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SOLAR ENERGY PROGRAM

RADIATION TRANSMISSION THROUGH A COMPOSITE MEDIUM
OF GLASS AND WATER

BY

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**RADIATION TRANSMISSION THROUGH A COMPOSITE MEDIUM
OF GLASS AND WATER**

BY

MICHAEL JAMES WITTE

B.S, Valparaiso University, 1981

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Mechanical Engineering
in the Graduate College of the
University of Illinois at Urbana-Champaign, 1983

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Nomenclature

a,b,c	real constant
D	material thickness (cm)
f	fraction of radiation
F	configuration factor
I	incoming radiation
k	extinction coefficient (cm^{-1})
K	real constant
L	radiation path length (cm)
n	number of glass layers
N	number of cells per layer
q	radiant flux ($\text{W}\cdot\text{m}^{-2}$)
r	geometric mean beam length
R	reflectance of composite layer
T	transmittance of composite layer
θ	angle of incidence; angle of refraction
λ	wavelength (μm)
ρ	reflectivity of interface
$\bar{\rho}$	effective reflectivity
τ	transmittance of absorbing layer

subscripts

a	air
A,B,C	distinguish different values of same variable
C	center cell
E	effective
g	glass
i	spectral band index; incident
in	incident
j	component of polarization index
o	outgoing
r	relative
s	water surface (air/water interface)
w	water
1,2,3,....	distinguish different values of same variable
(i,j)(m,n)	designate surface location

1. Introduction

Solar ponds have been shown to be a viable method of collecting solar energy. The most common type of solar pond is the salt gradient solar pond. Interest has also been shown in other types of ponds, such as a membrane stratified solar pond [1]. Another possible alternative is a porous medium solar pond, where a porous medium would be used to stratify the pond. The growing abundance of recycled glass could provide an inexpensive source of material for constructing a light transmitting porous medium. In order to establish the feasibility of such a pond, it is necessary to know the radiation transmission characteristics of the porous medium.

Two experiments were conducted to measure the transmittance properties of a porous medium of glass and water. The results of these experiments are compared with the transmittance of parallel glass plates in water, and a semi-empirical correlation is developed to express the data. In addition, a model consisting of a glass lattice in water is developed and compared with the experimental data.

2. Experimental Procedure

2.1 Basic Experimental Concept

Two experiments were conducted to obtain transmittance data for a porous medium of glass and water. As shown in Figure 1, the basic concept of these experiments consisted of measuring the radiant flux transmitted through a test layer given a known incident flux. The first experiment was conducted indoors using an artificial light source, and the second experiment was conducted outdoors using sunlight as the radiant source.

In both experiments the test layer consisted of a porous medium of clear glass bottles saturated with water. Five different types of bottles were used; the shape and size of each type are shown in Figure 2. The designations given in Figure 2 will be used to distinguish between the different bottle types. Bottles were used in the test layer since crushed glass is difficult to handle. Also, specification of the test layer -- number of interfaces and volume of glass -- was simplified by using the bottles. In order to know the volume of glass in each layer, the displacement of a sample of each bottle type was measured. The data from these measurements may be found in Appendix A.

2.2 The Indoor Experiment

The incident radiation for the indoor experiment was provided by a 1500 W metal halide multi-vapor lamp. The test layer was suspended above a pyranometer in the tank shown in Figure 3. A second pyranometer was mounted on the test stand with the tank to monitor the output of the lamp. Figure 4 illustrates the placement of the lamp, test tank, and

Figure 1 Basic experimental concept.

Figure 2 Bottles used in experiments

1. Small round (2.54 cm dia. x 6.99 cm high)
(1.0 in x 2.75 in.)
2. Medium round (3.81 cm dia. x 9.53 cm high)
(1.5 in x 3.75 in.)
3. Large round (5.08 cm dia. x 1.5 cm high)
(2.0 in x 4.5 in.)
4. Symmetric flat (5.08 cm x 1.90 cm x 12.7 cm high)
(2.0 in. x 0.75 in. x 5 in.)
5. Assymmetric flat (6.99 cm x 3.18 cm x 12.7 cm high)
(2.75 in. x 1.75 in. x 5 in.).

Figure 3 Indoor test tank.

Figure 4 Indoor test stand.

pyranometer. Figure 4 also shows a diffuser which consisted of several circular pieces of translucent polyethylene. The diffuser was used to provide a reasonably even flux ($\pm 30\%$) over the entire surface of the test layer, since the lamp produced a bright spot in the center of the test layer. More detailed information about the test equipment may be found in Appendix A.

Before each test session, the lamp was turned on for at least three hours to be sure that it had reached steady state. Also, before each test session, the incoming flux was measured across the top of the tank at 12.7 mm (0.5 in.) intervals along two perpendicular diameters. These measurements were used to determine the uniformity of the flux entering the test tank. The pyranometer used for these measurements was then mounted on the top of the test stand to monitor variations in the radiant output of the lamp. For each test, a layer of bottles was immersed in 25.4 cm (10 in.) of water. The outputs from the pyranometers were recorded simultaneously for each test. The test layers ranged over all five bottle types in horizontal and vertical orientations. In all cases the depth of water in the tank was 25.4 cm (10 in.). Data was also taken for 2.5 to 25.4 cm (1 to 10 in.) of plain water. Test layers were built by first placing a layer of bottles, either horizontally or vertically, at the bottom of the tank. After taking data for this arrangement, a second layer of bottles was placed on top of the first layer. Successive layers were built up until the tank was full, producing a series of data for a given bottle type and a given orientation.

Two series of tests were made in the tank. For the first series, the inside of the tank was painted black. For the second series, a sheet of reflective aluminized mylar was attached to the inside of the tank above the plexiglas, producing an effect similar to having a tank of infinite diameter.

2.3 The Outdoor Experiment

The outdoor experiment was conducted on the roof of the Mechanical Engineering Building at the University of Illinois at Urbana-Champaign. Using a galvanized steel platform, as shown in Figure 5, an underwater pyranometer was suspended in a 0.9 m (3 ft.) diameter tank. The test layer consisted of 43.2 cm (17 in.) of water with a layer of bottles randomly placed on the platform. The tank was initially filled with 1126 medium round bottles (see Figure 2) at the bottom and 388 asymmetric flat bottles on top. Data was taken for this full layer, and then data was taken for successively thinner layers of bottles. As bottles were removed to make the smaller test layers, the water level was always maintained at 43.2 cm (17 in.) from the platform. The inside of the tank was lined with black polyethylene to prevent reflection from the tank sides. Data was taken for eleven different test layers. For each layer, the incident solar radiation, the transmitted radiation, and the time of day were recorded at fifteen-minute intervals for a period of one to two days. Data was also taken for plain water, 12.7 to 43.2 cm (5 to 17. in.) deep.

The diffuse component of the incident solar radiation was measured with a pyranometer and shading ring, and the total incident solar

Figure 5 Outdoor test tank.

radiation was measured with a second pyranometer. In order to prevent biological growth in the test tank, swimming pool chemicals (chlorine and algicide) were added to the water as needed. Further details on the equipment used in the outdoor experiment are presented in Appendix B.

3. Analytical Modeling

3.1 Radiation Transmission Through Multiple Parallel Layers

The mathematical analysis of light transmission through multiple parallel layers is accomplished using Siegel's net radiation method [2]. Figure 6 illustrates flux designations for a single slab of absorbing material. For this layer, a set of four simultaneous equations may be written:

$$q_{01} = \rho_1 q_{in} + (1 - \rho_1) \tau q_{03} \quad (1)$$

$$q_{02} = (1 - \rho_1) q_{in} + \rho_1 \tau q_{03} \quad (2)$$

$$q_{03} = \rho_2 \tau q_{02} \quad (3)$$

$$q_{04} = (1 - \rho_2) \tau q_{02} \quad (4)$$

where q_0 = net flux leaving surface

ρ = reflectivity of interface

τ = transmittance of absorbing layer .

After solving this set of equations, the transmittance (T) and reflectance (R) of the layer are expressed as

$$T = \frac{q_{04}}{q_{in}} = \frac{(1 - \rho_1)(1 - \rho_2) \tau}{(1 - \rho_1 \rho_2 \tau^2)} \quad (5)$$

$$R = \frac{q_{01}}{q_{in}} = \rho_1 + \frac{(1 - \rho_1)^2 \tau^2 \rho_2}{(1 - \rho_1 \rho_2 \tau^2)} \quad (6)$$

This technique may be extended to multiple layers as shown in Figure 7. For the three layer system a set of eight equations must be solved, giving the transmittance:

$$T = \frac{(1-\rho_1)(1-\rho_2)(1-\rho_3)(1-\rho_4) \tau_A \tau_B \tau_C}{(1-\rho_3 \rho_4 \tau_C^2) (1-\rho_1 \rho_2 \tau_A^2) - \tau_B^2 [\rho_3 + \rho_4 \tau_C^2 (1-2\rho_3)] [\rho_2 + \rho_1 \tau_A^2 (1-2\rho_2)]} \quad (7)$$

For large systems it would be possible to determine the transmittance by numerically solving a set of simultaneous equations. However, this is not necessary as shown by Siegel and Howell [2]. Equation (7) may be found directly from equations (5) and (6) through a slight change in notation. Figure 8 is the same as Figure 6 except that the surfaces no longer represent a single interface, but each may be a multilayer system of parallel layers for which the reflectance and transmittance are already known. One detail which must be observed is that if a system of layers is not symmetric, then it will have two values of reflectance for a given angle of incidence. Equation (6) shows that the reflectance is different if radiation enters the bottom of the system instead of the top. Since surface A in Figure 8 reflects radiation from both the top and the bottom, both reflectances must be used. The transmittance of a system is always symmetric as can be seen in equations (5) and (7). Using the new notation of Figure 8, equations (5) and (6) become

$$T = \frac{T_A T_C \tau_B}{(1 - R_{A2} R_C \tau_B^2)} \quad (8)$$

Figure 6 Single absorbing layer.

Figure 7 Three parallel absorbing layers.

Figure 8 Single absorbing layer where surfaces represent multilayer systems.

$$R = R_{A1} + \frac{R_C T_A^2 T_B^2}{(1 - R_{A2} R_C T_B^2)} \quad (9)$$

Equations (5) and (6) may be reobtained with these substitutions:

$$R_{A1} = R_{A2} = \rho_1 \quad (10)$$

$$T_A = (1 - \rho_1) \quad (11)$$

$$R_C = \rho_2 \quad (12)$$

$$T_C = (1 - \rho_2) \quad (13)$$

$$\tau_B = \tau \quad (14)$$

Using equations (8) and (9), the transmittance for the three layer system in Figure 7 may be written directly by collapsing layers A and C into the surfaces of Figure 8.

The properties for this single slab are

$$R_{A1} = \rho_1 + \frac{\rho_2 (1 - \rho_1)^2 \tau_A^2}{(1 - \rho_1 \rho_2 \tau_A^2)} \quad (15)$$

$$R_{A2} = \rho_2 + \frac{\rho_1 (1 - \rho_2)^2 \tau_A^2}{(1 - \rho_1 \rho_2 \tau_A^2)} \quad (16)$$

$$T_A = \frac{(1 - \rho_1)(1 - \rho_2) \tau_A}{(1 - \rho_1 \rho_2 \tau_A^2)} \quad (17)$$

$$R_C = \rho_3 + \frac{\rho_4 (1 - \rho_3)^2 \tau_C^2}{(1 - \rho_3 \rho_4 \tau_C^2)} \quad (18)$$

$$\tau_C = \frac{(1 - \rho_3)(1 - \rho_4) \tau_C}{(1 - \rho_3 \rho_4 \tau_C^2)} \quad (19)$$

Substituting these into equation (8) yields

$$T = \frac{(1 - \rho_1)(1 - \rho_2) \tau_A (1 - \rho_3)(1 - \rho_4) \tau_B \tau_C}{(1 - \rho_1 \rho_2 \tau_A^2)(1 - \rho_3 \rho_4 \tau_C^2)(1 - K \tau_B^2)} \quad (20)$$

where

$$K = \left[\rho_2 + \frac{\rho_1(1 - \rho_2)^2 \tau_A^2}{(1 - \rho_1 \rho_2 \tau_A^2)} \right] \left[\rho_3 + \frac{\rho_4(1 - \rho_3)^2 \tau_C^2}{(1 - \rho_3 \rho_4 \tau_C^2)} \right]$$

With a little algebra, equation (20) becomes equation (7). Thus, the transmittance of a multiple layer system may be determined by successively adding one layer at a time using two simple equations, (8) and (9). These two equations become the basis for modeling parallel plate systems and a glass lattice to compare with the experimental data.

3.2 Physical Properties

The surface reflectivities (ρ) are determined using Snell's law and Fresnel's equations [4]. The refractive index of water is 1.333 [5], and the refractive index of glass is 1.526 [4].

The transmittance (τ) of glass and water for incident solar radiation are calculated using an approximation with five spectral bands. This approximation is based on a four-band approximation for water suggested by Rabl and Nielsen [5] and on transmission data for

glass from Hsieh and Su [6]. The extinction coefficients (k) and fractions of incident solar radiation (f) are presented in Table 1. Appendix C contains the details of how these values were obtained.

Table 1 Five-band Spectral Approximation for Glass and Water Transmission of Solar Radiation.

$\lambda_1 - \lambda_2$ (μm)	f	$k_{\text{glass}}(\text{cm}^{-1})$	$k_{\text{water}}(\text{cm}^{-1})$
0.30 - 0.40	0.040	0.688	0.32×10^{-3}
0.40 - 0.60	0.197	0.124	0.32×10^{-3}
0.60 - 0.75	0.193	0.180	4.5×10^{-3}
0.75 - 0.90	0.167	0.307	0.030
0.90 - 1.2	0.179	0.412	0.350

f = fraction of incident radiation within $\lambda_1 - \lambda_2$

k = extinction coefficient within $\lambda_1 - \lambda_2$

In computing the transmittance of a system of glass and water, each spectral band is considered separately. Also, as shown by Hottel and Sarofim [7], the entire system must be evaluated for each component of polarization, and then the results are averaged. The total transmittance is then

$$T = \frac{1}{2} \sum_{j=1}^2 \sum_{i=1}^5 f_i T(\rho_{1j}, \rho_{2j}, \dots, \tau_{1i}, \tau_{2i}, \dots) \quad (21)$$

where $\tau_i = e^{-k_i L}$

L = path length through material.

$T(\rho_{1j}, \dots, \tau_{1i}, \dots)$ represents an expression for the system transmittance, such as equation (7), which is a function of several ρ 's and τ 's. The summation on i covers the five spectral bands. The summation on j represents the two components of polarization. Thus, for a given system, $T(\rho_{1j}, \dots, \tau_{1i}, \dots)$ must be evaluated ten times to obtain the total transmittance.

3.3 Parallel Plates

When taking experimental data, the glass was always located at the bottom of the test tank with a layer of water on top of it. The question arises whether the transmittance of the test layer would change if the glass were spread evenly throughout the layer. Hull, in his discussion of membrane stratified solar ponds [1] states a formulation for the total transmission through parallel plates in a liquid:

$$T(z, \theta_a) = \tau_a(\theta_a) T_N \int T_L(\lambda, z/\cos\theta_i) d\lambda, \quad (22)$$

where z = depth of liquid

λ = wavelength

θ_a = angle of incidence in air

θ_i = angle of refraction in liquid

τ_a = transmission at surface due to
Fresnel reflection

T_N = transmission through N plates with
no absorption in liquid

T_L = transmission through liquid only.

This formula implies that placement of the plates is irrelevant since T_N is calculated assuming no absorption between plates. However, this formula is inaccurate because it does not account for the increased absorption in the liquid due to interreflections between the plates. Using Figure 7 once again, let layers A and B represent glass plates; and let layer C represent water. Recalling equation (7), the transmittance of this system is

$$T = \frac{(1-\rho_1)(1-\rho_2)(1-\rho_3)(1-\rho_4) \tau_A \tau_B \tau_C}{(1-\rho_3 \rho_4 \tau_C^2)(1-\rho_1 \rho_2 \tau_A^2) - \tau_B^2 [\rho_3 + \rho_4 \tau_C^2 (1-2\rho_3)] [\rho_2 + \rho_1 \tau_A^2 (1-2\rho_2)]} \quad (7)$$

By Hull's method, the transmittance would be

$$T = \frac{(1-\rho_1)(1-\rho_2)(1-\rho_3)(1-\rho_4) \tau_A \tau_C \tau_B}{(1-\rho_3 \rho_4 \tau_C^2)(1-\rho_1 \rho_2 \tau_A^2) - [\rho_3 + \rho_4 \tau_C^2 (1-2\rho_3)] [\rho_2 + \rho_1 \tau_A^2 (1-2\rho_2)]} \quad (23)$$

Equations (7) and (23) are identical except for a τ_B^2 in the second term of the denominator. This difference is negligible in some cases, but for large number of layers or a strongly absorbing liquid the difference can be come significant. For example, Hull plots values for the transmittance of solar radiation through one meter of water containing 200 horizontal Teflon membranes which are 12.7 μm thick and for the transmittance of one meter of water [1]. Calculating T_N by the method presented earlier in this chapter and using Hull's own four term approximation [8] for the integral in equation (22), Hull's values are reproduced in Figure 9. The lower curve in Figure 9 shows the

Figure 9 Transmittance of 200 teflon membranes ($12.7 \mu\text{m}$ thick) in 1.0 m of water as a function of angle of incidence in air (θ_a).

transmittance when the water absorption is properly accounted for. Note that Hull's method overestimated the transmittance by as much as 12% (at normal incidence).

Even though the transmittance of the glass and water cannot be calculated independently, it is still possible that the placement of the plates has a negligible effect on the overall transmittance. To determine this, the transmittance of twenty-five glass plates in 43.18 cm (17. in.) of water is calculated for varying plate positions. Table 2 presents these values for plates with uniform spacing from 0.07 to 1.4 cm with the plates always at the bottom of the layer. Even though the reflectance increases by 16% for normal incidence and by 14% for a 50° angle, the change in transmittance over this range is negligible. Since the experimental data was taken for less than 25 interfaces in 43.18 cm (17 in.) of water the data may be analyzed using the assumption that the vertical position of the glass shows no effect on the transmittance.

3.4 Glass Lattice

To model the radiation transmission through the glass bottles used in the experiments, a two-dimensional glass lattice is used. Figure 10 illustrates the model configuration. This lattice may be modeled in the same way as the parallel plates if the properties of the water in between the glass plates are changed to represent the water and vertical glass plates of the lattice. Therefore, it is necessary to determine the transmittance and reflectance of the water and glass layer shown in Figure 11. This layer may be treated as a system of N enclosures with partially transparent windows. The incoming radiation is assumed

Figure 10 Glass lattice configuration.

Figure 11 Lattice layer of water with vertical glass plates.

diffuse; and even though the glass/water interfaces reflect specularly, all reflections are treated as diffuse. This approximation does not introduce significant error for enclosures with several specular surfaces as noted by Siegel and Howell [3].

Table 2 Total transmittance and reflectance of solar radiation for 25 glass plates 0.3175 cm (1/8 in.) thick in 43.18 cm (17 in.) of water. Plates are always as far from the top of the layer as the spacing will allow.

Plate Spacing (cm)	Angle of Incidence in air			
	0.0°		50.0°	
	τ	ρ	τ	ρ
0.07	0.09284	0.04264	0.07390	0.04971
0.35	0.09283	0.04348	0.07389	0.05051
0.63	0.09283	0.04449	0.07389	0.05150
0.91	0.09283	0.04575	0.07389	0.05276
1.19	0.09282	0.04737	0.07389	0.05445
1.40	0.09282	0.04948	0.07389	0.05657

Each interior surface of this layer has the same area and is numbered as shown in Figure 12. Using Siegel's net radiation method [2], a set of $4N$ simultaneous equations may be written. Incoming radiation (I) is assumed to enter at surface 1 of the center cell (C). The equations for the flux leaving each surface are:

$$q_{o(1,C)} = (1 - R_{(1,C)})I + R_{(1,C)} \sum_{m=1}^4 \sum_{n=1}^4 q_{o(m,n)} (F\tau)_{(m,n)}(i,j) \quad (24)$$

and

$$q_{o(i,j)} = R_{(i,j)} \sum_{m=1}^4 \sum_{n=1}^N q_{o(m,n)} (F\tau)_{(m,n)}(i,j), \quad (25)$$

$$\text{for } i=1 \text{ to } 4, j=1 \text{ to } N, (i,j) \neq (1,C), \quad (26)$$

where

$$R_{(i,j)} = \text{reflectance of surface } (i,j)$$

$$(F\tau)_{(m,n)}(i,j) = \text{fraction of radiation leaving surface } (m,n) \text{ which is incident on surface } (i,j).$$

The factor $(F\tau)_{(m,n)}(i,j)$ is an approximation which accounts for the configuration factor and the transmittance of the water and glass between the two surfaces, (m,n) and (i,j) . The development of the actual expressions of $(F\tau)_{(m,n)}(i,j)$ may be found in Appendix D. The transmittance and reflectance of the layer may be calculated directly from the $q_{o(i,j)}$'s after the set of equations has been solved. The transmittance and reflectance are expressed as:

Figure 12 Surface designations for lattice layer.

$$T = \sum_{j=1}^N q_{o(3,j)} (1-R_{(3,j)})/R_{(3,j)} \quad (26)$$

and

$$R = \sum_{j=1}^{C-1} q_{o(1,j)} (1-R_{(1,j)})/R_{(1,j)} + \\ R_{(1,C)} + [q_{o(1,C)} - (1-R_{(1,C)})](1-R_{(1,C)})/R_{(1,C)} + \\ \sum_{j=C+1}^N q_{o(1,j)} (1-R_{(1,j)})/R_{(1,j)} \quad (27)$$

Since each surface is numbered individually, the reflectance must be specified for every surface. This provides flexibility in the model to eliminate surfaces or to vary properties from surface to surface. For the horizontal surfaces, the reflectance is the reflectivity of a simple interface of glass and water. For the vertical surfaces, the specified reflectance is for a single absorbing glass plate in water. All of the reflectances are calculated with Fresnel's equations [4] and equation (9). Fresnel's equations require a specified angle of incidence (θ), but the radiation analysis assumes diffuse radiation. The proper way to handle diffuse radiation would be to evaluate the transmittance of the entire model at θ and integrate over θ from zero to $\pi/2$. This, however, would require an enormous amount of computation. A reasonable approximation is to calculate an integrated value of reflectance at a single interface for each component of polarization.

This approximation is consistent with the previous decision to treat all reflection as diffuse when analyzing the enclosures. The integrated reflectance ($\bar{\rho}$) is given by

$$\bar{\rho} = \int_0^{\pi/2} \rho(\theta) 2 \sin\theta \cos\theta d\theta, \quad (28)$$

where

$\rho(\theta)$ = reflectivity at angle θ

$2 \sin\theta \cos\theta d\theta$ = fraction of incident energy in increment $d\theta$ at angle θ [3] .

For the initial interface of air and water, the diffuse radiation is incident at angles from 0 to $\pi/2$, so equation (28) may be integrated as given. For the interfaces of glass and water, the angles of incidence have been altered by the air/water interface, so equation (28) must be modified:

$$\bar{\rho} = \int_0^{\pi/2} \rho(\theta_2) 2 \sin\theta_1 \cos\theta_1 d\theta_1 \quad (29)$$

where

θ_1 = angle of incidence in air

θ_2 = angle of refraction in water .

The transmittance of an absorbing layer as given earlier is:

$$\tau = e^{-kL}, \quad (30)$$

where

k = extinction coefficient

L = path length through material .

The path length is affected by the angle of refraction and may be expressed as

$$L = D / \cos \theta \quad (31)$$

where

D = thickness of material .

The effective path length for the water is then

$$L_E = D \int_0^{\pi/2} [1/\cos \theta_2]^2 \sin \theta_1 \cos \theta_1 d\theta_1 . \quad (32)$$

Likewise, for the glass

$$L_E = D \int_0^{\pi/2} [1/\cos \theta_3]^2 \sin \theta_1 \cos \theta_1 d\theta_1 , \quad (33)$$

where

θ_3 = angle of refraction in glass (after passing from air to water to glass) .

When the expressions for ρ , θ_2 , and θ_3 are substituted in, these

integrals become very complicated; so they have been integrated numerically using the trapezoidal rule [9]. The results are given in Table 3.

Table 3 Effective Reflectivities and Path Lengths for Diffuse Radiation in Air Entering Water and then Entering Glass.

Material	
Air/Water	$\rho = 0.0308$ (parallel component)
	$\rho = 0.1019$ (perpendicular component)
Water/Glass	$\rho = 0.0021$ (parallel component)
	$\rho = 0.0090$ (perpendicular component)
Water	$L_E = 1.2038 D$
Glass	$L_E = 1.1393 D$

Using the values in Table 3, the model transmittance was computed for thirteen cases. The programs, subroutines and output for each case of the model are contained in Appendix E. The subroutines and output are all coded with case numbers between 21 and 36 which correspond to the numbers in the figure legends. Figures 13 through 15 illustrate the distribution of losses in the lattice by comparing four different cases for each of three different cell sizes:

Case A - Absorption in water only, reflection from horizontal glass plates, no vertical glass plates present;

Case B - Absorption in water only, reflection from vertical and horizontal glass plates;

Case C - Absorption in water and horizontal glass plates only, reflection from vertical and horizontal glass plates;

Case D - Complete lattice, absorption in water and all glass plates, reflection from all glass plates.

