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

UR-385

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.

A COMPARISON BETWEEN BARE AND BLACKENED PORCINE SKIN IN RESPONSE
TO PULSES OF HIGH INTENSITY RADIANT THERMAL ENERGY

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Date Completed: 3/11/55

Date of Issue: 3/29/55

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A COMPARISON BETWEEN BARE AND BLACKENED PORCINE SKIN IN
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By

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ABSTRACT

The median effective exposures for 2+ burns in pigs were determined for energy pulses of various lengths on bare skin and skin blackened with India ink. The ratio $\frac{2+ EE_{50} \text{ (blackened)}}{2+ EE_{50} \text{ (bare)}}$ was found to have a mean value of 0.413 for the shorter exposures; this ratio is time-dependent and increases with longer exposure times. It was discovered that there is a discrepancy between the absorbed doses necessary to produce 2+ burns in bare and blackened skin, as determined from their measured total reflectances. It is shown that this difference is of a significant magnitude, and its cause is attributed to the diathermancy, or translucency, of porcine skin.

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 a portion of its expenses defrayed under a grant from the Quartermaster Corps, U. S. Army.

Fig. 1. Schematic View of Pulse Shaper.

A. Carbon Arc
 B. Ellipsoidal Mirror
 C. Movable Diaphragm
 D. Protective Screen
 E. Pulse Shaping Wheel

F. Sliding Shutter
 G. Water-cooled Port
 H. Sprocket Wheels
 I. Timing Cam
 J. Main Shaft

INTRODUCTION

In the course of studying the protective qualities of fabrics against intense thermal radiation (1), it became of some theoretical interest to determine the protective index of a "lamina of zero weight and zero reflectance". A close practical approximation to this unattainable ideal is afforded by coating the skin with India ink prior to exposure. With this primary objective in mind, the following experiment was carried out.

Methods

In the convergent beam of the University of Rochester arc source (2) was placed the slotted perimeter of a rotating metal wheel (Fig. 1). The slots were so spaced as to produce a "pulse" of thermal energy with each revolution of the wheel. Wheel rotation rate could be controlled from 60 to 0.67 r.p.m. giving pulses of 1 to 40 sec duration (3).

After appropriate pilot exposures, four irradiances were chosen at each of 6 rotation speeds for bare and for blackened skin: a total of 48 exposure conditions so chosen as to center the resulting skin burns about the 2+ level. Young white pigs were anesthetized with Dial-Urethane (Ciba), 70 mg/kg intraperitoneally, clipped and washed. On the pig's side were then marked out the 36 available exposure areas, to which had been randomly assigned the required exposures. Two pigs supplied 144 individual areas, thus furnishing 3 replications of the required exposures. Immediately prior to exposure, the areas requiring blackening were painted with India ink to which a few drops of detergent had been added. When these had dried, the exposures were made. After the pilot studies, only

Table 1

Pulse Dura- tion	Bare Skin		Blackened	
	2+ EE ₅₀ (cal/cm ²)	95% Confidence Interval	2+ EE ₅₀ (cal/cm ²)	95% Confidence Interval
1.27	4.31	4.1 - 4.53	1.66	1.59 - 1.74
1.79	4.15	3.98 - 4.33	1.9	1.85 - 1.95
2.83	4.82	4.44 - 5.04	1.9	1.82 - 1.99
4.0	5.16	4.86 - 5.48	1.93	1.86 - 2.00
12.65	6.08	5.81 - 6.35	2.79	2.70 - 2.89
40.0	7.01	6.75 - 7.29	4.21	4.1 - 4.32

Fig. 2. Median Effective Exposure for 2+ Burns of Bare and Blackened Porcine Skin, as a Function of Pulse Length.

Fig. 3. Median Effective Dose (calculated) for 2+ Burns of Bare and Blackened Porcine Skin, as a Function of Pulse Length.

two rotation speeds were assigned to any given pair of pigs, giving nine replications per pair of animals. Since 18 replications were made, this spread the exposures for each rotation time out over at least four animals. In all cases, blackened and bare skin exposures for any given rotation time were run on randomly distributed areas of the same animals.

