AD-767 649

OPTICAL EFFECTS OF PIGMENTATION ON
TEMPERATURE RISE IN A TWO-LAYER SKIN
SIMULANT SYSTEM DURING IRRADIATION

John R. Piergallini, et al

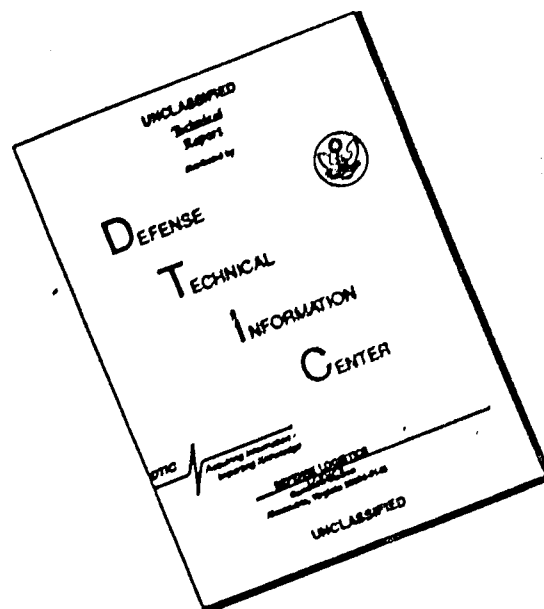Naval Air Development Center
Warminster, Pennsylvania

31 October 1972

DISCLAIMER NOTICE

THIS DOCUMENT IS BEST
QUALITY AVAILABLE. THE COPY
FURNISHED TO DTIC CONTAINED
A SIGNIFICANT NUMBER OF
PAGES WHICH DO NOT
REPRODUCE LEGIBLY.

DOCUMENT CONTROL DATA - R & D

Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Crew Systems Department Naval Air Development Center Warminster, Pa. 18974	Unclassified
	2b. GROUP

3. REPORT TITLE

OPTICAL EFFECTS OF PIGMENTATION ON TEMPERATURE RISE IN A TWO-LAYER SKIN SIMULANT SYSTEM DURING IRRADIATION

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Interim

5. AUTHOR(S) (First name, middle initial, last name)

John R. Piergallini and Alice M. Stoll

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
31 October 1972	43 50	7
8a. CONTRACT OR GRANT NO AirTask R0000-101	9a. ORIGINATOR'S REPORT NUMBER(S) NADC-72225-CS	
b. PROJECT NO Work Unit No. RB-6-01		
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.		

10. DISTRIBUTION STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Air Systems Command Department of the Navy Washington, D. C. 20390

13. ABSTRACT

It is demonstrated that from a knowledge of the thermal and optical properties of each layer of a two-layer system, together with the amplitude and distribution of the energy input, it is possible to predict temperature rises at depth in the second layer of a two-layer system. By varying the optical properties of the first layer and observing the temperature rises at depth in the second layer, the experimental results can be used to verify mathematical expressions for optical and heat transfer processes of the two layers.

Such a system was devised to determine the thermal conductivity between a silicone rubber patch and the living skin irradiated. It may also be used in evaluations of other two-layer systems where reflectance, transmittance and heat transfer properties are known and must be accounted for in the mathematical model.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	HOLE	WT
1. Skin heating model						
2. Optical effects of pigmentation						
3. Two-Layer heating model						
4. "Skin" temp.rise during irradiation						

AD-767649

DEPARTMENT OF THE NAVY
NAVAL AIR DEVELOPMENT CENTER
WARMINSTER, PA. 18974

Crew Systems Department

NADC-72225-CS   31 October 1972

OPTICAL EFFECTS OF PIGMENTATION ON TEMPERATURE
RISE IN A TWO-LAYER SKIN SIMULANT SYSTEM DURING IRRADIATION

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

Prepared by: John R. Piergallini

                                Alice M. Stoll

Reviewed by: Harald J. von Beckh, M. D.
                                Medical Research Director
                                Crew Systems Department

Approved by: J. H. Blackburn, CAPT, MC, USN
                                Director
                                Crew Systems Department

DDC

OCT 11 1973

B

i

SUMMARY

It is demonstrated that from a knowledge of the thermal and optical properties of each layer of a two-layer system, together with the amplitude and distribution of the energy input, it is possible to predict temperature rises at depth in the second layer of a two-layer system. By varying the optical properties of the first layer and observing the temperature rises at depth in the second layer, the experimental results can be used to verify mathematical expressions for optical and heat transfer processes of the two layers.

Such a system was devised to determine the thermal conductivity of intact living skin by measuring the interface temperature between a silicone rubber patch and the living skin when irradiated. It may also be used in evaluations of other two-layer systems where reflectance, transmittance and heat transfer properties are known and must be accounted for in the mathematical model.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENT

INTRODUCTION

Burn effects of exposure to non-ionizing radiation, whether
of low-level or thermonuclear intensity, depend upon the optical
as well as the thermal properties of skin and whatever protective
cover it may have. Pigmentation of the unprotected skin may great-
ly influence the magnitude and depth of penetration of incident
radiation depending upon its wavelength. It is therefore impor-
tant to be able to measure the thermal conductivity of intact
human skin and to be able to predict, from a knowledge of the op-
tical and thermal properties of both the skin and its covering,
the effect of incident radiation of known wavelength and inten-
sity.

We propose to adapt a two-layer heat transfer system to a
system for determining the thermal properties of one layer of
material from a knowledge of the thermal properties of the other
layer when the temperature rise on irradiation and intensity of
the energy are known (1). In this way a patch of suitable material
of known properties may be laid upon the living skin with inter-
face or surface temperature rise being measured during irradiation,
making it possible to calculate the thermal conductivity of living
skin. The validation of the proposed system entails the use of a
series of silicone rubber patches of different optical properties
representing various degrees of pigmentation. The patches are
combined with a skin simulant to form a two-layer system, analogous
to a rubber-covered living skin combination, in which mathematical

1

expressions of heat transfer relationships can be verified ex-
perimentally. This paper describes the heat transfer process
and may be used in general applications involving two-layer
systems as well as in our specific use.

PROCEDURE AND MATERIALS

The two-layer system is irradiated by a graphite imaging
furnace (2) to validate experimentally the temperature rises at
depth in the second layer which are determined mathematically. Com-
puter techniques are used to calculate the optical properties and
energy distribution of the two-layer system. An equation for tran-
sient heat flow through a two-layer wall as proposed by Griffith and
Horton (3) is used to determine temperature rise at depth in the sec-
ond layer as it varies with time.

Each of seven silicone rubber patches designated W(white),
W + 1, W + 2, W + 3, W + 4, W + 5 and Black is used as the first
layer. Silicone rubber was chosen because the thermal properties
are known, it can be prepared in fairly thin sheets, it does not
wrinkle or swell appreciably when irradiated and it forms a tight
contact with the backing material. The thickness of the patches
is 0.0532 cm $\pm$ 0.0008cm. Each patch was pigmented differently
to vary reflectance and transmittance properties. The backing
material is the skin simulant device fabricated by the Naval Mater-
ial Laboratory, N. Y. (4). Optical properties were measured with
the Beckman DK-2A Spectrophotometer. Reflectance and transmittance
were determined for each silicone rubber patch. Transmittance was

2

measured for a slice of the skin simulant 0.047 cm thick,
approximating the depth of the thermocouple beneath the surface,
and reflectance in the full thickness (1cm). Using computer tech-
niques the absorptance is calculated at each wavelength for each layer:

$$A1(\lambda) = 1 - [R1(\lambda) + T1(\lambda)] \qquad \text{Eq. (1)}$$

$$A2(\lambda) = 1 - [R2(\lambda) + T2(\lambda)] \qquad \text{Eq. (2)}$$

where

1 refers to top layer, 2 refers to base layer and

$A(\lambda)$ = Absorptance at each wavelength interval, %

$R(\lambda)$ = Reflectance at each wavelength interval = $R(\lambda)SC(\lambda)$,%

$T(\lambda)$ = Transmittance at each wavelength interval, %

λ = Wavelength of radiation, microns

$SC(\lambda)$ = Setting correction at each wavelength interval (5),%

A computer program was developed to calculate: H1 which is the
heat flux absorbed at the front surface of the first layer, H1B which
is the heat flux absorbed at the back surface of the first layer
and H2 which is the heat flux absorbed at the front surface of the
second layer. Knowing the color temperature and the transmittance
properties of pyrex, the equivalent black body radiation (BBR) curve
is determined. The graphite imaging furnace operates at a color
temperature of 1800 degrees Kelvin, the element being enclosed in
an argon-filled pyrex bell jar which limits the radiation to the
spectral region between 0.29 and 3.9 microns. By multiplying the
hemispherical black body radiation curve taken from the Internation-
al Critical Tables, Figure 1, by the transmittance curve of the pyrex

