperatures to determine the ground count-conversion equation coefficients in Eqs. 2.1 and 2.2.

In performing these calibration simulations, two assumptions are made. The first is that the field-of-view limiter, substrate, and primary aperture are isothermal over the time period of the simulations. The second assumption is that the source fields may be modeled as a diffuse source located in the plane of the field-of-view limiter aperture.

During these simulations it was determined that the response of the detector was very sensitive to the thickness of the cavity walls. The manufacturing
tolerance on the cavity thickness is quite large relative to its stated nominal value, that is \(0.0635 \pm 0.0254\) mm. The cavity thickness used in the model was adjusted within this tolerance to fine tune the model's response. The cavity thickness was varied until the steady-state response of the end-to-end model agreed with that of the actual instrument. The thickness variations used are all on the order of one-half or less of the stated tolerance. Final values for cavity thicknesses used in the model are given in Table 15.

The voltage outputs of the actual instruments, the voltage outputs of the end-to-end models, and the differences between the two outputs for each calibration run are given in Tables 16 through 19. Figures 11 through 14 display the voltage output of the wide and medium, total and visible channel end-to-end models during simulated ground calibrations as a function of both the magnitude of the incident radiation and the reference cavity heater voltage. The voltage output of the visible channel models is further subdivided according to the spectral distribution of the specified incident radiative flux. Defining the overall gains of these models as the slopes of the best-fit lines correlating the data in Figures 9 through 12, or

\[
\text{Gain} = \frac{\Delta V_{\text{out}}}{\Delta \text{Flux}_{\text{in}}},
\]

(6.1)
allows a direct comparison between the end-to-end models and the actual instruments. In certain cases there are only two data points, and so the best fit line is "perfect" in these cases. The calculated gains of the actual instruments and end-to-end models as a function of reference cavity heater voltage are shown in Table 20. Voltage outputs of the actual shortwave channel radiometers when subjected to longwave radiometric calibration sources (i.e. the MRBB) have not been obtained; therefore gains for the shortwave channel radiometers are not presented for longwave sources. Inspection of Table 20 shows that the differences between the instrument and model gains for normal Earth viewing (i.e. the voltage across the reference heater is set to zero) are small, 1.18 and 1.88 percent for the wide field-of-view total and visible channels, respectively, and 5.16 and 4.44 percent for the medium field-of-view total and visible channels, respectively.

Application of a multiple regression analysis to Eqs. 2.1 and 2.2 yields statistically based ground count-conversion coefficients. The results of such an analysis appear in Table 21, which displays the ground count conversion equations determined by the ERBE Science Team (EST) as well as those determined by the current end-to-end model (MODEL). The $A_v$, $A_r$, $B_r$, and $B_{sw}$ coefficients obtained with the end-to-end models agree well with the coefficients obtained during actual ground calibrations of the instruments. Tables 22 through 25 display the specified radiative fluxes emitted by the simulated radiometric calibration source, located in the plane of the field-of-view limiter aperture, during the calibration simulations, the

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radiative fluxes measured by the end-to-end models during the calibration simulations, and the differences between the specified and measured fluxes. The fluxes measured by the wide field-of-view models agree with the known fluxes within an average percent difference of -0.0025 and 0.0207 percent for the total and visible channels, respectively. The fluxes measured by the medium field-of-view models agree with the known fluxes within an average percent difference of -0.006 and 0.0085 percent for the total and visible channels, respectively. Agreement is better for the wide field-of-view total channel, as expected, since the medium field-of-view channels view a considerable portion of the field-of-view limiter walls, introducing more possibility for modelling error because of the isothermal field-of-view limiter assumption.

6.2 Comparison of Inflight Count-Conversion Equation Coefficients

Table 26 displays the inflight count conversion coefficients $A_F$ and $A_V$ determined by three methods: the low-order radiative model, the end-to-end model, and ground calibration by the ERBE science team. The three methods of calculating the $A_V$ coefficient agree to within four percent for the wide field-of-view channels and seven percent for the medium field-of-view channels. Agreement for the $A_F$ coefficient is not as good. An ideal application of a multiple regression analysis to Eqs. 2.1 and 2.2 would require two things. First, that each variable be
varied over a sufficiently large range. Second, that the matrix which must be inverted to complete the analysis must not be ill conditioned. Neither of these criteria were met. The field-of-view limiter temperature was varied over less than 2.5 K for the actual ground calibration runs, which was not adequate, and the matrix which must be inverted was ill conditioned, containing values from $10^1$ to $10^6$. Not meeting these criteria results in values for some of the count-conversion equation coefficients which are not physically realistic; however, the coefficients are quite adequate to model the fluxes within the calibration window. Since the inflight field-of-view limiter temperature does not differ greatly (<1.5 K) from the ground calibration field-of-view limiter temperature range, errors introduced by not varying the field-of-view limiter temperature over a large enough range are quite small.

6.3 Sources of Uncertainty in the ERBE Active-Cavity Radiometers

A benefit of the Kline and McClintock methodology of uncertainty analysis is that it allows the experimenter to determine the individual contributions each variable makes to the total uncertainty in the result, $\Delta R$. Table 6 displays the uncertainties of the count conversion equation coefficients for each of the four ERBS nonscanning radiometric channels. Tables 7 and 8 display the contributions to the total uncertainties in $A_F$ and $A_Y$ made by each independent variable in the
theoretical (low-order model) relations, Eqs. 2.11 and 2.12, representing $A_F$ and $A_V$, respectively. Results are displayed for each channel. Table 9 displays the contributions to the uncertainty in $B_T$ made by each independent variable in Eq. 3.14.

6.3.1 Uncertainty in the $A_F$ coefficient

From Table 7 it is apparent that the uncertainty in the $A_F$ coefficient for the total channels is largely due to uncertainty in the knowledge of the field-of-view limiter temperature. This uncertainty of the field-of-view limiter temperature is due mainly to the linearization of this temperature in the count conversion equation. For the visible channels, uncertainty in the knowledge of the transmissivity of the filter dome to longwave radiation is the major source of uncertainty in the $A_F$ coefficient.

6.3.2 Uncertainty in the $A_V$ coefficient

From Table 8 it is apparent that the uncertainty in the $A_V$ coefficient for the total channels is largely due to the manufacturing tolerances on the area of the primary aperture. For the visible channels uncertainty in the knowledge of the transmissivity of the filter dome to longwave radiation is the major source of uncertainty.
6.3.3 Uncertainty in the B\textsubscript{T} term

From Table 9 it is apparent that the uncertainty in the B\textsubscript{T} term for the WFOVT channel is associated with how well the A\textsubscript{v} coefficient is known. We have already seen that the uncertainty in the coefficient A\textsubscript{v} is largely due to the manufacturing tolerances on the area of the primary aperture. For the MFOVT channel the largest contributor of uncertainty is that of the coefficient A\textsubscript{r}. As we have seen, the uncertainty in the coefficient A\textsubscript{r} is due to the uncertainty in the knowledge of the temperature of the field-of-view limiter.

6.3.4 Orbital variation of the uncertainties

The results of the uncertainty calculations may be seen in Figures 15 and 16, which display fluxes based on the low-order physical model for the WFOV and MFOV total channels, respectively. Uncertainty ranges are also shown on these graphs, which display a 90-min running average of the actual data product. This means that each plotted point is the average value of the data ranging 45 min on either side of the point. This is also referred to as an orbital average since one orbit is 90 min in duration. For the WFOV total channel (Figure 15) the uncertainty is approximately ±7.5 W/m\textsuperscript{2}, or roughly ±2.5 percent, and for the MFOV total channel (Figure 16) the uncertainty is approximately ±15 W/m\textsuperscript{2}, or roughly ±10 percent.
6.3.5 Uncertainty as a function of solar zenith angle

Although it is not readily apparent from Figures 15 and 16, the magnitude of the uncertainty is a weak function of solar zenith angle (i.e., a function of the spectral mix of the incident energy). Further investigation is needed to determine whether this dependence is simply a function of the intensity of the incident thermal radiation, or if it is a function of the spectral distribution of the incident radiation, or some combination of both. When the solar zenith angle has a low value (\(-0\) to \(50\) deg) the incident radiation contains a large shortwave spectral component, and when the solar zenith angle is large (\(\geq 120\) deg) the incident thermal radiation has a spectral distribution that is almost entirely longwave.

The relationship between solar zenith angle and uncertainty in the data product is displayed in Figures 17 and 18. The labels "day" and "night" refer to the values of these uncertainties averaged over the time period when the solar zenith angle varies between 0 and 50 deg and 125 to 180 deg, respectively, while the satellite is looking at a typical Earth scene. The total uncertainty in the data product is the sum of these individual components. Figures 17 and 18 show that the uncertainty of the data product is slightly lower during typical "day" scenes than during typical "night" scenes, and that most of this difference is accounted for by the AV coefficient. These differences are shown to be statistically significant at P values of less than 0.0001.
6.3.6 Uncertainty Analysis Conclusions

The results of this investigation clearly show that the uncertainty associated with the WFOVT channel is much less than that of the MFOVT channel. The reasons for the much larger uncertainty in the MFOVT channel is the larger uncertainty in the $A_T T_F$ term of the count conversion equation for this channel. The uncertainty of this term for the MFOVT channel is inherently larger than in the case of the WFOVT channel because in the former case the field-of-view limiter fills a much larger portion of the cavity field of view than in the latter. However, this fact alone is not sufficient to explain the much larger values of the uncertainty for this channel. Rather, it is the combination of the relatively large uncertainty in the temperature of the field-of-view limiter and the inherently larger uncertainty in the $A_T T_F$ term for the MFOV count conversion equation which causes the observed uncertainty.

Analysis of the $A_T T_F$ terms for the visible channels shows that the uncertainty of this term is much smaller for these channels, as would be expected. The hemispherical filter dome absorbs essentially all of the longwave thermal radiation emitted from the field-of-view limiter, effectively eliminating the longwave component of any irradiance of the cavity by the field-of-view limiter.
6.4 Dynamic Simulation of the "Solar Blip" Event

The "solar blip" event is a phenomenon in which the wide field-of-view instruments are rapidly subjected to an excess of energy when the sun briefly enters the instrument field-of-view during the satellite’s entry and exit from the Earth’s shadow. Steep transients associated with this event saturate and introduce errors in the instrument data product, resulting in a loss of data. This event has been simulated utilizing the end-to-end model, thereby allowing the responses of the real instruments during this event to be investigated.

Two types of solar blip phenomena occur. Both the satellite's entry into the Earth's shadow and the satellite's exit from the Earth's shadow produce solar blip events. The solar blip event corresponding to the satellite's exit from the Earth's shadow has been simulated. This choice was based on the fact that the rise in radiative flux incident to the radiometers associated with the satellite's emergence from the Earth's shadow is steeper than for entrance, and therefore takes the instrument outside of its designed performance envelope more rapidly.

From April 17, 1985, solar blip data obtained from the Earth Radiation Budget Satellite (ERBS), the duration of a solar blip event was determined to be 120 s, where duration is defined as the length of time that the sun emits energy directly to the cavity. By fitting smooth curves to data during an April 17, 1985, solar blip event, it was determined that the magnitude of the radiative flux incident to the
radiometers and the field-of-view limiter temperatures during an event are as shown in Figures 19 and 20, respectively. Additionally it was determined that the solar zenith angles ranged from 64 to 71 deg, increasing by 0.5 deg every 8 s.

During the simulated event it is assumed that the longwave component of radiation remains constant since the only longwave source is the unchanging Earth. The shortwave component is then the difference between the total incident radiation and the assumed constant longwave source. The magnitude of the constant longwave component for purposes of the simulation was set equal 180 W/m², which is representative of the average total channel night-time Earth measurements for April 17, 1985. The results of implementing this procedure are shown in Figure 19.

In general, energy emitted by the sun that reaches the instrument directly is modeled as collimated radiation, incident at the solar zenith angle, and energy emitted by the Earth that reaches the instrument is modelled as diffuse. That is, in an event such as the solar blip, the incident radiation contains both diffuse and collimated components.

The monochromatic distribution factors discussed in Chapter 4 are, in general, calculated for either collimated radiation at a given angle, or diffuse radiation. The relation

\[ \sum_{i=1}^{n} D_{ijk} = 1.0, \ j=1,2,...n, \]  

(6.4)

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first seen in Eq. 4.5, makes it possible to calculate distribution factors for a mixed scene such as the solar blip event. The first step in modelling a source with both diffuse and collimated components is to calculate distribution factor matrices for both the collimated and diffuse sources. The collimated distribution factor matrix is then multiplied by a weighting factor $W_1$, such that

$$W_1 = \frac{\Phi_{col}}{\Phi_{col} + \Phi_{diff}} ,$$

where $\Phi_{col}$ represents the magnitude of the collimated component of flux emitted by surface $i$, and $\Phi_{diff}$ the diffuse component. The diffuse distribution factor matrix is multiplied by $W_2$ such that

$$W_2 = 1.0 - W_1 .$$

The two resulting distribution factor matrices are then added together, creating an appropriately weighted matrix which obeys Eq. 6.4 while accurately characterizing the mixed scene. In the case of time-varying scenes this method implies the need for calculating this weighted distribution factor matrix for each time step. For the case of the simulated solar blip event this means calculating 120 weighted distribution factor matrices for each channel. However only 16 collimated and one diffuse distribution factor matrices need to be calculated using the ray-trace model.
since the incident angle varies only every eight seconds.

The incident flux predicted by the total and shortwave channel models, due to the specified input flux for the simulated solar blip event, is shown in Figures 21 and 23. The corresponding average temperatures of the resistance temperature detectors are shown in Figures 22 and 24. The predicted longwave component of flux is shown along with the assumed incident value in Figure 25.

The end-to-end model shows that the total and visible channel models overpredict the specified incident flux by 3.5 and 17.6 percent, respectively. Additionally, the peak flux values predicted by both the total and visible channels lag the specified input fluxes by 7 s. However, by the end of the simulated event, the predicted fluxes once again agree with the specified incident fluxes. Thus, although the period of the predicted fluxes matches that of the specified incident fluxes, the shape of the curve is skewed upward and to the right for both the total and visible channels.

The predicted longwave component shown in Figure 25 was found by subtracting the predicted visible component from the predicted total flux. Inspection of this figure reveals that the predicted longwave component is considerably less than the specified input value, reaching a minimum 8 s after both the predicted total and predicted shortwave fluxes peak. This trend is representative of flight data which also significantly underpredicts the longwave component.

By integrating the actual and predicted fluxes over the length of the simulation
and multiplying by the area of the field-of-view limiter aperture, a comparison of the specified and predicted energy incident to the instruments can be made. Table 27 presents the results of this comparison. Following this methodology, the end-to-end model overpredicts the amount of energy received by 2.17 percent for the total channel and by 15.83 percent for the visible channel.
7.0 Conclusions and Recommendations

7.1 Conclusions

The following conclusions can be drawn from the results presented in this thesis:

1. An end-to-end model has been completed for the Earth-viewing, nonscanning, radiometric channels of the Earth Radiation Budget Experiment. The model permits the sensitivity of the instrument output to variations in the thermophysical properties of the detector to be determined.

2. The comparison of simulated and actual calibration procedures demonstrates that the model is a valid tool with which to investigate
anomalous behavior in the archived data product.

3. The three methods used to calculate the $A_v$ coefficient, the low-order physical model, the end-to-end model, and ground calibration by the ERBE science team, agree to within four percent for the wide field-of-view channels and seven percent for the medium field-of-view channels.

4. Uncertainty in the $A_F$ coefficient is largely due to uncertainty in the knowledge of the field-of-view limiter temperature for the total channels while uncertainty in the knowledge of the transmissivity of the filter dome to longwave radiation is the major source of uncertainty in the $A_F$ coefficient for the visible channels.

5. Uncertainty in the $A_v$ coefficient is largely due to the manufacturing tolerances on the area of the primary aperture for the total channels while uncertainty in the knowledge of the transmissivity of the filter dome to longwave radiation is the major source of uncertainty in the $A_v$ coefficient for the visible channels.

6. Uncertainty in the $B_T$ term for the wide field-of-view channel is due largely to uncertainty in the $A_v$ coefficient while uncertainty in the $B_T$ term for the medium field-of-view channel is due largely to uncertainty in the $A_F$ coefficient.

7. Simulation of a solar blip event demonstrates that the total channel model predicts the total energy arriving to the instrument during this
steep transient to within 2.25 percent. However, the visible channel model does not do as good a job of predicting the shortwave component of energy arriving at the instrument during these same transients, overpredicting the actual amount by nearly 16 percent.

6.2 Recommendations

The following recommendations are made as a result of this study:

1. The current end-to-end model should be coupled with a thermal diffusion model of the field-of-view limiter in order to assess the influence of field-of-view limiter temperature variations on the detectors' response.

2. A parametric analysis should be completed to assess the influence of perturbations of the thermophysical properties of the instrument on the detectors' response.
Table 1. Geometry for the Earth-viewing nonscanning radiometric channels located on the Earth Radiation Budget Satellite, ERBS. (all dimensions in mm)

<table>
<thead>
<tr>
<th>Dimension</th>
<th>WFOVT(^1)</th>
<th>MFOVT(^2)</th>
<th>WFOVSW(^3)</th>
<th>MFOVSW(^4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOVL(^5) radius</td>
<td>38.10</td>
<td>36.8554</td>
<td>38.10</td>
<td>36.8554</td>
</tr>
<tr>
<td>FOVL(^5) height</td>
<td>12.70</td>
<td>28.829</td>
<td>12.70</td>
<td>28.829</td>
</tr>
<tr>
<td>Primary Aperture Diameter</td>
<td>6.35</td>
<td>6.35</td>
<td>6.35</td>
<td>6.35</td>
</tr>
<tr>
<td>Cavity Diameter</td>
<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
</tr>
<tr>
<td>Cone Height</td>
<td>14.94</td>
<td>14.94</td>
<td>14.94</td>
<td>14.94</td>
</tr>
<tr>
<td>Cylinder Height</td>
<td>5.49</td>
<td>5.49</td>
<td>5.49</td>
<td>5.49</td>
</tr>
<tr>
<td>Thermal Impedance Diameter</td>
<td>10.28</td>
<td>10.28</td>
<td>10.28</td>
<td>10.28</td>
</tr>
<tr>
<td>Thermal Impedance Height</td>
<td>23.00</td>
<td>23.00</td>
<td>23.00</td>
<td>23.00</td>
</tr>
<tr>
<td>Cavity Thickness</td>
<td>0.0536</td>
<td>0.0498</td>
<td>0.0573</td>
<td>0.0659</td>
</tr>
</tbody>
</table>

\(^1\) Wide Field-of-View Total channel  
\(^2\) Medium Field-of-View Total channel  
\(^3\) Wide Field-of-View Shortwave channel  
\(^4\) Medium Field-of-View Shortwave channel  
\(^5\) Field-of-View Limiter
Table 2. Thermophysical properties for the Earth-viewing nonscanning radiometric channels located on the Earth Radiation Budget Satellite, ERBS.

<table>
<thead>
<tr>
<th>Property</th>
<th>WFOVT¹</th>
<th>MFOVT²</th>
<th>WFOVSW³</th>
<th>MFOVSW⁴</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOVL (\alpha)</td>
<td>0.04</td>
<td>0.04</td>
<td>0.95</td>
<td>0.95</td>
<td>-</td>
</tr>
<tr>
<td>FOVL (R)</td>
<td>0.90</td>
<td>0.90</td>
<td>0.90</td>
<td>0.90</td>
<td>-</td>
</tr>
<tr>
<td>Substrate absorptivity (\alpha)</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
<td>-</td>
</tr>
<tr>
<td>Substrate Reflectivity Ratio (R)</td>
<td>0.90</td>
<td>0.90</td>
<td>0.90</td>
<td>0.90</td>
<td>-</td>
</tr>
<tr>
<td>Primary Aperture absorptivity (\alpha)</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
<td>-</td>
</tr>
<tr>
<td>Cavity absorptivity (\alpha)</td>
<td>0.90</td>
<td>0.90</td>
<td>0.90</td>
<td>0.90</td>
<td>-</td>
</tr>
<tr>
<td>Cavity Conductivity (k)</td>
<td>429.0</td>
<td>429.0</td>
<td>429.0</td>
<td>429.0</td>
<td>W/m-K</td>
</tr>
<tr>
<td>Specific Heat (c)</td>
<td>235.0</td>
<td>235.0</td>
<td>235.0</td>
<td>235.0</td>
<td>J/Kg-K</td>
</tr>
<tr>
<td>Density (\rho)</td>
<td>10500.0</td>
<td>10500.0</td>
<td>10500.0</td>
<td>10500.0</td>
<td>Kg/m³</td>
</tr>
<tr>
<td>Electrical time constant (\tau)</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>s</td>
</tr>
</tbody>
</table>

¹ Wide Field-of-View Total channel  
² Medium Field-of-View Total channel  
³ Wide Field-of-View Shortwave channel  
⁴ Medium Field-of-View Shortwave channel  
⁵ Field-of-View Limiter
Table 3. Filter dome transmissivities for the shortwave Earth-viewing non-scanning radiometric channels located on the Earth Radiation Budget Satellite, ERBS.

<table>
<thead>
<tr>
<th>Wavelength Interval (μm)</th>
<th>Transmissivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0.15</td>
<td>0.0001</td>
</tr>
<tr>
<td>0.15 - 0.20</td>
<td>0.4350</td>
</tr>
<tr>
<td>0.20 - 0.30</td>
<td>0.8295</td>
</tr>
<tr>
<td>0.30 - 2.50</td>
<td>0.9275</td>
</tr>
<tr>
<td>2.50 - 3.00</td>
<td>0.9350</td>
</tr>
<tr>
<td>3.00 - 3.50</td>
<td>0.9225</td>
</tr>
<tr>
<td>3.50 - 4.00</td>
<td>0.8475</td>
</tr>
<tr>
<td>4.00 - 4.50</td>
<td>0.5850</td>
</tr>
<tr>
<td>4.50 - 5.00</td>
<td>0.1950</td>
</tr>
<tr>
<td>5.00 - ∞</td>
<td>0.0001</td>
</tr>
</tbody>
</table>
Table 4. Configuration factors between the primary aperture and the field-of-view limiter aperture for the Earth-viewing nonscanning radiometric channels located on the Earth Radiation Budget Satellite, ERBS.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Configuration Factor F</th>
</tr>
</thead>
<tbody>
<tr>
<td>WFOVT&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.8692</td>
</tr>
<tr>
<td>MFOVT&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.4240</td>
</tr>
<tr>
<td>WFOVSW&lt;sup&gt;3&lt;/sup&gt;</td>
<td>0.8797</td>
</tr>
<tr>
<td>MFOVSW&lt;sup&gt;4&lt;/sup&gt;</td>
<td>0.4240</td>
</tr>
</tbody>
</table>

<sup>1</sup> Wide Field-of-View Total channel  
<sup>2</sup> Medium Field-of-View Total channel  
<sup>3</sup> Wide Field-of-View Shortwave channel  
<sup>4</sup> Medium Field-of-View Shortwave channel
Table 5. Comparison of inflight count-conversion equation coefficients for April 17, 1985, determined by both a low order physical model and the utilization of multiple regression methodology by the ERBE Science Team (EST).

<table>
<thead>
<tr>
<th>Channel</th>
<th>Coefficient</th>
<th>EST</th>
<th>Physical Model</th>
<th>Percent Difference&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>WFOVT&lt;sup&gt;2&lt;/sup&gt;</td>
<td>A&lt;sub&gt;F&lt;/sub&gt;</td>
<td>-1.3968</td>
<td>-0.2391</td>
<td>82.89</td>
<td>W/m²K</td>
</tr>
<tr>
<td></td>
<td>A&lt;sub&gt;V&lt;/sub&gt;</td>
<td>-22.7873</td>
<td>-22.5212</td>
<td>1.17</td>
<td>W/m³V²</td>
</tr>
<tr>
<td></td>
<td>B&lt;sub&gt;T&lt;/sub&gt;</td>
<td>1703.58</td>
<td>1355.13</td>
<td>20.45</td>
<td>W/m²</td>
</tr>
<tr>
<td>MFOVT&lt;sup&gt;3&lt;/sup&gt;</td>
<td>A&lt;sub&gt;F&lt;/sub&gt;</td>
<td>-0.9230</td>
<td>-2.1244</td>
<td>-130.16</td>
<td>W/m²K</td>
</tr>
<tr>
<td></td>
<td>A&lt;sub&gt;V&lt;/sub&gt;</td>
<td>-22.7093</td>
<td>-22.6721</td>
<td>0.16</td>
<td>W/m³V²</td>
</tr>
<tr>
<td></td>
<td>B&lt;sub&gt;T&lt;/sub&gt;</td>
<td>1272.12</td>
<td>1625.32</td>
<td>-27.76</td>
<td>W/m²</td>
</tr>
<tr>
<td>WFOVSW&lt;sup&gt;4&lt;/sup&gt;</td>
<td>A&lt;sub&gt;F&lt;/sub&gt;</td>
<td>-0.6502</td>
<td>-0.0056</td>
<td>99.14</td>
<td>W/m²K</td>
</tr>
<tr>
<td></td>
<td>A&lt;sub&gt;V&lt;/sub&gt;</td>
<td>-25.7758</td>
<td>-24.8279</td>
<td>3.69</td>
<td>W/m³V²</td>
</tr>
<tr>
<td>MFOVSW&lt;sup&gt;5&lt;/sup&gt;</td>
<td>A&lt;sub&gt;F&lt;/sub&gt;</td>
<td>1.2242</td>
<td>-0.05631</td>
<td>104.60</td>
<td>W/m²K</td>
</tr>
<tr>
<td></td>
<td>A&lt;sub&gt;V&lt;/sub&gt;</td>
<td>-25.5630</td>
<td>-24.5551</td>
<td>3.94</td>
<td>W/m³V²</td>
</tr>
</tbody>
</table>

<sup>1</sup> percent difference = \( \frac{\text{EST} - \text{Model}}{\text{EST}} \times 100 \)

<sup>2</sup> Wide Field-of-View Total channel
<sup>3</sup> Medium Field-of-View Total channel
<sup>4</sup> Wide Field-of-View Shortwave channel
<sup>5</sup> Medium Field-of-View Shortwave channel
Table 6. Uncertainties in the count-conversion equation coefficients for the Earth Radiation Budget Satellite, ERBS, based on a low-order physical model.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Coefficient</th>
<th>Value</th>
<th>Uncertainty</th>
<th>Percent Uncertainty</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>WFOVT²</td>
<td>$A_F$</td>
<td>-0.2391</td>
<td>0.0030</td>
<td>1.25</td>
<td>W/m²K</td>
</tr>
<tr>
<td></td>
<td>$A_V$</td>
<td>-22.5212</td>
<td>0.0745</td>
<td>0.33</td>
<td>W/m²V²</td>
</tr>
<tr>
<td></td>
<td>$B_T$</td>
<td>1355.13</td>
<td>3.51</td>
<td>0.26</td>
<td>W/m²</td>
</tr>
<tr>
<td>MFOVT³</td>
<td>$A_F$</td>
<td>-2.1244</td>
<td>0.0242</td>
<td>1.14</td>
<td>W/m²K</td>
</tr>
<tr>
<td></td>
<td>$A_V$</td>
<td>-22.6721</td>
<td>0.0751</td>
<td>0.33</td>
<td>W/m²V²</td>
</tr>
<tr>
<td></td>
<td>$B_T$</td>
<td>1625.32</td>
<td>7.66</td>
<td>0.47</td>
<td>W/m²</td>
</tr>
<tr>
<td>WFOVSW⁴</td>
<td>$A_F$</td>
<td>-0.0056</td>
<td>0.0004</td>
<td>7.68</td>
<td>W/m²K</td>
</tr>
<tr>
<td></td>
<td>$A_V$</td>
<td>-24.8279</td>
<td>0.1586</td>
<td>0.64</td>
<td>W/m²V²</td>
</tr>
<tr>
<td>MFOVSW⁵</td>
<td>$A_F$</td>
<td>-0.05631</td>
<td>0.0042</td>
<td>7.47</td>
<td>W/m²K</td>
</tr>
<tr>
<td></td>
<td>$A_V$</td>
<td>-24.5551</td>
<td>0.1569</td>
<td>0.64</td>
<td>W/m²V²</td>
</tr>
</tbody>
</table>

1 percent uncertainty = \[
\frac{\text{Uncertainty}}{\text{Value}} \times 100
\]

2 Wide Field-of-View Total channel
3 Medium Field-of-View Total channel
4 Wide Field-of-View Shortwave channel
5 Medium Field-of-View Shortwave channel
Table 7. Sources of uncertainty in the $A_F$ coefficient for each radiometric channel based on a low-order physical model.

<table>
<thead>
<tr>
<th>Variable</th>
<th>WFOVT$^1$</th>
<th>MFOVT$^2$</th>
<th>WFOVSW$^3$</th>
<th>MFOVSW$^4$</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau_{\text{LW}}$</td>
<td>0</td>
<td>0</td>
<td>0.000415</td>
<td>0.004140</td>
<td>-</td>
</tr>
<tr>
<td>$\tau_{\text{SW}}$</td>
<td>0</td>
<td>0</td>
<td>0.000031</td>
<td>0.000162</td>
<td>-</td>
</tr>
<tr>
<td>$\epsilon$</td>
<td>0.00048</td>
<td>0.004249</td>
<td>0.000011</td>
<td>0.000113</td>
<td>-</td>
</tr>
<tr>
<td>$F_{\text{CF}}$</td>
<td>0.000954</td>
<td>0.008483</td>
<td>0.000022</td>
<td>0.000201</td>
<td>-</td>
</tr>
<tr>
<td>$F_{\text{CS}}$</td>
<td>0.000951</td>
<td>0.008518</td>
<td>0.000022</td>
<td>0.000226</td>
<td>-</td>
</tr>
<tr>
<td>$T_F$</td>
<td>0.002619</td>
<td>0.020566</td>
<td>0.000084</td>
<td>0.000657</td>
<td>K</td>
</tr>
<tr>
<td>$\Delta A_F$</td>
<td>0.002983</td>
<td>0.024198</td>
<td>0.000425</td>
<td>0.004207</td>
<td>W/m$^2$K</td>
</tr>
</tbody>
</table>

$^1$ Wide Field-of-View Total channel  
$^2$ Medium Field-of-View Total channel  
$^3$ Wide Field-of-View Shortwave channel  
$^4$ Medium Field-of-View Shortwave channel  
$^5$ $\Delta A_F = \sqrt{\sum (\text{Variables})^2}$
Table 8. Sources of uncertainty in the $A_v$ coefficient for each radiometric channel based on a low-order physical model.

<table>
<thead>
<tr>
<th>Variable</th>
<th>WFOVT$^1$</th>
<th>MFOVT$^2$</th>
<th>WFOVSW$^3$</th>
<th>MFOVSW$^4$</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau_{sw}$</td>
<td>0</td>
<td>0</td>
<td>0.1356</td>
<td>0.1342</td>
<td>-</td>
</tr>
<tr>
<td>$A_A$</td>
<td>0.0676</td>
<td>0.0680</td>
<td>0.0745</td>
<td>0.0737</td>
<td>m$^2$</td>
</tr>
<tr>
<td>$R$</td>
<td>0.0161</td>
<td>0.0163</td>
<td>0.0179</td>
<td>0.0175</td>
<td>$\Omega$</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.0270</td>
<td>0.0272</td>
<td>0.0298</td>
<td>0.0295</td>
<td>-</td>
</tr>
<tr>
<td>$\Delta A_v$ $^5$</td>
<td>0.0745</td>
<td>0.0751</td>
<td>0.1586</td>
<td>0.1568</td>
<td>W/m$^2$V$^2$</td>
</tr>
</tbody>
</table>

1 Wide Field-of-View Total channel
2 Medium Field-of-View Total channel
3 Wide Field-of-View Shortwave channel
4 Medium Field-of-View Shortwave channel
5 $\Delta A_v = \sqrt{\sum (\text{Variables})^2}$
Table 9. Sources of uncertainty in the $B_T$ term for the wide and medium field-of-view total channels based on a low-order physical model.

<table>
<thead>
<tr>
<th>Variable</th>
<th>WFOVT$^1$</th>
<th>MFOVT$^2$</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{CS}$</td>
<td>1.463</td>
<td>0.711</td>
<td>-</td>
</tr>
<tr>
<td>$T_F$</td>
<td>0.012</td>
<td>0.106</td>
<td>K</td>
</tr>
<tr>
<td>$T_{bb}$</td>
<td>0.251</td>
<td>0.121</td>
<td>K</td>
</tr>
<tr>
<td>$V_{bb}$</td>
<td>0.351</td>
<td>0.333</td>
<td>V</td>
</tr>
<tr>
<td>$A_F$</td>
<td>0.876</td>
<td>7.110</td>
<td>W/m$^2$K</td>
</tr>
<tr>
<td>$A_V$</td>
<td>3.035</td>
<td>2.728</td>
<td>W/m$^2$V$^2$</td>
</tr>
<tr>
<td>$\Delta B_T^3$</td>
<td>3.51</td>
<td>7.66</td>
<td>W/m$^2$</td>
</tr>
</tbody>
</table>

$^1$ Wide Field-of-View Total channel
$^2$ Medium Field-of-View Total channel
$^3$ $\Delta B_T = \sqrt{\sum (\text{Variables})^2}$
Table 10. Distribution of Surface and Volume Elements for the end-to-end model.

<table>
<thead>
<tr>
<th></th>
<th>Azimuthal Divisions</th>
<th>Horizontal Divisions</th>
<th>Radial Divisions</th>
<th>Number of Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOVL Aperture</td>
<td>0</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>FOVL</td>
<td>10</td>
<td>4</td>
<td>-</td>
<td>40</td>
</tr>
<tr>
<td>Substrate</td>
<td>10</td>
<td>-</td>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>Ring</td>
<td>10</td>
<td>1</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Dome</td>
<td>10</td>
<td>6</td>
<td>-</td>
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1 Field-of-View Limiter
Table 11. Wide field-of-view total (WFOVT) channel ground calibration data [35].

<table>
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<th>Flux (W/m²)</th>
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<th>$T_{\text{bs}}$ (K)</th>
<th>$T_{\text{fwi}}$ (K)</th>
<th>$T_{\text{pa}}$ (K)</th>
<th>Bias Voltage (V)</th>
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Table 12. Medium field-of-view total (MFOVT) channel ground calibration data [35].

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<th>$T_{\text{hs}}$ (K)</th>
<th>$T_{\text{fowl}}$ (K)</th>
<th>$T_{\text{pa}}$ (K)</th>
<th>Bias Voltage (V)</th>
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Table 13. Wide field-of-view shortwave (WFOVSW) channel ground calibration data [35].

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<th>T_{fov1} (K)</th>
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Table 14. Medium field-of-view shortwave (MFOVSW) channel ground calibration data [35].

<table>
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<th>T_{ha} (K)</th>
<th>T_{low} (K)</th>
<th>T_{pa} (K)</th>
<th>Bias Voltage (V)</th>
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Table 15. Cavity thicknesses used in end-to-end model simulations.

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<tr>
<th>Channel</th>
<th>Nominal Thickness (mm)</th>
<th>Thickness Used (mm)</th>
<th>Difference (mm)</th>
<th>Difference as Percent of Tolerance$^1$</th>
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$^1$ Difference as percent of tolerance = \( \frac{\text{Difference}}{\text{Tolerance}} \times 100 \)

$^2$ Wide Field-of-View Total channel
$^3$ Medium Field-of-View Total channel
$^4$ Wide Field-of-View Shortwave channel
$^5$ Medium Field-of-View Shortwave channel
Table 16. Wide field-of-view total (WFOVT) channel voltage outputs during calibration runs for the actual instrument [35] and the end-to-end model. (See also Table 11)

<table>
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<tr>
<th>Run</th>
<th>Radiometric Source(^1)</th>
<th>Instrument output (V)</th>
<th>Model output (V)</th>
<th>Difference (Inst - Model) (V)</th>
<th>Percent Difference(^2)</th>
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<td>8.061287</td>
<td>8.057542</td>
<td>0.003745</td>
<td>0.0465</td>
</tr>
</tbody>
</table>

\(^1\) MRBB = Master Reference Black Body

\(^2\) percent difference = \frac{\text{Instrument} - \text{Model}}{\text{Instrument}} \times 100

Average percent difference = 0.00632
Standard deviation = 0.0419
Table 17. Medium field-of-view total (MFOVT) channel voltage outputs during calibration runs for the actual instrument [35] and the end-to-end model. (See also Table 12)

<table>
<thead>
<tr>
<th>Run</th>
<th>Radiometric Source</th>
<th>Instrument Output (V)</th>
<th>Model Output (V)</th>
<th>Difference (Inst - Model) (V)</th>
<th>Percent Difference$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MRBB</td>
<td>6.657307</td>
<td>6.670171</td>
<td>-0.012864</td>
<td>-0.1932</td>
</tr>
<tr>
<td>2</td>
<td>MRBB</td>
<td>8.066171</td>
<td>8.075988</td>
<td>-0.009818</td>
<td>-0.1217</td>
</tr>
<tr>
<td>3</td>
<td>MRBB</td>
<td>6.540106</td>
<td>6.54761</td>
<td>-0.007504</td>
<td>-0.1147</td>
</tr>
<tr>
<td>4</td>
<td>MRBB</td>
<td>7.969724</td>
<td>7.97512</td>
<td>-0.005396</td>
<td>-0.0677</td>
</tr>
<tr>
<td>5</td>
<td>MRBB</td>
<td>9.188134</td>
<td>9.192275</td>
<td>-0.004141</td>
<td>-0.0451</td>
</tr>
<tr>
<td>6</td>
<td>MRBB</td>
<td>6.464413</td>
<td>6.468376</td>
<td>-0.003963</td>
<td>-0.0613</td>
</tr>
<tr>
<td>7</td>
<td>MRBB</td>
<td>7.90746</td>
<td>7.910227</td>
<td>-0.002767</td>
<td>-0.0350</td>
</tr>
<tr>
<td>8</td>
<td>MRBB</td>
<td>6.370407</td>
<td>6.366627</td>
<td>0.004142</td>
<td>0.0650</td>
</tr>
<tr>
<td>9</td>
<td>MRBB</td>
<td>7.830547</td>
<td>7.826951</td>
<td>0.003596</td>
<td>0.0459</td>
</tr>
<tr>
<td>10</td>
<td>MRBB</td>
<td>9.067269</td>
<td>9.063749</td>
<td>0.00352</td>
<td>0.0388</td>
</tr>
<tr>
<td>11</td>
<td>MRBB</td>
<td>6.294714</td>
<td>6.287961</td>
<td>0.006753</td>
<td>0.1073</td>
</tr>
<tr>
<td>12</td>
<td>MRBB</td>
<td>7.769504</td>
<td>7.763173</td>
<td>0.006331</td>
<td>0.0815</td>
</tr>
<tr>
<td>13</td>
<td>MRBB</td>
<td>6.214138</td>
<td>6.202924</td>
<td>0.011214</td>
<td>0.1805</td>
</tr>
<tr>
<td>14</td>
<td>MRBB</td>
<td>7.704799</td>
<td>7.694426</td>
<td>0.010373</td>
<td>0.1346</td>
</tr>
<tr>
<td>15</td>
<td>MRBB</td>
<td>8.958613</td>
<td>8.949531</td>
<td>0.009082</td>
<td>0.1014</td>
</tr>
</tbody>
</table>

$^1$ MRBB = Master Reference Black Body

$^2$ percent difference = $\frac{\text{Instrument} - \text{Model}}{\text{Instrument}} \times 100$

Average percent difference = 0.0078
Standard deviation = 0.1079
Table 18. Wide field-of-view shortwave (WFOVSW) channel voltage outputs during calibration runs for the actual instrument [35] and the end-to-end model. (See also Table 13)

<table>
<thead>
<tr>
<th>Run</th>
<th>Radiometric Source(^1)</th>
<th>Instrument Output (V)</th>
<th>Model Output (V)</th>
<th>Difference (Inst - Model) (V)</th>
<th>Percent Difference(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ISP</td>
<td>6.082285</td>
<td>6.0806768</td>
<td>0.001608</td>
<td>0.0264</td>
</tr>
<tr>
<td>2</td>
<td>ISP</td>
<td>7.509462</td>
<td>7.5075147</td>
<td>0.001947</td>
<td>0.0259</td>
</tr>
<tr>
<td>3</td>
<td>ISP</td>
<td>8.718105</td>
<td>8.7163506</td>
<td>0.001754</td>
<td>0.0201</td>
</tr>
<tr>
<td>4</td>
<td>ISP</td>
<td>6.162862</td>
<td>6.1628310</td>
<td>0.000031</td>
<td>0.0005</td>
</tr>
<tr>
<td>5</td>
<td>ISP</td>
<td>7.575388</td>
<td>7.5753361</td>
<td>0.000052</td>
<td>0.0007</td>
</tr>
<tr>
<td>6</td>
<td>ISP</td>
<td>6.317910</td>
<td>6.3207678</td>
<td>-0.002858</td>
<td>-0.0452</td>
</tr>
<tr>
<td>7</td>
<td>ISP</td>
<td>7.701135</td>
<td>7.7040700</td>
<td>-0.002935</td>
<td>-0.0381</td>
</tr>
<tr>
<td>8</td>
<td>ISP</td>
<td>8.882920</td>
<td>8.8860036</td>
<td>-0.003084</td>
<td>-0.0347</td>
</tr>
<tr>
<td>9</td>
<td>ISP</td>
<td>7.826883</td>
<td>7.8270771</td>
<td>-0.000194</td>
<td>-0.0025</td>
</tr>
<tr>
<td>10</td>
<td>MRBB</td>
<td>-</td>
<td>6.7511842</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>11</td>
<td>MRBB</td>
<td>-</td>
<td>8.0634469</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>12</td>
<td>MRBB</td>
<td>-</td>
<td>9.1999704</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>13</td>
<td>MRBB</td>
<td>-</td>
<td>6.7540802</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>14</td>
<td>MRBB</td>
<td>-</td>
<td>8.0659551</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>15</td>
<td>MRBB</td>
<td>-</td>
<td>6.7594729</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>16</td>
<td>MRBB</td>
<td>-</td>
<td>8.0704198</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>17</td>
<td>MRBB</td>
<td>-</td>
<td>9.2060693</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>18</td>
<td>MRBB</td>
<td>-</td>
<td>8.0748572</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^1\) MRBB = Master Reference Black Body  
ISP = Integrating Sphere  

\(^2\) percent difference = \(\frac{\text{Instrument} - \text{Model}}{\text{Instrument}}\) X 100  
Average percent difference = -0.0052  
Standard deviation = 0.0279
Table 19. Medium field-of-view shortwave (MFOVSW) channel voltage outputs during calibration runs for the actual instrument [35] and the end-to-end model. (See also Table 14)

<table>
<thead>
<tr>
<th>Run</th>
<th>Radiometric Source</th>
<th>Instrument Output (V)</th>
<th>Model Output (V)</th>
<th>Difference (Inst - Model) (V)</th>
<th>Percent Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ISP</td>
<td>6.911244</td>
<td>6.9064264</td>
<td>0.004818</td>
<td>0.0697</td>
</tr>
<tr>
<td>2</td>
<td>ISP</td>
<td>8.310341</td>
<td>8.3037823</td>
<td>0.006559</td>
<td>0.0079</td>
</tr>
<tr>
<td>3</td>
<td>ISP</td>
<td>9.514101</td>
<td>9.5085776</td>
<td>0.005523</td>
<td>0.0581</td>
</tr>
<tr>
<td>4</td>
<td>ISP</td>
<td>6.947870</td>
<td>6.9474149</td>
<td>0.000455</td>
<td>0.0065</td>
</tr>
<tr>
<td>5</td>
<td>ISP</td>
<td>8.338420</td>
<td>8.3382201</td>
<td>0.000200</td>
<td>0.0024</td>
</tr>
<tr>
<td>6</td>
<td>ISP</td>
<td>7.023562</td>
<td>7.0239572</td>
<td>-0.000395</td>
<td>-0.0056</td>
</tr>
<tr>
<td>7</td>
<td>ISP</td>
<td>8.401905</td>
<td>8.4020398</td>
<td>-0.000135</td>
<td>-0.0016</td>
</tr>
<tr>
<td>8</td>
<td>ISP</td>
<td>9.595898</td>
<td>9.5945255</td>
<td>0.004455</td>
<td>0.0464</td>
</tr>
<tr>
<td>9</td>
<td>ISP</td>
<td>7.091930</td>
<td>7.0954097</td>
<td>-0.003480</td>
<td>-0.0491</td>
</tr>
<tr>
<td>10</td>
<td>ISP</td>
<td>8.461726</td>
<td>8.4620933</td>
<td>-0.000367</td>
<td>-0.0043</td>
</tr>
<tr>
<td>11</td>
<td>MRBB</td>
<td>-</td>
<td>7.231473</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>12</td>
<td>MRBB</td>
<td>-</td>
<td>8.577088</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>13</td>
<td>MRBB</td>
<td>-</td>
<td>9.748290</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>14</td>
<td>MRBB</td>
<td>-</td>
<td>7.233369</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>15</td>
<td>MRBB</td>
<td>-</td>
<td>8.578452</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>16</td>
<td>MRBB</td>
<td>-</td>
<td>7.236463</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>17</td>
<td>MRBB</td>
<td>-</td>
<td>8.581001</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>18</td>
<td>MRBB</td>
<td>-</td>
<td>9.751672</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>19</td>
<td>MRBB</td>
<td>-</td>
<td>7.238604</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>MRBB</td>
<td>-</td>
<td>8.582913</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Average percent difference = 0.0130  
Standard deviation = 0.0354
Table 20. Comparison of instrument and end-to-end model gains.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Reference Cavity Heater Voltage (V)</th>
<th>Radiometric Source</th>
<th>End-to-End Model Gain (Vm²/W)</th>
<th>Instrument Gain (Vm²/W)</th>
<th>Percent Difference²</th>
</tr>
</thead>
<tbody>
<tr>
<td>WFOVT³</td>
<td>0</td>
<td>MRBB</td>
<td>-0.002786</td>
<td>-0.002753</td>
<td>1.185</td>
</tr>
<tr>
<td></td>
<td>4.33</td>
<td>MRBB</td>
<td>-0.002323</td>
<td>-0.002299</td>
<td>0.103</td>
</tr>
<tr>
<td></td>
<td>6.14</td>
<td>MRBB</td>
<td>-0.002026</td>
<td>-0.002003</td>
<td>1.135</td>
</tr>
<tr>
<td>MFOVT⁴</td>
<td>0</td>
<td>MRBB</td>
<td>-0.001551</td>
<td>-0.001471</td>
<td>5.158</td>
</tr>
<tr>
<td></td>
<td>4.33</td>
<td>MRBB</td>
<td>-0.001267</td>
<td>-0.001200</td>
<td>5.288</td>
</tr>
<tr>
<td></td>
<td>6.14</td>
<td>MRBB</td>
<td>-0.001101</td>
<td>-0.001041</td>
<td>5.450</td>
</tr>
<tr>
<td>WFOVSW⁵</td>
<td>0</td>
<td>ISP</td>
<td>-0.002929</td>
<td>-0.002874</td>
<td>1.878</td>
</tr>
<tr>
<td></td>
<td>4.33</td>
<td>ISP</td>
<td>-0.002365</td>
<td>-0.002350</td>
<td>0.634</td>
</tr>
<tr>
<td></td>
<td>6.14</td>
<td>ISP</td>
<td>-0.002065</td>
<td>-0.002006</td>
<td>2.857</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>MRBB</td>
<td>-0.000101</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>4.33</td>
<td>MRBB</td>
<td>-0.000084</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>6.14</td>
<td>MRBB</td>
<td>-0.000074</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MFOVSW⁶</td>
<td>0</td>
<td>ISP</td>
<td>-0.001240</td>
<td>-0.001185</td>
<td>4.435</td>
</tr>
<tr>
<td></td>
<td>4.33</td>
<td>ISP</td>
<td>-0.001035</td>
<td>-0.00099</td>
<td>4.348</td>
</tr>
<tr>
<td></td>
<td>6.14</td>
<td>ISP</td>
<td>-0.00091</td>
<td>-0.00086</td>
<td>5.495</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>MRBB</td>
<td>-0.000047</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>4.33</td>
<td>MRBB</td>
<td>-0.000038</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>6.14</td>
<td>MRBB</td>
<td>-0.000036</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

¹ MRBB = Master Reference Black Body
ISP = Integrating Sphere
² \[ \text{Percent Difference} = \frac{\text{Model} - \text{Instrument}}{\text{Model}} \times 100 \]
³ Wide Field-of-View Total channel
⁴ Medium Field-of-View Total channel
⁵ Wide Field-of-View Shortwave channel
⁶ Medium Field-of-View Shortwave channel
Table 21. Ground count-conversion equation coefficients as determined using multiple regression methodology by the ERBE Science Team (EST), and by using the end-to-end model.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Coefficient</th>
<th>EST</th>
<th>End-to-End Model</th>
<th>Percent Difference</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>WFOVT²</td>
<td>$A_v'$</td>
<td>-26.2164</td>
<td>-25.6298</td>
<td>2.24</td>
<td>W/m²V²</td>
</tr>
<tr>
<td></td>
<td>$A_f'$</td>
<td>-1.6070</td>
<td>-0.1224</td>
<td>92.38</td>
<td>W/m²K</td>
</tr>
<tr>
<td></td>
<td>$A_r'$</td>
<td>30.0461</td>
<td>29.36538</td>
<td>2.27</td>
<td>W/m²V²</td>
</tr>
<tr>
<td></td>
<td>$B_T'$</td>
<td>1560.32</td>
<td>1567.33</td>
<td>-0.45</td>
<td>W/m²</td>
</tr>
<tr>
<td>MFOVT³</td>
<td>$A_v'$</td>
<td>-53.5596</td>
<td>-50.2028</td>
<td>6.27</td>
<td>W/m²V²</td>
</tr>
<tr>
<td></td>
<td>$A_f'$</td>
<td>-2.1768</td>
<td>-0.5349</td>
<td>75.43</td>
<td>W/m²K</td>
</tr>
<tr>
<td></td>
<td>$A_r'$</td>
<td>59.2633</td>
<td>55.44413</td>
<td>6.44</td>
<td>W/m²V²</td>
</tr>
<tr>
<td></td>
<td>$B_T'$</td>
<td>2487.64</td>
<td>2506.689</td>
<td>-0.77</td>
<td>W/m²</td>
</tr>
<tr>
<td>WFOVSW⁴</td>
<td>$A_v'$</td>
<td>-28.2194</td>
<td>-28.5472</td>
<td>-1.16</td>
<td>W/m²V²</td>
</tr>
<tr>
<td></td>
<td>$A_f'$</td>
<td>-0.7097</td>
<td>0.7394</td>
<td>204.18</td>
<td>W/m²K</td>
</tr>
<tr>
<td></td>
<td>$A_r'$</td>
<td>29.2817</td>
<td>29.6613</td>
<td>-1.30</td>
<td>W/m²V²</td>
</tr>
<tr>
<td></td>
<td>$A_E'$</td>
<td>-0.02902</td>
<td>-0.04121</td>
<td>-42.01</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>$B_{SW}'$</td>
<td>1234.19</td>
<td>1093.73</td>
<td>11.38</td>
<td>W/m²</td>
</tr>
<tr>
<td>MFOVSW⁵</td>
<td>$A_v'$</td>
<td>-58.454</td>
<td>-59.7392</td>
<td>-2.20</td>
<td>W/m²V²</td>
</tr>
<tr>
<td></td>
<td>$A_f'$</td>
<td>2.7990</td>
<td>-1.51031</td>
<td>153.96</td>
<td>W/m²K</td>
</tr>
<tr>
<td></td>
<td>$A_r'$</td>
<td>66.4883</td>
<td>67.92095</td>
<td>-2.15</td>
<td>W/m²V²</td>
</tr>
<tr>
<td></td>
<td>$A_E'$</td>
<td>-0.03641</td>
<td>-0.03151</td>
<td>13.46</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>$B_{SW}'$</td>
<td>2984.17</td>
<td>3576.073</td>
<td>-19.83</td>
<td>W/m²</td>
</tr>
</tbody>
</table>

¹ percent difference = $\frac{\text{EST} - \text{Model}}{\text{EST}} \times 100$

² Wide Field-of-View Total channel
³ Medium Field-of-View Total channel
⁴ Wide Field-of-View Shortwave channel
⁵ Medium Field-of-View Shortwave channel
Table 22. Specified and predicted fluxes for the wide field-of-view total (WFOVT) channel calibration runs. (See also Tables 11 and 16)