Note: All glass is 0.3175 cm (1/8 in.) thick; twenty-one cells per layer; water depth is always 43.18 cm (17 in.).

The three different cell sizes are 1.2 cm high x 1.2 cm wide, 1.2 x 2.4, and 1.2 x 3.6. As a point of reference, the transmittance of 43.18 cm (17 in.) of plain water for diffuse radiation is 0.393, using the five-band approximation. Figures 13 through 15 show that the largest losses caused by the glass are from absorption in the horizontal glass plates. The second largest loss is from reflection at the horizontal glass plates and the increased absorption in the water which results from this reflection. The reflective and absorptive losses due to the vertical glass plates are significant, yet small. As expected, the transmittances increase as the cell width increases, since there are fewer vertical glass plates present.

For cases 21-30, there are twenty-one cells per layer. This causes a slight underestimate of transmittance, since some radiation is lost from the end cells. For better accuracy, the number of cells may be increased, but note that each additional cell adds four more unknowns to the solution matrix which is already 84 x 84. To illustrate the effect of additional cells, and to check the accuracy of the model, Figure 16 contains transmittance results for parallel glass plates which are

Figure 13 Lattice transmittance vs. number of layers for cell size 1.20 x 1.20 cm, glass 0.3175 cm thick. Case A: no absorption in glass, no vertical plate; Case B: no absorption in glass; Case C: absorption only in horizontal plates; Case D: absorption in all glass.

Figure 14 Lattice transmittance vs. number of layers for cell size 1.20 x 2.40 cm, glass 0.3175 cm thick. Case A: no absorption in glass, no vertical plates; Case B: no absorption in glass; Case C: absorption only in horizontal plates; Case D: absorption in all glass.

Figure 15 Lattice transmittance vs. number of layers for cell size 1.20 x 3.60 cm, glass 0.3175 cm thick. Case A: no absorption in glass, no vertical plates; Case B: no absorption in glass; Case C: absorption only in horizontal plates; Case D: absorption in all glass.

Figure 16 Lattice transmittance with no vertical plates compared with transmittance of parallel plates by net radiation method.
 Case A: net radiation method; Case B: 21 cells per layer;
 Case C: 25 cells per layer; Case D: 29 cells per layer.

0.3175 cm (1/8 in.) thick. Four cases are presented:

- Case A - Parallel plates by net radiation method;
- Case B - Model parallel plate limit (achieved by eliminating all vertical glass plates) with 21 cells per layer;
- Case C - Model parallel plate limit, 25 cells per layer;
- Case D - Model parallel plate limit, 29 cells per layer.

As the number of cells increases, the error between the model and the net radiation method decreases. With twenty-one cells per layer, the model underestimates the transmittance of one to twenty-five parallel plates by 10 percent or less. This error is tolerable, so twenty-one cells per layer are recommended for conservation of computer resources.

4. Experimental Results and Analysis

4.1 Indoor Experiment

Even though the accuracy of the indoor experimental data is questionable, the data is useful for determining some general trends. The accuracy of the data is questionable due to the unsteady output of the lamp. Even though the lamp was turned on at least three hours before each measurement session, its output would drift as much as 10% during the measurements. This eliminated any possibility of measuring the absolute transmittance, since the incoming radiation flux could not be known. Instead, the transmittance relative to 25.4 cm (10 in.) of water was measured. The relative transmittance is defined as

$$\tau_r = \frac{(\text{radiant flux leaving 25.4 cm of water with glass})}{(\text{radiant flux leaving 25.4 cm of water only})}$$

so that $\tau_r = 1.0$ for 25.4 cm of water with no glass. For each measurement session, the transmitted radiation was measured for 25.4 cm of plain water. As mentioned in Section 2.2, a second pyranometer was used to monitor the output of the lamp. The readings of this pyranometer were used to scale the transmitted flux measurements.

In Figures 17 through 20, the relative transmittance has been plotted against the number of glass layers and the glass volume for both the black tank and the reflective tank. The data shows a strong dependence on the type of bottle. Since the tank is small, the curved surfaces of the bottles could easily concentrate or diffuse the transmitted light and alter the measurements. For example, the relative transmittances which are greater than unity must be due to the bottle

Figure 17. Relative transmittance vs. number of layers from indoor data for black tank.

Figure 18 Relative transmittance vs. number of layers from indoor data for reflective tank.

Figure 19 Relative transmittance vs. volume of glass from indoor data for black tank.

Figure 20 Relative transmittance vs. volume of glass from indoor data for reflective tank.

surfaces concentrating the light toward the pyranometer. The effect of the curved surfaces probably could have been lessened by using a more random arrangement of the bottles and a larger tank. Figures 21 and 22 show the relative transmittance versus volume of glass with the number of layers as a parameter. (Note that the data for the asymmetric flat bottles is omitted, since it is so inconsistent with the other data.) It would be expected that for a given number of glass layers, the transmittance would decrease as the glass volume increases. This trend holds somewhat, but there are exceptions due to the bottle effects. In general, for a given type of bottle in a given orientation, the transmittance decreases as the number of bottles increases. Also, the decrease in transmittance is greatest for the first layer of bottles and the effect of each successive layer diminishes.

4.2 Outdoor Experiment

The outdoor data is presented as an absolute transmittance, which is the ratio of the radiant flux measured in the tank to the measured total incident radiation. The transmittances are accurate to ± 10 percent, allowing for the accuracies of the equipment. The data is sorted according to diffuse fraction and beam angle of incidence. The measured diffuse fraction is accurate to ± 10 percent, allowing for the accuracies of the equipment and of the shading ring correction factors [10].

A functional representation is sought which will express the experimental transmittance data as a function of the path length through the water, the path length through the glass, and the number of

Figure 21 Relative transmittance vs. volume of glass from indoor data for black tank (bottle types 1-4 only).

Figure 22 Relative transmittance vs. volume of glass from indoor data for reflective tank (bottle types 1-4 only).

interfaces. If there were no reflection from the water/glass interfaces, the transmittance of the layer would be

$$T = (1 - \rho_s) \sum_{j=1}^5 \exp((-k_j L)_w + (-k_j L)_g), \quad (34)$$

where ρ_s = reflectivity at the air/water interface. In order to account for the increased absorptive and reflective losses due to reflection at the water/glass interfaces, a function of the number of interfaces must be added to equation (34). By comparing the transmittances given in equation (34) with the transmittances for parallel glass plates in water, as determined by the net radiation method, a possible expression for T is found to be

$$T = (1 - \rho_s) \exp(-cn) \sum_{i=1}^5 \exp((-k_i L)_w + (-k_i L)_g), \quad (35)$$

where n = the number of glass plates and c = a real constant. For 1 to 25 plates, each 0.001 to 0.3175 cm (1/8 in.) thick, in 43.2 cm (17 in.) of water, a value of $c = 0.009$ provides good agreement between equation (35) and the net radiation method. The correlation agrees within ± 4 percent for beam radiation at angles of incidence from 0 to 75 degrees, and within ± 6 percent at angles of incidence up to 85 degrees. For diffuse radiation, the agreement is within ± 2 percent, using the average values of ρ_s and L (as given in Section 3.4) in both methods.

To compare the test data with the correlation given by equation (35), the number of bottles in the test layer must be converted to an effective number of horizontal glass plates and an average glass

thickness. Since the volume of glass present in the test layer is known, the average glass thickness is the volume of glass divided by the cross-sectional area of the tank. The effective number of horizontal glass plates is based on the volume of space occupied by each bottle. This volume is the volume of the smallest rectangular parallelepiped which would completely enclose the bottle. Since the bottles tended to lie on their sides in the tank, the smallest dimension of the parallelepiped is designated as the thickness of one layer of bottles. The volume of a layer is this thickness multiplied by the cross-sectional area of the tank. The number of layers is then the total volume occupied by the bottles divided by the single layer volume. As a check on the validity of this procedure, the total depth of bottles (layer thickness multiplied by number of layers) agrees with the measured depth for each test layer within ± 1.27 cm (1/2 in.). The effective number of horizontal glass plates is twice the number of layers, since radiation passing through a bottle passes through two distinct sections of glass. Note that the number of plates as calculated here is not necessarily an integer.

For sky conditions from 20 to 100 percent diffuse and beam angle of incidence from 25 to 55 degrees, the transmittances ranged from 0.06 to 0.29. Angles of incidence greater than 55 degrees are not considered due to shading effects in the test tank. The accuracy of the correlation is measured by comparing it with a least squares fit of the form $T = a \exp(bn)$ for the data within a specific interval. For intervals of 10 degrees angle of incidence and 10 percent diffuse

fraction, Table 4 presents the average absolute error and the maximum error of the correlation evaluated at the mid-points of the interval. The 25 to 35 degree range contains only a few data points per interval, so the errors are larger because the exponential curve fit is not based on enough points. For diffuse fractions from 20 to 50 percent, the correlation tends to underestimate the transmittance at the lower angles of incidence and to overestimate the transmittance at the higher angles of incidence. This indicates that the correlation is not sensitive enough to the angle of incidence. Its accuracy might be improved by changing the constant c in equation (35) to a function of the angle of incidence. Figures 23 through 46 compare the data and exponential fit with the correlation for all of the data.

To compare the numerical model (glass lattice) with the data, it is necessary to determine the appropriate cell size and glass thicknesses to input to the model. For the medium round bottles, the occupied parallelepiped mentioned earlier measured $3.81 \times 3.81 \times 9.53$ cm ($1.5 \times 1.5 \times 3.75$ in.). Since each bottle represents a cell, a good cell size would be 3.81×9.53 cm (1.5×3.75 in.). However, the cell length must be an exact multiple of the cell height, since the model is based on a basic cell which is square. A cell size of 3.81×7.62 (1.5×3.0 in.) is chosen as the best. Since the model is two-dimensional and assumes the depth of each cell is infinite, it is difficult to determine what thickness of glass should be used. It is desired to match the volume of glass present in the model with that in the test data. This is difficult since the test had finite dimensions, even

Table 4 Error of Correlation as Compared to Exponential Least Squares Fit of Data.

<u>Angle of Incidence (deg.)</u>	<u>Diffuse Fraction (%)</u>	<u>Average Error</u>	<u>Maximum Error</u>
25-35	20-30	0.026	0.069
25-35	30-40	0.007	0.011
25-35	40-50	0.022	0.055
25-35	90-100	0.013	0.024
35-45	20-30	0.010	0.014
35-45	30-40	0.016	0.036
35-45	40-50	0.008	0.013
35-45	50-60	0.010	0.018
35-45	60-70	0.010	0.019
35-45	70-80	0.007	0.012
35-45	80-90	0.007	0.014
35-45	90-100	0.008	0.016
45-55	20-30	0.006	0.011
45-55	30-40	0.012	0.030
45-55	40-50	0.017	0.026
45-55	50-60	0.010	0.017
45-55	60-70	0.013	0.022
45-55	70-80	0.003	0.007
45-55	80-90	0.011	0.023
45-55	90-100	0.009	0.017

Figure 23 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 25-35° angle of incidence, 20-30% diffuse.

Figure 24 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 25-35° angle of incidence, 30-40% diffuse.

Figure 25 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 25-35° angle of incidence, 40-50% diffuse.

Figure 26 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 25-35° angle of incidence, 50-60% diffuse.

Figure 27 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 25-35° angle of incidence, 60-70% diffuse.

Figure 28 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 25-35° angle of incidence, 70-80% diffuse.

Figure 29 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 25-35° angle of incidence, 80-90% diffuse.

Figure 30 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 25-35° angle of incidence, 90-100% diffuse.

Figure 31 Transmittance vs. number of glass layers, comparison of data, exponential curve Fit, and correlation; for 35-45° angle of incidence, 20-30% diffuse.

Figure 32 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 35-45° angle of incidence, 30-40% diffuse.

Figure 33 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 35-45° angle of incidence, 40-50% diffuse.

Figure 34 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 35-45° angle of incidence, 50-60% diffuse.

Figure 35 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 35-45° angle of incidence, 60-70% diffuse.

Figure 36 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 35-45° angle of incidence, 70-80% diffuse.

Figure 37 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 35-45° angle of incidence, 80-90% diffuse.

Figure 38 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 35-45° angle of incidence, 90-100% diffuse.

Figure 39 Transmittance vs. number of glass layers; comparison of data, exponential curve fit, and correlation; for 45-55° angle of incidence, 20-30% diffuse.

Figure 40 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 45-55° angle of incidence, 30-40% diffuse.

Figure 41 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 45-55° angle of incidence, 40-50% diffuse.

Figure 42 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 45-55° angle of incidence, 50-60% diffuse.

Figure 43 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 45-55° angle of incidence, 60-70% diffuse.

Figure 44 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 45-55° angle of incidence, 70-80% diffuse.

Figure 45 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 45-55° angle of incidence, 80-90% diffuse.

Figure 46 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, and correlation; for 45-55° angle of incidence, 90-100% diffuse.

though it represented an infinite system to the measuring pyranometer. In order to match the model with the experiment, it must be given finite dimensions also. If the area of the upper surface is matched, then the model will represent the test layer. This area is 6568 sq. cm (1018 sq. in.). For a cell length of 7.62 cm (3 in.) the cell depth is then 862 cm (339.3 in.). Figure 47 shows how the glass is apportioned to this cell. For the medium round bottles, each bottle layer contained 4621 cu. cm (282 cu. in.) of glass, which gives a glass thickness of 0.469 cm (0.1846 in.) for the model. Even though some of the deeper test layers contained asymmetric flat bottles with slightly different dimensions (3.18 cm thick vs. 3.81 cm thick, and 4077 cu. cm/layer vs. 4621), the layer based on the medium round bottles is used in the entire model. Figure 48 is a comparison of the data, exponential fit, correlation and model predictions for all data in the 90 to 100 percent diffuse range. (Note that the model assumes diffuse radiation, and is valid only in the high diffuse range.) The model transmittances are all 9-15 percent below the least squares fit. Remembering that the data is accurate to ± 10 percent, the model predictions can be considered reliable but conservative by 5-10 percent.

—— Glass Surfaces
- - - - Cell Boundaries

Figure 47 Distribution of glass in cells of lattice.

Figure 48 Transmittance vs. number of glass layers, comparison of data, exponential curve fit, correlation, and model; 25-55° angle of incidence, 90-100% diffuse.

5. Conclusion

The transmission of solar radiation through a transparent porous medium of glass and water is a complex problem. Two approaches have been developed for predicting the transmittance of such layers. The numerical model based on two-dimensional radiation exchange can predict the diffuse radiation transmission through the layers of bottles which were used in the experiment, although it tends to underestimate the transmittance by 5-10 percent. In addition, the model is flexible enough to allow configuration changes in different layers, and it should be extendable to more than the 24 layers used here. Also, a semi-empirical correlation has been developed which provides a simple way of expressing the transmission through a porous medium based on the angle of incidence, the diffuse fraction, the average glass thickness, the average water thickness, and the effective number of glass layers. The numerical model is directly applicable to materials other than glass in water. The correlation might be applicable to other materials by determining appropriate values of c . In addition, the correlation provides a simple expression to obtain a rough estimate of the transmittance of up to twenty-five parallel glass plates in water.

Appendix A - Details of Indoor Experiment

Pyranometers used:

Transmitted radiation measured with Eppley
Black and White Pyranometer (underwater)

Model 8-48

Serial number 21494

Output in volts

Lamp output monitored with Li-Cor LI-200S
Pyranometer Sensor

Serial number PY2218-8001

Output in amps

Data for Volumetric Displacement of Bottles:

Bottle volumes were measured by placing bottles in water and
measuring the change in water height.

Cross-sectional area of tank = 71.818 in^2

See Table A-1 for data.

Table A-1 Data for Volumetric Displacement of Bottles.

	Number of bottles	Change in water depth (in.)	Volume change (in. ³)	Volume per bottle (in. ³)
Bottle Type 1	5	3/64	3.3665	0.6733
	10	6/64	6.7329	0.6733
	15	9/64	10.099	0.6733
	25	15/64	16.832	0.6733
	Average = 0.6733			
Bottle type 2	5	7/64	7.855	1.571
	10	14/64	15.710	1.571
	15	21/64	23.565	1.571
	20	27/64	30.298	1.515
	Average = 1.557			
Bottle type 3	5	10/64	11.222	2.244
	10	20/64	22.443	2.244
	15	30/64	33.665	2.244
	Average = 2.244			
Bottle type 4	5	12/64	13.466	2.693
	10	23/64	25.810	2.581
	15	34/64	38.153	2.544
	Average = 2.606			
Bottle type 5	5	15/64	16.832	3.367
	10	30/64	33.665	3.367
	15	43/64	48.253	3.217
	Average = 3.317			

Appendix B - Details of Outdoor Experiment

Pyranometers used:

Transmitted radiation measured with Eppley Black and White
Pyranometer (underwater)

Model 8-48

Serial number 21494

Output in volts, multiplied by 1.77 to correct for indices of
refraction [12]

Diffuse incident radiation measured with Eppley Black and White
Pyranometer

Model 8-48

Serial number 19596

Output in volts

Total incident radiation measured with Li-Cor LI-200S
Pyranometer Sensor

Serial number PY2218-8001

Output in volts obtained by placing 100 Ω precision resistor
across leads

Diffuse and total pyranometers calibrated with Eppley Precision
Pyranometer

Model PSP

Serial number 19093F3

Output in volts

Shadow Band for Measuring Diffuse Incident Radiation:

Eppley shadow band and stand

Data Collection System

CR21 Micrologger

Campbell Scientific, Inc.

Serial number 1593 (Prom 195,138S)

Note: Some difficulty was encountered with the output timing. The following input and output instructions provided output of instantaneous and average values at fifteen minute intervals.

CR21 Input Table Coding Form

CR21 ID _____ Start Date _____ Start Time _____

NOTE: Select input program numbers from appendix A of the CR21 Operator's Manual. Specify a multiplier (a) and offset (b) for each sensor using the equation $EU = aX + b$ to convert the sensor output (X) to engineering units. EU = Final Output Engineering Units. IU = Input Units e.g. volts (V), millivolts (MV), and counts.

Sensor Number	Sensor Description and Calibration				Final Output (EU)	
	Range (EU)	Input Program	Program No.	Multiplier (EU/IU)	Offset (EU)	
	(V, MV, DC Resistance)					
1			11:	12:	13:	
	(V, MV, DC Resistance)					
2	Eppley Black and White Pyranometer	$12.14 \times 10^{-3} \text{ mV/W-m}^{-2}$			W-m^{-2}	
	0 to 1400 W-m^{-2}	DC millivolt	21: 2	22: 88.14	23: 0	
	(V, MV, DC Resistance)					
3	Eppley Black and White Pyranometer (Underwater)	$5.87 \times 10^{-3} \text{ mV/W-m}^{-2}$			W-m^{-2}	
	0 to 1400 W-m^{-2}	DC millivolt	31: 2	32: 170.3	33: 0	
	(V, MV, DC Resistance)					
4	Eppley Precision Pyranometer	$10.03 \times 10^{-3} \text{ mV/W-m}^{-2}$			W-m^{-2}	
	0 to 1400 W-m^{-2}	DC millivolt	41: 2	42: 99.7	43: 0	
	(V, MV, DC & AC Resistance)					
5	LiCor Pyranometer Sensor (see note)					
	(see note)	DC millivolt	51: 2	52: (see note)	53: 0	
	(V, MV, DC & AC Resistance)					
6	***. NOTE: LiCor values lost, output was calibrated to Precision Pyranometer					
	during experiment. ***		61:	62:	63:	
	(V, MV, DC & AC Resistance)					
7			71:	72:	73:	
	Pulse counter (4095 counts per scan maximum)					
8			81:	82:	83:	
	Pulse counter (15 counts per scan maximum)					
9			91:	92:	93:	

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CR21 Output Table Coding Form

CR21 ID _____ Start Date _____ Start Time _____

NOTE: Select output program number and parameters from appendix B of the CR21 Operator's Manual. Output ID numbers 1, 2 and 3 identify table number, day and time. ID numbers 4 and greater identify data generated by output programs. Only positive integers are used to program the output table.

Output Table Number (1, 2 or 3) 1 Output Time Interval (minutes) 03: 30 (see note)

Table Entry Number	Output Program and Data Description					Output ID No.
	Param 1 descrip.	Param 2 descrip.	Program No.	Parameter 1	Parameter 2	
1	Sample Diffuse Incident Radiation					4
	Input Channel	N/A	11: 50	12: 2	13: 0	
2	Sample Transmitted Radiation					5
	Input Channel	N/A	21: 50	22: 3	23: 0	
3	Sample Total Calibration Radiation					6
	Input Channel	N/A	31: 50	32: 4	33: 0	
4	Sample Total Incident Radiation					7
	Input Channel	N/A	41: 50	42: 5	43: 0	
5	Average Diffuse Radiation					8
	Input Channel	N/A	51: 51	52: 2	53: 0	
6	Average Total Incident Radiation					9
	Input Channel	N/A	61: 51	62: 5	63: 0	
7	Average Transmitted Radiation					10
	Input Channel	N/A	71: 51	72: 3	73: 0	
8	*** NOTE: Output timing does not work right; value of 30 = 15 minutes. ***					
			81:	82:	83:	
9						
			91:	92:	93:	

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Appendix C - Determination of Absorption Properties for Glass and Water

Rabl and Nielsen suggest the four-band approximation for water presented in Table C-1. Hsieh and Su present data for the group $(\lambda k/4\pi)$ for "window glass" having compositions: 71-73 per cent SiO_2 , 12-14 per cent Na_2O , 10-12 per cent CaO , 1-4 per cent MgO , and 0.5-1.5 per cent Al_2O_3 [6]. These values are converted to extinction coefficients in Table C-2. Note that "extinction coefficient" is not definite in meaning. Hsieh and Su call $(\lambda k/4\pi)$ the extinction coefficient [6], while Duffie and Beckmann call k the extinction coefficient [4]. This paper is consistent with the latter. In either case, k is used to determine transmittance (τ) by

$$\tau = e^{-kL} \quad (\text{C-1})$$

where L = path length through the material.

Table C-1 Four-band Approximation for Transmission of Solar Radiation Through Water [5].

$\lambda_1 - \lambda_2 (\mu\text{m})$	f	$k (\text{cm}^{-1})$
0.20-0.60	0.237	0.32×10^{-3}
0.60-0.75	0.193	4.5×10^{-3}
0.75-0.90	0.167	0.030
0.90-1.2	0.179	0.350

f = fraction of incident radiation within $\lambda_1 - \lambda_2$

k = extinction coefficient within $\lambda_1 - \lambda_2$

Table C-2 Absorption Properties of Window Glass
(adapted from Hsieh and Su [6]).

$\lambda(\mu\text{m})$	$\lambda k/4\pi(\times 10^{-6})$	$k(\text{cm}^{-1})$
0.32	15.94	6.260
0.33	6.937	2.642
0.34	3.038	1.123
0.35	1.336	0.480
0.36	0.6645	0.232
0.37	0.4428	0.150
0.38	0.9492	0.314
0.39	1.090	0.351
0.40	0.6794	0.213
0.45	0.3438	0.096
0.50	0.3510	0.088
0.55	0.4278	0.098
0.60	0.6043	0.127
0.65	0.8890	0.172
0.66	0.9437	0.180
0.67	0.9928	0.186
0.68	1.015	0.188
0.69	1.086	0.198
0.70	1.028	0.185
0.75	1.225	0.205
0.80	1.874	0.294
0.85	2.356	0.348
0.90	2.735	0.382
0.95	2.886	0.382
1.00	3.292	0.414
1.05	3.587	0.429
1.10	3.750	0.428
1.15	3.898	0.426
1.20	4.006	0.420

When the glass data is grouped in the same bands as the water values in Table C-1, the extinction coefficient for glass varies by less than 30 percent within each of the three bands from 0.40-1.20 μm . Since there is negligible incident radiation between 0.20 and 0.30 μm , the first water band limits are changed to 0.30-0.60 μm . According to the glass data, this band should be split into three portions: 0.30-0.32 μm , 0.32-0.40 μm , and 0.40-0.60 μm . However, since approximately only 4 percent of the incident radiation is in the 0.30-0.40 μm range [6], this is taken as the first band; and 0.40-0.60 μm is taken as the second band. Within each of the resulting five bands, the arithmetic mean is the value taken, with one exception being that the 6.260 value is dropped in the 0.30-0.40 μm band since it would improperly distort the mean. The resulting five-band approximation is presented in Table 1 of the main text. The accuracy of this approximation might be improved by weighting the various spectral values with the fractions of incident radiation, but this would not be worthwhile for the present purposes.

Appendix D - Determination of Configuration Factors and Geometric Mean Beam Lengths for the Glass Lattice

The fraction of radiation leaving surface (m,n) which is incident on surface (i,j) is given by $(F\tau)_{(m,n),(i,j)}$; where F is the configuration factor, and τ is the transmittance of the water and glass plates which lie between the two surfaces. This product is an approximation of the true geometric mean transmittance which greatly reduces computation and introduces little error [11].

