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A COMPARISON OF THE EFFECTS OF RADIANT THERMAL
ENERGY ON BARE, BLACKENED AND WHITENED PIG SKIN

by

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ABSTRACT

To study the properties required of a "flash cream" for protection against radiant thermal burns the surface of pigs' skin was altered by applying a black and white paint. Burns inflicted under these paints by a carbon arc source were compared with each other and with bare skin burns on the basis of surface appearance and microscopic measurement of damage. Expressions were obtained for the median effective exposures, in cal/cm², required to produce various surface grades and depths of damage for all three skin conditions.

The data indicate that the radiant exposure for equivalent burns was the same for both whitened and bare skin at 0.3 sec., but as exposure time increased, relatively more energy was required for the whitened skin. On the other hand, the radiant exposure required to produce equivalent burns under the black paint at the shortest exposure time was only one-third of that for a similar burn on bare skin; as exposure time increased, this difference was less marked.

The results could not be explained by difference in reflectance alone. From measurements of the transmittance of the paints the fraction of energy absorbed in the paint film was calculated. The data suggested that energy transmitted through the paint and energy absorbed by the paint were not equally effective in producing a burn. The ratios of their effectiveness have been

calculated for each exposure time and seem to indicate that at shorter exposure times the fraction absorbed by the paint contributes greatly to the production of the burn. The implications of this concept in the development of a "flash cream" are discussed.

INTRODUCTION

The bombing of Pearl Harbor, which caused many serious flash and flame burns, led the Navy to make studies on the protection of bare skin by a "flash cream." Experiments conducted by Fauley and Ivy (1), who used magnesium powder as a heat source, led to the first development of such a protective cream. Later, other creams were made, both commercially and by the Quartermaster Corps of the Army who have now issued a standard cream for use by troops. But little information is available on its relative effectiveness in preventing skin burns or on its mode of action.

In the past it was assumed that an essential characteristic of an effective flash cream was high reflectance. It is logical that a highly reflecting surface might be assumed to give maximum protection while one with a low reflectance might increase damage. But basic to the development of such a cream or lotion is an understanding of the reaction of bare skin to radiant thermal energy and how surface additives might alter this reaction to afford protection.

The simplest experiment to study this appeared to be a comparison of burn severity on blackened and whitened skin with that of normal unprotected skin. By this means the effect of maximum absorption or reflectance of radiant thermal energy applied to the surface could be evaluated in relation to that on an unmodified skin surface. The work is presented in two parts, one dealing with surface evaluation and the other with the microscopic pathology of the burns.

METHODS

Young Chester White pigs, anesthetized with 70 mg/Kg. of intraperitoneal Dial in Urea-urethane (Ciba), were used as the experimental animals. The hair was clipped from the sides of the animal and the skin was gently washed.

The two materials used to modify the surface of the skin were: 1) India ink with a small amount of detergent added, and 2) titanium dioxide paint*. Each substance was spread on the skin with a camel's hair brush so that the skin to be exposed was completely covered. Excess paint was removed and the remainder allowed to dry. Variation in reflectance of each painted burn site was controlled immediately before burning by monitoring with a device which indicates relative reflectance (2).

The experimental design was a simple randomized block in which exposure times of 0.3, 3.0 and 30.0 secs. on bare, blackened and whitened skin were compared. Eight irradiances, in two groups of four, were assigned to each time-skin condition, and in each group of four the irradiances were uniformly separated by ten per cent increments. For each time-skin condition one group of four irradiances was chosen to center about a 2+ burn and the second group was selected to center about a 4+ burn. (At some exposure times additional irradiances were necessary). The 72 treatments thus selected were randomly assigned to 36 exposure areas on each side of the experimental animal, and this treatment block was replicated 14 times giving a total of 1008 burns.

The heat source was the University of Rochester carbon arc (3, 4).

Eighteen to 24 hours after exposure each burn was graded by its surface appearance according to the criteria established in this laboratory (5). Since pig skin does not form a steam bleb at exposure times of 30 secs., a new criterion, the loss of dermal resistance to point pressure, was added to aid in the uniform grading of these burns. The grading system used may be summarized:

*TiO ₂	9 gms.
H ₂ O	7.5 cc.
"Joy" (a commercial liquid detergent)	6 drops
Glycerol	4.5 cc.