<table>
<thead>
<tr>
<th>Run</th>
<th>Specified Flux (W/m²)</th>
<th>Predicted Flux (W/m²)</th>
<th>Difference (Pred - Spec)</th>
<th>Percent Difference¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>116.9433</td>
<td>116.9991</td>
<td>0.055775</td>
<td>0.048</td>
</tr>
<tr>
<td>2</td>
<td>116.9433</td>
<td>116.7585</td>
<td>-0.1848</td>
<td>-0.158</td>
</tr>
<tr>
<td>3</td>
<td>197.7553</td>
<td>197.8338</td>
<td>0.078464</td>
<td>0.040</td>
</tr>
<tr>
<td>4</td>
<td>197.7228</td>
<td>197.5628</td>
<td>-0.16001</td>
<td>-0.081</td>
</tr>
<tr>
<td>5</td>
<td>197.7553</td>
<td>197.9896</td>
<td>023426</td>
<td>0.118</td>
</tr>
<tr>
<td>6</td>
<td>249.0759</td>
<td>249.1821</td>
<td>0.106192</td>
<td>0.043</td>
</tr>
<tr>
<td>7</td>
<td>249.1146</td>
<td>248.9822</td>
<td>-0.13239</td>
<td>-0.053</td>
</tr>
<tr>
<td>8</td>
<td>315.4354</td>
<td>315.5144</td>
<td>0.079031</td>
<td>0.025</td>
</tr>
<tr>
<td>9</td>
<td>315.4354</td>
<td>315.2848</td>
<td>-0.15057</td>
<td>-0.048</td>
</tr>
<tr>
<td>10</td>
<td>315.4354</td>
<td>315.6591</td>
<td>0.223706</td>
<td>0.071</td>
</tr>
<tr>
<td>11</td>
<td>364.6463</td>
<td>364.7025</td>
<td>0.056153</td>
<td>0.015</td>
</tr>
<tr>
<td>12</td>
<td>364.6463</td>
<td>364.4835</td>
<td>-0.16283</td>
<td>-0.045</td>
</tr>
<tr>
<td>13</td>
<td>418.0881</td>
<td>418.1754</td>
<td>0.087281</td>
<td>0.021</td>
</tr>
<tr>
<td>14</td>
<td>418.0881</td>
<td>417.9578</td>
<td>-0.13027</td>
<td>-0.031</td>
</tr>
</tbody>
</table>

¹ percent difference = \[ \frac{\text{Predicted} - \text{Specified}}{\text{Predicted}} \times 100 \]

Average percent difference = -0.0025
Standard deviation = 0.071
Table 23. Specified and predicted fluxes for the medium field-of-view total (MFOVT) channel calibration runs. (See also Tables 12 and 17)

<table>
<thead>
<tr>
<th>Run</th>
<th>Specified Flux (W/m²)</th>
<th>Predicted Flux (W/m²)</th>
<th>Difference (Pred - Spec)</th>
<th>Percent Difference ¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>116.9433</td>
<td>117.3689</td>
<td>0.425642</td>
<td>0.364</td>
</tr>
<tr>
<td>2</td>
<td>116.9433</td>
<td>116.0798</td>
<td>-0.86347</td>
<td>-0.738</td>
</tr>
<tr>
<td>3</td>
<td>197.7228</td>
<td>198.2796</td>
<td>0.556773</td>
<td>0.282</td>
</tr>
<tr>
<td>4</td>
<td>197.7228</td>
<td>196.9811</td>
<td>-0.74173</td>
<td>-0.375</td>
</tr>
<tr>
<td>5</td>
<td>197.7553</td>
<td>198.6354</td>
<td>0.880057</td>
<td>0.445</td>
</tr>
<tr>
<td>6</td>
<td>249.1146</td>
<td>249.7866</td>
<td>0.672017</td>
<td>0.270</td>
</tr>
<tr>
<td>7</td>
<td>249.1146</td>
<td>248.4757</td>
<td>-0.63889</td>
<td>-0.256</td>
</tr>
<tr>
<td>8</td>
<td>315.4816</td>
<td>315.7945</td>
<td>0.312917</td>
<td>0.099</td>
</tr>
<tr>
<td>9</td>
<td>315.4816</td>
<td>314.3749</td>
<td>-1.10672</td>
<td>-0.351</td>
</tr>
<tr>
<td>10</td>
<td>315.4354</td>
<td>316.2325</td>
<td>0.797143</td>
<td>0.253</td>
</tr>
<tr>
<td>11</td>
<td>364.6463</td>
<td>365.0683</td>
<td>0.422046</td>
<td>0.116</td>
</tr>
<tr>
<td>12</td>
<td>364.6463</td>
<td>363.8638</td>
<td>-0.78246</td>
<td>-0.215</td>
</tr>
<tr>
<td>13</td>
<td>418.2022</td>
<td>418.3986</td>
<td>0.196354</td>
<td>0.047</td>
</tr>
<tr>
<td>14</td>
<td>418.2022</td>
<td>417.1915</td>
<td>-1.0107</td>
<td>-0.242</td>
</tr>
<tr>
<td>15</td>
<td>418.2022</td>
<td>419.0832</td>
<td>0.881014</td>
<td>0.211</td>
</tr>
</tbody>
</table>

¹ percent difference = \( \frac{\text{Predicted} - \text{Specified}}{\text{Predicted}} \times 100 \)

Average percent difference = -0.006
Standard deviation = 0.3376
Table 24. Specified and predicted fluxes for the wide field-of-view shortwave (WFOVSW) channel calibration runs. (See also Tables 13 and 18)

<table>
<thead>
<tr>
<th>Run</th>
<th>Specified LW Flux (W/m²)</th>
<th>Specified SW Flux (W/m²)</th>
<th>Predicted Flux (W/m²)</th>
<th>Difference (Pred - Spec)</th>
<th>Percent Difference¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>245.9479</td>
<td>245.3763</td>
<td>-0.57121</td>
<td>-0.232</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>247.097</td>
<td>248.0715</td>
<td>0.974496</td>
<td>0.394</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>247.334</td>
<td>246.6638</td>
<td>-0.67015</td>
<td>-0.271</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>218.2678</td>
<td>217.5738</td>
<td>-0.69398</td>
<td>-0.318</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>218.9558</td>
<td>219.7999</td>
<td>0.844129</td>
<td>0.386</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>163.9693</td>
<td>163.4977</td>
<td>-0.4716</td>
<td>-0.288</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>164.7808</td>
<td>165.8069</td>
<td>1.02607</td>
<td>0.623</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>165.1577</td>
<td>164.5487</td>
<td>-0.60897</td>
<td>-0.369</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>111.999</td>
<td>112.2908</td>
<td>0.291838</td>
<td>0.261</td>
</tr>
<tr>
<td>10</td>
<td>245.9479</td>
<td>0</td>
<td>-0.23976</td>
<td>-0.23976</td>
<td>-</td>
</tr>
<tr>
<td>11</td>
<td>247.097</td>
<td>0</td>
<td>0.955148</td>
<td>0.955148</td>
<td>-</td>
</tr>
<tr>
<td>12</td>
<td>247.334</td>
<td>0</td>
<td>-0.6891</td>
<td>-0.6891</td>
<td>-</td>
</tr>
<tr>
<td>13</td>
<td>218.2678</td>
<td>0</td>
<td>-0.44472</td>
<td>-0.44472</td>
<td>-</td>
</tr>
<tr>
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<td>0</td>
<td>0.730793</td>
<td>0.730793</td>
<td>-</td>
</tr>
<tr>
<td>15</td>
<td>163.9693</td>
<td>0</td>
<td>-0.3169</td>
<td>-0.3169</td>
<td>-</td>
</tr>
<tr>
<td>16</td>
<td>164.7808</td>
<td>0</td>
<td>0.832881</td>
<td>0.832881</td>
<td>-</td>
</tr>
<tr>
<td>17</td>
<td>165.1577</td>
<td>0</td>
<td>-0.75844</td>
<td>-0.75844</td>
<td>-</td>
</tr>
<tr>
<td>18</td>
<td>111.999</td>
<td>0</td>
<td>-0.19053</td>
<td>-0.19053</td>
<td>-</td>
</tr>
</tbody>
</table>

¹ percent difference = \( \frac{\text{Predicted} - \text{Specified}}{\text{Predicted}} \) \times 100

Average percent difference = 0.0207
Standard deviation = 0.3880
Table 25. Specified and predicted fluxes for the medium field-of-view shortwave channel calibration runs. (See also Tables 14 and 19)

<table>
<thead>
<tr>
<th>Run</th>
<th>Specified LW Flux (W/m²)</th>
<th>Specified SW Flux (W/m²)</th>
<th>Predicted Flux (W/m²)</th>
<th>Difference (Pred - Spec)</th>
<th>Percent Difference¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>274.8957</td>
<td>273.9739</td>
<td>-0.92181</td>
<td>-0.335</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>275.7781</td>
<td>277.5075</td>
<td>1.729419</td>
<td>0.627</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>275.9143</td>
<td>274.1356</td>
<td>-1.77865</td>
<td>-0.645</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>242.2518</td>
<td>241.4119</td>
<td>-0.83986</td>
<td>-0.347</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>242.8004</td>
<td>244.5962</td>
<td>1.795792</td>
<td>0.740</td>
</tr>
<tr>
<td>6</td>
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<td>180.8951</td>
<td>180.4267</td>
<td>-0.46844</td>
<td>-0.259</td>
</tr>
<tr>
<td>7</td>
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<td>181.4509</td>
<td>183.4011</td>
<td>1.95017</td>
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</tr>
<tr>
<td>8</td>
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<td>179.8272</td>
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</tr>
<tr>
<td>9</td>
<td>0</td>
<td>122.4678</td>
<td>121.2135</td>
<td>-1.25426</td>
<td>-1.024</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>122.8437</td>
<td>124.2937</td>
<td>1.450042</td>
<td>1.180</td>
</tr>
<tr>
<td>11</td>
<td>274.8957</td>
<td>0</td>
<td>-0.55559</td>
<td>-0.55559</td>
<td>-</td>
</tr>
<tr>
<td>12</td>
<td>275.7781</td>
<td>0</td>
<td>1.892456</td>
<td>1.892456</td>
<td>-</td>
</tr>
<tr>
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<td>-1.62673</td>
<td>-1.62673</td>
<td>-</td>
</tr>
<tr>
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<td>-0.83313</td>
<td>-</td>
</tr>
<tr>
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<td>242.8004</td>
<td>0</td>
<td>1.820578</td>
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</tr>
<tr>
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<td>180.8951</td>
<td>0</td>
<td>-0.60842</td>
<td>-0.60842</td>
<td>-</td>
</tr>
<tr>
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<td>1.835446</td>
<td>1.835446</td>
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</tr>
<tr>
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<td>-1.79024</td>
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</tr>
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<td>-1.404</td>
<td>-</td>
</tr>
<tr>
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<td>0</td>
<td>1.268186</td>
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<td>-</td>
</tr>
</tbody>
</table>

Average percent difference = 0.0085  
Standard deviation = 0.8208
Table 26. Comparison of the Inflight count-conversion equation coefficients as determined by the ERBE Science Team (EST), the end-to-end model, and the low-order physical model.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Coefficient</th>
<th>EST</th>
<th>End-to-End Model</th>
<th>Physical Model</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>WFOVT(^1)</td>
<td>(A_v)</td>
<td>-22.7873</td>
<td>-22.277</td>
<td>-22.5212</td>
<td>W/m(^2)V(^2)</td>
</tr>
<tr>
<td></td>
<td>(A_F)</td>
<td>-1.3968</td>
<td>-0.1064</td>
<td>-0.2390</td>
<td>W/m(^2)K</td>
</tr>
<tr>
<td></td>
<td>(A_R)</td>
<td>26.1161</td>
<td>25.5244</td>
<td>-</td>
<td>W/m(^2)V(^2)</td>
</tr>
<tr>
<td>MFOVT(^2)</td>
<td>(A_v)</td>
<td>-22.7093</td>
<td>-21.286</td>
<td>-22.6721</td>
<td>W/m(^2)V(^2)</td>
</tr>
<tr>
<td></td>
<td>(A_F)</td>
<td>-0.9230</td>
<td>-0.2268</td>
<td>-2.1244</td>
<td>W/m(^2)K</td>
</tr>
<tr>
<td></td>
<td>(A_R)</td>
<td>25.1276</td>
<td>23.5071</td>
<td>-</td>
<td>W/m(^2)V(^2)</td>
</tr>
<tr>
<td>WFOVS(^3)</td>
<td>(A_v)</td>
<td>-25.7758</td>
<td>-25.1129</td>
<td>-24.8229</td>
<td>W/m(^2)V(^2)</td>
</tr>
<tr>
<td></td>
<td>(A_F)</td>
<td>-0.6502</td>
<td>0.6505</td>
<td>-0.0056</td>
<td>W/m(^2)K</td>
</tr>
<tr>
<td></td>
<td>(A_R)</td>
<td>25.7591</td>
<td>26.0930</td>
<td>-</td>
<td>W/m(^2)V(^2)</td>
</tr>
<tr>
<td></td>
<td>(A_E)</td>
<td>-0.0255</td>
<td>-0.3625</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MFOVS(^4)</td>
<td>(A_v)</td>
<td>-25.5630</td>
<td>-25.3294</td>
<td>-24.5551</td>
<td>W/m(^2)V(^2)</td>
</tr>
<tr>
<td></td>
<td>(A_F)</td>
<td>1.2242</td>
<td>-0.64037</td>
<td>-0.05631</td>
<td>W/m(^2)K</td>
</tr>
<tr>
<td></td>
<td>(A_R)</td>
<td>28.1910</td>
<td>28.7985</td>
<td>-</td>
<td>W/m(^2)V(^2)</td>
</tr>
<tr>
<td></td>
<td>(A_E)</td>
<td>-0.0154</td>
<td>-0.01336</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^1\) Wide Field-of-View Total channel  
\(^2\) Medium Field-of-View Total channel  
\(^3\) Wide Field-of-View Shortwave channel  
\(^4\) Medium Field-of-View Shortwave channel
Table 27. Comparison of incident and predicted energy during a solar blip.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Specified Energy (KJ)</th>
<th>Predicted Energy (KJ)</th>
<th>Percent Difference¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>WFOVT²</td>
<td>43.38</td>
<td>44.34</td>
<td>2.17</td>
</tr>
<tr>
<td>WFOVSW³</td>
<td>21.96</td>
<td>26.09</td>
<td>15.83</td>
</tr>
</tbody>
</table>

¹ percent difference = \( \frac{\text{Predicted} - \text{Specified}}{\text{Predicted}} \times 100 \\
² Wide Field-of-View Total channel \\
³ Wide Field-of-View Shortwave Channel
Fig. 1. Components of the Earth Radiation Budget.
Fig. 2. An ERBE Earth-Viewing Nonscanning Active-Cavity Radiometer.
Fig. 3. Nonscanner Assembly Drawing.
Fig. 4. Radiometer Sensing Element.
Fig. 5. Electrical Feedback Control (a) Block Diagram and (b) Simplified Electrical Schematic.
Fig. 6. ERBE Calibration Chamber [33].
Fig. 7. Differences in the Earth Radiation Budget Satellite (ERBS) Wide Field-of-View Total (WFOVT) Channel Fluxes Obtained Utilizing Low-Order Physical Model Coefficients and Coefficients Based on the ERBE Science Team's Statistical Regression (Model - Regressed).
Fig. 8. Differences in the Earth Radiation Budget Satellite (ERBS) Medium Field-of-View Total (MFOVT) Channel Fluxes Obtained Utilizing Low-Order Physical Model Coefficients and Coefficients Based on the ERBE Science Team's Statistical Regression (Model - Regressed).
Fig. 9. Illustration of Absorption, Reflection and Transmission.
Fig. 10. Illustration of (a) Diffuse and (b) Specular Reflections.
Fig. 11. Gains of the Wide Field-of-View (WFOVT) Channel End-to-End Model During Simulated Ground Calibration Runs as a Function of Reference Cavity Heater Voltage.
Fig. 12. Gains of the Medium Field-of-View Total (MFOVT) Channel End-to-End Model During Simulated Ground Calibration Runs as a Function of Reference Cavity Heater Voltage.
Fig. 13. Gains of the Wide Field-of-View Shortwave (WFOVSW) Channel End-to-End Model During Simulated Ground Calibration Runs as a Function of Reference Cavity Heater Voltage and Spectral Distribution of the Radiative Flux. (Solid Symbols = Shortwave Sources, Hollow Symbols = Longwave Sources)
Fig. 14. Gains of the Medium Field-of-View Shortwave (MFOVSW) Channel End-to-End Model During Simulated Ground Calibration Runs as a Function of Reference Cavity Heater Voltage and Spectral Distribution of the Radiative Flux. (Solid Symbols = Shortwave Sources, Hollow Symbols = Longwave Sources)
Fig. 15. Uncertainty in the Wide Field-of-View Total (WFOVT) Channel Data Product Derived Using a Low-Order Physical Model.
Fig. 16. Uncertainty in the Medium Field-of-View Total (MFOVT) Channel Data Product Derived Using a Low-Order Physical Model.
Fig. 17. Variation in the Wide Field-of-View Total (WFOVT) Channel Uncertainty as a Function of Solar Zenith Angle.
Fig. 18. Variation in the Medium Field-of-View Total (MFOVT) Channel Uncertainty as a Function of Solar Zenith Angle.
Fig. 19. Simulated Solar Blip Event Radiative Fluxes, Determined Using Data Recorded by the Earth Radiation Budget Satellite (ERBS) on April 17, 1985.
Fig. 20. Field-of-View Limiter Temperatures for the Simulated Solar Blip Event, Values were Obtained from Data Recorded by the Earth Radiation Budget Satellite (ERBS) on April 17, 1985.
Fig. 21. Wide Field-of-View Total (WFOVT) Channel Simulated Solar Blip Event, Showing the Specified Incident Flux, and the Corresponding Flux Predicted by the End-to-End Model.
Fig. 22. Average Resistance Temperature Detector (RTD) Temperature Predicted for the Wide Field-of-View Total (WFOVT) Channel Solar Blip Event.
Fig. 23. Wide Field-of-View Shortwave (WFOVSW) Channel Simulated Solar Blip Event, Showing the Specified Incident Flux, and the Corresponding Flux Predicted by the End-to-End Model.
Fig. 24. Average Resistance Temperature Detector (RTD) Temperature Predicted for the Wide Field-of-View Shortwave (WFOVSW) Channel Solar Blip Event.
Fig. 25. Specified Incident and the Corresponding Predicted Longwave Flux During a Simulated Solar Blip Event. (Longwave Flux = Total Flux - Shortwave Flux)
References


18. Gardiner, B. D., *An Analytical Study of Dynamic Response and Nonequivalence of an Absolute Active Cavity Radiometer Operating at Cryogenic Temperatures*, M. S. Thesis, Mechanical Engineering Department, Virginia Polytechnic Institute and State University,


References


Appendix A

Program ERBERT
****
PROGRAM ERBERT
****

* THIS CODE IS A MONTE-CARLO-BASED RAY-TRACE ANALYSIS OF THE ERBE
* EARTH-VIEWING NONSCANNING ACTIVE CAVITY RADIOMETERS.
* IT COMPUTES THE DISTRIBUTION FACTORS BETWEEN THE VARIOUS
* PARTS OF THE INSTRUMENT.
* THE DISTRIBUTION FACTORS CAN THEN BE USED TO COMPUTE A THERMAL
* DIFFUSION ANALYSIS IN THE FILTER DOME OR TO OBTAIN THE
* ELECTROTHERMAL RESPONSE OF THE ACTIVE CAVITY.
*
* THIS CODE WAS DEVELOPED BY MARTIAL HAEPFELIN & KORY PRIESTLEY
* UNDER NASA FUNDING.
*

** PROGRAM ERBERT
IMPLICIT NONE
*
******

C VARIABLES FOR THE SPECTRAL DISTRIBUTION OF ENERGY BUNDLES
C
REAL*8 FREMPO, TS
REAL*8 L6DA, LBDAMX
C
C VARIABLES FOR GEOMETRY AND PHYSICAL PROPERTIES OF THE MODULE
C
REAL*8 RFV, TTFPM, RPA, REXT, RINT, DENV, PI, ZMAX, CRADAN
REAL*8 ALPHA1, ALPHA2, ALPHA9, ALPHA11, ALPHA13, ALPHA14
REAL*8 ROSPEC1, ROSPEC2, ROSPEC3, ROSPEC4, ROSPEC5, ROSPEC6, ROSPEC7, ROSPEC14
REAL*8 RODIFF1, RODIFF2, RODIFF3, RODIFF4, RODIFF5, RODIFF6, RODIFF7, RODIFF14
REAL*8 RADF, PHIF, TTAF, SAREA, RCEN
REAL*8 RCAY, LBAR, LCON, CAVANG, DLCON
REAL*8 VOLUM, IVAC, IDOM
C
C VARIABLES FOR ABSORPTION/TRANSMISSION IN THE FILTER DOME
C
REAL*8 DELZ, ALPHAD, LEN, RDML, DOABCO, DOMTHC, RDM
C
C VARIABLES FOR LOCATION AND DIRECTION OF THE TRACED RAY
C
REAL*8 X0, Y0, ZC, X1, Y1, Z1, X2, Y2, Z2, XX, YY, ZZ, XPTSO, YPTSO
REAL*8 XT, YT, ZT, XTT, YTT, ZTT
REAL*8 L, M, N, INORM, ANORM, MAGNV, COSOLD, COSNEW
REAL*8 ANORM1, ANORM2, ANORM3
REAL*8 ANORM4, ANORM5, ANORM6
REAL*8 ANORM7, ANORM8, ANORM9
REAL*8 XMOD, YNOD, ZNOD
REAL*8 XFAC, YFAC, ZFAC
C
C
Program ERBERT
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List of functions

REAL*8 NORME, DOTP, FRAKEMI, P, SUM

OTHER VARIABLES

REAL*8 DT, DIST, MAGMAX, MAGMIN
REAL*8 COSDOM, carr
REAL*8 DFC, DFCIT, DFCSW, DFACLW, CHECKDP, CHECKL, checkj
REAL*8 CNTREF, DUMSUM, NBBSW, NBBULW
REAL*8 XDUM, YDUM, TH

VARIABLES TO SET UP THE SURFACE AND VOLUME ELEMENTS

INTEGER NBLAT, NBLONG, NWASH, NBPS, NBWLSU, NBLSU, NBSS, NBSE, NBPS
INTEGER NBPS, NBPS, NBPS, NBPS, NBPS, NBPS, NBPS, NBPS
INTEGER NB, NB2, NB3, NB4, NB5, NB6, NB7, NB9, NB10, NB11, NB12, NB13
INTEGER NB14, NB15, NB16, NB8, NB17, NB18
INTEGER NBBUEA, NBV
INTEGER EMISUR, NBSSURF, NSURI1, NSURI2, NSURI3
INTEGER CHANNEL, CH
INTEGER EXCAV

VARIOUS COUNTERS

INTEGER CNTBDL, CNTCCL, CNTRDM, CNTRRW, CNTRUN, CNTINT
INTEGER CNTBDL, CNTIN1(100), CNTIN2(100), CNTEMI

VARIOUS INDICES

INTEGER I, J, K, JMAX, SURFAC, BOOL, IN, SIZE, SURF
INTEGER MAXBDL, ANSWEK, FT, WIN, WINIT, IJ, KL
INTEGER NBWLIN, NBDLIN, NBBUEA
INTEGER MAXELT, MAXMAX, MAXWLI
INTEGER SEED, MENU3

BOOLEANS NECESSARY FOR TESTS

LOGICAL ABSR, REFL, TRANS, HITTEN, ENTER, EXIT, INDOME, PTSOUR, DIFUS
LOGICAL EXITCAV
PARAMETER (MAXELT=700, MAXMAX=750, SIZE=15, MAXWLI=15)

ARRAYS

DIMENSION FREMPO(MAXWLI)
DIMENSION DT(SIZE), FT(SIZE)
DIMENSION DFAC(MAXMAX, MAXMAX, MAXWLI)
DIMENSION X2(SIZE), Y2(SIZE), Z2(SIZE), MAGN(SIZE)
DIMENSION COSNEW(SIZE), HITTEN(SIZE), BOOL(SIZE), ANORM(SIZE)
DIMENSION INORM(SIZE, 3), DIST(MAXELT)

External functions

EXTERNAL NORME, DOTP, FRAKEMI, P, SUM

Common variables

COMMON /RIING/ NBHSR, NBPSR
COMMON /CHANNEL/ CHANNEL
COMMON /CAVUS/ NBHSR, NBPSB, NBPSB, NBPSB
COMMON /PLAZ/ CNTRDM
COMMON /REAL/ ALPHAX, ALPHAX, ALPHAX, ALPHAX, ALPHAX,
& ROSPEC1, ROSPEC2, ROSPEC9, ROSPEC11, ROSPEC13, ROSPEC14,
& ROFF1, ROFF2, ROFF9, ROFF11, ROFF13, ROFF14
COMMON /RETR/ ROSPEC3,RODIFF3
COMMON /TRAN/ IVAC,IDOM
COMMON /NB14/ NB1,NB2,NB3,NB4,NB9,NB11,NB13,NB14
COMMON /NB57/ NB5,NB6,NB7,NB15,NB16,NB8,NB17,NB18
COMMON /SER1/ NBUAEL(MAXELT)/SER2/ NBLAT,NBLONG
COMMON /SER3/ NBASH,MPBS,NBLSU,NEWLSU/SER4/ NSH,NBCO,NEPSD
COMMON /FOVL/ RFOV,TETAPM/SUBS/MFPE,SURFAC
COMMON /DOME/ REXT,RINT,DENIV
COMMON /NSUR/ NSUR1,NSUR2,NSUR3
COMMON /COIN/ CNTBNW
COMMON /PTSC/ XPTSO,YPTSO
COMMON /SETU/ RADF(MAXELT),PHIF(MAXELT),ttaf(maxelt),
& SAREA(MAXELT),RCEN
COMMON /NODE/ XNOD(MAXELT),YNOD(MAXELT),ZNOD(MAXELT)
COMMON /WLS1/ NBDLIN(MAXWLI),NBUBEA(MAXWLI),NBWLIN
COMMON /WLS2/ DOABCO(MAXWLI),LBDA(MAXWLI)
COMMON /CHAN/ CH
COMMON /FACE/ XFAC(MAXELT),YFAC(MAXELT),ZFAC(MAXELT)
COMMON /TECP/ DFACTT(1,MAXELT),DFACSW(1,MAXELT),DFACLV(1,MAXELT)
COMMON /CAVITY/ RCAV,LSAR,LCON,CAVANG
COMMON /CONSET/ DLCON(20)

C
OPEN(21,FILE='ttchanel.input',status='old')
OPEN(22,FILE='awchanel.input',status='old')
OPEN(12,FILE='earthflu.input',status='old')
OPEN(03,FILE='nsradan1.dat')
OPEN(07,FILE='dfacmtx.dat')
OPEN(08,FILE='tecpplot1.dat')
OPEN(09,FILE='tecpplot2.dat')
OPEN(10,FILE='curfile.dat10')
OPEN(16,FILE='curfile.dat16')

C MENU 1, choose which channel to simulate and specify the number
C energy bundles to be emitted from each element
C
10 WRITE(06,520)'=========================================
WRITE(06,520)' MONTE-CARLO-BASED RAY-TRACE METHOD FOR
WRITE(06,520)' SIMULATION OF RADIATION HEAT TRANSFER IN THE
WRITE(06,520)' FRONT END OF THE ERBE NONSCANNING RADIOMETER.
WRITE(06,520)' FOR TOTAL CHANNEL SIMULATION (1)
WRITE(06,520)' FOR SHORTWAVE CHANNEL SIMULATION (2)
WRITE(06,520)'=========================================
READ05,*)CHANEL
CH=CHANEL+20
WRITE(06,520)'=========================================
WRITE(06,520)' SPECIFY THE NUMBER OF BLUNDLES TO BE Emitted:
WRITE(06,520)'=========================================
WRITE(06,520)'=========================================
WRITE(06,520)' SPECIFY THE INTERVAL AT WHICH YOU WANT A RESPONSE
WRITE(06,520)'=========================================
READ05,*)WINIT

C initialization for random number generator. Get two seeds from user
C for initialization.
C
WRITE(06,520)'=========================================
WRITE(06,520)' GIVE AN INTEGER BETWEEN 0 AND 2,147,483,647:
WRITE(06,520)'=========================================
READ05,*)SEEDI
CALL RNSET(SEEDI)

C GET GEOMETRY OF THE PROBLEM FROM INPUT FILE
READ(CH,*)  
READ(CH,*)  
READ(CH,*),RFOV  
READ(CH,*)RCAV  
READ(CH,*)LCON  
READ(CH,*),LBAR  
READ(CH,*)TETAFM  
READ(CH,*)RPA  
READ(CH,*)REXT  
READ(CH,*)RINT  
READ(CH,*)DENV  
READ(CH,*)ALPHA1  
READ(CH,*)ALPHA2  
READ(CH,*)ALPHA9  
READ(CH,*)ALPHA11  
READ(CH,*)ALPHA13  
READ(CH,*)ALPHA14  
READ(CH,*)ROSPEC1  
READ(CH,*)ROSPEC2  
READ(CH,*)ROSPEC3  
READ(CH,*)ROSPEC9  
READ(CH,*)ROSPEC11  
READ(CH,*)ROSPEC13  
READ(CH,*)ROSPEC14  
READ(CH,*)RODIFF1  
READ(CH,*)RODIFF2  
READ(CH,*)RODIFF3  
READ(CH,*)RODIFF9  
READ(CH,*)RODIFF11  
READ(CH,*)RODIFF13  
READ(CH,*)RODIFF14  
READ(CH,*)TVAC  
READ(CH,*)IDOM  
READ(CH,*),NBLAT  
READ(CH,*)NBLONG  
READ(CH,*)NBLSU  
READ(CH,*)NBWLSU  
READ(CH,*)NBWASH  
READ(CH,*)NBPS  
READ(CH,*)NBSH  
READ(CH,*)NBCO  
READ(CH,*)NBPSD  
READ(CH,*)NBPSB  
READ(CH,*)NBPSC  
READ(CH,*)NBPSR  
READ(CH,*)NBHSB  
READ(CH,*)NBHSC  
READ(CH,*)NBPSCS  
READ(CH,*)NBHSR  
READ(CH,*)TS  

C Calculate the cone angle
C
CAVANG=DATAN(RCAV/LCON)
WRITE(96,*)'CAVANG',CAVANG

C INITIALIZE EXITCAV COUNTER
C
EXCAV=0

C Read wavelength of the wi intervals.
C LBDA(I) is the upper limit of the wi interval I
C
LBDAMX=50.0D0  
READ(CH,*)NBWLIN
DO 15 I=1,NBWLIN-1
   READ(CH,*)LBDA(I)
CONTINUE
LBDA(NBWLIN)=LBDA(MAX

Read the absorptivity for each wavelength interval

READ(CH,*)DOMTHC
DO 16 I=1,NBWLIN
   READ(CH,*)DOABCO(I)
DOABCO(I)=BLOG(1.DO/DOABCO(I))/DOMTHC
CONTINUE

Go back to top of input file

REWIND CH
WRITE(06,*)' FILE 1 READ, NO PB'

MENU 2, start execution or check the input file

WRITE(06,520)’=====================================
WRITE(06,520)’ INPUT FILE HAS BEEN READ. SPECIFY NEXT OPERATION
WRITE(06,520)’ TO EXECUTE:
WRITE(06,520)’ 1': START EXECUTION OF THE PROGRAM DIRECTLY,
WRITE(06,520)’ 2': VIEW INPUT FILE ON SCREEN.
WRITE(06,520)’=====================================
READ(05,*)ANSWER

IF (ANSWER.EQ.2) THEN

SHOW THE USER WHAT THE GEOMETRY IS

WRITE(06,520)’=====================================
WRITE(6,*)
WRITE(6,*)
WRITE(6,522)’RADIUS OF FOV LIMITER (MM)’,RF0V
WRITE(6,522)’OPENING OF FOV LIMITER (RAD)’,TETAFM
WRITE(6,522)’RADIUS OF PRECISION APERTURE’,RPA
WRITE(6,522)’EXTERNAL RADIUS OF DOME (MM)’,REX
WRITE(6,522)’INTERNAL RADIUS OF DOME (MM)’,RINT
WRITE(6,522)’DEPTH AT WHICH DOME IS BURIED IN SUBSTR. (MM)’,DENIV
WRITE(6,522)’RADIUS OF CAVITY’,RCAV
WRITE(6,522)’LENGTH OF BARREL’,LBAR
WRITE(6,522)’LENGTH OF CONE’,LCON
WRITE(6,522)’HALF ANGLE OF CONE’,CAVANG
WRITE(6,522)’COEF. OF ABSORPTION OF FOV LIMITER’,ALPHA1
WRITE(6,522)’COEF. OF ABSORPTION OF SUBSTRATE’,ALPHA2
WRITE(6,522)’COEF. OF ABSORPTION OF BARREL’,ALPHA9
WRITE(6,522)’COEF. OF ABSORPTION OF CONE’,ALPHA11
WRITE(6,522)’COEF. OF ABSORPTION OF CAV SUB’,ALPHA13
WRITE(6,522)’COEF. OF ABSORPTION OF RING’,ALPHA14
WRITE(6,522)’SPECULARITY OF FOV LIMITER’,ROSPEC1
WRITE(6,522)’SPECULARITY OF SUBSTRATE’,ROSPEC2
WRITE(6,522)’SPECULARITY OF DOME’,ROSPEC3
WRITE(6,522)’SPECULARITY OF BARREL’,ROSPEC9
WRITE(6,522)’SPECULARITY OF CONE’,ROSPEC11
WRITE(6,522)’SPECULARITY OF CAV SUB’,ROSPEC13
WRITE(6,522)’SPECULARITY OF RING’,ROSPEC14
WRITE(6,522)’DIFFUSIVITY OF FOV LIMITER’,RODIFF1
WRITE(6,522)’DIFFUSIVITY OF SUBSTRATE’,RODIFF2
WRITE(6,522)’DIFFUSIVITY OF DOME’,RODIFF3
WRITE(6,522)’DIFFUSIVITY OF BARREL’,RODIFF9
WRITE(6,522)’DIFFUSIVITY OF CONE’,RODIFF11
WRITE(6,522)’DIFFUSIVITY OF CAV SUB’,RODIFF13
WRITE(6,522)’DIFFUSIVITY OF RING’,RODIFF14

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WRITE(6,522) 'INDEX OF REFRACTION IN VACCUM',IVAC
WRITE(6,522) 'INDEX OF REFRACTION OF THE DOME',IDOM
WRITE(6,523) 'NBLAT',NBLAT
WRITE(6,523) 'NBLONG',NBLONG
WRITE(6,523) 'NBLSU',NBLSU
WRITE(6,523) 'NBWLSU',NBWLSU
WRITE(6,523) 'NBWASH',NBWASH
WRITE(6,523) 'NBPS',NBPS
WRITE(6,523) 'NBPSD',NBPSD
WRITE(6,523) 'NBPSB',NBPSB
WRITE(6,523) 'NBPSC',NBPSC
WRITE(6,523) 'NBHSB',NBHSB
WRITE(6,523) 'NBHC',NBHC
WRITE(6,523) 'NBHSC',NBHSC
WRITE(6,523) 'NBHSR',NBHSR
WRITE(6,523) 'NBPSCS',NBPSCS
WRITE(6,523) 'NBPSR',NBPSR
WRITE(6,522) 'SURROUNDING TEMP',TS
WRITE(06,523) 'NBER OF WL INTERVALS',NBWLIN
DO 19 I=1,NBWLIN
  WRITE(06,522) 'WAVELENGTH',LBDA(I)
  CONTINUE
DO 22 I=1,NBWLIN
  WRITE(06,522) 'ABSORPTIVITY OF DOME',DOABCO(I)
  CONTINUE
WRITE(06,520) '=====================================================================
WRITE(06,520) 'TO START PROGRAM: ENTER 1; TO EXIT: ENTER 0.'
WRITE(06,520) '=====================================================================
READ*,ANSWER
IF (ANSWER.EQ.0) GO TO 270
END IF
C Initialization of arrays and variables for each run of program
C
PI=DECOS(-1.D0)
CNTRUN=0
CNTRDM=0
NB1 = NBLAT*NBLONG
NB2 = NB1 + NBLSU*NBWLSU
NB3 = NB2 + NBWASH*NBPS
NB4 = NB3 + NBHSB*NBHSC
NB5 = NB4 + 1 + NBPSCS*NBHSC
NB9 = NB11 + NBPSB*NBHSB
NB13 = NB9 + NBPSCS
NB14 = NB13 + NBPSR*NBHSR
NB5 = (NBLAT + 1)*NBLONG
NB6 = NB5 + (NBWLSU+1)*NBLSU
NB7 = NB6 + (NBWASH + 1)*NBPS
NB15 = NB8 + (NBHSB + 1)*NBPSB
NB16 = NB15 + (NBHSC + 1)*NBPSC
NB17 = NB16 + 2*NBPSCS
NB18 = NB17 + (NBHSR + 1)*NBPSR
ZMAX=RFIV*DCOS(TETAFA)+DENIV
WRITE(*,*)(NB1,NB2,NB3,NB4,NB9,NB11',NB1,NB2,NB3,NB4,NB9,NB11
C Show indices range for each part of the optical front end
C
WRITE(03,520) '=====================================================================
WRITE(03,520) 'ELEMENT INDEX FOR PARTS OF THE OPTICAL FRONT-END '
WRITE(03,520) '=====================================================================
WRITE(03,520) 'OPNEING OF THE FOV LIMITER: ',NB4+1,' - ',NB4+1
WRITE(03,520) 'FOV LIMITER WALLS 
WRITE(03,520) 'LOWER SUBSTRATE 
WRITE(03,520) 'UPPER SUBSTRATE 

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WRITE(03,530) ' FILTER DOME              ',NB3+1,' - ',NB4
WRITE(03,530) ' BARREL                  ',NB11+1,' - ',NB9
WRITE(03,530) ' CONE                    ',NB4+2,' - ',NB11
WRITE(03,530) ' SUBST. VISIBLE TO CAVITY ',NB9+1,' - ',NB13
WRITE(03,530) ' RING                    ',NB13+1,' - ',NB14
WRITE(03,520) '========================================='
530 FORMAT(1X,A30,I4,A3,I4)
WRITE(03,*) 'NB5,NB6,NB7',NB5,NB6,NB7

C
C SET UP THE DOME IN VOLUME ELEMENTS
C
CALL DOMSETUP(DIST)
C
C SET UP THE CONE IN SURFACE ELEMENTS (FIND HEIGHTS OF RINGS FOR
C EQUAL AREA ELEMENTS)
C
CALL CONSETUP(DLCON)
C
C MENU 3, choose between complete DFAC generation procedure and emission
C from one element only
C
899 WRITE(06,520) '========================================='
WRITE(06,520) ' FOR COMPLETE DFAC GENERATION, ENTER (1)   '
WRITE(06,520) ' FOR EMISSION FROM A GIVEN ELEMENT, ENTER (2) '
WRITE(06,520) '========================================='
READ(05,*)MENU3
CNTIND = 1
IF (MENU3.EQ.1) THEN

C
C Procedure for computation of distribution factors
C Two indices are used. CNTIN1 contains the value of EMISUR (1,2,3,4,9,11)
C and CNTIN2 contains the value of NBSURF (1-235). The emission elements
C are in the order:
C
the aperture of the FOV Limiter
C the FOV limiter walls
C the lower substrate
C the upper substrate
C the filter dome
C the barrel
C the cone
C the cavsub
C the ring
C
CNTIND is a counter which keeps track of the number of emitting surfaces.
C CNTEMI is a counter which keeps track of how many surfaces have emitted
C so far. When CNTEMI reaches CNTIND the DFAC computation is completed.
C
C
C FOV APERTURE
C
CNTIN1(1) = 0
CNTIN2(1) = NB4 + 1
C
C
C FOVL
C
DO 900 I = 1,NBLAT
CNTIND = CNTIND + 1
CNTIN1(CNTIND) = 1
CNTIN2(CNTIND) = (I-1)*NBLONG + 1
900 CONTINUE
C
C
C LSUB
C
DO 901 I=1,NEWLSU
CNTIND = CNTIND + 1

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CNTIN1(CNTIND) = 2
CNTIN2(CNTIND) = NB1 + (I-1)*NBLSU + 1
901 CONTINUE

C
C USUB
C
DO 902 I=1,NBWASH
   CNTIND = CNTIND + 1
   CNTIN1(CNTIND) = 3
   CNTIN2(CNTIND) = (I-1)*NBPS + 1 + NB2
902 CONTINUE

C
C DOME
C
IF (CH.EQ.22) THEN
   DO 903 I=1,NBSSH*NBCO
      CNTIND = CNTIND + 1
      CNTIN1(CNTIND) = 4
      CNTIN2(CNTIND) = (I-1)*NBPSD + 1 + NB3
903 CONTINUE
END IF

C
C CONE
C
DO 905 I=1,NBHSC
   CNTIND = CNTIND + 1
   CNTIN1(CNTIND) = 11
   CNTIN2(CNTIND) = (I-1)*NBPS + 1 + NB9
905 CONTINUE

C
C BARREL
C
DO 904 I=1,NBHSB
   CNTIND = CNTIND + 1
   CNTIN1(CNTIND) = 9
   CNTIN2(CNTIND) = (I-1)*NBPSB + 1 + NB4 +1
904 CONTINUE

C
C CAVSUB
C
   CNTIND = CNTIND +1
   CNTIN1(CNTIND) = 13
   CNTIN2(CNTIND) = NB11 + 1

C
C RING
C
IF (CH.EQ.21) THEN
   DO 907 I=1,NBHSR
      CNTIND = CNTIND + 1
      CNTIN1(CNTIND) = 14
      CNTIN2(CNTIND) = NB13+1+(I-1)*NBFSR
907 CONTINUE
END IF

WRITE(03,520) '=========================================
WRITE(03,520) ' LIST OF EMITTING ELEMENTS FOR DFAC GENERATION
WRITE(03,520) '=========================================

DO 908 I=1,CNTIND
   IF (CNTIN1(I).EQ.0) WRITE(03,531)'FIELD' ,CNTIN1(I),CNTIN2(I)
   IF (CNTIN1(I).EQ.1) WRITE(03,531)'FOV_L' ,CNTIN1(I),CNTIN2(I)
   IF (CNTIN1(I).EQ.2) WRITE(03,531)'L_SUB' ,CNTIN1(I),CNTIN2(I)
   IF (CNTIN1(I).EQ.3) WRITE(03,531)'U_SUB' ,CNTIN1(I),CNTIN2(I)
   IF (CNTIN1(I).EQ.4) WRITE(03,531)'DOME' ,CNTIN1(I),CNTIN2(I)
   IF (CNTIN1(I).EQ.9) WRITE(03,531)'BARREL' ,CNTIN1(I),CNTIN2(I)
   IF (CNTIN1(I).EQ.11) WRITE(03,531)'CONE' ,CNTIN1(I),CNTIN2(I)
   IF (CNTIN1(I).EQ.13) WRITE(03,531)'CAVSUB' ,CNTIN1(I),CNTIN2(I)
IF (CNTIN1(I).EQ.14) WRITE(03,531) 'RING', CNTIN1(I), CNTIN2(I)
CONTINUE
WRITE(04,520) '================================================================================='
531 FORMAT(1X,A10,2I10)
ELSE IF (MENU3.EQ.2) THEN
C MENU 4, choose the emission element
WRITE(06,520) '================================================================================='
WRITE(06,520) ' FROM WHICH PART OF THE NONSCANNER MODULE DO YOU WANT TO SEND THE ENERGY BUNDLES?'
WRITE(06,520) ' 0' : THE APERTURE OF THE FOV LIMITER,' 
WRITE(06,520) ' 1' : THE FOV LIMITER ITSELF,' 
WRITE(06,520) ' 2' : THE LOWER SUBSTRATE,' 
WRITE(06,520) ' 3' : THE UPPER SUBSTRATE,' 
WRITE(06,520) ' 4' : THE FILTER DOME,' 
WRITE(06,520) ' 9' : THE BARREL,' 
WRITE(06,520) ' 11' : THE CONE,' 
WRITE(06,520) ' 13' : THE SUBST. VISIBLE TO THE CAVITY,' 
WRITE(06,520) ' 14' : THE RING
READ(05,*) CNTIN1(I)

C For emission from the secondary aperture specify the emission type
IF (CNTIN1(I).EQ.0) THEN
CNTIN2(I)=NB4+1
WRITE(06,520) '================================================================================='
WRITE(06,520) ' THE APERTURE OF THE FOV LIMITER IS NOT DIVIDED INTO SURFACE ELEMENTS.'
WRITE(06,520) ' PLEASE SPECIFY WHETHER EMISSION FROM THIS SURFACE SHOULD BE:
WRITE(06,520) ' DIFFUSE (1), COLIMINATED (2), POINT SOURCE COLLIMATED (3)
WRITE(06,520) '================================================================================='
READ(05,*) ANSWER

C FOR COLLIMINATED RADIATION THE INCIDENT ANGLE MUST BE SPECIFIED
IF (ANSWER.EQ.2.OR.ANSWER.EQ.3) THEN
WRITE(06,520) '================================================================================='
WRITE(06,520) ' PLEASE SPECIFY THE ANGLE OF THE COLLIMINATED RADIATION (BETWEEN 0 AND 90 DEGREES)
WRITE(06,520) '=================================================================================
READ(05,*) CRADAN
CRADAN=CRADAN*PI/180.D0
ELSE
CRADAN=-1.D0
ENDIF

C FOR A POINT SOURCE THE COORD. OF THE EMITTING POINT MUST BE SPECIFIED
IF (ANSWER.EQ.3) THEN
WRITE(06,520) '=================================================================================
WRITE(06,520) ' PLEASE SPECIFY THE X,Y COORDINATES OF THE POINT FROM WHICH THE POINT SOURCE COMES.'
WRITE(06,520) '=================================================================================
READ(05,*) XPTSO,YPTSO
PTSCUR=.TRUE.
ELSE
PTSCUR=.FALSE.
ENDIF

Program ERBETR 135
ELSE

For emission from all other surfaces specify emission element.

WRITE(06,520)'='
WRITE(06,520)' SPECIFY THE NUMBER OF THE ELEMENT FROM'
WRITE(06,520)' WHICH THE BUNDLES ARE GOING TO BE EMITTED:'
WRITE(06,*)

FOVL

IF (CNTIN1(1).EQ.1) THEN
WRITE(06,520)' THE FIRST ELEMENT ON THE FOV LIMITER IS LOCATED AT'
WRITE(06,520)' THE LOWEST LATITUDE AND NOON LONGITUDE.'
WRITE(06,526)' FOR EACH OF THE',NBLAT,'LATITUDES THERE ARE',NBLONG
WRITE(06,520)' LONGITUDES'
WRITE(06,525)' THE NUMBERS RUN BETWEEN',1,'AND',NB1
WRITE(06,520)'='
READ(05,*)CNTIN2(1)
WRITE(06,520)'='
END IF

LSUB

IF (CNTIN1(1).EQ.2) THEN
WRITE(06,520)' THE FIRST ELEMENT ON THE LOWER SUBSTRATE IS THE'
WRITE(06,520)' PRIMARY APERTURE, THE FOLLOWING ELEMENTS SURROUND'
WRITE(06,526)' FOR EACH OF THE',NBWLSU,'RINGS THERE ARE',NBLSU
WRITE(06,520)' PIE-SECTIONS'
WRITE(06,525)' THE NUMBERS RUN BETWEEN',NB1+1,'AND',NB2
WRITE(06,520)'='
READ(05,*)CNTIN2(1)
WRITE(06,520)'='
END IF

USUB

IF (CNTIN1(1).EQ.3) THEN
WRITE(06,520)' THE FIRST ELEMENT ON THE SUBSTRATE IS ON THE RING'
WRITE(06,520)' CLOSEST TO THE CENTER.'
WRITE(06,526)' FOR EACH OF THE',NBWSH,'RINGS THERE ARE',NBFS
WRITE(06,520)' PIE-SECTIONS'
WRITE(06,525)' THE NUMBERS RUN BETWEEN',NB2+1,'AND',NB3
WRITE(06,520)'='
READ(05,*)CNTIN2(1)
WRITE(06,520)'='
END IF

DOME

IF (CNTIN1(1).EQ.4) THEN
WRITE(06,520)' THE FIRST ELEMENT IN THE DOME IS LOCATED ON THE'
WRITE(06,520)' TOP OF THE DOME.'
WRITE(06,526)' FOR EACH OF THE',NBSH,'SHELLS THERE ARE',NBSCO
WRITE(06,526)' CONES, THERE ARE',NBPSD,'PIE-SECTIONS PER CONE'
WRITE(06,525)' THE NUMBERS RUN BETWEEN',NB3+1,'AND',NB4
WRITE(06,520)'='
READ(05,*)CNTIN2(1)
WRITE(06,520)'='
END IF

BARREL

Program ERTBERT
IF (CNTIN1(1).EQ.9) THEN
  WRITE(06,520) 'THE FIRST ELEMENT ON THE BARREL IS LOCATED ON THE ',
  WRITE(06,520) 'LOWEST RING AT NOON LONGITUDE. ',
  WRITE(06,526) 'FOR EACH OF THE',NBHSB,'RINGS THERE ARE ',NBPSB
  WRITE(06,520) 'AZIMUTHAL DIVISIONS. '
  WRITE(06,525) 'THE NUMBERS RUN BETWEEN',NB4+2,'AND',NB9
  READ(05,*)CNTIN2(1)
  WRITE(06,520) '=='
END IF

CONE

IF (CNTIN1(1).EQ.11) THEN
  WRITE(06,520) 'THE FIRST ELEMENT ON THE CONE IS LOCATED ON THE ',
  WRITE(06,520) 'LOWEST RING AT NOON LONGITUDE. ',
  WRITE(06,526) 'FOR EACH OF THE',NBHSC,'RINGS THERE ARE ',NBPS C
  WRITE(06,520) 'AZIMUTHAL DIVISIONS. '
  WRITE(06,525) 'THE NUMBERS RUN BETWEEN',NB9+1,'AND',NB11
  READ(05,*)CNTIN2(1)
  WRITE(06,520) '=='
END IF

CAVSUB

IF (CNTIN1(1).EQ.13) THEN
  WRITE(06,520) 'THE FIRST ELEMENT ON THE CAV SUB RING IS LOCATED ',
  WRITE(06,520) 'AT NOON LONGITUDE. ',
  WRITE(06,525) 'THE NUMBERS RUN BETWEEN',NB9+1,'AND',NB13
  READ(05,*)CNTIN2(1)
  WRITE(06,520) '=='
END IF

RING

IF (CNTIN1(1).EQ.14) THEN
  WRITE(06,520) 'THE FIRST ELEMENT ON THE RING IS LOCATED ON THE ',
  WRITE(06,520) 'HIGHEST LATITUDE AT NOON LONGITUDE. ',
  WRITE(06,526) 'FOR EACH OF THE',NBHSR,'RINGS THERE ARE ',NBPSR
  WRITE(06,520) 'AZIMUTHAL DIVISIONS. '
  WRITE(06,525) 'THE NUMBERS RUN BETWEEN',NB13+1,'AND',NB14
  READ(05,*)CNTIN2(1)
  WRITE(06,520) '=='
END IF

ELSE
  GO TO 899
END IF

C End of MENU 3

C Zero elements have emitted so far.
C
CNTEMI = 0
C
C Start loop for each emitting element
C
922  CNTINT=0

Program ERBERT
C TECM = CNTCL + 1
CNTBL = CNTBR + 1
CNTCL = CNTUN + 1
CNTBL = WIN - WINI
DO 20 I = 1, SIZE
   FT(I) = 0
   DT(I) = 0.0
20 CONTINUE
DO 21 I = 1, MAXILT
   NBSSURF(I) = 0
21 CONTINUE
CALL INIT(X2)
CALL INIT(T2)
CALL INIT(Z2)
CALL INIT(MAGNV)
CALL INIT(COSNEW)
CALL INIT(ANORM)

C Retrieve the i, j, k indices from EMISUR & NBSURF
C
CNTMI = CNTEN + 1
EMISUR = CNTIN(CNTMI)
NBSURF = CNTIN2(CNTMI)
IF (EMISUR.EQ.0 .AND. MENU3.EQ.1) THEN
   CRADA = -1.0
   ITSUR = .FALSE.
ELSE IF (EMISUR.EQ.1) THEN
   NSUR11 = INT((NBSURF-1)/NBLONG) + 1
   NSUR12 = NBSURF - NSUR11 - 1
   NSUR13 = 0
ELSE IF (EMISUR.EQ.2) THEN
   NSUR11 = 0
   NSUR12 = INT((NBSURF-1-NB1)/NBLSU) + 1
   NSUR13 = NBSURF - NSUR11 - 1
   NSUR21 = NBSURF - NB2 - (NSUR11 - 1) * NBPS
   NSUR31 = 0
ELSE IF (EMISUR.EQ.3) THEN
   NSUR11 = INT((NBSURF - NB1 - 1)/(NBPSB)) + 2
   NSUR12 = INT((REAL(NBSURF) - REAL(NB3) - (REAL(NSUR11) - 2.0) * 
                  & REAL(NBCO) * REAL(NBPSB) - 1.0)/(REAL(NBPSB))) + 2
   NSUR13 = NBSURF - NB3 - (NSUR11 - 2) * NBPSB - (NSUR12 - 2)
   & NBPSB
ELSE IF (EMISUR.EQ.9) THEN
   NSUR11 = INT((NBSURF-1-NB4-1)/(NBPSB)) + 1
   NSUR12 = (NBSURF-NB4-1)-(NSUR11-1)*NBPSB
   NSUR13 = 0
ELSE IF (EMISUR.EQ.11) THEN
   NSUR11 = INT((NBSURF-1-NB9)/(NBPSH)) + 1
   NSUR12 = (NBSURF-NB9)-(NSUR11-1)*NBPSH
   NSUR13 = 0
ELSE IF (EMISUR.EQ.13) THEN
   NSUR11 = INT((NBSURF-1-NB11)/(NBPSCH)) + 1
   NSUR12 = 0
   NSUR13 = 0
ELSE IF (EMISUR.EQ.14) THEN
   NSUR11 = INT((NBSURF-1-NB13)/(NBPSR)) + 1
   NSUR12 = (NBSURF-NB13)-(NSUR11-1)*NBPSR
   NSUR13 = 0
END IF

C Set up the spectral distribution of the energy bundles

Program ERBERT  138
CALL WSET(MAXBDL,EMISUR)

BEGINNING OF LOOP FOR EACH WAVELENGTH INTERVAL

CNTINT = CNTINT + 1
ALPHAD = DOABCO(CNTINT)
DO 28 J = 1, NB14
     NBBUAB(J) = 0
28 CONTINUE

BEGINNING OF LOOP FOR EACH Emitted BUNDLE

CNTBDL = CNTBDL + 1
CNTREF = CNTREF + 1.0
SURFAC = 0
INDOME = .FALSE.
ABSOR = .FALSE.
ENTER = .FALSE.
EXIT = .FALSE.
REFL = .FALSE.
DIFUS = .FALSE.
TRANS = .FALSE.
DO 40 I = 1, 15
     HIDDEN(I) = .FALSE.
40 CONTINUE

GIVE A MESSAGE TO THE USER THAT THE PROGRAM IS RUNNING

IF (CNTBDL.EQ.WIN) THEN
     WIN = WIN + WINIT
     WRITE(06,41) 'RUNNING FINE; SHOT MORE THAN ,CNTBDL,' BUNDLES
41 FORMAT(1X,A30,18,A10)
END IF

RANDOM EMISSION FROM RANDOM LOCATION ON DEFINED SURFACE ELEMENT

IF (EMISUR.EQ.0) THEN
     CALL EMIT0(X1,Y1,Z1,L,M,N,CRADAN,PTSOUR)
ELSE IF (EMISUR.EQ.1) THEN
     CALL EMIT1(X1,Y1,Z1,L,M,N)
ELSE IF (EMISUR.EQ.2) THEN
     CALL EMIT2(X1,Y1,Z1,L,M,N,INDOME)
ELSE IF (EMISUR.EQ.3) THEN
     CALL EMIT3(X1,Y1,Z1,L,M,N)
ELSE IF (EMISUR.EQ.4) THEN
     CALL EMIT4(X1,Y1,Z1,L,M,N,ANORM)
     INDOME = .TRUE.
ELSE IF (EMISUR.EQ.9) THEN
     CALL EMIT9(X1,Y1,Z1,L,M,N,ANORM1,ANORM2,ANORM3)
ELSE IF (EMISUR.EQ.11) THEN
     CALL EMIT11(X1,Y1,Z1,L,M,N)
ELSE IF (EMISUR.EQ.13) THEN
     CALL EMIT13(X1,Y1,Z1,L,M,N,ANORM4,ANORM5,ANORM6)
ELSE IF (EMISUR.EQ.14) THEN
     CALL EMIT14(X1,Y1,Z1,L,M,N,ANORM7,ANORM8,ANORM9)
END IF

XT = X1
YT = Y1
ZT = Z1

GET COORD. OF INTERSECTION OF THE FIRST Emitted BUNDLE WITH EACH SURFACE INSIDE THE FOV LIMITER

CALL FOVLIM(X1,Y1,Z1,L,M,N,X2,Y2,Z2,MAGNV,INORM,HIDDEN,EXIT)
CALL SUBSTR(X1,Y1,Z1,L,M,N,X2,Y2,Z2,MAGNV,INORM,HITLEN,ENTER)
IF (CH.EQ.22) THEN
   CALL SPHERE(X1,Y1,Z1,L,M,N,X2,Y2,Z2,3,MAGNV,INORM,HITLEN)
END IF
CALL SPHERE(X1,Y1,Z1,L,M,N,X2,Y2,Z2,4,MAGNV,INORM,HITLEN)
ELSE
   CALL RING(X1,Y1,Z1,L,M,N,X2,Y2,Z2,MAGNV,INORM,HITLEN)
END IF
CALL BARREL(X1,Y1,Z1,L,M,N,X2,Y2,Z2,MAGNV,INORM,HITLEN)
CALL CONE(X1,Y1,Z1,L,M,N,X2,Y2,Z2,MAGNV,INORM,HITLEN)
CALL CAVSUB(X1,Y1,Z1,L,M,N,X2,Y2,Z2,MAGNV,INORM,HITLEN, &
   EXITCAV,EXCAV)

C some special cases:
C FOR THE FIRST SHOT THE BUNDLE CANNOT LEAVE THE MODULE IF IT WAS
C SHOT FROM THE APERTURE OF THE FOV LIMITER.
C
IF (EMISUR.EQ.0) THEN
   IF (Z2(1).GT.ZMAX) THEN
      HITLEN(1)=.FALSE.
      EXIT=.FALSE.
   END IF
   IF (Z2(5).GT.ZMAX) THEN
      HITLEN(5)=.FALSE.
      EXIT=.FALSE.
   END IF
C FOR THE FIRST SHOT, THE BUNDLE CANNOT HIT THE CAVITY OR UPPER
C SUBSTRATE IF IT WAS SHOT FROM THE LOWER SUBSTRATE.
C
ELSE IF (EMISUR.EQ.2) THEN
   HITLEN(2)=.FALSE.
   HITLEN(9)=.FALSE.
   HITLEN(10)=.FALSE.
   HITLEN(11)=.FALSE.
   HITLEN(12)=.FALSE.
   HITLEN(13)=.FALSE.
C FOR THE FIRST SHOT, THE BUNDLE CANNOT GO BELOW Z1 IF IT WAS SHOT
C FROM THE SUBSTRATE
C
ELSE IF (EMISUR.EQ.3) THEN
   IF (Z2(3).LT.Z1) HITLEN(3)=.FALSE.
   IF (Z2(4).LT.Z1) HITLEN(4)=.FALSE.
   IF (Z2(6).LT.Z1) HITLEN(6)=.FALSE.
   IF (Z2(7).LT.Z1) HITLEN(7)=.FALSE.
   IF (Z2(8).LT.Z1) HITLEN(8)=.FALSE.
   IF (Z2(9).LT.Z1) HITLEN(9)=.FALSE.
   IF (Z2(10).LT.Z1) HITLEN(10)=.FALSE.
   IF (Z2(11).LT.Z1) HITLEN(11)=.FALSE.
   IF (Z2(12).LT.Z1) HITLEN(12)=.FALSE.
   HITLEN(13)=.FALSE.
   HITLEN(14)=.FALSE.
   HITLEN(15)=.FALSE.
C FOR THE FIRST SHOT, THE BUNDLE CANNOT GO ABOVE Z1 IF IT WAS SHOT
C FROM THE PORTION OF THE SUBSTRATE WHICH FACES THE CAVITY
C
ELSE IF (EMISUR.EQ.13) THEN
   HITLEN(1)=.FALSE.
   HITLEN(2)=.FALSE.
   HITLEN(6)=.FALSE.
   HITLEN(3)=.FALSE.
   HITLEN(4)=.FALSE.