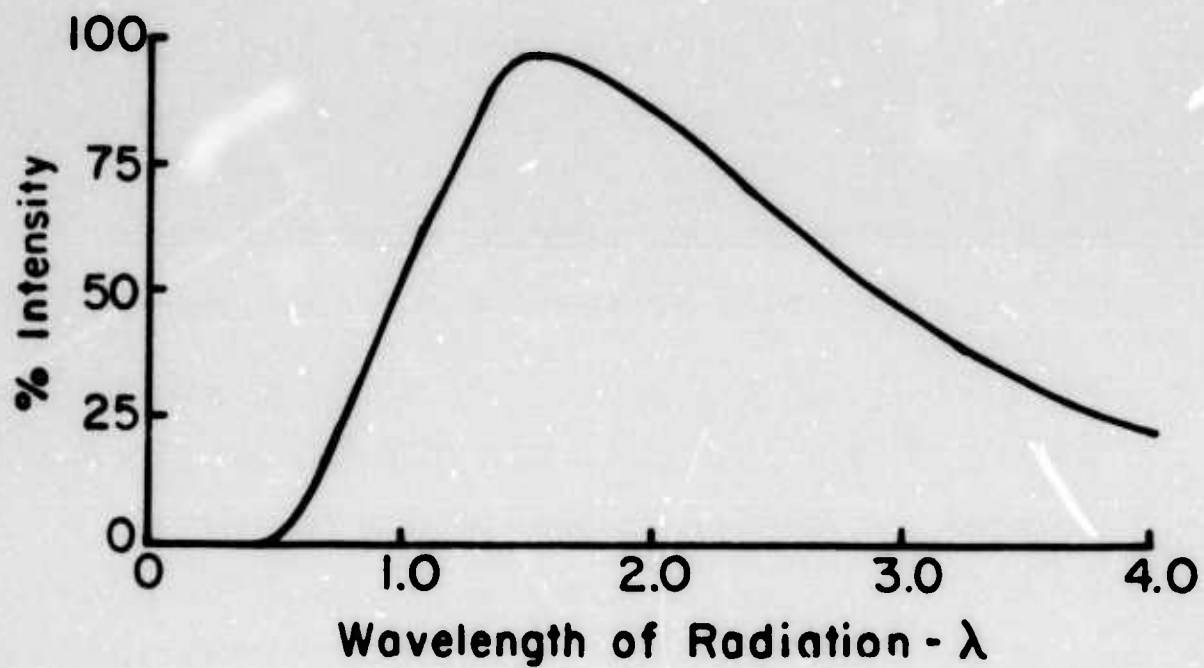# Hemispherical Black Body Radiator
1800° K

Fig. 1. Hemisherical Radiation of Black Body Radiator

4

bell jar, Figure 2, we can establish the black body radiation distribution of the incident energy, Figure 3. Black Body Radiation Data, Setting Correction Data, Reflectance and Transmittance Data and a copy of the computer programs and outputs can be found in Appendix A.

The energy under the BBR curve must be equal to the incident energy which is measured by a totally absorbing radiometer. This is accomplished by multiplying the incremental value of the BBR data by the incident energy of the source and dividing by the average value of the BBR data, thus the total energy, or area under the BBR curve, is equal to the energy measured by the radiometer in conformance with the BBR distribution.

The optical properties of the two-layer system are accounted for by use of the equations for determining H1, H1B and H2:

$$H1 = \frac{Q}{BBR_{(AV)}N} \sum_{\lambda = 0.375}^{\lambda = 3.825} BBR(\lambda)A1(\lambda) \qquad \text{Eq. (3)}$$

$$H1B = \frac{Q}{BBR_{(AV)}N} \sum_{\lambda = 0.375}^{\lambda = 3.825} BBR(\lambda)[T1(\lambda)R2(\lambda)A1(\lambda) + T1(\lambda)R2(\lambda)R1(\lambda)R2(\lambda)A1(\lambda)]$$

$$\text{Eq. (4)}$$

$$H2 = \frac{Q}{BBR_{(AV)}N} \sum_{\lambda = 0.375}^{\lambda = 3.825} BBR(\lambda)[T1(\lambda)A2(\lambda) + T1(\lambda)R2(\lambda)R1(\lambda)A2(\lambda)]$$

$$\text{Eq. (5)}$$

where
   1 refers to top layer, 2 refers to base layer, B refers to
   back surface

and
   $A(\lambda)$ = Absorptance at each wavelength interval, %

   $R(\lambda)$ = Reflectance at each wavelength interval, = $R(\lambda)SC(\lambda)$, %

   $T(\lambda)$ = Transmittance at each wavelength interval, %

   λ = Wavelength of radiation, microns

5

Transmittance of Pyrex Jar
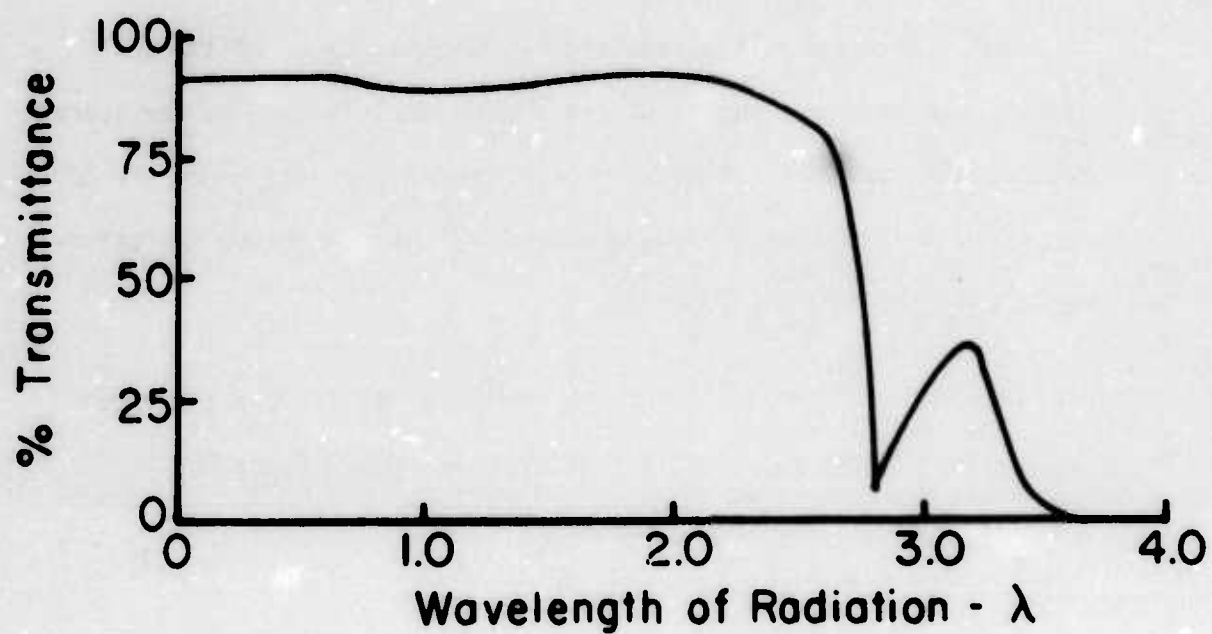
Fig. 2. Transmittance of Pyrex Bell Jar