After all exposures on the animals were completed, the ink was gently sponged off with detergent and the skin dried. The following day, 18 - 24 hours after exposure, the lesions were assessed by inspection and graded in the usual fashion on a scale from 0 to 3+ (4).

Results

The results of this experiment are presented in the form of exposure-response tables (Appendix). These data have been submitted to graphical probit analysis (5) to yield estimates of the mean effective exposure required to produce a minimal 2+ burn (the $2+ EE_{50}$), together with the 95% confidence limits about such estimates (Table 1). The latter information may conveniently be visualized graphically as in Fig. 2.

It is readily apparent that the blackened skin requires far less energy to produce the 2+ burn than does the bare skin. This is attributable in large part to the greater absorptance of the inked skin. Determinations in this laboratory indicate that the diffuse reflectance of excised pig's skin to the University of Rochester arc output is approximately 42% (6). The reflectivity of India ink is stated by Hardy to be approximately 6% for the spectral range 0.4 - 3.0 μ , (7). Multiplying the $2+ EE_{50}$ by $(1 - R)$ will now give the dose of energy entering the surface of the system; Fig. 3 presents the doses so calculated for the various pulse durations. It is quite evident that after correction is made for the absorptance of the system, the bare and blackened skin are still reacting differently.

Table 2

Pulse Time (sec)	$\frac{2 + EE_{50\ b}}{2 + EE_{50\ s}}$	$\frac{+ 2 \sigma}{-}$	$1 - R_s$	$\frac{+ 2 \sigma}{-}$
1.27	.377	.359 - .395	.576	.598 - .554
1.79	.458	.436 - .470	.576	.598 - .554
2.83	.394	.374 - .414	.576	.598 - .554
4.0	.375	.359 - .391	.576	.598 - .554
12.65	.459	.440 - .478	.576	.598 - .554
40.0	.602	.582 - .622	.576	.598 - .554

It is possible to test the statistical significance of these differences. Let us test the hypothesis that bare and blackened skin require the same absorbed dose to produce a $2+EE_{50}$. That is, that

$$(1 - R_s) (2+EE_{50})_s = (1 - R_b) (2+EE_{50})_b \quad (1)$$

or

$$\frac{2+EE_{50} b}{2+EE_{50} s} = \frac{1 - R_s}{1 - R_b} \quad (2)$$

and for the moment let us assume that the reflectance of inked skin is zero: that is

$$\frac{2+EE_{50} b}{2+EE_{50} s} = 1 - R_s \quad (3)$$

The standard deviation of this ratio can be computed (5), and the standard deviation of the several determinations of skin reflectance can also be computed. Table 2 presents the results of these computations. It is quite evident that, except for the case of the longest pulse, there is no overlap between the values of the two series of doses $\pm 2\sigma$. Thus it can be stated with a very high level of confidence that, for short pulses at least, our hypothesis (1, above) is disproven. In other words, the response of skin is not the same to identical doses of radiant energy when made opaque as it is when unmodified.

Discussion

The original purpose of the experiment, to determine $\frac{2+EE_{50} b}{2+EE_{50} s}$ has led to some interesting conclusions. The mean value of the above fraction is .413; this figure was used, as planned, in the establishment of basic constants in the empiric formula for protectivity of fabric (1). Perhaps of greater importance is the disproof of the negative hypothesis of equivalent behavior of bare and blackened skin under radiant energy.

For short pulses, at least, the quantity of radiant energy required by the bare skin system to produce the 2+ burn is greater than that required by the blackened skin. Energy in excess of that sufficient to cause a certain damage to blackened skin has been delivered at the same rates to bare skin without producing additional damage. Where, then, has this energy gone? The answer must lie in the physical difference between the two systems: blackened skin is essentially opaque, whereas bare skin is diathermanous. The precise spectral transmittance of skin is not currently known; its determination offers extremely severe technical problems. Recent work by Hardy (8) on human skin, however, gives an approximate quantitation of these translucent qualities of skin which have been remarked by surgeons and artists for centuries.