Program EKBERT

140
HITTEN(5) = .FALSE.
HITTEN(7) = .FALSE.
HITTEN(8) = .FALSE.
HITTEN(13) = .FALSE.
HITTEN(14) = .FALSE.
HITTEN(15) = .FALSE.
DO 53 I=1,15
   IF (.NOT.HITTEN(I)) GOTO 53
      COSDOM = DOTP(X2(I)-X1,Y2(I)-Y1,Z2(I)-Z1,
         ANORM4,ANORM5,ANORM6)
      IF (COSDOM.LE.0.D0) HITTEN(I) = .FALSE.
   CONTINUE
53
C FOR THE FIRST SHOT THE BUNDLE CANNOT HIT THE LOWER OR UPPER SUBSTRATE.
C IF IT WAS EMITTED FROM THE CONE
C ELSE IF (EMISUR.EQ.11) THEN
   HITTEN(2) = .FALSE.
   HITTEN(6) = .FALSE.
C FOR ENERGY BUNDLES EMITTED FROM THE BARREL CHOOSE WHICH SURFACES
C CANNOT BE HIT ACCORDING TO THE 2-PI SPHERE INTO WHICH THE
C BUNDLE IS EMITTED.
C ELSE IF (EMISUR.EQ.9) THEN
   HITTEN(2) = .FALSE.
   HITTEN(6) = .FALSE.
   DO 54 I=1,15
      IF (.NOT.HITTEN(I)) GOTO 54
      COSDOM = DOTP(X2(I)-X1,Y2(I)-Y1,Z2(I)-Z1,
         ANORM1,ANORM2,ANORM3)
      IF (COSDOM.LE.0.D0) HITTEN(I) = .FALSE.
   CONTINUE
54
C FOR ENERGY BUNDLES EMITTED FROM THE RING CHOOSE WHICH SURFACES
C CANNOT BE HIT ACCORDING TO THE 2-PI SPHERE INTO WHICH THE
C BUNDLE IS EMITTED.
C ELSE IF (EMISUR.EQ.14) THEN
   HITTEN(2) = .FALSE.
   HITTEN(3) = .FALSE.
   HITTEN(4) = .FALSE.
   HITTEN(7) = .FALSE.
   HITTEN(8) = .FALSE.
   HITTEN(13) = .FALSE.
   DO 57 I=1,15
      IF (.NOT.HITTEN(I)) GOTO 57
      IF (I.EQ.6) GOTO 57
      COSDOM = DOTP(X2(I)-X1,Y2(I)-Y1,Z2(I)-Z1,
         ANORM7,ANORM8,ANORM9)
      IF (COSDOM.LE.0.D0) THEN
         HITTEN(I) = .FALSE.
      END IF
57
C For an energy bundle emitted by the dome choose which surfaces
C cannot be hit according to the 2pi-sphere in which the bundle
C was emitted.
C ELSE IF (EMISUR.EQ.4) THEN
   CALL DRNUM(1,RDM)
   CNTRD = CNTRD + 1
   IF (RDM.GT.0.50D0) THEN
      DO 55 I=1,15
         COSDOM = DOTP(X2(I)-X1,Y2(I)-Y1,Z2(I)-Z1,
& ANORM(1), ANORM(2), ANORM(3)
                   IF (COSDOM. GE. 0.0) HITEN(I) = .FALSE.
55 CONTINUE
ELSE
   DO 56 I = 1, 15
      COSDOM = DOTP(X2(I) - X1, Y2(I) - Y1, Z2(I) - Z1,
      ANORM(1), ANORM(2), ANORM(3))
      IF (COSDOM. LT. 0.0) HITEN(I) = .FALSE.
56 CONTINUE
END IF
C THE SURFACE HIT IS THE CLOSEST ONE TO THE EMISSION POINT
C SURFAC=0
MAGMIN=10 DO*90 RFOV
DO 60 I = 1, 15
   IF (HITEN(I)) THEN
      IF (MAGNV(I) .LT. MAGMIN) THEN
         MAGMIN = MAGNV(I)
         SURFAC = I
      END IF
   END IF
   ***************
   IF (MAGNV(I) .EQ. 0.0) THEN
      WRITE(16, *) 'ATTENTION USER THE BUNDLE IS TRAPPED'
      WRITE(16, *) 'CNTREF', CNTREF
      WRITE(06, *) 'ERROR ! ! ! ! ! ! ! ! ! ! ! ! ! ! '
      WRITE(16, *) 'MAGNV ET SURFAC 11111', MAGNV(I), I
      CALL SHOW (X2, Y2, Z2, I)
   END IF
   ***************
60 CONTINUE
C IF THE BUNDLE IS Emitted ON THE BORDER OF THE IMAGINARY TOP SURFACE
C IT IS CONSIDERED TO BE ABSORBED BY THE FOV LIMITER
C IF (SURFAC .EQ. 0) THEN
   ABSCR = .TRUE.
   EXIT = .FALSE.
   SURFAC = 1
   CNTCC = CNTCC + 1
   WRITE(03, *) CNTCC, L, CNTCL
C END IF
C STORE THE COORDINATES OF THE POINT HIT
C XX=X2(SURFAC)
   YY=Y2(SURFAC)
   ZZ=Z2(SURFAC)
   XTT=XX
   YTT=YY
   ZTT=ZZ
C If the bundle was emitted within the dome check if it was extinguished
C before it actually reached the other surface
C IF (INDONE) THEN
C COMPUTE THE DISTANCE P1P2, GET A RANDOM NUMBER. AND COMPUTE THE MAXI
C NUM DISTANCE A BUNDLE CAN TRAVEL BASED ON THE ABSORPTIVITY
C LEN=NORMS(XX-X1,YY-Y1,ZZ-Z1)
   CALL DRNUM(1, RDM)
   CNTRDM = CNTRDM + 1
RDMLEN=DLOG(1.D0/(1.D0-RDM)) / ALPHAD

C IF THE DISTANCE P1P2 IS GREATER THAN THE MAXIMUM DISTANCE RDMLEN THEN
C THE ENERGY BUNDLE WILL BE ABSORBED IN THE DOME AT A DISTANCE "RDMLEN"
C BETWEEN P1(X1,Y1,Z1) AND P2(X2,Y2,Z2). LEAVE THE LOOP INCREASE COUNTER
C
IF (LEN .GT. RDMLEN) THEN
  ABSOR = .TRUE.
  SURFAC = 4
  DELZ = RDMLEN / DSQRT((L/N)*(L/N) + (M/N)*(M/N) + 1.D0) *
  & DAHS(ZZ-Z1)/(ZZ-Z1)
  XX = (L/N)*DELZ+X1
  YY = (M/N)*DELZ+Y1
  ZZ = DELZ+Z1
ELSE IF (SURFAC.EQ.6) THEN
  ABSOR = .TRUE.
END IF

C IF THE ENERGY BUNDLE LEAVES THE MODULE, LEAVE THE LOOP AND INCREASE
C THE CORRESPONDING ABSORPTION COUNTER
C
IF (EXIT.AND.(SURFAC.EQ.1.OR.SURFAC.EQ.5).OR.ABSOR) GO TO 222

C AFTER EMISSION THE PROGRAM GOES AROUND THE FOLLOWING LOOP UNTIL
C THE BUNDLE IS ABSORBED
C
*************** LOOOOOOOOOOOOOOOOOOOP ***********************

100  CNTREF = CNTREF+1.0
     ABSOR = .FALSE.
     REFL = .FALSE.
     TRANS = .FALSE.
     DIFUS = .FALSE.

C
CCCCCCCCCCCCC
IF (MAGNV(SURFAC).EQ.0.D0) THEN
  WRITE(16,'(A)') 'ATTENTION USER THE BUNDLE IS TRAPPED'
  WRITE(16,'(A)') 'CNTREF',CNTREF,JMAX
  WRITE(06,'(A)') 'ERROR !!!!!!!
  WRITE(16,'(A)') 'MAGNV ET SURFAC 2222222',MAGNV(SURFAC),SURFAC
END IF

CCCCCCCCCCCC

C COMPUTE THE COSINE OF THE ANGLE BETWEEN THE LINE P2P1 AND THE VECTOR
C NORMAL TO THE SURFACE AT P2.
C
ANORM(1) = INORM(SURFAC,1)
ANORM(2) = INORM(SURFAC,2)
ANORM(3) = INORM(SURFAC,3)
CCSLED = DOTP(XX-X1,Y1-Z1,ZZ-Z1,ANORM(1),ANORM(2),ANORM(3)) /
  & MAGNV(SURFAC)

C IF THE BUNDLE HITS THE FOV LIMITER, SUBSTRATE, BARREL, CONE, RING,
C OR CAV SUB, IT CAN BE EITHER REFLECTED OR ABSORBED
C
IF ((SURFAC.EQ.1).OR.(SURFAC.EQ.5).OR.
  & (SURFAC.EQ.2).OR.(SURFAC.EQ.6).OR.
  & (SURFAC.EQ.9).OR.(SURFAC.EQ.10).OR.
  & (SURFAC.EQ.11).OR.(SURFAC.EQ.12).OR.
  & (SURFAC.EQ.13).OR.
  & (SURFAC.EQ.14).OR.(SURFAC.EQ.15)) THEN

Program ERBERT
CALL REFSQLDL(L,M,N,XX,YY,ZZ,INORM,SURFAC,ABSOR,REFL,DIFUS)
TRANS=.FALSE.

C IF THE BUNDLE HIT THE DOME, IT CAN BE TRANSMITTED, REFLECTED OR
C ABSORBED
C
ELSE IF ((SURFAC.EQ.3).OR.(SURFAC.EQ.4).OR.(SURFAC.EQ.7).OR.
& (SURFAC.EQ.8)) THEN
C
FOR THE OUTER SURFACE OF THE DOME, IF THE Z-COORDINATE IS BELOW ZERO,
C THE RAY CAN NOT GO THRU THE INTERFACE. IT HAS TO BE REFLECTED SPECU-
C LARLY. IT CAN NOT BE TRANSMITTED!!!!!
C
IF ((SURFAC.EQ.3.OR.SURFAC.EQ.7).AND.Z2(SURFAC).LE.0.D0) THEN
TRANS=.FALSE,
CALL REFLEX(L,M,N,INORM,SURFAC)
REFL=.TRUE.
C
C OTHERWISE THE BUNDLE TRY TRANSMISSION
C
ELSE
CALL REFOTR(L,M,N,INORM,SURFAC,REFL,TRANS,INDOME)
C
END IF
END IF
C
IF THE ENERGY BUNDLE WAS ABSORBED BY THE FOV LIMITER OR BY THE SUB
C STRATE, KEEP P1 AND P0 AS THEY WERE GO TO THE END OF THE FOLLOWING
C "IF" AND CHECK FOR POSSIBLE EXTINCTION IN THE DOME. IF NOT ABSORBED
C EXECUTE THE FOLLOWING STEPS:
C
IF (.NOT.ABSOR) THEN
C
MEMORIZE P0 AND SET THE FORMER POINT P0 TO BE P1
C
X0=X1
Y0=Y1
Z0=Z1
X1=XX
Y1=YY
Z1=ZZ
C
C FIND THE POSSIBLE INTERSECTIONS WITH EACH SURFACE OF THE MODULE
C
CALL FOVLIM(X1,Y1,Z1,L,M,N,X2,Y2,Z2,MAGNV,INORM,HITTEM,EXIT)
CALL SUBSTR(X1,Y1,Z1,L,M,N,X2,Y2,Z2,MAGNV,INORM,HITTEM,ENTER)
IF (CH.EQ.22) THEN
CALL SPHERE(X1,Y1,Z1,L,M,N,X2,Y2,Z2,3,MAGNV,INORM,HITTEM)
ELSE
CALL RING(X1,Y1,Z1,L,M,N,X2,Y2,Z2,MAGNV,INORM,HITTEM)
END IF
CALL BARREL(X1,Y1,Z1,L,M,N,X2,Y2,Z2,MAGNV,INORM,HITTEM)
CALL CAVSUB(X1,Y1,Z1,L,M,N,X2,Y2,Z2,MAGNV,INORM,HITTEM,
& EXITCAV,EXCAV)
C
C IF A REFLECTION OCCURED LAST, A SURFACE CAN ONLY BE HIT IF THE COSINE
C OF THE ANGLE OF REFLEXION IS THE OPPOSITE TO THAT OF INCIDENCE
C
IF (REFL) THEN
J=0
DO 150 I=1,15
IF (HITTEM(I)) THEN

Program ERBBRT 144
IF (MAGNV(I) .EQ. 0.0) THEN
WRITE(16,'(I10)') 'ATTENTION USER THE BUNDLE IS TRAPPED'
WRITE(16,'(A20,1X,A10,1X,E10.6,1X,A10)') 'CNTREF', CNTREF, JMAX
WRITE(06,'(A20,1X,A10,1X,E10.6,1X,A10)') 'ERROR !!!'
WRITE(16,'(A20,1X,A10,1X,E10.6,1X,A10)') 'MAGNV ET SURFAC 333333', MAGNV(I), I
CALL SHOW (X1,Y1,Z1,I)
END IF

COSNEW(I)=DOTP(X2(I)-X1,Y2(I)-Y1,Z2(I)-Z1,ANORM(I),ANORM(I))
& IF (-COSOLD*COSNEW(I) .GT. 0.0) THEN
J=J+1
BOOL(J)=I
END IF
END IF
150 CONTINUE
JMAX=J

C IF NO SURFAC IS HIT, THE USER IS WARNED SINCE THE PROGRAM CAN NOT
C PERSUE EXECUTION

IF (JMAX .EQ. 0) THEN
WRITE(16,'(A20,1X,A10,1X,E10.6,1X,A10)') 'NO JMAX REFLECT', JMAX
DO 165 I=1,15
IF (HIDDEN(I)) THEN
WRITE(16,'(A20,1X,A10,1X,E10.6,1X,A10)') 'COSTTA PRECEDENT ', COSOLD
WRITE(16,'(A20,1X,A10,1X,E10.6,1X,A10)') 'COSTTA ACTUEL ', COSNEW(I), I
END IF
165 CONTINUE
GO TO 222
END IF

C BETWEEN THE ELIGIBLE SURFACES CHOOSE THE CLOSEST ONE

IF (JMAX .GT. 1) THEN
MAGMAX=MAGNV(BOOL(I))
SURFAC=BOOL(I)
DO 170 I=2,JMAX
IF (MAGNV(BOOL(I)) .LT. MAGMAX) THEN
MAGMAX=MAGNV(BOOL(I))
SURFAC=BOOL(I)
END IF
170 CONTINUE
ELSE
SURFAC=BOOL(JMAX)
END IF

C IF A TRANSMISSION OCCURED LAST, A SURFACE CAN ONLY BE HIT IF THE
C COSINES OF THE ANGLES ARE EQUAL.

ELSE IF (TRANS) THEN
J=0
DO 190 I=1,15
IF (HIDDEN(I)) THEN

ENDIF

IF (MAGNV(I) .EQ. 0.0) THEN
WRITE(16,'(A20,1X,A10,1X,E10.6,1X,A10)') 'ATTENTION USER THE BUNDLE IS TRAPPED'
WRITE(16,'(A20,1X,A10,1X,E10.6,1X,A10)') 'CNTREF AND JMAX', CNTREF, JMAX
WRITE(06,'(A20,1X,A10,1X,E10.6,1X,A10)') 'ERROR!!!!!! '
WRITE(16,'(A20,1X,A10,1X,E10.6,1X,A10)') 'MAGNV ET SURFAC', MAGNV(I), I

ENDIF

Program ERBERT
CALL SHOW(X1,Y1,Z1,I)
END IF

C

COSNEW(I)=DOTP(X2(I)-X1,Y2(I)-Y1,Z2(I)-Z1,ANORM(1),ANORM(2),ANORM(3))/MAGNV(I)

IF (COSOLD*COSNEW(I) .GT. 0.0D0) THEN
  J=J+1
  BOOL(J)=I
END IF

END IF

190 CONTINUE

JMAX=J

C IF NO SURFAC IS HIT, THE USER IS WARNED SINCE THE PROGRAM CAN NOT
C PERSUE EXECUTION

C

C IF JMAX.EQ.0 THEN
WRITE(16,*)'JMAX TRANSC',JMAX
CALL SHOW(X0,Y0,Z0,25)
CALL SHOW(X1,Y1,Z1,SURFAC)
DO 200 I=1,15
  IF (HITTEN(I)) THEN
    WRITE(16,*)'COSTTA PRECEDENT '-COSOLD
    WRITE(16,*)'COSTTA ACTUEL ',COSNEW(I),I
    CALL SHOW(X2(I),Y2(I),Z2(I),I)
  END IF
200 CONTINUE
GO TO 222

END IF

C BETWEEN THE ELIGIBLE SURFACES CHOOSE THE CLOSEST ONE
C

C IF (JMAX .GT. 1) THEN
  MAGMAX=MAGNV(BOOL(1))
  SURFAC=BOOL(1)
  DO 205 I=2,JMAX
    IF (MAGNV(BOOL(I)) .LT. MAGMAX) THEN
      MAGMAX=MAGNV(BOOL(I))
      SURFAC=BOOL(I)
    END IF
205 CONTINUE
ELSE
  SURFAC=BOOL(JMAX)
END IF

C CALL SHOW(X2(SURFAC),Y2(SURFAC),Z2(SURFAC),SURFAC)
C
C IF THE BUNDLE WAS NEITHER REFLECTED NOR TRANSMITTED: PROBLEM!
C
C IF DIFFUSE REFLECTION OCCURED TREAT THE BUNDLE AS IN DIFFUSE EMISSION
C
ELSE IF (DIFUS) THEN
IF (SURFAC.EQ.2) THEN
  IF (Z2(3).LT.0.0D0) HITTEN(3)=.FALSE.
  IF (Z2(4).LT.0.0D0) HITTEN(4)=.FALSE.
  IF (Z2(6).LT.0.0D0) HITTEN(6)=.FALSE.
  IF (Z2(7).LT.0.0D0) HITTEN(7)=.FALSE.
  IF (Z2(8).LT.0.0D0) HITTEN(8)=.FALSE.
  IF (Z2(9).LT.0.0D0) HITTEN(9)=.FALSE.
  IF (Z2(10).LT.0.0D0) HITTEN(10)=.FALSE.
  IF (Z2(11).LT.0.0D0) HITTEN(11)=.FALSE.
  IF (Z2(12).LT.0.0D0) HITTEN(12)=.FALSE.
  IF (Z2(13).LT.0.0D0) HITTEN(13)=.FALSE.
IF (Z2(14).LT.0.0D0) HITTEN(14)=.FALSE.
IF (Z2(15).LT.0.0D0) HITTEN(15)=.FALSE.
END IF

C THE SURFACE HIT IS THE CLOSEST ONE TO THE EMISSION POINT
C
MAGMIN=10.D0*RFOV
J=0
DO 210 I=1,15
   IF (HITTEN(I)) THEN
      IF (MAGNV(I).LT. MAGMIN) THEN
         MAGMIN=MAGNV(I)
         SURFAC=I
         J=J+1
      END IF
      WRITE(16,*)(ATTENTION USER THE BUNDLE IS TRAPPED')
      WRITE(15,*)('CNTREF',CNTREF
      WRITE(06,*)('ERROR!!!!!!!!!!!!!!!'
      WRITE(16,*)(MGNV ET SURFAC 1111',MAGNV(I),I
      CALL SHOW (X1,Y1,Z1,I)
   END IF

210 CONTINUE

C STOEE THE COORDINATES OF THE POINT HIT
C
XX=X2(SURFAC)
YY=Y2(SURFAC)
ZZ=Z2(SURFAC)
END IF
C IF THE ENERGY BDLE LEAVES THE MODULE LEAVE
C THE LOOP AND INCREASE THE CORRESPONDING ABSORPTION COUNTER
C
IF (EXIT.AND.(SURFAC.EQ.1.OR.SURFAC.EQ.5)) GOTO 222
END IF
C END OF THE (NOT ABSOR) IF
C
END IF
C
IF (ABS(Y2(SURFAC)).GT.RFOV.OR.ABS(X2(SURFAC)).GT.RFOV) THEN
   CALL SHOW(X2(SURFAC),Y2(SURFAC),Z2(SURFAC),SURFAC)
   CALL SHOW(X1,Y1,Z1,SURFAC)
   DO 211 I=1,15
      WRITE(06,*)(HITTEN(I)
   211 CONTINUE
   WRITE(06,*)('ERREUR QUELQUE PART',CNTBDL
   GO TO 260
END IF

Program ERBERT 147
C IF THE BUNDLE IS IN THE DOME CHECK IF IT WAS EXTINGUISHED BEFORE      
C IT ACTUALLY REACHED THE OTHER SURFACE                                  
C IF (INDOME) THEN                                                        
C COMPUTE THE DISTANCE P1P2, GET A RANDOM NUMBER, AND COMPUTE THE MAXI
C MUM DISTANCE A BUNDLE CAN TRAVEL BASED ON THE ABSORPTIVITY              
C LEN=NORME((XX-X1,YY-Y1,ZZ-Z1))                                         
C CALL DRUN(1,RDM)                                                        
C CNTRDM=CNTRDM+1                                                          
C RDMLEN=DLOG(1.0/(1.0-RDM))/ALPHAD                                        
C IF THE DISTANCE P1P2 IS GREATER THAN THE MAXIMUM DISTANCE RDMLEN THEN  
C THE ENERGY BUNDLE WILL BE ABSORBED IN THE DOME AT A DISTANCE "RDMLEN"   
C BETWEEN P1(X1,Y1,Z1) AND P2(X2,Y2,Z2). LEAVE THE LOOP INCREASE COUNTER 
C IF (LEN.GT.RDMLEN) THEN                                                
C ABSOR=.TRUE.                                                             
C SURFAC=4                                                                
C DELZ=RDMLEN/DSQRT((L/N)*(L/N)+(M/N)*(M/N)+1.0)*                          
C & DABS(ZZ-Z1)/(ZZ-Z1)                                                    
C XX=(L/N)*DELZ+X1                                                        
C YY=(M/N)*DELZ+Y1                                                        
C ZZ=DELZ+Z1                                                              
C ELSE IF (SURFAC.EQ.6) THEN                                             
C ABSOR=.TRUE.                                                             
C END IF                                                                  
C IF THE BUNDLE WAS NOT ABSORBED THIS TIME GO BACK TO TOP OF LOOP         
C 220 IF (.NOT.ABSOR) GO TO 100                                           
C 222 TEST SECTION TO INCREASE THE COUNTERS                               
C IF((SURFAC.EQ.1.OR.SURFAC.EQ.5).AND.(ABSOR.AND..NOT.EXIT)) THEN        
C PT(1)=PT(1)+1                                                           
C CALL SEARCH(XX,YY,ZZ,SURFAC,CNTBDL,DIST)                                
C ELSE IF ((SURFAC.EQ.2.AND.ABSOR) THEN                                   
C PT(12)=PT(12)+1                                                         
C CALL SEARCH(XX,YY,ZZ,SURFAC,CNTBDL,DIST)                                
C ELSE IF ((SURFAC.EQ.6).AND.(ABSOR.AND..NOT.ENTER)) THEN                
C PT(2)=PT(2)+1                                                           
C CALL SEARCH(XX,YY,ZZ,SURFAC,CNTBDL,DIST)                                
C ELSE IF ((SURFAC.EQ.3.OR.SURFAC.EQ.7).AND.ABSOR) THEN                  
C PT(3)=PT(3)+1                                                           
C CALL SEARCH(XX,YY,ZZ,SURFAC,CNTBDL,DIST)                                
C ELSE IF ((SURFAC.EQ.4.OR.SURFAC.EQ.8).AND.ABSOR) THEN                  
C PT(4)=PT(4)+1                                                           
C CALL SEARCH(XX,YY,ZZ,SURFAC,CNTBDL,DIST)                                
C ELSE IF ((SURFAC.EQ.1.OR.SURFAC.EQ.5).AND.EXIT) THEN                   
C FT(6)=FT(6)+1                                                           
C NBBUAB(NB4+1)=NBBUAB(NB4+1)+1                                         
C ABBR=.TRUE.                                                             
C ELSE IF ((SURFAC.EQ.9.OR.SURFAC.EQ.10).AND.ABSOR) THEN                 
C FT(7)=FT(7)+1                                                           
C CALL SEARCH(XX,YY,ZZ,SURFAC,CNTBDL,DIST)                                
C ELSE IF ((SURFAC.EQ.11.OR.SURFAC.EQ.12).AND.ABSOR) THEN                
C FT(8)=FT(8)+1                                                           
C CALL SEARCH(XX,YY,ZZ,SURFAC,CNTBDL,DIST)                                
C ELSE IF (SURFAC.EQ.13.AND.ABSOR) THEN                                   
C FT(9)=FT(9)+1                                                           
C CALL SEARCH(XX,YY,ZZ,SURFAC,CNTBDL,DIST)                                

Program ERBERT 148
ELSE IF (SURFAC.EQ.14.OR.SURFAC.EQ.15).AND.ABSOR) THEN
  FT(10)=FT(10)+1
  CALL SEARCH(XX,YY,ZZ,SURFAC,CNTBDL,DIST)
END IF

INCREMENT COUNTER FOR BUNDLES ENTERING CAVITY

IF (EMISUR.EQ.4.AND.ENTER) THEN
  FT(5)=FT(5)+1
END IF

INCREMENT COUNTER FOR BUNDLES LEAVING CAVITY

IF ((EMISUR.EQ.9.OR.EMISUR.EQ.11).AND.EXITCAV) THEN
  FT(11)=FT(11)+1
END IF

CHECK IF ALL THE BUNDLES HAVE BEEN EMITTED FOR THE CURRENT WL INTERVAL

IF (CNTBDL.LT.NBDLIN(CNTINT)) GO TO 30

COMPUTE THE DISTRIBUTION FACTORS:

DFAC(EMITTING ELM,.ABSORBING ELM,.SPECIFIC WAVELENGTH INTERVAL),
C DEFINED AS THE RATIO OF THE NUMBER OF BUNDLES EMITTED BY ELM "I"
C IN WL INTERVAL "K" THAT IS ABSORBED BY ELM "J" TO THE NUMBER OF
C BUNDLES EMITTED BY ELM "I" IN WL INTERVAL "K"

DO 300 J=1,NN14
  DFAC(NBSURF,J,CNTINT)=DBLE(NBBUAB(J))/DBLE(NBBUEA(CNTINT))
300 CONTINUE

CHECK IF ALL THE BUNDLES HAVE BEEN EMITTED FOR THE ENTIRE SPECTRUM

IF (CNTBDL.LT.MAXBDL) GO TO 29

If all energy bundles have been emitted write all the necessary
OUTPUT FILES.

If energy bundles were emitted from one element only,

IF (MENU3.EQ.2) THEN
  DT(1)=DBLE(FT(1))/DBLE(MAXBDL)
  DT(2)=DBLE(FT(2))/DBLE(MAXBDL)
  DT(3)=DBLE(FT(3))/DBLE(MAXBDL)
  DT(4)=DBLE(FT(4))/DBLE(MAXBDL)
  DT(5)=DBLE(FT(5))/DBLE(MAXBDL)
  DT(6)=DBLE(FT(6))/DBLE(MAXBDL)
  DT(7)=DBLE(FT(7))/DBLE(MAXBDL)
  DT(8)=DBLE(FT(8))/DBLE(MAXBDL)
  DT(9)=DBLE(FT(9))/DBLE(MAXBDL)
  DT(10)=DBLE(FT(10))/DBLE(MAXBDL)
  DT(11)=DBLE(FT(11))/DBLE(MAXBDL)
  DT(12)=DBLE(FT(12))/DBLE(MAXBDL)
WRITE(03,234) 'NUMBER OF ENERGY BUNDLES EMITTED : ', CNTBDL
WRITE(03,232) 'NUMBER OF RANDOM NUMBER USED : ', CNTRDM
WRIT(03,231) '-------------------------'
WRITE(03,230) 'DFAC TO CONE (DT8) ',DT(8)
WRITE(03,230) 'DFAC TO CAVITY SUBSTRATE (DT9) ',DT(9)
WRITE(03,230) 'DFAC TO RING (DT10) ',DT(10)
WRITE(03,*) ' ============'
WRITE(03,230) 'SUM OF DFACS ',DT(1)+DT(2)
& +DT(3)+DT(4)+DT(6)+DT(7)+DT(8)+DT(9)+DT(10)+DT(12)
WRITE(03,231) ' ============'
WRITE(03,230) 'POSSIBLE BUNDLES ENTERING CAVITY ',DT(6)
WRITE(03,230) 'BUNDLES LEAVING CAVITY ',DT(11)
WRITE(03,230) 'AVERAGE # OF REFLECTIONS PER BUNDLE ',CNTREF/CNTBDL
WRITE(03,232) 'NUMBER OF BUNDLES REFLECTED ON DOME ',CNTBRW

230 FORMAT(2X,A36,F10.5)
231 FORMAT(1X,A48)
232 FORMAT(2X,A34,F10.10)
240 FORMAT(1X,2I10,F15.9)

C Compute the DFAC for shortwave, longwave and total spectrum
C and output the DFAC to file for tecplot postprocessing
C
I = 1
DO 310 J=1,NB14
   DFACSW(I,J)=0.0D0
   DFACLW(I,J)=0.0D0
   DFACCT(I,J)=0.0D0
310 CONTINUE
DO 311 J=1,NB14
   DO 311 K=1,NBWLIN-1
      DFACSW(I,J)=(DFACSW(I,J)+DFAC(NBSURF,J,K))
      DFACCT(I,J)=(DFACCT(I,J)+DFAC(NBSURF,J,K))
311 CONTINUE
WRITE(18,*) 'DFAC TO ELEMENT',J,'=',DFACCT(I,J)
   CHECKDF=CHECKDF+DFACCT(I,J)
K=NBWLIN
DO 312 J=1,NB14
   DFACLW(I,J)=(DFACLW(I,J)+DFAC(NBSURF,J,K))
   DFACCT(I,J)=(DFACCT(I,J)+DFAC(NBSURF,J,K))
   WRITE(18,*) 'CHECKDF=',CHECKDF
312 CONTINUE
WRITE(18,*) CALL TECPLTP
CONTINUE
IF (EMISUR.EQ.0) WRITE(07,770) 'FIELD',NBSURF
IF (EMISUR.EQ.1) WRITE(07,770) 'FOV_L',NBSURF
IF (EMISUR.EQ.2) WRITE(07,770) 'L_SUB',NBSURF
IF (EMISUR.EQ.3) WRITE(07,770) 'U_SUB',NBSURF
IF (EMISUR.EQ.4) WRITE(07,770) 'DOME ',NBSURF
IF (EMISUR.EQ.9) WRITE(07,770) 'BARREL',NBSURF
IF (EMISUR.EQ.11) WRITE(07,770) 'CONE',NBSURF
IF (EMISUR.EQ.13) WRITE(07,770) 'CAVSUB',NBSURF
IF (EMISUR.EQ.14) WRITE(07,770) 'RING',NBSURF
DO 350 K=1,NBWLIN
   IF (EMISUR.EQ.1) WRITE(07,770) J,K,DAC(NBSURF,J,K)
350 CONTINUE
770 FORMAT(1X,A6,I4)
780 FORMAT(1X,2I16,15.20)
790 FORMAT(1X,16,15.20)

C C END-OF-PROGRAM MENU
C
Program ERBERT

150
IF (CNTEMI.LT.CNTIND) GO TO 922
WRITE(03,*'/CNSRM,' RANDOM NUMBER USED FOR DFAC COMPUTATION'

WRITE(06,520)'===================================================================='
WRITE(06,520)' TO QUIT, ENTER (0)'
WRITE(06,520)' IF YOU WANT TO RUN THIS PROGRAM AGAIN, ENTER (1)'
WRITE(06,520)'===================================================================='
READ(05,*'ANSWER'
IF (ANSWER.EQ.1) THEN
   GO TO 10
ELSE
   GO TO 261
END IF

FORMAT OF ALL WRITE AND READ STATEMENTS

FORMAT (1X,A52)
FORMAT (1X,F10.3,A11,F10.3)
FORMAT (1X,A30,F10.6)
FORMAT (1X,A10.15)
FORMAT (1X,A25,I4,A6,I4)
FORMAT (1X,A16,I4,A22,I4)
FORMAT (1X,F9.3,1X,F9.3,1X,F9.3,1X,F15.9)
FORMAT (1X,416)

END

SUBROUTINE EMIT0 (X1,Y1,Z1,L,M,N,CRADAN,PTSOUR)
IMPLICIT NONE
REAL*8 X1,Y1,Z1,PHI1,TETA1,TETA,PI,RDM,RF0V,TETAFM
REAL*8 R,L,M,N,LP,MP,NP,RADIUS,CRADAN
REAL*8 XPTSO,YPTSO
REAL*8 REXT,RINT,DENIV

INTEGER CNTRD2
LOGICAL PTSOUR

COMMON /RAN1/ CNTRD2
COMMON /FOV1/ RF0V,TETAFM
COMMON /PTSO/ XPTSO,YPTSO
COMMON /DOM1/ REXT,RINT,DENIV

PI=ACOS(-1.0D0)

WHEN EMITTING FROM THE APERTURE OF THE FOV LIMITER Z1 IS GIVEN

Z1=RF0V*DCOS(TETAFM)+DENIV

IF POINT SOURCE OPTION IS SET X1=XPTSO AND Y1=YPTSO

IF (PTSOUR) THEN
   X1=XPTSO
   Y1=YPTSO
ELSE
GET RANDOM POSITION ON EMISSION DISC *
CALL DRNUN(1,RDM)
CNTEDM=CNTRD2+1
R=DSQRT(RDM)*RF0V*DSIN(TETAFM)
CALL DRUNM(1,RDM)
CNT RDM=CNT RDM+1
TETA=RDM*2.D0*PI

C OBTAIN X Y COORDINATES *

X1=R*DCOS(TETA)
Y1=R*DSIN(TETA)
RADIUS=DSQRT(X1*X1+Y1*Y1)
END IF

C IF THE ANGLE CRADAN IS >0, THE RADIATION IS EMITTED WITH CST DIRECTION

IF (CRADAN.GE.0.D0) THEN
L=0.D0
M=DSIN(CRADAN)
N=DCOS(CRADAN)
ELSE

C GET RANDOM EMISSION DIRECTION IN THE LOCAL COORDINATE SYSTEM

CALL DRUNM(1,RDM)
CNT RDM=CNT RDM+1
PHI1=DSIN(2.0.D0*RDM))
CALL DRUNM(1,RDM)
CNT RDM=CNT RDM+1
TETA1=2.D0*PI*RDM

C COMPUTE THE DIRECTION COSINES IN THE LOCAL COORDINATE SYSTEM

LP=DSIN(PHI1)*DCOS(TETA1)
MP=DSIN(PHI1)*DSIN(TETA1)
NP=DCOS(PHI1)

C TRANSFORMATION OF THE DIRECTION COSINES INTO GLOBAL COORD. SYSTEM

L=LP
M=MP
N=NP
END IF

*************************************************************************************************
* *
* THIS SUBROUTINE EMITS BUNDLES IN RANDOM DIRECTION FROM A RANDOM *
* LOCATION OF A SURFACE ELEMENT OF THE FOV LIMITER. *
* *
*************************************************************************************************

SUBROUTINE EMIT1 (X1,Y1,Z1,L,M,N)

IMPLICIT NONE
REAL*8 X1,Y1,Z1,PHI,TETA,L,M,N,LP,MP,NP,ZED,DZED,DTETA
REAL*8 RFOV,TETAFM,ZMAX,PI,RDM,PHILOC,TTALOC
REAL*8 REXT,RINT,DENIV

INTEGER NBLAT,NBLONG,NSURI1,NSURI2,NSURI3
INTEGER CNT RDM

COMMON /RAND/ CNT RDM
COMMON /FCVL/ RFOV,TETAFM
COMMON /SER2/ NBLAT,NBLONG
COMMON /NSUR/ NSURI1,NSURI2,NSURI3
COMMON /DOME/ REXT,RINT,DENIV
PI = DACOS(-1.0D0)
ZMAX = RFOV*DCOS(TETAFM) + DENIV

DZED = ZMAX/NBLAT
DTETA = 2.0D0*PI/NBLONG

C GET RANDOM POSITION ON EMISSION SURFACE

CALL DRNUN(1, RDM)
CNTRDM = CNTRDM + 1
ZED = (DBLE(NSUR11) - 1.0D0 + DSQRT(RDM)) * DZED - DENIV

CALL DRNUN(1, RDM)
CNTRDM = CNTRDM + 1
TETA = (DBLE(NSUR12) - 1.0D0 + RDM) * DTETA
PHI = DACOS(ZED/RFOV)

C OBTAIN X Y Z COORDINATES *

X1 = RFOV * DSIN(PHI) * DSIN(TETA)
Y1 = RFOV * DSIN(PHI) * DSIN(TETA)
Z1 = RFOV * DCOS(PHI) + DENIV

C RANDOM EMISSION DIRECTION IN THE LOCAL COORD. SYSTEM

CALL DRNUN(1, RDM)
CNTRDM = CNTRDM + 1
PHILOC = DSIN(DSQRT(RDM))
CALL DRNUN(1, RDM)
CNTRDM = CNTRDM + 1
TTALOC = 2.0D0*PI*RDM

C COMPUTE THE SLOPE OF THE Emitted RAY IN THE LOCAL COORD. SYSTEM

LP = DSIN(PHILOC) * DCOS(TTALOC)
MP = DSIN(PHILOC) * DSIN(TTALOC)
NP = DCOS(PHILOC)

C TRANSFORMATION OF THE DIRECTION COSINES INTO GLOBAL COORD. SYSTEM

L = -(X1*Z1/(RFOV*DSQRT(RFOV*RFOV-Z1*Z1)))*LP
   & +Y1/DSQRT(RFOV*RFOV-Z1*Z1)*MP
   & +X1/RFOV*NP
M = -(Y1*Z1/(RFOV*DSQRT(RFOV*RFOV-Z1*Z1)))*LP
   & +X1/DSQRT(RFOV*RFOV-Z1*Z1)*MP
   & +Y1/RFOV*NP
N = DSQRT(RFOV*RFOV-Z1*Z1)/RFOV*LP-Z1/RFOV*NP

END

******************************************************************************
* * THIS SUBROUTINE EMITS BUNDLES IN RANDOM DIRECTION FROM A RANDOM *
* LOCATION OF A SURFACE ELEMENT OF THE LOWER SUBSTRATE. *
* * **************************************************************************

SUBROUTINE EMIT2 (X1, Y1, Z1, L, M, N, INDOME)

IMPLICIT NONE
REAL*8 X1, Y1, Z1, TETA, L, M, N, LP, MP, NP, DTETA
REAL*8 RFOV, TETAFM, PI, RDM, PHILOC, TTALOC
REAL*8 RADIUS, REXT, RINT, RPA, DENIV

Program ERBERT  153
INTEGER NBWASH,NBPS,NBLSU,NBWLSU,NSURI1,NSURI2,NSURI3,SURFAC
INTEGER CNTRDM

LOGICAL INDOME

COMMON /RAND/ CNTRDM
COMMON /FOVL,/ RFOV,TETAFM /SUBS/ RPA,SURFAC
COMMON /SV3/ NBWASH,NBPS,NBLSU,NBWLSU
COMMON /DOME/ REXT,RINT,DENIV
COMMON /NSUR/ NSURI1,NSURI2,NSURI3

PI=DACOS(-1.D0)
INDOME=.FALSE.

C GET RANDOM POSITION ON EMISSION SURFACE (LOWER SUBSTRATE)

IF (NSURI1.EQ.1) THEN
  DTETA=2.D0*PI
  CALL DRUN(R1,RDM)
  CNTRDM=CNTRDM+1
  RADIUS=DSQRT(RDM)*RPA
  CALL DRUN(R1,RDM)
  CNTRDM=CNTRDM+1
  TETA=(DBLE(NSURI2)-1.D0*RDM)*DTETA
ELSE
  DTETA=2.D0*PI/DBLE(NBLSU)
  CALL DRUN(R1,RDM)
  CNTRDM=CNTRDM+1
  IF (NSURI2.EQ.1) THEN
    RADIUS=DSQRT(RDM*(RINT*RINT+RPA*RPA)+RPA*RPA)
  ELSE
    RADIUS=DSQRT(RDM*(REXT*REXT-RINT*RINT)+RINT*RINT)
  END IF
  INDOME=.TRUE.
  END IF
  CALL DRUN(R1,RDM)
  CNTRDM=CNTRDM+1
  TETA=(DBLE(NSURI3)-1.D0*RDM)*DTETA
END IF

C OBTAIN X Y Z COORDINATES *

X1=RADIUS*DCOS(TETA)
Y1=RADIUS*DSIN(TETA)
Z1=DENIV

C RANDOM EMISSION DIRECTION IN THE LOCAL COORD. SYSTEM

CALL DRUN(R1,RDM)
CNTRDM=CNTRDM+1
PHILOC=DSIN(DSQRT(RDM))
CALL DRUN(R1,RDM)
CNTRDM=CNTRDM+1
TTALOC=2.D0*PI*RDM

C COMPUTE THE SLOPE OF THE Emitted Ray IN THE LOCAL COORD. SYSTEM

LP=DSIN(PHILOC)*DCOS(TTALOC)
MP=DSIN(PHILOC)*DSIN(TTALOC)
NP=DCOS(PHILOC)

C TRANSFORMATION OF THE DIRECTION COSINES INTO GLOBAL COORD. SYSTEM

L=(X1*LP-Y1*MP)/RADIUS
M=(Y1*LP+X1*MP)/RADIUS
N=NP
END

******************************************************************************
*   THIS SUBROUTINE EMITS BUNDLES IN RANDOM DIRECTION FROM A RANDOM        *
*   LOCATION OF A SURFACE ELEMENT OF THE UPPER SUBSTRATE.                  *
*                                                                          *
******************************************************************************

SUBROUTINE EMIT3 (X1,Y1,Z1,L,M,N)

IMPLICIT NONE
REAL*8 X1,Y1,Z1,THETA,L,M,N,LP,MP,NP,DTETA
REAL*8 RHOV,TETAFM,PI,RDM,PHILOC,TTALOC
REAL*8 RADIUS,RADIUS1,RADIUS2,REXT,RINT,DENIV,RAD1,RAD2

C
INTEGER NBWSH,NBPS,NBLSU,NBWSU,NSURI1,NSURI2,NSURI3
INTEGER CNTRDM

C
COMMON /RAND// CNTRDM
COMMON /FOV/ RHOV,TETAFM
COMMON /SER3// NBWSH,NBPS,NBLSU,NBWSU
COMMON /NSUR// NSURI1,NSURI2,NSURI3
COMMON /DOME// REXT,RINT,DENIV

C
FI=DCOS(-1.D0)
DTHETA=2.D0*PI/NBPS
RAD1=DSQRT(REXT*REXT-DENIV*DENIV)
RAD2=DSQRT(RHOV*RHOV-DENIV*DENIV)
RADIUS1=DSQRT(DBLE(NSURI1-1)/DBLE(NBWSH)*RAD2*(RAD2*RAD2-
& RADIUS*RADIUS1)+RAD1*RADIUS1)
RADIUS2=DSQRT(DBLE(NSURI1)/DBLE(NBWSH)*RAD2*(RAD2*RAD2-
& RADIUS*RADIUS1)+RAD1*RADIUS1)

C
GET RANDOM POSITION ON EMISSION SURFACE

C
CALL DRNN(1,RDM)
CNTRDM=CNTRDM+1
RADIUS=DSQRT(RDM*(RADIUS2*RADIUS2-RADIUS1*RADIUS1)+RADIUS1
& RADIUS1)
IF (RADIUS.EQ.0.D0) THEN
  WRITE(16,*) 'RADIUS1,RADIUS2,RADIUS,NSURI1,NSURI2'
  WRITE(16,*) RADIUS1,RADIUS2,RADIUS,NSURI1,NSURI2
END IF
CALL DRNN(1,RDM)
CNTRDM=CNTRDM+1
TETRA=(DBLE(NSURI2)-1.D0+RDM)*DTETA

C
OBTAIN X Y Z COORDINATES

C
X1=RADIUS*DCOS(TETRA)
Y1=RADIUS*DSIN(TETRA)
Z1=0.D0

C
RANDOM EMISSION DIRECTION IN THE LOCAL COORD. SYSTEM

C
CALL DRNN(1,RDM)
CNTRDM=CNTRDM+1
PHILOC=DSIN(DSQRT(RDM))
CALL DRNN(1,RDM)
CNTRDM=CNTRDM+1
TTALOC=2.D0*FI*RDM

C
COMPUTE THE SLOPE OF THE EMITTED RAY IN THE LOCAL COORD. SYSTEM

Program ERBERT

155
LP = DSIN(PHILOC) * DCOS(TTALOC)
MP = DSIN(PHILOC) * DSIN(TTALOC)
NP = DCOS(PHILOC)

C TRANSFORMATION OF THE DIRECTION COSINES INTO GLOBAL COORD. SYSTEM
C
L = (X1 * LP - Y1 * MP) / RADIUS
M = (Y1 * LP + X1 * MP) / RADIUS
N = NP

******************************************************************************
* This subroutine emits bundles in a random direction from the centroid of a volume element in the DOME *
******************************************************************************

SUBROUTINE EMIT4 (X1, Y1, Z1, L, M, N, ANORM)
IMPLICIT NONE
REAL*8 X1, Y1, Z1, L, M, N, LP, MP, NP
REAL*8 DENV, REXT, RINT
REAL*8 PHI, TETA, PHILOC, TTALOC, RDM, PI, DISTTOC
REAL*8 RADP, PHIP, TTAP, SAREA, RCEN
REAL*8 RADP1, PHIP1, TTAP1
REAL*8 ANORM(15)

INTEGER NSH, NBCO, NBPSD, NSURI1, NSURI2, NSURI3
INTEGER CNTRDM, NBVELT, MAXELT

PARAMETER (MAXELT=700)
COMMON /SER4/ NSH, NBCO, NBPSD
COMMON /NSURI/ NSURI1, NSURI2, NSURI3
COMMON /DOME/ REXT, RINT, DENV
COMMON /SETU/ RADP(MAXELT), PHIP(MAXELT), TTAP(MAXELT), SAREA(MAXELT), RCEN
COMMON /RAND/ CNTRDM

PI = DACOS(-1.0D0)

Get emission location. point P1(X1,Y1,Z1)

CALL DRNUM(1, RDM)
CNTRDM = CNTRDM + 1
RADP1 = (((RADP(NSURI1))**3)*(1.0D0-RDM) +
&             ((RADP(NSURI1-1))**3)*RDM)**(1.0D0/3.0D0)
CALL DRNUM(1, RDM)
CNTRDM = CNTRDM + 1
PHIP1 = DACOS(DCOS(PHIP(NSURI2))*1.0D0-RDM) +
& DCOS(PHIP(NSURI2-1))*RDM
CALL DRNUM(1, RDM)
CNTRDM = CNTRDM + 1
TTAP1 = TTAF(NSURI3)*1.0D0-RDM + TTAF(NSURI3+1)*RDM
X1 = RADP1*DSIN(PHIP1)*DCOS(TTAP1)
Y1 = RADP1*DSIN(PHIP1)*DSIN(TTAP1)
Z1 = RADP1*DCOS(PHIP1) + DENV
DISTTOC = DSQRT(X1*X1 + Y1*Y1 + (Z1-DENV)*(Z1-DENV))

C Compute the vector normal to the shell of point P1
C
ANORM(1) = -X1/RADP1
ANORM(2) = -Y1/RADP1
ANORM(3) = -(Z1-DENV)/RADP1