6
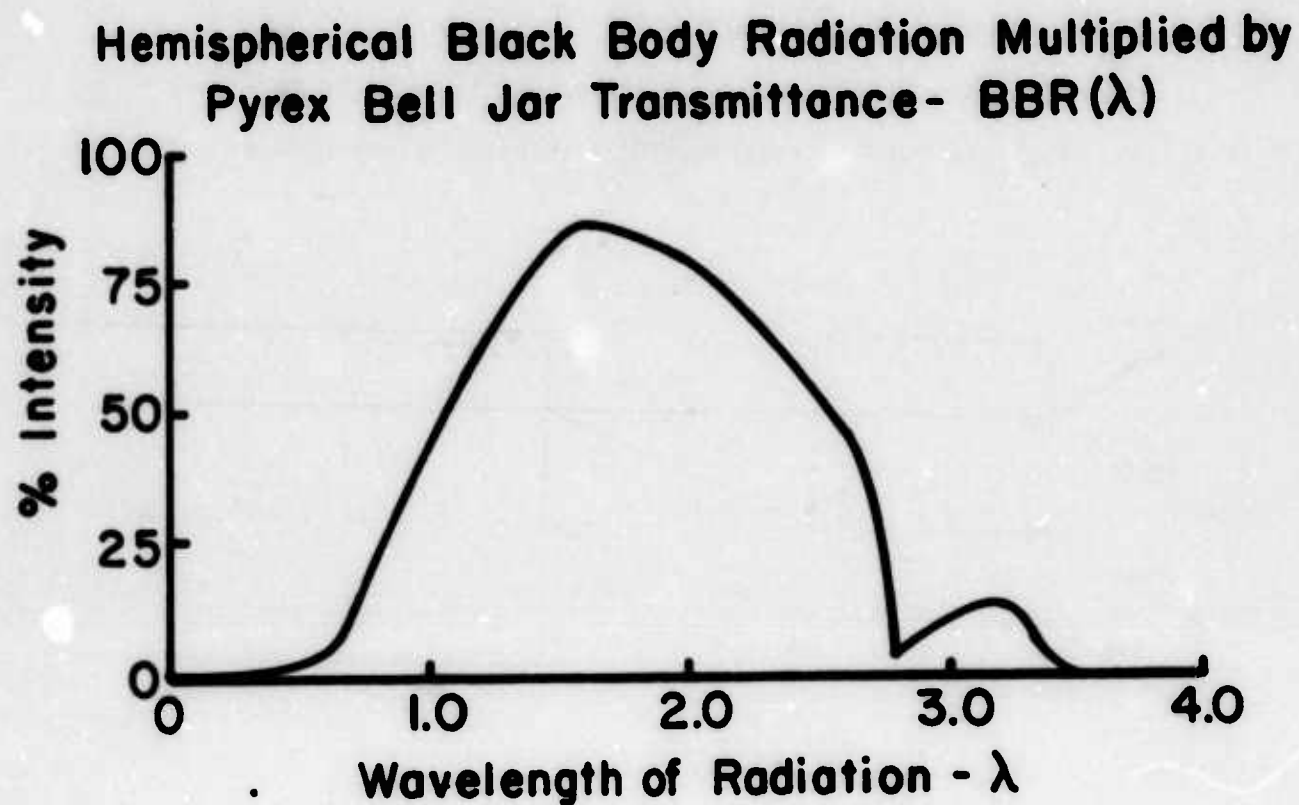
Fig. 3. Black Body Radiation Distribution

7

H = Heat flux perpendicular to surface, $cal/cm^2 sec$

Q = Incident energy measured with a radiometer, $cal/cm^2 sec$

$BBR(\lambda)$= Black Body Radiation at each wavelength interval, %

$$BBR_{(AV)} = \frac{1}{N} \sum_{\lambda = 0.375}^{\lambda = 3.825} BBR(\lambda)$$

N = Number of wavelengths of λ

Figure 4 shows the energy Q as it passes through the two-layer system. The interface is separated only to exhibit the optical paths of Q.
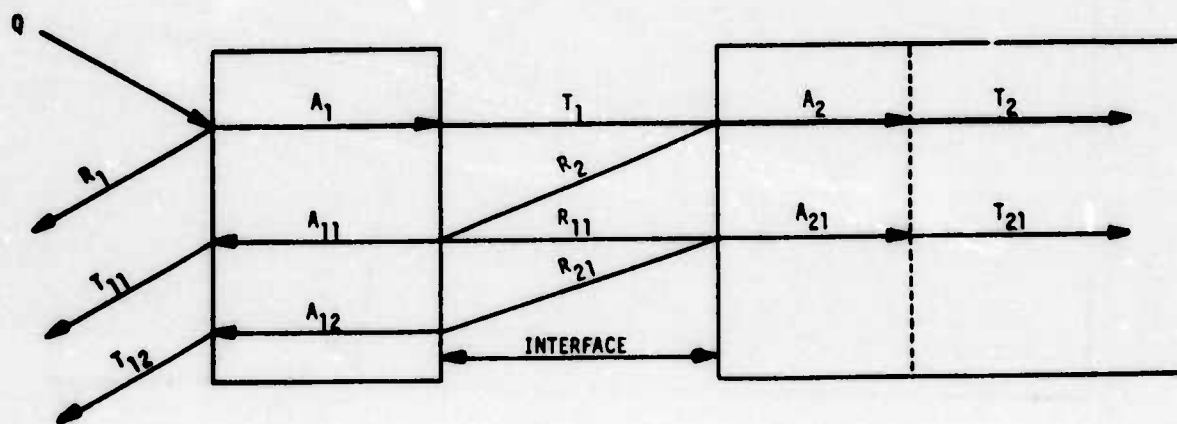
Fig. 4. Optical Paths of Energy through Two-Layer System

Referring to Figure 4, it is evident that Q measured by the radiometer is equal to the total energy incident, or:

$$Q = H1 + H1B + H2 + \frac{Q}{BBR_{(AV)}N} \sum_{\lambda = 0.375}^{\lambda = 3.825} BBR(\lambda)[R_1(\lambda) + T_1(\lambda) R_2(\lambda) T_{11}(\lambda) + T_1(\lambda) R_2(\lambda) R_{11}(\lambda) R_{21}(\lambda) T_{12}(\lambda)$$
$$+ T_1(\lambda) T_2(\lambda) + T_1(\lambda) R_2(\lambda) R_{11}(\lambda) T_{21}(\lambda)]$$

8

where for all wavelengths:

$$R_1(\lambda) = R_{11}(\lambda)$$

$$A_1(\lambda) = A_{11}(\lambda) = A_{12}(\lambda)$$

$$T_1(\lambda) = T_{11}(\lambda) = T_{12}(\lambda)$$

$$R_2(\lambda) = R_{21}(\lambda)$$

$$A_2(\lambda) = A_{21}(\lambda)$$

$$T_2(\lambda) = T_{21}(\lambda)$$

Where the first subscript refers to the layer and the second subscript refers to the iteration of reflectance, transmittance or absorptance.

The values of H1, and H1B and H2 established in terms of the optical properties of the first and second layer and the energy output, color temperature and transmittance through pyrex of the source radiation are used in a Griffith and Horton equation which considers the thermal properties of the first and second layer. The equation for calculating temperature rise caused by H1, H1B and H2 follows:

$$U_2 = \frac{2H\lambda\sqrt{D_1}}{\gamma}\sum_{n=0}^{n=\infty}\left(-\frac{1}{\gamma}\right)^n\left\{2\sqrt{\frac{D_2 t}{\pi}}\,e^{-\{x-a\{1-\sqrt{D_2/D_1}\,(2n+1)\}\}^2/4D_2 t}\right.$$

$$\left. -[x-a\{1-\sqrt{D_2/D_1}\,(2n+1)\}]\left(1-erf\,\frac{x-a\{1-\sqrt{D_2/D_1}\,(2n+1)\}}{2\sqrt{D_2 t}}\right)\right\}$$

Eq. (6)

where
subscript 1 refers to top layer 1, subscript 2 refers to base layer 2
and U = Temperature rise
H = Heat flux perpendicular to surface
X = Total thickness from surface to point of temperature
rise measurement
a = Thickness of layer 1
D = Thermal diffusivity = k/S
k = Thermal conductivity
S = Volume specific heat (density x specific heat)
$\gamma = \dfrac{k_2 S_2 + \sqrt{k_1 S_1 k_2 S_2}}{k_2 S_2 - \sqrt{k_1 S_1 k_2 S_2}}$
$\lambda = (k_2\sqrt{D_1} - k_1\sqrt{D_2})^{-1}$
t = Time

9

Equation 6 is used to calculate the temperature rise caused
by H1, H1B and H2. When calculating the temperature rise caused by:

H1, x equals 0.1032 cm and α equals 0.0532 cm,

H1B, x equals 0.050 cm and α equals 0.0532 $\ddot{\text{cm}}$, or

H2, x equals 0.050 cm and α equals 0.0 cm.

The total temperature rise at depth in the second layer is
equal to the sum of the individual temperature rises:

$$U2 = U21 + U22 \qquad\qquad \text{Eq.(7)}$$

where

U2 = Total temperature rise at depth in layer 2

U21 = Temperature rise caused by H1

U22 = Temperature rise caused by H2 plus H1B

H1B is added to H2 because the levels of energy contributed by
H1B were found to be small in our particular application.

The physical and thermal properties of the silicone rubber and
the skin simulant are shown in Table I.

