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U N C L A S S I F I E D

UR-388

Health and Biology

THE UNIVERSITY OF ROCHESTER
Atomic Energy Project
P. O. Box 287, Station 3
Rochester 20, New York

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Contract W-7401-eng-49 between the U. S. Atomic
Energy Commission and the University of Rochester,
administered by the Department of Radiation Biology
of the School of Medicine and Dentistry.

STUDIES OF FLASH BURNS: THE INFLUENCE OF
TRANSMITTANCE OF FABRICS ON PROTECTIVITY

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Date Completed: 5/20/55

Date of Issue: 6/10/55

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ABSTRACT

The spectral transmittance of certain fabrics has been studied and the specific transmittance by them to the 24" carbon arc output has been calculated. A method is proposed of correcting, for the transmittance parameter, previously published predictions of the median effective exposure for porcine skin under cotton fabrics (based on exposure time, reflectance and fabric weight). The degree of correspondence between these corrected estimates and the observed data is shown.

NOTE: This study was carried out through the facilities of the University of Rochester Atomic Energy Project, under contract with the U. S. Atomic Energy Commission, and its expenses defrayed under grant from the Quartermaster Corps, U. S. Army.

INTRODUCTION

In a previous publication (1), this laboratory has published data obtained on anesthetized white pigs, showing the dependence of sub-fabric burn severity from a 24" carbon arc source upon four parameters: exposure time, irradiance, fabric reflectance and fabric weight. Divergence of predicted values from observed results in the case of lighter, and more translucent, fabrics, led to the present study. This report consists essentially of two parts: the first describing the determination of transmittance of fabric; and the second applying these data to the burn data reported earlier.

Apparatus and Equipment

A block diagram of the equipment used appears in Figure 1. All of the apparatus has been previously described (2) in detail. Light from the source S, a General Electric 10 v 18 amp spectroscopic lamp, was focused on the entrance slit of the Perkin-Elmer model 83 universal monochromator by means of two spherical mirrors M_1 and M_2 . The monochromatic radiation passing through the exit slit of the monochromator was focussed on the cloth sample and the PbS cell by means of two off-axis parabolic mirrors M_3 and M_4 . The PbS cell was a 4 mm by 4 mm Ektron detector with butyl methacrylate overcoating made by Eastman Kodak Co., Rochester, New York.

METHOD

The PbS cell was placed in front of the focal point of mirror M_4 in such a way that the monochromatic radiation more than covered the sensitive area of the cell. A run was made through the spectrum between 0.4 and 2.6 μ with no cloth sample over the PbS cell. A similar run was then made with

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Figure 1

the cloth sample placed over the PbS cell and in contact with the surface. The slit and gain program was such that the deflection of the Speedomax recorder for the bare PbS cell never fell below 5 mv on a 10 mv full scale chart.

The traces were read every 0.05 μ starting at 0.4 μ and ending at 2.6 μ . Now if

T_{λ} = transmittance of cloth at wavelength λ or
ratio of Speedomax deflections

J_{λ} = relative spectral energy at wavelength λ of
24" arc

then

$$\frac{\sum T_{\lambda} J_{\lambda} \Delta \lambda}{\sum J_{\lambda} \Delta \lambda} = \text{total transmittance of material}$$

RESULTS

A. Transmittance of fabrics

Figure 2 presents a typical spectral transmittance curve, in this instance for a 9 oz. white cotton sateen. Using the spectral emission curve for the carbon arc source obtained by Davis and Krolak (3) and the values of T_{λ} in the above formula, total transmittances were found. Table 1 presents a summary of the physical characteristics, including the total transmittances, of the fabrics studied in this laboratory over the past 2-1/2 years.

B. Effect of transmittance upon sub-fabric burns

It will be noted in Table 1 that the lighter fabrics transmit up to 20% of the energy incident upon them; in some cases this constitutes more than half of the total energy absorbed by the fabric system. In

Figure 2

Specific Spectral Transmittance By White 9 oz.

Sateen for Univ. of Rochester Carbon Arc Source.