C Random emission direction in the local coordinate system

Program ERBERT 156
CALL DRNUN(1,RDM)
CNTRDM = CNTRDM + 1
PHILOC = DASIN(DSQR(T(RDM))
CALL DRNUN(1,RDM)
CNTRDM = CNTRDM + 1
TTALOC = 2.*D0*PI*RDM

Compute the slope of the emitted ray in the local coordinate system

LP = DSIN(PHILOC)*DCOS(TTALOC)
MP = DSIN(PHILOC)*DSIN(TTALOC)
NP = DCOS(PHILOC)

Transformation of the direction cosines into the global coordinate system

L = -(X1*(Z1-DENIV)/(DISTTOC*DSQRT(DISTTOC*DISTTOC - (Z1-DENIV)*
  1 (Z1-DENIV)))*LP + Y1/DSQRT(DISTTOC*DISTTOC - (Z1-DENIV)*
  2 (Z1-DENIV))*MP + X1/DISTTOC*NP)
M = -(Y1*(Z1-DENIV)/(DISTTOC*DSQRT(DISTTOC*DISTTOC - (Z1-DENIV)*
  1 (Z1-DENIV)))*LP - X1/DSQRT(DISTTOC*DISTTOC - (Z1-DENIV)*
  2 (Z1-DENIV))*MP + Y1/DISTTOC*NP
N = DSQRT(DISTTOC*DISTTOC - (Z1-DENIV)*(Z1-DENIV))/DISTTOC*LP -
  1 (Z1-DENIV)/DISTTOC*NP

END

**************************************************************************
* *
* This subroutine emits energy bundles from a random location on a given surface element of the barrel *
* *
**************************************************************************

SUBROUTINE EMIT9(X1,Y1,Z1,L,M,N,ANORM1,ANORM2,ANORM3)
IMPLICIT NONE
REAL*8 X1,Y1,Z1,L,M,N,LP,MP,NP
REAL*8 RCAV,LBAR,DLBAR,HEIGHT,DENIV,LCON,CAVANG
REAL*8 TETA,DTETA,PI,PHILOC,TTALOC,RDM,REXT,RINT
REAL*8 ANORM1,ANORM2,ANORM3

INTEGER NBHSC,NBHSC,NBPSC,NBPSC,NSURI1,NSURI2,NSURI3,SURFAC
INTEGER CNTRDM,NBPCS

COMMON /RAND/ CNTRDM
COMMON /NSUR/NSURI1,NSURI2,NSURI3
COMMON /CAVITY/ RCAV,LBAR,LCON,CAVANG
COMMON /DOME/ REXT,RINT,DENIV
COMMON /CAVSUR/ NBHSC,NBHSC,NBPSC,NBPSC,NBPCS

DLBAR=ABS(LBAR/DBLE(NBHSC))
PI=DAOS(-1.0D0)
DTETA=2.*D0*PI/NBPSC

CALL DRNUN(1,RDM)
CNTRDM=CNTRDM+1
HEIGHT=LBAR-DLAB*(RDM+DBLE(NSURI1)-1.0D0)
CALL DRNUN(1,RDM)
CNTRDM=CNTRDM+1
TETA=(DBLE(NSURI2)-1.0D0+RDM)*DTETA

C OBTAIN X Y Z COORDINATES

Program ERBERT
X1=RCAV*DCOS(TETA)
Y1=RCAV*DSIN(TETA)
Z1=DENIV-HEIGHT

C
C OBTAIN NORMAL VECTOR FROM EMISSION POINT
C
ANORM1=-1.0*X1/RCAV
ANORM2=-1.0*Y1/RCAV
ANORM3=0.0

C
C RANDOM EMISSION DIRECTION IN THE LOCAL COORDINATE SYSTEM
C
CALL DRNUN(1, RDM)
CNTRDM=CNTRDM+1
PHILOC=DSIN(DSQRT(RDM))
CALL DRNUN(1, RDM)
CNTRDM=CNTRDM+1
TTALOC=2.0*RPI*RDM

C
C COMPUTE THE SLOPE OF THE Emitted RAY IN THE LOCAL COORDINATE SYSTEM
C
LP=DSIN(PHILOC)*DCOS(TTALOC)
MP=DSIN(PHILOC)*DSIN(TTALOC)
NP=DCOS(PHILOC)

C
C TRANSFORMATION OF THE DIRECTION COSINES INTO GLOBAL COORDINATE SYSTEM
C
L=-MP*DSIN(TETA)-NP*DCOS(TETA)
M= MP*DCOS(TETA)-NP*DSIN(TETA)
N=LP

END

******************************************************************************
**
** This subroutine emits energy bundles from a random**
** location on a given surface element of the cone**
**
******************************************************************************

SUBROUTINE EMIT11(X1,Y1,Z1,L,M,N)
IMPLICIT NONE
REAL*8 X1,Y1,Z1,L,M,N,LP,MP,NP
REAL*8 RCAV,LCON,LBL,DLCON,DENIV,HEIGHT,RPRIME,CAVANG
REAL*8 TETA,DTETA,PI,PHILOC,**TALOC,RDM,REXT,RINT
REAL*8 DSNCAV,DCSCAV,LCONP
REAL*8 RIN,ROUT,RADIUS,LCAV,TANCAV

INTEGER NBHSH,NBHSC,NBPSS,NBPSC,NSURI1,NSURI2,NSURI3,NBPSCS
INTEGER CNTRDM

COMMON /RAND/ CNTRDM
COMMON /NSUR/ NSURI1,NSURI2,NSURI3
COMMON /CAVITY/ RCAV,LBL,LCON,CAVANG
COMMON /DOME/ REXT,RINT,DENIV
COMMON /CAVSUR/ NBHSH,NBHSC,NBPSS,NBPSC,NBPSCS
COMMON /CONSET/ DLCON(20)

PI=DCOS(-1.0)
LCAV=LCON+LIBAR-DENIV
DTETA=2.0*PI/NBPSC
DSNCAV=RCAV/(DSQRT(RCAV*RCAV+LCON*LCON))
DCSCAV = LCON / (DSQRT (RCAV * RCAV + LCON * LCON))
TANCAV = RCAV / LCON

C
ROUT = (LCON *((NBHSC + 1) - NSURI1) + LCAV) * TANCAV
RIN = (LCON *((NBHSC + 1) - (NSURI1 - 1)) + LCAV) * TANCAV

C
GET RANDOM POSITION ON EMISSION SURFACE
CALL DRNUN (1, RDM)
CNTRDM = CNTRDM + 1
RADIUS = DSQRT (RDM * (ROUT * ROUT - RIN * RIN) + RIN * RIN)
HEIGHT = (RADIUS / TANCAV) - LCAV
CALL DRNUN (1, RDM)
CNTRDM = CNTRDM + 1
TETA = (DBLE (NSURI2) - 1.0D0 + RDM) * DTETA

C
OBTAIN X Y Z COORDINATES
LCONP = LCON + HEIGHT - DENIV + LBAR
RPRIME = RCAV * (LCONP / LCON)
X1 = RPRIME * DSIN (TETA)
Y1 = RPRIME * DSIN (TETA)
Z1 = HEIGHT

C
RANDOM EMISSION DIRECTION IN THE LOCAL COORDINATE SYSTEM
CALL DRNUN (1, RDM)
CNTRDM = CNTRDM + 1
PHILOC = DSIN (DSQRT (RDM))
CALL DRNUN (1, RDM)
CNTRDM = CNTRDM + 1
TTALOC = 2.0D0 + PI * RDM

C
COMPUTE THE SLOPE OF THE Emitted ray IN THE LOCAL COORDINATE SYSTEM
LP = DSIN (PHILOC) * DCOS (TTALOC)
MP = DSIN (PHILOC) * DSIN (TTALOC)
NP = DCOS (PHILOC)

C
TRANSFORMATION OF THE DIRECTION COSINES INTO GLOBAL COORDINATE SYSTEM
L = LP * DCOS (TETA) * DSNCAV - MP * DSIN (TETA) - &
NP * DCOS (TETA) * DCSCAV
M = LP * DSIN (TETA) * DSNCAV + MP * DCOS (TETA) - &
NP * DSIN (TETA) * DCSCAV
N = LP * DCSCAV + NP * DSNCAV

END

******************************************************************************
*
* THIS SUBROUTINE EMITS BUNDLES IN A RANDOM DIRECTION FROM A RANDOM *
* LOCATION OF A SURFACE ELEMENT OF THE PORTION OF THE LOWER *
* SUBSTRATE WHICH FACES THE CAVITY. *
*
******************************************************************************

SUBROUTINE EMIT13 (X1, Y1, Z1, L, M, N, ANORM4, ANORM5, ANORM6)

IMPLICIT NONE
REAL * 8 X1, Y1, Z1, TETA, L, M, N, LP, MP, NP, DTETA
REAL * 8 RCAV, RPA, PI, RDM, PHILOC, TTALOC, RADIUS
REAL * 8 LBAR, LCON, CAVANG, SURFAC
REAL * 8 TETAFM, RFOV
REAL*8 ANORM4,ANORM5,ANORM6
REAL*8 REXT, RINT, DENIV

INTEGER NSURI1, NSURI2, NSURI3
INTEGER NBHSC, NBHSC, NBPS5, NBPS6, NBPS6
INTEGER CNTRDM

COMMON / RAND/, CNTRDM
COMMON / CAVSUR/, NBHSC, NBHSC, NBPS5, NBPS6, NBPS6
COMMON / CAVITY/, RCAV, LBAR, LCON, CAVANG
COMMON / FOV1/, RFOUT, TETAFM, / SUS1, RPA, SURFAC
COMMON / DOME/, REXT, RINT, DENIV

PI=DACOS(-1.0D0)

C GET RANDOM POSITION ON EMISSION SURFACE

DTETA=2.0D0*PI/DBLE(NBPS6)
CALL DRNUN(1, RDM)
CNTRDM=CNTRDM+1
RADIUS=DSQRT(RDM*(RCAV*RCAV-RPA*RPA)+RPA*RPA)
CALL DRNUN(1, RDM)
CNTRDM=CNTRDM+1
TETA=(DBLE(NSURI1)-1.0D0+RDM)*DTETA

C OBTAIN X Y Z COORDINATES

X1=RADIUS*DCOS(TETA)
Y1=RADIUS*DSIN(TETA)
Z1=DENIV

C OBTAIN NORMAL VECTOR FROM EMISSION POINT

ANORM4=0.0D0
ANORM5=0.0D0
ANORM6=-1.0D0

C RANDOM EMISSION DIRECTION IN THE LOCAL COORDINATE SYSTEM

CALL DRNUN(1, RDM)
CNTRDM=CNTRDM+1
PHILOC=DSIN(DSQRT(RDM))
CALL DRNUN(1, RDM)
CNTRDM=CNTRDM+1
TTLLOC=2.0D0*PI*RDM

C COMPUTE THE SLOPE OF THE Emitted RAY IN THE LOCAL COORDINATE SYSTEM

LP=DSIN(PHILOC)*DCOS(TTLLOC)
MP=DSIN(PHILOC)*DSIN(TTLLOC)
NP=DCOS(PHILOC)

C TRANSFORMATION OF THE DIRECTION COsINES INTO GLOBAL COORD. SYSTEM

L=(Y1*LP+X1*MP)/RADIUS
M=(X1*LP-Y1*MP)/RADIUS
N=NP

END

******************************************************************************
* This subroutine emits energy bundles from a random *
* location on a given surface element of the ring *
******************************************************************************
SUBROUTINE EMIT14(X1,Y1,Z1,L,M,N,ANORM7,ANORM8,ANORM9)
IMPLICIT NONE
REAL*8 X1,Y1,Z1,L,M,N,LP,MP,NP
REAL*8 DLRING,HEIGHT,DENIV
REAL*8 TETA,DTETA,PI,PHILOC,TTALOC,RDM,REXT,RINT
REAL*8 ANORM7,ANORM8,ANORM9
REAL*8 PHI,DISTTOC,ZED

INTEGER NSUR11,NSUR12,NSUR13,SURFAC,CNTRDM
INTEGER NBHSR,NBPSR

COMMON /RIING/ NBHSR,NBPSR
COMMON /RAND/ CNTRDM
COMMON /NSUR/NSUR11,NSUR12,NSUR13
COMMON /DOME/ REXT,RINT,DENIV

DLRING=DABS(DENIV/DBL(DENIV))
PI=DCOS(-1.D0)
DTETA=2.D0*PI/NBPSR

GET RANDOM POSITION ON EMISSION SURFACE

CALL DRNUN(1,RDM)
CNTRDM=CNTRDM+1
ZED=DQRT(DRM)+DENIV
PHI=DCOS(-ZED/REXT)
IF ((PHI.LT.1.412658D0).OR.(PHI.GT.(PI/2.D0))) THEN
   WRITE(6,'(A)'PHI out of range for RING'
END IF
CALL DRNUN(1,RDM)
CNTRDM=CNTRDM+1
TETA=(DUBL(NSUR12)-1.D0+RDM)*DTETA

OBTAIN X Y Z COORDINATES

X1=REXT*DCOS(TETA)*DSIN(PHI)
Y1=REXT*DSIN(TETA)*DSIN(PHI)
Z1=REXT*DCOS(PHI)+DENIV
DISTTOC=DQRT((X1*X1+Y1*Y1+Z1*Z1)*N(DENIV))

OBTAIN NORMAL VECTOR FROM EMISSION POINT

ANORM7=-X1/REXT
ANORM8=-Y1/REXT
ANORM9=-(Z1-DENIV)/REXT

RANDOM EMISSION DIRECTION IN THE LOCAL COORDINATE SYSTEM

CALL DRNUN(1,RDM)
CNTRDM=CNTRDM+1
PHILOC=DSIN(DQRT(DRM))
CALL DRNUN(1,RDM)
CNTRDM=CNTRDM+1
TTALOC=2.D0*PI*RDM

COMPUTE THE SLOPE OF THE Emitted RAY IN THE LOCAL COORDINATE SYSTEM

LP=DSIN(PHILOC)*DCOS(TTALOC)
MP=DSIN(PHILOC)*DSIN(TTALOC)
NP=DCOS(PHILOC)

TRANSFORMATION OF THE DIRECTION COSINES INTO GLOBAL COORDINATE SYSTEM

L = -(X1*(Z1-DENIV)/(DISTTOC*DQRT(DISTTOC*DSTT+DISTTOC-DENIV)) + 1)
   (Z1-DENIV))*LP + Y1/DSTT*DSTT*DSTT-DSTT - (Z1-DENIV)
\[ \begin{align*}
2 & \quad (Z1-DENIV) \cdot MP + X1/DISTTOC\cdot NP \\
M & = -(Y1*(Z1-DENIV)/(DISTTOC*DSQRT(DISTTOC*DISTTOC - (Z1-DENIV)\cdot \\
1 & \quad (Z1-DENIV)\cdot LP - X1/DSQRT(DISTTOC*DISTTOC - (Z1-DENIV)\cdot \\
2 & \quad (Z1-DENIV)\cdot MP + Y1/DISTTOC\cdot NP) \}
N & = DSQRT(DISTTOC*DISTTOC - (Z1-DENIV)*(Z1-DENIV))/(DISTTOC\cdot LP - \\
1 & \quad (Z1-DENIV)/DISTTOC\cdot NP
\end{align*} \]

*****************************************************************************

* * This function computes the norm of a vector * *
* *****************************************************************************

REAL*8 FUNCTION NORME(A,B,C)
IMPLICIT NONE
REAL*8 A,B,C
NORME=SQRT(A*A+B*B+C*C)
END

*****************************************************************************

* * This function computes the dot product between two vectors * *
* *****************************************************************************

REAL*8 FUNCTION DOTP(A1,B1,C1,A2,B2,C2)
IMPLICIT NONE
REAL*8 A1,B1,C1,A2,B2,C2
END

*****************************************************************************

* * THIS SUBROUTINE FINDS THE ROOTS OF A SECOND ORDER POLYNOMIAL. THIS * *
* IS USED TO FIND THE Z-COORDINATE OF A POSSIBLE NEW POINT HIT BY A * *
* BUNDLE. THE SOLUTION CAN NOT BE THE PREVIOUS POINT HIT BY THE BUNDLE * *
* AND NOT BE OUT OF THE FOV LIMITER IF THE BUNDLE WAS SHOT FROM THE * *
* IMAGINARY TOP SURFACE. * *
* *****************************************************************************

SUBROUTINE POL2 (R,P,Q,SOLPLU,SOLMIN,ROOTS)

IMPLICIT NONE
REAL*8 R,P,Q,DDELTA,SOLPLU,SOLMIN
LOGICAL ROOTS
ROOTS=.TRUE.
DDELTA=P*P-4.D0*R*Q
IF (DDELTA .GT. 0.D0) THEN
   SOLPLU=(-P+DSQRT(DDELTA))/(2.D0*R)
   SOLMIN=(-P-DSQRT(DDELTA))/(2.D0*R)
ELSE IF (DDELTA .EQ. 0.D0) THEN
   SOLPLU=(-P+DSQRT(DDELTA))/(2.D0*R)
   SOLMIN=SOLPLU
ELSE
   ROOTS=.FALSE.
   SOLPLU=-1.0D0
   SOLMIN=-1.0D0
END IF
END
* THIS SUBROUTINE FINDS THE POSSIBLE POINTS THAT WOULD BE AT THE INTER-
* SECTION OF THE FOV LIMITER SURFACE AND THE LINE REPRESENTING THE DI-
* RECTION OF THE BUNDLE. THE NUMBER OF POINTS CAN BE 0, 1, OR 2.
* *
* ***********************************************************************

SUBROUTINE FOVLIM (X1,Y1,Z1,L,M,N,X2,Y2,Z2,MAGNV,INORM, &
& HITTEN,EXIT)

IMPLICIT NONE
REAL*8 X1,Y1,Z1,L,M,N,X2,Y2,Z2,R,P,Q,MAGNV,PI,TETAFM
REAL*8 INORM,RFOV,ZMAX,NORME,SOLPLU,SOLMIN
REAL*8 REXT,RINT,DENIV
LOGICAL HITTEN,EXIT,ROOTS
DIMENSION MAGNV(15),HITTEN(15),X2(15),Y2(15),Z2(15),INORM(15,3)
EXTERNAL NORME
COMMON /FOVL/ RFOV,TETAFM
COMMON /DOME/ REXT,RINT,DENIV

PI=DACOS(-1.0D0)
ZMAX=RFOV*DCOS(TETAFM)+DENIV
HITTEN(1)=.FALSE.
HITTEN(5)=.FALSE.
EXIT=.FALSE.

R=L*L+M*M+N*N
P=2.0D0*(L*X1+M*Y1+N*Z1-N*DENIV)
Q=X1*X1+Y1*Y1+Z1*Z1-RFOV*RFOV-2*Z1*DENIV+DENIV*DENIV
CALL POL2(R,P,Q,SOLPLU,SOLMIN,ROOTS)

C CHECK IF THE FOV LIMITER WAS HIT AT ALL
C IF (.NOT.ROOTS) RETURN
C ELSE COMPUTE THE POSSIBLE POINTS OF INTERSECTION
C
Z2(1)=SOLPLU*N+Z1
Z2(5)=SOLMIN*N+Z1
C Z2(1) IS CONSIDERED ONLY IF GREATER THAN 0.0
C IF (Z2(1).GT.0.0D0) THEN
X2(1)=SOLPLU*L+X1
Y2(1)=SOLPLU*M+Y1
C THE POINT P2(X2,Y2,Z2) IS ACCEPTED IF NOT EQUAL TO Z1
C IF (.NOT.(DABS(X2(1)-X1).LT.1.0D-06.AND.DABS(Y2(1)-Y1).LT.1.0D-06 &
& .AND.DABS(Z2(1)-Z1).LT.1.0D-06)) THEN
HITTEN(1)=.TRUE.
INORM(1,1)=-X2(1)/RFOV
INORM(1,2)=-Y2(1)/RFOV
INORM(1,3)=-(Z2(1)-DENIV)/RFOV
MAGNV(1)=NORME(X2(1)-X1,Y2(1)-Y1,Z2(1)-Z1)
IF (Z2(1).GT.ZMAX) EXIT=.TRUE.
END IF
END IF
C Z2(5) IS CONSIDERED ONLY IF GREATER THAN 0.0
C IF (Z2(5).GT.0.0D0) THEN
X2(5)=SOLMIN*L+X1
Y2(5)=SOLMIN*M+Y1

Program ERBERT
C THE POINT P2(X2, Y2, Z2) IS ACCEPTED IF NOT EQUAL TO Z1 C
    IF (.NOT. (DABS(X2(5) - X1).LT.1.0D-06 .AND. DABS(Y2(5) - Y1).LT.1.0D-06
      .AND. DABS(Z2(5) - Z1).LT.1.0D-06)) THEN
      HITTEN(5) = .TRUE.
      INORM(5, 1) = -X2(5)/RFOV
      INORM(5, 2) = -Y2(5)/RFOV
      INORM(5, 3) = -(Z2(5) - DENIV)/RFOV
      MGNIV(5) = NORME*(X2(5) - X1, Y2(5) - Y1, Z2(5) - Z1)
      IF (Z2(5) .GT. ZMAX) EXIT = .TRUE.
    END IF
  END IF
END

*********************************************************************************************

* SUBROUTINE SUBSTR(X1, Y1, Z1, L, M, N, X2, Y2, Z2, MAGNV, INORM,
  & HITTEN, ENTER)

IMPLICIT NONE
REAL*8 X1, Y1, Z1, L, M, N, X2, Y2, Z2, CARRE, MAGNV, INORM
REAL*8 RFOV, RPA, NORME, PI, TETAFM, REXT, RINT, DENIV
INTEGER SURFC
LOGICAL HITTEN, ENTER
DIMENSION MAGNV(15), INORM(15), X2(15), Y2(15), Z2(15), NORM(15, 3)
EXTERNAL NORME
COMMON /FOVL/ RFOV, TETAFM
COMMON /SUBS/ RPA, SURFC
COMMON /DOME/ REXT, RINT, DENIV

C INITIALIZE CONSTANTS AND VARIABLES

PI = DACOS(-1.0D0)
HITTEN(2) = .FALSE.
HITTEN(6) = .FALSE.
ENTER = .FALSE.

C COORD. OF THE POINT THAT WOULD HIT THE UPPER PART OF THE SUBSTRATE

Z2(2) = 0.0D0
Y2(2) = (Z2(2) - Z1)*M/N + Y1
X2(2) = (Z2(2) - Z1)*L/N + X1
CARRE = X2(2)*X2(2) + Y2(2)*Y2(2)

C THE SOLUTION IS ACCEPTED IF ON DEFINED DISC (R1<=R<=R2)

IF (CARRE.GT.(REXT*REXT-DENIV*DENIV).AND.CARRE.LT.(RFOV*RFOV-
  & DENIV*DENIV)) THEN
C THE SOLUTION IS ACCEPTED IF NOT EQUAL TO P1

IF (.NOT. (DABS(X2(2) - X1).LT.1.0D-06 .AND. DABS(Y2(2) - Y1).LT.1.0D-06
  .AND. DABS(Z2(2) - Z1).LT.1.0D-06)) THEN

Program ERBERT 164
C IF THE BUNDLE DOES HIT THE UPPER PART OF THE SUBSTRATE

HITENN(2) = .TRUE.
MAGNV(2) = NORME(X2(2) - X1, Y2(2) - Y1, Z2(2) - Z1)
INORM(2, 1) = 0.0D0
INORM(2, 2) = 0.0D0
INORM(2, 3) = 1.0D0
END IF
END IF

COORD. OF THE POINT THAT WOULD HIT THE LOWER PART OF THE SUBSTRATE

Z2(6) = DENIV
Y2(6) = (Z2(6) - Z1) * M/N + Y1
X2(6) = (Z2(6) - Z1) * L/N + X1
CARRR = X2(6) * X2(6) + Y2(6) * Y2(6)

C THE SOLUTION IS ACCEPTED IF ON DEFINED DISC (RPA <= R <= R1)

IF (CARRR.GT.(RPA*RPA) .AND. CARRR.LT.(REXT*REXT)) THEN

C THE SOLUTION IS NOT ACCEPTED IF EQUAL TO P1

IF (.NOT.(DABS(X2(6) - X1).LT.1.0D-06 .AND. DABS(Y2(6) - Y1).LT.1.0D-06
& .AND. DABS(Z2(6) - Z1).LT.1.0D-06)) THEN

C IF THE BUNDLE DOES HIT THE LOWER PART OF THE SUBSTRATE

HITENN(6) = .TRUE.
MAGNV(6) = NORME(X2(6) - X1, Y2(6) - Y1, Z2(6) - Z1)
INORM(6, 1) = 0.0D0
INORM(6, 2) = 0.0D0
INORM(6, 3) = 1.0D0
END IF
END IF

* WRITE(16,*) 'IF THE SURFACE IS CHOSEN THE BUNDLE ENTERS THE CAVITY'

C ALSO CHECK IF THE BUNDLE ENTERS THE CAVITY

IF (CARRR.LE.(RPA*RPA)) THEN
  HITENN(6) = .FALSE.
END IF
END

******************************************************************************

* THIS SUBROUTINE FINDS THE POSSIBLE POINTS THAT WOULD BE AT THE INTER-
* SECTION OF ONE SURFACE OF THE DOME AND THE LINE REPRESENTING THE
* DIRECTION OF THE BUNDLE. THE NUMBER OF POINTS CAN BE 0, 1, OR 2.
******************************************************************************

SUBROUTINE SPHERE(X1, Y1, Z1, L, M, N, X2, Y2, Z2, NO, MAGNV, INORM, &
  HITENN)

IMPLICIT NONE
REAL*8 X1, Y1, Z1, L, M, N, X2, Y2, Z2, A, B, C, RAD, R, P, Q, MAGNV
REAL*8 INORM, NORME, REXT, RINT, DENIV, SOLPLU, SOLMIN
LOGICAL HITENN, ROOTS
DIMENSION MAGNV(15), HITENN(15), RAD(15), X2(15), Y2(15)
DIMENSION X2(15), A(15), B(15), C(15), INORM(15), 3
INTEGER NO
EXTERNAL NORME
COMMON /DOME/, REXT, RINT, DENIV
DATA A, B, C, /45*0.0D0/
RAD(3)=REXT
RAD(4)=RINT
C(3)=DENIV
C(4)=DENIV
HITTEN(NO)=.FALSE.
HITTEN(NO+4)=.FALSE.

c
R=1.D0*((L/N)*(L/N)+(M/N))*(M/N)
P=2.D0*((X1-A(NO))*L/N+(Y1-B(NO))*M/N-Z1*((L/N)*(L/N)
&+(M/N)*(M/N))-C(NO))
Q=(Z1*L/N-X1)*(Z1*L/N-X1)+(Z1*M/N-Y1)*(Z1*M/N-Y1)
&+2.D0*A(NO)*((Z1*L/N-X1)+2.D0*B(NO)*((Z1*M/N-Y1)
&+A(NO)*A(NO)+B(NO)*B(NO)+C(NO)*C(NO)-RAD(NO)*RAD(NO)

c
CALL POL2(R,P,Q,SOLPLU,SOLMIN,ROOTS)

c
CHECK IF THE DOME WAS HIT AT ALL

c
IF (.NOT.ROOTS) RETURN

c
ELSE COMPUTE THE POSSIBLE POINTS OF INTERSECTION

c
Z2(NO)=SOLPLU
Z2(NO+4)=SOLMIN

c
IF THE Z-COORDINATE Z2(NO) IS GREATER THAN DENIV X & Y ARE COMPUTED

c
IF (Z2(NO).GT.DENIV) THEN
   X2(NO)=(Z2(NO)-Z1)*L/N+X1
   Y2(NO)=(Z2(NO)-Z1)*M/N+Y1

c
POINT P2(X2,Y2,Z2) IS ACCEPTED IF NOT EQUAL TO P1(X1,Y1,Z1)

c
IF (.NOT. (DABS(X2(NO)-X1).LT.1.0D-06 AND DABS(Y2(NO)-Y1).LT.
& 1.0D-06 AND DABS(Z2(NO)-Z1).LT.1.0D-06)) THEN
   HITTEN(NO)=.TRUE.

c
IF NOT REJECTED THE VECTOR NORMAL TO THE SURFACE AT P2, AND THE
C DISTANCE P1P2 ARE COMPUTED

c
INORM(NO,1)=-(X2(NO)-A(NO))/RAD(NO)
INORM(NO,2)=-(Y2(NO)-B(NO))/RAD(NO)
INORM(NO,3)=-(Z2(NO)-C(NO))/RAD(NO)
MAGHV(NO)=NORME(X2(NO)-X1,Y2(NO)-Y1,Z2(NO)-Z1)
END IF
ENDE IF

c
IF THE Z-COORDINATE Z2(NO+4) IS GREATER THAN DENIV X & Y ARE COMPUTED

c
IF (Z2(NO+4).GT.DENIV) THEN
   X2(NO+4)=(Z2(NO+4)-Z1)*L/N+X1
   Y2(NO+4)=(Z2(NO+4)-Z1)*M/N+Y1

c
POINT P2(X2,Y2,Z2) IS ACCEPTED IF NOT EQUAL TO P1(X1,Y1,Z1)

c
IF (.NOT. (DABS(X2(NO+4)-X1).LT.1.0D-06 AND DABS(Y2(NO+4)-Y1).LT.
& 1.0D-06 AND DABS(Z2(NO+4)-Z1).LT.1.0D-06)) THEN
   HITTEN(NO+4)=.TRUE.

c
IF NOT REJECTED THE VECTOR NORMAL TO THE SURFACE AT P2, AND THE
C DISTANCE P1P2 ARE COMPUTED
C
INORM(NO+4,1)=-(X2(NO+4)-A(NO))/RAD(NO)
INORM(NO+4,2)=-(Y2(NO+4)*B(NO))/RAD(NO)
INORM(NO+4,3)=-(Z2(NO+4)*C(NO))/RAD(NO)
MAGNV(NO+4)=NORME(X2(NO+4)-X1,Y2(NO+4)-Y1,Z2(NO+4)-Z1)
END IF
END IF
END

***********************************************************************
* * This subroutine finds the possible points that would be at the * *
* intersection of the barrel and the line representing the * *
* direction of the bundle. The number of point can be 0, 1, or 2. * *
***********************************************************************

SUBROUTINE BARREL (X1,Y1,Z1,L,M,N,X2,Y2,Z2,MAGNV,INORM,HITTEN)

IMPLICIT NONE
REAL*8 X1,Y1,Z1,L,M,N,X2,Y2,Z2,R,P,Q,MAGNV,NORME
REAL*8 INORM,RCAV,LBAR,SOLPLU,SOLMIN,LCAV,LCON,CAVANG
REAL*8 REXT,RINT,DENIV
LOGICAL HITTEN,ROOTS
DIMENSION MAGNV(15),HITTEN(15),X2(15),Y2(15),Z2(15),INORM(15,3)
EXTERNAL NORME
COMMON/CAVITY/RCAV,LBAR,LCON,CAVANG
COMMON /DOME/REXT,RINT,DENIV

HITTEN(9)=.FALSE.
HITTEN(10)=.FALSE.

R=L*L+M*M
P=2.0D0*(X1*L+Y1*M)
Q=X1*X1+Y1*Y1-RCAV*RCAV

CALL POL2(R,P,Q,SOLPLU,SOLMIN,ROOTS)
C CHECK IF THE BARREL WAS HIT AT ALL
C IF(.NOT.ROOTS) RETURN
C ELSE COMPUTE THE POINTS OF INTERSECTION
Z2(9)=SOLPLU*N+Z1
Z2(10)=SOLMIN*N+Z1
C Z2(9) IS CONSIDERED ONLY IF BETWEEN -(LBAR + DENIV) AND -DENIV
C IF ((DENIV-LBAR).LE.Z2(9).AND.Z2(9).LE.DENIV) THEN
X2(9)=SOLPLU*L+X1
Y2(9)=SOLPLU*M+Y1
C THE POINT P2(X2,Y2,Z2) IS ACCEPTED IF NOT EQUAL TO P1
C IF (.NOT.(DABS(X2(9)-X1).LT.1.0D-06.AND.DABS(Y2(9)-Y1).LT.1.0D-06
& .AND.DABS(Z2(9)-Z1).LT.1.0D-06)) THEN
HITTEN(9)=.TRUE.
INORM(9,1)=-1.0D0*X2(9)/RCAV
INORM(9,2)=-1.0D0*Y2(9)/RCAV
INORM(9,3)=0.0D0
MAGNV(9)=NORME(X2(9)-X1,Y2(9)-Y1,Z2(9)-Z1)
END IF
END IF

Program ERBERT
C Z2(10) IS ONLY CONSIDERED IF BETWEEN -(LBAR + DENIV) AND -DENIV
C
IF ((DENIV-LBAR) .LE. Z2(10) .AND. Z2(10) .LE. DENIV) THEN
   X2(10)=SOLMIN*L+X1
   Y2(10)=SOLMIN*M+Y1
C
C THE POINT P2(X2,Y2,Z2) IS ACCEPTED IF NOT EQUAL TO P1
C
IF (.NOT.(DABS(X2(10)-X1).LT.1.0D-06 .AND. DABS(Y2(10)-Y1).LT.
   & 1.0D-06 .AND. DABS(Z2(10)-Z1).LT.1.0D-06)) THEN
   HITTEN(10)=.TRUE.
   INORM(10,1)=-1.0D0*X2(10)/RCAV
   INORM(10,2)=-1.0D0*Y2(10)/RCAV
   INORM(10,3)=0.0D0
   MAGNV(10)=NORME(X2(10)-X1,Y2(10)-Y1,Z2(10)-Z1)
END IF
END IF
END

***********************************************************************
This subroutine finds the possible points that would be at the
intersection of the cone and the line representing the direction
of the bundle. The number of points can be 0, 1, or 2.
***********************************************************************

SUBROUTINE CONE(X1,Y1,Z1,L,M,N,X2,Y2,Z2,MAGNV,INORM,HITTEN)

IMPLICIT NONE
REAL*8 X1,Y1,Z1,L,M,N,X2,Y2,Z2,MAGNV,INORM
REAL*8 RCAV,LCON,CAVANG,C,P,Q,R,SOLPLU,SOLMIN,NORME
REAL*8 LCAV,LBAR,DENIV,REXT,RINT,TANCAV

LOGICAL HITTEN,ROOTS
DIMENSION MAGNV(15),HITTEN(15),X2(15),Y2(15),Z2(15),INORM(15,3)
EXTERNAL NORME,COMMON /CAVITY/RCAV,LBAR,LCON,CAVANG,
COMMON /DOME/REXT,RINT,DENIV

HITTEN(11)=.FALSE.
HITTEN(12)=.FALSE.
C=DENIV-LBAR
LCAV=-1.0D0*(LBAR+LCON-DENIV)
TANCAV=RCAV/LCON

R=L*L+M*M-N*N*TANCAV*TANCAV
P=2.0D0*(L*X1+M*Y1+N*TANCAV*TANCAV*(LCAV-Z1))
Q=(X1*X1+Y1*Y1+TANCAV*TANCAV*(2.0D0*LCAV*Z1-LCAV+LCAV-Z1)+Z1)

CALL POL2(R,P,Q,SOLPLU,SOLMIN,ROOTS)

C CHECK TO SEE IF THE CONE WAS HIT AT ALL
C
IF (.NOT. ROOTS) RETURN
C
C ELSE COMPUTE THE POSSIBLE POINTS OF INTERSECTION
C
   Z2(11)=SOLPLU*N+Z1
   Z2(12)=SOLMIN*N+Z1
C
C Z2(11) IS CONSIDERED ONLY IF BETWEEN -(LCON+LBAR-DENIV) AND
C -(LBAR+DENIV)

Program ERBET 168
IF ((LCAV) .LE. Z2(11) .AND. Z2(11) .LT. C) THEN
  X2(11) = SOLPLU*1 + X1
  Y2(11) = SOLPLU*M + Y1
END IF

THE POINT P2(X2, Y2, Z2) IS ACCEPTED IF NOT EQUAL TO P1

IF (.NOT. (DABS(X2(11) - X1) .LT. 1.0D-06 .AND. DABS(Y2(11) - Y1) .LT. 1.0D-06)) THEN
  HIDDEN(11) = .TRUE.
  INCRM(11, 1) = -1.0D*(X2(11)/(DSQRT(X2(11)**2 + Y2(11)**2)))**DCOS(CAVANG)
  &
  INORM(11, 2) = -1.0D*(Y2(11)/(DSQRT(X2(11)**2 + Y2(11)**2)))**DCOS(CAVANG)
  &
  INORM(11, 3) = DSIN(CAVANG)
  MAGNV(11) = NORME(X2(11) - X1, Y2(11) - Y1, Z2(11) - Z1)
END IF
END IF

Z2(12) IS CONSIDERED ONLY IF BETWEEN -(LCON + LBAR - DENV) AND
-(LBAR + DENV)

IF ((LCAV) .LE. Z2(12) .AND. Z2(12) .LT. C) THEN
  X2(12) = SOLMIN*L + X1
  Y2(12) = SOLMIN*M + Y1
END IF

THE POINT P2(X2, Y2, Z2) IS ACCEPTED IF NOT EQUAL TO P1

IF (.NOT. (DABS(X2(12) - X1) .LT. 1.0D-06 .AND. DABS(Y2(12) - Y1) .LT. 1.0D-06)) THEN
  HIDDEN(12) = .TRUE.
  INORM(12, 1) = -1.0D*(X2(12)/(DSQRT(X2(12)**2 + Y2(12)**2)))**DCOS(CAVANG)
  &
  INORM(12, 2) = -1.0D*(Y2(12)/(DSQRT(X2(12)**2 + Y2(12)**2)))**DCOS(CAVANG)
  &
  INORM(12, 3) = DSIN(CAVANG)
  MAGNV(12) = NORME(X2(12) - X1, Y2(12) - Y1, Z2(12) - Z1)
END IF
END IF
END

*******************************************************************************
*  THIS SUBROUTINE FINDS THE POSSIBLE POINT THAT WOULD BE AT THE            *
*  INTERSECTION OF THE PORTION OF THE SUBSTRATE WHICH IS VISIBLE TO         *
*  THE CAVITY AND THE LINE REPRESENTING THE PATH OF THE BUNDLE              *
*******************************************************************************

SUBROUTINE CAVSUB(X1, Y1, Z1, L, M, N, X2, Y2, Z2, MAGNV, INORM,       *
  HIDDEN, EXITCAV, EXCAV)

IMPLICIT NONE
REAL*8 X1, Y1, Z1, L, M, N, X2, Y2, Z2, MAGNV, INORM, CARRE
REAL*8 RFOV, RPA, NORME, PI, TETAFM, REXT, RINT, DENV, RCAV
REAL*8 LBAR, LCON, CAVANG
INTEGER SURFAC, EXCAV
LOGICAL HIDDEN, ENTER, EXITCAV
DIMENSION MAGNV(15), HIDDEN(15), X(15), Y(15), Z(15), INCRM(15, 3)
EXTERNAL NORME
COMMON /FOVL/ RFOV, TETAFM
COMMON /SUBS/ RPA, SURFAC
COMMON /DOME/ REXT, RINT, DENV
COMMON /CAVITY/ RCAV, LBAR, LCON, CAVANG

Program ERBERT 169
INITIALIZE CONSTANTS AND VARIABLES
PI=DACOS(-1.D0)
HIT1EN(13)=.FALSE.
EXITCAV=.FALSE.

COORD. OF THE POINT THAT WOULD HIT THE DISC VISIBLE TO THE CAVITY
Z2(13)=DEN1IV
Y2(13)=(Z2(13)-Z1)*M/N+Y1
X2(13)=(Z2(13)-Z1)*L/N+X1
CARRB=DSQRT(X2(13)*X2(13)+Y2(13)*Y2(13))

THE SOLUTION IS ACCEPTED IF ON DEFINED DISC (RPA<=k<=RCAV)
IF (CARRB.GT.(RPA).AND.CARRB.LE.(RCAV)) THEN

THE SOLUTION IS NOT ACCEPTED IF EQUAL TO P1
IF (.NOT.((DABS(X2(13)-X1).LT.1.0D-06).AND.(DABS(Y2(13)-Y1)
& .LT.1.0D-06).AND.(DABS(Z2(13)-Z1).LT.1.0D-06)) THEN

IF THE BUNDLE DOES HIT THE DISC FACING THE CAVITY
HIT1EN(13)=.TRUE.
MAGNV(13)=NORME(X2(13)-X1,Y2(13)-Y1,Z2(13)-Z1)
INORM(13,1)=0.0D0
INORM(13,2)=0.0D0
INORM(13,3)=-1.0D0
END IF

IF THE BUNDLE LEAVES THE CAVITY
IF (CARRB.LE.(RPA)) THEN
HIT1EN(13)=.FALSE.
EXITCAV=.TRUE.
EXCAV=EXCAV+1
END IF

******************************************************************************
* This subroutine finds the possible points that would be at the intersection of the ring and the line representing the direction of the bundle. The number of points can be 0, 1, or 2. *
******************************************************************************

SUBROUTINE RING (X1,Y1,Z1,L,M,N,X2,Y2,Z2,MAGNV,INORM,HIT1EN)
IMPLICIT NONE
REAL*8 X1,Y1,Z1,L,M,N,X2,Y2,Z2,R,P,Q,MAGNV,NORME
REAL*8 INORM,SOLPLU,SOLMIN
REAL*8 REXT,RINT,DEN1IV
LOGICAL HIT1EN
DIMENSION MAGNV(15),HIT1EN(15),X2(15),Y2(15),Z2(15),INORM(15,3)
EXTERNAL NORME
COMMON /DOMES/REXT,RINT,DEN1IV
HIT1EN(14)=.FALSE.
HIT1EN(15)=.FALSE.
R=L*L+M*M+N*N

Program ERBERT

170
P = 2.0D0*(X1*L+Y1*M+N*Z1-N*DENIV)
Q = X1*X1+Y1*Y1+Z1*Z1-REXT*REXT-2*Z1*DENIV-DENIV*DENIV

CALL PCL2(R,P,Q,SOLPLU,SOLMIN,ROOTS)

C CHECK IF THE RING WAS HIT AT ALL
C IF (.NOT.ROOTS) THEN
   RETURN
END IF
C ELSE COMPUTE THE POINTS OF INTERSECTION
C Z2(14) = SOLPLU*N+Z1
Z2(15) = SOLMIN*N+Z1
C Z2(14) IS CONSIDERED ONLY IF BETWEEN 0.0D0 AND DENIV
C IF ((DENIV) .LE. Z2(14) .AND. Z2(14) .LE. 0.0D0) THEN
   X2(14) = SOLPLU*L+X1
   Y2(14) = SOLPLU*M+Y1
C THE POINT P2(X2,Y2,Z2) IS ACCEPTED IF NOT EQUAL TO P1
C IF (.NOT.(DABS(X2(14)-X1).LT.1.0D-06 .AND. DABS(Y2(14)-Y1).LT. & 1.0D-06 .AND. DABS(Z2(14)-Z1).LT.1.0D-06)) THEN
   HITTEN(14) = .TRUE.
   INORM(14,1) = X2(14)/REXT
   INORM(14,2) = Y2(14)/REXT
   INORM(14,3) = (-Z2(14)-DENIV)/REXT
   MAGNV(14) = NORME(X2(14)-X1,Y2(14)-Y1,Z2(14)-Z1)
END IF
C Z2(15) IS ONLY CONSIDERED IF BETWEEN 0.0D0 AND DENIV
C IF ((DENIV) .LE. Z2(15) .AND. Z2(15) .LE. 0.0D0) THEN
   X2(15) = SOLMIN*L+X1
   Y2(15) = SOLMIN*M+Y1
C THE POINT P2(X2,Y2,Z2) IS ACCEPTED IF NOT EQUAL TO P1
C IF (.NOT.(DABS(X2(15)-X1).LT.1.0D-06 .AND. DABS(Y2(15)-Y1).LT. & 1.0D-06 .AND. DABS(Z2(15)-Z1).LT.1.0D-06)) THEN
   HITTEN(15) = .TRUE.
   INORM(15,1) = X2(15)/REXT
   INORM(15,2) = Y2(15)/REXT
   INORM(15,3) = (-Z2(15)+DENIV)/REXT
   MAGNV(15) = NORME(X2(15)-X1,Y2(15)-Y1,Z2(15)-Z1)
END IF
END IF
END

*********************************************************************
* THIS SUBROUTINE DETERMINES WHETHER A BUNDLE IS ABSORBED OR REFLECTED *
* WHEN IT IS FOUND TO HAVE HIT THE FOV LIMITER OR THE SUBSTRATE      *
*********************************************************************

SUBROUTINE REFOAB(L,M,N,X,Y,Z,INORM,SURFAC,ABSOR,REFL,DIFUS)

IMPLICIT NONE
REAL*8 L,M,N,INORM,PI,RS,X,Y,Z,RDM,ALPHA,ROSPEC,RODIFF

Program ERBERT
REAL*8 ALPHA1, ALPHA2, ALPHA9, ALPHA11, ALPHA13, ALPHA14
REAL*8 ROSPEC1, ROSPEC2, ROSPEC9, ROSPEC11, ROSPEC13, ROSPEC14
REAL*8 RODIFF1, RODIFF2, RODIFF9, RODIFF11, RODIFF13, RODIFF14

C
DIMENSION INORM(15,3)
C
INTEGER SURFAC
INTEGER CNTRDM
C
LOGICAL ABSOR, REFL, DIFUS
C
COMMON /RAND/ CNTRDM
COMMON /REAB/ ALPHA1, ALPHA2, ALPHA9, ALPHA11, ALPHA13, ALPHA14,
&           ROSPEC1, ROSPEC2, ROSPEC9, ROSPEC11, ROSPEC13, ROSPEC14,
&           RODIFF1, RODIFF2, RODIFF9, RODIFF11, RODIFF13, RODIFF14

PI=DACOS(-1.0D0)

C
SET THE FLAGS TO FALSE
C
ABSOR=.FALSE.
REFL=.FALSE.
DIFUS=.FALSE.
C
IF CURRENT SURFACE IS THE FOV LIMITER SET ITS PROPERTIES TO BE CURRENT
C
IF (SURFAC.EQ.1.OR.SURFAC.EQ.5) THEN
    ALPHA=ALPHA1
    ROSPEC=ROSPEC1
    RODIFF=RODIFF1
C
IF CURRENT SURFACE IS THE SUBSTRATE SET ITS PROPERTIES TO BE CURRENT
C
ELSE IF (SURFAC.EQ.2.OR.SURFAC.EQ.6) THEN
    ALPHA=ALPHA2
    ROSPEC=ROSPEC2
    RODIFF=RODIFF2
C
IF CURRENT SURFACE IS THE BARREL SET ITS PROPERTIES TO BE CURRENT
C
ELSE IF (SURFAC.EQ.9.OR.SURFAC.EQ.10) THEN
    ALPHA=ALPHA9
    ROSPEC=ROSPEC9
    RODIFF=RODIFF9
C
IF CURRENT SURFACE IS THE CONE SET ITS PROPERTIES TO BE CURRENT
C
ELSE IF (SURFAC.EQ.11.OR.SURFAC.EQ.12) THEN
    ALPHA=ALPHA11
    ROSPEC=ROSPEC11
    RODIFF=RODIFF11
C
IF CURRENT SURFACE IS CAVSUB SET ITS PROPERTIES TO BE CURRENT
C
ELSE IF (SURFAC.EQ.13) THEN
    ALPHA=ALPHA13
    ROSPEC=ROSPEC13
    RODIFF=RODIFF13
C
IF CURRENT SURFACE IS RING SET ITS PROPERTIES TO BE CURRENT
C
ELSE IF (SURFAC.EQ.14.OR.SURFAC.EQ.15) THEN
    ALPHA=ALPHA14
    ROSPEC=ROSPEC14
    RODIFF=RODIFF14
ELSE
   WRITE(06,*)'CASE IGNORED IN REFLECTION!!!'
   STOP
END IF
RS = ROSPEC / (ROSPEC + RODIFF)

C GET A RANDOM NUMBER TO SELECT BETWEEN ABSORPTION AND REFLECTION
C
   CALL DRNUN(1, RDM)
   CNTRDM = CNTRDM + 1

C IF THE RANDOM NUMBER IS LESS THAN ALPHA, THE BUNDLE IS ABSORBED
C
   IF (RDM .LE. ALPHA) THEN
      ABSOR = .TRUE.
   END IF

C IF THE RANDOM NUMBER IS GREATER THAN ALPHA, THE BUNDLE IS REFLECTED
C
   ELSE
   END IF

C GET A RANDOM NUMBER TO SELECT BETWEEN SPECULAR AND DIFFUSE REFLECTION
C
   CALL DRNUN(1, RDM)
   CNTRDM = CNTRDM + 1

C IF THE RANDOM NUMBER IS LESS THAN RS, THE BUNDLE IS SPECULARLY REFLECTED
C
   IF (RDM .LE. RS) THEN
      CALL REFLEX(L, M, N, INORM, SURFACE)
      REFL = .TRUE.
   END IF

C IF THE RANDOM NUMBER IS GREATER THAN RS, THE BUNDLE IS DIFFUSELY REFLECTED
C
   ELSE
      CALL DIFEMI(L, M, N, X, Y, Z, SURFACE)
      DIFUSE = .TRUE.
   END IF
END

*******************************************************************************
* THIS SUBROUTINE DETERMINES WHETHER A BUNDLE IS TRANSMITTED OR REFLECTED WHEN IT IS FOUND TO HAVE HIT THE DOME
*******************************************************************************

SUBROUTINE REFOTR(L, M, N, INORM, SURFACE, REFL, TRANS, INDOME)
IMPLICIT NONE
REAL*8 L, M, N, INORM
REAL*8 R
DIMENSION INORM(15, 3)
INTEGER SURFACE, CNTRBW, CHANEL
LOGICAL ABSOR, REFL, TRANS, OK, INDONE
COMMON /COUN/ CNTRBW, CHANEL

C SET FLAGS TO FALSE
C
   OK = .FALSE.
   ABSOR = .FALSE.
   REFL = .FALSE.
   TRANS = .FALSE.