- 0 - No burn
- 1+ - Erythema
- 2+ - Patchy coagulation
- 3+ - Uniform coagulation
- 4+ - Steam bleb or loss of dermal
resistance to point pressure
- 5+ - Carbonization

At the time of surface assessment each burn was biopsied. Biopsies from the first nine animals were fixed in Bouin's solution and stained with hematoxylin and eosin; the remainder were fixed with 10% formalin and stained by Hinshaw's differential method for burned tissue (6).

Burn damage was measured in millimeters with a calibrated eyepiece in the microscope. The greatest depth of damage observed on the section was recorded.

Data on both surface appearance and depth of damage were treated by the graphic probit analysis method of Litchfield and Wilcoxon (7) to give an expression of the median effective energy for 2+ and 4+ burns and for varying depths of damage under each time-skin condition.

RESULTS

I Surface Assessment

The surface assessment of each burn is listed in an exposure-response table (Appendix 1) arranged according to time, skin condition and radiant thermal energy. Each time-skin condition was analyzed by the graphic probit method to give an expression, within stated 95% confidence limits, of the median effective exposure (Q) in cal/cm^2 which will produce 2+ and 4+ burns. These determinations are listed in Table I. The results for 2+ burns for each skin condition

TABLE I

MEDIAN RADIANT THERMAL ENERGY REQUIRED TO PRODUCE
2+ AND 4+ BURNS ON BARE AND PAINTED PIG SKIN.

Time (Sec)	Skin Surface	Median Exposure for 2+ Burns (cal/cm ²)	95% Confidence Limits	Median Exposure for 4+ Burns (cal/cm ²)	95% Confidence Limits
0.3	Black	0.90	.82- .99	2.5	2.3 - 2.7
	Bare	3.0	2.8 - 3.2	8.2	7.5 - 8.9
	White	3.4	3.2 - 3.6	9.5	8.6 -10.4
3.0	Black	1.9	1.7 - 2.1	5.6	5.2 - 6.0
	Bare	4.1	3.8 - 4.4	13.2	12.5 -13.8
	White	5.6	5.2 - 6.0	17.3	16.0 -18.6
30.0	Black	3.8	3.5 - 4.0	10.0	9.3 -10.7
	Bare	6.7	6.3 - 7.0	16.8	15.5 -18.2
	White	10.1	9.4 -10.8	24.4	22.3 -26.7

Black = Skin covered with India ink

White = Skin covered with titanium dioxide

are plotted on a double logarithmic scale in Fig. 1, and those for 4+ burns in Fig. 2. Confidence limits for each point are indicated by the symbol "I." Since these data do not allow construction of an interpolative graph, the points have been connected by broken lines to indicate the trend.

The data indicate that, in general, the white paint protects and the black paint increases the damage from radiant thermal energy. However, at the shortest exposure time, 0.3 sec., there is overlapping of the confidence limits for both 2+ and 4+ burns for bare and whitened skin. As exposure time increases, relatively more protection is afforded by the titanium dioxide. On the other hand, skin painted with India ink has greater damage than bare skin at all the exposure times. This difference is most striking at the shortest exposure time. These relationships are tabulated in Table II as a "protective index" for each paint. This index is derived by dividing the median effective exposure for painted skin by that for bare skin.

The observation made by previous workers (4, 8) that the median radiant energy for producing a 2+ burn on bare skin increases with exposure time is substantiated by the control group for this experiment. Fig. 2 indicates that a similar relationship is true for the 4+ burn. Figs. 1 and 2 also suggest that there is a linear time-energy relationship for 2+ and possibly for 4+ burns on skin covered with black or white pigment.

II Microscopic Evaluation

Appendices 2, 3 and 4 list the depth of each burn on blackened, bare and whitened skin respectively. It is apparent that in the more severe exposures and with longer exposure times there is a greater spread of the data. In Table III a median depth of damage has been expressed for each block of exposures with the range expressed as the middle quartiles. With the exception

Figure 1

Median Effective Exposure vs Exposure Time for 2+ Burns

Figure 2

Median Effective Exposure vs Exposure Time for 4+ Burns

TABLE II

RELATIONSHIP OF DAMAGE UNDER PAINT TO DAMAGE OF
BARE SKIN BASED ON SURFACE APPEARANCE OF BURNS.