Table 1

Description	d (oz/yd ²)	R (Reflect- ance)	T (Transmit- tance)	1-R-T (Absorp- tance)
1. H-W (tropical 2 layers)	8.32	.183	.0504	.767
2. H-W 50/50 (same, but with wool underwear)	15.75	.183	.0176	.799
3. H-W FR (#1, fire- resistant)	9.52	.283	.0415	.665
4. H-W FR 50/50 (#2, fire-resistant)	16.95	.283	.0217	.695
5. 9 oz. OG sateen	9.4	.202	.0215	.776
6. OG FR (same, fire- resistant)	10.5	.275	.0422	.683
7. 9 oz OGx2 (2 lay- ers of #5)	18.8	.202	.0000	.798
W 9 oz sateen ser- ies	8.26	.746	.1612	.093
W (CMC) "	8.21	(.746)	.1903	(.064)
LG "	7.85	.539	.0611	.400
MG "	8.21	.276	.0101	.714
DG "	8.25	.060	.0000	.940
B "	9.05	.035	.0000	.965
6 oz grey, varied weight	6.12	.073	.0000	.927
7.5 oz "	7.51	.073	.0000	.927
12 oz "	12.12	.070	.0000	.930
CF ₁ cotton oxfords, unbleached	7.96	.658	.2008	.141
CF ₂ "	7.54	.666	.2007	.133
CF ₃ "	7.58	.685	.1977	.117
CF ₄ "	7.11	.664	.2056	.130
CF ₅ "	7.08	.649	.2135	.137

other words, the energy reaching the skin arrives there in two forms: as radiant energy, transmitted through the fabric; and as heat, transferred from the fabric which has absorbed radiant energy and undergone a rise in temperature.

It has been previously shown (4) that porcine skin responds to radiant energy in a manner empirically described by the formula

$$Q = At^{\alpha} \quad (1)$$

where Q is the energy necessary to produce a 2+ burn in half the observed instances (the 2+ EE₅₀),

t is the exposure time in seconds,

A and α are empiric constants.

In the case of skin protected by opaque fabrics, it has been shown (1) that

$$Q = At^{\alpha} (k + k'd t^{\beta}) \quad (2)$$

where d is the surface density of fabric; k , k' and β are empiric constants.

Lacking any suitable knowledge of how these two types of energy

summate to produce a skin burn, let us assume that the transmitted portion of that which enters the system contributes a fraction, x , to the whole

burn. The transported fraction of energy (absorbed by fabric and raising its temperature) would then contribute the remainder of the burn, $1-x$.

That is,

$$T Q_{if} = x^{\alpha} (At^{\alpha}) \quad (3)$$

where T is the transmittance of fabric and Q_{if} is the energy incident on the fabric. Also, it is considered that the energy absorbed by the fabric is

$$(1-R-T) Q_{if} = (1-x) \left[At^{\alpha} (k + k'd t^{\beta}) \right] \quad (4)$$

where R is the reflectance of fabric; and Q_{if} is the energy incident on the fabric.

By rearranging (3) above, and substituting in (4) and rearranging,

$$Q_{if} = \frac{A_t \alpha}{1-R-T} (k + k' d t^\beta) \quad (5)$$

and substituting in (4) and rearranging,

$$Q_{if} = \frac{A_t \alpha}{1-R-T} (k + k' d t^\beta) \quad (6)$$

This expression, based upon a purely arbitrary assumption, reduces to suitable statements in certain limiting conditions. For example, if the fabric is opaque, $T = 0$, and

which we have seen is a satisfactory empiric description of this situation.

$$Q_{if} = \frac{A_t \alpha}{1-R} (k + k' d t^\beta)$$

Again, if the "fabric" were to absorb nothing, but transmit a portion, in the manner of a half-silvered mirror, the absorptance is zero:

i.e., $1-R-T = 0$ and

skin partially protected by a neutral screen.

$$Q_{if} = \frac{A_t \alpha}{T} (k + k' d t^\beta)$$

Finally, for the situation where bare skin is blackened with India ink, we assume $d = 0$, and both R equals and T equals zero. Thus we obtain

$$Q_{if} = A_t \alpha k$$

It has been shown in this laboratory that this sort of expression does

indeed describe the energy requirements of blackened skin for the production of 24 burns, although it appears probable that k is not constant, but is a time-dependent function of the diathermancy of skin. For short exposures, at least, the value of k is approximately 0.4 (5).

When the arbitrarily chosen expression (6) is used to predict burn thresholds beneath various fabric combinations, as reported in previous publications, a better "fit" to the actual data is formed than is obtained by the use of less complex expressions which do not take into consideration the transmittance of the fabric. Table 2 presents a comparison between the observed $2+EE_{50}$'s beneath various fabrics at various times of exposure and the required energy as calculated by formula (6) above.