The present study was not designed to quantitate this physical attribute of skin; indeed, its results do not afford a basis for calculation of diathermancy of skin. The results do indicate unequivocally, however, that in its reaction to radiant thermal energy, skin is significantly translucent. In considering the thermal behavior of skin, it must be treated as a diathermanous, rather than an opaque, solid.

It can be shown that the actual temperature rises at the surface of semi-infinite solids predicted for trapezoidal energy pulses delivered to opaque and diathermanous systems, while widely different at short exposure times, will tend to approach one another at the longer exposure times. It seems probable that the 40 sec. pulse in this experiment has reached those times where the bare and blackened skin give substantially the same surface responses to a given dose of radiant energy.

In considering the behavior of skin under fabrics, it is sometimes convenient to speak of the "apparent reflectance" of skin. This is the value of R calculated on the assumption that equation (1) above is valid. It has been shown here that, in fact, this is not the case, and the expression should be rewritten in some form such as

$$\frac{2 + EE_{50\ b}}{2 + EE_{50\ s}} = \frac{(1 - R_s) X}{(1 - R_b)} \quad (4)$$

where $1 > X > 0$. "X" here expresses the fraction of incident energy lost by the reacting outer layers of bare skin by transmission to, and dissipation in, the depths of the dermis. It appears clear that "X" will be a function not only of incident spectral energy distribution and the optical qualities of skin, but also of exposure time, and that consequently the "apparent reflectance" of skin will vary with exposure time, and presumably also with the shape of the incident energy pulse.

SUMMARY

1. The ratio $\frac{2 + EE_{50\ \text{blackened}}}{2 + EE_{50\ \text{bare}}}$ for pigs' skin has a mean value of 0.413 for short pulses.
2. For a 40 sec. pulse the value of the ratio is 0.6.
3. When correction is made for the absorptance of bare and blackened skin, it is found that the dose required to produce a $2 + EE_{50}$ is smaller for blackened skin than for bare.
4. This difference is shown to have statistical significance, except at the 40 sec. exposure.
5. It is postulated that this difference is due to the diathermancy of normal porcine skin, and it is pointed out that in elucidating the physics of flash burns from radiant sources, skin must be considered as a diathermanous, rather than an opaque, solid.

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Appendix A

Pulse Length (sec)	Skin	Q	BURN					
			0	1+ Mild	1+ Sev	2+ Mild	2+ Mod	2+ Sev
1.27	Bare	3.56		7	11			
		3.94		3	13	2		
		4.33			7	11		
		4.75			2	13	3	
	Inked	1.49		2	15	1		
		1.64		1	6	11		
		1.80			2	15	1	
		1.98			1	10	5	1
1.79	Bare	3.41		5	4			
		3.76		1	16	1		
		4.13			9	9		
		4.55			2	15	1	
		5.0				5	4	
	Inked	1.74		3	15			
		1.90			9	9		
		2.10				6	7	5
		2.31				1	7	10
2.83	Bare	4.0		4	14			
		4.43		1	15	2		
		4.88			8	10		
		5.38			1	9	8	
	Inked	1.62		8	9	1		
		1.84		2	8	8		
		2.00			4	14		
		2.23			2	12	4	
4.0	Bare	4.25		12	6			
		4.69			13	5		
		5.15		2	8	4	4	
		5.67			1	12	5	
	Inked	1.65		8	10			
		1.81		4	11	3		
		2.05			3	11	4	
		2.28				15	4	

Appendix A (Continued)

Pulse Length (sec)	Skin	Q	BURN					
			0	1+ Mild	1+ Sev	2+ Mild	2+ Mod	2+ Sev
12.65	Bare	5.25		9	8	1		
		5.75			11	7		
		6.5			6	12		
		7.25				6	12	
	Inked	2.41		8	10			
		2.60		3	14	1		
		2.82			5	13		
		3.07			1	13	4	
40.0	Bare	6.31		7	6	5		
		6.85		7	8	3		
		6.95			10	8		
		7.58			4	13	1	
	Inked	3.63	1	6	11			
		4.02			13	5		
		4.35			6	12		
		4.61			1	12	5	