Since the system of enclosures is two-dimensional, Hottel's crossed-string method [3] may be used to evaluate the configuration factors. Keeping in mind that all surfaces in the lattice have equal area, there are three basic configurations: perpendicular surfaces, parallel vertical surfaces, and parallel horizontal surfaces. Figures D-1 through D-3 show the three configuration factors.

The transmission factor (τ) represents the transmission through the water and glass plates which lie between surfaces (m,n) and (i,j). The effect of the water and the glass may be separated, giving

$$\tau_{(m,n),(i,j)} = e^{-kr}(T_1)(T_2)\dots(T_n) , \quad (D-1)$$

where

k = extinction coefficient of water

r = geometric mean beam length between surfaces (m,n)
and (i,j)

$$F_{1-2} = 1/2[\sqrt{2} - 1 + (A^2 - 1)^{1/2} - ((A - 1)^2 + 1)^{1/2}]$$

Figure D-1 Configuration factor for parallel horizontal surfaces.

$$F_{1-2} = (A^2 + 1)^{1/2} - A$$

Figure D-2 Configuration factor for parallel vertical surfaces.

$$F_{1-2} = 1/2[1 - (A^2 + 1)^{1/2} + ((A-1)^2 + 1)^{1/2}]$$

Figure D-3 Configuration factor for perpendicular surfaces.

$(T_1)(T_2)...(T_n)$ = product of transmittances of all
 glass plates which lie between surfaces (m,n)
 and (i,j).

Note that in this case the transmittance of the plates and the water may be multiplied directly, rather than using an expression such as equation (7). This is because the only radiation of interest for τ is that which passes directly from surfaces (m,n) to (i,j). All reflected radiation is accounted for elsewhere as radiation leaving the reflecting surface. The evaluation of the geometric mean beam lengths involves complicated double integrals. Dunkle [11] presents explicit expressions for the geometric mean beam length between finite perpendicular rectangles with a common edge and for equal finite parallel rectangles which are directly opposed. For the present case, Dunkle's expressions must be applied to a two-dimensional situation, which means that one length is infinite. The equation for the parallel rectangles accepts an infinite length well, but the perpendicular rectangle equation becomes indefinite. To resolve this with the computer, a length of 1000, instead of infinity, provides reasonable results. It will, if anything, slightly underestimate the absorption in the water between the perpendicular surfaces. In order to convert these two cases to the configurations encountered in the lattice, flux algebra must be used. Dunkle [11] states that the group (FAR) may be manipulated according to the same rules which apply to the group (FA) [3]. Figure D-4 illustrates the situation for the perpendicular plates. Using flux algebra rules,

$$(FAR)_{1-(2,3)} = (FAR)_{1-2} + (FAR)_{1-3} , \quad (D-2)$$

giving

$$(FAR)_{1-3} = (FAR)_{1-(2,3)} - (FAR)_{1-2} . \quad (D-3)$$

The terms on the right hand side of equation (D-3) can be found directly from Dunkle's equations. Since the parallel vertical plates are all directly opposed, Dunkle's equations apply as given. The parallel horizontal plates require manipulation involving six surfaces as shown in Figure D-5. It is necessary to find $(FAR)_{1-6}$ in terms of the (FAR) 's for any pair of directly opposed surfaces in Figure D-5. To begin,

$$\begin{aligned} (FAR)_{(1,2,3)-(4,5,6)} &= (FAR)_{1-(4,5,6)} + (FAR)_{2-(4,5,6)} \\ &\quad + (FAR)_{3-(4,5,6)} . \end{aligned} \quad (D-4)$$

This may be further expanded to

$$\begin{aligned} (FAR)_{(1,2,3)-(4,5,6)} &= (FAR)_{1-4} + (FAR)_{1-5} + (FAR)_{1-6} \\ &\quad + (FAR)_{2-4} + (FAR)_{2-5} + (FAR)_{2-6} \\ &\quad + (FAR)_{3-4} + (FAR)_{3-5} + (FAR)_{3-6} . \end{aligned} \quad (D-5)$$

Noting that

$$(FAR)_{2-6} = (FAR)_{2-4}, \quad (FAR)_{3-5} = (FAR)_{1-5} ,$$

$$(FAR)_{3-4} = (FAR)_{1-6}, \text{ and } (FAR)_{3-6} = (FAR)_{1-4} ,$$

Figure D-4 Surface designations for flux algebra of perpendicular rectangular surfaces.

Figure D-5 Surface designations for flux algebra of parallel horizontal surfaces.

$$\begin{aligned}
 (\text{FAR})_{(1,2,3)-(4,5,6)} &= 2(\text{FAR})_{1-4} + 2(\text{FAR})_{1-5} + 2(\text{FAR})_{1-6} \\
 &\quad + 2(\text{FAR})_{2-4} + [2(\text{FAR})_{2-5} - (\text{FAR})_{2-5}] \cdot (\text{D-6})
 \end{aligned}$$

Finally,

$$\begin{aligned}
 (\text{FAR})_{1-6} &= \frac{1}{2} (\text{FAR})_{(1,2,3)-(4,5,6)} - (\text{FAR})_{(1,2)-(4,5)} \\
 &\quad + \frac{1}{2} (\text{FAR})_{2-5} \cdot \quad (\text{D-7})
 \end{aligned}$$

Appendix E
Listings of Computer Programs and Output

NOTE: Programs and output are listed in the order in which their results are referred to in the main text.

1 HULL4

HULL4 calculates the transmittance of 200 parallel Teflon plates in water by Hull's method [1]. File H4OUT is generated for printed output, and file PFIN4 is generated as an input file for plotting routines.

2 H4OUT

H4OUT is output from HULL4. Column 1 is the angle of incidence, column 2 is the transmittance of 1.0 meter of water, column 3 is the transmittance of 1.0 meter of water and 200 parallel Teflon plates. The first 19 rows are for plates 2.54 microns thick; the last 19 rows are for plates 12.7 microns thick.

3 HULL5

HULL5 calculates the transmittance of 200 parallel Teflon plates in water by Siegel's net radiation method [2]. File H5OUT is generated for printed output, and file PFIN4 is generated as an input file for plotting routines.

4 H5OUT

H5OUT is output from HULL5; the format is the same as H4OUT.

5 LAYED8

LAYED8 calculates the transmittance and reflectance of 25 parallel glass plates in 43.2 cm (17 in.) of water by Siegel's net radiation method [2] to determine the sensitivity of transmittance to plate placement. The plates are initially spaced 0.07 cm apart and are then spread out to 1.14 cm apart. The bottom plate is at the bottom of the water layer in all cases. File L8OUT is generated for printed output.

6 L8OUT

L8OUT is output from LAYED8.

7 LAYERC

LAYERC calculates the transmittance of a layer of vertical glass plates in water, assuming that there is glass above and below the layer. Subroutine REFTRAN sets the transmittance and reflectance for each surface in the layer; REFTRAN is discussed later. File LAYIN is generated as an input file for program LAYED2 or LAYED9; file LAYOUT is generated for printed output.

8 LAYED2

LAYED2 calculates the transmittance of a lattice of glass in water by stacking horizontal plates of glass between layers of vertical glass plates in water. The properties of the layer of vertical glass plates in water are input from file LAYIN which is generated by program LAYERC. File NMOUT is generated for printed output, and file LPIN is generated as an input file for plotting routines.

9 REFT21-REFT30

Subroutine REFTRAN is used to set the transmittance and reflectance of each surface within the glass lattice for use by program LAYERC. For each case of the model, REFTRAN must be changed. REFT21-REFT30 are the versions of REFTRAN used for cases 21-30. Note that cases 34-36 use REFT21.

10 LYOUT21-LYOUT30, LYOUT35, LYOUT36

LYOUT is output from LAYERC. Note that case 34 uses LYOUT21.

11 NMOUT21-NMOUT30, NMOUT34-NMOUT36

NMOUT is output from LAYED2.

12 REFT32

REFT32 is subroutine REFTRAN for case 32, which models the bottles used in the experiments. For more information see REFT21-REFT30, above.

13 LYOUT32

LYOUT32 is output from LAYERC for case 32.

14 LAYED9

LAYED9 is a special version of LAYED2 which places two layers of horizontal glass plates between each layer of vertical glass plates in water. This is to simulate bottles which are laying on top of each other with a thin layer of water in between. Files are the same as for LAYED2.

15 NMOUT32

NMOUT32 is output from LAYED9 for case 32.

16 LAYED6

LAYED6 calculates the transmittance of 1 to 25 parallel glass plates in water for diffuse radiation by Siegel's net radiation method [2]. File NMOUT is generated for printed output, and file LPIN is generated as an input file for plotting routines.

17 NMOUTPP

NMOUTPP is output from LAYED6.

18 THETA2, OUTPUT FROM THETA2

THETA2 calculates the effective reflectance at an interface between materials 1 and 2, assuming diffuse radiation is incident at that interface. It also calculates the effective path length correction ($1/\cos(\theta)$) for material 2. File THOUT is generated for printed output.

19 THETA3, OUTPUT FROM THETA3

THETA3 calculates the effective reflectance at an interface between materials 2 and 3, assuming diffuse radiation is incident at the interface between materials 1 and 2. It also calculates the effective path length correction ($1/\cos(\theta)$) for material 3. File THOUT is generated for printed output.

20 CORR4, OUTPUT FROM CORR4

CORR4 calculates the transmittance of glass in 43.2 cm (17 in.) of water for the eleven experimental cases, given the beam angle of incidence and the diffuse fraction. The transmittance is given by equation 35 in section 3.4.

PROGRAM HULL4(H4OUT,INPUT,OUTPUT,TAPE3=H4OUT,PFIN4,TAPE4=PFIN4)

C
C THIS PROGRAM CALCULATES THE TRANSMITTANCE OF A SERIES OF
C ABSORBING TEFLON PLATES IN WATER.
C IT ALSO CALCULATES THE ABSORPTANCE OF ONE METER OF WATER USING
C HULL'S FOUR TERM APPROXIMATION. THEN THE PRODUCT IS PRESENTED
C AS THE TRANSMITTANCE OF THE PLATES AND WATER, AS IN HULL'S PAPER.
C

REAL NA,NW,NG,KW(4),FQ(4),GHL(2),KG
GHL(1)=0.000254 \$ GHL(2)=0.00127
DO 800 ICK=1,2
DO 900 ITH=1,19
THETA=5.*(ITH-1.)
THI=THETA*3.14159/180.
NA=1.00 \$ NW=1.333 \$ NG=1.343
THW=ASIN(SIN(THI)*NA/NW)
THG=ASIN(SIN(THW)*NW/NG)
DATA FQ/0.190,0.230,0.301,0.141/
DATA KW/0.20,0.0175,0.000656,0.000102/

C
C SPECTRAL LOOP FOR WATER ABSORPTANCE
C

T=0.
DO 300 I=1,4
T=T+EXP(-KW(I)*100./COS(THW))*FQ(I)
300 CONTINUE

C
C *****
C ***
C *** CALCULATE LAYER TRANSMITTANCE ***
C ***
C *****

TR=0. \$ TW=0.
KG=0.59
DO 121 NPOLAR=1,2

C
C NPOLAR=1 FOR PERPENDICULAR COMPONENT OF POLARIZATION
C NPOLAR=2 " PARALLEL " " "
C

IF(THI.NE.0.)GOTO 2
RAW=((NA-NW)/(NA+NW))**2
RWG=((NW-NG)/(NW+NG))**2
GOTO 3
2 RAW=PDREFL(THI,THW)
RWG=PDREFL(THW,THG)
IF(NPOLAR.EQ.1)GOTO 3
RAW=PLREFL(THI,THW)
RWG=PLREFL(THW,THG)
3 RS=(RAW+RWG-2.*RAW*RWG)/(1.-RAW*RAW)
TGH=EXP(-KG*GHL(ICK)/COS(THG))
TW=TW+T*(1.-RAW)

```

C
C WATER LAYER
C   CALL LAYER(RWG,RWG,(1.-RWG),RWG,(1.-RWG),1.0,RCB,RCC,TCB)
C
C INITIAL PLATE LAYER ASSUMING LAYER OF WATER ON TOP
C
C   CALL LAYER(RWG,RWG,(1.-RWG),RCB,TCB,TGH,RL1,RL2,TL)
C   DO 20 J=1,199
C
C ADDING BOTTOM PLATE LAYER
C
C   CALL LAYER(RL1,RL2,TL,RWG,(1.-RWG),TGH,RC1,RC2,TC)
C   IF(J.EQ.199)TR=TR+TC*T*(1.-RAW)
C
C ADDING WATER LAYER AND PLATE LAYER
C
C   CALL LAYER(RL1,RL2,TL,RCB,TCB,TGH,RC1,RC2,TC)
C   RL1=RC1
C   RL2=RC2
C   TL=TC
C 20 CONTINUE
C 121 CONTINUE
C   WRITE(3,130)THETA,TW/2.,TR/2.
C   IF(ICK.EQ.2)WRITE(4,130)THETA,TW/2.,TR/2.
C 130 FORMAT(3F9.6)
C 900 CONTINUE
C 800 CONTINUE
C   STOP
C   END
C   FUNCTION PDREFL(T1,T2)
C
C REFLECTANCE FUNCTION
C
C   PDREFL=SIN(T2-T1)**2/SIN(T2+T1)**2
C   RETURN
C   END
C   FUNCTION PLREFL(T1,T2)
C   PLREFL=TAN(T2-T1)**2/TAN(T2+T1)**2
C   RETURN
C   END
C   SUBROUTINE LAYER(RA1,RA2,TA,RB,TB,TAUL,RC1,RC2,TC)
C
C LAYER SUBROUTINE
C
C   RK=(1.-RA2*RB*TAUL**2)
C   TC=TB*TA*TAUL/RK
C   RC1=RA1+(TA*TAUL)**2*RB/RK
C   RC2=RB+(TB*TAUL)**2*RA2/RK
C   RETURN
C   END

```


H4OUT

0.000000	.452025	.436241
5.000000	.451836	.436031
10.000000	.451268	.435399
15.000000	.450314	.434338
20.000000	.448963	.432833
25.000000	.447193	.430861
30.000000	.444967	.428380
35.000000	.442217	.425320
40.000000	.438832	.421569
45.000000	.434612	.416933
50.000000	.429218	.411084
55.000000	.422056	.403466
60.000000	.412090	.393116
65.000000	.397509	.378362
70.000000	.375121	.356259
75.000000	.339267	.321568
80.000000	.279812	.264827
85.000000	.178283	.168629
90.000000	.000004	.000003
0.000000	.452025	.386954
5.000000	.451836	.386669
10.000000	.451268	.385815
15.000000	.450314	.384384
20.000000	.448963	.382365
25.000000	.447193	.379737
30.000000	.444967	.376468
35.000000	.442217	.372506
40.000000	.438832	.367763
45.000000	.434612	.362094
50.000000	.429218	.355254
55.000000	.422056	.346818
60.000000	.412090	.336044
65.000000	.397509	.321625
70.000000	.375121	.301220
75.000000	.339267	.270599
80.000000	.279812	.222013
85.000000	.178283	.141023
90.000000	.000004	.000003

```
PROGRAM HULL5(H5OUT,INPUT,OUTPUT,TAPE3=H5OUT,PFIN5,TAPE5=PFIN5)
```

```
C
C THIS PROGRAM CALCULATES THE TRANSMITTANCE OF A SERIES OF
C ABSORBING TEFLON PLATES IN WATER.
C IT ALSO CALCULATES THE ABSORPTANCE OF ONE METER OF WATER USING
C HULL'S FOUR TERM APPROXIMATION.
```

```
REAL NA,NW,NG,KW(4),FQ(4),GHL(2),KG
GHL(1)=0.000254 $ GHL(2)=0.00127
DO 800 ICK=1,2
DO 900 ITH=1,19
THETA=5.*(ITH-1.)
THI=THETA*3.14159/180.
NA=1.00 $ NW=1.333 $ NG=1.343
THW=ASIN(SIN(THI)*NA/NW)
THG=ASIN(SIN(THW)*NW/NG)
DATA FQ/0.190,0.230,0.301,0.141/
DATA KW/0.20,0.0175,0.000656,0.000102/
```

```
C
C SPECTRAL LOOP FOR WATER ABSORPTANCE
```

```
C
C TR=0. $ TW=0.
C DO 300 I=1,4
C T=EXP(-KW(I)*100./COS(THW))
C TWL=EXP(-KW(I)*0.5/COS(THW))
```

```
C
C *****
C ***
C ***          CALCULATE LAYER TRANSMITTANCE          ***
C ***
C *****
```

```
C
C KG=0.59
C DO 121 NPOLAR=1,2
```

```
C
C NPOLAR=1 FOR PERPENDICULAR COMPONENT OF POLARIZATION
C NPOLAR=2 " PARALLEL " " "
```

```
C
C IF(THI.NE.0.)GOTO 2
C RAW=((NA-NW)/(NA+NW))**2
C RWG=((NW-NG)/(NW+NG))**2
C GOTO 3
C 2 RAW=PDREFL(THI,THW)
C RWG=PDREFL(THW,THG)
C IF(NPOLAR.EQ.1)GOTO 3
C RAW=PLREFL(THI,THW)
C RWG=PLREFL(THW,THG)
C 3 RS=(RAW+RWG-2.*RAW*RWG)/(1.-RWG*RAW)
C TGH=EXP(-KG*GHL(ICK)/COS(THG))
C TW=TW+T*(1.-RAW)*FQ(I)
```

```
C
C WATER LAYER
```

```

      CALL LAYER(RWG,RWG,(1.-RWG),RWG,(1.-RWG),TWL,RCB,RCC,TCB)
C
C  INITIAL PLATE LAYER ASSUMING LAYER OF WATER ON TOP
C
      CALL LAYER(RWG,RWG,(1.-RWG),RCB,TCB,TGH,RL1,RL2,TL)
      DO 20 J=1,199
C
C  ADDING BOTTOM PLATE LAYER
C
      CALL LAYER(RL1,RL2,TL,RWG,(1.-RWG),TGH,RC1,RC2,TC)
      IF(J.EQ.199)TR=TR+TC*T*(1.-RAW)*FQ(I)
C
C  ADDING WATER LAYER AND PLATE LAYER
C
      CALL LAYER(RL1,RL2,TL,RCB,TCB,TGH,RC1,RC2,TC)
      RL1=RC1
      RL2=RC2
      TL=TC
20  CONTINUE
121  CONTINUE
300  CONTINUE
      WRITE(3,130)THETA,TW/2.,TR/2.
      IF(ICK.EQ.2)WRITE(5,130)THETA,TW/2.,TR/2.
130  FORMAT(3F9.6)
900  CONTINUE
800  CONTINUE
      STOP
      END
      FUNCTION PDREFL(T1,T2)
C
C  REFLECTANCE FUNCTION
C
      PDREFL=SIN(T2-T1)**2/SIN(T2+T1)**2
      RETURN
      END
      FUNCTION PLREFL(T1,T2)
      PLREFL=TAN(T2-T1)**2/TAN(T2+T1)**2
      RETURN
      END
      SUBROUTINE LAYER(RA1,RA2,TA,RB,TB,TAUL,RC1,RC2,TC)
C
C  LAYER SUBROUTINE
C
      RK=(1.-RA2*RB*TAUL)**2
      TC=TB*TA*TAUL/RK
      RC1=RA1+(TA*TAUL)**2*RB/RK
      RC2=RB+(TB*TAUL)**2*RA2/RK
      RETURN
      END

```

H5OUT

0.000000	.452025	.386906
5.000000	.451836	.386756
10.000000	.451268	.386304
15.000000	.450314	.385542
20.000000	.448963	.384456
25.000000	.447193	.383021
30.000000	.444967	.381195
35.000000	.442217	.378906
40.000000	.438832	.376039
45.000000	.434612	.372405
50.000000	.429218	.367687
55.000000	.422056	.361359
60.000000	.412090	.352528
65.000000	.397509	.339665
70.000000	.375121	.320104
75.000000	.339267	.289121
80.000000	.279812	.238207
85.000000	.178283	.151715
90.000000	.000004	.000003
0.000000	.452025	.343193
5.000000	.451836	.342973
10.000000	.451268	.342311
15.000000	.450314	.341201
20.000000	.448963	.339629
25.000000	.447193	.337574
30.000000	.444967	.335001
35.000000	.442217	.331855
40.000000	.438832	.328044
45.000000	.434612	.323423
50.000000	.429218	.317751
55.000000	.422056	.310623
60.000000	.412090	.301349
65.000000	.397509	.288731
70.000000	.375121	.270650
75.000000	.339267	.243295
80.000000	.279812	.199697
85.000000	.178283	.126878
90.000000	.000004	.000003

```

PROGRAM LAYED8(L8OUT,INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,
1          TAPE7=L8OUT)

C
C THIS PROGRAM DETERMINES THE SENSITIVITY OF TRANSMITTANCE TO
C PLAT PLACEMENT. 25 PLATES ARE ALWAYS AT THE BOTTOM AND ARE
C THEN SPREAD OUT THROUGH THE 17 IN. WATER LAYER.
C (THIS IS A REVISED PROGRAM TO PERFORM THE SAME FUNCTION AS
C 'LAYED5'.)
C
C MICHAEL J. WITTE / APRIL 1983
C
C REAL N(3),KW(5),KG(5),FQ(5),TR(20),TH(3),RF1(20),RF2(20),PSP(20)
C COMMON/1/TH,N
C
C INPUT AND/OR SET PARAMETERS
C
C DATA N/1.00,1.333,1.526/
C WRITE(6,100)
C READ(5,*)THETA
100 FORMAT("PLEASE INPUT THETA, THE ANGLE OF INCIDENCE.")
C TH(1)=THETA*3.14159/180.
C TH(2)=ASIN(SIN(TH(1))*N(1)/N(2))
C TH(3)=ASIN(SIN(TH(2))*N(2)/N(3))
C WRITE(6,110)
C READ(5,*)GHL
110 FORMAT(/"PLEASE ENTER THICKNESS OF GLASS PLATES(CM).")
C DO 5 I=1,20
C RF1(I)=0.
C RF2(I)=0.
C 5 TR(I)=0.
C TH20=0.
C
C POLARIZATION LOOP:
C IPZ=1 FOR PARALLEL COMPONENT OF POLARIZATION
C IPZ=2 " PERPENDICULAR " " "
C
C DO 10 IPZ=1,2
C RAW=REFL(1,2,IPZ)
C RWG=REFL(2,3,IPZ)
C
C PLATE SPACING LOOP
C
C DO 20 ICL=1,20
C CL=0.07*ICL
C PSP(ICL)=CL
C
C SPECTRAL LOOP
C
C DATA FQ/0.040,0.197,0.193,0.167,0.179/
C DATA KG/0.688,0.124,0.180,0.307,0.412/
C DATA KW/0.00032,0.00032,0.0045,0.03,0.35/
C DO 30 ISP=1,5

```

```

TGH=EXP(-KG(ISP)*GHL/COS(TH(3)))
TWL=EXP(-KW(ISP)*CL/COS(TH(2)))
C... TRANSMITTANCE OF WATER LAYER WITH INTERFACES
      CALL LAYER(RWG,RWG,(1.-RWG),RWG,(1.-RWG),TWL,RWL1,RWL2,TWL)
C... TRANSMITTANCE OF 43.18 CM OF WATER ONLY
      IF(ICL.GT.1)GOTO 21
      TW=EXP(-KW(ISP)*43.18/COS(TH(2)))
      CALL LAYER(RAW,RAW,(1.-RAW),0.,1.,TW,R1,R2,TRW)
      TH20=TH20+TRW*FQ(ISP)
C
C 24 PLATE LOOP -- GIVES 24 PLATES AND 24 LAYERS OF WATER
C
21 RA1=RWG
   RA2=RWG
   TA=1.-RWG
   DO 40 IPL=1,24
     CALL LAYER(RA1,RA2,TA,RWL1,TWL,TGH,RC1,RC2,TC)
     RA1=RC1
     RA2=RC2
40  TA=TC
C... ADD 25TH PLATE
     CALL LAYER(RA1,RA2,TA,RWG,(1.-RWG),TGH,RC1,RC2,TC)
C... ADD WATER LAYER IN TOP TO FORM 43.18 CM
     DW=43.18-CL*24.-GHL*25.
     IF(DW.GE.0.)GOTO 41
     WRITE(6,120)DW
120  FORMAT("ERROR!! LAYERS GREATER THAN 17 IN., DW=",F7.5)
     STOP
41  TWL=EXP(-KW(ISP)*DW/COS(TH(2)))
     CALL LAYER(RAW,RAW,(1.-RAW),RC1,TC,TWL,ROUT1,ROUT2,TOUT)
     TR(ICL)=TR(ICL)+TOUT*FQ(ISP)
     RF1(ICL)=RF1(ICL)+ROUT1*FQ(ISP)
     RF2(ICL)=RF2(ICL)+ROUT2*FQ(ISP)
C... TERMINATE SPECTRAL LOOP
30  CONTINUE
C... TERMINATE PLATE SPACING LOOP
20  CONTINUE
C... TERMINATE POLARIZATION LOOP
10  CONTINUE
C
C PRINT OUTPUT
C
      WRITE(7,200)
      WRITE(7,210)THETA,GHL
      WRITE(7,220)
      WRITE(7,230)
200  FORMAT("/OUTPUT FROM LAYED8"/)
210  FORMAT("THETA=",F4.1,"DEG.",6X,"PLATE THICKNESS=",F6.4,"CM")
220  FORMAT("//3X,"PLATE",8X,"RELATIVE",24X,2("UPPER",8X,"LOWER",8X))
230  FORMAT("SPACING(CM)",2X,"TRANSMITTANCE=TRANS./H20TRANS.",
1      2(2X,"REFLECTANCE"),2(2X,"ABSORPTANCE"))
DO 50 I=1,20

```

```

WRITE(7,240)PSP(I),TR(I)/TH20,TR(I)/2.,TH20/2.,
1      RF1(I)/2.,RF2(I)/2.,(2.-TR(I)-RF1(I))/2.,
2      (2.-TR(I)-RF2(I))/2.
240 FORMAT(3X,F5.3,9X,F7.5,"=",F7.5,"/",F7.5,4(6X,F7.5))
50 CONTINUE
STOP
END
FUNCTION REFL(IA,IB,NPZ)
REAL TH(3),NR(3)
COMMON/1/TH,NR
IF(TH(IA).NE.0.)GOTO 5
REFL=((NR(IA)-NR(IB))/(NR(IA)+NR(IB)))**2
RETURN
5 IF(NPZ.EQ.2)GOTO 10
REFL=TAN(TH(IA)-TH(IB))**2/TAN(TH(IA)+TH(IB))**2
RETURN
10 REFL=SIN(TH(IA)-TH(IB))**2/SIN(TH(IA)+TH(IB))**2
RETURN
END
SUBROUTINE LAYER(RA1,RA2,TA,RB,TB,TAUL,RC1,RC2,TC)
C
C LAYER SUBROUTINE
C
RK=(1.-RA2*RB*TAUL**2)
TC=TB*TA*TAUL/RK
RC1=RA1+(TA*TAUL)**2*RB/RK
RC2=RB+(TB*TAUL)**2*RA2/RK
RETURN
END

```

L8OUT

OUTPUT FROM LAYED8

THETA= 0.0DEG.