TABLE 1

Physical And Thermal Properties of Silicone Rubber And Skin Simulant

Symbol	Property	Units	Silicone Rubber subscript 1	Skin Simulant subscript 2
RHO	Density	gm/cm^3	1.0968	1.8200
C	Specific Heat	$cal/gm°C$	0.3500	0.3571
K	Thermal Conductivity	$cal/cm°C \; sec$	5.00×10^{-4}	1.31×10^{-3}
S	Volume Specific Heat	$cal/cm^3°C$	0.3839	0.6499
D	Diffusivity	cm^2/sec	13.02×10^{-4}	20.16×10^{-4}
α	Thickness	cm	0.0532	1.0

The heat flow relationships of the silicone rubber patches and the skin simulant, and the corresponding values for x and α are indicated in Figure 5.

FIGURE 5
Heat Flow Relationships and Distances
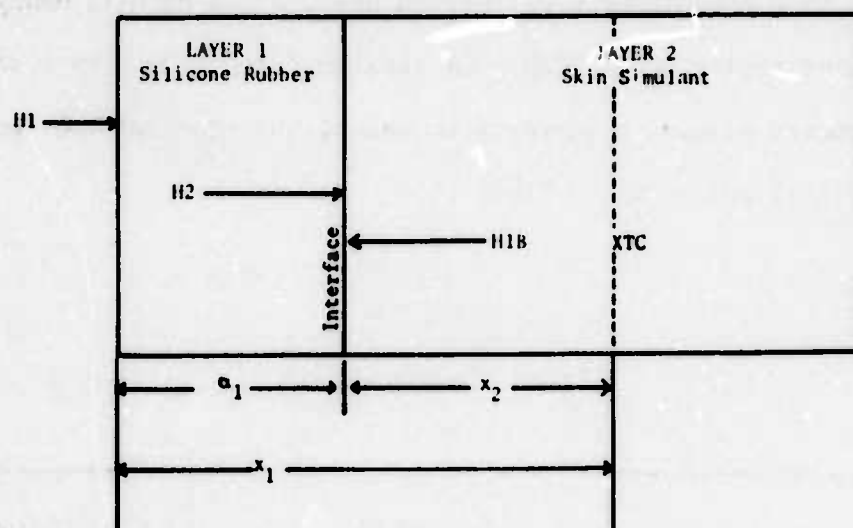
x_1 = distance from surface where H1 is absorbed to TC = 0.1032 cm

α_1 = thickness of layer 1 = .0532 cm

x_2 = distance from surface where H2 is absorbed to TC = 0.050 cm

TC = site of thermocouple embedded 0.050 cm beneath surface of simulated skin

The instrumentation required follows:

A Honeywell Oscillograph Model 1508 with type M40-350 gal-vanometers is used to record experimental data. A Hy-Cal Engineering Model C-1301-A-15-072 Radiometer is used to measure the Heat Flux output of an Arthur D. Little, Inc. Model CSAF-3 Compound Radiation-Imaging System. The radiation system is capable of heating a square area 1/2 inch on a side with a flux of up to 15 cal/cm^{2}sec with a uniformity of $\pm$ 1%. It consists of a resistance heated graphite element used in conjunction with a compound thermal

11

imaging system and a heat flux-redistributor to provide the
desired flux uniformity (2). The skin simulant has a fine copper-
constantan thermocouple embedded .050 cm beneath its surface to
measure the temperature at depth. The radiometer and the skin
simulant thermocouple were calibrated using a Minneapolis Honey-
well Potentiometer Model 2720. Calibrations are made with a vol-
tage standard placed in series with each transducer and the system-
sentitivities are shown in Table II.

TABLE II

System Sensitivities

	Radiometer	Skin Simulant
Transducer Sensitivity	0.4255 cal/cm^2sec/MV	23.66°C/MV
System Sensitivity	0.01198 cal/cm^2sec/MM	0.3697°C/MM

The protocol for conducting the experiment follows:

1) adjust radiation source to desired level of heat flux output.

2) take 4-second exposure using radiometer.

3) take 10-second exposure of one pigmented patch on skin simulant.

4) take 4-second exposure using radiometer.

5) allow 5-minute cooling period for skin simulant.

6) change to another pigmented patch.

12

7) repeat steps 2 through 6 until all pigmented patches are
   irradiated.

8) adjust radiation source to higher level of heat flux output.

9) repeat steps 2 through 8 until completion.

EXPERIMENTAL RESULTS

The experimental data is used to validate two computer pro-
grams (Appendix A). Q, the incident energy measured with a radi-
ometer, is entered into the H1H2 program. Table III is generated
by the computer and gives values of H1 and H2 for each combination
of pigmented patch and skin simulant for Q equal to 1.00 cal/cm^{2}sec.

TABLE III

Output From Computer Program H1H2

	W	W+1	W+2	W+3	W+4	W+5	BLACK
H1 =	.34970	.55450	.69526	.77211	.82475	.84806	.87556
H2 =	.25776	.16892	.10797	.07405	.04530	.03446	.02061

H1 and H2, the heat fluxes absorbed at the first and second
layer, are entered into the DELT program and the computer generates
the data in Table IV, i.e., time in seconds vs the temperature rise
at depth in °C in the second layer caused by H1, H2 plus H1B and H1
plus H2 plus H1B for the W(white) patch on the skin simulant when

13

irradiated with a heat flux of 1.00 cal/cm^{2}sec. As observed in Table IV, a correction of -0.03 sec is applied to give an exact comparison with the experimental data at each recorded data point by compensating for the shutter opening time of 0.03 sec.

TABLE IV

Output From Computer Program DELT

H1 = .34970 H2 = .25776

TIME	DELTA T-H1	DELTA T-H2	TOTAL DELTA T
2.97	5.75	9.11	14.86
5.97	13.07	15.78	29.65
9.97	22.83	22.63	45.46

TIME	DELTA T-H1	DELTA T-H2	TOTAL DELTA T
.97	.56	2.96	3.52
1.97	2.90	6.30	9.20
2.97	5.75	9.11	14.86
3.97	8.59	11.56	20.16
4.97	11.31	13.77	25.07
5.97	13.87	15.78	29.65
6.97	16.29	17.65	33.94
7.97	18.58	19.40	37.98
8.97	20.75	21.06	41.81
9.97	22.83	22.63	45.46

Table V identifies the pigmented patch and the experimental and theoretical temperature rises per unit flux at 3 and 6 seconds. The column labelled "Experimental Δt/cal/cm^{2}sec corrected for Edge Effect" shows the influence of edge losses which is discussed in Stoll(6). At 6 seconds' exposure time a 4% edge effect must be made for the heat loss at the site of measurement because of the relatively small size of the radiation aperture. This edge effect correction increases with both time and intensity of heat

flux exposure.

TABLE V
COMPARISON OF EXPERIMENTAL AND THEORETICAL
TEMPERATURE RISE DURING IRRADIATION

Pigmented Patch	Experimental $\Delta t/cal/cm^2sec$ @ 3 sec	Theoretical $\Delta t/cal/cm^2sec$ @ 3 sec	Experimental $\Delta t/cal/cm^2sec$ @ 6 sec corrected for edge effect	Theoretical $\Delta t/cal/cm^2sec$ @ 6 sec
W	15.41	14.86	29.54	29.65
W + 1	15.40	15.08	31.96	32.33
W + 2	15.07	15.24	31.84	31.18
W + 3	15.32	15.31	32.47	35.15
W + 4	15.17	15.16	32.88	35.48
W + 5	15.11	15.16	32.83	35.74
BLACK	15.53	15.12	34.67	35.98

DISCUSSION AND CONCLUSION

The agreement achieved between the experimental and the
theoretical results throughout the range of varied optical proper-
ties in the irradiated layers indicates that the method is reliable
within experimental limits. The accuracy of the radiometer used
for measuring the incident energy is ± 2.93% (7) and the accuracy
of the galvanometer recording system is approximately 2%.

The fact that the experimental temperature rise is always
lower than the theoretical at longer exposure times is ascribed
to a systematic loss not accounted for in this method. Such a
loss can occur through scattering or re-radiation from the surfaces.
Much difficulty was encountered in measuring the reflectance of the

white silicone rubber patch. Also, we suspect that the thermal and optical properties of the patches change somewhat with increasing temperature. The value of the thermal conductivity constant of the silicone rubber was supplied by the manufacturer; individual measurements were not made for each silicone rubber patch and it is expected that each will vary somewhat from the value used in the equations. The overall level of accuracy, about 5%, is considered adequate for the application intended, namely, the measurement of the thermal conductivity in living human skin.