C CALL ROUTINE WHICH WILL FIND THE NEW DIR. COSINES AFTER TRANSMISSION
C
   CALL TRANSM(L, M, N, INORM, SURFACE, INDOME, OK)
C IF THE ANGLE OF INCIDENCE IS SUCH THAT THE RAY CAN NOT GO THRU THE
C INTERFACE DOME/VACUUM, THE RAY IS REFLECTED SPECULARLY.
C
IF (.NOT.OK) THEN
  CNTBWR=CNTBWR+1
  CALL REFLEX(L,M,N,INORM,SURFAC)
  REFL=.TRUE.
ELSE
  TRANS=.TRUE.
  IF (INDOME) THEN
    INDOM=.FALSE.
  ELSE
    INDOM=.TRUE.
  END IF
END IF
END

******************************************************************************
* *
* THIS SUBROUTINE CALCULATES THE NEW DIRECTION COSINES AFTER A REFLEXION OCCURRED ON THE FOV LIMITER OR SUBTRATE *
* *
******************************************************************************
SUBROUTINE REFLEX(L,M,N,INORM,SURFAC)
IMPLICIT NONE
REAL*8 L,M,N,INORM,PI,N1,N2,N3,LP,MP,NP,KA
INTEGER SURFAC
DIMENSION INORM(15,3)

PI=DACOS(-1.0D0)
N1=INORM(SURFAC,1)
N2=INORM(SURFAC,2)
N3=INORM(SURFAC,3)
KA=L*N1+M*N2+N*N3
LP=L-2.0D0*KA*N1
MP=M-2.0D0*KA*N2
NP=N-2.0D0*KA*N3
L=LP
M=MP
N=NP
END

******************************************************************************
* *
* THIS SUBROUTINE CALCULATES THE NEW DIRECTION COSINES WHEN TRANSMNSSION OCCURS THROUGH THE FILTER DOME *
* *
******************************************************************************
SUBROUTINE TRANSM(L,M,N,INORM,SURFAC,INDOME,OK)
IMPLICIT NONE
REAL*8 L,M,N,INORM,RIND1,RIND2,N1,N2,N3,KA,KB,KC,KD,LP,MP,NP
REAL*8 TETA1,TETA2,IVAC,IDOM,TAMPON
INTEGER IS,SURFAC,CHANEL
PARAMETER (IS=15)
DIMENSION INORM(15,3)
LOGICAL OK,INDOME
COMMON /TRAN/ IVAC,IDOM
COMMON /CHANNEL/ CHANEL
OK=.FALSE.
C Assign the correct indices of refraction according to whether
C the bundle is inside or outside the dome
C
IF (INDOME) THEN
   RIND1 = IDOM
   RIND2 = IVAC
ELSE
   RIND1 = IVAC
   RIND2 = IDOM
END IF
C Compute the angle of transmission in the transmission plan
C
N1=INORM(SURFAC,1)
N2=INORM(SURFAC,2)
N3=INORM(SURFAC,3)
KA=L*N1+M*N2+N*N3
IF (DABS(KA).GT.1.0D0) THEN
   IF (DABS(DABS(KA)-1.0D0).*LT.1.0D-04) THEN
      KA=1.0D0
   ELSE
      WRITE(16,*)'PB AVEC KA DANS TRANS'
      WRITE(16,*)L,M,N,N1,N2,N3
   END IF
END IF
KD=KIND1/RIND2
TETA1=DACOS(ABS(KA))
C CHECK IF TETA1 IS LARGER THAN THE BREWSTER ANGLE
C
IF (KD.LE.1.0D0) THEN
   OK=.TRUE.
   TETA2=TASIN(KD)
   KA=DCOS(TETA2)/DCOS(TETA1)-RIND1/RIND2
   LF=RIND1/RIND2*L+KA*N1*KB
   MP=RIND1/RIND2*M+KA*N2*KB
   NP=RIND1/RIND2*N+KA*N3*KB
   L=LF
   M=MP
   N=NP
END IF
END

*******************************************************************************
** THIS SUBROUTINE GENERATES A RANDOM DIRECTION WHEN A DIFFUSE **
** REFLEXION OCCURS ON THE FOV LIMITER OR THE SUBSTRATE **
*******************************************************************************
SUBROUTINE DIFEMI(L,M,N,X,Y,Z,SURFAC)

IMPLICIT NONE
REAL*8 L,M,N,LP,MP,NP,X,Y,Z,PHILOC,TTLLOC,PI,RDM
REAL*8 RFQV,TETAFM,RADIUS
REAL*8 REXT,RINT,DENIV,DISTLOC
C INTEGER SURFAC
INTEGER CNTRDM
C
COMMON /RAND/ CNTRDM
COMMON /FOVL/ RFQV,TETAFM
COMMON /DOME/ REXT,RINT,DENIV

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PI=DACOS(-1.0D0)

C RANDOM EMISSION DIRECTION IN THE LOCAL COORD. SYSTEM
C
CALL DRNUN(1,RDM)
CNTRDM=CNTRDM+1
PHILOC=DSIN(DSQRTH(RDM))
CALL DRNUN(1,RDM)
CNTRDM=CNTRDM+1
TTALOC=2.0D0*PI*RDM

C COMPUTE THE SLOPE OF THE Emitted RAY IN THE LOCAL COORD. SYSTEM
C
LP=DSIN(PHILOC)*DCOS(TTALOC)
MP=DSIN(PHILOC)*DSIN(TTALOC)
NP=DCOS(PHILOC)

C IF EMISSION FROM THE FOV LIMITER
C
   IF (SURFAC.EQ.1.OR.SURFAC.EQ.5) THEN
C
   C TRANSFORMATION OF THE DIRECTION COSINES INTO GLOBAL COORD. SYSTEM
C
   L = -(X*Z/(RFOV*DSQRT(RFOV*RFOV-Z*Z)))*LP
   & +Y/DSQRT(RFOV*RFOV-Z*Z)*MP
   & +X/RFOV*NP
   M = -(Y*Z/(RFOV*DSQRT(RFOV*RFOV-Z*Z)))*LP
   & -X/DSQRT(RFOV*RFOV-Z*Z)*MP
   & +Y/RFOV*NP
   N = DSQRT(RFOV*RFOV-Z*Z)/RFOV*LP-Z/RFOV*NP

   C ELSE IF (SURFAC.EQ.2.OR.SURFAC.EQ.6) THEN
C
   C TRANSFORMATION OF THE DIRECTION COSINES INTO GLOBAL COORD. SYSTEM
C
   RADIUS=DSQRT(X*X+Y*Y)
   L = (X*LP-Y*MP)/RADIUS
   M = (Y*LP+X*MP)/RADIUS
   N = NP

   C ELSE IF (SURFAC.EQ.14.OR.SURFAC.EQ.15) THEN
C
   C TRANSFORMATION OF THE DIRECTION COSINES INTO GLOBAL COORD. SYSTEM
C
   DISTTOC=DSQRT(X*X+Y*Y+(Z-DENIV)*Z-DENIV))
   L = -(X*(Z-DENIV)/(DISTTOC*DSQRT(DISTTOC*DISTTOC - (Z-DENIV))*
   1 (Z-DENIV)))*LP + Y/DSQRT(DISTTOC*DISTTOC - (Z-DENIV))*
   2 (Z-DENIV))*MP + X/DISTTOC*NP
   M = -(Y*(Z-DENIV)/(DISTTOC*DSQRT(DISTTOC*DISTTOC - (Z-DENIV))*
   1 (Z-DENIV)))*LP - X/DSQRT(DISTTOC*DISTTOC - (Z-DENIV))*
   2 (Z-DENIV))*MP + Y/DISTTOC*NP
   N = DSQRT(DISTTOC*DISTTOC - (Z-DENIV)*(Z-DENIV))/DISTTOC*LP -
   1 (Z-DENIV)/DISTTOC*NP

   END IF

END

******************************************************************************
*                           * THIS SUBROUTINE INITIALIZES AN ARRAY OF SIZE 13  *
******************************************************************************

Program ERBERT

176
* *******************************************************
* 
* SUBROUTINE INIT(X)
* 
* IMPLICIT NONE
REAL*8 X
INTEGER I
DIMENSION X(15)

DO 284 I=1,15
  X(I)=0.0D0
284 CONTINUE

END

* *******************************************************
* 
* THIS SUBROUTINE SETS UP THE GEOMETRY FOR ALL SUBELEMENTS
* OF THE OPTICAL FRONT-END OF THE NONSCANNER. IT BRAKES
* UP THE DIFFERENT PARTS INTO SURFACE AND VOLUME ELEMENTS
* IT ALSO COMPUTES THE SURFACE AREAS AND VOLUMES OF THE
* DIFFERENT ELEMENTS.
* 
* *******************************************************

SUBROUTINE DOMSETUP(DIST)

IMPLICIT NONE
REAL*8 PI,DIST
REAL*8 CE,CI,REXT,RINT,DENIV,RCEN
REAL*8 RADF,RADP,DRAD
REAL*8 PHIDEN,PHIF,PHIP,PHIT,DZPHI,ZPHIF,ZPHIP
REAL*8 TTAF,TTAP,DTPA
REAL*8 XNOD,YNOD,ZNOD,XFAC,YFAC,ZFAC
REAL*8 VOLUM,REALSUM,SAREA,SURFAC
REAL*8 ZMAX,Z,DZ,RFOV,TETAFM,FI,TH,RAD1,RAD2,RPA
REAL*8 LBAR,RCAV,LCON,CAVANG
REAL*8 DR,R,COSRNG
REAL*8 AREA,TANCAV,H,INDEX,ZZ

C
INTEGER I,J,K,MAXELT
INTEGER NBSH,NBCO,NBCOL,NBPSD,NBLAT,NBLONG,NBPS,NBWASH,NBLSU
INTEGER NBHCSB,NBHSC,NBPSB,NBPC,NBPCS,NBWSU
INTEGER NB11,NB2,NB3,NB4,NB5,NB6,NB7,NB13
INTEGER NB14,NB15,NB16,NB8,NB17,NB18
INTEGER NBHCR,NBPSR

C
PARAMETER(MAXELT=700)

C
DIMENSION RADP(MAXELT),DRAD(MAXELT)
DIMENSION PHIP(MAXELT),PHIF(MAXELT)
DIMENSION TTAF(MAXELT)
DIMENSION DIST(MAXELT)
DIMENSION VOLUM(MAXELT)

C
COMMON /RIING/ NBHCR,NBPSR
COMMON /SER2/ NBLAT,NBLONG /SER3/ NBWASH,NBPS,NBLSU,NBWLSU
COMMON /SER4/ NBSH,NBCO,NBPSD
COMMON /FOVL/ RFOV,TETAFM
COMMON /DOME/ REXT,RINT,DENIV
COMMON /NB14/ NB1,NB2,NB3,NB4,NB5,NB6,NB7,NB13,NB14
COMMON /NB57/ NB1,NB6,NB7,NB15,NB16,NB8,NB17,NB18
COMMON /SETU/ RADP(MAXELT),PHIF(MAXELT),TTAF(maxelt),
  & SAREA(MAXELT),RCEN
COMMON /NODE/ XNOD(MAXELT),YNOD(MAXELT),ZNOD(MAXELT)
COMMON /FACE/ XFAC(MAXELT),YFAC(MAXELT),ZFAC(MAXELT)
COMMON /CAVITY/ RCAV,LBAR,LCON,CAVANG

Program ERBERT

177
COMMON /CAVSUR/, NBHSC, NBPSB, NBPSD, NBSCS
COMMON /SBS/, RBA, SURFAC

PI=DACOS(-1.D0)

C DOME DOME DOME MESHE DEFINITION DOME DOME DOME DOME DOME DOME
C
C DEFINITION OF THE RADIUS OF THE CV FACES AND THE CV NODES:
C THE 1ST CV FACE COINCIDES WITH THE OUTER SURFACE OF THE DOME.
C THE 1ST CV NODE HAS A RADIUS = REXT.
C THE INDEX OF THE CV NODES ARE THE SAME AS THE FACE FOLLOWING THEM
C IF YOU MOVE IN THE "DECREASING RAD" DIRECTION.
C THE LAST CV FACE COINCIDES WITH THE INNER SURFACE OF THE DOME.
C THERE IS AN EXTRA SET OF NODES AT RADIUS = RINT FOR B.C. PURPOSES.
C
RADF(1)=REXT
RADF(1)=REXT
DO 10 I=2,NBSSH+1
RADF(I)=((RADF(I-1))**3 -(REXT**3 - RINT**3)/NBSSH)**(1.D0/3.D0)
RADF(I)=(0.5D0*(RADF(I))**3 + (RADF(I-1))**3))**(1.D0/3.D0)
DRAD(I-1)=RADF(I-1) - RADF(I)
10 CONTINUE
RADF(NBSSH+2)=RINT
DRAD(NBSSH+1)=RADF(NBSSH+1) - RADF(NBSSH+2)

C DEFINITION OF THE ZENITH ANGLE OF THE CV FACES AND CV NODES:
C PHI=0 AT NADIR, (FIRST CV FACE)
C PHIDEN IS THE ANGLE AT WHICH THE DOME STARTS TO BE BURIED IN THE
C SUBSTRATE.
C THE INDEX OF THE CV NODES ARE THE SAME AS THE FACE FOLLOWING THEM
C IF YOU MOVE IN THE "INCREASING PHI" DIRECTION.
C SINCE THERE IS NO CV NODE BEFORE THE 1ST CV FACE, THE 1ST CV NODE IS
C INDEXED BY # 2.
C
RCEN=(0.5D0*(REXT*REXT*REXT+RINT*RINT*RINT))**(1.D0/3.D0)
DZPHI=(RCEN-DENIV)/(NBCD-1)
ZPHIF=RCEN
ZPHIF=RCEN+DZPHI/2.D0
PHIF(I)=0.0D0
PHIF(I)=0.0D0
DO 20 J=2,NBCO
ZPHIF=ZPHIF-DZPHI
ZPHIF=ZPHIF-DZPHI
PHIF(J)=DACOS(ZPHIF/RCEN)
PHIF(J)=DACOS(ZPHIF/RCEN)
ZPHIF=(PHIF(J))**2 - PHIF(J-1)
20 CONTINUE
PHIF(NBCO+1)=PI/2.D0
PHIF(NBCO+1)=DACOS((-DENIV/2.D0)/RCEN)
PHIF(NBCO)=PHIF(NBCO+1) - PHIF(NBCD)
PHIF(NBCO+2)=PHIF(NBCO+1) - PHIF(NBCO+1)
PHIF(NBCO+1)=PHIF(NBCO+2) - PHIF(NBCO+1)

C DEFINITION OF THE AZIMUTHAL ANGLE OF THE CV FACES AND CV NODES
C THE 1ST CV FACE IS AT THETA = 0.
C !!!NOTE: THE CV NODE HAS THE SAME # AS THE CV FACE PRECEDING IT!!!!
C THE CV FACES ARE CALCULATED TO NBPSD+1 JUST SO THAT ALL THE CV NODES
C CAN BE CALCULATED WITH THE SAME FORMULA.
C
DTHA=2.D0*PI/NBPSD
TTAF(1)=0.0D0
DO 40 K=2,NBPSD+1
TTAF(K)=TTAF(K-1) + DTHA
40 CONTINUE
DO 41 K=1,NBPSD

Program ERBERT

178
TTAP(K)=0.5D0*(TTAF(K+1) + TTAF(K))

CONTINUE

SAVE RADF(I) AS DIST(I)

DO 60 I=1,NBSH+1
    DIST(I)=RADF(I)

60 CONTINUE

COMPUTE THE COORDINATES OF THE CENTROID OF EACH VOLUME ELEMENT

DO 80 I=2,NBSH+1
DO 80 J=2,NBCO+1
DO 80 K=1,NBPSD

NBVE=(I-2)*NBCO*NBPSD + (J-2)*NBPSD + K + NB3

XNOD(NBVE)=RADF(I)*DSIN(PHIP(J))*DCOS(TTAP(K))
YNOD(NBVE)=RADF(I)*DSIN(PHIP(J))*DSIN(TTAP(K))
ZNOD(NBVE)=RADF(I)*DCOS(PHIP(J)) + DENIV

80 CONTINUE

COMPUTE THE COORDINATES OF THE POINTS AT THE INTERSECTIONS OF THE
CONTROL VOLUME FACES

DO 90 I=1,NBSH+1
    NBVE=(I-1)*(NBCO*NBPSD + 1) + 1 + NB7
    XFAC(NBVE)=0.0D0
    YFAC(NBVE)=0.0D0
    ZFAC(NBVE)=RADF(I)

DO 90 J=2,NBCO+1
DO 90 K=1,NBPSD

NBVE=(I-1)*(NBCO*NBPSD + 1) + (J-2)*NBPSD + K + 1 + NB7

XFAC(NBVE)=RADF(I)*DSIN(PHIP(J))*DCOS(TTAP(K))
YNOD(NBVE)=RADF(I)*DSIN(PHIP(J))*DSIN(TTAP(K))
ZNOD(NBVE)=RADF(I)*DCOS(PHIP(J)) + DENIV

NB8=NBVE

90 CONTINUE

COMPUTE THE VOLUME OF THE VOLUME ELEMENTS BRACING UP THE DOME

REALSUM=0.0D0

DO 100 I=2,NBSH+1
DO 100 J=2,NBCO+1
DO 100 K=1,NBPSD

NBVE=(I-2)*NBCO*NBPSD + (J-2)*NBPSD + K + NB3

VOLUM(NBVE)=(DCOS(PHIP(J-1)) - DCOS(PHIP(J)))*

1    *(RADF(I-1)*RADF(I-1)*RADF(I-1) - RADF(I)*RADF(I) + 3.0D0)*DTTA

SArea(NBVE)=(DCOS(PHIP(J-1)) - DCOS(PHIP(J)))*

1    *(RADF(I-1)*RADF(I-1)*DTTA

REALSUM=REALSUM+VOLUM(NBVE)

WRITE(10,*)NBVE,SArea(NBVE),VOLUM(NBVE)

100 CONTINUE

COMPUTE THE COORDINATES OF THE POINTS AT THE INTERSECTION OF THE
CONTROL SURFACE FACES FOR THE FOV LIMITER

ZMAX=RFOV*DCOS(TETAFM) + DENIV
Z=0.0D0

DZ=ZMAX/DBLE(NBLAT)

DO 120 I=1,NBLAT+1
TH=0.0D0
FI=DACOS(Z/RFOV)

DO 120 J=1,NBLONG

NBVE=(I-1)*NBLONG + J

XFAC(NBVE)=RFOV*DSIN(FI)*DCOS(TH)

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YFAC(NBVE)=RFOV*DSIN(PI)*DSIN(TH)
ZFAC(NBVE)=RFOV*DCOS(PI)+DENIV
TH=TH + 2.0*PI/DBLE(NBLONG)

121 CONTINUE
Z=Z+DZ

120 CONTINUE
DO 122 I=1,NBLAT
DO 122 J=1,NBLONG
NBVE=(I-1)*NBLONG + J
SAREA(NBVE)=DCOS(TETAFL) * 2.0*PI*RFOV*RFOV/NB1
WRITE(10,*)NBVE,SAREA(NBVE)

122 CONTINUE
C
C COMPUTE THE COORDINATES OF THE POINTS AT THE INTERSECTION OF THE
C CONTROL SURFACE FACES FOR THE LOWER SUBSTRATE
C
DO 130 J=1,NBLSU
TH=DBLE(J-1)*2.0*PI/DBLE(NBLSU)
NBVE=NB5+J
XFAC(NBVE)=RPA*DCOS(TH)
YFAC(NBVE)=RPA*DSIN(TH)
ZFAC(NBVE)=DENIV
SAREA(J+NB1)=PI*(RINT*RINT-RPA*RPA)/NBLSU
WRITE(10,*)J+NB1,SAREA(J+NB1)

130 CONTINUE
DO 131 J=1,NBLSU
TH=DBLE(J-1)*2.0*PI/DBLE(NBLSU)
NBVE=NB5+NBLSU+J
XFAC(NBVE)=RINT*DCOS(TH)
YFAC(NBVE)=RINT*DSIN(TH)
ZFAC(NBVE)=DENIV

131 CONTINUE
DO 132 J=1,NBLSU
TH=DBLE(J-1)*2.0*PI/DBLE(NBLSU)
NBVE=NB5+J+2*NBLSU
XFAC(NBVE)=REXT*DCOS(TH)
YFAC(NBVE)=REXT*DSIN(TH)
ZFAC(NBVE)=DENIV
SAREA(J+NB1+NBLSU)=PI*(REXT*REXT-RINT*RINT)/NBLSU
WRITE(10,*)J+NB1+NBLSU,SAREA(J+NB1+NBLSU)

132 CONTINUE
C
C COMPUTE THE COORDINATES OF THE POINTS AT THE INTERSECTION OF THE
C CONTROL SURFACE FACES FOR THE SUBSTRATE
C
RAD1=DSQRT(REXT*REXT-DENIV*DENIV)
RAD2=RFOV
DO 140 I=1,NBWSH+1
R=DSQRT(DBLE(I-1)/NBWSH*(RAD2*RAD2-RAD1*RAD1) + RAD1*RAD1)
TH=0
DO 140 J=1,NBPS
NBVE=(I-1)*NBPS + J + NB6
XFAC(NBVE)=R*DCOS(TH)
YFAC(NBVE)=R*DSIN(TH)
ZFAC(NBVE)=0.000
TH=TH + 2*PI/NBPS

140 CONTINUE
DO 145 I=1,NBWSH*NEPS
NBVE=NB2+I
SAREA(NBVE)=PI*(RFOV*RFOV-RAD1*RAD1)/(NBWSH*NBPS)
WRITE(10,*)NBVE,SAREA(NBVE)

145 CONTINUE
C
C Compute the surface area of the FOV limiting aperture
C
SAREA(NB4+1) = PI * RFcov * DSIN(TETAFM) * RFcov * DSIN(TETAFM)

C
C COMPUTE THE COORDINATES OF THE POINTS AT THE INTERSECTION OF THE
C CONTROL SURFACE FACES FOR THE BARREL
C
NBVE=NB8+1
Z=DENIV
DZ=LBAR/DBLE(NHHSB)
DO 150 I=1,NHHSB+1
   DO 151 J=1,NBPSB
      TH=(J-1)*2.0D0*PI/DBLE(NBPSB)
      XFAC(NBVE)=RCAV*DCOS(TH)
      YFAC(NBVE)=RCAV*DSIN(TH)
      ZFAC(NBVE)=Z
      NBVE=NBVE+1
   151 CONTINUE
   Z=Z-DZ
150 CONTINUE
NBVE=NB8+1
DO 152 I=1,(NHHSB*NBPSC)
   SAREA(NBVE)=PI*2.0D0*RCAV*DZ/NBPSB
NBVE=NBVE+1
152 CONTINUE
C
C COMPUTE THE COORDINATES OF THE POINTS AT THE INTERSECTION OF THE
C CONTROL SURFACE FACES FOR THE CONE
C
NBVE=NB15+1
Z=DENIV-LBAR
AREA=PI*RCAV*DSQRT(RCAV**2+LCON**2)
TANCAV=RCAV/LCON
H=DSQRT(1.0D0+TANCAV**2)
DO 160 I=1,NBHSC+1
   INDEX=INDBL(NBHSC)+1.D0-DBLE(I))/DBLE(NBHSC)
   DZ=LCON*DSQRT((AREA*INDEX)/((PI*H*TANCAV))
   Z=Z-DZ
   R=(LBAR+LCON-DENIV+Z)*RCAV/LCON
   WRITE(*,*)Z
   DO 161 J=1,NBPSC
      TH=(J-1)*2.0D0*PI/DBLE(NBPSC)
      XFAC(NBVE)=Z
      XFAC(NBVE)=RCAV*DCOS(TH)
      YFAC(NBVE)=RCAV*DSIN(TH)
      ZFAC(NBVE)=1.0D0
      NBVE=NBVE+1
   161 CONTINUE
160 CONTINUE
NBVE=NB9+1
DO 162 I=1,(NHSC*NBPSC)
   SAREA(NBVE)=AREA/DBLE(NBHSC*NBPSC)
NBVE=NBVE+1
162 CONTINUE
C
C COMPUTE THE COORDINATES OF THE POINTS AT THE INTERSECTION OF THE
C CONTROL SURFACE FACES FOR THE CAVSUB
C
NBVE=NB16+1
DO 170 J=1,NBPSCS
   TH=(J-1)*2.0D0*PI/DBLE(NBPSCS)
   XFAC(NBVE)=RPA*DCOS(TH)
   YFAC(NBVE)=RPA*DSIN(TH)
   ZFAC(NBVE)=1.0D0
   NBVE=NBVE+1
170 CONTINUE
NBVE=NBVE+NBPSCS+1
DO 171 J=1,NBPSCS
TH=(J-1)*2.0D0*PI/DBLE(NBFS0C)
XFAC(NBVE)=RCAV*DCOS(TH)
YFAC(NBVE)=RCAV*DSIN(TH)
ZFAC(NBVE)=-1.0D0
NBVE=NBVE+1
171 CONTINUE
NBVE=#B11+1
DO 172 I=1,NBPSCS
SAREA(NBVE)=PI*(REXT**2-RPA**2)/DBLE(NBPSCS)
NBVE=NBVE+1
172 CONTINUE
C
C COMPUTE THE COORDINATES OF THE POINTS AT THE INTERSECTION OF THE
C CONTROL SURFACE FACES FOR THE RING
C
NBVE=NB17+1
Z=0.0D0
DZ=DABS(DENIV/DBLE(NBHRSR))
COSRNG=DSQRT(1.0D0-DENIV*DENIV/REXT*REXT)
DO 180 I=1,NBHSR+1
DO 181 J=1,NBPSR
TH=(J-1)*2.0D0*PI/DBLE(NBPSR)
XFAC(NBVE)=REXT*DCOS(TH)*COSRNG
YFAC(NBVE)=REXT*DSIN(TH)*COSRNG
ZFAC(NBVE)=Z
NBVE=NBVE+1
181 CONTINUE
Z=Z-DZ
COSRNG=1.0D0
180 CONTINUE
NBVE=NB13+1
DO 182 I=1,(NBHRSR*NBPSS)
SAREA(NBVE)=PI*2.0D0*REXT*DZ/NBPSR
NBVE=NBVE+1
182 CONTINUE
END

******************************************************************************
* * THIS SUBROUTINE RETRIEVE THE SURFACE OR VOLUME ELEMENT THAT WAS HIT FROM X,Y,Z COORDINATES.*
******************************************************************************

SUBROUTINE SEARCH(X,Y,Z,SURFAC,CNTBDL,DIST)
IMPLICIT NONE
C
REAL*8 PI,DZED,ZMAX,RFOV,TETAFM,RADIUS,X,Y,Z
REAL*8 CE,C1,REXT,RINT,DIST,DTHETA,DPHI,VOLUM
REAL*8 RAD1,RAD2,SINTTA,COSTTA,RPA
REAL*8 DITOCD,ANGPHI,ANGTTA,DENIV,PHIDEN
REAL*8 RADF,PHIF,TTFAP,SAREA,RCEN
REAL*8 RCAV,LEAR,LCON,CVANG
REAL*8 ZBAR,ZCON
REAL*8 DLCON
REAL*8 ZRING
C
INTEGER I,J,K,W,N,SURFAC,MAXELT,NBUAB,SS,CNTBDL
INTEGER NB1,NB2,NB3,NB4,Nd9,NB11,NB13,NB14
INTEGER NB1AT,NB1AT1,NB1AT2,NB1AT3,NB1AT4
INTEGER NBHSHB,NBHSN,NBPSS,NBPSN,NBPSN1,NBPSC,NBPSCS,NBWLSU
INTEGER NBHSHR,NBPSR,SURFC
C
PARAMETER (MAXELT=700)

Program ERBERT
C

DIMENSION DIST(MAXELT)

COMMON /RING/, NBHRSR, NBPSR
COMMON /SER1/, NBUAB(MAXELT), /SER2/, NBLAT, NBLONG
COMMON /SER3/, NBWASH, NBPS, NBLSU, NBWLSU, /SER4/, NBSH, NBCO, NBPED
COMMON /FOVL/, RFOV, TETAFM
COMMON /DOME/, REXT, RINT, DENIV
COMMON /NB14/, NB1, NB2, NB3, NB4, NB9, NB11, NB13, NB14
COMMON /SETU/, RADF(MAXELT), PHIF(MAXELT), TTAF(MAXELT),
&
SAREA(MAXELT), RCEN
COMMON /CAVITY/, RCAV, LBAR, LCON, CAVANG
COMMON /CAVSUR/, NBHSB, NBHSC, NBPSB, NBPSC, NBSCS
COMMON /CONSET/, DLCON(20)
COMMON /SUSB/, RPA, SURFC
PI=DACOS(-1.0D0)
ZMAX=RFOV*DCOS(TETAFM)+DENIV
CE=DENIV
CI=DENIV
RAD1=DSQRT(REXT*REXT-DENIV*DENIV)
RAD2=RFOV
C
FIND THE ELEMENT THAT WAS HIT, ACCORDING TO THE GEO. PART INVOLVED
C FOR THE FOV LIMITER:
C
IF (SURFAC.EQ.1.OR.SURFAC.EQ.5) THEN
D2ED=ZMAX/DBLE(NBLAT)
DTETA=2.0D0*PI/DBLE(NBLONG)
ANGPHI=DACOS(Z/RFOV)
SINTTA=(Y/RFOV)/DSIN(ANGPHI)
COSTTA=(X/RFOV)/DSIN(ANGPHI)
ANGTTA=PI+(DABS(SINTTA)/SINTTA)*(DACOS(COSTTA)-PI)
I=INT(Z/D2ED)+1
J=INT(ANGTTA/DTETA)+1
SS= (I-1)*NBLONG+J
C
C FOR THE UPPER SUBSTRATE
C
ELSE IF (SURFAC.EQ.2) THEN
DTETA=2.0D0*PI/DBLE(NBPS)
RADIUS=DSQRT(X**2+Y**2)
SINTTA=Y/RADIUS
COSTTA=X/RADIUS
ANGTTA=PI+(DABS(SINTTA)/SINTTA)*(DACOS(COSTTA)-PI)
I=INT(DBLE(NBWASH)*((RADIUS*RADIUS-RAD1*RAD1)/(RAD2*RAD2-
&
RAD1*RAD1))) +1
J=INT(ANGTTA/DTETA)+1
SS= (NB2)+ (I-1)*NBPS+J
C
C FOR THE LOWER SUBSTRATE
C
ELSE IF (SURFAC.EQ.6) THEN
DTETA=2.0D0*PI/DBLE(NBLSU)
RADIUS=DSQRT(X**2+Y**2)
SINTTA=Y/RADIUS
COSTTA=X/RADIUS
ANGTTA=PI+(DABS(SINTTA)/SINTTA)*(DACOS(COSTTA)-PI)
J=INT(ANGTTA/DTETA)+1
IF (RADIUS.GT.RINT) THEN
I=2
ELSE
I=1
END IF
SS=NB1+ (I-1)*NBLSU+J

Program ERBERT

183
C FOR THE BARREL

ELSE IF (SURFAC.EQ.9.OR.SURFAC.EQ.10) THEN
  ZBAR=Z+LBAR-DENIV
  DTETA=2.0*DPI DBLE(NBPSB)
  DZED=LBAR/DBLE(NBHSB)
  RADIUS=DSQRT(X*X+Y**2)
  SINTTA=Y/RADIUS
  COSTTA=X/RADIUS
  ANGTTA=PI+(DABS(SINTTA)/SINTTA)*(DACOS(COSTTA)-PI)
  I=(INT(ZBAR/DZED)+1)
  J=(INT(ANGTTA/DTETA)+1)
  SS=NB11+(I-1)*NBPSB+J

C FOR THE CONE

ELSE IF (SURFAC.EQ.11.OR.SURFAC.EQ.12) THEN
  DTETA=2.0*DPI DBLE(NBPSC)
  RADIUS=DSQRT(X*X+Y**2)
  J=0
  DO 5 K=NBHSC+1,1,-1
      J=J+1
      IF (2.0*DLCON(K)) THEN
          I=J-1
          GOTO 6
      END IF
  CONTINUE
  6
  SINTTA=Y/RADIUS
  COSTTA=X/RADIUS
  ANGTTA=PI+(DABS(SINTTA)/SINTTA)*(DACOS(COSTTA)-PI)
  J=INT(ANGTTA/DTETA)+1
  SS=NB4+1+(I-1)*NBPSC+J

C FOR THE SUBSTRATE VISIBLE TO THE CAVITY

ELSE IF (SURFAC.EQ.13) THEN
  DTETA=2.0*DPI DBLE(NBPSCS)
  RADIUS=DSQRT(X*X+Y**2)
  SINTTA=Y/RADIUS
  COSTTA=X/RADIUS
  ANGTTA=PI+(DABS(SINTTA)/SINTTA)*(DACOS(COSTTA)-PI)
  I=INT(ANGTTA/DTETA)+1
  SS=NB11+I

C FOR THE RING

ELSE IF (SURFAC.EQ.14.OR.SURFAC.EQ.15) THEN
  ZRING=-1.0*DZED
  DTETA=2.0*DPI DBLE(NBPSR)
  DZED=1.0000000000000000000
  ANGPHI=DACOS(Z/DSQRT(X*X+Y*Y+Z*Z))
  SINTTA=(Y/((X*X+Y*Y+Z*Z)/DSIN(ANGPHI))
  COSTTA=(X/((X*X+Y*Y+Z*Z)/DSIN(ANGPHI))
  ANGTTA=PI+(DABS(SINTTA)/SINTTA)*(DACOS(COSTTA)-PI)
  I=(INT(ZRING/DZED)+1)
  J=INT(ANGTTA/DTETA)+1
  SS=NB13+(I-1)*NBPSR+J

C FOR THE DOME

ELSE
  DTETA=2*PI DBLE(NBPSD)

C
C DISTANCE FROM BASE OF DOME TO POINT P (X,Y,Z)
C
DITOCOD=DSQRT(X*X+Y*Y+(Z-DENV)*(Z-DENV))
C
ZENITH ANGLE FROM BASE OF DOME
C
ANGPHI=DACOS((Z-DENV)/DITOCOD)
C
AZIMUTHAL ANGLE CORRESPONDING TO X,Y,Z
C
SINTTA=(Y/DITOCOD)/DSIN(ANGPHI)
COSTTA=(X/DITOCOD)/DSIN(ANGPHI)
ANGTTA=PI+(DABS(SINTTA)/SINTTA)*(DACOS(COSTTA)-PI)
C
RETRIEVE CONTROL VOLUME INDECES FROM DITOCOD, PHI, AND THETA
C
K=INT(ANGTTA/DETA)+1
DO 10 J=2,NBCD+1
   IF (ANGPHI.LT.PHIF(J)) GO TO 1
10 CONTINUE
DO 20 I=2,NBNS+1
   IF (DITOCOD.GT.DIST(I)) GO TO 2
20 CONTINUE
SS=(I-2)*(NBCD*NBPSD)+(J-2)*NBPSD+K+NB3
END IF
C
UPDATE THE BUNDLE COUNTER FOR THE ELEMENT WHICH ABSORBED THE LAST
C BUNDLE
C
NBBUAB(SS)=NBBUAB(SS)+1
END

**********************************************************************
* THIS FUNCTION COMPUTES THE FRACTION OF EMISSIVE POWER FOR *
* A GIVEN WAVELENGTH INTERVAL USING PLANCK'S BLACKBODY *
* DISTRIBUTION *
**********************************************************************

REAL*8 FUNCTION FRAKEMI(LBDA1, LBDA2, T)

IMPLICIT NONE
REAL*8 LBDA1, LBDA2, INT1, INT2, T, SUM, X1, X2, X, W
INTEGER IS, N, I
PARAMETER (IS=1000)
DIMENSION X(IS), W(IS)
EXTERNAL SUM

N=100
INT=0.0D0
INT1=0.0D0
INT2=0.0D0
C
C COMPUTE THE INTEGRAL FROM 0 TO LBDA1
C
IF (LBDA1.LE.0.0D0) GO TO 7
DO 10 I = 1, IS
   X(I) = 0.0D0
   W(I) = 0.0D0
10 CONTINUE
X1=0.0D0
X2=LBDA1*T
CALL GAULEG(IS,X1,X2,X,W,N)
INT1=SUM(IS,X,W,N)
C
Program ERBERT
C COMPUTE THE INTEGRAL FROM 0 TO LBDA2

    IF (LBDA2.LE.0.D0) THEN
        WRITE(06,*)'ERROR IN FRAKEMI'
        RETURN
    END IF
    DO 20 I = 1,IS
        X(I) = 0.0D0
        W(I) = 0.0D0
    20    CONTINUE
    X1=0.D0
    X2=LBDA2*T
    CALL GAULEG(IS,X1,X2,X,W,N)
    INT2=SUM(IS,X,W,N)

C COMPUTE THE INTEGRAL FROM LBDA1 TO LBDA2

    FRAKEMI=INT2-INT1
    RETURN
END

***********************************************************************

* THIS FUNCTION COMPUTES THE POINTS AND WEIGHTS NECESSARY          *
* TO COMPUTE A NUMERICAL INTEGRAL USING A GAUSS-LEGENDRE            *
* POLYNOMIAL                                                        *
* COURTESY OF DR. J.R. THOMAS OF THE MECHANICAL ENGINEERING         *
* DEPT. OF VIRGINIA TECH                                            *

***********************************************************************

SUBROUTINE GAULEG(IS,X1,X2,X,W,N)

IMPLICIT REAL*8 (A-H,O-Z)
DIMENSION X(IS),W(IS)
PARAMETER (EPS=1.D-15)

PI=3.141592653589793D0
M=(N+1)/2
XM=0.5D0*(X2+X1)
XL=0.5D0*(X2-X1)
DO 12 I=1,M
    Z=DCOS(PI*(DBLE(I)-.25D0)/(DBLE(N)+.5D0))
1   CONTINUE
    P1=1.D0
    P2=0.D0
    DO 11 J=1,N
        DJ=DBLE(J)
        P3=P2
        P2=P1
        P1=((DBLE(2.D0*J)-1.D0)*Z*P2-(DJ-1.D0)*P3)/DJ
11   CONTINUE
    PP=DBLE(N)*(Z*P1-P2)/(Z*Z-1.D0)
    Z1=Z
    Z=Z1-P1/PP
    IF (ABS(Z-Z1).GT.EPS) GO TO 1
    X(I)=XM-XL*Z
    X(N+1-I)=XM+XL*Z
    W(I)=2.D0*XL/((1.D0-Z*Z)*PP*PP)
    W(N+1-I)=W(I)
12   CONTINUE
RETURN
END

***********************************************************************

* THIS FUNCTION IS USED BY THE FUNCTION FRAKEMI TO COMPUTE          *

Program ERBERT 186
* THE FOLLOWING EXPRESSION

* ---------------------------------------------------------------
REAL*8 FUNCTION F(X)

IMPLICIT NONE
REAL*8 PI,C1,C2,X,SIGMA

PI=3.141592653589793D0
C1=0.5954443534D0
C2=14388D0
SIGMA=5.6696D-8

F=2.0*PI*C1*DEXP(-C2/X)/(SIGMA*(X**5)*(1.0D0-DEXP(-C2/X)))
RETURN

END

******************************************************************************
* THIS FUNCTION IS USED BY THE FUNCTION FRAKMI TO COMPUTE
* THE FOLLOWING SUM

******************************************************************************
REAL*8 FUNCTION SUM(IS,X,W,N)

IMPLICIT NONE
REAL*8 X,W,F
INTEGER IS,N,I
DIMENSION X(IS),W(IS)
EXTERNAL F
SUM=0.0D0
DO 200 I=1,N
SUM=SUM+F(X(I))*W(I)
200 CONTINUE
RETURN
END

******************************************************************************
* THIS SUBROUTINE OBTAINS A VALUE BY LINEAR INTERPOLATION

******************************************************************************
SUBROUTINE LINREG(LBDAL,LBDAI,LBD2,SFEPI,SFEP1,SFEP2)

IMPLICIT NONE
REAL*8 SFEP1,SFEP2,SFEPI,LBDAL,LBDA2,LBDAI
REAL*8 A,B

A=(SFEP2-SFEP1)/(LBDA2-LBDA1)
B=(SFEP1-LBDA2*SFEP2+LBDA1)/(LBDA2-LBDA1)
SFEPI=A*LBDAI+B
RETURN
END

******************************************************************************
* This subroutine distributes the energy bundles over a given spectrum
* The spectrum can be that of a typical day light Earth scene, or that
* of a grey surface at a given temperature or just a uniform spectrum
* between 0 and 50.0 microns
* In addition the user can choose to emit in the shortwave band of the
* previously defined spectrum or over the entire spectrum.

******************************************************************************
Program ERBERT
SUBROUTINE WLSET(MAXDL, EMISUR)

IMPLICIT NONE

REAL*8 LBDAMX, LBDA, LBDA1, LBDA2
REAL*8 FEP, FEP1, FEP2, SFEP, SFEP1, SFEP2
REAL*8 TEMP, FRAKMI, FRAK
REAL*8 DOABCO, DOMTHC

INTEGER I, J, ANSWER, CH
INTEGER NEWLIN, MAXDL, NBDLIN, NBBUEA
INTEGER MAXWL, EMISUR

PARAMETER (MAXWL=15)
DIMENSION SFEP(MAXWL)
EXTERNAL FRAKMI

COMMON /WLS1/ NBDLIN(MAXWL), NBBUEA(MAXWL), NEWLIN
COMMON /WLS2/ DOABCO(MAXWL), LBDA(MAXWL)
COMMON /CHAN/ CH

Use the spectrum of a surface at temperature T

NBBUEA(I) = IDNINT(DBLE(MAXDL)/DBLE(NEWLIN))
NBDLIN(I) = NBBUEA(I)
DO 45 I=2, NEWLIN
NBBUEA(I) = IDNINT(DBLE(MAXDL)/DBLE(NEWLIN))
NBDLIN(I) = NBDLIN(I-1) + NBBUEA(I)
45 CONTINUE

Write the spectral distribution of energy bundles to the screen

WRITE(03,520) '----------------------------------------'
WRITE(03,520) ' SPECTRAL DISTRIBUTION OF EMLUDED ENERGY BUNDLES '
WRITE(03,520) '
WRITE(03,520) ' WAVELENGTH | PARTIAL | CUMULATIVE | ABSORPTION '
WRITE(03,520) ' INTERVAL | NUMBER OF ENERGY BUNDLES | COEFFICIENT'
WRITE(03,520) '----------------------------------------'
WRITE(03,521) 0.0, LBDA(I), NBBUEA(I), NBDLIN(I), DOABCO(I)
DO 90 I=2, NEWLIN
WRITE(03,521) LBDA(I-1), LBDA(I), NBBUEA(I), NBDLIN(I), DOABCO(I)
90 CONTINUE
WRITE(03,520) '----------------------------------------'

520 FORMAT(1X, A52)
521 FORMAT(1X, F5.2, ',', F5.2, ',', I10, ',', I10, ',', G10.3, 3X)

RETURN
END

*************************************************************************

SUBROUTINE RNSET

*************************************************************************

* This subroutine must be run before RNUN to set * the seed for the random number generator. The * seed must be an integer in the range * (0, 2147483647).

*************************************************************************

SUBROUTINE RNSET(ISEED)

C Set up variables.

Program ERBERT 188
REAL*8 X1,A,P
INTEGER ISEED

Create a common storage block for the random number data.

COMMON /RANDOM/ X1,A,P

Set up constants used in RNUN.

A = 16807.0D0
P = 2147483647.0D0

Set up seed for first random number.

X1 = DBLE(ISEED)
RETURN
END

******************************************************************************

* *
* SUBROUTINE DRNUN *
* *
* This subroutine returns the same pseudo-random numbers as the IMSL routine of the same name, *
* provided it is set with the same seed value. *
* Developed by Rob Bongiovi and Martial Haeffelin *
* at VPI&SU, April 1993. *
*
******************************************************************************

* *
* SUBROUTINE DRNUN(NR, R) *
* *
* Set up variables. *
*
INTEGER NR
REAL*8 X1, X2, A, P, R(NR)

Use common block created by RNSET

COMMON /RANDOM/ X1,A,P

Calculate NR random numbers.

DO 1 I=1,NR
   X2 = DMOD(X1*A,P)
   R(I) = X2/P
   X1 = X2
1 CONTINUE
RETURN
END

******************************************************************************

* *
* THIS SUBROUTINE OUTPUTS DATA FOR TECPLOT *
* USES WRITE STATEMENTS TO FILE EXTENSION 8,9,10... *
* *
******************************************************************************

* *
* SUBROUTINE TECPLOT *
* *
REAL*8 XFAC,YFAC,ZFAC
REAL*8 RADF,PHIF,TTAF,SAREA,RCEN
REAL*8 REXT,RINT,DENIV
REAL*8 DUMSUM
REAL*4 RC, LV, LC, CAVANG
REAL*4 TH, XDUM, YDUM
REAL*4 DFAC, DFACS, DFACLO

INTEGER NBLAT, NBLONG, NBSU, NBSW, NBSU, NBSW, NBSH, NBSH, NBSH, NBSH
INTEGER NBLA, NBLA, NBLA, NBLA, NBLA, NBLA, NBLA, NBLA
INTEGER NBLA, NBLA, NBLA, NBLA, NBLA, NBLA, NBLA, NBLA
INTEGER NBLA, NBLA, NBLA, NBLA, NBLA, NBLA, NBLA, NBLA
INTEGER NBLA, NBLA, NBLA, NBLA, NBLA, NBLA, NBLA, NBLA
INTEGER NBLA, NBLA, NBLA, NBLA, NBLA, NBLA, NBLA, NBLA
INTEGER NBLA, NBLA, NBLA, NBLA, NBLA, NBLA, NBLA, NBLA
INTEGER NBLA, NBLA, NBLA, NBLA, NBLA, NBLA, NBLA, NBLA

PARAMETER (MAXELT=700)

COMMON /TBL/ DFAC, DFACS, DFACLO
COMMON /SRL/ NBLAT, NBLONG
COMMON /SRS/ NBSU, NBSW, NBSU, NBSW
COMMON /SRS/ NBSU, NBSW, NBSU, NBSW
COMMON /SRS/ NBSU, NBSW, NBSU, NBSW
COMMON /SRS/ NBSU, NBSW, NBSU, NBSW
COMMON /SRS/ NBSU, NBSW, NBSU, NBSW
COMMON /SRS/ NBSU, NBSW, NBSU, NBSW
COMMON /SRS/ NBSU, NBSW, NBSU, NBSW
COMMON /SRS/ NBSU, NBSW, NBSU, NBSW

COMMON /NR/ RADE, RADE, RADE, RADE
COMMON /NRS/ NBLAT, NBLONG
COMMON /NRS/ NBSU, NBSW, NBSU, NBSW
COMMON /NRS/ NBSU, NBSW, NBSU, NBSW
COMMON /NRS/ NBSU, NBSW, NBSU, NBSW
COMMON /NRS/ NBSU, NBSW, NBSU, NBSW
COMMON /NRS/ NBSU, NBSW, NBSU, NBSW
COMMON /NRS/ NBSU, NBSW, NBSU, NBSW
COMMON /NRS/ NBSU, NBSW, NBSU, NBSW
COMMON /NRS/ NBSU, NBSW, NBSU, NBSW

C OUTPUT OF TOTAL DFAC TO FOV LIMITER

WRITE(0,*) 'TITLE = "EMISSION FROM EARTH SCENE; IMAGE ON DOME"'
WRITE(0,*) 'VARIABLES = X, Y, Z, DFAC'
WRITE(0,*) 'ZONE T="FOV", I=25, J=7, F=POINT'

I=1
J=1
DUMSUM=(DFAC(I,NBLONG)+DFAC(I,J))/2.D0
WRITE(0,700) X, Y, Z, DFAC(I,J), DUMSUM
DO 400 J=2, NBLONG
   DUMSUM=(DFAC(I,J-1)+DFAC(I,J))/2.D0
   WRITE(0,700) X, Y, Z, DFAC(I,J), DUMSUM
   400 CONTINUE

J=1
DUMSUM=(DFAC(I,NBLONG)+DFAC(I,J))/2.D0
WRITE(0,700) X, Y, Z, DFAC(I,J), DUMSUM
DO 400 J=(K-1)*NBLONG+1
   DUMSUM=(DFAC(I,J+NBLONG-1)+
   1 DFAC(I,J)+
   2 DFAC(I,J-NBLONG)+
   3 DFAC(I,J-1))/4.0
   WRITE(0,700) X, Y, Z, DFAC(I,J), DUMSUM
   400 CONTINUE

J=(K-1)*NBLONG+1
DUMSUM=(DFAC(I,J+NBLONG-1)+
   1 DFAC(I,J)+
   2 DFAC(I,J-NBLONG)+
   3 DFAC(I,J-1))/4.0
   WRITE(0,700) X, Y, Z, DFAC(I,J), DUMSUM
   400 CONTINUE

J=NBLAT*NBLONG+1
DUMSUM=(DFAC(I,J-1)+DFAC(I,J-NBLONG))/2.D0
WRITE(0,700) X, Y, Z, DFAC(I,J), DUMSUM
DO 403 J=NBLAT*NBLONG+2, (NBLAT+1)*NBLONG
DUMSUM=DFACCT(I,J-NBLONG)+DFACCT(I,J-NBLONG))/2.D0
WRITE(09,700) XFAC(J), YFAC(J), ZFAC(J), DUMSUM
403 CONTINUE
J=NBLAT*NBLONG+1
DUMSUM=DFACCT(I,J-1)+DFACCT(I,J-NBLONG))/2.D0
WRITE(09,700) XFAC(J), YFAC(J), ZFAC(J), DUMSUM
C OUTPUT OF TOTAL DFAC TO THE LOWER SUBSTRATE
C
NB5=(NBLAT+1)*NBLONG
WRITE(09,*)'ZONE T="SUBLOW", I=25, J=3, F=POINT'
I=1
J=1
DUMSUM=DFACCT(I,NB1)+
1 DFACCT(I,NB1+J)+
2 DFACCT(I,NB1+NBSU))/3.D0
WRITE(09,700) XFAC(NB5+J), YFAC(NB5+J), ZFAC(NB5+J), DUMSUM
DO 404 J=2,NBSU+1
DUMSUM=DFACCT(I,NB1)+
1 DFACCT(I,NB1+J)+
2 DFACCT(I,NB1+J-1))/3.D0
WRITE(09,700) XFAC(NB5+J), YFAC(NB5+J), ZFAC(NB5+J), DUMSUM
404 CONTINUE
J=1
DUMSUM=DFACCT(I,NB1)+
1 DFACCT(I,NB1+J)+
2 DFACCT(I,NB1+NBSU))/3.D0
WRITE(09,700) XFAC(NB5+J), YFAC(NB5+J), ZFAC(NB5+J), DUMSUM
J=NBSU+1
DUMSUM=DFACCT(I,NB1+J-1)+DFACCT(I,NB1+J-NBSU))/2.D0
WRITE(09,700) XFAC(NB5+J), YFAC(NB5+J), ZFAC(NB5+J), DUMSUM
DO 405 J=NBSU+2,2*NBSU
DUMSUM=DFACCT(I,NB1+J-NBSU)+DFACCT(I,NB1+J-NBSU))/2.D0
WRITE(09,700) XFAC(NB5+J), YFAC(NB5+J), ZFAC(NB5+J), DUMSUM
405 CONTINUE
J=NBSU+1
DUMSUM=DFACCT(I,NB1+J-1)+DFACCT(I,NB1+J-NBSU))/2.D0
WRITE(09,700) XFAC(NB5+J), YFAC(NB5+J), ZFAC(NB5+J), DUMSUM
C OUTPUT OF TOTAL DFAC TO THE UPPER SUBSTRATE
C
NB6=NB5+(NBWLSU+1)*NBSU
WRITE(09,*)'ZONE T="SUBUPP", I=25, J=7, F=POINT'
I=1
J=1
DUMSUM=DFACCT(I,NB2+NBPS)+DFACCT(I,NB2+J))/2.D0
WRITE(09,700) XFAC(NB6+J), YFAC(NB6+J), ZFAC(NB6+J), DUMSUM
DO 406 J=2,NBPS
DUMSUM=DFACCT(I,NB2+J-1)+DFACCT(I,NB2+J))/2.D0
WRITE(09,700) XFAC(NB6+J), YFAC(NB6+J), ZFAC(NB6+J), DUMSUM
406 CONTINUE
J=2
DUMSUM=DFACCT(I,NB2+NBPS)+DFACCT(I,NB2+J))/2.D0
WRITE(09,700) XFAC(NB6+J), YFAC(NB6+J), ZFAC(NB6+J), DUMSUM
DO 407 K=2,NBWASH
J=(K-1)*NBPS+1
DUMSUM=DFACCT(I,NB2+J-1)+
1 DFACCT(I,NB2+J-NBPS)+
2 DFACCT(I,NB2+J)+
3 DFACCT(I,NB2+J-NBPS-1))/4.0
WRITE(09,700) XFAC(NB6+J), YFAC(NB6+J), ZFAC(NB6+J), DUMSUM
DO 408 J=(K-1)*NBPS+2,K*NBPS
DUMSUM=DFACCT(I,NB2+J-1-NBPS)+
1 DFACCT(I,NB2+J-NBPS)+
Program ERBERT 191
2      DFACTT(I,NB2+J)+
3      DFACTT(I,NB2+J-1))/4
408   CONTINUE
   J=(K-1)*NBPS+1
   DUMSUM=(DFACTT(I,NB2+J-1)+
   1      DFACTT(I,NB2+J-NBPS)+
   2      DFACTT(I,NB2+J)+
   3      DFACTT(I,NB2+J+NBPS-1))/4.0
   WRITE(9,700)XFACT(NB6+J),YFACT(NB6+J),ZFACT(NB6+J),DUMSUM
407   CONTINUE
   J=NBWASH*NBPS+1
   DUMSUM=(DFACTT(I,NB2+J-1)+DFACTT(I,NB2+J-NBPS))/2.0
   WRITE(9,700)XFACT(NB6+J),YFACT(NB6+J),ZFACT(NB6+J),DUMSUM
   DO 409 J=NBWASH*NBPS+2,(NBWASH+1)*NBPS
      DUMSUM=(DFACTT(I,NB2+J-NBPS-1)+DFACTT(I,NB2+J-NBPS))/2.0
   END
409   CONTINUE
   J=NBWASH*NBPS+1
   DUMSUM=(DFACTT(I,NB2+J-1)+DFACTT(I,NB2+J-NBPS))/2.0
   WRITE(9,700)XFACT(NB6+J),YFACT(NB6+J),ZFACT(NB6+J),DUMSUM
C
C OUTPUT OF SHORTWAVE DFACT TO DOME
C
   NB7=NB6+(NBWASH+1)*NBPS
   WRITE(9,*),'ZONE T="SW",I=25, J=10, F=POINT'
   I=1
   DUMSUM=0.0
   DO 410 J=1,NBPSD
      DUMSUM=DUMSUM+DFACSW(I,NB3+J)
410   CONTINUE
   DUMSUM=DUMSUM/REAL(NBPSD)
   DO 411 J=1,NBPSD+1
      TH=REAL(J-1)*2.0?I/REAL(NBPSD)
      XDUM=0.001*COS(TH)
      YDUM=0.001*SIN(TH)
      WRITE(05,700)XDUM,YDUM,RADF(I)+DENIV,DUMSUM
411   CONTINUE
   DO 412 K=1,NBCO
      J=(K-1)*NBPSD+2
      DUMSUM=(DFACSW(I,NB3+J-1)+
      1      DFACSW(I,NB3+J+NBPSD-1)+
      2      DFACSW(I,NB3+J+NBPSD-2)+
      3      DFACSW(I,NB3+J+2*NBPSD-2))/4.0
   END
412   CONTINUE
   J=(K-1)*NBPSD+3,K*NBPSD+1
   DUMSUM=(DFACSW(I,NB3+J-1)+
   1      DFACSW(I,NB3+J-2)+
   2      DFACSW(I,NB3+J+NBPSD-1)+
   3      DFACSW(I,NB3+J+NBPSD-2))/4
   WRITE(09,700)XFACT(NB7+J),YFACT(NB7+J),ZFACT(NB7+J),DUMSUM
413   CONTINUE
   J=(K-1)*NBPSD+2
   DUMSUM=(DFACSW(I,NB3+J-1)+
   1      DFACSW(I,NB3+J+NBPSD-1)+
   2      DFACSW(I,NB3+J+NBPSD-2)+
   3      DFACSW(I,NB3+J+2*NBPSD-2))/4.0
   WRITE(09,700)XFACT(NB7+J),YFACT(NB7+J),ZFACT(NB7+J),DUMSUM
412   CONTINUE
C
C OUTPUT OF LONGWAVE DFACT TO DOME
C
   WRITE(9,*),'ZONE T="LW",I=25, J=10, F=POINT'
   I=1
   DUMSUM=0.0