PLATE THICKNESS= .3175CM

PLATE SPACING(CM)	RELATIVE TRANSMITTANCE=TRANS./H2OTRANS.	UPPER REFLECTANCE	LOWER REFLECTANCE
.070	.21618= .09284/ .42946	.04264	.04336
.140	.21617= .09284/ .42946	.04284	.04263
.210	.21617= .09284/ .42946	.04304	.04203
.280	.21617= .09284/ .42946	.04326	.04152
.350	.21617= .09283/ .42946	.04348	.04109
.420	.21616= .09283/ .42946	.04372	.04070
.490	.21616= .09283/ .42946	.04396	.04036
.560	.21616= .09283/ .42946	.04422	.04005
.630	.21616= .09283/ .42946	.04449	.03977
.700	.21615= .09283/ .42946	.04478	.03950
.770	.21615= .09283/ .42946	.04509	.03926
.840	.21615= .09283/ .42946	.04541	.03903
.910	.21615= .09283/ .42946	.04575	.03881
.980	.21614= .09282/ .42946	.04612	.03861
1.050	.21614= .09282/ .42946	.04650	.03842
1.120	.21614= .09282/ .42946	.04692	.03823
1.190	.21614= .09282/ .42946	.04737	.03806
1.260	.21614= .09282/ .42946	.04788	.03789
1.330	.21613= .09282/ .42946	.04852	.03773
1.400	.21613= .09282/ .42946	.04948	.03757


```

PROGRAM LAYERC(LAYIN,LAYOUT,INPUT,OUTPUT,TAPE5=INPUT,
&TAPE7=LAYOUT,TAPE6=OUTPUT,TAPE2=LAYIN)

```

```

C
C THIS PROGRAM DETERMINES THE TRANSMITTANCE AND REFLECTANCE OF
C A LAYER OF WATER WITH VERTICAL GLASS PLATES ASSUMING THAT
C THE LAYER IS BOUNDED BY GLASS. THE SUBROUTINE 'REFTRAN' SETS
C THE TRANSMITTANCE AND REFLECTANCE OF EACH SURFACE OF THE
C N ENCLOSURES.

```

```

C MICHAEL J. WITTE / DECEMBER 1982 / FEBRUARY 1983

```

```

C REAL RF(100),T(100),B(100),X(100),KW(5),TVP(25),
C &FN(25),FHP(25),FVP(25),RHP(25),RN(25),RVP(25),TN(25),THP(25)
C COMMON /ONE/F(100,100)
C COMMON /TWO/TRAN(100,100)
C COMMON /THREE/A(100,100)

```

```

C *****
C ***
C ***          SET PARAMETERS          ***
C ***
C *****

```

```

C KW -- THE EXTINCTION COEFFICIENT OF WATER
C N -- THE NUMBER OF CELLS IN THE LAYER (MUST BE ODD AND <=25)
C ICENTR -- THE INDEX OF THE CENTER CELL

```

```

DATA KW/0.00032,0.00032,0.0045,0.03,0.35/

```

```

N=21

```

```

ICENTR=(N+1)/2

```

```

WRITE(7,703)N

```

```

703 FORMAT(/I2," CELLS PER LAYER"/)

```

```

C *****
C ***
C ***          CALCULATE CONFIGURATION FACTORS          ***
C ***
C *****

```

```

C CALCULATE NORMAL (PERPENDICULAR) CONFIG. FACTORS

```

```

FOLD=0.

```

```

DO 20 I=1,N

```

```

FNEW=(1.+1./I-SQRT(1.+1./I/I))/2.*I

```

```

FN(I)=FNEW-FOLD

```

```

FOLD=FNEW

```

```

20 CONTINUE

```

```

C CALCUALTE HORIZONTAL PARALLEL CONFIG. FACTORS

```

```

FOLD=0.

```

```

DO 30 I=1,N

```

```

FNEW=(SQRT(2.)-1.+SQRT(I*I+1.)-SQRT((I-1.)**2+1.))/2.

```

```

FHP(I)=FNEW-FOLD

```

```

      FOLD=FNEW
30  CONTINUE
C
C      CALCULATE VERTICAL PARALLEL CONFIG. FACTORS
C
      DO 40 I=1,N
      FVP(I)=SQRT(I*I+1.)-I
40  CONTINUE
C
C      *****
C      ***
C      ***          ESTABLISH "F" MATRIX          ***
C      ***          NOTE:SINCE ALL AREAS ARE EQUAL, F(I,J)=F(J,I)      ***
C      ***
C      *****
C
C      SET ALL F'S TO ZERO
C
      N4=4*N
      DO 50 I=1,N4
      DO 60 J=1,N4
      F(I,J)=0.
60  CONTINUE
50  CONTINUE
C
C      SET F'S BETWEEN HORIZONTAL PLATES AND VERTICAL PLATES
C
      DO 70 I=1,N
      IP1=I+1
      IM1=I-1
      I41=4*(I-1)
      IF(IM1.EQ.0.)GOTO 81
      DO 80 J=1,IM1
      J41=4*(J-1)
      F(I41+1,J41+4)=FN(I-J+1)
      F(J41+4,I41+1)=FN(I-J+1)
      F(I41+3,J41+4)=FN(I-J+1)
      F(J41+4,I41+3)=FN(I-J+1)
80  CONTINUE
81  F(I41+1,I41+4)=FN(1)
      F(I41+4,I41+1)=FN(1)
      F(I41+1,I41+2)=FN(1)
      F(I41+2,I41+1)=FN(1)
      F(I41+3,I41+4)=FN(1)
      F(I41+4,I41+3)=FN(1)
      F(I41+3,I41+2)=FN(1)
      F(I41+2,I41+3)=FN(1)
      IF(I.EQ.N)GOTO 91
      DO 90 J=IP1,N
      J41=4*(J-1)
      F(I41+1,J41+2)=FN(J-I+1)
      F(J41+2,I41+1)=FN(J-I+1)

```

```

      F(I41+3,J41+2)=FN(J-I+1)
      F(J41+2,I41+3)=FN(J-I+1)
90 CONTINUE

```

C
C
C

```

      SET F'S BETWEEN HORIZ. PLATES AND HORIZ. PLATES

```

```

91 IF(IM1.EQ.0)GOTO 101
   DO 100 J=1,IM1
     J41=4*(J-1)
     F(I41+1,J41+3)=FHP(I-J+1)
     F(J41+3,I41+1)=FHP(I-J+1)
100 CONTINUE
101 F(I41+1,I41+3)=FHP(1)
     F(I41+3,I41+1)=FHP(1)
     IF(I.EQ.N)GOTO 111
     DO 110 J=IP1,N
       J41=4*(J-1)
       F(I41+1,J41+3)=FHP(J-I+1)
       F(J41+3,I41+1)=FHP(J-I+1)
110 CONTINUE

```

C
C
C

```

      SET F'S BETWEEN VERT. PLATES AND VERT. PLATES

```

```

111 IF(IM1.EQ.0.)GOTO 121
   DO 120 J=1,IM1
     J41=4*(J-1)
     F(I41+2,J41+4)=FVP(I-J+1)
     F(J41+4,I41+2)=FVP(I-J+1)
120 CONTINUE
121 F(I41+2,I41+4)=FVP(1)
     F(I41+4,I41+2)=FVP(1)
     IF(I.EQ.N)GOTO 70
     DO 130 J=IP1,N
       J41=4*(J-1)
       F(I41+2,J41+4)=FVP(J-I+1)
       F(J41+4,I41+2)=FVP(J-I+1)
130 CONTINUE
70 CONTINUE

```

C
C
C
C
C
C
C
C
C
C
C

```

*****
***
***      CALCULATE GEOMETRIC MEAN BEAM LENGTHS      ***
***
*****

```

```

CALCULATE NORMAL (PERPENDICULAR) GMBL'S

```

```

FAROLD=0.
DO 400 I=1,N
  RI=I
  FARNEW=FARN2D(1.,RI)

```

```

      RN(I)=(FARNEW-FAROLD)/FN(I)/1000.
      FAROLD=FARNEW
400 CONTINUE
C
C   CALCULATE VERTICAL PARALLEL GMBL'S
C
      BETA=1.E8
      DO 410 I=1,N
        ETA=1./FLOAT(I)
        RVP(I)=ZP(ETA,BETA)/FVP(I)/ETA
410 CONTINUE
C
C   CALCULATE HORIZONTAL PARALLEL GMBL'S
C
      RHP(1)=RVP(1)
      RHP(2)=(2.*ZP(2.,BETA)/2.-ZP(1.,BETA))/FHP(2)
      DO 420 I=3,N
        RI=I
        RHP(I)=(RI*ZP(RI,BETA)/2.-(RI-1.)*ZP((RI-1.),BETA)+(RI-2.)
        &*ZP((RI-2.),BETA)/2.)/FHP(I)
420 CONTINUE
C
C   POLARIZATION LOOP
C
      IPZ=1 FOR PARALLEL COMPONENT OF POLARIZATION
      IPZ=2 FOR PERPENDICULAR COMPONENT OF POLARIZATION
C
      DO 6 IPZ=1,2
        IF(IPZ.EQ.1)WRITE(7,708)"PARALLEL"
        IF(IPZ.EQ.2)WRITE(7,708)"PERPEND."
708 FORMAT(///A13," COMPONENT OF POLARIZATION"/)
C
C   SPECTRAL LOOP
C
      DO 5 III=1,5
        WRITE(7,706)III
706 FORMAT(// "FOR SPECTRAL BAND NUMBER ",I1," :")
C
C   SET REFLECTANCES AND TRANSMITTANCES
C
      CALL REFTRAN(RF,N,T,III,IPZ,CL)
C
C   *****
C   ***
C   ***          ESTABLISH "T" MATRIX          ***
C   ***
C   *****
C
C   CONVERT GMBL'S TO TRANSMITTANCES
C
      DO 430 I=1,N
        TN(I)=EXP(-RN(I)*CL*KW(III))

```

```

      THP(I)=EXP(-RHP(I)*CL*KW(III))
      TVP(I)=EXP(-RVP(I)*CL*KW(III))
430  CONTINUE
C
C      SET ALL T'S TO ZERO
C
      N4=4*N
      DO 140 I=1,N4
      DO 150 J=1,N4
      TRAN(I,J)=0.
150  CONTINUE
140  CONTINUE
C
C      SET TRAN'S BETWEEN HORIZONTAL PLATES AND VERTICAL PLATES
C
      DO 170 I=1,N
      IP1=I+1
      IM1=I-1
      I41=4*(I-1)
      IF(IM1.EQ.0.)GOTO 181
      DO 180 J=1,IM1
      J41=4*(J-1)
      TR=TN(I-J+1)
      JP1=J+1
      DO 190 K=JP1,I
      TR=TR*T(4*(K-1)+4)
190  CONTINUE
      TRAN(I41+3,J41+4)=TR
      TRAN(J41+4,I41+3)=TR
      TRAN(I41+1,J41+4)=TR
      TRAN(J41+4,I41+1)=TR
180  CONTINUE
181  TRAN(I41+1,I41+4)=TN(1)
      TRAN(I41+4,I41+1)=TN(1)
      TRAN(I41+1,I41+2)=TN(1)
      TRAN(I41+2,I41+1)=TN(1)
      TRAN(I41+3,I41+4)=TN(1)
      TRAN(I41+4,I41+3)=TN(1)
      TRAN(I41+3,I41+2)=TN(1)
      TRAN(I41+2,I41+3)=TN(1)
      IF(I.EQ.N)GOTO 201
      DO 200J=IP1,N
      J41=4*(J-1)
      TR=TN(J-I+1)
      JM1=J-1
      DO 210 K=I,JM1
      TR=TR*T(4*(K-1)+2)
210  CONTINUE
      TRAN(I41+3,J41+2)=TR
      TRAN(J41+2,I41+3)=TR
      TRAN(I41+1,J41+2)=TR
      TRAN(J41+2,I41+1)=TR

```

200 CONTINUE

C
C
C

SET TRAN'S BETWEEN HORIZ. PLATES AND HORIZ. PLATES

201 IF(IM1.EQ.0.)GOTO 221

DO 220 J=1,IM1

J41=4*(J-1)

TR=THP(I-J+1)

JP1=J+1

DO 230 K=JP1,I

TR=TR*T(4*(K-1)+4)

230 CONTINUE

TRAN(I41+1,J41+3)=TR

TRAN(J41+3,I41+1)=TR

220 CONTINUE

221 TRAN(I41+1,I41+3)=THP(1)

TRAN(I41+3,I41+1)=THP(1)

IF(I.EQ.N)GOTO 241

DO 240 J=IP1,N

J41=4*(J-1)

TR=THP(J-I+1)

JM1=J-1

DO 250 K=I,JM1

TR=TR*T(4*(K-1)+2)

250 CONTINUE

TRAN(I41+1,J41+3)=TR

TRAN(J41+3,I41+1)=TR

240 CONTINUE

C
C
C

SET TRAN'S BETWEEN VERT. PLATES AND VERT. PLATES

241 IF(IM1.EQ.0.)GOTO 261

DO 260 J=1,IM1

J41=4*(J-1)

TR=TVP(I-J+1)

JP1=J+1

DO 270 K=JP1,I

TR=TR*T(4*(K-1)+4)

270 CONTINUE

TRAN(I41+2,J41+4)=TR

TRAN(J41+4,I41+2)=TR

260 CONTINUE

261 TRAN(I41+2,I41+4)=TVP(1)

TRAN(I41+4,I41+2)=TVP(1)

IF(I.EQ.N)GOTO 170

DO 280 J=IP1,N

J41=4*(J-1)

TR=TVP(J-I+1)

JM1=J-1

DO 290 K=I,JM1

TR=TR*T(4*(K-1)+2)

290 CONTINUE

```

      TRAN(I41+4,J41+2)=TR
      TRAN(J41+2,I41+4)=TR
280 CONTINUE
170 CONTINUE

```

```

C
C *****
C ***
C ***      SET UP "A" MATRIX      ***
C ***                               ***
C *****

```

```

C
C
C      SET DIAGONAL
C

```

```

      N4=4*N
      DO 300 I=1,N4
        A(I,I)=1.
300 CONTINUE

```

```

C
C      SET ALL OTHER ELEMENTS
C

```

```

      DO 310 I=1,N
        I41=4*(I-1)
        DO 320 J=1,4
          M=I41+J
          C=-RF(M)
          CALL SIGMA(M,C,N)
320 CONTINUE
310 CONTINUE

```

```

C
C      SET UP "B" MATRIX
C

```

```

      N4=N*4
      DO 340 I=1,N4
        B(I)=0.
340 CONTINUE
      IC1=4*(ICENTR-1)+1
      B(IC1)=1.-RF(IC1)

```

```

C
C *****
C ***
C ***      CALCULATE T(LAYER) AND R(LAYER)      ***
C ***                               ***
C *****

```

```

      N4=N*4
371 CALL GAUSSY(A,B,X,N4)
      IC3=4*(ICENTR-1)+3
      IC1=4*(ICENTR-1)+1
      TTL=X(IC3)*(1.-RF(IC3))/RF(IC3)
      RFL=RF(IC1)+(X(IC1)-(1.-RF(IC1)))*(1.-RF(IC1))/RF(IC1)
      DO 15 I=1,N

```

```

      IF(I.EQ.ICENTR)GOTO 15
      I41=4*(I-1)
      TTL=TTL+X(I41+3)*(1.-RF(I41+3))/RF(I41+3)
      RFL=RFL+X(I41+1)*(1.-RF(I41+1))/RF(I41+1)
15  CONTINUE
      WRITE(7,707)TTL,RFL
      WRITE(2,*)TTL,RFL
707  FORMAT(/6X,"LAYER TRANSMITTANCE=",F7.5,4X,"LAYER REFLECTANCE=",
      &F7.5)
      5  CONTINUE
      6  CONTINUE
      STOP
      END
      FUNCTION ZP(E,B)

```

```

C
C  THIS FUNCTION CALCULATES THE GEOMETRIC MEAN BEAM LENGTH
C  BETWEEN TWO DIRECTLY OPPOSED PARALLEL EQUAL RECTANGLES
C  BY THE METHOD OF DUNKLE (RP1/20.1).
C
C
C  MICHAEL J. WITTE / FEBRUARY 1983
C

```

```

      SRE=SQRT(1.+E*E)
      SRB=SQRT(1.+B*B)
      SREB=SQRT(1.+E*E+B*B)
      ZP=ATAN(E*B/SREB)
      ZP=ZP+ALOG((B+SREB)/SRE/(B+SRB))/E
      ZP=ZP+ALOG((E+SREB)/SRB/(E+SRE))/B
      ZP=ZP+(SRE+SRB-1.-SREB)/E/B
      ZP=ZP*4./3.14159
      RETURN
      END
      FUNCTION FARN2D(AA,CC)

```

```

C
C  THIS FUNCTION CALCULATES THE FAR FACTOR FOR B APPROACHING
C  INFINITY FOR PERPENDICULAR PLATES USING THE METHOD OF DUNKLE.
C  (RP1/20.1)
C
C
C  MICHAEL J. WITTE / FEBRUARY 1983
C

```

```

      BB=1000.
      A=AA/BB
      G=CC/BB
      SRA=SQRT(1.+A*A)
      SRG=SQRT(1.+G*G)
      SRAG=SQRT(A*A+G*G)
      SR1AG=SQRT(1.+A*A+G*G)
      FARN2D=AA*CC*BB*ALOG((1.+SRG)*SRAG/G/(1.+SR1AG))*G/A
      FARN2D=FARN2D+AA*BB*CC*ALOG((1.+SRA)*SRAG/A/(1.+SR1AG))*A/G
      FARN2D=FARN2D+AA*CC*BB*(SRG**3+SRA**3+SRAG**3-SR1AG**3)/3./G/A
      FARN2D=FARN2D+AA*CC*BB*(SR1AG-SRAG-SRA)*A/G
      FARN2D=FARN2D+AA*BB*CC*(SR1AG-SRAG-SRG)*G/A
      FARN2D=FARN2D+AA*BB*CC*(G*G/A+A*A/G-1./2./G/A)*2./3.

```


FARN2D=FARN2D/3.14159

RETURN

END

SUBROUTINE SIGMA(M,C,N)

C
C
C
C
C
C
C

THIS SUBROUTINE SETS THE COEFFICIENTS OF THE A MATRIX WHICH
REPRESENT THE INCOMING FLUXES TO PLATE 'M'.

X(M)= . . . +SIGMA X(I)*F(I,M)*T(I,M)
I=1 TO 4*N

COMMON /ONE/F(100,100)

COMMON /TWO/TRAN(100,100)

COMMON /THREE/A(100,100)

N4=N*4

DO 600 MS=1,N4

IF(MS.EQ.M)GOTO 600

A(M,MS)=C*F(MS,M)*TRAN(MS,M)

600 CONTINUE

RETURN

END

SUBROUTINE GAUSSY (A, B, X, N)

C
C
C

SOLUTION OF SIMULTANEOUS EQUATIONS BY GAUSS ELIMINATION

DIMENSION A(100,100), X(100), B(100)

C

BEGINNING OF ELIMINATION PROCESS

DO 28 K = 1,N

C

MOVING LARGEST COEFFICIENT INTO DIAGONAL POSITION

AMAX = 0.

DO 4 I = K,N

IF(ABS(A(I,K)) - ABS(AMAX)) 4, 4, 2

2 AMAX = A(I,K)

IMAX = I

4 CONTINUE

C

TESTING FOR INDEPENDENCE OF EQUATIONS

IF(ABS(AMAX) - 0.1E-15) 10, 10, 14

10 PRINT 12

12 FORMAT ("0 EQUATIONS ARE NOT INDEPENDENT")

RETURN

C

EXCHANGING ROW IMAX AND ROW K

14 BTEMP = B(K)

B(K) = B(IMAX)

B(IMAX) = BTEMP

DO 18 J = K,N

ATEMP = A(K,J)

A(K,J) = A(IMAX, J)

18 A(IMAX,J) = ATEMP

C

SUBTRACTING A(I,K)/A(K,K) TIMES TERM IN FIRST EQ FROM OTHERS

KPLUS = K + 1

IF(K - N) 22, 28, 28

22 DO 24 I = KPLUS,N

```
B(I) = B(I) - B(K)*A(I,K)/A(K,K)
ACON = A(I,K)
DO 24 J = K,N
24 A(I,J) = A(I,J) - A(K,J)*ACON/A(K,K)
28 CONTINUE
C    BACK SUBSTITUTION
    L = N
32 SUM = 0.0
    IF(L - N) 34, 38, 38
34 LPLUS = L + 1
    DO 36 J = LPLUS, N
36 SUM = SUM + A(L,J)*X(J)
38 CONTINUE
    X(L) = (B(L) - SUM)/A(L,L)
    IF(L - 1) 42, 42, 40
40 L = L - 1
    GO TO 32
42 RETURN
    END
```

```

PROGRAM LAYED2(LAYIN,LPIN,NMOUT,INPUT,OUTPUT,TAPE5=INPUT,
&TAPE7=NMOUT,TAPE6=OUTPUT,TAPE8=LAYIN,TAPE9=LPIN)

```

```

C THIS PROGRAM DETERMINES THE TRANSMITTANCE OF A COMPOSITE LAYER
C OF GLASS PLATES AND WATER LAYERS CONTAINING VERTICAL GLASS
C PLATES, EFFECTIVELY FORMING A GLASS LATTICE IN WATER. THE
C TRANSMITTANCE AND REFLECTANCE OF THE WATER/GLASS LAYER ARE
C READ FROM 'LAYIN' AND THE COMPOSITE LAYER IS BUILT BY
C SUCCESSIVELY ADDING A GLASS PLATE AND A WATER/GLASS LAYER.

```

```

C THIS PROGRAM REQUIRES THE THICKNESS OF THE HORIZONTAL GLASS
C PLATES TO BE INPUT.

```

```

C THE REFLECTANCES USED ARE INTEGRATED VALUES FOR DIFFUSE
C RADIATION AS DETERMINED BY PROGRAM 'THETA2'.