In conclusion, the validation of the two-layer system for describing transient heat flow was obtained by irradiating a series of increasingly dark, black-pigmented patches, overlaid on a skin simulant, comparing observed and theoretical temperature rise values. Energy was supplied by a graphite imaging furnace and temperature rise was measured at 0.05 cm beneath the surface of the skin simulant. Incident energy levels up to 1.0 cal/cm^{2}sec were used and close agreement was found between the experimental and theoretical results. Validation of the equations ensures that measurements of the temperature rise at the interface of the rubber patch and intact living skin may be used to determine the thermal conductivity of the skin. Furthermore, since the primary site of the skin burn injury is the epidermal-dermal interface, and all the pigment is contained in the epidermis, the system may also be adapted to evaluations of the effect of natural pigmentation by treating the skin itself as a two-layer system.

REFERENCES

1. Stoll, A. M., M. A. Chianta and L. R. Munroe. Flame
       Contact Studies (III). J. Heat Transfer 86: 449-456,
    1964.

2. Richardson, D. L. A Thermal Radiation Heat Source and
       Imaging System for Biomedical Research. Naval Air
    Development Center, Warminster, Pa. March 1962, Report
       NADC-MR-6503, Dec. 1965.

3. Griffith, M. V. and G. K. Horton. The Transient Flow of
       Heat through a Two-Layer Wall. Proc. Philosophical
    Soc. (London) 58; 481, 1946.

4. Derksen, W. L., G. P. DeLhery and T. I. Monahan. Thermal
       and Optical Properties of the NML Skin Simulant. Lab.
    Proj. 5046-3, 18 Jan 1960. Naval Material Laboratory, Brook-
       lyn, N. Y.

5. Stoll, A. M. and M. A. Chianta. Measurement of Optical Proper-
       ties of Fabrics. Textile Research 39:   #7, 657-662, July
    1969.

6. Stoll, A. M. Assessment of Temperature Rise Suppression by
       Edge Losses during Irradiation. Aerospace Med. 44 (2):
    174-178, 1973.

7. Hy-cal Engineering Co., Error Analysis of the Hy-Cal Engineering
       Calorimeter Calibration Facility and Procedure. TR 141,
    Janurary 17, 1964, Hy-Cal Engineering Company, Santa Fe, Calif.

APPENDIX A

Equation 1 - Absorptance at each wavelength interval in layer 1.

$$A1(\lambda) = 1 - [R1(\lambda) + T1(\lambda)]$$

Equation 2 - Absorptance at each wavelength interval in layer 2.

$$A2(\lambda) = 1 - [R2(\lambda) + T2(\lambda)]$$

Equation 3 - Heat Flux absorbed at the front surface of the first layer.

$$H1 = \frac{Q}{BBR_{(AV)}N} \sum_{\lambda = 0.375}^{\lambda = 3.825} BBR(\lambda) \, A1(\lambda)$$

Equation 4 - Heat Flux absorbed at the back surface of the first layer.

$$H1B = \frac{Q}{BBR_{(AV)}N} \sum_{\lambda = 0.375}^{\lambda = 3.825} BBR(\lambda)[T1(\lambda)R2(\lambda)A1(\lambda) + T1(\lambda)R2(\lambda)R1(\lambda)R2(\lambda)A1(\lambda)]$$

Equation 5 - Heat Flux absorbed at the front surface of the second layer.

$$H2 = \frac{Q}{BBR_{(AV)}N} \sum_{\lambda = 0.375}^{\lambda = 3.825} BBR(\lambda)[T1(\lambda)A2(\lambda) + T1(\lambda)R2(\lambda)R1(\lambda)A2(\lambda)]$$

where

1 refers to top layer, 2 refers to base layer, B refers to back
surface.

and

$A(\lambda)$ = Absorptance at each wavelength interval, %

$R(\lambda)$ = Reflectance at each wavelength interval, = $R(\lambda)SC(\lambda)$, %

$T(\lambda)$ = Transmittance at each wavelength interval, %

λ = Wavelength of radiation, microns

$SC(\lambda)$= Setting correction at each wavelength interval (5), %

H = heat flux perpendicular to surface, $cal/cm^2 sec$

Q = Incident energy measured with a radiometer, $cal/cm^2 sec$

$BBR(\lambda)$ = Black Body Radiation at each wavelength interval, %

$$BBR_{(AV)} = \frac{1}{N} \sum_{\lambda = 0.375}^{\lambda = 3.825} BBR(\lambda)$$

N = Number of wavelengths of λ

Equation 6 - Temperature Rise at Depth in Layer 2.

$$U_2 = \frac{2H\lambda\sqrt{D_1}}{\gamma} \sum_{n=0}^{n=\infty} \left(-\frac{1}{\gamma}\right)^n \left\{ 2\sqrt{\frac{D_2 t}{\pi}} e^{-\left\{x-a\left\{1-\sqrt{D_2/D_1}(2n+1)\right\}\right\}^2/4D_2 t} \right.$$

$$\left. -\left[x-a\left\{1-\sqrt{D_2/D_1}(2n+1)\right\}\right]\left(1-erf\frac{x-a\left\{1-\sqrt{D_2/D_1}(2n+1)\right\}}{2\sqrt{D_2 t}}\right)\right\}$$

where
subscript 1 refers to top layer 1, subscript 2 refers to base layer 2
and U = Temperature rise
H = Heat flux perpendicular to surface
X = Total thickness from surface to point of temperature
rise measurement
a = Thickness of layer 1
D = Thermal diffusivity = k/S
k = Thermal conductivity
S = Volume specific heat (density x specific heat)
$\gamma = \dfrac{k_2 S_2 + \sqrt{k_1 S_1 k_2 S_2}}{k_2 S_2 - \sqrt{k_1 S_1 k_2 S_2}}$
$\lambda = (k_2\sqrt{D_1} - k_1\sqrt{D_2})^{-1}$
t = Time

$$erf(Z) = 2/\sqrt{\pi} \int_0^Z e^{-y^2} dy$$

Total Temperature Rise at Depth in the Second Layer

$$U_2 = U_{21} + U_{22} \qquad\qquad\qquad \text{Eq.(7)}$$

where

U_2 = Total temperature rise at depth in layer 2

U_{21} = Temperature rise caused by H1

U_{22} = Temperature rise caused by H2 plus H1B

The programs are written for a Control Data Corporation 6600 Computer System using Fortran Extended language.