Time (sec)	Skin Surface	Median Exposure for 2+ Burns (cal/cm ²)	Index of Protection	Median Exposure for 4+ Burns (cal/cm ²)	Index of Protection
0.3	Black	.90	.30	2.5	.30
	Bare	3.0	1.00	8.2	1.00
	White	3.4	1.13	9.5	1.15
3.0	Black	1.9	.46	5.6	.42
	Bare	4.1	1.00	13.2	1.00
	White	5.6	1.36	17.3	1.31
30.0	Black	3.8	.57	10.0	.59
	Bare	6.7	1.00	16.8	1.00
	White	10.1	1.51	24.4	1.45

TABLE III

MEDIAN DEPTH OF DAMAGE FOR EACH TIME-COLOR CONDITION

Time (sec)	Skin Surface	No. of Burns	Radiant Exposure Range (cal/cm ²)	Median Depth (mm)	2nd and 3rd Quartile Range (mm)	No. of Burns	Radiant Exposure Range (cal/cm ²)	Median Depth (mm)	2nd and 3rd Quartile Range (mm)
0.3	Black	53	.88- 1.7	.10	.025 - .175	55	2.3 - 3.1	.325	.25 - .40
	Bare	54	2.8 - 3.8	.075	.01 - .175	55	6.6 - 8.9	.30	.225- .40
	White	53	3.1 - 4.3	.05	.01 - .15	52	6.5 - 9.9	.25	.15 - .375
3.0	Black	54	1.8 - 2.8	.075	.01 - .16	53	4.7 - 7.1	.575	.475- .70
	Bare	52	3.8 - 5.8	.05	CED - .15	53	12.1 -16.6	1.02	.75 - 1.35
	White	53	5.2 - 7.1	.05	CED - .15	53	13.4 -20.4	.625	.475- .88
30.0	Black	54	3.4 - 5.6	CED	0 - .1	53	8.7 -12.3	1.1	.75 - 1.6
	Bare	54	5.7 - 8.7	CED	CED - .075	51	14.7 -22.3	1.0	.625- 1.68
	White	55	8.7 -11.9	CED	0 - .125	55	20.1 -27.6	.925	.45 - 1.53

CED = Complete Epidermal Damage

of bare skin at 3.0 sec., each exposure time has provided comparable depths of damage at two different levels for all three skin conditions (Appendices 2, 3 and 4). From these data median effective exposures in cal/cm^2 are derived by the graphic probit analysis method for the different depths of damage at each exposure time and skin condition. These are listed in Table IV, with 95% confidence limits for each. It is evident from this table that by microscopic, as well as by surface assessment, the white pigment provides no protection against superficial burns and very little against deeper burns at the 0.3 sec. exposure time. But as exposure time increases there is a significant protection. On the other hand, damage under black paint is unusually severe at 0.3 sec., but the difference becomes less at longer exposure times. If a "protective index" is assigned to each condition by dividing the median effective exposure for painted skin by that for bare skin (Table V), these relationships become obvious.

DISCUSSION

Mixter, working in this laboratory on bare and blackened porcine skin (9), found that at short times the $2+ \text{EE}_{50}$ (median effective exposure in cal/cm^2) for blackened skin is only about 39% of that for bare skin. As exposure time is lengthened, there is less difference between the $2+ \text{EE}_{50}$'s. He was unable to account for the great difference at the shorter times on the basis of altered reflectance alone and, for this reason, stated "blackened skin is essentially opaque, whereas bare skin is diathermanous."

If this is the case, then two paints differing in reflectance but sharing the property of opacity might be expected to have parallel response curves. By both microscopic and surface criteria the data of this experiment show that

TABLE IV
MEDIAN EFFECTIVE EXPOSURE (CAL/CM²) FOR DEPTH OF DAMAGE

Time (sec)	Skin Sur- face	Dermal Damage		0.1 Dermal Damage		0.3 Dermal Damage		0.6 Dermal Damage		1.0 Dermal Damage	
		Median Effec- tive Exposure (cal/cm ²)	Confidence Limits	Median Effec- tive Exposure (cal/cm ²)	Confidence Limits	Median Effec- tive Exposure (cal/cm ²)	Confidence Limits	Median Effec- tive Exposure (cal/cm ²)	Confidence Limits	Median Effec- tive Exposure (cal/cm ²)	Confidence Limits
0.3	Black			1.2	0.99- 1.4	2.5	2.2- 2.7				
	Bare	2.8	2.6- 3.1	3.5	3.2- 3.7	7.0	6.5- 7.7				
	White	3.0	2.7- 3.3	4.2	3.6- 4.8	8.9	8.2- 9.6				
3.0	Black	1.8	1.6- 2.0					5.8	5.3- 6.3		
	Bare	4.2	3.8- 4.6							13.8	12.7- 14.9
	White	5.4	4.8- 6.1					18.0	15.0- 21.0		
30.0	Black	4.1	3.7- 4.5							9.7	8.6- 10.8
	Bare	7.8	7.0- 8.7							18.0	16.5- 19.6
	White	10.8	10.0- 11.7							25.0	23.1- 27.0

TABLE V

RELATIONSHIP OF DAMAGE UNDER PAINT TO DAMAGE OF BARE SKIN

BASED ON MICROSCOPIC MEASUREMENT OF DERMAL DAMAGE.