```

```

C MICHAEL J. WITTE / DECEMBER 1982 / JANUARY 1983 / FEBRUARY 1983

```

```

C REAL NA,NW,NG,KW(5),KG(5),FQ(5),TR(24),TCUBE(5),
C &TTR(24),TRF(24),RCUBE(5),RWG(2),RAW(2)
C DIMENSION COMMENT(7)
C READ(8,*)CL
C WRITE(6,100)

```

```

100 FORMAT("/THICKNESS OF GLASS PLATES? (CM)")
C READ(5,*)GHL
C DATA FQ/0.040,0.197,0.193,0.167,0.179/
C DATA KG/0.688,0.124,0.180,0.307,0.412/
C DATA KW/0.00032,0.00032,0.0045,0.03,0.35/
C DATA RWG/0.0021,0.0090/
C DATA RAW/0.0308,0.1019/

```

```

C *****
C *****
C ***** CALCULATE LAYER TRANSMITTANCE *****
C *****
C *****

```

```

C DO 4 M=1,24
C TR(M)=0.
C 4 CONTINUE
C TRW=0.
C DO 121 NPZ=1,2

```

```

C NPZ=1 FOR PARALLEL COMPONENT OF POLARIZATION
C NPZ=2 " PERPENDICULAR " " "

```

```

C DO 200 I=1,5
C READ(8,*)TCUBE(I),RCUBE(I)
200 CONTINUE

```

```

C INITIAL GLASS LAYER AND CUBE LAYER ASSUMING LAYER OF WATER ON TOP
C

```

```

TTRW=0.
DO 120 I=1,5
TTRW=TTRW+EXP(-43.18*KW(I)*1.2038)*FQ(I)
TGH=EXP(-KG(I)*GHL*1.1393)
TCB=TCUBE(I)
RCB=RCUBE(I)
CALL LAYER(RWG(NPZ),RWG(NPZ),(1.-RWG(NPZ)),RCB,TCB,TGH,
&RL1,RL2,TL)
DO 20 J=1,24
C
C   ADDING BOTTOM LAYER OF GLASS
C
CALL LAYER(RL1,RL2,TL,RWG(NPZ),(1.-RWG(NPZ)),TGH,RC1,RC2,TC)
TTR(J)=TC
TRF(J)=RC1
C
C   ADDING GLASS LAYER AND CUBE LAYER
C
CALL LAYER(RL1,RL2,TL,RCB,TCB,TGH,RC1,RC2,TC)
RL1=RC1
RL2=RC2
TL=TC
20 CONTINUE
C
C   ADDING WATER TO MAKE 43.18 CM (17IN.) TOTAL THICKNESS
C
DO 150 J=1,24
TEST=J*(CL+GHL)+GHL-43.18
IF(TEST.LE.0.)GOTO 25
IF(NPZ.NE.1)GOTO 25
IF(I.NE.1)GOTO 25
WRITE(6,110)
110 FORMAT("LAYER THICKNESS HAS EXCEEDED 17 IN.")
25 TW=EXP((J*(CL+GHL)+GHL-43.18)*KW(I)*1.2038)
RL=TRF(J)
TL=TTR(J)
CALL LAYER(RAW(NPZ),RAW(NPZ),(1.-RAW(NPZ)),RL,TL,TW,RF1,RF2,TF)
TR(J)=TR(J)+TF*FQ(I)
150 CONTINUE
120 CONTINUE
CALL LAYER(RAW(NPZ),RAW(NPZ),(1.-RAW(NPZ)),0.,1.,TTRW,RC1,RC2,TC)
TRW=TRW+TC
121 CONTINUE
C
C   OUTPUT
C
WRITE(7,123)
123 FORMAT("OUTPUT FROM PROGRAM LAYED2"/)
WRITE(7,124)
WRITE(7,122)GHL
WRITE(7,126)CL
122 FORMAT("THE HORIZONTAL GLASS PLATES ARE ",F6.3," CM THICK.")

```

```

124 FORMAT(// "COMPONENTS OF POLARIZATION AVERAGED")
126 FORMAT("CELL SIZE (CM) IS ",F6.3," CM")
    WRITE(7,125)
    WRITE(7,130)
125 FORMAT(//18X,"RELATIVE")
130 FORMAT("NO. OF PLATES    TRANSMITTANCE = TRANS./H2OTRANS.")
140 FORMAT(5X,I2,12X,F7.5,4X,"=",F7.5,"/",F7.5)
    DO 30 M=1,24
        WRITE(7,140)M+1,TR(M)/TRW,TR(M)/2.,TRW/2.
        WRITE(9,*)TR(M)/2.
30 CONTINUE
    STOP
    END
    SUBROUTINE LAYER(RA1,RA2,TA,RB,TB,TAUL,RC1,RC2,TC)
C
C   LAYER SUBROUTINE
C
C   THIS SUBROUTINE CALCULATES THE TRANSMITTANCE (TC),
C   UPPER REFLECTANCE (RC1), AND LOWER REFLECTANCE (RC2)
C   OF A SLAB GIVEN:
C
C       UPPER REFLECTANCE OF SURFACE A          (RA1)
C       LOWER REFLECTANCE OF SURFACE A          (RA2)
C       TRANSMITTANCE OF SURFACE A              (TA)
C       UPPER REFLECTANCE OF SURFACE B          (RB)
C       TRANSMITTANCE OF SURFACE B              (TB)
C       SLAB TRANSMITTANCE BETWEEN SURFACES    (TAUL)
C
C   THE EQUATIONS ARE BASED ON SIEGEL'S NET RADIATION
C   METHOD.
C
    RK=(1.-RA2*RB*TAUL**2)
    TC=TB*TA*TAUL/RK
    RC1=RA1+(TA*TAUL)**2*RB/RK
    RC2=RB+(TB*TAUL)**2*RA2/RK
    RETURN
    END

```

```

      SUBROUTINE REFTRAN(RF,N,T,III,IPZ,CL)
C   REFT21
C   REFTRAN INITIALIZES THE REFLECTANCES AND TRANSMITTANCES OF THE
C   SURFACES OF THE GLASS/WATER LATTICE FOR PROGRAM LAYER.
C
      DIMENSION RF(100),T(100)
      REAL KG(5),RWG(2)
      IF(III.GT.1)GOTO 299
C
C   COMMENTS TO IDENTIFY TYPE OF LATTICE FOR PRINTED OUTPUT
C
      WRITE(7,201)
      WRITE(7,202)
      WRITE(7,203)
201  FORMAT("NO ABSORPTION - HORIZ. PLATES ONLY, CELL SIZE=1.20 CM")
202  FORMAT("VERTICAL PLATES: DXG=0.0 AND RHO=0.0")
203  FORMAT("HORIZONTAL PLATES: DGH=0.0 AND RHO=RWG")
C
C   SET PARAMETERS
C
C   DXG -- THICKNESS OF VERTICAL GLASS PLATES
C   KG -- EXTINCTION COEFFICIENT OF GLASS
C   CL -- CELL SIZE (HEIGHT OF VERTICAL PLATES)
C   RWG -- REFLECTANCE OF WATER/GLASS INTERFACE
C           RWG(1)=PARALLEL COMPONENT OF POLARIZATION
C           RWG(2)=PERPENDICULAR COMPONENT OF POLARIZATION
C
      DATA KG/0.688,0.124,0.180,0.307,0.412/
299  DXG=0.0
      CL=1.20
      DATA RWG/0.0021,0.0090/
      IF((III.EQ.1).AND.(IPZ.EQ.1))WRITE(2,*)CL
      DO 10 I=1,N
      I41=4*(I-1)
      RF(I41+1)=RWG(IPZ)
      RF(I41+3)=RWG(IPZ)
C   *** 1.1393 IS THE EFFECTIVE INCREASE IN PATH LENGTH FOR
C   *** GLASS PLATES TRANSMITTING DIFFUSE RADIATION (IN WATER).
      TAU=EXP(-KG(III)*DXG*1.1393)
      RR=RWG(IPZ)+(1.-RWG(IPZ))*2*TAU*TAU*RWG(IPZ)/(1.-(RWG(IPZ)*TAU)
      & **2)
      RR=0.0
      TT=1.0
      RF(I41+2)=RR
      RF(I41+4)=RR
      T(I41+2)=TT
      T(I41+4)=TT
10  CONTINUE
      RETURN
      END

```

```

      SUBROUTINE REFTRAN(RF,N,T,III,IPZ,CL)
C  REFT22
C  REFTRAN INITIALIZES THE REFLECTANCES AND TRANSMITTANCES OF THE
C  SURFACES OF THE GLASS/WATER LATTICE FOR PROGRAM LAYER.
C
      DIMENSION RF(100),T(100)
      REAL KG(5),RWG(2)
      IF(III.GT.1)GOTO 299
C
C  COMMENTS TO IDENTIFY TYPE OF LATTICE FOR PRINTED OUTPUT
C
      WRITE(7,201)
      WRITE(7,202)
      WRITE(7,203)
201  FORMAT("NO ABSORPTION - CELL SIZE=1.20 CM")
202  FORMAT("VERTICAL PLATES:  DXG=0.0")
203  FORMAT("HORIZONTAL PLATES:  DGH=0.0 AND RHO=RWG")
C
C  SET PARAMETERS
C
C  DXG -- THICKNESS OF VERTICAL GLASS PLATES
C  KG -- EXTINCTION COEFFICIENT OF GLASS
C  CL -- CELL SIZE (HEIGHT OF VERTICAL PLATES)
C  RWG -- REFLECTANCE OF WATER/GLASS INTERFACE
C         RWG(1)=PARALLEL COMPONENT OF POLARIZATION
C         RWG(2)=PERPENDICULAR COMPONENT OF POLARIZATION
C
      DATA KG/0.688,0.124,0.180,0.307,0.412/
299  DXG=0.0
      CL=1.20
      DATA RWG/0.0021,0.0090/
      IF((III.EQ.1).AND.(IPZ.EQ.1))WRITE(2,*)CL
      DO 10 I=1,N
      I41=4*(I-1)
      RF(I41+1)=RWG(IPZ)
      RF(I41+3)=RWG(IPZ)
C  *** 1.1393 IS THE EFFECTIVE INCREASE IN PATH LENGTH FOR
C  *** GLASS PLATES TRANSMITTING DIFFUSE RADIATION (IN WATER).
      TAU=EXP(-KG(III)*DXG*1.1393)
      RR=RWG(IPZ)+(1.-RWG(IPZ))*2*TAU*TAU*RWG(IPZ)/(1.-(RWG(IPZ)*TAU)
& **2)
      TT=(1.-RWG(IPZ))*2*TAU/(1.-(RWG(IPZ)*TAU)**2)
      RF(I41+2)=RR
      RF(I41+4)=RR
      T(I41+2)=TT
      T(I41+4)=TT
10  CONTINUE
      RETURN
      END

```

```

      SUBROUTINE REFTRAN(RF,N,T,III,IPZ,CL)
C  REFT23
C  REFTRAN INITIALIZES THE REFLECTANCES AND TRANSMITTANCES OF THE
C  SURFACES OF THE GLASS/WATER LATTICE FOR PROGRAM LAYER.
C
      DIMENSION RF(100),T(100)
      REAL KG(5),RWG(2)
      IF(III.GT.1)GOTO 299
C
C  COMMENTS TO IDENTIFY TYPE OF LATTICE FOR PRINTED OUTPUT
C
      WRITE(7,201)
      WRITE(7,202)
      WRITE(7,203)
201 FORMAT("ABSORPTION IN HORIZONTAL PLATES ONLY - CELL SIZE=1.20 CM")
202 FORMAT("VERTICAL PLATES: DXG=0.0")
203 FORMAT("HORIZONTAL PLATES: DGH=0.3175 CM AND RHO=RWG")
C
C  SET PARAMETERS
C
C  DXG -- THICKNESS OF VERTICAL GLASS PLATES
C  KG -- EXTINCTION COEFFICIENT OF GLASS
C  CL -- CELL SIZE (HEIGHT OF VERTICAL PLATES)
C  RWG -- REFLECTANCE OF WATER/GLASS INTERFACE
C          RWG(1)=PARALLEL COMPONENT OF POLARIZATION
C          RWG(2)=PERPENDICULAR COMPONENT OF POLARIZATION
C
      DATA KG/0.688,0.124,0.180,0.307,0.412/
299 DXG=0.0
      CL=1.20
      DATA RWG/0.0021,0.0090/
      IF((III.EQ.1).AND.(IPZ.EQ.1))WRITE(2,*)CL
      DO 10 I=1,N
      I41=4*(I-1)
      RF(I41+1)=RWG(IPZ)
      RF(I41+3)=RWG(IPZ)
C  *** 1.1393 IS THE EFFECTIVE INCREASE IN PATH LENGTH FOR
C  *** GLASS PLATES TRANSMITTING DIFFUSE RADIATION (IN WATER).
      TAU=EXP(-KG(III)*DXG*1.1393)
      RR=RWG(IPZ)+(1.-RWG(IPZ))**2*TAU*TAU*RWG(IPZ)/(1.-(RWG(IPZ)*TAU)
& **2)
      TT=(1.-RWG(IPZ))**2*TAU/(1.-(RWG(IPZ)*TAU)**2)
      RF(I41+2)=RR
      RF(I41+4)=RR
      T(I41+2)=TT
      T(I41+4)=TT
10 CONTINUE
      RETURN
      END

```



```

SUBROUTINE REFTRAN(RF,N,T,III,IPZ,CL)
C REFT24
C REFTRAN INITIALIZES THE REFLECTANCES AND TRANSMITTANCES OF THE
C SURFACES OF THE GLASS/WATER LATTICE FOR PROGRAM LAYER.
C
  DIMENSION RF(100),T(100)
  REAL KG(5),RWG(2)
  IF(III.GT.1)GOTO 299
C
C COMMENTS TO IDENTIFY TYPE OF LATTICE FOR PRINTED OUTPUT
C
  WRITE(7,201)
  WRITE(7,202)
  WRITE(7,203)
201 FORMAT("ABSORPTION IN ALL PLATES - CELL SIZE=1.20 CM")
202 FORMAT("VERTICAL PLATES: DXG=0.3175 CM")
203 FORMAT("HORIZONTAL PLATES: DGH=0.3175 CM AND RHO=RWG")
C
C SET PARAMETERS
C
C DXG -- THICKNESS OF VERTICAL GLASS PLATES
C KG -- EXTINCTION COEFFICIENT OF GLASS
C CL -- CELL SIZE (HEIGHT OF VERTICAL PLATES)
C RWG -- REFLECTANCE OF WATER/GLASS INTERFACE
C       RWG(1)=PARALLEL COMPONENT OF POLARIZATION
C       RWG(2)=PERPENDICULAR COMPONENT OF POLARIZATION
C
  DATA KG/0.688,0.124,0.180,0.307,0.412/
299 DXG=0.3175
  CL=1.20
  DATA RWG/0.0021,0.0090/
  IF((III.EQ.1).AND.(IPZ.EQ.1))WRITE(2,*)CL
  DO 10 I=1,N
    I41=4*(I-1)
    RF(I41+1)=RWG(IPZ)
    RF(I41+3)=RWG(IPZ)
C *** 1.1393 IS THE EFFECTIVE INCREASE IN PATH LENGTH FOR
C *** GLASS PLATES TRANSMITTING DIFFUSE RADIATION (IN WATER).
    TAU=EXP(-KG(III)*DXG*1.1393)
    RR=RWG(IPZ)+(1.-RWG(IPZ))**2*TAU*TAU*RWG(IPZ)/(1.-(RWG(IPZ)*TAU)
    & **2)
    TT=(1.-RWG(IPZ))**2*TAU/(1.-(RWG(IPZ)*TAU)**2)
    RF(I41+2)=RR
    RF(I41+4)=RR
    T(I41+2)=TT
    T(I41+4)=TT
10 CONTINUE
  RETURN
  END

```

```

      SUBROUTINE REFTRAN(RF,N,T,III,IPZ,CL)
C   REFT25
C   REFTRAN INITIALIZES THE REFLECTANCES AND TRANSMITTANCES OF THE
C   SURFACES OF THE GLASS/WATER LATTICE FOR PROGRAM LAYER.
C
      DIMENSION RF(100),T(100)
      REAL KG(5),RWG(2)
      IF(III.GT.1)GOTO 299
C   COMMENTS TO IDENTIFY TYPE OF LATTICE FOR PRINTED OUTPUT
      WRITE(7,201)
      WRITE(7,202)
      WRITE(7,203)
201  FORMAT("NO ABSORPTION - CELL SIZE=1.2 X 2.4 CM")
202  FORMAT("VERTICAL PLATES: DXG=0.0")
203  FORMAT("HORIZONTAL PLATES: DGH=0.0 AND RHO=RWG")
C
C   SET PARAMETERS
C   DXG -- THICKNESS OF VERTICAL GLASS PLATES
C   KG -- EXTINCTION COEFFICIENT OF GLASS
C   CL -- CELL SIZE (HEIGHT OF VERTICAL PLATES)
C   RWG -- REFLECTANCE OF WATER/GLASS INTERFACE
C           RWG(1)=PARALLEL COMPONENT OF POLARIZATION
C           RWG(2)=PERPENDICULAR COMPONENT OF POLARIZATION
C
      DATA KG/0.688,0.124,0.180,0.307,0.412/
299  DXG=0.0
      CL=1.20
      DATA RWG/0.0021,0.0090/
      IF((III.EQ.1).AND.(IPZ.EQ.1))WRITE(2,*)CL
      DO 10 I=1,N
      I41=4*(I-1)
      RF(I41+1)=RWG(IPZ)
      RF(I41+3)=RWG(IPZ)
C   *** 1.1393 IS THE EFFECTIVE INCREASE IN PATH LENGTH FOR
C   *** GLASS PLATES TRANSMITTING DIFFUSE RADIATION (IN WATER).
      TAU=EXP(-KG(III)*DXG*1.1393)
      RR=RWG(IPZ)+(1.-RWG(IPZ))**2*TAU*TAU*RWG(IPZ)/(1.-(RWG(IPZ)*TAU)
& **2)
      TT=(1.-RWG(IPZ))**2*TAU/(1.-(RWG(IPZ)*TAU)**2)
      RF(I41+2)=RR
      RF(I41+4)=RR
      T(I41+2)=TT
      T(I41+4)=TT
      NTEST=I/2.
      NTEST=NTEST*2
      IF(NTEST.EQ.I)RF(I41+4)=0.
      IF(NTEST.EQ.I)T(I41+4)=1.
      IF(NTEST.NE.I)RF(I41+2)=0.
      IF(NTEST.NE.I)T(I41+2)=1.
10  CONTINUE
      RETURN
      END

```

```

      SUBROUTINE REFTRAN(RF,N,T,III,IPZ,CL)
C  REFT26
C  REFTRAN INITIALIZES THE REFLECTANCES AND TRANSMITTANCES OF THE
C  SURFACES OF THE GLASS/WATER LATTICE FOR PROGRAM LAYER.
C
      DIMENSION RF(100),T(100)
      REAL KG(5),RWG(2)
      IF(III.GT.1)GOTO 299
C  COMMENTS TO IDENTIFY TYPE OF LATTICE FOR PRINTED OUTPUT
      WRITE(7,201)
      WRITE(7,202)
      WRITE(7,203)
201  FORMAT("ABSORPTION IN HORIZ. PLATES ONLY-CELL SIZE=1.2 X 2.4 CM")
202  FORMAT("VERTICAL PLATES:  DXG=0.0")
203  FORMAT("HORIZONTAL PLATES:  DGH=0.3175 CM AND RHO=RWG")
C
C  SET PARAMETERS
C  DXG -- THICKNESS OF VERTICAL GLASS PLATES
C  KG -- EXTINCTION COEFFICIENT OF GLASS
C  CL -- CELL SIZE (HEIGHT OF VERTICAL PLATES)
C  RWG -- REFLECTANCE OF WATER/GLASS INTERFACE
C          RWG(1)=PARALLEL COMPONENT OF POLARIZATION
C          RWG(2)=PERPENDICULAR COMPONENT OF POLARIZATION
C
      DATA KG/0.688,0.124,0.180,0.307,0.412/
299  DXG=0.0
      CL=1.20
      DATA RWG/0.0021,0.0090/
      IF((III.EQ.1).AND.(IPZ.EQ.1))WRITE(2,*)CL
      DO 10 I=1,N
      I41=4*(I-1)
      RF(I41+1)=RWG(IPZ)
      RF(I41+3)=RWG(IPZ)
C  *** 1.1393 IS THE EFFECTIVE INCREASE IN PATH LENGTH FOR
C  *** GLASS PLATES TRANSMITTING DIFFUSE RADIATION (IN WATER).
      TAU=EXP(-KG(III)*DXG*1.1393)
      RR=RWG(IPZ)+(1.-RWG(IPZ))**2*TAU*TAU*RWG(IPZ)/(1.-(RWG(IPZ)*TAU)
& **2)
      TT=(1.-RWG(IPZ))**2*TAU/(1.-(RWG(IPZ)*TAU)**2)
      RF(I41+2)=RR
      RF(I41+4)=RR
      T(I41+2)=TT
      T(I41+4)=TT
      NTEST=I/2.
      NTEST=NTEST*2
      IF(NTEST.EQ.I)RF(I41+4)=0.
      IF(NTEST.EQ.I)T(I41+4)=1.
      IF(NTEST.NE.I)RF(I41+2)=0.
      IF(NTEST.NE.I)T(I41+2)=1.
10  CONTINUE
      RETURN
      END