Computer Program to Calculate H1 and H1B plus H2:

```
100=      PROGRAM H1H2(INPUT,OUTPUT,TAPE1)

110=      DIMENSION BBR(70),SC(70),RQ(14,70),SSR(70),SST(70)

120=      DIMENSION H1(7,70),H1B(7,70),H2(7,70)

130=      DIMENSION TRUEH1(7),TRUH1B(7),TRUEH2(7)

140=      DIMENSION R(7,70),T(7,70),A(7,70),SSA(70),AQ(70)

150=      REWIND 1

160=      READ (1,3) (BBR(I),I=1,70)

170=      READ (1,3) (SC(I),I=1,70)

180=      READ (1,3) ((RQ(K,I),I=1,70),K=1,14)

190=      READ (1,3) (SSR(I),I=1,70)

200=      READ (1,3) (SST(I),I=1,70)

210=    1 FORMAT (1X,*Q=*)

220=    3 FORMAT (10(F5.4,1X))

230=    5 FORMAT (F15.0)

240=      PRINT 1
```

```
250=      READ 5,Q

260=      SUM=0.0

270=      DO 7 I=1,70

280=      SUM=SUM+BBR(I)

290=    7 CONTINUE

300=      B=SUM/70.0

310=      TOT=0.0

320=      D=B/Q

330=      DO 9 I=1,70

340=      AQ(I)=BBR(I)/D

350=      TOT=TOT+AQ(I)

360=    9 CONTINUE

370=      C=TOT/70.0

380=      PRINT 11,C

390=   11 FORMAT(* Q=*,1X,F8.6,//)

400=      J=0

410=      DO 15 K=1,13,2

420=      J=J+1

430=      DO 13 I=1,70
```

```
440=      R(J,I)=RQ(K,I)*SC(I)

450=   13 CONTINUE

460=   15 CONTINUE

470=      J=0

480=      DO 19 K=2,14,2

490=      J=J+1

500=      DO 17 I=1,70

510=      T(J,I)=RQ(K,I)

520=   17 CONTINUE

530=   19 CONTINUE

540=      DO 27 J=1,7

550=      DO 25 I=1,70

560=      A(J,I)=1.0-(R(J,I)+T(J,I))

570=      IF(A(J,I))21,23,23

580=   21 A(J,I)=0.0

590=   23 CONTINUE

600=   25 CONTINUE

610=   27 CONTINUE

620=      DO 29 I=1,70
```

```
630=      SSA(I)=1.0-((SSR(I)*SC(I))+SST(I))

640=   29 CONTINUE

650=      DO 33 J=1,7

660=      DO 31 I=1,70

670=      H1(J,I)=(BBR(I)/D)*A(J,I)

680=      H1B(J,I)=((BBR(I)/D)*T(J,I)*SSR(I)*SC(I)*A(J,I))+

690=     1((BBR(I)/D)*T(J,I)*SSR(I)*SC(I)*R(J,I)*SSR(I)*SC(I)*

700=     2A(J,I))

710=      H2(J,I)=((BBR(I)/D)*T(J,I)*SSA(I))+((BBR(I)/D)*T(J,I)*

720=     1SSR(I)*SC(I)*R(J,I)*SSA(I))+((BBR(I)/D)*T(J,I)*SSR(I)*

730=     2SC(I)*R(J,I)*SSR(I)*SC(I)*R(J,I)*SSA(I))

740=   31 CONTINUE

750=   33 CONTINUE

760=      L=0

770=      DO 41 J=1,7

780=      SUMH1=0.0

790=      SUMH1B=0.0

800=      SUMH2=0.0

810=      L=L+1                   A-7
```

```
820=        DO 35 I=1,70

830=        SUMH1=SUMH1+H1(J,I)

840=     35 CONTINUE

850=        TRUEH1(L)=SUMH1/70.0

860=        DO 37 I=1,70

870=        SUMH1B=SUMH1B+H1B(J,I)

880=     37 CONTINUE

890=        TRUH1B(L)=SUMH1B/70.0

900=        DO 39 I=1,70

910=        SUMH2=SUMH2+H2(J,I)

920=     39 CONTINUE

930=        TRUEH2(L)=(SUMH2/70.0)+TRUH1B(L)

940=     41 CONTINUE

950=        PRINT 43

960=        PRINT 45,(TRUEH1(L),L=1,7)

970=        PRINT 49,(TRUEH2(L),L=1,7) ·

980=     43 FORMAT(10X,*W*,7X,*W+1*,6X,*W+2*,6X,*W+3*,

990=        16X,*W+4*,6X,*W+5*,5X,*BLACK*)

1000=    45 FORMAT(* H1=*,7F9.5,/)
```

```
1010=    49 FØRMAT(* H2=*,7F9.5,/)

1020=       END
```

Output Generated by H1H2 Program:

Q= 1.000000

	W	W+1	W+2	W+3	W+4	W+5	BLACK
H1=	.34970	.55450	.69526	.77211	.82475	.84806	.87556
H2=	.25776	.16892	.10797	.07405	.04530	.03446	.02061

Computer Program to Calculate Temperature Rise at Depth in Layer 2:

```
100=       PROGRAM DELT(INPUT,OUTPUT)

110=       DIMENSION U2(100),U21(100),U22(100),TIME(100)

120=       REAL K1,K2,LAMBDA

130=       RHO1=1.0968

140=       RHO2=1.8200

150=       C1=0.3500

160=       C2=0.3571

170=       K1=5.00E-4

180=       K2=1.31E-3
```

```
190=        X1=0.1032

200=        ALPHA1=0.0532

210=        X2=0.05

220=        ALPHA3=0.00

230=     3 FORMAT(F15.0)

240=     5 FORMAT(2X,*H1=*)

250=     7 FORMAT(2X,*H2=*)

260=        PRINT 5

270=        READ 3,H1

280=        PRINT 7

290=        READ 3,H2

300=        S1=RHO1*C1

310=        S2=RHO2*C2

320=        D1=K1/S1

330=        D2=K2/S2

340=        LAMBDA=1.0/(K2*SQRT(D1)-K1*SQRT(D2))

350=        GAMMA=(K2*S2+SQRT(K1*S1*K2*S2))/

360=      1(K2*S2-SQRT(K1*S1*K2*S2))

370=        G=-1.0/GAMMA
```

```
380=      MAX=10

390=      DØ 11 I=1,MAX

400=      TIME(I)=I-0.83

410=      SUM1=0.0

420=      N=-1

430=  33 CØNTINUE

440=      N=N+1

450=      A1=(2.0*H1*LAMBDA*SQRT(D1))/GAMMA

460=      B1=2.0*SQRT(D2*TIME(I)/3.1415927)

470=      F1=(X1)-((ALPHA1)*(1.0-(SQRT(D2/D1)*((2.0*N)+1.0))))

480=      G1=-(F1**2)/(4.0*D2*TIME(I))

490=      E1=F1/(2.0*SQRT(D2*TIME(I)))

500=      P1=(0**N)*((B1*EXP(G1))-(F1*CØMERF(E1)))

510=      SUM1=SUM1+P1

520=      IF(N-5)33,33,35

530=  35 CØNTINUE

540=      U21(I)=A1*SUM1

550=  11 CØNTINUE

560=      DØ 19 I=1,MAX
```

A-11

```
570=      TIME(I)=I-0.03

580=      SUM2=0.0

590=      N=-1

600=   37 CONTINUE

610=      N=N+1

620=      A2=(2.0*H2*LAMBDA*SQRT(D1))/GAMMA

630=      B2=2.0*SQRT(D2*TIME(I)/3.1415927)

640=      F2=(X2)-((ALPHA3)*(1.0-(SQRT(D2/D1)*((2*N)+1))))

650=      G2=-(F2**2)/(4.0*D2*TIME(I))

660=      E2=F2/(2.0*SQRT(D2*TIME(I)))

670=      P2=(0**N)*((B2*EXP(G2))-(F2*COMERF(E2)))

680=      SUM2=SUM2+P2

690=      IF(N-5)37,37,39

700=   39 CONTINUE

710=      U22(I)=A2*SUM2

720=   19 CONTINUE

730=      DO 21 I=1,MAX

740=      U2(I)=U21(I)+U22(I)

750=   21 CONTINUE
```

```
760=      PRINT 23,H1,H2

770=   23 FORMAT(2X,*H1=*,F8.5,2X,*H2=*,F8.5,/)

780=      PRINT 25

790=   25 FORMAT(3X,*TIME*,11X,*DELTA T-H1*,8X,*DELTA T-H2*,6X,

800=    1*TOTAL DELTA T*,/)

810=      PRINT 27,TIME(3),U21(3),U22(3),U2(3)

820=      PRINT 27,TIME(6),U21(6),U22(6),U2(6)

830=      PRINT 27,TIME(10),U21(10),U22(10),U2(10)

840=   27 FORMAT(2X,F5.2,12X,F6.2,12X,F6.2,12X,F6.2)

850=      PRINT 29

860=   29 FORMAT(/)

870=      PRINT 25

880=      DO 31 I=1,MAX

890=      PRINT 27,TIME(I),U21(I),U22(I),U2(I)

900=   31 CONTINUE

910=      PRINT 29

920=      END

930=      FUNCTION CCMERF (U)

935=C     APPROXIMATION FORMULA - COMPLEMENTARY ERROR FUNCTION
```

```
940=       CØMERF=1./((((((.430638E-4*U+2.765672E-4)*U+1.52 J143E-4)

950=       1*U+92.705272E-4)*U+422.820123E-4)*U+705.230784E-4)*U+1.)*

960=       2*16.

970=       RETURN

980=       END
```

Output Generated By DELT Program:

W(White) Silicone Rubber Patch on Skin Simulant

H1= .34970 H2= .25776

TIME	DELTA T-H1	DELTA T-H2	TOTAL DELTA T
2.97	5.75	9.11	14.86
5.97	13.87	15.78	29.65
9.97	22.83	22.63	45.46

TIME	DELTA T-H1	DELTA T-H2	TOTAL DELTA T
.97	.56	2.96	3.52
1.97	2.90	6.30	9.20
2.97	5.75	9.11	14.86
3.97	8.59	11.56	20.16
4.97	11.31	13.77	25.07
5.97	13.87	15.78	29.65
6.97	16.29	17.65	33.94
7.97	18.58	19.40	37.98
8.97	20.75	21.06	41.81
9.97	22.83	22.63	45.46