Program ERBERT
DO 420 J=1,NBPSD
      DUMSUM=DUMSUM+DFACLW(I,NB3+J)
420  CONTINUE
      DUMSUM=DUMSUM/REAL(NBPSD)
DO 421 J=1,NBPSD+1
      TH=REAL(J-1)*2.0*PI/REAL(NBPSD)
      XDUM=0.001*COS(TH)
      YDUM=0.001*SIN(TH)
      WRITE(09,700)XDUM,YDUM,RADF(I)=DENIV,DUMSUM
421  CONTINUE
DO 422 K=1,NBCO
      J=(K-1)*NBPSD+2
      DUMSUM=(DFACLW(I,NB3+J-1)+1
               DFACLW(I,NB3+J+NBPSD-1)+2
               DFACLW(I,NB3+J+NBPSD-2)+3
           DFACLW(I,NB3+J+2*NBPSD-2))/4.0
      WRITE(09,700)XFAC(NB7+J),YFAC(NB7+J),ZFAC(NB7+J),DUMSUM
DO 423 J=(K-1)*NBPSD+3,K*NBPSD+1
      DUMSUM=DFACLW(I,NB3+J-1)+1
      DFACLW(I,NB3+J-2)+2
      DFACLW(I,NB3+J+NBPSD-1)+3
      DFACLW(I,NB3+J+NBPSD-2))/4.0
      WRITE(09,700)XFAC(NB7+J),YFAC(NB7+J),ZFAC(NB7+J),DUMSUM
422  CONTINUE
C
C OUTPUT OF TOTAL DFAC OF FIRST SHELL OF THE DOME
C
      WRITE(09,*),'ZONE T="TT2",I=25, J=10, F=POINT'
      DUMSUM=0.0
      I=1
DO 440 J=1,NBPSD
      NBVE= J + (I-1)*NBCO*NBPSD + NB3
      DUMSUM=DUMSUM+DFACTT(I,NBVE)
440  CONTINUE
      DUMSUM=DUMSUM/REAL(NBPSD)
DO 441 J=1,NBPSD+1
      TH=REAL(J-1)*2.0*PI/REAL(NBPSD)
      XDUM=0.001*COS(TH)
      YDUM=0.001*SIN(TH)
      WRITE(09,700)XDUM,YDUM,RADF(I)=DENIV,DUMSUM
441  CONTINUE
DO 442 K=1,NBCO
      J=(K-1)*NBPSD + 2 + (I-1)*(NBCO*NBPSD+1)
      DUMSUM=DFACTT(I,NB3+J-1)+1
      DFACTT(I,NB3+J+NBPSD-1)+2
      DFACTT(I,NB3+J+NBPSD-2)+3
      DFACTT(I,NB3+J+2*NBPSD-2))/4.0
      WRITE(09,700)XFAC(NB7+J),YFAC(NB7+J),ZFAC(NB7+J),DUMSUM
DO 443 J=(K-1)*NBPSD + 3 + (I-1)*(NBCO*NBPSD+1),
      + K*NBPSD + 1 + (I-1)*(NBCO*NBPSD+1)
      DUMSUM=(DFACTT(I,NB3+J-1)+1
               DFACTT(I,NB3+J-2)+2
               DFACTT(I,NB3+J+NBPSD-1)+3
               DFACTT(I,NB3+J+NBPSD-2))/4
      WRITE(09,700)XFAC(NB7+J),YFAC(NB7+J),ZFAC(NB7+J),DUMSUM
443  CONTINUE
      J=(K-1)*NBPSD + 2 + (I-1)*(NBCO*NBPSD+1)
      DUMSUM=(DFACTT(I,NB3+J-1)+
`DFACTT(I,NB3+J*NBPSD-1)+
2 DFACTT(I,NB1+J*NBPSD-2)+
3 DFACTT(I,NB3+J+2*NBPSD-2))/4.0
WRITE(09,700)XFAC(NB7+J),YFAC(NB7+J),ZFAC(NB7+J),DUMSUM
CONTINUE
C OUTPUT OF TOTAL DFAC TO BARREL
C
WRITE(09,'(I,*)')'ZONE T="BARREL",I=25, J=5, P=POINT'
I=1
J=1
DUMSUM=(DFACTT(I,NB4+1+NBPSB)+DFACTT(I,NB4+1+J))/2.D0
WRITE(09,700)XFAC(NB8+J),YFAC(NB8+J),ZFAC(NB8+J),DUMSUM
DO 460 J=2,NBPSB
DUMSUM=(DFACTT(I,NB4+1+J-1)+DFACTT(I,NB4+1+J))/2.D0
WRITE(09,700)XFAC(NB8+J),YFAC(NB8+J),ZFAC(NB8+J),DUMSUM
CONTINUE
J=1
DUMSUM=(DFACTT(I,NB4+1+NBPSB)+DFACTT(I,NB4+1+J))/2.D0
WRITE(09,700)XFAC(NB8+J),YFAC(NB8+J),ZFAC(NB8+J),DUMSUM
DO 461 K=2,NBHSB
J=(K-1)*NBPSB+1
DUMSUM=(DFACTT(I,NB4+1+J+NBPSB-1)+
1 DFACTT(I,NB4+1+J)+
2 DFACTT(I,NB4+1+J-NBPSB)+
3 DFACTT(I,NB4+1+J-1))/4.0
WRITE(09,700)XFAC(NB8+J),YFAC(NB8+J),ZFAC(NB8+J),DUMSUM
DO 462 J=(K-1)*NBPSB+2,K*NBPSB
DUMSUM=(DFACTT(I,NB4+1+J-1)+
1 DFACTT(I,NB4+1+J)+
2 DFACTT(I,NB4+1+J-NBPSB)+
3 DFACTT(I,NB4+1+J-NBPSB-1))/4
WRITE(09,700)XFAC(NB8+J),YFAC(NB8+J),ZFAC(NB8+J),DUMSUM
CONTINUE
J=(K-1)*NBPSB+1
DUMSUM=(DFACTT(I,NB4+1+J+NBPSB-1)+
1 DFACTT(I,NB4+1+J)+
2 DFACTT(I,NB4+1+J-NBPSB)+
3 DFACTT(I,NB4+1+J-1))/4.0
WRITE(09,700)XFAC(NB8+J),YFAC(NB8+J),ZFAC(NB8+J),DUMSUM
CONTINUE
J=NBHSB*NBPSB+1
DUMSUM=(DFACTT(I,NB4+1+J-1)+DFACTT(I,NB4+1+J-NBPSB))/2.D0
WRITE(09,700)XFAC(NB8+J),YFAC(NB8+J),ZFAC(NB8+J),DUMSUM
DO 463 J=NBHSB*NBPSB+2,(NBHSB+1)*NBPSB
DUMSUM=(DFACTT(I,NB4+1+J-NBPSB-1)+DFACTT(I,NB4+1+J-NBPSB))/2.D0
WRITE(09,700)XFAC(NB8+J),YFAC(NB8+J),ZFAC(NB8+J),DUMSUM
CONTINUE
J=NBHSB*NBPSB+1
DUMSUM=(DFACTT(I,NB4+1+J-1)+DFACTT(I,NB4+1+J-NBPSB))/2.D0
WRITE(09,700)XFAC(NB8+J),YFAC(NB8+J),ZFAC(NB8+J),DUMSUM
C OUTPUT OF TOTAL DFAC TO CONE
C
WRITE(09,'(I,*)')'ZONE T="CONE",I=25, J=7, P=POINT'
I=1
J=1
DUMSUM=(DFACTT(I,NB9+NBPSC)+DFACTT(I,NB9+J))/2.D0
WRITE(09,700)XFAC(NB15+J),YFAC(NB15+J),ZFAC(NB15+J),DUMSUM
DO 464 J=2,NBPSC
DUMSUM=(DFACTT(I,NB9+J-1)+DFACTT(I,NB9+J))/2.D0
WRITE(09,700)XFAC(NB15+J),YFAC(NB15+J),ZFAC(NB15+J),DUMSUM
CONTINUE
J=1
DUMSUM=(DFACTT(I,NB9+NBPSC)+DFACTT(I,NB9+J))/2.D0
Program ERBERT
WRITE(09,700) XFAC(NB15+J), YFAC(NB15+J), ZFAC(NB15+J), DUMSUM
DO 465 K=2, NBHSC
   J=(K-1)*NBPSC+1
   DUMSUM=(DFACTT(I,NB9+J+NBPSC-1) +
            1  DFACTT(I,NB9+J) +
            2  DFACTT(I,NB9+J-NBPSC) +
            3  DFACTT(I,NB9+J-1))/4.0
   WRITE(09,700) XFAC(NB15+J), YFAC(NB15+J), ZFAC(NB15+J), DUMSUM
466 CONTINUE
   J=(K-1)*NBPSC+1
   DUMSUM=(DFACTT(I,NB9+J+NBPSC-1) +
            1  DFACTT(I,NB9+J) +
            2  DFACTT(I,NB9+J-NBPSC) +
            3  DFACTT(I,NB9+J-1))/4.0
   WRITE(09,700) XFAC(NB15+J), YFAC(NB15+J), ZFAC(NB15+J), DUMSUM
465 CONTINUE
   J=NBHSC*NBPSC+1
   DUMSUM=(DFACTT(I,NB9+J-1)+ DFACTT(I,NB9+J-NBPSC))/2.0
   WRITE(09,700) XFAC(NB15+J), YFAC(NB15+J), ZFAC(NB15+J), DUMSUM
DO 467 J=NBHSC*NBPSC+2, (NBHSC+1)*NBPSC
   DUMSUM=(DFACTT(I,NB9+J-NBPSC-1)+ DFACTT(I,NB9+J-NBPSC))/2.0
   WRITE(09,700) XFAC(NB15+J), YFAC(NB15+J), ZFAC(NB15+J), DUMSUM
467 CONTINUE
   J=NBHSC*NBPSC+1
   DUMSUM=(DFACTT(I,NB9+J-1)+ DFACTT(I,NB9+J-NBPSC))/2.0
   WRITE(09,700) XFAC(NB15+J), YFAC(NB15+J), ZFAC(NB15+J), DUMSUM
C OUTPUT OF TOTAL DFACT TO THE PORTION OF THE SUBSTRATE WHICH
C IS VISIBLE TO THE CAVITY (CAVSUB)
C WRITE(09,*),' ZONE T="CAVSUB", I=25, J=2, F=POINT'
I=1
J=1
   DUMSUM=(DFACTT(I,NB11+NBPSCS)+ DFACTT(I,NB11+J)) /2.0
   WRITE(09,700) XFAC(NB16+J), YFAC(NB16+J), ZFAC(NB16+J), DUMSUM
DO 468 J=2, NBPSCS
   DUMSUM=(DFACTT(I,NB11+J-1)+ DFACTT(I,NB11+J))/2.0
   WRITE(09,700) XFAC(NB16+J), YFAC(NB16+J), ZFAC(NB16+J), DUMSUM
468 CONTINUE
   J=NBPSCS+1
   DUMSUM=(DFACTT(I,NB11+J-1)+ DFACTT(I,NB11+J-NBPSCS))/2.0
   WRITE(09,700) XFAC(NB16+J), YFAC(NB16+J), ZFAC(NB16+J), DUMSUM
DO 469 J=NBPSCS+1,2*NBPSCS
   DUMSUM=(DFACTT(I,NB11+J-1)+ DFACTT(I,NB11+J-NBPSCS))/2.0
   WRITE(09,700) XFAC(NB16+J), YFAC(NB16+J), ZFAC(NB16+J), DUMSUM
469 CONTINUE
   J=NBPSCS+1
   DUMSUM=(DFACTT(I,NB11+J-1)+ DFACTT(I,NB11+J-NBPSCS))/2.0
   WRITE(09,700) XFAC(NB16+J), YFAC(NB16+J), ZFAC(NB16+J), DUMSUM
C FOR THE TOTAL CHANNEL ADD A LITTLE RING
C WRITE(09,*),' ZONE T="RING", I=25, J=1, F=POINT'
I=1
J=1
   DUMSUM=(DFACTT(I,NB13+NBPSR)+ DFACTT(I,NB13+J))/2.0
   WRITE(09,700) XFAC(NB17+J), YFAC(NB17+J), ZFAC(NB17+J), DUMSUM
DO 450 J=2, NBPSR
   DUMSUM=(DFACTT(I,NB13+J-1)+ DFACTT(I,NB13+J))/2.0

Program ERBERT 195
WRITE(0,700) XFAC(NB17+J),YFAC(NB17+J),ZFAC(NB17+J),DUMSUM
450 CONTINUE
J=1
DUMSUM=(DFACCT(I,NB13+NBPSC)+DFACCT(I,NB13+J))/(2.*D0)
WRITE(0,700) XFAC(NB17+J),YFAC(NB17+J),ZFAC(NB17+J),DUMSUM
DO 491 K=2,NBHRS
   J=(K-1)*NBPSC+1
   DUMSUM=(DFACCT(I,NB13+J+NBPSC-1)+
   DFACCT(I,NB13+J)+
   DFACCT(I,NB13+J-NBPSC)+
   DFACCT(I,NB13+J-1))/4.0
WRITE(0,700) XFAC(NB17+J),YFAC(NB17+J),ZFAC(NB17+J),DUMSUM
491 CONTINUE
J=(K-1)*NBPSC+1
DUMSUM=(DFACCT(I,NB13+J+NBPSC-1)+
   DFACCT(I,NB13+J)+
   DFACCT(I,NB13+J-NBPSC)+
   DFACCT(I,NB13+J-1))/4.0
WRITE(0,700) XFAC(NB17+J),YFAC(NB17+J),ZFAC(NB17+J),DUMSUM
451 CONTINUE
J=NBPSC*NBPSC+1
DUMSUM=(DFACCT(I,NB13+J-1)+DFACCT(I,NB13+J-NBPSC))/2.*D0
WRITE(0,700) XFAC(NB17+J),YFAC(NB17+J),ZFAC(NB17+J),DUMSUM
DO 453 J=NBSR+2.,(NBPSR+1)1.*NBPSR
   DUMSUM=(DFACCT(I,NB13+J-NBPSC-1)+DFACCT(I,NB13+J-NBPSC))/2.*D0
WRITE(0,700) XFAC(NB17+J),YFAC(NB17+J),ZFAC(NB17+J),DUMSUM
453 CONTINUE
J=NBHSR*NBPSC+1
DUMSUM=(DFACCT(I,NB13+J-1)+DFACCT(I,NB13+J-NBPSC))/2.*D0
WRITE(0,700) XFAC(NB17+J),YFAC(NB17+J),ZFAC(NB17+J),DUMSUM
C
C
END

*********************************************************************)
*) THIS SUBROUTINE DIVIDES THE CONE HORIZONTALLY SO THAT THE *)
*) SURFACE ELEMENTS ARE ALL EQUAL IN SIZE.
*)
*********************************************************************)
SUBROUTINE CONSETUP(DLCON)
IMPLICIT NONE
REAL*8 AREA,PI,DZ,Z,ZZ,H,TANCAV,INDEX
REAL*8 RCAV,LBAR,LCON,CAVANG
REAL*8 REXT,RINT,DENIV
REAL*8 DLCON
INTEGER I
INTEGER NBHSR,NBPSC,NBPSC,NBPSC,NBPSC
DIMENSION DLCON(20)
COMMON /CAVUR/ NBHSR,NBHSC,NBPSC,NBPSC,NBPSC
COMMON /CAVITY/ RCAV,LBAR,LCON,CAVANG
COMMON /DOME/ REXT,RINT,DENIV

Program ERBERT
196
PI = DACOS(-1.0D0)
AREA = PI * RCAV * DSQRT(RCAV**2 + LCON**2)
TANCAV = RCAV / LCON
H = DSQRT(1.0D0 + TANCAV**2)
ZZ = DENV - LB
DO 100 I = 1, NBHSC + 1
   INDEX = (DBLE(NBHSC) + 1.0D0 - DBLE(I)) / DBLE(NBHSC)
   DZ = LCON - DSQRT((AREA * INDEX) / (PI * H * TANCAV))
   DLCON(I) = ZZ - DZ
100 CONTINUE
RETURN
END
Appendix B

Program ERBER1
This FORTRAN 77 program prompts the user for mesh geometry data and then writes the data to input files for the mesh generator and thermal analysis programs. The mesh geometry data is also tabulated for user reference.

Written by Nour E. Tira, and modified by Kory J. Priestley

NOMENCLATURE

ATIP ........ Area of the truncated tip of the cone.
DIM(I) ...... Radiometer part dimension.
DM(I) ...... The element dimensions along dimension I if NUNIF(I) is given as zero.
H0 ........ Height of the cone tip.
MDIV(I) ..... Number of element divisions along dimension I.
NUNIF(I) ... Mesh uniformity flag for dimension I. If its value is zero, then elements along dimension I are spaced unequally and the element dimensions must be input by the user. If its value is one, then elements along dimension I are equally spaced and further mesh computation is done by the mesh generator.
N1 .......... The number of elements around the circumference of the radiometer cavity.
N2 .......... The number of elements around the ring (cavity radius).
N3 .......... The outside radius of the ring.
RT .......... The cone tip radius.

C Request double precision real variables.
C IMPLICIT REAL*8 (A-H,O-Z)
C
C Dimension the arrays and specify the lengths of the character strings.
C
DIMENSION NUNIF(4),DIM(4),MDIV(4),CH(4),DM(60)
CHARACTER*6 CHAR
CHARACTER*1 CH
CHARACTER*3 UNIF

C Open all input and output files.
C
OPEN(1,FILE='msh.dat')
OPEN(3,FILE='rundat.dat')

C Set the logical unit numbers for I/O data files and set the constants in the program.
C
CHAR  = 'ABCDSEF'
PI  = 3.141592654D0

C Set the mesh uniformity flags for the cone and the cylinder.
C The cone mesh will always be non-uniform and the cylinder mesh will always be uniform to allow the elements in each of these sections of the cavity to have equal areas.

Program ERBER1
NUNIF(1) = 0
NUNIF(2) = 1
NUNIF(3) = 1
NUNIF(4) = 1

Read the radiometer dimensions.

WRITE(6,1)
WRITE(6,2)
READ(6,*) DIM(1)
WRITE(6,3)
READ(6,*) DIM(2)
WRITE(6,4)
READ(6,*) RI
WRITE(6,5)
READ(6,*) RO
DIM(3) = RO - RI
WRITE(6,6)
READ(6,*) DIM(4)
WRITE(6,7)
READ(6,*) RT
HO = RT*DIM(1)/(RI-RT)

Read the number of horizontal slices across each dimension.

WRITE(6,9)
WRITE(6,10)
READ(6,*) MDIV(1)
WRITE(6,11)
READ(6,*) MDIV(2)
WRITE(6,12)
READ(6,*) MDIV(3)
WRITE(6,14)
READ(6,*) MDIV(4)

Read the number of elements (pie slices) around the circumference of the cavity.

WRITE(6,19)
READ(6,*) N1

write the mesh geometry data file.

WRITE(1,21) DIM(1),DIM(2),RI,RO,DIM(4),RT,HO
WRITE(1,22) N1,(MDIV(I),I=1,4)
WRITE(1,22) (NUNIF(I),I=1,4)

Since the cone mesh is always non-uniform, (i.e. delta z is not constant) calculate the element dimensions along the cone height so that all the elements of the cone have the same area.

BETA = DATAN(RI/(DIM(1)+HO))
ATIP = PI*RT*DSQRT(RT**2+HO**2)
AREA = PI*RI*DSQRT(RI**2+(DIM(1)+HO)**2) - ATIP
C = (AREA/MDIV(1))**DCOS(BETA)/(PI*DTAN(BETA))
H = HO
DO 50 I = 2, MDIV(1)*2, 2
HI = DSQRT(C + H**2)
DM(I) = (HI - H)/2.0D0
DM(I+1) = DM(I)
H = HI
50 CONTINUE

Write these dimensions to the mesh geometry data file.
WRITE(1,21) (DM(I),I=1,2*MDIV(1))

Write the mesh geometry data to the run data record.

WRITE(3,26)
WRITE(3,27)
WRITE(3,28)
WRITE(3,29)
DO 90 I=1,4
UNTIL = 'YES'
IF (UNTIL.EQ.0) UNTIL = 'NO'
CH(I) = CHAR(I:I)
WRITE(3,30) CH(I),DIM(I),MDIV(I),UNTIL
90 CONTINUE
WRITE(3,26)
WRITE(3,31) RI
WRITE(3,32) RT
WRITE(3,33) N1
STOP

The format statements follow:

1 FORMAT(//,10X,41('*'),//,10X,'*',//,7X,'RADIOMETER GEOMETRY INPUT',
& \ 7X,'*',//,10X,41('**'),///,1X,'THE RADIOMETER DIMENSIONS',
& \ 'FOLLOW',//,1X,32('='),//)
2 FORMAT(1X,'Cone height? (mm)')
3 FORMAT(1X,'Cylinder height? (mm)')
4 FORMAT(1X,'Inside radius of the ring? (mm)')
5 FORMAT(1X,'Outside radius of the ring? (mm)')
6 FORMAT(1X,'Length of the thermal impedance? (mm)')
8 FORMAT(1X,'Cone tip radius? (mm)')
9 FORMAT(//,1X,'THE RADIOMETER MESH SPECIFICATIONS FOLLOW',//, 
& \ 1X,41('='),//)
10 FORMAT(1X,'Number of horizontal slices along cone height?')
11 FORMAT(1X,'Number of horizontal slices along cylinder height?')
12 FORMAT(1X,'Number of washers along ring radius?')
14 FORMAT(1X,'Number of horizontal slices along thermal impedance?')
19 FORMAT(//,1X,'Number of azimuthal divisions around cavity?',
& \ /3X,'(this must be an even number greater than 8)')
21 FORMAT(6D12.5)
22 FORMAT(141S)
23 FORMAT(//,1X,'Enter the subdivisional dimensions for',
& \ 'measurement ','A1',' ','')
24 FORMAT(1X,I2,,' values are required over length ','F5.2',/, 
& \ (separate each by a space)')
26 FORMAT(12X,50(' '))
27 FORMAT(11X,'DIMENSION | MEASUREMENT | NO. OF 
& \ DIVISIONS | UNIFORMITY |')
28 FORMAT(11X,'DIMENSION | (mm) | DIVISIONS | UNIFORMITY |')
29 FORMAT(11X,'DIMENSION | ,50('='),',')
30 FORMAT(11X,'DIMENSION | ,5X,AS,5X,','4X,F5.2,4X,'','4X,I2,5X,'','4X,AS, 
& \ &5X,','')
31 FORMAT(//,10X,'Radius of cavity aperture ..........',
& \ /F4.2, ' (mm)')
32 FORMAT(10X,'Cone tip radius..................... ','F6.4, ' (mm)')
33 FORMAT(10X,'Number of elements around cavity .... ','I3')
END
Appendix C

Program ERBER2
ERBER2 FORTRAN

This FORTRAN 77 program prompts the user for thermal analysis data and then writes this data to input files for the thermal analysis program, 'ERBETA', and 'ERBE EXEC'. A complete record of all run variables, including the mesh geometry data, is also created by this program.

Written by Nour E. Tira, and modified by Kory J. Priestley

NOMENCLATURE

ABS     Absorptivity of the radiometer material.
ALPHA   Resistance-temperature constant.
APJ(I)   Illuminated area at angle I.
COND     Conductivity of the radiometer material.
CP       Specific heat of the radiometer material.
DELT     Temperature drop between resistors and heat sink.
DENS     Density of the radiometer material.
DT       Time increment.
EM       Emissivity of the radiometer material.
E0       Bridge voltage for the feedback circuit.
E2       The steady-state or initial voltage across the electrical substitution heater wire.
FILE1    The name of the disk file which contains the non-uniform initial conditions.
FILE2    The name of the disk file which contains the cavity distribution factors (DFC's).
FILE3    The name of the disk file which contains the aperture distribution factors (DFA's).
FILE4    The name of the disk file which contains the distribution factors for a collimated beam (DPS's).
FMAG(I)  The magnitude of the source field for each time step. Dimensioned NDT.
FMAX     The maximum magnitude of the source field.
HWIRE    Height to which the heater wire is wound above the cone tip.
INIT     The indicator for transient analysis.
          INIT = 0 steady-state analysis
          INIT = 1 transient, uniform initial condition
          INIT = 2 transient, non-uniform i.c.
NPDF(I)  The array of node numbers with specified temperature boundary conditions. Dimensioned NPDF.
LNOD(I)  Array of nodes located at the base of the thermal impedance. Dimensioned nnn.
LNRES(I) Array of nodes along the thermal impedance. Dimensioned NNRES.
NAME     The name of the radiometer material.
NAP      Imaginary aperture element used to describe the position of the entering irradiance vector.
NCAV     The cavity element used to describe the position of the entering irradiance vector.
NDT      Number of time steps in the analysis--equal to one for a steady-state analysis.
NDTS     Number of time steps corresponding to a complete span of the collimated beam.
NF       Indicator for the type of source field.
          NF = 1 constant FMAG
          NF = 2 sinusoidal FMAG
NHEAT    Indicator for the electrical cavity heater.
* NHEAT = 0    heater not utilized in the analysis
* NHEAT = 1    heater utilized in the analysis
* NNB        The number of nodes at the thermal impedance base.
* NNRES      The number of node levels along the thermal
*             impedance, used to select the position of the
*             resistance thermometer.
* NPDF       The number of specified temperature boundary
*             conditions.
* NRAD       Flag indicating thermal radiative analysis.
* NRAD = 0   radiation analysis not performed
* NRAD = 1   radiative analysis performed
* NVEC       Flag indicating the presence of an incoming
*             irradiance vector.
* NVEC = 0   no vector entering cavity
* NVEC = 1   vector entering cavity
* NRES       The first node on the thermal impedance which
*             is covered by the resistance thermometer.
* PHIM       Maximum span angle of the collimated beam.
* REFR       Reflectivity ratio of the radiometer material.
* RI         Inside radius of the cavity.
* SMAG(I)    The magnitude of the collimated beam for each
*             time step. Dimensioned NDT.
* SMAX       The maximum magnitude of the collimated beam.
* TAU        Time constant in the analysis of the voltage
*             across the heater wire.
* TFON       Time during which FMAG is on.
* THETA      Time approximation parameter.
* Theta = 0  forward-difference scheme
* Theta = 1/2 Crank-Nicolson scheme
* Theta = 2/3 Galerkin scheme
* THICK      Thickness of the radiometer material.
* THS        Temperature of the heat sink.
* TMAX       Upper bound on time for a transient analysis.
* TINIT      Radiometer predominant initial temperature.
* TSON       Time during which SMAG is on.
* TVON       Time during which VMAG is on.
* VMAG(I)    The irradiance vector magnitude for each time
*             step. Dimensioned NDT.
* VMAX       The maximum magnitude of the irradiance vector.
* VPDF(I)    Nodal temperatures specified as boundary condi-
*             tions. Dimensioned NPDF.

*****************************************************************************
C Request double precision real variables.
C IMPLICIT REAL*8(A-H,O-Z)
C Dimension the arrays and specify the lengths of the character
C strings.
C
INTEGER CHANEL,CH

DIMENSION IPDF(60),VPDF(60),LNOD(60)
DIMENSION LINE(20),LRES(30),LNRES(20)
DIMENSION FMAG(250)
CHARACTER*1 CHAR
CHARACTER*20 NAME,FILE1,FILE2,FILE3,FILE4
C
C Open all necessary input and output files.
C
OPEN(2,FILE='rundat.dat',status='old')
OPEN(4,FILE='mesh.dat',status='old')
OPEN(5,FILE='nodes.dat',status='old')
OPEN(3,FILE='source.dat')
OPEN(8,FILE='flags.dat')
OPEN(9,FILE='props.dat')
OPEN(10,FILE='time.dat')
OPEN(11,FILE='bdntmp.dat')
OPEN(12,FILE='emiss.dat')
OPEN(13,FILE='heater.dat')
OPEN(15,FILE='temp.dat')
OPEN(21,FILE='ttchanel.input')
OPEN(22,FILE='swchanel.input')
OPEN(43,FILE='init.dat')

Set the logical unit numbers for I/O data files, and initialize the program flags.

DATA NDT,NDTF,NDTV,NDTS/1,1,1,1/
DATA CP,DENS,EM,REFR,ABSP/0.0D0,0.0D0,0.0D0,0.0D0,0.0D0/
PI = 3.141592654D0
READ(4,*) NEM,NNM
READ(4,*) DM1,DM2,DM3,DM4,RI

Input whether the total or visible channel is being considered.

WRITE(6,*)'Which channel is being modeled?'
WRITE(6,*)'Enter 1 for the total channel, or'
WRITE(6,*)'Enter 2 for the visible channel.'
READ(6,*)CHAN
CH=CHANEL=20

Input if the analysis is steady-state or transient.

10 WRITE(6,301)
READ(6,201) CHAR
IF(CHAR.NE.'S'.AND. CHAR.NE.'T') GO TO 10
IF(CHAR.EQ.'S') INIT = 0

If the analysis is transient, input the type of initial conditions present in the model.

IF(CHAR.EQ.'T') THEN
20 WRITE(6,302)
READ(6,201) CHAR
IF(CHAR.NE.'U'.AND. CHAR.NE.'N') GO TO 20
IF(CHAR.EQ.'U') INIT = 1
IF(CHAR.EQ.'N') INIT = 2
ENDIF
WRITE(43,*) INIT

Input the material properties.

WRITE(6,305)
READ(6,202) NAME
WRITE(6,305)
READ(6,*) COND
IF(INIT.GT.0) THEN
WRITE(6,307)
READ(6,*) CP
WRITE(6,308)
READ(6,*) DENS
DENS = DENS/(1000.0D0**2)
ENDIF
DO 11 I=1,11

Program ERBER2
READ(CHK,*)
CONTINUE
READ(CHK,*),EMFOVL
READ(CHK,*),EMUSUB
EMLSUB=EMUSUB
READ(CHK,*),EMBAR
READ(CHK,*),EMCONE
READ(CHK,*),EMCAVSUB
READ(CHK,*),EMRING
WRITE(6,312)
READ(6,*),THCK

C If the analysis is transient, input transient analysis parameters.

IF(INIT.GT.0) THEN
  WRITE(6,313)
  READ(6,*),TMAX
  WRITE(6,314)
  READ(6,*),DT
  WRITE(6,315)
  READ(6,*),THETA
  WRITE(6,316)
  NDT = NINT(TMAX/DT)
ENDIF

C For steady state,

C If the initial conditions are uniform for each zone (i.e. fowl, dome, etc.)
C or semi-uniform, input the predominant initial temperature.

IF(INIT.EQ.0) THEN
  WRITE(6,507)
  READ(6,*),TFOWL
  WRITE(6,508)
  READ(6,*),TUSUB
  WRITE(6,509)
  READ(6,*),TLSUB
  WRITE(6,510)
  READ(6,*),TDOME
  WRITE(6,512)
  READ(6,*),TCAVSUB
  WRITE(6,513)
  READ(6,*),THRING
ENDIF

C If the initial conditions are non-uniform, input the disk file where
C the initial conditions are located.

IF(INIT.EQ.2) THEN
  WRITE(6,323)
  READ(6,202) FILE1
ENDIF

C Read the node numbers located at the base of the T.I, and input the
C temperature of the heat sink. The heat sink temperature will be
C applied to these nodes as a boundary condition after other
C possible boundary conditions are input.

READ(5,*),NNB
DO 50 I=1,NNB
  50 READ(5,*),LNOD(I)
WRITE(6,324)
  READ(6,*),THS

Program ERBER2
Input the number of applied temperature boundary conditions not including the boundary conditions located at the thermal impedance base. The nodes with applied temperature boundary conditions and their temperatures are then input.

WRITE(6,325)
READ(6,*) NPDF
IF(NPDF.NE.0) THEN
  WRITE(6,326)
  WRITE(6,320)
  READ(6,*) (IPDF(I),I=1,NPDF)
  WRITE(6,321)
  WRITE(6,322)
  READ(6,*) (VPDF(I),I=1,NPDF)
ENDIF

Since thermal radiation is considered in the analysis, input the data needed for the thermal analysis.

Initialize the active radiative input arrays
DO 60 I = 1,NDT+1
  FMAG(I) = 0.0D0
  CONTINUE

Input the maximum magnitude of the source field and specify whether it is constant or sinusoidal.
WRITE(6,330)
READ(6,*) FMAX
IF(INIT.EQ.0) THEN
  FMAG(I) = FMAX
ELSE
  WRITE(6,345)
  READ(6,*) NF

Input time during which FMAG is on, and calculate the corresponding number of time steps.
WRITE(6,346)
READ(6,*) TFON
NDTF = NINT(TFON/DT)

Calculate FMAG for each time step.
T = 0.0D0
DO 65 I = 1,NDTF
  IF(NF.EQ.1) THEN
    FMAG(I) = FMAX
  ELSE
    T = T + DT
    FMAG(I) = FMAX*DSIN(PI*T/TFON)
    IF(FMAG(I).LE.0.1E-08) FMAG(I) = 0.0D0
  ENDIF
  65 CONTINUE
END IF

Since the electrical substitution heater is being utilized in the analysis, read the heater voltage, resistance and wire height.
WRITE(6,336)
READ(6,*) E2
WRITE(6,337)
READ(6,*) RH
WRITE(6,338)
READ(6,*) HWIRE

If the analysis is transient, read the bridge voltage, circuit time
constant, resistance-temperature constant and the temperature drop.

IF(INIT.GT.0) THEN
  WRITE(6,339)
  READ(6,*) ALPHA
  WRITE(6,340)
  READ(6,*) E0
  WRITE(6,341)
  READ(6,*) TAU
  WRITE(6,342)
  READ(6,*) DELT
ENDIF

Read the node numbers along the edge of leg 1 which are used to selec
the position of the resistance thermometers on the legs, input the
node on leg 1 describing the position of the resistance thermometers,
then determine the nodes covered by the thermometers.

READ(5,204) NNRES
DO 70 I = 1,NNRES
  READ(5,204) LNRES(I)
WRITE(6,343) (LNRES(I),I=1,NNRES)
READ(6,*) NRES
DO 80 I = 1,NNB
  LRES(I) = NRES + I - 1
80 CONTINUE

Write the thermal analysis data necessary for the thermal analysis
program ‘ERBETA’. First, assign the temperature of the heat sink
as an applied temperature boundary condition to the nodes at the
ends of the legs.

K1 = 1 + NPDF
K2 = NNB + NPDF
K = 0
DO 90 I = K1,K2
  K = K+1
  IPDF(I) = LNOD(K)
  VPDF(I) = THS
90 CONTINUE
NPDF = NPDF + NNB

Write the program flags,

WRITE(8,*) CHANEL
WRITE(8,204) INIT,NPDF,NRES

the material properties,

WRITE(9,206) COND,THCK,CP,DENS

the applied temperature boundary condition data,

IF(NPDF.NE.0) THEN
  WRITE(11,204) (IPDF(I),I=1,NPDF)
  WRITE(11,206) (VPDF(I),I=1,NPDF)
ENDIF

For a transient analysis, write the time increment, the time limit, time approximation parameter, and the initial conditions if they are uniform or semi-uniform.

IF (INIT.NE.0) WRITE(10,206) DT,TMAX,THETA,TSNO
IF (INIT.NE.0) WRITE(10,204) NDT,NDTF,NDTV,NDTS
IF(INIT.EQ.1) WRITE(10,206) TINIT

Write the source field magnitude for each timestep.

WRITE(3,206) (FMAG(I),I=1,NDT)

Write the parameters needed for the analysis of the heater circuit.

WRITE(13,206) E2,RH,HWIRE
WRITE(13,204) NRES
IF (INIT.GT.0) WRITE(13,206) E0,TAU,ALPHA,DELT

Write the surface radiative properties to a file to be read by the thermal analysis code.

WRITE(12,*)EMPOVL
WRITE(12,*)EMUSUB
WRITE(12,*)EMLSUB
WRITE(12,*)EMDOME
WRITE(12,*)EMBAR
WRITE(12,*)EMCONE
WRITE(12,*)EMCAGSUB
WRITE(12,*)EMRING

Write the zonal surface temperatures for uniform and constant conditions.

WRITE(15,*)TPOVL
WRITE(15,*)TUSUB
WRITE(15,*)TLSUB
WRITE(15,*)TDOME
WRITE(15,*)TCAV
WRITE(15,*)TCAVSUB
WRITE(15,*)TRIN3

Read the mesh geometry data chart provided by 'ERBER1', and write the chart into the run data record.

DO 120 I=1,12
READ(2,205) LINE
120 WRITE(42,205) LINE

Read the number of elements and nodes in the mesh and write them to the data record along with the name of the radiometer material.

WRITE(42,401) NEM,NNM
WRITE(42,402) NAME

Write all the data needed for the thermal analysis to the run data record in the same manner as previously described. First, write the material properties.

WRITE(42,403) COND
IF(INIT.GT.0) THEN
WRITE(42,404) CP
WRITE(42,405) DENS
ENDIF
WRITE(42,406) EM
WRITE(42,408) REFR
WRITE(42,409) THCK

Write the type of analysis.

IF (INIT.EQ.0) THEN
    WRITE(42,410)
Write the data necessary for a transient analysis including the
initial conditions.

ELSE
    WRITE(42,411) TMAX, DT, THETA
    WRITE(42,412)
    IF (INIT.EQ.1) WRITE(42,413) TINIT
    IF (INIT.EQ.2) WRITE(42,416) FILE1
ENDIF

Write the boundary conditions.

IF (NPDF.NE.0) THEN
    WRITE(42,417)
    DO 140 I = 1, NPDF
140         WRITE(42,415) IPDF(I), VPDF(I)
    ENDIF
Write the position and the magnitudes of the source irradiance

WRITE(42,420)
WRITE(42,422)
DO 160 I = 1, NDT
160       WRITE(42,423) I, FMAG(I)

Write the data for the electrical substitution heater.

WRITE(42,424) LRES(1), LRES(NNB)
WRITE(42,426)
WRITE(42,427) E2, RH
IF (INIT.GT.0) WRITE(42,428) E0, TAU, ALPHA, DELT
WRITE(42,429) HWIRE
STOP

The format statements for data input follow:

201 FORMAT(A1)
202 FORMAT(20A)
203 FORMAT(3F5.2, 5I5, 2F10.5)
204 FORMAT(16I5)
205 FORMAT(20A4)
206 FORMAT(6D12.5)
207 FORMAT(I5, D14.5)
208 FORMAT(30A)

The format statements to prompt the user for input follow:

301 FORMAT(/, 10X, 36('**'), //, 10X, '**', 6X, 'THERMAL ANALYSIS INPUT',
         & 6X, '**', //, 10X, 36('**'), //, 1X, 'Transient or steady-state ',
         & 'analysis? (T/S)'
302 FORMAT(1X, 'Zonally uniform or non-unif. initial conditions? (U/N)')
305 FORMAT(1X,'Radiometer material? (20 character limit)')
306 FORMAT(1X,'Material properties follow::',/5X,
  'Conductivity? (W/m-K)')
307 FORMAT(5X,'Specific heat? (J/kg-K)')
308 FORMAT(5X,'Density? (kg/cu meter)')
312 FORMAT(5X,'Cavity thickness? (mm)')
313 FORMAT(1X,'Transient analysis parameters follow::',/5X,
  'The maximum time limit? (sec)')
314 FORMAT(5X,'Time increment? (s)')
315 FORMAT(5X,'Time approximation parameter (THETA)?',/5X,
  '& 10X,'THETA = 0.00 Forward-difference scheme',/5X,
  '& 10X,'THETA = 0.50 Crank-Nicolson scheme',/5X,
  '& 10X,'THETA = 0.66 Galerkin scheme',/5X,
  '& 10X,'THETA = 1.00 Backward-difference scheme')
316 FORMAT(1X,'Initial conditions follow::')
507 FORMAT(5X,'Predominant initial FOV temperature? (K)')
508 FORMAT(5X,'Predominant initial usub temperature? (K)')
509 FORMAT(5X,'Predominant initial lsu sub temperature? (K)')
510 FORMAT(5X,'Predominant initial dome temperature? (K)')
512 FORMAT(5X,'Predominant initial cav sub temperature? (K)')
513 FORMAT(5X,'Predominant initial ring temperature? (K)')
320 FORMAT(10X,'(separate each with a space)')
321 FORMAT(5X,'Temperatures of these nodes? (K)')
322 FORMAT(10X,'(give in same order and separate each with a space)')
323 FORMAT(5X,'File where initial conditions are located?::',/5X,
  '<fn> <ft> <fm> '5X,' file and format specified')
324 FORMAT(1X,'Boundary conditions follow::',/5X,'Temperature of ',
  'the heat sink? (K)')
325 FORMAT(5X,'How many nodes with an applied temperature boundary',
  'condition (32 Max)?',/10X,'(Do not include nodes at ',
  'thermal impedance base)')
326 FORMAT(5X,'Node numbers with applied temperature?')
330 FORMAT(1X,'Radiative environment input follows::',/5X,
  'Maximum magnitude of the source field? (mW)')
351 FORMAT(5X,'Maximum magnitude of the irradiance vector? (mW)')
345 FORMAT(5X,'Inter 1 if FMAG is constant, and 2 if it is sinusoidal.')
346 FORMAT(5X,'Time during which FMAG is on? (sec)')
555 FORMAT(5X,'Angle of incidence w/r to aperture normal? (Deg.)')
331 FORMAT(5X,'File where the DFC values are located?::',/5X,
  '<fn> <ft> <fm> '5X,' file and format specified')
332 FORMAT(5X,'Is there an irradiance vector entering the ',
  'cavity? (Y/N)')
333 FORMAT(5X,'Aperature and cavity elements describing its',
  'position?')
334 FORMAT(5X,'Magnitude of the irradiance vector for each time',
  'step? mW',/5X,' values required.')
335 FORMAT(5X,'File where the DFAC values from the FOVL aperture',
  'are located?::',/5X,
  '<fn> <ft> <fm> '5X,' file and format specified')
336 FORMAT(1X,'Electrical substitution heater data input follows::',
  '5X,'Initial/Steady-state heater voltage? (V)')
337 FORMAT(5X,'The resistance of the heater wire? (ohms)')
338 FORMAT(5X,'The height of heater wire on the cavity? (mm)')
339 FORMAT(5X,'The temperature-resistance constant? (1/K)')
340 FORMAT(5X,'The bridge voltage? (V)')
341 FORMAT(5X,'The circuit time constant? (sec)')
342 FORMAT(5X,'The desired temperature drop between the resistor',
  'and the heat sink? (K)')
343 FORMAT(5X,'The lowest node number on the thermal impedance',
  'covered by the resistor?::',/5X,
  'the following nodes are valid choices::',/5X,'1215,')
The format statements for the run data record follow:

401 FORMAT(1X,'Number of elements in mesh ......... ',I3,/, &
          10X,'Number of nodes in mesh ......... ',I3,/)  
402 FORMAT(10X,'Radiometer material: ',20A)  
403 FORMAT(15X,'Conductivity ............ ',F10.5, 'mW/mm-K')  
404 FORMAT(15X,'Specific heat ............ ',F10.5, 'mW-s/g-K')  
405 FORMAT(15X,'Density ............ ',F10.5, 'g/mm**3')  
406 FORMAT(15X,'Emissivity ............ ',F10.5)  
407 FORMAT(15X,'Absorptivity ............ ',F10.5)  
408 FORMAT(15X,'Reflectivity ratio ............ ',F10.5)  
409 FORMAT(15X,'Thickness ............ ',F10.5, 'mm')  
410 FORMAT(/,10X,'Analysis: Steady-state')  
411 FORMAT(/,10X,'Analysis: Transient',/, &
          15X,'Time limit ............. ',F10.5, 's',/, &
          15X,'Time increment ............. ',F10.5, 's',/, &
          15X,'Time parameter ............. ',F7.2)  
412 FORMAT(/,10X,'Initial conditions:')  
413 FORMAT(15X,'Predominant initial temperature ...,F6.2, 'K')  
415 FORMAT(18X,I3,13X,F6.2)  
416 FORMAT(15X,'Non-uniform initial temperatures from file: ',20A)  
417 FORMAT(/,10X,'Boundary conditions:',/, &
          18X,'Node',10X,'Temperature K')  
419 FORMAT(/,10X,'Thermal radiation neglected')  
420 FORMAT(/,10X,'Radiative environment:')  
421 FORMAT(15X,'Irradiance vector position: ',I2, ' to ',I2,/)  
430 FORMAT(15X,'Collimated beam angle: ',F6.2, 'Deg')  
418 FORMAT(15X,'Collimated beam angle span: from ',F6.2, ' to ',F6.2, &
          ' Deg')  
422 FORMAT(15X,'Time',6X,'Field',9X,'Vector',9X,/, &
          15X,'step',4X,'magnitude',6X,'magnitude',/,,26X,'mW',11X, &
          ' mW')  
722 FORMAT(15X,'Magnitude of the collimated beam: ',F10.5, 'mW/mm**2' &
          /)  
423 FORMAT(14X,I3,5X,E10.5,5X,E10.5)  
424 FORMAT(/,15X,'Thermometer location',/, &
          15X,'Thermal Impedance Nodes ............ ',I3, ' TO ',I3)  
425 FORMAT(/,10X,'Electrical substitution heater not utilized')  
426 FORMAT(/,10X,'Electrical substitution heater:')  
427 FORMAT(/,15X,'Heater voltage ............ ',F7.2, 'volts')  
428 FORMAT(/,15X,'Bridge voltage ............ ',F7.2, 'volts',/, &
          15X,'Time constant ............ ',F7.2, 's',/, &
          15X,'Resistance-temperature',/, &
          15X,'constant ............ ',F7.5, '1/K',/, &
          15X,'Temperature drop ............ ',F7.5, 'K')  
429 FORMAT(/,15X,'Heater wire height ............ ',F7.2, 'mm')  
433 FORMAT(5X,'Time during which SMAG is on? (sec)')  
454 FORMAT(5X,'Maximum angle w/r to aperture normal? (Deg.)')  
455 FORMAT(5X,'Solar port Radius? (mm)')  
456 FORMAT(5X,'Distance between Solar port and aperture planes? (mm)')
Appendix D

Program ERBER3
PROGRAM ERBER3

C This program modifies the output of erbert.f into the
form needed by erbeta.f. (DFAC's). It also creates the
file numb.dat

IMPLICIT DOUBLE PRECISION (A-H,O-Z)
INTEGER CH, CHANSEL

DIMENSION DFBAR(200,100,15),DFCONE(200,100,15),DFRING(200,100,15)
DIMENSION DFSCLN(1,100,15),DFOPT(200,100,15)
DIMENSION DFSOME(200,100,15),DFCSUB(200,100,15)
DIMENSION DFSUSUB(200,100,15),DFLSUB(200,100,15)

OPEN(7,FILE='dfacmtx.dat',status='old')
OPEN(11,FILE='ttchanel.inp',status='old')
OPEN(12,FILE='swchanel.inp',status='old')
OPEN(16,FILE='numb.dat')
OPEN(17,FILE='dfac.dat')
OPEN(20,FILE='dfopt.dat')
OPEN(21,FILE='dfscn.dat')
OPEN(22,FILE='dfscav.dat')
OPEN(23,FILE='dfsdome.dat')
OPEN(24,FILE='dfring.dat')
OPEN(65,FILE='dfcsub.dat')
OPEN(66,FILE='dfusub.dat')
OPEN(67,FILE='dflsub.dat')
OPEN(68,FILE='dfbar.dat')
OPEN(69,FILE='dfcone.dat')

WRITE(6,'(A)')'Which channel do you wish to model?'
WRITE(6,'(A)')'For total channel enter 1.'
WRITE(6,'(A)')'For visible channel enter 2.'
READ(6,'(A)')CHANSEL
IF (CHANSEL.NE.1.AND.CHANSEL.NE.2) GO TO 1
CHANSEL=CHANSEL+10
DO 10 I=1,33
 READ(CH,*)
10 CONTINUE
READ(CH,*),NBLAT
READ(CH,*),NBLONG
READ(CH,*),NBLSU
READ(CH,*),NBWLSU
READ(CH,*),NBWASH
READ(CH,*),NBPS
READ(CH,*),NBSH
READ(CH,*),NBFCO
READ(CH,*),NBPSD
READ(CH,*),NBPSB
READ(CH,*),NBPSO
READ(CH,*),NBPSR
READ(CH,*),NBHSB

Program ERBER3
READ(CH,*)NBHSC
READ(CH,*)NBPSCS
READ(CH,*)NBHSR
READ(CH,*)NBWLN
write(6,*)'nbwlin =',nbwlin

CREATE DATA FOR FILE NUMB.DAT

NBFOVL=NBPS*NBLAT
NBUSUB=NBPS*NBWASH
NBLSUB=NBPS*NBLWSU
NBCAVSUB=NBPS
NBRRING=NBPS*NBHSR
NBDOME=NBPS*NBSH*NBCO
NBSCENE=1
NBBAR=NBPS*NBHSB
NBONE=NBPS*NBHSC
NCAV=NBBAR+NBONE
NBDUM=NBFOVL+NBUSUB+NELSUB+NBDOME+NBSCENE
NBDUM2=NBRRING+NCAV
write(6,*)'nbdum =',nbdum
write(6,*)'nbdum2 =',nbdum2
write(6,*)'ncav =',ncav
write(6,*)'nbfovl =',nbfovl
write(6,*)'nbusub =',nbusub
write(6,*)'nblsub =',nblsub
write(6,*)'nbdom =',nbdom
write(6,*)'nbscene =',nbscene

CALL ZERO(DFSCE)
CALL ZERO(DFSCE)
CALL ZERO(DFSCE)
CALL ZERO(DFSCE)

SET UP DFSCE
nn=0
DO 20 I=1,NBSCENE
   READ(7,*)
   nn=nn+1
   DO 22 K=1,NBWLN
      DO 30 L=1,NBDUM
         READ(7,*)
         nn=nn+1
      30 CONTINUE
   22 CONTINUE
   DO 24 J=1,NBCAV
      READ(7,*)M,N,DFSCE(I,J,K)
      nn=nn+1
   24 CONTINUE
   DO 32 L=1,NBDUM2
      READ(7,*)
      nn=nn+1
  32 CONTINUE
   DO 20 L=1,NBDUM2
      READ(7,*)
      nn=nn+1
   20 CONTINUE
   write(6,*)'nn','nn

SET UP DFSCE
DO 40 I=1,NBFOVL,NBPS
   READ(C,*)
   nn=nn+1

Program ERBER3
DO 42 K=1,NBWLIN
   DO 50 L=1,NBDUM
      nn=nn+1
      READ(7,*)
      CONTINUE
   DO 44 J=1,NBCAV
      nn=nn+1
      READ(7,*)M,N,DFOPT(I,J,K)
   CONTINUE
   DO 52 L=1,NBDUM2
      nn=nn+1
      READ(7,*)
      CONTINUE
50 CONTINUE
42 CONTINUE
40 CONTINUE
CALL DFCALC(NBWLIN,(NBFOVL/NBPS),NBPS,DFOPT)
WRITE(6,*)'nn'.nn

SET UP DFLSUB

DO 60 I=1,NBLSUB,NBPS
   READ(7,*)
   nn=nn+1
   DO 62 K=1,NBWLIN
      DO 70 L=1,NBDUM
         nn=nn+1
         READ(7,*)
      CONTINUE
      DO 64 J=1,NBCAV
         nn=nn+1
         READ(7,*)M,N,DFLSUB(I,J,K)
      CONTINUE
   CONTINUE
   DO 72 L=1,NBDUM2
      nn=nn+1
      READ(7,*)
   CONTINUE
62 CONTINUE
60 CONTINUE
60 CALL DFCALC(NBWLIN,(NBLSUB/NBPS),NBPS,DFLSUB)
WRITE(6,*)'nn',nn

SET UP DFUSUB

DO 80 I=1,NBUSUB,NBPS
   READ(7,*)
   nn=nn+1
   DO 82 K=1,NBWLIN
      DO 90 L=1,NBDUM
         nn=nn+1
         READ(7,*)
      CONTINUE
      DO 84 J=1,NBCAV
         nn=nn+1
         READ(7,*)M,N,DFUSUB(I,J,K)
      CONTINUE
   CONTINUE
   DO 92 L=1,NBDUM2
      nn=nn+1
      READ(7,*)
   CONTINUE
82 CONTINUE
80 CONTINUE
80 CALL DFCALC(NBWLIN,(NBUSUB/NBPS),NBPS,DFUSUB)
WRITE(6,*)'nn',nn
SET UP DF Dome

IF (CHANEL .EQ. 2) THEN
   DO 100 I=1, NB Dome, NBPS
      nn=nn+1
      READ(7,*)
      DO 102 K=1, NBW LIN
         DO 110 L=1, NB Dome
            nn=nn+1
            READ(7,*)
            CONTINUE
      102   CONTINUE
      DO 104 J=1, NB CAV
         nn=nn+1
         READ(7,*) M, N, DF Dome(I, J, K)
      104   CONTINUE
   100  CONTINUE
   CONTINUE
   ELSE
      DO 114 I=1, NB Dome, NBPS
      DO 114 K=1, NBW LIN
      DO 114 J=1, NBCAV
         DF Dome(I, J, K)=0.0D0
      114  CONTINUE
   END IF
   CALL DFCALC(NBW LIN, (NB Dome/NBPS), NBPS, DF Dome)
   write(6,*)’nn’, nn

SET UP DFBAR

DO 120 I=1, NB BAR, NBPS
   nn=nn+1
   READ(7,*)
   DO 122 K=1, NBW LIN
      DO 130 L=1, NBCUM
         nn=nn+1
         READ(7,*)
      130   CONTINUE
   DO 124 J=1, NBCAV
      nn=nn+1
      READ(7,*) M, N, DFBAR(I, J, K)
   124  CONTINUE
   DO 128 L=1, NB Dome2
      nn=nn+1
      READ(7,*)
   128  CONTINUE
   CONTINUE
   CALL DFCALC(NBW LIN, (NB BAR/NBPS), NBPS, DFBAR)
   write(6,*)’nn’, nn

SET UP DF Cone

DO 125 I=1, NBCONE, NBPS
   write(6,*)’i=’, I
   nn=nn+1
   READ(7,*)
   DO 126 K=1, NBW LIN
      DO 128 L=1, NBCUM
         nn=nn+1
         READ(7,*)
      128   CONTINUE
   126  CONTINUE
   CONTINUE
   CALL DFCALC(NBW LIN, (NBCONE/NBPS), NBPS, DF Cone)
   write(6,*)’nn’, nn

Program ERBER3
128 CONTINUE
   DO 127 J=1,NBCAV
      nn=nn+1
      READ(7,*),M,N,DFCON(I,J,K)
127 CONTINUE
   DO 129 L=1,NBDUM2
      nn=nn+1
   READ(7,*)
129 CONTINUE
126 CONTINUE
125 CONTINUE
   NNN=6
   CALL DFCALC(NBWLIN,NNN,NBPS,DFCON)

C SET UP DFCSUB

   DO 140 I=1,NECAVSUB,NBPS
      nn=nn+1
      READ(7,*)
   DO 142 K=1,NBWLIN
   DO 150 L=1,NBDUM
      nn=nn+1
      READ(7,*)
150 CONTINUE
   DO 144 J=1,NBCAV
      nn=nn+1
      READ(7,*),M,N,DFCSUB(I,J,K)
144 CONTINUE
   DO 152 L=1,NBDUM2
      nn=nn+1
      READ(7,*)
152 CONTINUE
142 CONTINUE
140 CONTINUE
   CALL DFCALC(NBWLIN,(NBCAVSUB/NBPS),NBPS,DFCSUB)
   WRITE(6,*),'nn',nn

C SET UP DFRING

   IF (CHANEL.EQ.1) THEN
      DO 160 I=1,NBRING,NBPS
         nn=nn+1
         READ(7,*)
      DO 162 K=1,NBWLIN
      DO 170 L=1,NBDUM
         nn=nn+1
         READ(7,*)
170 CONTINUE
      DO 164 J=1,NBCAV
         nn=nn+1
         READ(7,*),M,N,DFRING(I,J,K)
164 CONTINUE
      DO 172 L=1,NBDUM2
         nn=nn+1
         READ(7,*)
172 CONTINUE
162 CONTINUE
160 CONTINUE
164 CONTINUE
   ELSE
      DO 174 I=1,NBRING,NBPS
      DO 174 K=1,NBWLIN
      DO 174 J=1,NBCAV
         DFRING(I,J,K)=0.0D0
174 CONTINUE
   END IF
CALL DFCALC(NBWLIN,(NBRING/NBPS),NBPS,DFRING)
write(6,*)'nn',nn

WRITE OUTPUT TO PROPER FILES FOR ERBETA.F

FIRST CREATE NUMB.DAT

WRITE(16,*),NBFOVL
WRITE(16,*),NBUSUB
WRITE(16,*),NBLSUB
WRITE(16,*),NBCAVSUB
WRITE(16,*),NBRING
WRITE(16,*),NBDOME
WRITE(16,*),NBSCENE
WRITE(16,*),NBBAR
WRITE(16,*),NBBONE

CREATE DFSCN.DAT

DO 180 I=1,NBSCENE
    DO 180 K=1,NBWLIN
    DO 180 J=1,NBCAV
        WRITE(21,*),DFSCN(I,J,K)
    180 CONTINUE

CREATE DFOPT.DAT

DO 190 I=1,NBFOVL
    DO 190 K=1,NBWLIN
    DO 190 J=1,NBCAV
        WRITE(20,*),DFOPT(I,J,K)
    190 CONTINUE

CREATE DFEMOE.DAT

DO 200 I=1,NBDOME
    DO 200 K=1,NBWLIN
    DO 200 J=1,NBCAV
        WRITE(23,*),DFDOME(I,J,K)
    200 CONTINUE

CREATE DFRING.DAT

DO 210 I=1,NBRING
    DO 210 K=1,NBWLIN
    DO 210 J=1,NBCAV
        WRITE(24,*),DFRING(I,J,K)
    210 CONTINUE

CREATE DFBAR.DAT

DO 220 I=1,NBBAR
    DO 220 K=1,NBWLIN
    DO 220 J=1,NBCAV
        WRITE(68,*),DFBAR(I,J,K)
    220 CONTINUE

CREATE DFCONE.DAT

DO 225 I=1,NBBCONE
    DO 225 K=1,NBWLIN
    DO 225 J=1,NBCAV
        WRITE(69,*),DFCONE(I,J,K)

Program ERBER3
225 CONTINUE

CREATE DFCSUB.DAT

DO 230 I=1,NBCAVSUB
DO 230 K=1,NBWLIN
DO 230 J=1,NBCAV
   WRITE(65,*)DFCSUB(I,J,K)
230 CONTINUE

CREATE DFUSUB.DAT

DO 240 I=1,NBHUSUB
DO 240 K=1,NBWLIN
DO 240 J=1,NBCAV
   WRITE(66,*)DFUSUB(I,J,K)
240 CONTINUE

CREATE DFLSUB.DAT

DO 250 I=1,NBLSUB
DO 250 K=1,NBWLIN
DO 250 J=1,NBCAV
   WRITE(67,*)DFLSUB(I,J,K)
250 CONTINUE

END

**********************************************************************

*  *
*  *
**********************************************************************

SUBROUTINE ZERO(DF)

REAL*8 DF
INTEGER I,J,K
DIMENSION DF(200,100,15)

DO 10 K=1,15
DO 10 I=1,200
DO 10 J=1,100
   DF(I,J,K)=0.0D0
10 CONTINUE

END

**********************************************************************

*  *
*  *
**********************************************************************

SUBROUTINE DFCALC(NBWLIN,NBHS,NBPS,DFAC)

REAL*8 DFAC
INTEGER NBWLIN,NBHS,NBPS
INTEGER I,J,K,I1,I2,I3,LL
DIMENSION DFAC(200,100,15)
write(17,*)nbhs

Create three dimensional DFAC matrix

DO 250 K=1,NBWLIN
   DO 120 I1=1,NBHS
      write(17,*)i1
   DO 130 J=1,NBPS
      DO 130 I2=1,10
         DFAC((I1-1)*NBPS+J,(I2-1)*NBPS+K) =
         DFAC((I1-1)*NBPS+1,(I2-1)*NBPS+1,K)
250 CONTINUE
120 CONTINUE
130 CONTINUE
130    CONTINUE
   DO 140 LL=1,NBPS-1
   DO 150 J=1,NBPS-LL
   DO 150 I2=1,10
      DPAC((I1-1)*NBPS+J,(I2-1)*NBPS+J*LL,K) =
      & DPAC((I1-1)*NBPS+1,(I2-1)*NBPS+1+LL,K)
150    CONTINUE
   I3=0
   DO 160 J=NBPS-LL+1,NBPS
      I3=I3+1
   DO 160 I2=1,10
      DPAC((I1-1)*NBPS+J,(I2-1)*NBPS+I3,K) =
      & DPAC((I1-1)*NBPS+1,(I2-1)*NBPS+1+LL,K)
160    CONTINUE
140    CONTINUE
120    CONTINUE
250    CONTINUE
   DO 1 I=1,NBHS*NBPS
   DO 1 K=1,NBWLIN
   DO 1 J=1,100
1     CONTINUE
END
Appendix E

Program ERBER4
ERBER4 FORTRAN

This FORTRAN 77 program sets up the temperature distribution files needed by 'ERBETA'. The user is prompted for all necessary information.