```

```

      SUBROUTINE REFTRAN(RF,N,T,III,IPZ,CL)
C   REFT27
C   REFTRAN INITIALIZES THE REFLECTANCES AND TRANSMITTANCES OF THE
C   SURFACES OF THE GLASS/WATER LATTICE FOR PROGRAM LAYER.
C
      DIMENSION RF(100),T(100)
      REAL KG(5),RWG(2)
      IF(III.GT.1)GOTO 299
C   COMMENTS TO IDENTIFY TYPE OF LATTICE FOR PRINTED OUTPUT
      WRITE(7,201)
      WRITE(7,202)
      WRITE(7,203)
201  FORMAT("ABSORPTION IN ALL PLATES - CELL SIZE=1.2 X 2.4 CM")
202  FORMAT("VERTICAL PLATES:  DXG=0.3175 CM")
203  FORMAT("HORIZONTAL PLATES:  DGH=0.3175 CM AND RHO=RWG")
C
C   SET PARAMETERS
C   DXG -- THICKNESS OF VERTICAL GLASS PLATES
C   KG -- EXTINCTION COEFFICIENT OF GLASS
C   CL -- CELL SIZE (HEIGHT OF VERTICAL PLATES)
C   RWG -- REFLECTANCE OF WATER/GLASS INTERFACE
C           RWG(1)=PARALLEL COMPONENT OF POLARIZATION
C           RWG(2)=PERPENDICULAR COMPONENT OF POLARIZATION
C
      DATA KG/0.688,0.124,0.180,0.307,0.412/
299  DXG=0.3175
      CL=1.20
      DATA RWG/0.0021,0.0090/
      IF((III.EQ.1).AND.(IPZ.EQ.1))WRITE(2,*)CL
      DO 10 I=1,N
      I41=4*(I-1)
      RF(I41+1)=RWG(IPZ)
      RF(I41+3)=RWG(IPZ)
C   *** 1.1393 IS THE EFFECTIVE INCREASE IN PATH LENGTH FOR
C   *** GLASS PLATES TRANSMITTING DIFFUSE RADIATION (IN WATER).
      TAU=EXP(-KG(III)*DXG*1.1393)
      RR=RWG(IPZ)+(1.-RWG(IPZ))**2*TAU*TAU*RWG(IPZ)/(1.-(RWG(IPZ)*TAU)
& **2)
      TT=(1.-RWG(IPZ))**2*TAU/(1.-(RWG(IPZ)*TAU)**2)
      RF(I41+2)=RR
      RF(I41+4)=RR
      T(I41+2)=TT
      T(I41+4)=TT
      NTEST=I/2.
      NTEST=NTEST*2
      IF(NTEST.EQ.I)RF(I41+4)=0.
      IF(NTEST.EQ.I)T(I41+4)=1.
      IF(NTEST.NE.I)RF(I41+2)=0.
      IF(NTEST.NE.I)T(I41+2)=1.
10  CONTINUE
      RETURN
      END

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      SUBROUTINE REFTRAN(RF,N,T,III,IPZ,CL)
C   REFT28
C   REFTRAN INITIALIZES THE REFLECTANCES AND TRANSMITTANCES OF THE
C   SURFACES OF THE GLASS/WATER LATTICE FOR PROGRAM LAYER.
      DIMENSION RF(100),T(100)
      REAL KG(5),RWG(2)
      IF(III.GT.1)GOTO 299
C   COMMENTS TO IDENTIFY TYPE OF LATTICE FOR PRINTED OUTPUT
      WRITE(7,201)
      WRITE(7,202)
      WRITE(7,203)
201  FORMAT("NO ABSORPTION - CELL SIZE=1.2 X 3.6 CM")
202  FORMAT("VERTICAL PLATES: DXG=0.0")
203  FORMAT("HORIZONTAL PLATES: DGH=0.0 AND RHO=RWG")
C
C   SET PARAMETERS
C   DXG -- THICKNESS OF VERTICAL GLASS PLATES
C   KG -- EXTINCTION COEFFICIENT OF GLASS
C   CL -- CELL SIZE (HEIGHT OF VERTICAL PLATES)
C   RWG -- REFLECTANCE OF WATER/GLASS INTERFACE
C           RWG(1)=PARALLEL COMPONENT OF POLARIZATION
C           RWG(2)=PERPENDICULAR COMPONENT OF POLARIZATION
C
      DATA KG/0.688,0.124,0.180,0.307,0.412/
299  DXG=0.0
      CL=1.20
      DATA RWG/0.0021,0.0090/
      IF((III.EQ.1).AND.(IPZ.EQ.1))WRITE(2,*)CL
      NK=1
      DO 10 I=1,N
        I41=4*(I-1)
        RF(I41+1)=RWG(IPZ)
        RF(I41+3)=RWG(IPZ)
C   *** 1.1393 IS THE EFFECTIVE INCREASE IN PATH LENGTH FOR
C   *** GLASS PLATES TRANSMITTING DIFFUSE RADIATION (IN WATER).
        TAU=EXP(-KG(III)*DXG*1.1393)
        RR=RWG(IPZ)+(1.-RWG(IPZ))**2*TAU*TAU*RWG(IPZ)/(1.-(RWG(IPZ)*TAU)
& **2)
        TT=(1.-RWG(IPZ))**2*TAU/(1.-(RWG(IPZ)*TAU)**2)
        RF(I41+2)=RR
        RF(I41+4)=RR
        T(I41+2)=TT
        T(I41+4)=TT
        IF((NK.EQ.2).OR.(NK.EQ.3))RF(I41+4)=0.
        IF((NK.EQ.2).OR.(NK.EQ.3))T(I41+4)=1.
        IF((NK.EQ.1).OR.(NK.EQ.2))RF(I41+2)=0.
        IF((NK.EQ.1).OR.(NK.EQ.2))T(I41+2)=1.
        NK=NK+1
        IF(NK.EQ.4)NK=1
10  CONTINUE
      RETURN
      END

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      SUBROUTINE REFTRAN(RF,N,T,III,IPZ,CL)
C  REFT29
C  REFTRAN INITIALIZES THE REFLECTANCES AND TRANSMITTANCES OF THE
C  SURFACES OF THE GLASS/WATER LATTICE FOR PROGRAM LAYER.
      DIMENSION RF(100),T(100)
      REAL KG(5),RWG(2)
      IF(III.GT.1)GOTO 299
C  COMMENTS TO IDENTIFY TYPE OF LATTICE FOR PRINTED OUTPUT
      WRITE(7,201)
      WRITE(7,202)
      WRITE(7,203)
201 FORMAT("ABSORPTION IN HORIZ. PLATES ONLY-CELL SIZE=1.2 X 3.6 CM")
202 FORMAT("VERTICAL PLATES: DXG=0.0")
203 FORMAT("HORIZONTAL PLATES: DGH=0.3175 CM AND RHO=RWG")
C
C  SET PARAMETERS
C  DXG -- THICKNESS OF VERTICAL GLASS PLATES
C  KG -- EXTINCTION COEFFICIENT OF GLASS
C  CL -- CELL SIZE (HEIGHT OF VERTICAL PLATES)
C  RWG -- REFLECTANCE OF WATER/GLASS INTERFACE
C          RWG(1)=PARALLEL COMPONENT OF POLARIZATION
C          RWG(2)=PERPENDICULAR COMPONENT OF POLARIZATION
C
      DATA KG/0.688,0.124,0.180,0.307,0.412/
299 DXG=0.0
      CL=1.20
      DATA RWG/0.0021,0.0090/
      IF((III.EQ.1).AND.(IPZ.EQ.1))WRITE(2,*)CL
      NK=1
      DO 10 I=1,N
      I41=4*(I-1)
      RF(I41+1)=RWG(IPZ)
      RF(I41+3)=RWG(IPZ)
C  *** 1.1393 IS THE EFFECTIVE INCREASE IN PATH LENGTH FOR
C  *** GLASS PLATES TRANSMITTING DIFFUSE RADIATION (IN WATER).
      TAU=EXP(-KG(III)*DXG*1.1393)
      RR=RWG(IPZ)+(1.-RWG(IPZ))**2*TAU*TAU*RWG(IPZ)/(1.-(RWG(IPZ)*TAU)
&***2)
      TT=(1.-RWG(IPZ))**2*TAU/(1.-(RWG(IPZ)*TAU)**2)
      RF(I41+2)=RR
      RF(I41+4)=RR
      T(I41+2)=TT
      T(I41+4)=TT
      IF((NK.EQ.2).OR.(NK.EQ.3))RF(I41+4)=0.
      IF((NK.EQ.2).OR.(NK.EQ.3))T(I41+4)=1.
      IF((NK.EQ.1).OR.(NK.EQ.2))RF(I41+2)=0.
      IF((NK.EQ.1).OR.(NK.EQ.2))T(I41+2)=1.
      NK=NK+1
      IF(NK.EQ.4)NK=1
10 CONTINUE
      RETURN
      END

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      SUBROUTINE REFTRAN(RF,N,T,III,IPZ,CL)
C   REFT30
C   REFTRAN INITIALIZES THE REFLECTANCES AND TRANSMITTANCES OF THE
C   SURFACES OF THE GLASS/WATER LATTICE FOR PROGRAM LAYER.
      DIMENSION RF(100),T(100)
      REAL KG(5),RWG(2)
      IF(III.GT.1)GOTO 299
C   COMMENTS TO IDENTIFY TYPE OF LATTICE FOR PRINTED OUTPUT
      WRITE(7,201)
      WRITE(7,202)
      WRITE(7,203)
201  FORMAT("ABSORPTION IN ALL PLATES - CELL SIZE=1.2 X 3.6 CM")
202  FORMAT("VERTICAL PLATES:  DXG=0.3175 CM")
203  FORMAT("HORIZONTAL PLATES:  DGH=0.3175 CM AND RHO=RWG")
C
C   SET PARAMETERS
C   DXG -- THICKNESS OF VERTICAL GLASS PLATES
C   KG -- EXTINCTION COEFFICIENT OF GLASS
C   CL -- CELL SIZE (HEIGHT OF VERTICAL PLATES)
C   RWG -- REFLECTANCE OF WATER/GLASS INTERFACE
C           RWG(1)=PARALLEL COMPONENT OF POLARIZATION
C           RWG(2)=PERPENDICULAR COMPONENT OF POLARIZATION
C
      DATA KG/0.688,0.124,0.180,0.307,0.412/
299  DXG=0.3175
      CL=1.20
      DATA RWG/0.0021,0.0090/
      IF((III.EQ.1).AND.(IPZ.EQ.1))WRITE(2,*)CL
      NK=1
      DO 10 I=1,N
      I41=4*(I-1)
      RF(I41+1)=RWG(IPZ)
      RF(I41+3)=RWG(IPZ)
C   *** 1.1393 IS THE EFFECTIVE INCREASE IN PATH LENGTH FOR
C   *** GLASS PLATES TRANSMITTING DIFFUSE RADIATION (IN WATER).
      TAU=EXP(-KG(III)*DXG*1.1393)
      RR=RWG(IPZ)+(1.-RWG(IPZ))**2*TAU*TAU*RWG(IPZ)/(1.-(RWG(IPZ)*TAU)
& **2)
      TT=(1.-RWG(IPZ))**2*TAU/(1.-(RWG(IPZ)*TAU)**2)
      RF(I41+2)=RR
      RF(I41+4)=RR
      T(I41+2)=TT
      T(I41+4)=TT
      IF((NK.EQ.2).OR.(NK.EQ.3))RF(I41+4)=0.
      IF((NK.EQ.2).OR.(NK.EQ.3))T(I41+4)=1.
      IF((NK.EQ.1).OR.(NK.EQ.2))RF(I41+2)=0.
      IF((NK.EQ.1).OR.(NK.EQ.2))T(I41+2)=1.
      NK=NK+1
      IF(NK.EQ.4)NK=1
10  CONTINUE
      RETURN
      END

```

LYOUT21

21 CELLS PER LAYER

PARALLEL COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :
NO ABSORPTION - HORIZ. PLATES ONLY, CELL SIZE=1.20 CM
VERTICAL PLATES: DXG=0.0 AND RHO=0.0
HORIZONTAL PLATES: DGH=0.0 AND RHO=RWG

LAYER TRANSMITTANCE= .99059 LAYER REFLECTANCE= .00417

FOR SPECTRAL BAND NUMBER 2 :

LAYER TRANSMITTANCE= .99059 LAYER REFLECTANCE= .00417

FOR SPECTRAL BAND NUMBER 3 :

LAYER TRANSMITTANCE= .98128 LAYER REFLECTANCE= .00413

FOR SPECTRAL BAND NUMBER 4 :

LAYER TRANSMITTANCE= .92693 LAYER REFLECTANCE= .00391

FOR SPECTRAL BAND NUMBER 5 :

LAYER TRANSMITTANCE= .47998 LAYER REFLECTANCE= .00259

PERPEND. COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :

LAYER TRANSMITTANCE= .97702 LAYER REFLECTANCE= .01774

FOR SPECTRAL BAND NUMBER 2 :

LAYER TRANSMITTANCE= .97702 LAYER REFLECTANCE= .01774

FOR SPECTRAL BAND NUMBER 3 :

LAYER TRANSMITTANCE= .96783 LAYER REFLECTANCE= .01758

FOR SPECTRAL BAND NUMBER 4 :

LAYER TRANSMITTANCE= .91422 LAYER REFLECTANCE= .01665

FOR SPECTRAL BAND NUMBER 5 :

LAYER TRANSMITTANCE= .47338 LAYER REFLECTANCE= .01105

LYOUT22

21 CELLS PER LAYER

PARALLEL COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :
NO ABSORPTION - CELL SIZE=1.20 CM
VERTICAL PLATES: DXG=0.0
HORIZONTAL PLATES: DGH=0.0 AND RHO=RWG

LAYER TRANSMITTANCE= .98874 LAYER REFLECTANCE= .00606

FOR SPECTRAL BAND NUMBER 2 :
LAYER TRANSMITTANCE= .98874 LAYER REFLECTANCE= .00606

FOR SPECTRAL BAND NUMBER 3 :
LAYER TRANSMITTANCE= .97945 LAYER REFLECTANCE= .00599

FOR SPECTRAL BAND NUMBER 4 :
LAYER TRANSMITTANCE= .92525 LAYER REFLECTANCE= .00557

FOR SPECTRAL BAND NUMBER 5 :
LAYER TRANSMITTANCE= .47931 LAYER REFLECTANCE= .00318

PERPEND. COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :
LAYER TRANSMITTANCE= .96944 LAYER REFLECTANCE= .02553

FOR SPECTRAL BAND NUMBER 2 :
LAYER TRANSMITTANCE= .96944 LAYER REFLECTANCE= .02553

FOR SPECTRAL BAND NUMBER 3 :
LAYER TRANSMITTANCE= .96035 LAYER REFLECTANCE= .02522

FOR SPECTRAL BAND NUMBER 4 :
LAYER TRANSMITTANCE= .90731 LAYER REFLECTANCE= .02348

FOR SPECTRAL BAND NUMBER 5 :
LAYER TRANSMITTANCE= .47057 LAYER REFLECTANCE= .01351

LYOUT23

21 CELLS PER LAYER

PARALLEL COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :
NO ABSORPTION - CELL SIZE=1.20 CM
VERTICAL PLATES: DXG=0.0
HORIZONTAL PLATES: DGH=0.0 AND RHO=RWG

LAYER TRANSMITTANCE= .98874 LAYER REFLECTANCE= .00606

FOR SPECTRAL BAND NUMBER 2 :
LAYER TRANSMITTANCE= .98874 LAYER REFLECTANCE= .00606

FOR SPECTRAL BAND NUMBER 3 :
LAYER TRANSMITTANCE= .97945 LAYER REFLECTANCE= .00599

FOR SPECTRAL BAND NUMBER 4 :
LAYER TRANSMITTANCE= .92525 LAYER REFLECTANCE= .00557

FOR SPECTRAL BAND NUMBER 5 :
LAYER TRANSMITTANCE= .47931 LAYER REFLECTANCE= .00318

PERPEND. COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :
LAYER TRANSMITTANCE= .96944 LAYER REFLECTANCE= .02553

FOR SPECTRAL BAND NUMBER 2 :
LAYER TRANSMITTANCE= .96944 LAYER REFLECTANCE= .02553

FOR SPECTRAL BAND NUMBER 3 :
LAYER TRANSMITTANCE= .96035 LAYER REFLECTANCE= .02522

FOR SPECTRAL BAND NUMBER 4 :
LAYER TRANSMITTANCE= .90731 LAYER REFLECTANCE= .02348

FOR SPECTRAL BAND NUMBER 5 :
LAYER TRANSMITTANCE= .47057 LAYER REFLECTANCE= .01351

LYOUT24

21 CELLS PER LAYER

PARALLEL COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :

ABSORPTION IN ALL PLATES - CELL SIZE=1.20 CM

VERTICAL PLATES: DXG=0.3175 CM

HORIZONTAL PLATES: DGH=0.3175 CM AND RHO=RWG

LAYER TRANSMITTANCE= .81661 LAYER REFLECTANCE= .00460

FOR SPECTRAL BAND NUMBER 2 :

LAYER TRANSMITTANCE= .95061 LAYER REFLECTANCE= .00568

FOR SPECTRAL BAND NUMBER 3 :

LAYER TRANSMITTANCE= .92620 LAYER REFLECTANCE= .00548

FOR SPECTRAL BAND NUMBER 4 :

LAYER TRANSMITTANCE= .84634 LAYER REFLECTANCE= .00489

FOR SPECTRAL BAND NUMBER 5 :

LAYER TRANSMITTANCE= .43887 LAYER REFLECTANCE= .00299

PERPEND. COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :

LAYER TRANSMITTANCE= .80176 LAYER REFLECTANCE= .01947

FOR SPECTRAL BAND NUMBER 2 :

LAYER TRANSMITTANCE= .93228 LAYER REFLECTANCE= .02397

FOR SPECTRAL BAND NUMBER 3 :

LAYER TRANSMITTANCE= .90846 LAYER REFLECTANCE= .02311

FOR SPECTRAL BAND NUMBER 4 :

LAYER TRANSMITTANCE= .83043 LAYER REFLECTANCE= .02068

FOR SPECTRAL BAND NUMBER 5 :

LAYER TRANSMITTANCE= .43110 LAYER REFLECTANCE= .01271

LYOUT25

21 CELLS PER LAYER

PARALLEL COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :
NO ABSORPTION - CELL SIZE=1.2 X 2.4 CM
VERTICAL PLATES: DXG=0.0
HORIZONTAL PLATES: DGH=0.0 AND RHO=RWG

LAYER TRANSMITTANCE= .98967 LAYER REFLECTANCE= .00512

FOR SPECTRAL BAND NUMBER 2 :
LAYER TRANSMITTANCE= .98967 LAYER REFLECTANCE= .00512

FOR SPECTRAL BAND NUMBER 3 :
LAYER TRANSMITTANCE= .98036 LAYER REFLECTANCE= .00506

FOR SPECTRAL BAND NUMBER 4 :
LAYER TRANSMITTANCE= .92609 LAYER REFLECTANCE= .00474

FOR SPECTRAL BAND NUMBER 5 :
LAYER TRANSMITTANCE= .47965 LAYER REFLECTANCE= .00288

PERPEND. COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :
LAYER TRANSMITTANCE= .97319 LAYER REFLECTANCE= .02166

FOR SPECTRAL BAND NUMBER 2 :
LAYER TRANSMITTANCE= .97319 LAYER REFLECTANCE= .02166

FOR SPECTRAL BAND NUMBER 3 :
LAYER TRANSMITTANCE= .96405 LAYER REFLECTANCE= .02142

FOR SPECTRAL BAND NUMBER 4 :
LAYER TRANSMITTANCE= .91073 LAYER REFLECTANCE= .02009

FOR SPECTRAL BAND NUMBER 5 :
LAYER TRANSMITTANCE= .47197 LAYER REFLECTANCE= .01228

21 CELLS PER LAYER

PARALLEL COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :

ABSORPTION IN HORIZ. PLATES ONLY-CELL SIZE=1.2 X 2.4 CM

VERTICAL PLATES: DXG=0.0

HORIZONTAL PLATES: DGH=0.3175 CM AND RHO=RWG

LAYER TRANSMITTANCE= .98967 LAYER REFLECTANCE= .00512

FOR SPECTRAL BAND NUMBER 2 :

LAYER TRANSMITTANCE= .98967 LAYER REFLECTANCE= .00512

FOR SPECTRAL BAND NUMBER 3 :

LAYER TRANSMITTANCE= .98036 LAYER REFLECTANCE= .00506

FOR SPECTRAL BAND NUMBER 4 :

LAYER TRANSMITTANCE= .92609 LAYER REFLECTANCE= .00474

FOR SPECTRAL BAND NUMBER 5 :

LAYER TRANSMITTANCE= .47965 LAYER REFLECTANCE= .00288

PERPEND. COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :

LAYER TRANSMITTANCE= .97319 LAYER REFLECTANCE= .02166

FOR SPECTRAL BAND NUMBER 2 :

LAYER TRANSMITTANCE= .97319 LAYER REFLECTANCE= .02166

FOR SPECTRAL BAND NUMBER 3 :

LAYER TRANSMITTANCE= .96405 LAYER REFLECTANCE= .02142

FOR SPECTRAL BAND NUMBER 4 :

LAYER TRANSMITTANCE= .91073 LAYER REFLECTANCE= .02009

FOR SPECTRAL BAND NUMBER 5 :

LAYER TRANSMITTANCE= .47197 LAYER REFLECTANCE= .01228

LYOUT27

21 CELLS PER LAYER

PARALLEL COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :
ABSORPTION IN ALL PLATES - CELL SIZE=1.2 X 2.4 CM
VERTICAL PLATES: DXG=0.3175 CM
HORIZONTAL PLATES: DGH=0.3175 CM AND RHO=RWG

LAYER TRANSMITTANCE= .89552 LAYER REFLECTANCE= .00446

FOR SPECTRAL BAND NUMBER 2 :
LAYER TRANSMITTANCE= .97018 LAYER REFLECTANCE= .00497

FOR SPECTRAL BAND NUMBER 3 :
LAYER TRANSMITTANCE= .95293 LAYER REFLECTANCE= .00485

FOR SPECTRAL BAND NUMBER 4 :
LAYER TRANSMITTANCE= .88487 LAYER REFLECTANCE= .00446

FOR SPECTRAL BAND NUMBER 5 :
LAYER TRANSMITTANCE= .45885 LAYER REFLECTANCE= .00280

PERPEND. COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :
LAYER TRANSMITTANCE= .88114 LAYER REFLECTANCE= .01892

FOR SPECTRAL BAND NUMBER 2 :
LAYER TRANSMITTANCE= .95412 LAYER REFLECTANCE= .02104

FOR SPECTRAL BAND NUMBER 3 :
LAYER TRANSMITTANCE= .93721 LAYER REFLECTANCE= .02057

FOR SPECTRAL BAND NUMBER 4 :
LAYER TRANSMITTANCE= .87042 LAYER REFLECTANCE= .01891

FOR SPECTRAL BAND NUMBER 5 :
LAYER TRANSMITTANCE= .45163 LAYER REFLECTANCE= .01194

LYOUT28

21 CELLS PER LAYER

PARALLEL COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :
NO ABSORPTION - CELL SIZE=1.2 X 3.6 CM
VERTICAL PLATES: DXG=0.0
HORIZONTAL PLATES: DGH=0.0 AND RHO=RWG

LAYER TRANSMITTANCE= .99021 LAYER REFLECTANCE= .00460

FOR SPECTRAL BAND NUMBER 2 :
LAYER TRANSMITTANCE= .99021 LAYER REFLECTANCE= .00460

FOR SPECTRAL BAND NUMBER 3 :
LAYER TRANSMITTANCE= .98090 LAYER REFLECTANCE= .00455

FOR SPECTRAL BAND NUMBER 4 :
LAYER TRANSMITTANCE= .92659 LAYER REFLECTANCE= .00427

FOR SPECTRAL BAND NUMBER 5 :
LAYER TRANSMITTANCE= .47989 LAYER REFLECTANCE= .00267

PERPEND. COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :
LAYER TRANSMITTANCE= .97542 LAYER REFLECTANCE= .01951

FOR SPECTRAL BAND NUMBER 2 :
LAYER TRANSMITTANCE= .97542 LAYER REFLECTANCE= .01951

FOR SPECTRAL BAND NUMBER 3 :
LAYER TRANSMITTANCE= .96625 LAYER REFLECTANCE= .01930

FOR SPECTRAL BAND NUMBER 4 :
LAYER TRANSMITTANCE= .91281 LAYER REFLECTANCE= .01815

FOR SPECTRAL BAND NUMBER 5 :
LAYER TRANSMITTANCE= .47297 LAYER REFLECTANCE= .01142

LYOUT29

21 CELLS PER LAYER

PARALLEL COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :

ABSORPTION IN HORIZ. PLATES ONLY-CELL SIZE=1.2 X 3.6 CM

VERTICAL PLATES: DXG=0.0

HORIZONTAL PLATES: DGH=0.3175 CM AND RHO=RWG

LAYER TRANSMITTANCE= .99021 LAYER REFLECTANCE= .00460

FOR SPECTRAL BAND NUMBER 2 :

LAYER TRANSMITTANCE= .99021 LAYER REFLECTANCE= .00460

FOR SPECTRAL BAND NUMBER 3 :

LAYER TRANSMITTANCE= .98090 LAYER REFLECTANCE= .00455

FOR SPECTRAL BAND NUMBER 4 :

LAYER TRANSMITTANCE= .92659 LAYER REFLECTANCE= .00427

FOR SPECTRAL BAND NUMBER 5 :

LAYER TRANSMITTANCE= .47989 LAYER REFLECTANCE= .00267

PERPEND. COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :

LAYER TRANSMITTANCE= .97542 LAYER REFLECTANCE= .01951

FOR SPECTRAL BAND NUMBER 2 :

LAYER TRANSMITTANCE= .97542 LAYER REFLECTANCE= .01951

FOR SPECTRAL BAND NUMBER 3 :

LAYER TRANSMITTANCE= .96625 LAYER REFLECTANCE= .01930

FOR SPECTRAL BAND NUMBER 4 :

LAYER TRANSMITTANCE= .91281 LAYER REFLECTANCE= .01815

FOR SPECTRAL BAND NUMBER 5 :

LAYER TRANSMITTANCE= .47297 LAYER REFLECTANCE= .01142

LYOUT30

21 CELLS PER LAYER

PARALLEL COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :
ABSORPTION IN ALL PLATES - CELL SIZE=1.2 X 3.6 CM
VERTICAL PLATES: DXG=0.3175 CM
HORIZONTAL PLATES: DGH=0.3175 CM AND RHO=RWG

LAYER TRANSMITTANCE= .94836 LAYER REFLECTANCE= .00428

FOR SPECTRAL BAND NUMBER 2 :
LAYER TRANSMITTANCE= .98167 LAYER REFLECTANCE= .00453

FOR SPECTRAL BAND NUMBER 3 :
LAYER TRANSMITTANCE= .96891 LAYER REFLECTANCE= .00445

FOR SPECTRAL BAND NUMBER 4 :
LAYER TRANSMITTANCE= .90908 LAYER REFLECTANCE= .00414

FOR SPECTRAL BAND NUMBER 5 :
LAYER TRANSMITTANCE= .47372 LAYER REFLECTANCE= .00264

PERPEND. COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :
LAYER TRANSMITTANCE= .93446 LAYER REFLECTANCE= .01817

FOR SPECTRAL BAND NUMBER 2 :
LAYER TRANSMITTANCE= .96705 LAYER REFLECTANCE= .01922

FOR SPECTRAL BAND NUMBER 3 :
LAYER TRANSMITTANCE= .95452 LAYER REFLECTANCE= .01890

FOR SPECTRAL BAND NUMBER 4 :
LAYER TRANSMITTANCE= .89566 LAYER REFLECTANCE= .01760

FOR SPECTRAL BAND NUMBER 5 :
LAYER TRANSMITTANCE= .46693 LAYER REFLECTANCE= .01129

LYOUT35

25 CELLS PER LAYER

PARALLEL COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :

NO ABSORPTION - HORIZ. PLATES ONLY, CELL SIZE=1.20 CM

VERTICAL PLATES: DXG=0.0 AND RHO=0.0

HORIZONTAL PLATES: DGH=0.0 AND RHO=RWG

LAYER TRANSMITTANCE= .99191 LAYER REFLECTANCE= .00417

FOR SPECTRAL BAND NUMBER 2 :

LAYER TRANSMITTANCE= .99191 LAYER REFLECTANCE= .00417

FOR SPECTRAL BAND NUMBER 3 :

LAYER TRANSMITTANCE= .98250 LAYER REFLECTANCE= .00413

FOR SPECTRAL BAND NUMBER 4 :

LAYER TRANSMITTANCE= .92772 LAYER REFLECTANCE= .00391

FOR SPECTRAL BAND NUMBER 5 :

LAYER TRANSMITTANCE= .47999 LAYER REFLECTANCE= .00259

PERPEND. COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :

LAYER TRANSMITTANCE= .97831 LAYER REFLECTANCE= .01777

FOR SPECTRAL BAND NUMBER 2 :

LAYER TRANSMITTANCE= .97831 LAYER REFLECTANCE= .01777

FOR SPECTRAL BAND NUMBER 3 :

LAYER TRANSMITTANCE= .96903 LAYER REFLECTANCE= .01760

FOR SPECTRAL BAND NUMBER 4 :

LAYER TRANSMITTANCE= .91499 LAYER REFLECTANCE= .01667

FOR SPECTRAL BAND NUMBER 5 :

LAYER TRANSMITTANCE= .47338 LAYER REFLECTANCE= .01105

LYOUT36

29 CELLS PER LAYER

PARALLEL COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :

NO ABSORPTION - HORIZ. PLATES ONLY, CELL SIZE=1.20 CM

VERTICAL PLATES: DXG=0.0 AND RHO=0.0

HORIZONTAL PLATES: DGH=0.0 AND RHO=RWG

LAYER TRANSMITTANCE= .99272 LAYER REFLECTANCE= .00418

FOR SPECTRAL BAND NUMBER 2 :

LAYER TRANSMITTANCE= .99272 LAYER REFLECTANCE= .00418

FOR SPECTRAL BAND NUMBER 3 :

LAYER TRANSMITTANCE= .98324 LAYER REFLECTANCE= .00414

FOR SPECTRAL BAND NUMBER 4 :