DISCUSSION

There seems little doubt that the method used to obtain measurements of the fabric transmittance are technically satisfactory. It is of some interest to report that a check on the transmittance determination was carried out in an entirely different fashion from that described in this paper for the 9 oz. white (CMC) fabric, but proved unusable for the darker ones. The sphere calorimeter (6) was used to measure alternately the irradiance of the arc beam, and the irradiance transmitted by fabric directly interposed in the arc beam up against the sphere aperture. The mean of five such "direct" measurements of the specific transmittance of fabric was found to be 0.19; in Table 1 it will be noted this is the same value arrived at using the monochromator.

With the introduction of the transmittance parameter, it became necessary to adjust one of the empiric constants reported in reference (1), in order to bring the data into line: the value of β was changed from -.41 to -.25.

It will be noted that there is still a considerable discrepancy between observed and predicted values for the more highly transmissive fabrics:

Table 2

Fabric	Exposure Time (sec)	Hypothesis (UR-386)	Current Hypothesis	Observed
OG	.25	4.67	4.0	4.9
	.5	4.53	4.22	5.1
	1.0	4.48	4.48	5.5
OG-FR	0.5	5.35	4.93	4.45
B	.25	3.76	3.24	3.32
	.5	3.66	3.42	3.15
	1.0	3.63	3.62	3.5
	2.0	3.67	3.85	3.17
	5.0	3.85	4.27	3.86
	10.0	4.06	4.62	4.3
	20.0	4.39	5.07	5.0
DG	.25	3.63	3.14	3.35
	.5	3.55	3.33	3.3
	1.0	3.55	3.54	3.34
	2.0	3.61	3.78	3.64
	5.0	3.81	4.21	4.7
	10.0	4.05	4.58	5.1
	20.0	4.40	5.04	5.96
MG	.25	4.70	4.07	3.71
	.5	4.60	4.31	5.2
	1.0	4.59	4.59	4.18
	2.0	4.67	4.91	4.6
	5.0	4.95	5.47	5.72
	10.0	5.25	5.95	6.15
	20.0	5.71	6.56	7.0
LG	.25	8.12	6.18	6.05
	.5	7.97	6.64	7.05
	1.0	7.98	7.16	5.95
	2.0	8.15	7.74	6.8
	5.0	8.66	8.73	7.85
	10.0	9.22	9.57	9.3
	20.0	10.1	10.62	11.1
W	.5	13.2	12.47	12.0
	1.0	13.1	14.05	12.4
	2.0	13.4	15.80	12.6
	5.0	14.1	18.65	15.5
	10.0	15.0	21.08	16.3
	20.0	16.3	24.01	18.8

Table 2 (Continued)

Fabric	Exposure Time (sec)	Hypothesis (UR-386)	Current Hypothesis	Observed
6 oz.	.25	3.06	2.69	2.98
	.5	3.05	2.88	2.97
	1.0	3.11	3.11	3.2
7.5 oz.	.25	3.46	3.02	2.86
	.5	3.41	3.20	3.47
	1.0	3.34	3.42	3.53
12 oz.	.25	4.80	4.08	5.65
	.5	4.58	4.25	4.40
	1.0	4.46	4.45	4.5
CF ₁	.5	9.56	8.95	6.95
	5.0	10.35	10.95	7.2
CF ₂	.5	9.49	9.03	7.45
	5.0	10.40	11.10	7.8
CF ₃	.5	10.10	9.61	6.75
	5.0	11.05	11.89	7.8
CF ₄	.5	9.13	8.87	7.05
	5.0	10.14	10.96	7.6
CF ₅	.5	8.71	8.48	6.55
	5.0	9.70	10.47	7.4

the observed being significantly lower than the predicted. This cannot be accounted for by scorching of the fabric during exposure, as this phenomenon was not observed. It is more likely that it is attributable to a decrease in the "diathermanous losses" in skin, introduced by alteration of the spectral distribution of radiation by the fabric barrier.

No attempt is made, in this paper, to discuss the effect of fabric transmittance upon systems in which fabric has been separated from skin. It has previously been suggested (1) that accurate quantitative prediction of protection in such systems is not practicable in the present state of knowledge. Insofar as the results of the present study are concerned, there appears to be no reason to alter this point of view.

It would be of great interest to perform further studies of highly transmissive fabrics, in order to test more widely the hypotheses presented. Limitations of time made such further study impossible prior to the publication of this paper.

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