Time (sec)	Skin Sur- face	Median Exposure for Dermal Damage (cal/cm ²)	Index of Protec- tion	Median Exposure for 0.1 mm Dermal Damage (cal/cm ²)	Index of Protec- tion	Median Exposure for 0.3 mm Dermal Damage (cal/cm ²)	Index of Protec- tion	Median Exposure for 1.0 mm Dermal Damage (cal/cm ²)	Index of Protec- tion
0.3	Black			1.2	.34	2.5	.36		
	Bare	2.8	1.00	3.5	1.00	7.0	1.00		
	White	3.0	1.07	4.2	1.20	8.9	1.27		
3.0	Black	1.8	.43						
	Bare	4.2	1.00						
	White	5.4	1.29						
30.0	Black	4.1	.53					9.7	.54
	Bare	7.8	1.00					18.0	1.00
	White	10.8	1.39					25.0	1.39

this is not the case. Hence, there must be a difference between various surface additives which is not dependent on alteration of the diathermancy of skin.

Krolak (2) has made reflectance determinations under identical conditions on bare skin of living pigs and pig skin covered with the two paints used in this experiment. He also measured the transmittance through films of the black and white paints. The results are tabulated below:

TABLE VI

Skin Surface	Mean Reflectance	Mean Transmittance
Black	.10	.11
Bare	.39	
White	.55	.27

Measurements on painted skin before and after representative burns showed no appreciable difference in reflectance. Bare skin undergoes continuous changes in color both during and after burning. Since it is not yet possible to carry out reflectometry studies on an unstable surface, we have used for bare skin only the values taken from pre-burn measurements.

It is obvious that energy which is reflected does not contribute to the burn. Hence we may say that the energy effective in producing a burn is that which actually enters the system. This effective energy, known as radiant dose, may be expressed as $Q(1-R)$ where Q is the incident energy, or radiant exposure, and R is the fraction of energy reflected. If the experimental differences noted are due entirely to a change in reflectance

brought about by the paints, then $Q(1-R)$ should be the same for all three conditions. The values of radiant dose for equal severities of burns by both surface and microscopic grading are listed in Table VII. It is obvious from inspection that a considerably greater dose is still required on both whitened and bare skin to produce burns of a severity equal to those on blackened skin.

One can conceive of the radiant dose delivered to painted surfaces consisting of two components: the first is a fraction, T , which is transmitted directly through the paint and into the skin. This has been measured and is listed in Table VI. The remainder of the effective fraction, A , is absorbed by the paint film. This concept is diagrammed in Fig. 3. From the measurements of transmittance of the paints given in Table VI, the actual values for transmitted energy have been calculated and, by subtraction, the energy absorbed into the paint film has been found. By using the median exposures derived from the surface assessment and the microscopic evaluation, actual values of transmitted and absorbed energy have been tabulated (Tables VIII and IX). It is readily apparent that, at any one exposure time and damage level, more energy is absorbed by the black paint than by the white and more energy is transmitted through the white paint than through the black. We cannot, then, explain our results by any of these three hypothesis:

1. Only the energy absorbed by the paint contributes to the burns.
2. Only the energy transmitted through the paint contributes to the burn.
3. Energy absorbed by the paint and energy transmitted through the paint are equally effective in producing the burn.

The most reasonable hypothesis remaining is that both the energy absorbed by the paint and that transmitted through the paint contribute to the injury

TABLE VII

MEDIAN RADIANT EXPOSURE AND MEDIAN RADIANT DOSE FOR EACH TIME-
SKIN CONDITION BY BOTH SURFACE AND MICROSCOPIC CRITERIA.