LAYER TRANSMITTANCE= .92816 LAYER REFLECTANCE= .00392

FOR SPECTRAL BAND NUMBER 5 :

LAYER TRANSMITTANCE= .47999 LAYER REFLECTANCE= .00259

PERPEND. COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :

LAYER TRANSMITTANCE= .97911 LAYER REFLECTANCE= .01778

FOR SPECTRAL BAND NUMBER 2 :

LAYER TRANSMITTANCE= .97911 LAYER REFLECTANCE= .01778

FOR SPECTRAL BAND NUMBER 3 :

LAYER TRANSMITTANCE= .96976 LAYER REFLECTANCE= .01762

FOR SPECTRAL BAND NUMBER 4 :

LAYER TRANSMITTANCE= .91543 LAYER REFLECTANCE= .01668

FOR SPECTRAL BAND NUMBER 5 :

LAYER TRANSMITTANCE= .47338 LAYER REFLECTANCE= .01105

NMOUT21
OUTPUT FROM PROGRAM LAYED2

COMPONENTS OF POLARIZATION AVERAGED
THE HORIZONTAL GLASS PLATES ARE 0.000 CM THICK.
CELL SIZE (CM) IS 1.200 CM

NO. OF PLATES	RELATIVE TRANSMITTANCE	= TRANS./H2OTRANS.
2	.97240	= .38217/ .39302
3	.95534	= .37547/ .39302
4	.93877	= .36895/ .39302
5	.92265	= .36262/ .39302
6	.90696	= .35645/ .39302
7	.89169	= .35045/ .39302
8	.87682	= .34461/ .39302
9	.86232	= .33891/ .39302
10	.84819	= .33336/ .39302
11	.83442	= .32794/ .39302
12	.82097	= .32266/ .39302
13	.80786	= .31750/ .39302
14	.79505	= .31247/ .39302
15	.78254	= .30756/ .39302
16	.77032	= .30275/ .39302
17	.75838	= .29806/ .39302
18	.74671	= .29347/ .39302
19	.73530	= .28899/ .39302
20	.72414	= .28460/ .39302
21	.71322	= .28031/ .39302
22	.70254	= .27611/ .39302
23	.69208	= .27200/ .39302
24	.68184	= .26798/ .39302
25	.67182	= .26404/ .39302

NMOUT22
 OUTPUT FROM PROGRAM LAYED2

COMPONENTS OF POLARIZATION AVERAGED
 THE HORIZONTAL GLASS PLATES ARE 0.000 CM THICK.
 CELL SIZE (CM) IS 1.200 CM

NO. OF PLATES	RELATIVE TRANSMITTANCE	=	TRANS./H2O	TRANS.
2	.96824	=	.38054/	.39302
3	.94735	=	.37233/	.39302
4	.92724	=	.36442/	.39302
5	.90785	=	.35680/	.39302
6	.88914	=	.34945/	.39302
7	.87107	=	.34235/	.39302
8	.85360	=	.33548/	.39302
9	.83670	=	.32884/	.39302
10	.82033	=	.32241/	.39302
11	.80448	=	.31618/	.39302
12	.78911	=	.31013/	.39302
13	.77419	=	.30427/	.39302
14	.75972	=	.29858/	.39302
15	.74565	=	.29306/	.39302
16	.73199	=	.28769/	.39302
17	.71871	=	.28247/	.39302
18	.70578	=	.27739/	.39302
19	.69321	=	.27245/	.39302
20	.68096	=	.26763/	.39302
21	.66904	=	.26295/	.39302
22	.65742	=	.25838/	.39302
23	.64610	=	.25393/	.39302
24	.63505	=	.24959/	.39302
25	.62428	=	.24535/	.39302

NMOUT23
OUTPUT FROM PROGRAM LAYED2

COMPONENTS OF POLARIZATION AVERAGED
THE HORIZONTAL GLASS PLATES ARE .318 CM THICK.
CELL SIZE (CM) IS 1.200 CM

NO. OF PLATES	RELATIVE TRANSMITTANCE	= TRANS./H2OTRANS.
2	.83809	= .32939/ .39302
3	.76589	= .30101/ .39302
4	.70166	= .27577/ .39302
5	.64422	= .25319/ .39302
6	.59260	= .23290/ .39302
7	.54602	= .21460/ .39302
8	.50384	= .19802/ .39302
9	.46551	= .18295/ .39302
10	.43057	= .16922/ .39302
11	.39866	= .15668/ .39302
12	.36943	= .14519/ .39302
13	.34262	= .13466/ .39302
14	.31798	= .12497/ .39302
15	.29530	= .11606/ .39302
16	.27439	= .10784/ .39302
17	.25510	= .10026/ .39302
18	.23728	= .09326/ .39302
19	.22080	= .08678/ .39302
20	.20555	= .08079/ .39302
21	.19143	= .07524/ .39302
22	.17835	= .07009/ .39302
23	.16621	= .06532/ .39302
24	.15495	= .06090/ .39302
25	.14450	= .05679/ .39302

NMOUT24

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OUTPUT FROM PROGRAM LAYED2

COMPONENTS OF POLARIZATION AVERAGED

THE HORIZONTAL GLASS PLATES ARE .318 CM THICK.

CELL SIZE (CM) IS 1.200 CM

NO. OF PLATES	RELATIVE TRANSMITTANCE	= TRANS./H2O TRANS.
2	.79043	= .31066/ .39302
3	.68428	= .26894/ .39302
4	.59578	= .23415/ .39302
5	.52105	= .20478/ .39302
6	.45731	= .17973/ .39302
7	.40251	= .15819/ .39302
8	.35508	= .13955/ .39302
9	.31382	= .12334/ .39302
10	.27779	= .10918/ .39302
11	.24622	= .09677/ .39302
12	.21849	= .08587/ .39302
13	.19407	= .07627/ .39302
14	.17254	= .06781/ .39302
15	.15352	= .06034/ .39302
16	.13669	= .05372/ .39302
17	.12180	= .04787/ .39302
18	.10859	= .04268/ .39302
19	.09688	= .03807/ .39302
20	.08647	= .03399/ .39302
21	.07723	= .03035/ .39302
22	.06901	= .02712/ .39302
23	.06169	= .02425/ .39302
24	.05517	= .02168/ .39302
25	.04937	= .01940/ .39302

NMOUT25
OUTPUT FROM PROGRAM LAYED2

COMPONENTS OF POLARIZATION AVERAGED
THE HORIZONTAL GLASS PLATES ARE 0.000 CM THICK.
CELL SIZE (CM) IS 1.200 CM

NO. OF PLATES	RELATIVE TRANSMITTANCE	= TRANS./H2O TRANS.
2	.97030	= .38135/ .39302
3	.95130	= .37388/ .39302
4	.93292	= .36666/ .39302
5	.91512	= .35966/ .39302
6	.89788	= .35289/ .39302
7	.88116	= .34631/ .39302
8	.86493	= .33994/ .39302
9	.84918	= .33374/ .39302
10	.83387	= .32773/ .39302
11	.81900	= .32188/ .39302
12	.80453	= .31620/ .39302
13	.79046	= .31067/ .39302
14	.77676	= .30528/ .39302
15	.76341	= .30004/ .39302
16	.75041	= .29493/ .39302
17	.73774	= .28995/ .39302
18	.72539	= .28509/ .39302
19	.71334	= .28036/ .39302
20	.70159	= .27574/ .39302
21	.69011	= .27123/ .39302
22	.67891	= .26682/ .39302
23	.66797	= .26252/ .39302
24	.65728	= .25832/ .39302
25	.64683	= .25422/ .39302

NMOUT26
OUTPUT FROM PROGRAM LAYED2

COMPONENTS OF POLARIZATION AVERAGED
THE HORIZONTAL GLASS PLATES ARE .318 CM THICK.
CELL SIZE (CM) IS 1.200 CM

NO. OF PLATES	RELATIVE TRANSMITTANCE	= TRANS./H2O TRANS.
2	.83989	= .33010/ .39302
3	.76914	= .30229/ .39302
4	.70606	= .27749/ .39302
5	.64953	= .25528/ .39302
6	.59863	= .23527/ .39302
7	.55261	= .21719/ .39302
8	.51085	= .20077/ .39302
9	.47283	= .18583/ .39302
10	.43812	= .17219/ .39302
11	.40635	= .15970/ .39302
12	.37720	= .14825/ .39302
13	.35041	= .13772/ .39302
14	.32575	= .12803/ .39302
15	.30301	= .11909/ .39302
16	.28201	= .11084/ .39302
17	.26260	= .10321/ .39302
18	.24464	= .09615/ .39302
19	.22801	= .08961/ .39302
20	.21259	= .08355/ .39302
21	.19828	= .07793/ .39302
22	.18501	= .07271/ .39302
23	.17267	= .06786/ .39302
24	.16121	= .06336/ .39302
25	.15056	= .05917/ .39302

NMOUT27
OUTPUT FROM PROGRAM LAYED2

COMPONENTS OF POLARIZATION AVERAGED
THE HORIZONTAL GLASS PLATES ARE .318 CM THICK.
CELL SIZE (CM) IS 1.200 CM

NO. OF PLATES	RELATIVE TRANSMITTANCE	= TRANS./H2OTRANS.
2	.81503	= .32032/ .39302
3	.72580	= .28526/ .39302
4	.64897	= .25506/ .39302
5	.58220	= .22882/ .39302
6	.52375	= .20584/ .39302
7	.47224	= .18560/ .39302
8	.42661	= .16766/ .39302
9	.38600	= .15171/ .39302
10	.34973	= .13745/ .39302
11	.31724	= .12468/ .39302
12	.28806	= .11321/ .39302
13	.26179	= .10289/ .39302
14	.23810	= .09358/ .39302
15	.21671	= .08517/ .39302
16	.19736	= .07757/ .39302
17	.17985	= .07068/ .39302
18	.16397	= .06444/ .39302
19	.14957	= .05878/ .39302
20	.13650	= .05365/ .39302
21	.12462	= .04898/ .39302
22	.11383	= .04474/ .39302
23	.10401	= .04088/ .39302
24	.09507	= .03736/ .39302
25	.08693	= .03416/ .39302

NMOUT28
OUTPUT FROM PROGRAM LAYED2

COMPONENTS OF POLARIZATION AVERAGED
THE HORIZONTAL GLASS PLATES ARE 0.000 CM THICK.
CELL SIZE (CM) IS 1.200 CM

NO. OF PLATES	RELATIVE TRANSMITTANCE	= TRANS./H2OTRANS.
2	.97153	= .38183/ .39302
3	.95367	= .37481/ .39302
4	.93635	= .36800/ .39302
5	.91953	= .36139/ .39302
6	.90320	= .35497/ .39302
7	.88732	= .34874/ .39302
8	.87189	= .34267/ .39302
9	.85687	= .33677/ .39302
10	.84226	= .33102/ .39302
11	.82802	= .32543/ .39302
12	.81416	= .31998/ .39302
13	.80064	= .31467/ .39302
14	.78746	= .30949/ .39302
15	.77461	= .30444/ .39302
16	.76207	= .29951/ .39302
17	.74983	= .29470/ .39302
18	.73788	= .29000/ .39302
19	.72620	= .28541/ .39302
20	.71480	= .28093/ .39302
21	.70365	= .27655/ .39302
22	.69275	= .27227/ .39302
23	.68210	= .26808/ .39302
24	.67167	= .26398/ .39302
25	.66148	= .25997/ .39302

NMOUT29
OUTPUT FROM PROGRAM LAYED2

COMPONENTS OF POLARIZATION AVERAGED
THE HORIZONTAL GLASS PLATES ARE .318 CM THICK.
CELL SIZE (CM) IS 1.200 CM

NO. OF PLATES	RELATIVE TRANSMITTANCE	= TRANS./H2OTRANS.
2	.84097	= .33052/ .39302
3	.77108	= .30305/ .39302
4	.70870	= .27853/ .39302
5	.65273	= .25654/ .39302
6	.60228	= .23671/ .39302
7	.55661	= .21876/ .39302
8	.51513	= .20246/ .39302
9	.47732	= .18760/ .39302
10	.44276	= .17401/ .39302
11	.41109	= .16157/ .39302
12	.38200	= .15014/ .39302
13	.35524	= .13962/ .39302
14	.33058	= .12992/ .39302
15	.30781	= .12098/ .39302
16	.28677	= .11271/ .39302
17	.26730	= .10505/ .39302
18	.24926	= .09796/ .39302
19	.23254	= .09139/ .39302
20	.21702	= .08529/ .39302
21	.20261	= .07963/ .39302
22	.18922	= .07437/ .39302
23	.17677	= .06947/ .39302
24	.16519	= .06492/ .39302
25	.15441	= .06069/ .39302

NMOUT30
OUTPUT FROM PROGRAM LAYED2

COMPONENTS OF POLARIZATION AVERAGED
THE HORIZONTAL GLASS PLATES ARE .318 CM THICK.
CELL SIZE (CM) IS 1.200 CM

NO. OF PLATES	RELATIVE TRANSMITTANCE	= TRANS./H2O TRANS.
2	.83008	= .32624/ .39302
3	.75188	= .29551/ .39302
4	.68314	= .26849/ .39302
5	.62230	= .24458/ .39302
6	.56813	= .22329/ .39302
7	.51966	= .20424/ .39302
8	.47610	= .18712/ .39302
9	.43679	= .17167/ .39302
10	.40121	= .15768/ .39302
11	.36891	= .14499/ .39302
12	.33953	= .13344/ .39302
13	.31273	= .12291/ .39302
14	.28825	= .11329/ .39302
15	.26586	= .10449/ .39302
16	.24535	= .09643/ .39302
17	.22654	= .08904/ .39302
18	.20927	= .08225/ .39302
19	.19341	= .07601/ .39302
20	.17882	= .07028/ .39302
21	.16539	= .06500/ .39302
22	.15303	= .06014/ .39302
23	.14164	= .05567/ .39302
24	.13114	= .05154/ .39302
25	.12145	= .04773/ .39302

NMOUT34
OUTPUT FROM PROGRAM LAYED2

COMPONENTS OF POLARIZATION AVERAGED
THE HORIZONTAL GLASS PLATES ARE .318 CM THICK.
CELL SIZE (CM) IS 1.200 CM

NO. OF PLATES	RELATIVE TRANSMITTANCE	= TRANS./H2OTRANS.
2	.84173	= .33082/ .39302
3	.77246	= .30359/ .39302
4	.71057	= .27927/ .39302
5	.65501	= .25743/ .39302
6	.60488	= .23773/ .39302
7	.55947	= .21988/ .39302
8	.51818	= .20366/ .39302
9	.48052	= .18885/ .39302
10	.44607	= .17532/ .39302
11	.41448	= .16290/ .39302
12	.38545	= .15149/ .39302
13	.35871	= .14098/ .39302
14	.33405	= .13129/ .39302
15	.31127	= .12233/ .39302
16	.29020	= .11405/ .39302
17	.27068	= .10638/ .39302
18	.25259	= .09927/ .39302
19	.23581	= .09268/ .39302
20	.22023	= .08655/ .39302
21	.20574	= .08086/ .39302
22	.19228	= .07557/ .39302
23	.17975	= .07064/ .39302
24	.16808	= .06606/ .39302
25	.15722	= .06179/ .39302

NMOUT35
OUTPUT FROM PROGRAM LAYED2

COMPONENTS OF POLARIZATION AVERAGED
THE HORIZONTAL GLASS PLATES ARE .318 CM THICK.
CELL SIZE (CM) IS 1.200 CM

NO. OF PLATES	RELATIVE TRANSMITTANCE	= TRANS./H2OTRANS.
2	.84279	= .33123/ .39302
3	.77441	= .30436/ .39302
4	.71327	= .28033/ .39302
5	.65833	= .25874/ .39302
6	.60873	= .23924/ .39302
7	.56375	= .22157/ .39302
8	.52282	= .20548/ .39302
9	.48545	= .19079/ .39302
10	.45123	= .17734/ .39302
11	.41982	= .16500/ .39302
12	.39092	= .15364/ .39302
13	.36428	= .14317/ .39302
14	.33968	= .13350/ .39302
15	.31693	= .12456/ .39302
16	.29587	= .11628/ .39302
17	.27634	= .10861/ .39302
18	.25821	= .10148/ .39302
19	.24137	= .09486/ .39302
20	.22572	= .08871/ .39302
21	.21115	= .08299/ .39302
22	.19760	= .07766/ .39302
23	.18496	= .07269/ .39302
24	.17319	= .06807/ .39302
25	.16221	= .06375/ .39302

NMOUT36
 OUTPUT FROM PROGRAM LAYED2

COMPONENTS OF POLARIZATION AVERAGED
 THE HORIZONTAL GLASS PLATES ARE .318 CM THICK.
 CELL SIZE (CM) IS 1.200 CM

NO. OF PLATES	RELATIVE TRANSMITTANCE = TRANS./H2OTRANS.
2	.84344 = .33149/ .39302
3	.77560 = .30483/ .39302
4	.71492 = .28098/ .39302
5	.66037 = .25954/ .39302
6	.61109 = .24017/ .39302
7	.56638 = .22260/ .39302
8	.52568 = .20660/ .39302
9	.48849 = .19199/ .39302
10	.45442 = .17860/ .39302
11	.42312 = .16630/ .39302
12	.39431 = .15497/ .39302
13	.36773 = .14453/ .39302
14	.34318 = .13488/ .39302
15	.32045 = .12594/ .39302
16	.29939 = .11767/ .39302
17	.27986 = .10999/ .39302
18	.26171 = .10286/ .39302
19	.24484 = .09623/ .39302
20	.22915 = .09006/ .39302
21	.21454 = .08432/ .39302
22	.20093 = .07897/ .39302
23	.18824 = .07398/ .39302
24	.17640 = .06933/ .39302
25	.16535 = .06499/ .39302


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      SUBROUTINE REFTRAN(RF,N,T,III,IPZ,CL)
C   REFT32
C   REFTRAN INITIALIZES THE REFLECTANCES AND TRANSMITTANCES OF THE
C   SURFACES OF THE GLASS/WATER LATTICE FOR PROGRAM LAYER.
C
      DIMENSION RF(100),T(100)
      REAL KG(5),RWG(2)
      IF(III.GT.1)GOTO 299
C
C   COMMENTS TO IDENTIFY TYPE OF LATTICE FOR PRINTED OUTPUT
      WRITE(7,201)
      WRITE(7,202)
      WRITE(7,203)
201  FORMAT("ABSORPTION IN ALL PLATES - CELL SIZE=3.81 X 7.62 CM")
202  FORMAT("VERTICAL PLATES:  DXG=0.469 CM")
203  FORMAT("HORIZONTAL PLATES:  DGH=0.469 CM AND RHO=RWG")
C   SET PARAMETERS
C   DXG -- THICKNESS OF VERTICAL GLASS PLATES
C   KG -- EXTINCTION COEFFICIENT OF GLASS
C   CL -- CELL SIZE (HEIGHT OF VERTICAL PLATES)
C   RWG -- REFLECTANCE OF WATER/GLASS INTERFACE
C           RWG(1)=PARALLEL COMPONENT OF POLARIZATION
C           RWG(2)=PERPENDICULAR COMPONENT OF POLARIZATION
C
      DATA KG/0.688,0.124,0.180,0.307,0.412/
299  DXG=0.469
      CL=3.81
      DATA RWG/0.0021,0.0090/
      IF((III.EQ.1).AND.(IPZ.EQ.1))WRITE(2,*)CL
      DO 10 I=1,N
      I41=4*(I-1)
      RF(I41+1)=RWG(IPZ)
      RF(I41+3)=RWG(IPZ)
C   *** 1.1393 IS THE EFFECTIVE INCREASE IN PATH LENGTH FOR
C   *** GLASS PLATES TRANSMITTING DIFFUSE RADIATION (IN WATER).
      TAU=EXP(-KG(III)*DXG*1.1393)
      RR=RWG(IPZ)+(1.-RWG(IPZ))*2*TAU*TAU*RWG(IPZ)/(1.-(RWG(IPZ)*TAU)
&***2)
      TT=(1.-RWG(IPZ))*2*TAU/(1.-(RWG(IPZ)*TAU)*2)
      RF(I41+2)=RR
      RF(I41+4)=RR
      T(I41+2)=TT
      T(I41+4)=TT
      NTEST=I/2.
      NTEST=NTEST*2
      IF(NTEST.EQ.I)RF(I41+4)=0.
      IF(NTEST.EQ.I)T(I41+4)=1.
      IF(NTEST.NE.I)RF(I41+2)=0.
      IF(NTEST.NE.I)T(I41+2)=1.
10  CONTINUE
      RETURN
      END

```

LYOUT32

21 CELLS PER LAYER

PARALLEL COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :

ABSORPTION IN ALL PLATES - CELL SIZE=3.81 X 7.62 CM

VERTICAL PLATES: DXG=0.469 CM

HORIZONTAL PLATES: DGH=0.469 CM AND RHO=RWG

LAYER TRANSMITTANCE= .85931 LAYER REFLECTANCE= .00424

FOR SPECTRAL BAND NUMBER 2 :

LAYER TRANSMITTANCE= .95984 LAYER REFLECTANCE= .00489

FOR SPECTRAL BAND NUMBER 3 :

LAYER TRANSMITTANCE= .92083 LAYER REFLECTANCE= .00466

FOR SPECTRAL BAND NUMBER 4 :

LAYER TRANSMITTANCE= .75691 LAYER REFLECTANCE= .00383

FOR SPECTRAL BAND NUMBER 5 :

LAYER TRANSMITTANCE= .11080 LAYER REFLECTANCE= .00217

PERPEND. COMPONENT OF POLARIZATION

FOR SPECTRAL BAND NUMBER 1 :

LAYER TRANSMITTANCE= .84576 LAYER REFLECTANCE= .01801

FOR SPECTRAL BAND NUMBER 2 :

LAYER TRANSMITTANCE= .94400 LAYER REFLECTANCE= .02073

FOR SPECTRAL BAND NUMBER 3 :

LAYER TRANSMITTANCE= .90573 LAYER REFLECTANCE= .01975

FOR SPECTRAL BAND NUMBER 4 :

LAYER TRANSMITTANCE= .74473 LAYER REFLECTANCE= .01628

FOR SPECTRAL BAND NUMBER 5 :

LAYER TRANSMITTANCE= .10914 LAYER REFLECTANCE= .00930

```

PROGRAM LAYED9(LAYIN,LPIN,NMOUT,INPUT,OUTPUT,TAPE5=INPUT,
&TAPE7=NMOUT,TAPE6=OUTPUT,TAPE8=LAYIN,TAPE9=LPIN)

```

```

C
C THIS PROGRAM DETERMINES THE TRANSMITTANCE OF A COMPOSITE LAYER
C OF GLASS PLATES AND WATER LAYERS CONTAINING VERTICAL GLASS
C PLATES, EFFECTIVELY FORMING A GLASS LATTICE IN WATER. THE
C TRANSMITTANCE AND REFLECTANCE OF THE WATER/GLASS LAYER ARE
C READ FROM 'LAYIN' AND THE COMPOSITE LAYER IS BUILT BY
C SUCCESSIVELY ADDING A GLASS PLATE AND A WATER/GLASS LAYER.
C A BOTTLE LAYER IS BUILT BY ADDING ANOTHER GLASS LAYER. THEN
C THE BOTTLE LAYERS ARE BUILT UP WITH A VERY THIN (I.E. T=1.0)
C WATER LAYER IN BETWEEN.

```

```

C THIS PROGRAM REQUIRES THE THICKNESS OF THE HORIZONTAL GLASS
C PLATES TO BE INPUT.

```

```

C THE REFLECTANCES USED ARE INTEGRATED VALUES FOR DIFFUSE
C RADIATION AS DETERMINED BY PROGRAM 'THETA2'.

```

```

C MICHAEL J. WITTE / DECEMBER 1982 / JANUARY 1983 / FEBRUARY 1983
C

```

```

      REAL NA,NW,NG,KW(5),KG(5),FQ(5),TR(24),TCUBE(5),
      &TTR(24),TRF(24),RCUBE(5),RWG(2),RAW(2)
      DIMENSION COMMENT(7)
      READ(8,*)CL
      WRITE(6,100)
100 FORMAT(/"THICKNESS OF GLASS PLATES? (CM)")
      READ(5,*)GHL
      DATA FQ/0.040,0.197,0.193,0.167,0.179/
      DATA KG/0.688,0.124,0.180,0.307,0.412/
      DATA KW/0.00032,0.00032,0.0045,0.03,0.35/
      DATA RWG/0.0021,0.0090/
      DATA RAW/0.0308,0.1019/

```

```

C
C *****
C ***                                     ***
C ***          CALCULATE LAYER TRANSMITTANCE          ***
C ***                                     ***
C *****

```