Written by Kory J. Priestley

IMPLICIT DOUBLE PRECISION(A-L,O-Z)

OPEN(29,FILE='tfovl.dat')
OPEN(30,FILE='tusub.dat')
OPEN(31,FILE='tlsub.dat')
OPEN(32,FILE='tdome.dat')
OPEN(33,FILE='tring.dat')
OPEN(34,FILE='tcavsub.dat')
OPEN(35,FILE='tcav.dat')
OPEN(36,FILE='tscn.dat')
OPEN(3,FILE='source.dat')

WRITE(6,*)'Number of rows needed in files?'
READ(6,*)NROW
NROW=60
WRITE(6,*)'Flux from shortwave source?'
READ(6,*)SWFLUX
SWFLUX=0.0D0
WRITE(6,*)'Temperature of shortwave source?'
READ(6,*)SWTEMP
SWTEMP=5780.0D0
WRITE(6,*)'Flux from longwave source?'
READ(6,*)LWFLUX
WRITE(6,*)'Temperature of longwave source?'
READ(6,*)LWTEMP
WRITE(6,*)'Temperature of the FOVL?'
READ(6,*)TFOVL
WRITE(6,*)'Temperature of the USUB?'
READ(6,*)TUSUB
TUSUB=TFOVL
WRITE(6,*)'Temperature of the LSUB?'
READ(6,*)TLSUB
WRITE(6,*)'Temperature of the primary aperture?'
READ(6,*)TAPER
TLSUB=TAPER
TCAVSUB=TAPER
WRITE(6,*)'Temperature of the CAVSUB?'
READ(6,*)TCAVSUB
WRITE(6,*)'Temperature of the RING?'
READ(6,*)TRING
TING=TFOVL
WRITE(6,*)'Temperature of the DOME?'
READ(6,*)TDOME
TDOME=0.0D0
WRITE(6,*)'Temperature of the cavity?'
READ(6,*)TCAV
TCAV=308.0D0

DO 10 N=1,NROW
  WRITE(3,*)SWFLUX,LWFLUX
  WRITE(29,*)TFOVL
  WRITE(30,*)TUSUB
  WRITE(31,*)TLSUB

Program ERBER4

223
WRITE(32,*)TDOME
WRITE(33,*)TRING
WRITE(34,*)TCAVSUB
WRITE(35,*)TCAV
WRITE(36,*)SWTEMP,LWTEMP
10 CONTINUE
END
Appendix F

Program ERBEMESH
ERBEMSH FORTRAN

This FORTRAN 77 program generates three-dimensional mesh geometry data required for 'MOVIE.BYU' and two-dimensional mesh geometry data required for 'ERBETA FORTRAN'. The global node coordinates, connectivity array and parts array for a three-dimensional mesh are determined for 'MOVIE.BYU', and the local node coordinates and connectivity array for a two-dimensional mesh are determined for 'ERBETA FORTRAN'.

Written by Nour E. Tira, and modified by Kory J. Priestley

Nomenclature

ATIP ........ Area of the truncated tip of the cone.

DIM(I) ....... Radiometer part dimension. Dimensioned 4.
  I = 1  cone height
  I = 2  cylinder height
  I = 3  radial width of ring (RO - RI)
  I = 4  thermal impedance length.

DM(J) ....... The element dimensions along DIM(I), for
  0 < I < 4. Dimensioned two times the sum
  of MDIV(I), for I = 1 to 4.

DN(I) ....... The element dimensions over the leg width.
  Dimensioned two times MDIV(4).

H0 .......... The cone tip height.

JP(I) ....... Connectivity array of the three-dimensional mesh
  for 'MOVIE.BYU'. Dimensioned NEDGE.

K1 .......... The last node level in the cone mesh.

K2 .......... The last node level in the cavity mesh.

K3 .......... The last node level in the ring mesh.

K4 .......... Number of node levels in the entire model.

MDIV(I) .... Number of element divisions along DIM(I).
  Dimensioned 4.

NESC ........ Number of elements in the cone mesh.

NCY ........ Number of elements in the cylinder mesh.

NEDGE ...... Number of element edges in the three-dimensional
  mesh.

NEM .......... Total number of elements in the mesh.

NERG .......... Number of elements in the ring mesh.

NETI .......... Number of elements in the thermal impedance.

NMB .......... Number of nodes at the thermal impedance base,
  used as heat sink boundary conditions nodes.

NNM .......... Total number of global nodes in the mesh.

NRT .......... First node of each node level on the thermal
  impedance, used to select the position of the
  resistance thermometer.

NOD(N,J) .... Global node number corresponding to local node J
  of element N (connectivity array) of the
  two-dimensional mesh. Dimensioned NEM by 9.

NP .......... Number of parts in the three-dimensional mesh.

NPL(I,J) .... The lower (I = 1) and upper (I = 2) limits on the
  element numbers in radiometer part J. Dimensioned
  2 by NP.
  J = 1  cone
  J = 2  cylinder
  J = 3  ring
  J = 4  Thermal impedance

NUNIF(I) .... Mesh uniformity flag for DIM(I). If its
* value is zero, then elements along dimension I
* are spaced unequally and the element dimensions
* must be input by the user. If its value is one,
* then elements along dimension I are equally
* spaced and the element dimensions are calculated
* by the mesh generator. Dimensioned E.
* N1 ........ The number of elements around the circumference
* of the radiometer cavity.
* RI ........ The inside radius of the ring (cavity radius).
* RO ........ The outside radius of the ring.
* RT ........ The cone tip radius.
* X(J) ...... X-coordinate of global node J. Dimensioned NN.M.
* XT(N,J) ... X-coordinate of local node J of element N of the
* two-dimensional finite element mesh. Dimensioned
* NEM by 9.
* Y(J) ...... Y-coordinate of global node J. Dimensioned NN.M.
* YT(N,J) ... Y-coordinate of local node J of element N of the
* two-dimensional finite element mesh. Dimensioned
* NEM by 9.
* Z(J) ...... Z-coordinate of global node J. Dimensioned NN.M.

********************************************************************************
C Request double precision real variables.
C
IMPLICIT REAL*8 (A-H,O-Z)
C
Dimension the arrays and place variables used by the subroutines
in common storage blocks.
C
 & DM(100),RI,RO,RT
COMMON /BLOCK2/ N1,MDIV(4),K1,K2,K3,K4,NOD(900,9),
 & NBN,NECN,NECY,NEK9,NETI
DIMENSION XT(400,9),YT(400,9)
DIMENSION NUNIF(4),JP(5000),NPL(3,4)
C
Open all necessary input and output files.
C
OPEN(1,FILE='mesh.dat',status='old')
OPEN(4,FILE='mesh.dat')
OPEN(5,FILE='nodes.dat')
C
Set the logical unit numbers for I/O files and set the value of pi.
C
PI = 3.141592654D0
C
Read the radiometer dimensions, mesh discretization data and the
mesh uniformity flags,
C
READ(1,3) DIM(1),DIM(2),RI,RO,DIM(4),RT,H0
READ(1,1) N1,(MDIV(I),I=1,4)
READ(1,1) (NUNIF(I),I=1,4)
C
then determine the radial width of the ring.
C
DIM(3) = RO - RI
C
Examine each uniformity flag to determine if any part of the mesh
is non-uniform. Run a DO-loop over the number of dimensions.
C
M = 0
DO 40 I = 1,4
C
Determine the lower and upper bounds on the subscripts of DM(J)
for the dimension in question.

\[
N = M + 1 \\
M = M + (2*MDIV(I))
\]

If the mesh is non-uniform along dimension I, read the element dimensions for all DIM(I) except the leg width.

\[
\text{IF(NUNIF(I).EQ.0) THEN} \\
\text{READ(1,3) (DNM(J),J=N,M)}
\]

If the mesh is uniform along dimension I, then determine the element dimensions.

\[
\text{ELSE} \\
\text{DO 30 } J = \text{N,M} \\
\text{30 } \text{DM(J)} = \text{DIM(I)}/(M \text{ - N + 1})
\]

\text{ENDIF}

\text{40 CONTINUE}

Generate the three-dimensional nodal coordinates for 'MOVIE.BYU'.
First, determine the number of node levels in the cavity and ring meshes.

\[
K_1 = 1 + (MDIV(1)*2) \\
K_2 = K_1 + (MDIV(2)*2) \\
K_3 = K_2 + (MDIV(3)*2) \\
K_4 = K_3 + (MDIV(4)*2)
\]

Find the last node number, i.e. The total number of elements.

\[
\text{NNM} = 2*\text{N1*K4}
\]

Calculate the three-dimensional nodal coordinates of the model.

\text{CALL MSHCOR (X1,Y1,Z1)}

Determine the number of elements in each part of the radiometer mesh and the total number of elements in the mesh.

\[
\text{NECN} = MDIV(1)*\text{N1} \\
\text{NECY} = MDIV(2)*\text{N1} \\
\text{NERG} = MDIV(3)*\text{N1} \\
\text{NETI} = MDIV(4)*\text{N1} \\
\text{NEM} = \text{NECN} + \text{NECY} + \text{NERG} + \text{NETI}
\]

\text{CALL CUNET (LGNODE,KK,JJ)}

Determine the connectivity array for the three-dimensional mesh needed for 'MOVIE.BYU' from the two-dimensional connectivity array.

\[
K = 0 \\
\text{DO 80 } I = 1,\text{NEM} \\
\text{30 } J = 1,\text{N} \\
K = K + 1 \\
\text{JP(K)} = \text{NOD(I,J)} \\
\text{IF(J.EQ.N) JP(K) = -NOD(I,J)} \\
\text{70 CONTINUE} \\
\text{80 CONTINUE}
\]

Determine the parts array for 'MOVIE.BYU'. There are four parts in the model.

\[
\text{NP} = 4
\]
NPL(1,1) = 1
NPL(2,1) = NECN
NPL(1,2) = NECN + 1
NPL(2,2) = NECN + NECY
NPL(1,3) = NECN + NECY + 1
NPL(2,3) = NECN + NECY + NERG
NPL(1,4) = NECN + NECY + NERG + 1
NPL(2,4) = NECN + NECY + NERG + NETI

C Determine the number of edges in the model for 'MOVIE.BYU'.
C Each quadrilateral element has eight edges.
C
NEDGE = 0
DO 90 I = 1,NEM
90 NEDGE = NEDGE + 8
C
C Calculate the two-dimensional local node coordinates for the finite
C element mesh.
C
CALL TWODIM (XT,YT)
C
C Determine the nodes at the base of the thermal impedance,
C and write them to the data file.
C
NNB = 2*N1
WRITE(5,1) NNB
DO 100 I = 1,NNB
100 WRITE(5,1) NBTI

C Determine the nodes along the thermal impedance, used to select
C the position of the resistance thermometer, and write them to
C the data file.
C
N = MDIV(4)*2
WRITE(5,1) N
NRT = NNM - 2*N1 + 1
DO 110 I = 1,N
110 WRITE(5,1) NRT
C
C Write the mesh geometry data file for 'ERBETA FORTRAN'.
C
WRITE(4,1) NEM,NNM,(MDIV(I),I=1,4),N1
WRITE(4,3) (DTM(I),I = 1,4),RI,RO,RT,H0
WRITE(4,3) (DM(I),I=1,(MDIV(1)+MDIV(2)+MDIV(3)+MDIV(4))*2)
DO 120 I=1,NEM
120 WRITE(4,1) (NOD(I,J),J=1,9)
DO 130 I=1,NEM
130 WRITE(4,3) (XT(I,J),YT(I,J),J=1,9)
CONTINUE
STOP
C
C The format statements follow:
C
1 FORMAT(16I5)
2 FORMAT(6EL12.5)
3 FORMAT(6DL12.5)
4 FORMAT(11S,1X,6D12.5)
END

******************************************************************************
*                        SUBROUTINE MSHCOR                             *
* * This subroutine is called by the main program to determine       *

Program ERBEMSH 229
the three-dimensional coordinates of the nodes of the entire mesh.

Nomenclature

A ........... Depth of the node level below the aperture.
DIM(I) ....... Radiometer part dimension. Dimensioned 6.
I = 1  cone height
I = 2  cylinder height
I = 3  radial width of ring (RO - RI)
I = 4  thermal impedance length.
DM(J) ...... The element dimensions along DIM(I), for
I = 1 to 4. Dimensioned two times the sum
of MDIV(I), for I = 1 to 4.
DTHETA ...... The angle between nodes on a common level.
I ............ The node level.
K1 .......... Number of node levels in the cone mesh.
K2 .......... Number of node levels in the cavity mesh.
K3 .......... Number of node levels in the cavity plus ring mesh.
K4 .......... Number of node levels in the entire mesh.
M ........... Upper limit on the node numbers of node level I.
N ........... Lower limit on the node numbers of node level I.
N1 .......... The number of elements around the circumference
of the radiometer cavity.
PI ........... Mathematical constant.
R ............ Radius of the node level.
RI .......... The inside radius of the ring (cavity radius).
RT .......... The cone tip radius.
THETA ...... The nodal angle measured counter-clockwise from
the positive x-axis.
X(J) .......... X-coordinate of global node J. Dimensioned NNM.
Y(J) .......... Y-coordinate of global node J. Dimensioned NNM.
Z(J) .......... Z-coordinate of global node J. Dimensioned NNM.

SUBROUTINE MSHCOR(X1,Y1,Z1)

Request double precision real variables and place variables used by
the subroutine in common storage blocks.

IMPLICIT REAL*8 (A-H,O-Z)
& DM(100),RI,RO,RT
COMMON /BLOCK2/ N1,MDIV(4),K1,K2,K3,K4,NOD(900,9),
& NECN,NECY,NERG,NETI

Define the mathematical constant pi, and initialize the depth of the
cavity.

PI = 3.141592654D0
A = DIM(1) + DIM(2)
RR = DSQRT(RI*2+DIM(1)**2)

Run a DO-loop over the number of node levels in the cavity. The
lower and upper limits on the node numbers of the node level in
question are determined on each loop.

M = 0
DO 20 I = 1,K4
N = M + 1
M = N + (2*N1) - 1

Program ERBEMSH 230
Determine the radius of each node level on the cone.
At the tip, the radius is RT.

IF(I.EQ.1) R = RT

IF(I.LT.K1.AND.I.GT.1) R = R + ((RI-RT)*DM(I-1)/DIM(1))

For all node levels in the cylinder, the radius is RI.

IF(I.GR.K1.AND.I.LE.K2) R = RI

Determine the radius of each node level on the ring.

IF(I.GT.K2.AND.I.LT.K3) R = R + DM(I)

For all node levels on the thermal impedance, the radius is RO.

IF(I.GE.K3) R = RO

Determine the angle between two consecutive nodes, and initialize
the angle of the first node.

DTHETA = PI*2.0D0/(M - N + 1)

THETA = PI + DTHETA

Run a DO-loop over the node numbers of the level in question.

DO 10 J = N,M

Calculate the coordinates of node J on node level I, then increment
the node angle.

X(J) = R*DCOS(THETA)
Y(J) = R*DSIN(THETA)
Z(J) = A

THETA = THETA - DTHETA

Increment the depth of the node level. "A" at cone tip, zero on the
upper edge of the cylinder, and DIM(5) at bottom of the thermal
impedance.

IF(I.LT.K2) A = A - DM(I)
IF(I.GE.K2.AND.I.LT.K3) A = 0.0D0
IF(I.GE.K3) A = A + DM(I)

10 CONTINUE

Return to the main program.

RETURN
END

******************************************************************************

SUBROUTINE CUNET

THIS SUBROUTINE IS CALLED BY THE MAIN PROGRAM TO CALCULATE
THE CONNECTIVITY ARRAY FOR THE FINITE ELEMENT MESH.

******************************************************************************

NOMENCLATURE

I ........... NODE WHICH DEFINES ONE ENDPOINT OF THE LINE NEEDED
to determine the coordinates of node NC.
K .......... Element level.
NB .......... Node which defines one endpoint of the line needed
to determine the coordinates of node NC.
NC .......... Node which lies at the intersection of a circle of
radius R and the line defined by nodes NA and NB.
NERG ...... Number of elements in the ring mesh.
PI .......... Mathematical constant.
R1 .......... Radius of the I-2 node level.
R .......... Radius of the I-th node level.
RI .......... The inside radius of the ring (cavity radius).
RO .......... The outside radius of the ring.
RR .......... Radius of the I-1 node level.
THETA ...... The nodal angle measured counter-clockwise from
the positive x-axis.
X(J) .......... X-coordinate of global node J. Dimensioned NN.
Y(J) .......... Y-coordinate of global node J. Dimensioned NN.
Z(J) .......... Z-coordinate of global node J. Dimensioned NN.

*****************************************************************************

C                                   C
C SUBROUTINE CUNECT (LONODE, KK, JJ)
C C Request double precision real variables and place variables used
C by the subroutine in common storage blocks.
C
C IMPLICIT REAL*8 (A-H, O-Z)
&                  RI, RO, RT
C COMMON /BLOCK2/ N1, MDIV(4), K1, K2, K3, K4, NOD(900,9),
&                  NENC, NENCY, NERG, NETI
C
C Determine the terms of the connectivity array for the model.
C
K = MDIV(1) + MDIV(2) + MDIV(3) + MDIV(4)
DO 30 N = 1, K
   DO 20 I = ((N1*(N-1)+1)), (N*NN)
      NOD(I,1) = 2*I-1
      IF (N.EQ.1) GO TO 39
      NOD(I,1) = NOD(I-N1,7)
   39 NOD(I,2) = NOD(I,1) + 1
      NOD(I,3) = NOD(I,1) + 2
      NOD(I,4) = NOD(I,1) + 2*N1
      NOD(I,5) = NOD(I,1) + 4*N1
      NOD(I,6) = NOD(I,7) + 1
      NOD(I,7) = NOD(I,8) + 2
      NOD(I,8) = NOD(I,9) + 2
      NOD(I,9) = NOD(I,8) + 1
      NOD(I-1,3) = NOD((N1*(N-1))+1,1)
      NOD(I-1,4) = NOD((N1*(N-1))+1,8)
      NOD(I-1,5) = NOD((N1*(N-1))+1,7)
   20 CONTINUE
RETURN

*****************************************************************************

C                                   C
C SUBROUTINE TWODIM
C C This subroutine is called by the main program to calculate
C the two-dimensional local node coordinates of the finite element
C mesh. Only the relative positions of the nodes of an element 
C need be calculated as defined by 'ERBETA'.
C The cone and cylinder are each cut between the first and 
C last elements on the same element level and laid flat in an
C xy-plane to produce two-dimensional surfaces. The local node

Program ERBEMESH

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coordinates of the first element on each level of the cavity can then be calculated and repeated for each element of that level due to the radial symmetry of the cavity.

NOMENCLATURE

DIM(I) ...... Diameter part dimension. Dimensioned 6.
I = 1     cone height
I = 2     cylinder height
I = 3     radial width of ring (RO - RI)
I = 4     cylinder leg length
DTHETA ...... The angle between nodes on a common level.
DR(I) ...... The radius of the I-th cone node level.
            Dimensioned 2*MDIV(1).
ELX(I,J) ... The x-coordinate of local node I of the first element (J) of a level. Dimensioned 9 by MDIV(1)+MDIV(2).
ELY(I,J) ... The y-coordinate of local node I of the first element (J) of a level. Dimensioned 9 by MDIV(1)+MDIV(2).
MDIV(I) ..... Number of element divisions along DIM(I).
            Dimensioned 4.
NECN ....... Number of elements in the cone mesh.
NECY ....... Number of elements in the cylinder mesh.
N1 ........... Global node number.
NOD(N,J) ... Global node number corresponding to local node J of element N (connectivity array) of the two-dimensional mesh. Dimensioned NEM by 9.
NPE .......... Number of local nodes in an element.
N1 .......... The number of elements around the circumference of the radiometer cavity.
PI .......... Mathematical constant.
RI .......... The inside radius of the ring (cavity radius).
RT .......... The cone tip radius.
THETA ...... The nodal angle measured counter-clockwise from the positive x-axis.
X(J) ........ X-coordinate of global node J. Dimensioned NNM.
XT(N,J) ..... X-coordinate of local node J of element N of the two-dimensional finite element mesh. Dimensioned NEM by 9.
Y(J) ........ Y-coordinate of global node J. Dimensioned NNM.
YT(N,J) ..... Y-coordinate of local node J of element N of the two-dimensional finite element mesh. Dimensioned NEM by 9.
Z(J) ........ Z-coordinate of global node J. Dimensioned NNM.

SUBROUTINE TWODIM (XT,YT)
C Request double precision real variables, place variables used
C by the subroutine in common storage blocks and dimension the arrays.
C
IMPLICIT REAL*8 (A-H,O-Z)
              & DM(100),RI,RO,RT
COMMON /BLOCK2/ N1,MDIV(4),K1,K2,K3,K4,NOD(900,9),
              & NECN,NECY,NERG,NETI
DIMENSION XT(400,9),YT(400,9)
DIMENSION ELX(9,20),ELY(9,20),DR(20)
C Define the mathematical constant pi, and determine the radius of the C sector of a circle created by the two-dimensional cone surface.

Program ERBEMSH
PI = 3.141592654D0  
RR = DSQRT((RI**2) + (DIM(1)+H0)**2)  

Determine the angle between the nodes on the second node level and 
the radial distance between node levels.

DTHETA = (RI*PI)/(RR*N1)  
SUM = 0.0D0  
DO 10 I = 1,2*MDIV(1)  
SUM = SUM + DM(I)  
10 DR(I) = SUM*RR/DIM(1)

INITIALIZE THE NODE ANGLE AND THE COORDINATES OF NODE 1.

If there is more than one division along the cone height, then 
determine the local coordinates of the nodes of the first 
quadrilateral element on each remaining level of the cone.

A DO-loop is run over the number of remaining element levels 
c of the cone, and the angle and radius of the first local node 
c are defined on each loop.

DO 60 J = 1,MDIV(1)  
THETA = PI/2.0D0  
IF(J.EQ.1) GO TO 11  
RAD = DR(2*J-2)  
GO TO 12
11
RAD = RT*(RR/RI)

Determine the coordinates of the first three local nodes,

DO 30 I = 1,3  
ELX(I,J) = RAD*DCOS(THETA)  
ELY(I,J) = RAD*DSIN(THETA)

30
THETA = THETA - DTHETA

c

the fourth local node,
c

RAD = DR(2*J-1)  
THETA = (PI/2.0D0) - 2.0D0*DTHETA  
ELX(4,J) = RAD*DCOS(THETA)  
ELY(4,J) = RAD*DSIN(THETA)
cc
the fifth through seventh local nodes,
c

RAD = DR(2*J)  
DO 40 I = 5,7  
ELX(I,J) = RAD*DCOS(THETA)  
ELY(I,J) = RAD*DSIN(THETA)

40
THETA = THETA + DTHETA
cc
and the eighth and ninth local nodes.

THETA = PI/2.0D0  
RAD = DR(2*J-1)  
DO 50 I = 8,9  
ELX(I,J) = RAD*DCOS(THETA)  
ELY(I,J) = RAD*DSIN(THETA)

50
THETA = THETA - DTHETA  
60 CONTINUE

The coordinates of the local nodes of the first element on each 
level of the cylinder are calculated by running a DO-loop over the 
number of element levels in the cylinder. The distance between 
the nodes on a common level is determined first.
DC1 = (RI*PI)/N1
L1 = MDIV(1) + 1
DO 70 J = L1,MDIV(2)+MDIV(1)
    C
    C Calculate the coordinates of all nine nodes of the element.
    C
    ELX(1,J) = 0.0D0
    ELX(2,J) = DC1
    ELX(3,J) = 2.0D0*DC1
    ELX(4,J) = 2.0D0*DC1
    ELX(5,J) = 2.0D0*DC1
    ELX(6,J) = DC1
    ELX(7,J) = 0.0D0
    ELX(8,J) = 0.0D0
    ELX(9,J) = DC1
    ELY(1,J) = 0.0D0
    ELY(2,J) = 0.0D0
    ELY(3,J) = 0.0D0
    ELY(4,J) = DM(2*MDIV(1)+1)
    ELY(5,J) = 2.0D0*ELY(4,J)
    ELY(6,J) = ELY(5,J)
    ELY(7,J) = ELY(5,J)
    ELY(8,J) = ELY(4,J)
    ELY(9,J) = ELY(4,J)
70 CONTINUE
    C
    DC2 = (RO*PI)/N1
    L2 = MDIV(1) + MDIV(2) + MDIV(3) + 1
    DO 71 J = L2,(L2 + MDIV(4)-1)
        ELX(1,J) = 0.0D0
        ELX(2,J) = DC2
        ELX(3,J) = 2.0D0*DC2
        ELX(4,J) = ELY(3,J)
        ELX(5,J) = ELX(3,J)
        ELX(6,J) = DC2
        ELX(7,J) = 0.0D0
        ELX(8,J) = 0.0D0
        ELX(9,J) = DC2
        ELY(1,J) = 0.0D0
        ELY(2,J) = 0.0D0
        ELY(3,J) = 0.0D0
        ELY(4,J) = DM(2*L2-1)
        ELY(5,J) = 2.0D0*ELY(4,J)
        ELY(6,J) = ELY(5,J)
        ELY(7,J) = ELY(5,J)
        ELY(8,J) = ELY(4,J)
        ELY(9,J) = ELY(4,J)
71 CONTINUE
    C
    Now that the local node coordinates of the first element on each
    C level of the cavity are known, determine the local coordinates
    C of all the element nodes in the cavity. DO-loops are run over the
    C number of element levels and the element numbers of the level.
    C
    N = 1
    M = N1
    DO 100 J = 1,MDIV(1)+MDIV(2)
        DO 90 I = N,M
            C
            Determine the number of nodes in the element, then loop over each of
            C these nodes to determine the nodal coordinates of the element.
            C
            NPE = 9
            DO 80 K = 1,NPE
                XT(I,K) = ELX(K,J)
YT(I,K) = ELY(K,J)
80 CONTINUE
90 CONTINUE

Increment the element numbers for the next level.
N = M + 1
M = M + N1
100 CONTINUE

The local coordinates of the nodes of the ring and thermal impedance can be found by using the three-dimensional coordinates and the connectivity array.
Initialize the element limits as the element numbers in the ring, and then run a DO-loop over the two pieces.
L3 = L2 + MDIV(4) - 1
N = (L2-1)*N1 + 1
M = N + N1 - 1
DO 101 J = L2,L3
   KI = 1
   DC = 0
   DO 91 I = N,M
       DO 81 K = 1,9
           XT(I,K) = ELX(K,J) + 2*DC
           YT(I,K) = ELY(K,J)
       CONTINUE
       DC = KI*DC2
       KI = KI + 1
91 CONTINUE
   DO 82 K = 1,9
   CONTINUE
82 ELY(K,J+1) = YT(I-1,K) + 2*DM(2*L2-1)

Increment the element number for the next level.
N = M + 1
M = M + N1
101 CONTINUE
N = NECN + NECY + 1
M = N - 1 + NERS
DO 120 I = N,M
   DO 110 J = 1,9
       NI = NOD(I,J)
       XT(I,J) = X(NI) + RI
       YT(I,J) = Y(NI) + RI
110 CONTINUE
120 CONTINUE
RETURN
END

Program ERBEMSH
Appendix G

Program ERBETA
This program performs a steady-state or transient thermal analysis on an active cavity radiometer using a finite element method which uses quadratic quadrilateral elements. The analysis considers thermal conduction and radiation.

The utilization of program flags allows the user several options in the type of analysis performed. The three major flags are as follows:

1. Steady-state or transient analysis
2. Conduction with or without radiative effects
3. Electrical substitution heater on or off.

The analysis considers radiative interaction between the source field and the inside surface of the cavity with the option of having one irradiance vector entering the cavity. Radiative interaction between the outside of the cavity or any other part of the radiometer with its surroundings will not be considered in this analysis.

Written by Nour E. Tira, and modified by Kory J. Priestley

NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALPHA</td>
<td>Resistance-temperature constant</td>
</tr>
<tr>
<td>ATIP</td>
<td>Area of the truncated tip of the cone</td>
</tr>
<tr>
<td>COND</td>
<td>Conductivity of the radiometer material</td>
</tr>
<tr>
<td>CP</td>
<td>Specific heat of the radiometer material</td>
</tr>
<tr>
<td>DENS</td>
<td>Density of the radiometer material</td>
</tr>
<tr>
<td>DIM(I)</td>
<td>Radiometer part dimensions. Dimensioned 6</td>
</tr>
<tr>
<td></td>
<td>I = 1 cone height</td>
</tr>
<tr>
<td></td>
<td>I = 2 cylinder height</td>
</tr>
<tr>
<td></td>
<td>I = 3 radial width of the ring (RO - RI)</td>
</tr>
<tr>
<td></td>
<td>I = 4 thermal impedance length</td>
</tr>
<tr>
<td>DM(I)</td>
<td>The element dimensions along the cavity height. Dimensioned 2*(MDIV(I) + MDIV(1))</td>
</tr>
<tr>
<td>DT</td>
<td>Time increment</td>
</tr>
<tr>
<td>EM</td>
<td>Emissivity of the radiometer material</td>
</tr>
<tr>
<td>ERROR</td>
<td>Convergence error of the solution</td>
</tr>
<tr>
<td>EO</td>
<td>Bridge voltage for the feedback circuit</td>
</tr>
<tr>
<td>E2</td>
<td>Voltage across the heater wire</td>
</tr>
<tr>
<td>GEN(N,K)</td>
<td>Volumetric heat generation in element N. Dimensioned NEM by 2.</td>
</tr>
<tr>
<td>GTA(I,J)</td>
<td>Assembled global conductivity matrix</td>
</tr>
<tr>
<td></td>
<td>Dimensioned NNM by NHHW.</td>
</tr>
<tr>
<td>GTF(I)</td>
<td>Assembled global flux vector. Dimensioned NNM.</td>
</tr>
<tr>
<td>HWIRE</td>
<td>Height to which the heater wire is wound above the cone tip.</td>
</tr>
<tr>
<td>INIT</td>
<td>The indicator for transient analysis. INIT = 0 steady-state analysis</td>
</tr>
<tr>
<td></td>
<td>INIT = 1 transient, uniform initial conditions</td>
</tr>
<tr>
<td></td>
<td>INIT = 2 transient, non-uniform i.c.</td>
</tr>
<tr>
<td>IPDF(I)</td>
<td>The array of node numbers with specified temperature boundary conditions. Dimensioned NPDF.</td>
</tr>
<tr>
<td>MDIV(I)</td>
<td>Number of element divisions along DIM(I).</td>
</tr>
</tbody>
</table>
* Dimensioned 6.
* NC .......... Column of the global conductivity matrix.
* NCMAX ........ Column-dimension of GTA(I,J).
* NDT .......... Number of time steps in the analysis--equal to
* one for a steady-state analysis.
* NEC .......... Number of elements in the cavity mesh.
* NEM .......... Number of elements in the mesh.
* NHBW .......... Half-band width of the system of global equations.
* NN .......... Number of nodes in the mesh
* NOD(N,J) ....... Global node number corresponding to the J-th node
* of element N (connectivity array) of the mesh.
* The local nodes are defined counter-clockwise
* from any element corner with the central node
* of the quadrilateral elements given last
* Dimensioned NEM by 9.
* NPDF .......... The number of specified temperature boundary
* conditions.
* NR .......... Row of the global conductivity matrix and
* flux vector.
* NRMAX ........ Row-dimension of GTA(I,J) and GTF(I).
* NSTEP ......... Time step number.
* NRES .......... The first node on the thermal impedance which
* is covered by the resistance thermometer.
* NL .......... The number of elements around the circumference
* of the cavity.
* PHI ........... The collimated beam angle of incidence w/r to the
* aperture normal. Dimensioned NPHI.
* RH .......... Resistance of the heater wire.
* RI .......... Inside radius of the ring (cavity radius).
* RIP .......... Precision aperture radius.
* RO .......... Outside radius of the ring.
* TARBS ......... Average temperature of the two resistance
* thermometers.
* TAU .......... Time constant in the analysis of the heater
* circuit.
* TAVE(I) ...... Average temperature of cavity element I.
* Dimensioned NEC.
* THETA .......... Time approximation parameter.
* Theta = 0 forward-difference scheme
* Theta = 1/2 Crank-Nicolson scheme
* Theta = 2/3 Galerkin scheme
* Theta = 1 backward-difference scheme
* THCK .......... Thickness of the radiometer material.
* THS .......... Temperature of the heat sink.
* TIME .......... The running time for a transient analysis.
* TMAX .......... Upper bound on time for a transient analysis.
* TNEW(I) ...... Global node temperatures calculated for the
* current time step. Dimensioned NNM.
* TOLD(I) ...... Column of local node temperatures from the
* previous time step.
* TINIT ...... Radiometer predominant initial temperature.
* VPDF(I) ...... Nodal temperatures specified as boundary condi-
* tions. Dimensioned NPDF.
* X(N,J) ........ X-coordinate of local node J of element N of the
* mesh. Dimensioned NEM by 9.
* Y(N,J) ........ Y-coordinate of local node J of element N of the
* mesh. Dimensioned NEM by 9.
*
*******************************************************************************

C Request double precision real variables.

C IMPLICIT REAL*8 (A-H,O-Z)

Program ERLBETA 239
REAL*8 LBDA

dimension the arrays, and specify variables used by the subroutines
in common storage blocks.

DIMENSION GTA(800,120),GTF(800),GEN(200,2),TA(9,9),TF(9)
DIMENSION IPDF(60),VPDF(60),FMAG(256)
DIMENSION NOD(200,9),MDIV(4),DM(40),PHI(35)
DIMENSION TNEW(800),TAVE(150),TOLD(9),X(200,9),Y(200,9)

DIMENSION DFOPT(200,100,15),DFSCN(200,100,15),DFBAR(200,100,15)
DIMENSION DFDMOE(200,100,15),DFRING(200,100,15),DFCSUB(200,100,15)
DIMENSION DFUSUB(200,100,15),DFLSUB(200,100,15),DFCNS(200,100,15)
DIMENSION DOABCO(25),LBDA(20)

COMMON/ RADI1/ AREA1,AREA2,PI,RI,THCK,DIM(4),NVEC,NSUN,NS
COMMON/ RADI3/ AFQVL,AUSUB,ALSUBI,ALSUBO,ARING, VOL1, VOL2,
& ACAVSUB,AFOVAP,ABAR,ACON
COMMON/ HEAT1/ HEATEL(15),EC,ALPHA,TAU,THS,DELT,NRES
COMMON/ ELEMI/ DT,THETA,COND,CP,DENS
COMMON/ NB/ NBFOVL,NBSUB,NBSUB,NBCASUB,NBRING,
& NBDOME,NBSCENE,NBBAR,NBCON,NBCAV
COMMON/ EMISS/ EMFOVL,EMSUB,EMLSUB,EMDOME,EMBAR,EMCON,
& EMCAVSUB,EMRING
COMMON/ DFSAC/ DFOPT,DFSCN,DFBAR,DFCON,DFDMOE,DFRING,DFCSUB,
& DFUSUB,DFLSUB
COMMON/ DOME/ DOMTHC,DOABCO,NBWLIN
COMMON/ CHAN/ CHANEL
COMMON/ LMBDA/LBDA
COMMON/ FLUX/ SCNFLUX

Open input files

OPEN(3,FILE='source.dat',status='old')
OPEN(4,FILE='mesh.dat',status='old')
OPEN(8,FILE='flags.dat',status='old')
OPEN(9,FILE='props.dat',status='old')
OPEN(10,FILE='time.dat',status='old')
OPEN(11,FILE='bndtmp.dat',status='old')
OPEN(12,FILE='emiss.dat',status='old')
OPEN(13,FILE='heater.dat',status='old')
OPEN(15,FILE='temp.dat',status='old')
OPEN(16,FILE='numb.dat',status='old')
OPEN(17,FILE='er.dat')
OPEN(20,FILE='dfopt.dat',status='old')
OPEN(21,FILE='dfscn.dat',status='old')
OPEN(22,FILE='dfcav.dat',status='old')
OPEN(25,FILE='fdmoe.dat',status='old')
OPEN(24,FILE='dfring.dat',status='old')
OPEN(25,FILE='dome.dat',status='old')
OPEN(26,FILE='out.dat')
OPEN(27,FILE='tmpdsgst.dat')
OPEN(28,FILE='hout.dat')
OPEN(29,FILE='tfqovl.dat',status='old')
OPEN(30,FILE='tsusub.dat',status='old')
OPEN(31,FILE='tlsub.dat',status='old')
OPEN(32,FILE='tdomoe.dat',status='old')
OPEN(33,FILE='tfring.dat',status='old')
OPEN(34,FILE='tcavsub.dat',status='old')
OPEN(35,FILE='tcav.dat',status='old')
OPEN(36,FILE='tscn.dat',status='old')
OPEN(40,FILE='area.dat', STATUS='OLD')
OPEN(50,FILE='lbs.dat', STATUS='OLD')
OPEN(65,FILE='dfsub.dat', STATUS='OLD')
OPEN(66,FILE='dfsub.dat', STATUS='OLD')
OPEN(67,FILE='dfsub.dat', STATUS='OLD')
OPEN(68,FILE='dfsub.dat', STATUS='OLD')
OPEN(70,FILE='dfc.dat', STATUS='OLD')
OPEN(99,FILE='wswblip.dfc', STATUS='OLD')

C Define program constants.
C
WRITE(26,*) TIME TARBS VOLTAGE
& POWER SCNPOW
DATA NMAX,NCMAX/800,120/
DATA MD,MOUNT,E2,RH,SMAX/20.0,0.0,1.0,0.0/
DATA NDT,NDTS,NDTSH/1,1,1/
PI = 3.141592654D0
ERMAX = 0.50D-05

******************************************************************************

* * * PREPROCESSOR UNIT
* * *
* * Reads and generates data
* * *
******************************************************************************

C Read the mesh geometry data and determine the number of elements
C in the cavity.
C
READ(4,310) NEM,NNM,(MDIV(I),I=1,4),N1
READ(4,310) (DM(I),I=1,4),RI,RO,RT,HO
READ(4,310) (DM(I),I=1,4),MDIV(1)+MDIV(2)+MDIV(3)+MDIV(4))*2
N0 = (MDIV(1) + MDIV(2)) *N1
write(17,*) 'NEM, NNM, N1',NEM,NNM,N1
write(17,*) 'RI,RO,RT,HO',RI,RO,RT,HO
write(17,*) 'N0',N0

C Read the areas for each surface of the radiometer
C
READ(40,*) AFOVL
READ(40,*) AUSUB
READ(40,*) ALSUBI
READ(40,*) ALSUBO
READ(40,*) ARING
READ(40,*) VOL1
READ(40,*) VOL2
READ(40,*) ACAVSUB
READ(40,*) AFOVAP
READ(40,*) ABAR
READ(40,*) ACON

WRITE(17,*) AFOVL, AFOVL
WRITE(17,*) AUSUB, AUSUB
WRITE(17,*) ALSUBI, ALSUBI
WRITE(17,*) ALUSUBO, ALSUBO
WRITE(17,*) ARING, ARING
WRITE(17,*) VOL1, VOL1
WRITE(17,*) VOL2, VOL2
WRITE(17,*) ACAVSUB, ACAVSUB
WRITE(17,*) AFOVAP, AFOVAP
WRITE(17,*) ABAR, ABAR
WRITE(17,*) ACON, ACON

Program ERBETA
Calculate the areas of the cut-off cone tip, the element on
the cone and those on the cylinder.
ATIP = PI*RT*DSQRT(RT**2+HO**2)
AREA1 = (PI*RI*DSQRT(RI**2+(DIM(1)+HO)**2)-ATIP)/(N1*MDIV(1))
AREA2 = (PI*RI*2.0D0*DIM(2))/(N1*MDIV(2))

Read the connectivity array.
DO 10 I = 1,NEM
   READ(4,300) (NOD(I,J),J=1,9)
10 CONTINUE

Read the local node coordinates of each element in the mesh.
DO 20 I = 1,NEM
   READ(4,310) (X(I,J),Y(I,J),J=1,9)
20 CONTINUE

Read the program flags.
READ(8,*) CHANEL
READ(8,300) INIT,NPDF,NRES

Read the cavity material properties.
READ(9,310) COND,THCK,CP,DENS

If the number of specified temperature boundary conditions is
greater than zero, then read the nodes and their specified
temperatures.
IF(NPDF.GT.0) THEN
   READ(11,300) (IPDF(I),I=1,NPDF)
   READ(11,310) (VPDF(I),I=1,NPDF)
   TSH = VPDF(NPDF)
ENDIF

If a transient thermal analysis is desired, then read the time
increment, the time limit, and the time approximation parameter.
IF (INIT.GT.0) THEN
   READ(10,*) DT,TMAX,THETA,TSON
   READ(10,*) NDT,NDTF,NDTV,NDTS
ENDIF
READ(35,*) TCAV
DO 32 I=1,NNM
   TNEW(I) = TCAV
32 CONTINUE

If the initial conditions are non-uniform, i.e. different
zones have varying temperatures, read the initial temperature
distribution for each zone.
IF (INIT.EQ.2) READ(9,305) (TNEW(I), I = 1,NNM)

Read the radiative surface properties for the instrument
READ(12,*) EMFOVL
READ(12,*) EMUSUB
READ(12,*) EMLSUB
READ(12,*) EMODE

Program ERBETA
READ(12,*) EMBAR
READ(12,*) EMCON
READ(12,*) EMCAVSUB
READ(12,*) EMRING

C Read the number of elements on each surface of the instrument.
C
READ(16,*) NBFOVL
READ(16,*) NBUSSUB
READ(16,*) NBLSUB
READ(16,*) NBCAVSUB
READ(16,*) NBRING
READ(16,*) NBDOME
READ(16,*) NBSCENE
READ(16,*) NBBAR
READ(16,*) NBCON

NBCAV = NBBAR+NBCON

C Read the distribution of wavelength intervals.
C
READ(25,*) NBWLIN
WRITE(6,*) nbwlin
DO 400 I=1,NBWLIN
   READ(50,*) LBDA(I)
400 CONTINUE

C Read the distribution factors for the front end.
C
WRITE(6,*) NBWLIN
DO 50 I = 1,NBFOVL
   WRITE(6,1) I,NBFOVL(I)
50 CONTINUE

DO 50 K=1,NBWLIN
   WRITE(6,1) K,NBWLIN(K)
50 CONTINUE

DO 50 J = 1,NEC
   WRITE(6,1) J,NEC(J)
50 CONTINUE

READ(20,*) DFOPT(I,J,K)

C For the upper substrate.
C
DO 52 I=1,NBUSSUB
   READ(66,*) DUSUB(I,J,K)
52 CONTINUE

DO 52 K=1,NBWLIN
   READ(66,*) DUSUB(I,J,K)
52 CONTINUE

DO 52 J = 1,NEC
   READ(66,*) DUSUB(I,J,K)
52 CONTINUE

C For the lower substrate.
C
DO 58 I=1,NBLSUB
   READ(67,*) DFLSUB(I,J,K)
58 CONTINUE

DO 58 K=1,NBWLIN
   READ(67,*) DFLSUB(I,J,K)
58 CONTINUE

DO 58 J = 1,NEC
   READ(67,*) DFLSUB(I,J,K)
58 CONTINUE

C For the barrel.
C
DO 70 I=1,NBBAR
   READ(68,*) DBAR(I,J,K)
70 CONTINUE

DO 70 K=1,NBWLIN
   READ(68,*) DBAR(I,J,K)
70 CONTINUE

C For the cone.
C
DO 75 I=1,NBCON
   READ(68,*) DCONE(I,J,K)
75 CONTINUE

DO 75 K=1,NBWLIN
   READ(68,*) DCONE(I,J,K)
75 CONTINUE

DO 75 J = 1,NEC
   READ(68,*) DCONE(I,J,K)
75 CONTINUE

Program ERBETA
READ(70,*)DFCONE(I,J,K)
75 CONTINUE

For the dome

READ(25,*)DOMTHC
DO 81 K=1,NBWLIN
   READ(25,*)DCABCO(K)
   WRITE(6,*)doabco(k)
81 CONTINUE
DO 80 I=1,NBDOME
DO 80 K=1,NBWLIN
DO 80 J=1,NEC
   READ(23,*)DFDOME(I,J,K)
80 CONTINUE

For the ring

DO 82 I=1,NBRING
DO 82 K=1,NBWLIN
DO 82 J=1,NEC
   READ(24,*)DFRING(I,J,K)
82 CONTINUE

For the cavsub

DO 83 I=1,NBCAWSUB
DO 83 K=1,NBWLIN
DO 83 J=1,NEC
   READ(65,*)DFCSUB(I,J,K)
83 CONTINUE

NOTE: DPACS for both the dome and ring are read for both
canals although the dome is not a part of the total
cannel and the ring is not a part of the visible channel.
Values of 0.000 are read in for these DPACS for the
corresponding channels, and then considered in the
subroutine radiate.

For the electrical substitution heater to be utilized in the
analysis, read the appropriate data.

READ(13,310) E2,RH,HWIRE
IF (INIT.GT.0) READ(13,310) EO,TAU(ALPHA,DLT

Determine the highest element ring which is completely covered
by the heater wire, and calculate the cavity surface area which
is covered by the heater wire.

HROW = -0.01D0
WAREA = 0.000
AREA = AREA1
DO 90 I = 1,MDIV(1)+MDIV(2)
   HROW = HROW + DM(2*I) + DM(2*I - 1)
   IF (HWIRE.GE.HROW) HEATEL(I) = 1.000
   IF (HWIRE.LT.HROW) HEATEL(I) = 0.000
   IF (I.GT.MDIV(1)) AREA = AREAB
   WAREA = WAREA + HEATEL(I)*NI*AREA
90 CONTINUE
DO 100 I=1,MDIV(1)+MDIV(2)
   HEATEL(I) = HEATEL(I)/(WAREA*THCK)
100 CONTINUE

Program ERBETA
C If a steady-state analysis with radiation is desired, an iterative
C solution will be necessary. An initial guess at the solution is
C determined by assigning the heat sink temperature to all nodes in
C the mesh.
C
C IF (INIT.EQ.0) THEN
     DO 110 I = 1,NNM
     TNEW(I) = THS
     110 CONTINUE
ENDIF
C
C Determine the half bandwidth of the system by calculating the
C maximum difference between two related nodes.
C
C NHBW = 0
DO 120 N = 1,NEM
     DO 120 J = 1,9
          NW = |IABS(NOD(N,I) - NOD(N,J)) + 1|
     IF (NHBW.LT.NW) NHBW = NW
     120 CONTINUE
******************************
* *
* PROCESSOR UNIT *
* *
* Performs the following functions: *
* *
* 1. generates the element matrices and vectors *
* 2. assembles the element matrices and vectors into the *
*    global form *
* 3. imposes the boundary conditions *
* 4. solves the equations. *
* *
******************************

DO 125 I=1,NEM
125 GEN(I,1) = 0.0D0
C
C Initialize the iteration counter, the number of time steps and
C the time.
C
C TIME = 0.0D0
C
C Run a DO-loop over the number of time steps while incrementing the
C time on each loop.
C
C DO 250 NSTEP = 1,NDT
     NCOUNT = 0
     IF (INIT.EQ.0) THEN
          NS = 1
     ELSE
          TIME = TIME + DT
     END IF
C
C Read the DFAC's for the scene
C
C IF (NSTEP.LE.120.OR.NSTEP.GT.240) THEN
     DO 60 I=1,WSSCENE
     DO 60 K=1,NBMLIN
     DO 60 J=1,NEC

Program ERBETA

245
The iteration loop begins for a steady-state analysis with radiation. The iteration counter is incremented on each loop.