W + 1 Silicone Rubber Patch on Skin Simulant

H1= .55450   H2= .16892

TIME	DELTA T-H1	DELTA T-H2	TOTAL DELTA T
2.97	9.11	5.97	15.08
5.97	21.99	10.34	32.33
9.97	36.20	14.83	51.03

TIME	DELTA T-H1	DELTA T-H2	TOTAL DELTA T
.97	.88	1.94	2.83
1.97	4.59	4.13	8.72
2.97	9.11	5.97	15.08
3.97	13.63	7.58	21.20
4.97	17.93	9.02	26.95
5.97	21.99	10.34	32.33
6.97	25.82	11.57	37.39
7.97	29.45	12.72	42.17
8.97	32.91	13.80	46.71
9.97	36.20	14.83	51.03

W + 2 Silicone Rubber Patch on Skin Simulant

H1= .69526   H2= .10797

TIME	DELTA T-H1	DELTA T-H2	TOTAL DELTA T
2.97	11.43	3.82	15.24
5.97	27.57	6.61	34.18
9.97	45.39	9.48	54.87

TIME	DELTA T-H1	DELTA T-H2	TOTAL DELTA T
.97	1.11	1.24	2.35
1.97	5.76	2.64	8.40
2.97	11.43	3.82	15.24
3.97	17.08	4.84	21.93
4.97	22.48	5.77	28.25
5.97	27.57	6.61	34.18
6.97	32.38	7.39	39.77
7.97	36.93	8.13	45.06
8.97	41.26	8.82	50.08
9.97	45.39	9.48	54.87

W + 3 Silicone Rubber Patch on Skin Simulant

H1 = .77211   H2 = .07405

TIME	DELTA T-H1	DELTA T-H2	TOTAL DELTA T
2.97	12.69	2.62	15.31
5.97	30.62	4.53	35.15
9.97	50.41	6.50	56.91

TIME	DELTA T-H1	DELTA T-H2	TOTAL DELTA T
.97	1.23	.85	2.08
1.97	6.39	1.81	8.21
2.97	12.69	2.62	15.31
3.97	18.97	3.32	22.29
4.97	24.96	3.95	28.92
5.97	30.62	4.53	35.15
6.97	35.96	5.07	41.03
7.97	41.01	5.57	46.59
8.97	45.82	6.05	51.87
9.97	50.41	6.50	56.91

W + 4 Silicone Rubber Patch on Skin Simulant

H1 = .82475   H2 = .04530

TIME	DELTA T-H1	DELTA T-H2	TOTAL DELTA T
2.97	13.56	1.60	15.16
5.97	32.71	2.77	35.48
9.97	53.84	3.98	57.82

TIME	DELTA T-H1	DELTA T-H2	TOTAL DELTA T
.97	1.32	.52	1.84
1.97	6.83	1.11	7.94
2.97	13.56	1.60	15.16
3.97	20.27	2.03	22.30
4.97	26.67	2.42	29.08
5.97	32.71	2.77	35.48
6.97	38.41	3.10	41.51
7.97	43.81	3.41	47.22
8.97	48.94	3.70	52.65
9.97	53.84	3.98	57.82

W + 5 Silicone Rubber Patch on Skin Simulant

H1= .84806   H2=   .03446

TIME	DELTA T-H1	DELTA T-H2	TOTAL DELTA T
2.97	13.94	1.22	15.16
5.97	33.63	2.11	35.74
9.97	55.37	3.02	58.39

TIME	DELTA T-H1	DELTA T-H2	TOTAL DELTA T
.97	1.35	.40	1.75
1.97	7.02	.84	7.87
2.97	13.94	1.22	15.16
3.97	20.84	1.55	22.39
4.97	27.42	1.84	29.26
5.97	33.63	2.11	35.74
6.97	39.49	2.36	41.85
7.97	45.05	2.59	47.64
8.97	50.33	2.82	53.14
9.97	55.37	3.02	58.39

Black Silicone Rubber Patch on Skin Simulant

H1= .87556   H2=   .02061

TIME	DELTA T-H1	DELTA T-H2	TOTAL DELTA T
2.97	14.39	.73	15.12
5.97	34.72	1.26	35.98
9.97	57.16	1.81	58.97

TIME	DELTA T-H1	DELTA T-H2	TOTAL DELTA T
.97	1.40	.24	1.63
1.97	7.25	.50	7.76
2.97	14.39	.73	15.12
3.97	21.52	.92	22.44
4.97	28.31	1.10	29.41
5.97	34.72	1.26	35.98
6.97	40.78	1.41	42.19
7.97	46.51	1.55	48.06
8.97	51.96	1.68	53.64
9.97	57.16	1.81	58.97

Data is presented in groups of 70 data points corresponding
to 70 wavelenghts from 0.375 to 3.825 microns as illustrated below:

10=0.375,0.424,0.475,0.525,0.575,0.625,0.675,0.725,0.775,0.825

20=0.875,0.925,0.975,1.025,1.075,1.125,1.175,1.225,1.275,1.325,

30=1.375,1.425,1.475,1.525,1.575,1.625,1.675,1.725,1.775,1.825,

40=1.875,1.925,1.975,2.025,2.075,2.125,2.175,2.225,2.275,2.235,

50=2.375,2.425,2.475,2.525,2.575,2.625,2.675,2.725,2.775,2.825,

60=2.875,2.925,2.975,3.025,3.075,3.125,3.175,3.225,3.275,3.325,

70=3.375,3.425,3.475,3.525,3.575,3.625,3.675,3.725,3.775,3.825,

The Data File Key used in the H1H2 program follows. Each
data point has a corresponding wavelength associated with it as
described previously.

Data File Key

Lines 100 to 160 - Black Body Radiation Data - BBR(λ)

Lines 180 to 240 - Setting Correction Data - SC(λ)

Lines 260 to 320 - Reflectance of White Patch - R(λ)

Lines 330 to 390 - Transmittance of White Patch - T(λ)

Lines 400 to 460 - Reflectance of W + 1 Patch - R(λ)

Lines 470 to 530 - Transmittance of W + 1 Patch - T(λ)

Lines 540 to 600 - Reflectance of W + 2 Patch - R(λ)

Lines 610 to 670 - Transmittance of W + 2 Patch - T(λ) ·

Lines 680 to 740 - Reflectance of W + 3 Patch - R(λ)

Lines 750 to 810 - Transmittance of W + 3 Patch - T(λ)

Lines 820 to 880 - Reflectance of W + 4 Patch - R(λ)