```

C
C      DO 4 M=1,24
C        TR(M)=0.
C      4 CONTINUE
C        TRW=0.
C        DO 121 NPZ=1,2

```

```

C
C      NPZ=1 FOR PARALLEL      COMPONENT OF POLARIZATION
C      NPZ=2  "  PERPENDICULAR  "      "      "

```

```

C
C      DO 200 I=1,5
C        READ(8,*)TCUBE(I),RCUBE(I)
200 CONTINUE

```

```

C
C INITIAL GLASS LAYER AND CUBE LAYER ASSUMING LAYER OF WATER ON TOP
C
  TTRW=0.
  DO 120 I=1,5
    TTRW=TTRW+EXP(-43.18*KW(I)*1.2038)*FQ(I)
    TGH=EXP(-KG(I)*GHL*1.1393)
    TCB=TCUBE(I)
    RCB=RCUBE(I)
    CALL LAYER(RWG(NPZ),RWG(NPZ),(1.-RWG(NPZ)),RCB,TCB,TGH,
&RL1,RL2,TL)
C
C ADDING BOTTOM LAYER OF GLASS
C
  CALL LAYER(RL1,RL2,TL,RWG(NPZ),(1.-RWG(NPZ)),TGH,RB1,RB2,TB)
C
C RB1,RB2,TB NOW REPRESENT THE PROPERTIES OF A LAYER OF BOTTLES
C
  TTR(1)=TB
  TRF(1)=RB1
  RL1=RB1
  RL2=RB2
  TL=TB
  DO 20 J=2,12
C
C ADDING BOTTLE LAYER WITH VERY THIN WATER LAYER (T=1.0) BETWEEN
C
  CALL LAYER(RL1,RL2,TL,RB1,TB,1.0,RC1,RC2,TC)
  TTR(J)=TC
  TRF(J)=RC1
  RL1=RC1
  RL2=RC2
  TL=TC
20 CONTINUE
C
C ADDING WATER TO MAKE 43.18 CM (17IN.) TOTAL THICKNESS
C
  DO 150 J=1,12
    TEST=J*(CL+GHL)+GHL-43.18
    IF(TEST.LE.0.)GOTO 25
    IF(NPZ.NE.1)GOTO 25
    IF(I.NE.1)GOTO 25
    WRITE(6,110)
110 FORMAT("LAYER THICKNESS HAS EXCEEDED 17 IN.!!")
    25 TW=EXP((J*(CL+GHL)+GHL-43.18)*KW(I)*1.2038)
    RL=TRF(J)
    TL=TTR(J)
    CALL LAYER(RAW(NPZ),RAW(NPZ),(1.-RAW(NPZ)),RL,TL,TW,RF1,RF2,TF)
    TR(J)=TR(J)+TF*FQ(I)
150 CONTINUE
120 CONTINUE
    CALL LAYER(RAW(NPZ),RAW(NPZ),(1.-RAW(NPZ)),0.,1.,TTRW,RC1,RC2,TC)

```

```

      TRW=TRW+TC
121 CONTINUE
C
C   OUTPUT
C
C   OUTPUT
C
      WRITE(7,123)
123 FORMAT("OUTPUT FROM PROGRAM LAYED2"/)
      WRITE(7,124)
      WRITE(7,122)GHL
      WRITE(7,126)CL
122 FORMAT("THE HORIZONTAL GLASS PLATES ARE ",F6.3," CM THICK.")
124 FORMAT("//COMPONENTS OF POLARIZATION AVERAGED")
126 FORMAT("CELL SIZE (CM) IS ",F6.3," CM")
      WRITE(7,125)
      WRITE(7,130)
125 FORMAT("//18X,"RELATIVE")
130 FORMAT("NO. OF PLATES   TRANSMITTANCE = TRANS./H2OTRANS.")
140 FORMAT(5X,I2,12X,F7.5,4X,"=",F7.5,"/",F7.5)
      DO 30 M=1,12
      WRITE(7,140)M*2,TR(M)/TRW,TR(M)/2.,TRW/2.
      WRITE(9,*)TR(M)/2.
30 CONTINUE
      STOP
      END
      SUBROUTINE LAYER(RA1,RA2,TA,RB,TB,TAUL,RC1,RC2,TC)
C
C   LAYER SUBROUTINE
C
C   THIS SUBROUTINE CALCULATES THE TRANSMITTANCE (TC),
C   UPPER REFLECTANCE (RC1), AND LOWER REFLECTANCE (RC2)
C   OF A SLAB GIVEN:
C
C       UPPER REFLECTANCE OF SURFACE A           (RA1)
C       LOWER REFLECTANCE OF SURFACE A           (RA2)
C       TRANSMITTANCE OF SURFACE A               (TA)
C       UPPER REFLECTANCE OF SURFACE B           (RB)
C       TRANSMITTANCE OF SURFACE B               (TB)
C       SLAB TRANSMITTANCE BETWEEN SURFACES      (TAUL)
C
C   THE EQUATIONS ARE BASED ON SIEGEL'S NET RADIATION
C   METHOD.
C
      RK=(1.-RA2*RB*TAUL**2)
      TC=TB*TA*TAUL/RK
      RC1=RA1+(TA*TAUL)**2*RB/RK
      RC2=RB+(TB*TAUL)**2*RA2/RK
      RETURN
      END

```

NMOUT32

OUTPUT FROM PROGRAM LAYED9

COMPONENTS OF POLARIZATION AVERAGED

THE HORIZONTAL GLASS PLATES ARE .234 CM THICK.

CELL SIZE (CM) IS 3.810 CM

NO. OF PLATES	RELATIVE TRANSMITTANCE = TRANS./H2OTRANS.
2	.82883 = .32575/ .39302
4	.69420 = .27284/ .39302
6	.58672 = .23059/ .39302
8	.49935 = .19625/ .39302
10	.42729 = .16794/ .39302
12	.36719 = .14431/ .39302
14	.31660 = .12443/ .39302
16	.27372 = .10758/ .39302
18	.23719 = .09322/ .39302
20	.20592 = .08093/ .39302
22	.17906 = .07037/ .39302
24	.15593 = .06128/ .39302

```

PROGRAM LAYED6(LPIN,NMOUT,INPUT,OUTPUT,TAPE5=INPUT,
&TAPE7=NMOUT,TAPE6=OUTPUT,TAPE9=LPIN)

```

```

C THIS PROGRAM DETERMINES THE TRANSMITTANCE OF A COMPOSITE LAYER
C OF GLASS PLATES AND WATER LAYERS. THE COMPOSITE LAYER IS
C BUILT BY SUCCESSIVELY ADDING A GLASS PLATE AND A WATER LAYER.

```

```

C THIS PROGRAM REQUIRES THE THICKNESS OF THE HORIZONTAL GLASS
C PLATES TO BE INPUT.

```

```

C THE REFLECTANCES USED ARE INTEGRATED VALUES FOR DIFFUSE
C RADIATION AS DETERMINED BY PROGRAMS 'THETA2' AND 'THETA3'.

```

```

C MICHAEL J. WITTE / DECEMBER 1982 / JANUARY 1983 / FEBRUARY 1983

```

```

C REAL NA,NW,NG,KW(5),KG(5),FQ(5),TR(24),TCUBE(5),
C &TTR(24),TRF(24),RCUBE(5),RWG(2),RAW(2)
C DIMENSION COMMENT(7)
C CL=1.2
C WRITE(6,100)

```

```

100 FORMAT("/THICKNESS OF GLASS PLATES? (CM)")

```

```

C READ(5,*)GHL
C DATA FQ/0.040,0.197,0.193,0.167,0.179/
C DATA KG/0.688,0.124,0.180,0.307,0.412/
C DATA KW/0.00032,0.00032,0.0045,0.03,0.35/
C DATA RWG/0.0021,0.0090/
C DATA RAW/0.0308,0.1019/

```

```

C *****
C ***
C ***          CALCULATE LAYER TRANSMITTANCE          ***
C ***
C *****

```

```

C DO 4 M=1,24
C TR(M)=0.
C 4 CONTINUE
C TRW=0.
C DO 121 NPZ=1,2

```

```

C NPZ=1 FOR PARALLEL      COMPONENT OF POLARIZATION
C NPZ=2 " PERPENDICULAR  " " "

```

```

C INITIAL GLASS LAYER AND WATER LAYER ASSUMING LAYER OF WATER ON TOP

```

```

C TTRW=0.

```

```

C DO 120 I=1,5

```

```

C *** DETERMINE PROPERTIES OF WATER LAYER ***

```

```

C TAUW=EXP(-KW(I)*CL*1.2038)
C CALL LAYER(RWG(NPZ),RWG(NPZ),(1.-RWG(NPZ)),RWG(NPZ),(1.-RWG(NPZ)),
C &TAUW,RCB,RCB2,TCB)

```

```

TTRW=TTRW+EXP(-43.18*KW(I)*1.2038)*FQ(I)
TGH=EXP(-KG(I)*GHL*1.1393)
CALL LAYER(RWG(NPZ),RWG(NPZ),(1.-RWG(NPZ)),RCB,TCB,TGH,
&RL1,RL2,TL)
DO 20 J=1,24
C
C   ADDING BOTTOM LAYER OF GLASS
C
CALL LAYER(RL1,RL2,TL,RWG(NPZ),(1.-RWG(NPZ)),TGH,RC1,RC2,TC)
TTR(J)=TC
TRF(J)=RC1
C
C   ADDING GLASS LAYER AND WATER LAYER
C
CALL LAYER(RL1,RL2,TL,RCB,TCB,TGH,RC1,RC2,TC)
RL1=RC1
RL2=RC2
TL=TC
20 CONTINUE
C
C   ADDING WATER TO MAKE 43.18 CM (17IN.) TOTAL THICKNESS
C
DO 150 J=1,24
TEST=J*(CL+GHL)+GHL-43.18
IF(TEST.LE.0.)GOTO 25
WRITE(6,110)
110 FORMAT("LAYER THICKNESS HAS EXCEEDED 17 IN.!!")
STOP
25 TW=EXP((J*(CL+GHL)+GHL-43.18)*KW(I)*1.2038)
RL=TRF(J)
TL=TTR(J)
CALL LAYER(RAW(NPZ),RAW(NPZ),(1.-RAW(NPZ)),RL,TL,TW,RF1,RF2,TF)
TR(J)=TR(J)+TF*FQ(I)
150 CONTINUE
120 CONTINUE
CALL LAYER(RAW(NPZ),RAW(NPZ),(1.-RAW(NPZ)),0.,1.,TTRW,RC1,RC2,TC)
TRW=TRW+TC
121 CONTINUE
WRITE(7,123)
123 FORMAT("OUTPUT FROM PROGRAM LAYED6 : PARALLEL PLATES ***"/)
WRITE(7,124)
WRITE(7,122)GHL
WRITE(7,126)CL
122 FORMAT("THE HORIZONTAL GLASS PLATES ARE ",F6.3," CM THICK.")
124 FORMAT("//COMPONENTS OF POLARIZATION AVERAGED")
126 FORMAT("CELL SIZE (CM) IS ",F6.3," CM")
WRITE(7,125)
WRITE(7,130)
125 FORMAT("//18X,"RELATIVE")
130 FORMAT("NO. OF PLATES   TRANSMITTANCE = TRANS./H2OTRANS.")
140 FORMAT(5X,I2,12X,F7.5,4X,"=",F7.5,"/",F7.5)
DO 30 M=1,24

```



```
WRITE(7,140)M+1,TR(M)/TRW,TR(M)/2.,TRW/2.  
WRITE(9,*)TR(M)/2.  
30 CONTINUE  
STOP  
END  
SUBROUTINE LAYER(RA1,RA2,TA,RB,TB,TAUL,RC1,RC2,TC)  
C  
C LAYER SUBROUTINE  
C  
RK=(1.-RA2*RB*TAUL**2)  
TC=TB*TA*TAUL/RK  
RC1=RA1+(TA*TAUL)**2*RB/RK  
RC2=RB+(TB*TAUL)**2*RA2/RK  
RETURN  
END
```

NMOUTPP

OUTPUT FROM PROGRAM LAYED6 : PARALLEL PLATES ***

COMPONENTS OF POLARIZATION AVERAGED
 THE HORIZONTAL GLASS PLATES ARE .318 CM THICK.
 CELL SIZE (CM) IS 1.200 CM

NO. OF PLATES	RELATIVE TRANSMITTANCE	=	TRANS./H2OTRANS.
2	.84840	=	.33344/ .39302
3	.78464	=	.30838/ .39302
4	.72730	=	.28585/ .39302
5	.67546	=	.26547/ .39302
6	.62834	=	.24695/ .39302
7	.58535	=	.23006/ .39302
8	.54597	=	.21458/ .39302
9	.50979	=	.20036/ .39302
10	.47644	=	.18725/ .39302
11	.44563	=	.17514/ .39302
12	.41711	=	.16393/ .39302
13	.39066	=	.15354/ .39302
14	.36608	=	.14388/ .39302
15	.34322	=	.13489/ .39302
16	.32193	=	.12652/ .39302
17	.30208	=	.11872/ .39302
18	.28355	=	.11144/ .39302
19	.26625	=	.10464/ .39302
20	.25008	=	.09829/ .39302
21	.23496	=	.09234/ .39302
22	.22081	=	.08678/ .39302
23	.20757	=	.08158/ .39302
24	.19516	=	.07670/ .39302
25	.18354	=	.07214/ .39302

```

      PROGRAM THETA2(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,
&THOUT,TAPE7=THOUT)

```

```

C
C  THIS PROGRAM DETERMINES AN EFFECTIVE
C  REFLECTANCE FOR EACH COMPONENT OF POLARIZATION AT A SINGLE
C  INTERFACE.  (INTEGRATION BY TRAPEZOIDAL RULE)
C
C  PD... REFERS TO THE PERPENDICULAR COMPONENT OF POLARIZATION
C  PL... REFERS TO THE PARALLEL COMPONENT OF POLARIZATION
C

```

```

      REAL N1,N2
      COMMON N1,N2
      WRITE(6,100)
      READ(5,*)N1,N2
100  FORMAT(// "PLEASE INPUT INDICES OF REFRACTION(N1,N2)"//)
      PDSUM=0.  $  PLSUM=0.  $  SECTH=0.
      PI=3.14159
      N=100
      DTHETA=PI/N/2.
      TH1=0.
      NP1=N+1
      DO 10 I=1,NP1
      RK=SIN(TH1)*COS(TH1)*2.*DTHETA
      IF((I.EQ.1).OR.(I.EQ.NP1))RK=RK/2.
      TH2=ASIN(SIN(TH1)*N1/N2)
      PDSUM=PDSUM+PDREFL(TH1,TH2)*RK
      PLSUM=PLSUM+PLREFL(TH1,TH2)*RK
      SECTH=SECTH+RK/COS(TH2)
      TH1=TH1+DTHETA
10  CONTINUE
      WRITE(7,110)
110  FORMAT(// "OUTPUT FROM PROGRAM THETA2")
      WRITE(7,120)N1,N2
120  FORMAT(// "INDICES OF REFRACTION ARE ",F5.3," AND ",F5.3/)
      WRITE(7,130)PDSUM,PLSUM
130  FORMAT("THE INTEGRATED REFLECTANCES ARE:  PERPENDICULAR=",
&F6.4,4X,"PARALLEL=",F6.4//)
      WRITE(7,135)SECTH
135  FORMAT("THE EFFECTIVE 1/COS(THETA) IN MATERIAL 2 IS",F7.4/)
      WRITE(7,140)
140  FORMAT(// "THE FOLLOWING IS A TABLE OF REFLECTANCES FOR THETA",
&" FROM 30 TO 90 DEGREES"//)
      WRITE(7,150)
150  FORMAT("THETA",5X,"PERPENDICULAR",5X,"PARALLEL"//)
      NTHETA=25
      DO 20 I=1,13
      NTHETA=NTHETA+5
      TH1=NTHETA*PI/180.
      TH2=ASIN(SIN(TH1)*N1/N2)
      PD=PDREFL(TH1,TH2)
      PL=PLREFL(TH1,TH2)
      WRITE(7,160)NTHETA,PD,PL

```

```
160 FORMAT(/2X,I2,10X,F6.4,9X,F6.4)
20 CONTINUE
  STOP
  END
  FUNCTION PDREFL(T1,T2)
C
C  REFLECTANCE FUNCTION
C
  COMMON N1,N2
  IF(T1.NE.0.)GOTO 5
  PDREFL=((N1-N2)/(N1+N2))**2
  RETURN
5 PDREFL=SIN(T2-T1)**2/SIN(T2+T1)**2
  RETURN
  END
  FUNCTION PLREFL(T1,T2)
  COMMON N1,N2
  IF(T1.NE.0.)GOTO 5
  PLREFL=((N1-N2)/(N1+N2))**2
  RETURN
5 PLREFL=TAN(T2-T1)**2/TAN(T2+T1)**2
  RETURN
  END
```

OUTPUT FROM PROGRAM THETA2

INDICES OF REFRACTION ARE 1.000 AND 1.333

THE INTEGRATED REFLECTANCES ARE: PERPENDICULAR= .1019 PARALLEL= .0308

THE EFFECTIVE 1/COS(THETA) IN MATERIAL 2 IS 1.2038

```

PROGRAM THETA3(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,
&THOUT,TAPE7=THOUT)

```

```

C
C THIS PROGRAM DETERMINES AN EFFECTIVE
C REFLECTANCE FOR EACH COMPONENT OF POLARIZATION AT A SINGLE
C INTERFACE. (INTEGRATION BY TRAPEZOIDAL RULE)
C THIS PROGRAM ASSUMES DIFFUSE RADIATION INCIDENT AT AN
C INTERFACE BETWEEN MATERIALS 1 AND 2, AND THEN CALCULATES
C THE REFLECTANCE FOR AN INTERFACE BETWEEN MATERIALS 2 AND 3.
C
C PD... REFERS TO THE PERPENDICULAR COMPONENT OF POLARIZATION
C PL... REFERS TO THE PARALLEL COMPONENT OF POLARIZATION
C

```

```

      REAL N1,N2,N3
      COMMON N1,N2,N3
      WRITE(6,100)
      READ(5,*)N1,N2,N3
100  FORMAT(// "PLEASE INPUT INDICES OF REFRACTION(N1,N2,N3)"//)
      PDSUM=0. $ PLSUM=0. $ SECTH=0.
      PI=3.14159
      N=100
      DTHETA=PI/N/2.
      TH1=0.
      NP1=N+1
      DO 10 I=1,NP1
      RK=SIN(TH1)*COS(TH1)*2.*DTHETA
      IF((I.EQ.1).OR.(I.EQ.NP1))RK=RK/2.
      TH2=ASIN(SIN(TH1)*N1/N2)
      TH3=ASIN(SIN(TH2)*N2/N3)
      PDSUM=PDSUM+PDREFL(TH2,TH3)*RK
      PLSUM=PLSUM+PLREFL(TH2,TH3)*RK
      SECTH=SECTH+RK/COS(TH3)
      TH1=TH1+DTHETA
10  CONTINUE
      WRITE(7,110)
110  FORMAT(// "OUTPUT FROM PROGRAM THETA3")
      WRITE(7,120)N1,N2,N3
120  FORMAT(// "INDICES OF REFRACTION ARE ",F5.3," AND ",F5.3,
&" AND ",F5.3/)
      WRITE(7,130)PDSUM,PLSUM
130  FORMAT("THE INTEGRATED REFLECTANCES ARE: PERPENDICULAR=",
&F6.4,4X,"PARALLEL=",F6.4//)
      WRITE(7,135)SECTH
135  FORMAT("THE EFFECTIVE 1/COS(THETA) IN MATERIAL 3 IS",F7.4/)
      WRITE(7,140)
140  FORMAT(// "THE FOLLOWING IS A TABLE OF REFLECTANCES FOR THETA",
&" FROM 30 TO 90 DEGREES"//)
      WRITE(7,150)
150  FORMAT("THETA",5X,"PERPENDICULAR",5X,"PARALLEL"/)
      NTHETA=25
      DO 20 I=1,13
      NTHETA=NTHETA+5

```

```

      TH1=NTHETA*PI/180.
      TH2=ASIN(SIN(TH1)*N1/N2)
      PD=PDREFL(TH1,TH2)
      PL=PLREFL(TH1,TH2)
      WRITE(7,160)NTHETA,PD,PL
160  FORMAT(/2X,I2,10X,F6.4,9X,F6.4)
20  CONTINUE
      STOP
      END
      FUNCTION PDREFL(T1,T2)
C
C  REFLECTANCE FUNCTION
C
      COMMON N1,N2,N3
      IF(T1.NE.0.)GOTO 5
      PDREFL=((N3-N2)/(N3+N2))**2
      RETURN
5  PDREFL=SIN(T2-T1)**2/SIN(T2+T1)**2
      RETURN
      END
      FUNCTION PLREFL(T1,T2)
      COMMON N1,N2,N3
      IF(T1.NE.0.)GOTO 5
      PLREFL=((N3-N2)/(N3+N2))**2
      RETURN
5  PLREFL=TAN(T2-T1)**2/TAN(T2+T1)**2
      RETURN
      END

```

OUTPUT FROM PROGRAM THETA3

INDICES OF REFRACTION ARE 1.000 AND 1.333 AND 1.526

THE INTEGRATED REFLECTANCES ARE: PERPENDICULAR= .0090 PARALLEL= .0021

THE EFFECTIVE $1/\cos(\text{THETA})$ IN MATERIAL 3 IS 1.1393

```

PROGRAM CORR4(CROUT,INPUT,OUTPUT,TAPE2=CROUT,TAPE5=INPUT,
&TAPE6=OUTPUT,CRPIN,TAPE7=CRPIN)

```

```

C
C THIS PROGRAM CALCULATES THE TRANSMITTANCE OF 17IN. OF WATER
C WITH GLASS BY AN APPROXIMATE EQUATION TO AID IN DETERMINING A
C CORRELATION FOR THE DATA. DIFFUSE FRACTION AND ANGLE
C OF INCIDENCE ARE INPUT.
C
  REAL KW(5),KG(5),FQ(5),VOL(11),RINT(11),NR(3),TH(3)
  COMMON/1/TH,NR
  RAWD=0.0664
  AREA=1018.
  DATA FQ/0.040,0.197,0.193,0.167,0.179/
  DATA KG/0.688,0.124,0.180,0.307,0.412/
  DATA KW/0.00032,0.00032,0.0045,0.03,0.35/
  DATA VOL/741.,944.,1146.,1348.,1551.,1879.,2111.,2344.,2576.,
&2808.,3040./
  DATA RINT/5.2,6.6,8.2,9.6,11.,13.4,15.3,17.2,19.,20.9,22.8/
  DATA NR/1.00,1.333,1.526/
  WRITE(6,200)
100 FORMAT("/PLEASE INPUT THETA, DIFFUSE."/)
  READ(5,*)THDG,DIFF
  TH(1)=THDG*3.14159/180.
  DO 40 I=2,3
  TH(I)=ASIN(SIN(TH(I-1))*NR(I-1)/NR(I))
  40 CONTINUE
  RAWB=(REFL(1,2,1)+REFL(1,2,2))/2.
  WRITE(2,100)
  WRITE(2,105)THDG,DIFF
  WRITE(2,110)
100 FORMAT("OUTPUT FROM CORR4")
105 FORMAT("//"THETA=",F4.1,5X,"DIFFUSE=",F4.2//)
110 FORMAT("GLASS VOL. (CU. IN.)",3X,"EFF. GLASS THICKNESS (CM)",
&3X,"TRANSMITTANCE"/)
C *** 1.2038 IS THE COSINE CORRECTION FOR DIFFUSE RADIATION IN WATER
C
C CALCULATE TRANSMITTANCE OF DIFFUSE COMPONENT
C
  DO 20 N=1,11
C *** 2.54 CONVERTS INCHES TO CM
C *** 1.1393 IS THE COSINE CORRECTION FOR DIFFUSE RADIATION IN GLASS
  GL=VOL(N)/AREA*2.54
  TRD=0.
  TRB=0.
  DO 30 I=1,5
  TWD=EXP(-KW(I)*(43.18-GL)*1.2038)
  TWB=EXP(-KW(I)*(43.18-GL)/COS(TH(2)))
  TRD=TRD+TWD*EXP(-KG(I)*GL*1.1393)*FQ(I)
  TRB=TRB+TWB*EXP(-KG(I)*GL/COS(TH(3)))*FQ(I)
  30 CONTINUE
  TR=(TRD*(1.-RAWD)*DIFF+TRB*(1.-RAWB)*(1.-DIFF))
  &*EXP(-RINT(N)*0.009)

```

```

WRITE(2,130)VOL(N),GL,TR
WRITE(7,*)RINT(N),TR
130 FORMAT(7X,F5.0,21X,F6.3,15X,F7.5)
20 CONTINUE
STOP
END
FUNCTION REFL(IA,IB,NPZ)
REAL TH(3),NR(3)
COMMON/1/TH,NR
IF(TH(IA).NE.0.)GOTO 5
REFL=((NR(IA)-NR(IB))/(NR(IA)+NR(IB)))**2
RETURN
5 IF(NPZ.EQ.2)GOTO 10
REFL=TAN(TH(IA)-TH(IB))**2/TAN(TH(IA)+TH(IB))**2
RETURN
10 REFL=SIN(TH(IA)-TH(IB))**2/SIN(TH(IA)+TH(IB))**2
RETURN
END

```

OUTPUT FROM CORR4

THETA=50.0 DIFFUSE= .85

GLASS VOL. (CU. IN.)	EFF. GLASS THICKNESS (CM)	TRANSMITTANCE
741.	1.849	.25386
944.	2.355	.22736
1146.	2.859	.20393
1348.	3.363	.18364
1551.	3.870	.16559
1879.	4.688	.14032
2111.	5.267	.12480
2344.	5.848	.11107
2576.	6.427	.09907
2808.	7.006	.08836
3040.	7.585	.07886

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