130 CONTINUE
NCOUNT = NCOUNT + 1

Initialize the generation vector, global conductivity matrix and flux vector to zero.

DO 140 I = 1,NEM
   GEN(I,2) = 0.0D0
   GTP(I) = 0.0D0
   DO 140 J = 1,NHBW
   GTA(I,J) = 0.0D0

Since thermal radiation is present in the model, determine the average temperature of each element in the cavity and the effective generation in each element of the cavity due to thermal diffuse-specular radiation.

CALL TEMPAV (NEC,NNM,NCOD,X,Y,TNEW,TAVE)
CALL RADIAT (NEC,N1,MDIV,NSTEP,NDTS,NDTSH,TAVE,GEN,EM)

Determine the generation in each element of the cavity due to the electric heating wires wound around the cavity.

CALL HEATER (INIT,N1,MDIV,TNEW,GEN,RH,E2,DT)

For the first time step of a transient analysis, set the volumetric heat generation in each element from the previous time step equal to that of the present time step.

IF ((INIT.GT.0) .AND. (NSTEP.EQ.1)) THEN
   DO 160 I = 1,NEM
      GEN(I,1) = GEN(I,2)
   ENDIF

Run a DO-loop over the number of elements in the mesh. The matrices of each element are determined in this loop and added to the global matrices.

DO 190 N = 1,NEM

If a transient solution is desired, determine the temperatures of each node in the element from the previous solution. For the first time step the initial conditions are used as the previous solution.

IF (INIT.GT.0) THEN
   DO 170 I = 1,2
      TOLD(I) = TNEW(NOD(N,I))
ENDIF

Determine the element conductivity matrix and flux vector.

CALL ELEM (N,INIT.X,Y,TOLD,GEN,TA,TF,EM)

Assemble the element matrices into the global matrices in
banded symmetric form.

DO 180 I = 1,9
   NR = NOD(N,I)

Add the element flux vector to the global flux vector.

   GTF(NR) = GTF(NR) + TF(I)
   DO 180 J = 1,9
      NC = NOD(N,J) - NOD(N,I) + 1

Add the element conductivity matrix to the global conductivity
matrix.

   IF(NC.GT.0) GTA(NR,NC) = GTA(NR,NC) + TA(I,J)
   180 CONTINUE
   190 CONTINUE

Impose the specified temperature boundary conditions on the
global matrices.

CALL BNLY (NRMAX,NCMAX,NNM,NHBW,GA,T,A,TF,IPDF,IPDF)

Solve the equations of the banded symmetric system. The solution
is returned by subroutine SOLVE as the flux vector {GTF}.

   WRITE(6,*) 'SOLVING...'
   CALL SOLVE (NRMAX,NCMAX,NNM,NHBW,GA,T,A)
   DO 1 I = 1,NNM
      WRITE(27,*)'I, GTF(I)'
   1 CONTINUE

If a steady-state solution is desired and thermal radiation
exists in the model, then determine if the solution has
converged within the specified limit (ERRMAX or MOUNT).

   IF (INIT.EQ.0) THEN
      ERR = 0.0D0
      DNORM = 0.0D0
      DO 210 I = 1,NNM
         DNORM = DNORM + GTF(I)**2
      210   ERR = ERR + (GTF(I) - TNEW(I))**2
      ERROR = DSQRT(ERR/DNORM)
   ENDIF

Assign the new temperature values.

   DO 220 I = 1,NNM
      TNEW(I) = GTF(I)
   220 IF (INIT.EQ.0) THEN
      WRITE(6,325) NCOUNT,ERROR
      IF ((ERROR.GT.ERRMAX).AND.(NCOUNT.LT.MCOUNT)) GO TO 130
   ENDIF

Calculate the average temperature of of the resistance thermometer.

Program ERBETA
N = 2*N1
TARE = 0.0D0
DO 230 I = 1,N
TARE = TARE + TNEW(NRES+I-1)
230 CONTINUE
TARES = TARE/N
WRITE(6,'(*)')'n',n

C Determine the heat transferred to the heat sink by conduction,
C and the heat emitted out through the aperture.
C
TCOND = 0.0D0
DO 235 I = NNM-4*N1+1,NNM-2*N1
235 TCOND = TCOND + TCOND
TCOND = TCOND/(2*N1)
ACOND = 2.0D0*PI*RO*THCK
K = (MDIV(1)+MDIV(2)+MDIV(3)+MDIV(4))*2
QCOND = K*ACOND*(TCOND-THS)/DM(K)

C Often it is desirable to obtain a specified temperature drop between
C the resistance thermometers and the heat sink in a steady-state
C analysis based upon the radiative and/or the electrical input.
C Write the radiative input, resistor temperature and electrical
C input values, then.
C
IF (INIT.EQ.0) THEN
C
C Since the heater is utilized in the analysis and radiation is considered
C ask for a new heater voltage. A negative number terminates program
C execution.
C
WRITE(6,'(*)')'NEW E2? A negative number will stop execution.'
READ(6,'(*)') E2
IF (E2.GT.0.0D0) THEN
  E2 = E2
  GOTO 130
ENDIF
ENDIF

C If the analysis is steady-state, write the temperature of the
C resistance thermometer, and the radiative and electrical power input.
C
PE2 = (1000.0D0/RH)**2*E2
IF (INIT.EQ.0) WRITE(24,330) TARES,FMAG,SM,PE2

C If the analysis is transient, write the average temperature of the
C resistance thermometers, the heater power and the radiative input
C power for each time step to the terminal screen and a disk file.
C
IF (INIT.EQ.0) THEN
  WRITE(26,330) TIME,TARES,E2,PE2,SCN,PE2+SCN
ENDIF

C Write the temperature distribution for the current time step to a
C disk file.
C
WRITE(27,'(*)')'TIME = ',TIME,' SECONDS'
WRITE(27,305) (TNEW(I),I=1,NNM)

C Assign the heat generation from present time step to that of the
C previous time step, and then, for a transient analysis, proceed to
C the next time step.
DO 240 I = 1,NEM
    GEN(I,1) = GEN(I,2)
240 CONTINUE
250 CONTINUE
STOP

*** FORMAT STATEMENTS ***

300 FORMAT(1615)
305 FORMAT(6E12.5)
310 FORMAT(6D12.5)
320 FORMAT(15X,D14.5)
325 FORMAT(1X,'ITERATION NO. = ',I2,3X,'$ERROR = ',F10.6)
330 FORMAT(6(3X,F12.7))
335 FORMAT(1X,'VMAG = ','F10.5,3X,'FMAG = ','F10.5,3X,'SMAG = ','F10.5,
     &3X,'TARES = ','F10.5,3X,'E2 = ','F8.5)
340 FORMAT(20X,D14.5)
345 FORMAT(1X,'Heat conducted to the heat sink = ','F13.5, (mW)')
350 FORMAT(1X,'Energy emitted from the cavity = ','F13.5, (mW)')
END

******************************************************************************

SUBROUTINE TEMPAV
******************************************************************************

This subroutine calculates, by linear interpolation, the
* average temperature of each element in the radiometer cavity 
* 
******************************************************************************

SUBROUTINE TEMPAV(NEC,NNM,NOD,X,Y,TNEW,TAVE)
IMPLICIT REAL*8(A-H,O-Z)
DIMENSION NOD(200,9)
DIMENSION TNEW(800),TAVE(100),X(200,9),Y(200,9),TOLD(9)

run a do-loop over the number of elements.
DO 30 I=1,NEC

Initialize the area and temperature of this element to zero
AREA=0.0D0
TEMP=0.0D0

Determine the element local node temperatures.
NPE=9
DO 10 J=1,9
TOLD(J)=TNEW(NOD(I,J))
10 CONTINUE

The area is calculated by subdividing the element into
8 triangles for quadrilateral elements or 4 triangles for
triangular elements. The total area is then found by summing
the areas of these small triangles. A do-loop is run over
the number of triangles in the element.
L=8
DO 20 J=1,L

Determine the three vertices of the triangular area
PT1X=X(I,J)
PT1Y=Y(I,J)

Program ERBETTA
PT2X=X(I,J+1)
PT2Y=Y(I,J+1)
PT3X=X(I,(J+L)+1)
PT3Y=Y(I,(J+L)+1)
IF (J.EQ.8) THEN
  PT2X=X(I,1)
  PT2Y=Y(I,1)
END IF

C CALCULATE THE LENGTHS OF SIDES 1 AND 3 OF THE TRIANGLE
SIDE1=DSQRT((PT1X-PT2X)**2+(PT1Y-PT2Y)**2)
SIDE3=DSQRT((PT3X-PT1X)**2+(PT3Y-PT1Y)**2)

C TAKE THE DOT PRODUCT OF THE UNIT VECTORS ALONG SIDES 1 AND 3
C TO DETERMINE THE ANGLE BETWEEN THESE TWO SIDES.
AI=(PT2X-PT1X)/SIDE1
AJ=(PT2Y-PT1Y)/SIDE1
BI=(PT3X-PT1X)/SIDE3
BJ=(PT3Y-PT1Y)/SIDE3
THETA=ACOS((AI*BI)+(AJ*BJ))

C DEFPITE THE BASE AS SIDE 1 AND THE HEIGHT AS THE LENGTH OF THE
C SIDE OPPOSITE THE ANGLE BETWEEN THESE TWO SIDES
BASE=SIDE1
HEIGHT=SIDE3*DSIN(THETA)

C CALCULATE THE AREA OF THE TRIANGLE, THEN ADD THIS TO THE
C SUM TO DETERMINE THE ELEMENTAL AREA
TAREA=(0.5D0*BASE*HEIGHT)
AREA=AREA+TAREA

C DETERMINE THE TEMPERATURES OF THE THREE VERTICES OF THE
C TRIANGLE.
TA=TOLD(J)
TB=TOLD(J+1)
TC=TOLD(1+8/L)
IF (J.EQ.8) TB=TOLD(1)

C DETERMINE THE TEMPERATURE AT THE MIDPOINT OF EACH SIDE OF THE
C TRIANGLE
TP=(TA+TB)/2.0D0
TQ=(TB+TC)/2.0D0
TR=(TC+TA)/2.0D0

C COORDINATES OF THE CENTROID, AND THE LENGTH FROM EACH VERTEX
C TO THE CENTROID ARE DETERMINED.
AQ=DSQRT((PT1X-(PT2X+PT3X)/2.0)**2+
         (PT1Y-(PT2Y+PT3Y)/2.0)**2)
&  =DSQRT((PT2X-(PT1X+PT3X)/2.0)**2+
         (PT2Y-(PT1Y+PT3Y)/2.0)**2)
BB=DSQRT((PT3X-(PT1X+PT2X)/2.0)**2+
         (PT3Y-(PT1Y+PT2Y)/2.0)**2)
&  =DSQRT((PT1X-(PT2X+PT3X)/2.0)**2)
YZ=HEIGHT/3.0D0
SLOPE=(PT1X-(PT2X+PT3Y)/2.0D0)/(PT1X-(PT2X+PT3X)/2.0D0)
YINT=PT1Y-SLOPE*PT1X
XZ=(YZ-YINT)/SLOPE

Program ERBETA  250
AZ = DSQRT((PT1X - XZ)**2 + (PT1Y - YZ)**2)
BZ = DSQRT((PT2X - XZ)**2 + (PT2Y - YZ)**2)
CZ = DSQRT((PT3X - XZ)**2 + (PT3Y - YZ)**2)

C NOW, DETERMINE THE TEMPERATURE AT THE CENTROID OF THE TRIANGLE.
C MULTIPLY THIS BY THE AREA OF THE TRIANGLE, AND ADD THIS VALUE
C TO THE RUNNING TOTAL.
C
TZ1 = (AZ/AQ) * TAU + (1 - AZ/AQ) * TQ
TZ2 = (BZ/BR) * TB + (1 - BZ/BR) * TR
TZ3 = (CZ/CPP) * TC + (1 - CZ/CPP) * TP
TZ = (TZ1 + TZ2 + TZ3) / 3.0D0
TEMP = TEMP + TAREA * TZ

C WRITE(27, *) 'TEMP, TAREA, TZ', TEMP, TAREA, TZ
C WRITE(27, *) 'TA, TB, TZ', TA, TB, TZ
C WRITE(27, *) 'AZ, BZ, CZ', AZ, BZ, CZ
C WRITE(27, *) 'AQ, BR, CPP', AQ, BR, CPP
C 20 CONTINUE
C
C DETERMINE THE ELEMENT TEMPERATURE
C
TAVE(I) = TEMP / AREA
C
WRITE(27, *) 'I, TAVE(I)', I, TAVE(I)
C 30 CONTINUE
C
RETURN
END

******************************************************************************
**
** SUBROUTINE RADIAT
**
** This subroutine calculates the effective generation in *
** each cavity element due to thermal radiation.
**
******************************************************************************

SUBROUTINE RADIAT(NEC, N1, MDIV, NSTEP, NDT1, NDTSH, TAVE, GEN, EM)
C
C Request double precision and real variables, place variables used
C by the subroutine in common storage blocks and dimension the arrays.
C
IMPLICIT REAL*8 (A-H, O-Z)
DIMENSION GEN(200, 2), TAVE(200), IS(20), IT(20), MDIV(4)
DIMENSION DFOPT(200, 100, 15), DFSCN(200, 100, 15)
DIMENSION DFMOM(200, 100, 15), DFRING(200, 100, 15), DFCSUB(200, 100, 15)
DIMENSION DFUSUB(200, 100, 15), DFLUSUB(200, 100, 15)
DIMENSION DFCONE(200, 100, 15), DFBAR(200, 100, 15)
DIMENSION DOABCO(25), KAPPA(25)
DIMENSION EMIPW(600, 20), Genn(100)
DIMENSION GENOPT(100), GENSCN(100), GENRING(100)
DIMENSION GEM (100), GENDOME(100), GENCSUB(100)
DIMENSION GENUSB(100), GENLSUB(100), GENCON(100), GENBAR(100)
DIMENSION GCNBAR(100), GFCNCON(100)

COMMON /RADI1/ AREA1, AREAB, PI, R1, THCKDIM(4), NVEC, NSUN, NS
COMMON /RADI3/ AFOVL, AUSUB, ASUBI, ASUBO, ARING, VOL1, VOL2,
& ACSV, AFOVAP, AAR, ACON
COMMON /NB/ NBFOVL, NBUSUB, NLSUB, NCAVSUB, NBRING,
& NBDMOE, NBSCENE, NBBAR, NCON, NCAV
COMMON /EMISS/ EMFOVL, EMUSUB, EMLSUB, EMDOME, EMBAR, EMCON, EMCUSUB,
& EMRING
COMMON /DFACS/
DFOPT, DFSCN, DFBAR, DFCONE, DFDOME, DFBRING, DFCSUB,
& DFUSUB, DFLUSUB

Program ERBETA

251
COMMON /CHAN/ CHANEL
COMMON /DOM/ DOMTHC, DOABCO, NBWLIN
COMMON /FLUX/ SCNFLUX

C Define the Stefan-Boltzmann constant in the correct units.
C
SIGMA=5.6696D-8
N=MDIV(1)+MDIV(2)

C Determine the emissive power from each zone as a function of the
C wavelength interval
C
CALL EMPOW(EMIPOW, TAVE, NBWLIN)

C The effective thermal generation in each element of the cavity is
C determined from the total flux incident upon the element from all
C the other elements of the instrument including itself and the FOVL aperture,
C and then subtracting the energy emitted by the element.
C
C Loop over the number of elements in the cavity, initializing the
C total flux incident upon the element to zero.
C
DO 10 J=1, NEC
   GEN(J,2)=0.0D0
10 CONTINUE

C Since the cavity mesh is radially symmetric, the distribution factors
C are calculated for the first element for each level. The distribution
C factors are calculated using programs provided by HAUFFELIN and PRIESTLEY.
C The distribution factor for each cavity element
C to all other cavity elements, including itself and the optical front end
C is determined from the calculated values.
C
C BARREL TO CAVITY
C Loop over the number of elements (I) in the cavity to determine the
C total flux incident upon cavity element J.
C
SUM=0.0D0
DO 19 I=1, 100
   genbar(i)=0.0D0
19 CONTINUE

WRITE(17,*) 'HELLO'
DO 20 K=1, NBWLIN
   DO 20 I=1, NBBAR
      DO 20 J=1, NEC
         genbar(j)=genbar(j)+embar*abar*emipow(i+66, k)*dfbar(i, j, k)
20 CONTINUE

DO 25 I=1, NEC
   IF (I .LT. 60) THEN
      AREA=ACON*1.0D6
   ELSE
      AREA=ABAR*1.0D6
   END IF
   SUM=SUM+GENBAR(I)
25 CONTINUE

C Add the energy from the cone
C
SUM=0.0D0
DO 26 I=1, 1100
   GENCON(I)=0.0D0
26 CONTINUE
DO 27 K=1,NEWLIN
DO 27 I=1,NBCON
DO 27 J=1,NEC
GENCON(J)=GENCON(J)+EMCON*ACON*EMIPOW(I+6,K)*DFCONE(I,J,K)
27 CONTINUE
DO 28 I=1,NEC
IF (I.LE.60) THEN
   AREA=ACON*1.0D6
ELSE
   AREA=ABAR*1.0D6
END IF
SUM=SUM+GENCON(I)
GENNCON(I)=GENCON(I)
GENCON(I)=GENCON(I)/(AREA*THCK)
28 CONTINUE

C Subtract the amount of energy which each element
in the cavity emits to surfaces other than the cavity.
C
sum=0.0d0
DO 29 I=1,100
   genemi(i)=0.0d0
29 CONTINUE

DO 30 I=1,NEC
DO 30 K=1,NBWLIN
IF (J.GE.1.AND.I.LE.NBCON) THEN
   EM=EMCON
   AREA=ACON
ELSE
   EM=EMBAR
   AREA=ABAR
END IF
   genemi(i)=genemi(i)+em*area*EMIPOW(I+6,K)
30 CONTINUE
DO 35 I=1,NEC
   IF (I.LE.60) THEN
      AREA=ACON*1.0D6
   ELSE
      AREA=ABAR*1.0D6
   END IF
   SUM=SUM+GENEMI(I)
   GENEMI(I)=GENEMI(I)/(AREA*THOK)
35 CONTINUE
WRITE(17,*) 'sum of surfac genemi',SUM

C Add the energy incident upon element I from the dome for the visible
C channels, or for the ring for the total channel.
C
sum=0.0d0
DO 39 I=1,100
   gendome(i)=0.0d0
genring(i)=0.0d0
39 CONTINUE

IF (CHANSEL.EQ.2) THEN
   DO 40 K=1,NBWLIN
      KAPPA(K)=DLOG(1.0D0/DOABC0(K))/DOMTHC
   DO 40 I=1,NBDOME
   DO 40 J=1,NEC
      IF (I.GE.1.AND.I.LE.(NBDOME-1)) THEN
         VOL=VOL1
      ELSE IF (I.GT.(NBDOME-1)).AND.I.LE.NBDOME) THEN
         VOL=VOL2
   ELSE
END IF
GEN(J,2)=GEN(J,2)+4.0D0*KAPPA(K)*VOL*EMIPOW(I+106,K)
&
gendome(j)=gendome(j)+4.0D0*kappa(k)*vol*emipow(I+106,k)
&
*dfdome(i,j,k)
IF (KAPPA(K).LT.0.0D0) THEN
WRITE(17,*)'K, KAPPA(K)’, K,KAPPA(K)
ELSE IF(EMIPOW(I+106,K).LT.0.0D0) THEN
WRITE(17,*)’I+106, K, EMIPOW(I+106,K)’, I+106,K,EMIPOW(I+106,K)
ELSE IF(DFDOME(I,J,K).LT.0.0D0) THEN
WRITE(17,*)’I, J, K, DFDOME(I,J,K)’, I,J,K,DFDOME(I,J,K)
ELSE IF(GENDOME(J).LT.0.0D0) THEN
WRITE(17,*)’I, J, K, GENDOME(J)’, I,J,K,GENDOME(J)
END IF
40 CONTINUE
DO 45 I=1,NEC
IF (I.LE.60) THEN
AREA=ACON*1.0D6
ELSE
AREA=abar*1.0D6
END IF
SUM=SUM+GENDOME(I)
GENDOME=GEN/AREA/THCK
45 CONTINUE
ELSE
DO 50 K=1,NBWLIN
DO 50 I=1,NBRING
DO 50 J=1,NEC
EM=EMRING
AREA=ARING
GEN(J,2)=GEN(J,2)+EM*AREA*EMIPOW(S,K)*DFRING(I,J,K)
genring(j)=genring(j)+EM*AREA*EMIPOW(S,K)*DFRING(I,J,K)
50 CONTINUE
DO 55 I=1,NEC
IF (I.LE.60) THEN
AREA=ACON*1.0D6
ELSE
AREA=abar*1.0D6
END IF
SUM=SUM+GENRING(I)
genring=GENRING/AREA/THCK
55 CONTINUE
END IF
C
C Add the energy incident upon element I from the field of view limiter
C
SUM=0.0D0
DO 59 I=1,100
GENOPT(I)=0.0D0
59 CONTINUE
DO 60 K=1,NBWLIN
DO 60 I=1,NBFOVL
DO 60 J=1,NEC
GENOPT(J)=GENOPT(J)+EMFOVL*AFOVL*EMIPOW(2,K)*DFOPT(I,J,K)
60 CONTINUE
DO 65 I=1,NEC
IF (I.LE.60) THEN
AREA=ACON*1.0D6
ELSE
AREA=abar*1.0D6
END IF
SUM=SUM+GENOPT(I)
genopt(i)=genopt(i)/AREA/THCK
Program ERBETA
254
65 continue
C Add the energy incident upon element I from the upper substrate
C
    sum=0.0d0
    DO 61 I=1,100
        genusub(i)=0.0d0
    61 CONTINUE
    DO 62 K=1,NBWLIN
        DO 62 I=1,NBUSUB
            DO 62 J=1,NEC
                GENUSUB(J)=GENUSUB(J)+EMUSUB*AUSUB*EMIPOW(3,K)*DFUSUB(I,J,K)
    62 CONTINUE
    do 63 i=1,nec
        if (i.le.60) then
            area=acon*1.0D6
        else
            area=abar*1.0D6
        end if
        sum=sum+genusub(i)
        genusub(i)=genusub(i)/(area*thck)
    63 continue
C Add the energy incident upon element I from the lower substrate
C
    sum=0.0d0
    DO 66 I=1,100
        genLSUB(i)=0.0d0
    66 CONTINUE
    DO 67 K=1,NBWLIN
        DO 67 I=1,NBLSUB
            DO 67 J=1,NEC
                IF (1.LE.10) THEN
                    AREA=ALSUBI
                ELSE
                    AREA=ALSUBO
                END IF
                GENLSUB(J)=GENLSUB(J)+EMLSUB*AREA*EMIPOW(4,K)*DFLSUB(I,J,K)
    67 CONTINUE
    do 68 i=1,nec
        if (i.lt.60) then
            area=acon*1.0D6
        else
            area=abar*1.0D6
        end if
        sum=sum+genLSUB(i)
        genLSUB(i)=genLSUB(i)/(area*thck)
    68 continue
C Add the energy incident upon element I from the aperture.
C
    SCNFLUX=0.0d0
    sum=0.0d0
    DO 69 I=1,100
        genscn(i)=0.0d0
    69 CONTINUE
    I=1
    DO 70 K=1,NBWLIN
        DO 70 J=1,NEC
            genscn(j)=genscn(j)+afovap*emipow(1,k)*dfscn(i,j,k)
    70 CONTINUE
    do 75 i=1,nec
        if (i.lt.60) then

Program ERBETA

255
area=acon*1.0D6
else
area=abar*1.0D6
end if
sum=sum+genscn(i)
genscn(i)=genscn(i)/(area*thck)
75 continue
SCNFLUX=SUM*1000.0D0
C
C Add the energy incident upon element j from the cavsub
C
SUM=0.0D0
DO 79 I=1,100
GENCSUB(I)=0.0D0
79 CONTINUE
DO 80 I=1,NCAVSUB
DO 80 K=1,NBWLIN
DO 80 J=1,NEC
GENCSUB(J)=GENCSUB(J)+EMCAVSUB*ACAVSUB*EMIPOW(6,K)*DFCSUB(I,J,K)
80 CONTINUE
DO 85 I=1,NEC
IF (I.LE.60) THEN
AREA=ACON*1.0D6
ELSE
AREA=ABAR*1.0D6
ENDIF
SUM=SUM+GENCSUB(I)
GENCSUB(I)=GENCSUB(I)/(AREA*THCK)
85 CONTINUE
C
C Determine the effective volumetric generation in element I.
C
DO 90 J=1,NEC
GEN(J,2)=1000.0D0*(GENSCN(J)+GENOPT(J)+GENOM(J)+GENBAR(J)
&+GENRNG(J)+GENEMI(J)+GENSUB(J)+GENSUB(J)
&+GENLSUB(J)+GENCON(J))
90 CONTINUE
C
C Return to the main program
C
RETURN
END

***********************************************************************
SUBROUTINE HEATER
***********************************************************************
* This subroutine calculates the voltage across the electrical *
* substitution heater wire, and then determining the *
* volumetric heat generation in each cavity element due to this *
* voltage. The subroutine is called by the main program. *
***********************************************************************
SUBROUTINE HEATER(INIT,N1,MDIV,TNEW,GEN,RH,E2,DT)

C Request double precision real variables and dimension the arrays.
C
IMPLICIT REAL*8 (A-H,O-Z)
DIMENSION MDIV(4),TNEW(800),GEN(200,2)
COMMON /HEAT1/ HEATEL(15),EO,ALPHA,TAU,THS,DELT,NRES
C
C If the analysis is transient, determine the average temperature of *
C the two resistance thermometers,
C
IF (INIT.GT.0) THEN

Program ERBETA 256
N=2*N1
TARE=0.0D0
DO 10 I=1,N
    TARE=TARE+TNEXT(NRES+I-1)
    TARE=TARE/TARE/N
C and the corresponding voltage across the heater wire.
C
    E2=E2+(DT*ALPHA*EO/(4.0D0*TAU))*((DELT+(THS-TARE))
C END IF
C Determine the total power output of the heater and write
C it to a file.
C
    Q=1000.0D0*(E2**2)/RH
    WRITE(28,*)'E2, Q',E2,Q
C Calculate the volumetric heat generation in each cavity element due
C to the heater, and add this to the volumetric heat generation due to
C thermal radiation.
C
    DO 70 N=1,N1*(MDIV(1)+MDIV(2))
           I=1+INT((N-1)/N1)
           GEN(N,2)=GEN(N,2)+Q*HEATEL(I)
           70 CONTINUE
C Return to the main program.
C
RETURN
END

**************************************************************************

SUBROUTINE ELEM

This subroutine generates the element matrices for quadratic
quadrilateral elements for either a steady-state or transient
analysis using the two-dimensional heat conduction equation.
This subroutine is called by the main program and by subroutine
INTER.

**************************************************************************

SUBROUTINE ELEM(N,INIT,X,Y,TOLD,GEN,TA,TF,EM)
C
C Request double precision real variables, dimension the arrays, and
C provide Gauss quadratic data.
C
C IMPLICIT REAL*8 (A-H,O-Z)
DIMENSION GAUSS(3,2),WEIGH(3,2),A(9,9),B(9,9),F(9,2),C(9,9),D(9)
DIMENSION SF(9),DSF(9,2),TF(9),TA(9,9),GINV(2,2)
DIMENSION TOLD(9),GEN(200,2),X(200,9),Y(200,9)
COMMON /KLEM1/ DT,THETA,COND,CP,DENS
DATA GAUSS/-0.77459667D0,0.00000000D0,0.77459667D0,
     0.50000000D0,0.50000000D0,0.00000000D0/
DATA WEIGH/0.55555555D0,0.88888888D0,0.55555555D0,
     0.33333333D0,0.33333333D0,0.33333333D0/
C
C Determine the number of Gauss points in the element.
C
    NQP1=3
    NQP2=3
C
C Initialize the element submatrices to zero.
C
Program ERBETA
DO 10 I=1,9
F(I,1)=0.0D0
F(I,2)=0.0D0
D(I)=0.0D0
DO 10 J=1,9
A(I,J)=0.0D0
B(I,J)=0.0D0
10 CONTINUE
C Begin the gauss-quadrature to determine the element submatrices
C by running DO-loops over the number of gauss points.
C
DO 30 LL=1,NQP1
DO 30 KK=1,NQP2
C If the element is quadrilateral, determine the coordinates of the
C gauss point, then determine the values of the interpolation functions
C inverse jacobian matrix and the jacobian.
C
XI=GAUSS(LL,1)
ETA=GAUSS(KK,1)
CALL INTER (X,KI,XI,ETA,X,Y,SF,DSF,GINV,DET)
CONST=DET*WEIGH(LL,1)*WEIGH(KK,1)
C
C Evaluate the element submatrices for the gauss points using the
C equations given in the analysis. DO-loops are run over the
C number of nodes in the element.
C
DO 20 I=1,9
F(I,1)=F(I,1)+CONST*GEN(N,1)*SF(I)
F(I,2)=F(I,2)+CONST*GEN(N,2)*SF(I)
DO 20 J=1,9
IF (INIT.GT.0) A(I,J)=A(I,J)+CONST*SF(I)*SF(J)*CP*DENS
B1=(GINV(1,1)*DSF(I,1)+GINV(1,2)*DSF(I,2))
B2=(GINV(1,1)*DSF(J,1)+GINV(1,2)*DSF(J,2))
B3=(GINV(2,1)*DSF(I,1)+GINV(2,2)*DSF(I,2))
B4=(GINV(2,1)*DSF(J,1)+GINV(2,2)*DSF(J,2))
B(I,J)=B(I,J)+CONST*COND*((B1*B2)+(B3*B4))
20 CONTINUE
30 CONTINUE
C
C If the analysis is steady state, the element matrices are the
C same as the corresponding submatrices calculated above. If the
C analysis is transient, the element conductivity matrix can be
C found directly from the element submatrices, but the element
C flux vector must be determined after an additional submatrix is
C found.
C
DO 40 I=1,9
IF (INIT.EQ.0) TF(I)=F(I,2)
DO 40 J=1,9
IF (INIT.EQ.0) THEN
TA(I,J)=B(I,J)
ELSE
TA(I,J)=A(I,J)+THETA*DT*B(I,J)
C(I,J)=A(I,J)-(1-THETA)*DT*B(I,J)
ENDIF
40 CONTINUE
C
C If the analysis is steady-state, return to the main program
C
IF (INIT.EQ.0) RETURN
C
C If the analysis is transient, determine the final submatrix
C needed to determine the element flux vector.
C
DO 50 I=1,9
DO 50 J=1,9
D(I)=D(I)+C(I,J)*TOLD(J)
50 CONTINUE
C
The flux vector can now be found for the transient analysis.
C
DO 60 I=1,9
TF(I)=D(I)+THETA*DT*F(I,2)+(1.0D0-THETA)*DT*F(I,1)
60 CONTINUE
RETURN
RND

********************************************************************************
*  
*     SUBROUTINE INTER
*  
*  This subroutine determines the interpolation functions
*  and their derivatives, the jacobian and the inverse of
*  the jacobian matrix for the gauss points of a quadratic
*  quadrilateral element. This subroutine is called by
*  subroutine ELEM.
*  
********************************************************************************

SUBROUTINE INTER(N,XI,ETA,X,Y,SP,DSF,GINV,DET)
C
C Request double precision real variables, and dimension the arrays.
C
IMPLICIT REAL*8 (A-H,O-Z)
DIMENSION SF(9),DSF(9,2),TF(9),TA(9,9),GINV(2,2),GJ(2,2)
DIMENSION X(200,9),Y(200,9)
C
C The interpolation functions and their derivatives are calculated at
C the Gauss point for a quadrilateral element.
C
SP(1)=0.25D0*ETA*XI*(1.0D0-XI)*(1.0D0-ETA)
SP(2)=0.5D0*ETA*(1.0D0-XI*XI)*ETA*(1.0D0-ETA)
SP(3)=-0.25D0*ETA*XI*(1.0D0-XI)*(1.0D0-ETA)
SP(4)=-0.5D0*XI*(1.0D0-ETA**2)*(1.0D0-XI)
SP(5)=(1.0D0-XI**2)*(1.0D0-ETA**2)
SP(6)=0.5D0*XI*(1.0D0-ETA**2)*(1.0D0+XI)
SP(7)=-0.25D0*ETA*XI*(1.0D0-XI)*(1.0D0+ETA)
SP(8)=0.5D0*ETA*(1.0D0-XI**2)*(1.0D0+ETA)
SP(9)=(1.0D0-XI)*ETA*(1.0D0+XI)

DSF(1,2)=0.25D0*ETA*XI*(1.0D0-XI)*(1.0D0-2.0D0*ETA)
DSF(2,1)=ETA*XI*(1.0D0-ETA)
DSF(2,2)=-0.5D0*(1.0D0-XI**2)*(1.0D0-2.0D0*ETA)
DSF(3,1)=-0.25D0*ETA*(1.0D0-ETA)*(1.0D0+2.0D0*XI)
DSF(3,2)=-0.25D0*XI*(1.0D0-XI)*(1.0D0-2.0D0*ETA)
DSF(4,1)=0.5D0*(1.0D0-ETA**2)*(1.0D0+2.0D0*XI)
DSF(4,2)=ETA*XI*(1.0D0-XI)
DSF(5,1)=0.25D0*ETA*(1.0D0+ETA)*(1.0D0+2.0D0*XI)
DSF(5,2)=0.25D0*ETA*(1.0D0+XI)*(1.0D0+2.0D0*ETA)
DSF(6,1)=ETA*XI*(1.0D0+ETA)
DSF(6,2)=0.5D0*(1.0D0-XI**2)*(1.0D0+2.0D0*ETA)
DSF(7,1)=-0.25D0*ETA*(1.0D0-ETA)*(1.0D0-2.0D0*XI)
DSF(7,2)=-0.25D0*XI*(1.0D0-XI)*(1.0D0+2.0D0*ETA)
DSF(8,1)=-0.5D0*(1.0D0-ETA**2)*(1.0D0+2.0D0*XI)
DSF(8,2)=ETA*XI*(1.0D0-XI)
DSF(9,1)=-2.0D0*XI*(1.0D0-ETA**2)
DSF(9,2)=-2.0D0*ETA*(1.0D0-XI**2)

Program ERGBETA

259
C Initialize the jacobian matrix
C
DO 10 II=1,2
  DO 10 JJ=1,2
    GJ(II, JJ)=0.0D0
10 CONTINUE
C Determine the jacobian matrix and its determinant (the jacobian)
C
DO 20 K=1,9
  GJ(1,1)=GJ(1,1)+DSF(K,1)*X(N,K)
  GJ(1,2)=GJ(1,2)+DSF(K,1)*Y(N,K)
  GJ(2,1)=GJ(2,1)+DSF(K,2)*X(N,K)
  GJ(2,2)=GJ(2,2)+DSF(K,2)*Y(N,K)
20 CONTINUE
  DET=GJ(1,1)*GJ(2,2)-GJ(2,1)*GJ(1,2)
C Determine the inverse of the jacobian matrix
C
  GINV(1,1)=GJ(2,2)/DET
  GINV(1,2)=-GJ(1,2)/DET
  GINV(2,1)=-GJ(2,1)/DET
  GINV(2,2)=GJ(1,1)/DET
RETURN
END

*******************************************************************************

* *
* \textbf{SUBROUTINE BNDY} *
* *
* This subroutine imposes the temperature boundary conditions on the banded symmetric system of equations. *
* Provided by J.N. Reddy *
* *
*******************************************************************************

SUBROUTINE BNDY(NRMAX, NCMAX, NNM, NHBW, GTA, GTF, NPDF, IPDF, VPDF)
IMPLICIT REAL*8 (A-H, O-Z)
DIMENSION GTA(NRMAX, NCMAX), GTF(NRMAX)
DIMENSION IPDF(NPDF), VPDF(NPDF)
C
C Run a DO-loop over the number of specified temperature boundary conditions.
C
DO 30 NR=1, NPDF
  IB=IPDF(NR)
  SVAL=VPDF(NR)
  IT=NHBW-1
  I = IB-NHBW
  DO 10 II=1, IT
    I=I+1
    IF (I.GE.1) THEN
      J=IB-I+1
      GTF(I)=GTF(I)-GTA(I,J)*SVAL
      GTA(I,J)=0.0D0
    ENDIF
 10 CONTINUE
  GTA(IB,1)=1.0D0
  GTF(IB)=SVAL
  I=IB
  DO 20 II=2, NHBW
    I=I+1
    IF (I.LE.NNM) THEN
      GTF(I)=GTF(I)-GTA(IB,II)*SVAL
 20 CONTINUE
Program ERBETA
GTA(IE,II)=0.0D0
ENDIF
20 CONTINUE
30 CONTINUE
RETURN
END

******************************************************************************

*     *  
*     SUBROUTINE SOLVE     *  
*     *  
* Solves a banded symmetric system of equations.     *  
*     Provided by J.N. Reddy     *  
*     *  
******************************************************************************

SUBROUTINE SOLVE(NRM,NCM,NEQNS,NBW,BAND,RHS)
IMPLICIT REAL*8 (A-H,O-Z)
DIMENSION BAND(NRM,NCM),RHS(NRM)
NEQNS=NEQNS-1
DO 30 NPIV=1,NEQNS
NPIV=NPIV+1
LSTSUB=NPIV+NBW-1
IF(LSTSUB.GT.NEQNS) LSTSUB=NEQNS
DO 20 NROW = NPIVOT,LSTSUB

C C Invert rows and columns for row factor C
C
NCOL=NROW-NPIV+1
FACTOR=BAND(NPIV,NCOL)/BAND(NPIV,1)
DO 10 NCOL=NROW,LSTSUB
ICOL=NCOL-NROW+1
JCOL=NCOL-NPIV+1
BAND(NROW,ICOL)=BAND(NROW,ICOL)-FACTOR*BAND(NPIV,JCOL)
10 CONTINUE
RHS(NROW)=RHS(NROW)-FACTOR*RHS(NPIV)
20 CONTINUE
30 CONTINUE

C C Back substitution. C
C
DO 70 IJK=2,NEQNS
NPIV=NEQNS-IJK+2
RHS(NPIV)=RHS(NPIV)/BAND(NPIV,1)
LSTSUB=NPIV-NBW+1
IF (LSTSUB.LT.1) LSTSUB=1
NPIV=NPIV-1
DO 60 JKI=LSTSUB,NPIVOT
NROW=NPIVOT-JKI+LSTSUB
NCOL=NPIV-NROW+1
FACTOR=BAND(NROW,NCOL)
60 RHS(NROW)=RHS(NROW)-FACTOR*RHS(NPIV)
70 CONTINUE
RHS(1)=RHS(1)/BAND(1,1)
RETURN
END

******************************************************************************

*     *  
*     SUBROUTINE EMMIT     *  
*     *  
******************************************************************************

SUBROUTINE EMMIT(NEC,N1,MDIV,RI,EM,TAVE,DFC,DIM,HQ,ATIP,SM2)
C C Request double precision real variables, place variables used C by the subroutine in common storage blocks and dimension the arrays. C

Program ERBETA 261
IMPLICIT REAL*8 (A-H,O-Z)
DIMENSION tAVe(200),DFC(15,351)
DIMENSION IS(20),IT(20),MDIV(4),DIM(4)

C Define the Stefan-Boltzmann constant in the correct units are the
C constant pi.
SIGMA=5.6696D-8
Pi=3.141592654D0
IF (MDIV(1).EQ.0) THEN
AREA1=0.0D0
GO TO 47
END IF
AREA1=(Pi*RI*DSQRT(RI**2+(DIM(1)+HO)**2)-ATIP)/(N1*MDIV(1))
47 IF (MDIV(2).EQ.0) THEN
AREA2=0.0D0
GO TO 48
END IF
AREA2=(Pi*RI*2.0D0*DIM(2))/(N1*MDIV(2))

C Determine the number of element levels in the cavity, and
C initialize the distribution factor subscript.
C
48 N=MDIV(1)+MDIV(2)
LL=0
DO 10 I=1,N1
10 IS(I)=NEC-I+1
NECC=NEC+1
SUM2=0.0D0
LL=LL+1
IF (LL.GT.N1) LL=1

C then determine the distribution factor subscripts for the element
C from those of the previously considered element.
C
DO 20 L=1,N1
IF (L.EQ.1) IT(L)=IS(N1)
20 IF (L.NE.1) IT(L)=IS(L-1)
DO 30 L=1,N1
30 IS(L)=IT(L)

C Loop over the number of elements in the cavity to determine the
C total flux incident upon element 1 from the radiometer cavity.
C
I1=0
DO 40 J=1,N
DO 40 K=1,N1

C Determine the subscript of the distribution factor corresponding
C to element II.
C
jj=IS(K)
IF (j.NE.1) jj=jj-n1*(j-1)
IF (LL.EQ.N1) JJ=NECC-II
I1=I1+1

C Determine energy escaped from the cavity.
C
AREA=AREA1
IF (J.GT.MDIV(1)) AREA=AREA2
JL=N-J+1
SUM2=SUM2+EM*SIGMA*AREA*(TAVE(I1)**4)*DFC(JL,NECC)
40 CONTINUE
RETURN
END
The following subroutine computes the emissive power of all the elements of the optical front end either from known surface or volum temperatures or from a given power value.

**SUBROUTINE EMPOW(EMIPOW, TAVE, NBWLIN)**

```plaintext
IMPLICIT NONE

REAL*8 LBDA, DLBDA, INT1, INT2, X1, X2, X, W, EMIPOW
REAL*8 TPELMT, SWRADFLU, LWRADFLU
REAL*8 C1, C2, SIGMA, SWTSCN, LWTSCN
REAL*8 PI
REAL*8 DOMTHC, DOABCO
REAL*8 TFOVL, TUSUB, TLSUB, TDOME, TRING, TCAVSUB, TAVE

INTEGER IS, NMAX, INDX, MAXWLI, MAXELT
INTEGER ELT, ELT1, ELT2, WVL, I, II
INTEGER NBWLIN, K

PARAMETER (IS=1000, MAXWLI=20, MAXELT=600)

DIMENSION X(IS), W(IS), EMIPOW(MAXELT, MAXWLI)
DIMENSION LBDA(20), TAVE(100), TPELMT(200)
DIMENSION TDOME(60)

COMMON /DOME/DOMTHC, DOABCO, NBWLIN
COMMON /LMBDA/LBDA
OPEN(98, FILE= 'surfac.tmp')

C Read the distribution of wavelength intervals and calculate dbda

NMAX=20
PI=3.1415926535897931D0
C1=0.595444D8
C2=14388.000D0
SIGMA=5.6696D-8
X1=0.000D0

C Read the radiative flux incident to the instrument, as well as the temperatures of the zones, including the scene temp.

READ(03, *) SWRADFLU, LWRADFLU
WRITE(6, *) SWRADFLU, LWRADFLU
READ(36, *) SWTSCN, LWTSCN
READ(29, *) TFOVL
READ(30, *) TUSUB
READ(31, *) TLSUB
READ(32, *)
DO 10 I=1, 60
   READ(32, *) II, TDOME(I)
10 CONTINUE
REWIND 32
READ(33, *) TRING
READ(34, *) TCAVSUB

C TPELMT(1)=SWTSCN
TPELMT(2)=TFOVL
TPELMT(3)=TUSUB
```

Program ERBETA
TPELMT(4) = TLSUB
TPELMT(5) = TRING
TPELMT(6) = TCAVSUB
DO 20 I = 1, 100
   TPELMT(I+6) = TAVE(I)
20 CONTINUE
   DO 30 I = 1, 60
      TPELMT(I+106) = TDOME(I)
30 CONTINUE

Compute the spectral emissive power of each element.

DO 100 ELT = 2, 166
   DO 101 WVL = 1, NBWLIN - 1
   Compute the integral from 0 to lbd(k)
   INT1 = 0.00
   IF (LBD(A(WVL) .LE. 0.00)) GO TO 99
   X2 = LBD(A(WVL)) * TPELMT(ELT)
   CALL GAULEG(IS, X1, X2, X, W, NMAX)
   DO 110 IND = 1, NMAX
      INT1 = INT1 + 2.00 * PI * C1 * DEXP(-C2/X(INDX)) / (SIGMA*(X(INDX)**5)*
      & (1.00 - DEXP(-C2/X(INDX)))**W(INDX))
110 CONTINUE
   Compute the integral from 0 to lbd(k+1)
99   INT2 = 0.00
   X2 = LBD(A(WVL+1)) * TPELMT(ELT)
   CALL GAULEG(IS, X1, X2, X, W, NMAX)
   DO 120 IND = 1, NMAX
      INT2 = INT2 + 2.00 * PI * C1 * DEXP(-C2/X(INDX)) / (SIGMA*(X(INDX)**5)*
      & (1.00 - DEXP(-C2/X(INDX)))**W(INDX))
120 CONTINUE
   Compute the emissive power in the wavelength interval lbd(k) - lbd(k+1)
   EMIPW(ELT, WVL) = (INT2 - INT1) * SIGMA * TPELMT(ELT) * TPELMT(ELT) *
      & TPELMT(ELT) * TPELMT(ELT)
101 CONTINUE
   WVL = NBWLIN
   INT1 = 0.00
   INT2 = 0.00
   X2 = LBD(A(WVL)) * TPELMT(ELT)
   CALL GAULEG(IS, X1, X2, X, W, NMAX)
   DO 130 IND = 1, NMAX
      INT2 = INT2 + 2.00 * PI * C1 * DEXP(-C2/X(INDX)) / (SIGMA*(X(INDX)**5)*
      & (1.00 - DEXP(-C2/X(INDX)))**W(INDX))
130 CONTINUE
   EMIPW(ELT, WVL) = (1.00 - INT2) * SIGMA * TPELMT(ELT) * TPELMT(ELT) *
      & TPELMT(ELT) * TPELMT(ELT)
100 CONTINUE

Emissive power from the Scene
   ELT = 1
Shortwave power:
   DO 200 WVL = 1, NBWLIN - 1
   Compute the integral from 0 to lbd(k)

Program ERBETA

264
INT1 = 0.0D0
IF (LBDA(WVL).LE.0.0D0) GO TO 97
X2 = LBDA(WVL)*SWTSCN
CALL GAULEG(IS,X1,X2,X,W,NMAX)
DO 210 INDEX=1,NMAX
   INT1=INT1 + 2.0D0*PI*C1*DEXP(-C2/X(INDX))/(SIGMA*(X(INDX)**5)*
   & (1.0D0-DEXP(-C2/X(INDX)))**5)*W(INDX)
210  CONTINUE
C C Compute the integral from 0 to lbda(k+1)
C
98  INT2 = 0.0D0
   X2=LBDA(WVL+1)*SWTSCN
   CALL GAULEG(IS,X1,X2,X,W,NMAX)
   DO 220 INDEX=1,NMAX
      INT2=INT2 + 2.0D0*PI*C1*DEXP(-C2/X(INDX))/(SIGMA*(X(INDX)**5)*
      & (1.0D0-DEXP(-C2/X(INDX)))**5)*W(INDX)
220  CONTINUE
C C Compute the emissive power in the wl interval lbda(k)-lbda(k+1)
C
   EMIPOW(ELT,WVL)=(INT2-INT1)*SWRADFLU
200  CONTINUE
WVL = NBWLIN
   INT1 = 0.0D0
   INT2 = 0.0D0
   X2 = LBDA(WVL)*SWTSCN
   CALL GAULEG(IS,X1,X2,X,W,NMAX)
   DO 230 INDEX=1,NMAX
      INT2=INT2 + 2.0D0*PI*C1*DEXP(-C2/X(INDX))/(SIGMA*(X(INDX)**5)*
      & (1.0D0-DEXP(-C2/X(INDX)))**5)*W(INDX)
230  CONTINUE
   EMIPOW(ELT,WVL)=(1.0D0 - INT2)*SWRADFLU
C C Longwave Power (added to the shortwave power)
C
   DO 250 WVL=1,NBWLIN-1
C C Compute the integral from 0 to lbda(k)
C
97  INT1 = 0.0D0
   IF (LBDA(WVL).LE.0.0D0) GO TO 97
   X2 = LBDA(WVL)*LWTSCN
   CALL GAULEG(IS,X1,X2,X,W,NMAX)
   DO 260 INDEX=1,NMAX
      INT1=INT1 + 2.0D0*PI*C1*DEXP(-C2/X(INDX))/(SIGMA*(X(INDX)**5)*
      & (1.0D0-DEXP(-C2/X(INDX)))**5)*W(INDX)
260  CONTINUE
C C Compute the integral from 0 to lbda(k+1)
C
97  INT2 = 0.0D0
   X2=LBDA(WVL+1)*LWTSCN
   CALL GAULEG(IS,X1,X2,X,W,NMAX)
   DO 270 INDEX=1,NMAX
      INT2=INT2 + 2.0D0*PI*C1*DEXP(-C2/X(INDX))/(SIGMA*(X(INDX)**5)*
      & (1.0D0-DEXP(-C2/X(INDX)))**5)*W(INDX)
270  CONTINUE
C C Compute the emissive power in the wl interval lbda(k)-lbda(k+1)
C
   EMIPOW(ELT,WVL) = EMIPOW(ELT,WVL) + (INT2-INT1)*LWRADFLU
250  CONTINUE
WVL = NBWLIN

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265
INT1 = 0.0D0
INT2 = 0.0D0
X2 = LMDA(WVL)*LTWSCN
CALL GAULEG(IS,X1,X2,X,W,NMAX)
DO 280 INDX=1,NMAX
   INT2=INT2 + 2.0D0*PI*C1*DEXP(-C2/X(INDX))/(SIGMA*(X(INDX)**5) &
   * (1.0D0-DEXP(-C2/X(INDX)))*W(INDX))
280 CONTINUE
EMIPOW(ELT,WVL) = EMIPOW(ELT,WVL) + (1.0D0 - INT2)*LWRADFLU
C
RETURN
END

******************************************************************************

* THE FOLLOWING SUBROUTINE PERFORMS A GAUSS-LEGENDRE
* QUADRATURE TO
* EXECUTE A NUMERICAL INTEGRATION. THE X'S ARE THE ROOTS OF THE
* LEGENDRE POLYNOMIAL AND THE W'S ARE THEIR CORRESPONDING
* WEIGHTS.
* (COURTESY OF DR. J.R. THOMAS, ME DEPARTMENT AT VIRGINIA TECH)
*
******************************************************************************

SUBROUTINE GAULEG(IS,X1,X2,X,W,N)

IMPLICIT REAL*8 (A-H,O-Z)
DIMENSION X(IS),W(IS)
PARAMETER (EPS=1.D-15)
PI=4DACOS(-1.D0)
M=(N+1)/2
XM=0.5D0*(X2+X1)
XL=0.5D0*(X2-X1)
DO 12 I=1,M
   Z=DCOS(PI*(DBLE(I)-.5D0)/(DBLE(N)+.5D0))
1 CONTINUE
   P1=1.D0
   P2=0.D0
   DO 11 J=1,N
      DJ=DBLE(J)
      P3=P2
      P2=P1
      P1=((DBLE(2.D0*J)-1.D0)*Z-P2-(DJ-1.D0)*P3)/DJ
11 CONTINUE
   PP=DBLE(N)*(Z*P1-P2)/(Z-Z-1.D0)
   Z1=Z
   Z=Z1-P1/PP
   IF(ABS(Z-Z1).GT.EPS)GO TO 1
   X(I)=XM-XL*Z
   X(N+1-I)=XM-XL*Z
   W(I)=2.0D0*XL/((1.0D0-Z*Z)*PP*PP)
   W(N+1-I)=W(I)
12 CONTINUE
RETURN
END

Program ERBETA
Vita

Kory J. Priestley was born on April 14, 1969 in Panorama City, California. He grew up in the cities of Ft. Lauderdale, FL, San Juan, Puerto Rico, Oklahoma City, OK, Memphis, TN, and Lancaster, CA. In May, 1987 he graduated from Paraclete High School in Lancaster, CA.

In September, 1987 Kory began his undergraduate studies in Mechanical Engineering at Antelope Valley College in Lancaster, CA. In September, 1989 he transferred to California Polytechnic State University at San Luis Obispo, where he received his Bachelor of Science Degree in March, 1992. He spent the summer of that same year working as a Langley Research Summer Scholar at NASA's Langley Research Center.

In August of 1992, Kory began his graduate studies at Virginia Polytechnic Institute & State University and earned a Master of Science Degree from the Mechanical Engineering Department in October, 1993. He served as a Graduate Research Assistant until June of 1993 when he was awarded a Fellowship from NASA's Graduate Student Researcher's Program.

Kory J. Priestley