Lines 890 to 950 - Transmittance of W + 4 Patch - $T(\lambda)$

Lines 960 to 1020 - Reflectance of W + 5 Patch - $R(\lambda)$

Lines 1030 to 1090 - Transmittance of W + 5 Patch - $T(\lambda)$

Lines 1100 to 1160 - Reflectance of Black Patch - $R(\lambda)$

Lines 1170 to 1230 - Transmittance of Black Patch - $T(\lambda)$

Lines 1250 to 1310 - Reflectance of Skin Simulant - $SSR(\lambda)$

Lines 1330 to 1390 - Transmittance of Skin Simulant - $SST(\lambda)$

TAPE 1

100=.0002,.0007,.0030,.0090,.0214,.0423,.0817,.1164,.1679,.2297,

110=.2944,.3620,.4302,.4834,.5243,.5645,.6089,.6515,.6942,.7372,

120=.7750,.8209,.8691,.8878,.8833,.8758,.8682,.8607,.8541,.8446,

130=.8380,.8368,.8227,.8062,.7837,.7511,.7216,.6982,.6883,.6664,

140=.6300,.5981,.5718,.5451,.5267,.4946,.4303,.0624,.0189,.0334,

150=.0523,.0761,.0884,.1079,.1194,.1298,.1423,.1467,.1397,.1186,

160=.0729,.0320,.0072,.0031,.0000,.0000,.0000,.0000,.0029,.0025,

170=*EOR

180=.9763,.9688,.9650,.9650,.9625,.9575,.9537,.9513,.9475,.9425,

190=.9400,.9400,.9372,.9318,.9277,.9252,.9228,.9202,.9185,.9175,

200=.9165,.9155,.9138,.9112,.9093,.9073,.9073,.9073,.9073,.9058,

210=.9020,.8960,.8920,.8900,.8863,.8807,.8762,.8727,.8690,.8650,

220=.8645,.8675,.8682,.8667,.8690,.8750,.8810,.8800,.8800,.8800,

230=.8800,.8800,.8800,.8800,.8800,.8800,.8800,.8800,.8800,.8800,

240=.8800,.8800,.8800,.8800,.8800,.8800,.8800,.8800,.8800,.8800,

250=*EOR

260=.9999,.9999,.8554,.8293,.7698,.7578,.7090,.6819,.6454,.6312,

270=.6210,.5887,.5701,.5265,.5078,.4742,.3811,.4235,.4203,.3861,

A-20

280=.2838,.2316,.2966,.2443,.2921,.2791,.1765,.0634,.1170,.1683,

290=.2106,.1664,.1438,.1401,.1516,.1398,.0626,.0000,.0000,.0000,

300=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

310=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

320=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

330=.2510,.3360,.3570,.3680,.3740,.3890,.4120,.4270,.4430,.4550,

340=.4640,.4770,.4910,.5090,.5260,.5280,.4690,.5490,.5600,.5670,

350=.5100,.5160,.5610,.5490,.5960,.6020,.4720,.4120,.5280,.6000,

360=.6460,.6610,.6520,.6680,.6830,.6600,.5680,.4290,.2400,.3190,

370=.3320,.3890,.3930,.0510,.0600,.0350,.0250,.0190,.0000,.0000,

380=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

390=.0000,.0000,.0000,.0080,.0160,.0650,.1400,.1400,.1500,.2130,

400=.2310,.2330,.2260,.2110,.2010,.1940,.1920,.1900,.1890,.1920,

410=.2080,.2460,.2890,.2950,.2710,.2380,.2030,.2080,.2120,.2280,

420=.2380,.2610,.2950,.2990,.3130,.3090,.2420,.2020,.2380,.2580,

430=.2640,.2560,.2400,.2330,.2280,.2090,.1690,.1190,.0710,.0810,

440=.0810,.0860,.0830,.0900,.0800,.0590,.0590,.0590,.0590,.0590,

450=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

460=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

470=.0280,..0370,..0400,..0430,..0470,..0500,..0560,..0610,..0690,..0790,

480=.0980,..1310,..1780,..2010,..1900,..1720,..1520,..1690,..1830,..2110,

490=.2280,..2630,..3120,..3270,..3610,..3700,..3000,..2690,..3330,..3670,

500=.3880,..3960,..3930,..4000,..4090,..4000,..3530,..2770,..1520,..2080,

510=.2190,..2560,..2640,..3130,..3030,..2100,..2100,..0280,..0280,..0280,

520=.0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,

530=.0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,

540=.1530,..1510,..1470,..1370,..1280,..1220,..1200,..1180,..1170,..1210,

550=.1360,..1700,..2120,..2170,..1920,..1630,..1400,..1390,..1420,..1600,

560=.1760,..2030,..2330,..2420,..2570,..2520,..2080,..1770,..1980,..2060,

570=.2080,..1990,..1860,..1790,..1720,..1590,..1370,..1010,..0680,..0760,

580=.0750,..0790,..0770,..0810,..0760,..0580,..0580,..0580,..0580,..0580,

590=.0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,

600=.0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,

610=.0040,..0060,..0080,..0080,..0100,..0100,..0120,..0140,..0180,..0210,

620=.0310,..0490,..0800,..0960,..0860,..0710,..0620,..0680,..0770,..0960,

630=.1150,..1480,..1860,..2040,..2320,..2390,..1980,..1780,..2190,..2400,

640=.2550,..2600,..2580,..2620,..2680,..2620,..2370,..1820,..1010,..1410,

650=.1480,..1740,..1810,..2180,..2100,..1440,..1440,..0090,..0090,..0090,

660=.0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,

670=.0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,

680=.1210,..1180,..1120,..1030,..0980,..0930,..0900,..0880,..0880,..0910,

690=.1020,..1350,..1710,..1760,..1510,..1230,..1070,..1040,..1090,..1230,

700=.1420,..1680,..1960,..2070,..2170,..2110,..1760,..1530,..1660,..1720,

710=.1720,..1640,..1540,..1480,..1420,..1310,..1120,..0880,..0630,..0710,

720=.0700,..0730,..0710,..0720,..0740,..0580,..0580,..0580,..0580,..0580,

730=.0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,

740=.0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,

750=.0000,..0000,..0000,..0000,..0000,..0000,..0020,..0040,..0060,..0090,

760=.0120,..0230,..0430,..0530,..0480,..0390,..0310,..0340,..0400,..0520,

770=.0680,..0920,..1220,..1400,..1610,..1680,..1390,..1250,..1530,..1690,

780=.1790,..1810,..1800,..1820,..1880,..1820,..1630,..1280,..0700,..0970,

790=.1030,..1230,..1280,..1550,..1490,..1010,..1010,..0000,..0000,..0000,

800=.0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,

810=.0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,..0000,

820=.1030,..1010,..0980,..0900,..0860,..0810,..0790,..0770,..0770,..0790,

830=.0890,..1180,..1490,..1540,..1380,..1100,..0970,..0940,..0980,..1110,

840=.1290,..1520,..1790,..1900,..1980,..1930,..1680,..1480,..1550,..1570,

850=.1550,.1490,.1410,.1340,.1280,.1200,.1060,.0880,.0670,.0700,

860=.0710,.0720,.0700,.0720,.0710,.0570,.0570,.0570,.0570,.0570,

870=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

880=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

890=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0020,

900=.0040,.0100,.0200,.0270,.0210,.0180,.0130,.0140,.0180,.0260,

910=.0370,.0530,.0740,.0880,.1020,.1070,.0890,.0810,.0990,.1080,

920=.1120,.1120,.1110,.1120,.1140,.1110,.1000,.0770,.0410,.0590,

930=.0620,.0750,.0790,.0980,.0930,.0620,.0620,.0000,.0000,.0000,

940=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

950=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

960=.0940,.0910,.0880,.0800,.0760,.0720,.0700,.0690,.0690,.0720,

970=.0810,.1060,.1390,.1450,.1230,.1010,.0880,.0850,.0900,.1010,

980=.1190,.1430,.1680,.1800,.1860,.1820,.1580,.1430,.1480,.1470,

990=.1460,.1390,.1300,.1230,.1190,.1100,.0990,.0840,.0630,.0700,

1000=.0700,.0710,.0700,.0710,.0710,.0560,.0560,.0560,.0560,.0560,

1010=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

1020=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

1030=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

1040=.0020,.0060,.0110,.0170,.0120,.0100,.0080,.0090,.0100,.0130,

1050=.0220,.0360,.0520,.0630,.0770,.0800,.0670,.0610,.0730,.0810,

1060=.0870,.0880,.0870,.0880,.0890,.0870,.0780,.0590,.0320,.0480,

1070=.0500,.0600,.0620,.0780,.0730,.0500,.0500,.0000,.0000,.0000,

1080=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

1090=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

1100=.0810,.0790,.0750,.0690,.0640,.0620,.0600,.0600,.0600,.0620,

1110=.0720,.0940,.1230,.1290,.1100,.0890,.0780,.0770,.0800,.0930,

1120=.1100,.1330,.1550,.1660,.1730,.1710,.1500,.1380,.1400,.1390,

1130=.1370,.1290,.1210,.1150,.1100,.1030,.0950,.0800,.0610,.0670,

1140=.0680,.0690,.0690,.0710,.0700,.0520,.0520,.0520,.0520,.0520,

1150=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

1160=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

1170=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

1180=.0020,.0030,.0060,.0080,.0060,.0030,.0030,.0030,.0040,.0070,

1190=.0100,.0180,.0300,.0390,.0470,.0490,.0400,.0380,.0470,.0510,

1200=.0530,.0530,.0520,.0520,.0530,.0520,.0460,.0350,.0190,.0280,

1210=.0300,.0370,.0390,.0480,.0460,.0290,.0290,.0000,.0000,.0000,

1220=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

1230=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

1240=*EOR

1250=.1710,.2700,.2650,.3000,.3680,.4250,.4390,.4390,.4350,.4300,

1260=.4200,.4080,.3910,.3750,.3710,.3520,.3080,.2850,.2830,.2640,

1270=.2090,.1390,.0890,.0810,.0950,.1090,.1130,.0950,.0960,.0990,

1280=.0870,.0550,.0320,.0280,.0280,.0260,.0230,.0220,.0210,.0220,

1290=.0210,.0190,.0180,.0180,.0180,.0190,.0190,.0180,.0180,.0180,

1300=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

1310=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

1320=*EOR

1330=.0000,.0540,.1160,.1800,.2460,.2870,.3070,.3240,.3390,.3550,

1340=.3670,.3800,.3920,.4000,.4200,.4310,.4290,.4390,.4530,.4640,

1350=.4480,.3900,.3300,.3590,.3980,.4520,.4500,.4360,.4560,.4830,

1360=.4560,.2850,.2920,.2180,.2190,.2240,.2140,.1930,.1690,.2040,

1370=.2320,.2000,.1240,.1140,.1550,.1990,.1750,.1140,.1140,.1140,

1380=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

1390=.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,.0000,

1400=*EOR

1410=*EOF