Time (sec)	Skin Surface	Surface Grade	Median Radiant Exposure (Q) (cal/cm ²)	Median Radiant Dose Q (1-R) (cal/cm ²)	Depth of Damage in mm.	Median Radiant Exposure (Q) (cal/cm ²)	Median Radiant Dose Q (1-R) (cal/cm ²)
0.3	Black Bare White	2+	.90 3.0 3.4	.81 1.8 1.5	0.1	1.2 3.5 4.2	1.1 2.1 1.9
	Black Bare White	4+	2.5 8.2 9.5	2.2 5.0 4.3	0.3	2.5 7.0 8.9	2.2 4.3 4.0
3.0	Black Bare White	2+	1.9 4.1 5.6	1.7 2.5 2.5	*DD	1.8 4.2 5.4	1.6 2.6 2.4
	Black Bare White	4+	5.6 13.2 17.3	5.0 8.0 7.8	0.6	5.8 - 18.0	5.2 - 8.1
30.0	Black Bare White	2+	3.8 6.7 10.1	3.4 4.1 4.5	*DD	4.1 7.8 10.8	3.7 4.7 4.9
	Black Bare White	4+	10.0 16.8 24.4	9.0 10.0 11.0	1.0	9.7 18.0 25.0	8.7 11.0 11.0

*DD = Threshold Dermal Damage

LEGEND FOR TABLES VIII AND IX

Q = radiant exposure in cal/cm^2

R = fraction of energy reflected

$Q (1-R)$ = radiant dose in cal/cm^2

T = fraction of energy transmitted through the paint

t = energy transmitted through the paint, cal/cm^2

a = energy absorbed by the paint, $\text{cal}/\text{cm}^2 = Q (1-R-T)$

a_b = energy absorbed by black paint, cal/cm^2

a_w = energy absorbed by white paint, cal/cm^2

t_b = energy transmitted through black paint, cal/cm^2

t_w = energy transmitted through white paint, cal/cm^2

$$K = \frac{t_w - t_b}{a_b - a_w}$$

TABLE VIII

BREAKDOWN OF RADIANT DOSE USING SURFACE GRADE VALUES

Time (sec)	Surface Grade	Skin Surface	Median Radiant Dose $Q (1-R)$ (cal/cm ²)	a $Q (1-R-T)$ (cal/cm ²)	t $Q (T)$ (cal/cm ²)	K $\frac{t_w - t_b}{a_b - a_w}$
0.3	2+	Black	.81	.71	.10	8.2
		White	1.5	.61	.92	
	4+	Black	2.2	2.0	.28	7.7
		White	4.3	1.7	2.6	
3.0	2+	Black	1.7	1.5	.21	2.4
		White	2.5	1.0	1.4	
	4+	Black	5.0	4.4	.62	3.1
		White	7.8	3.1	4.7	
30.0	2+	Black	3.4	3.0	.42	1.9
		White	4.5	1.8	2.7	
	4+	Black	9.0	7.9	1.1	1.4
		White	11.0	4.3	6.1	

TABLE IX

BREAKDOWN OF RADIANT DOSE USING MICROSCOPIC VALUES

Time (sec)	Depth of Damage (mm)	Skin Surface	Median Radiant Dose Q (1-R) (cal/cm ²)	a Q (1-R-T) (cal/cm ²)	t Q (T) (cal/cm ²)	K $\frac{t_w - t_b}{a_b - a_w}$
0.3	0.1	Black	1.1	.95	.13	5.1
		White	1.9	.76	1.1	
	0.3	Black	2.2	2.0	.28	5.3
		White	4.0	1.6	2.4	
3.0	DD*	Black	1.6	1.4	.20	3.0
		White	2.4	.97	1.5	
	0.6	Black	5.2	4.6	.64	3.0
		White	8.1	3.2	4.9	
30.0	DD*	Black	3.7	3.2	.45	1.9
		White	4.9	1.9	2.9	
	1.0	Black	8.7	7.7	1.1	1.8
		White	11.0	4.5	6.7	

*DD = Threshold Dermal Damage

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Figure 3
Diagram of Components of Incident Energy on Painted Skin

but they are not equally effective.

If the above statement is true, it should be possible to learn which is more effective and to what degree.

$$\text{Let } \frac{\text{Effectiveness of energy absorbed by the paint}}{\text{Effectiveness of energy transmitted through the paint}} =$$

a constant, K. K may then be derived for a single exposure time and single type of damage in the following manner:

$$Ka_b + t_b = Ka_w + t_w \quad (1)$$

where

a_b = energy absorbed by black paint

t_b = energy transmitted through black paint

a_w = energy absorbed by white paint

t_w = energy transmitted through white paint

$$Ka_b - Ka_w = t_w - t_b \quad (2)$$

$$K(a_b - a_w) = t_w - t_b \quad (3)$$

$$K = \frac{t_w - t_b}{a_b - a_w} \quad (4)$$

In this manner K has been computed for each exposure time and for each level of damage. The results are shown in Tables VIII and IX. It is seen that, at any one exposure time, there may be a nearly constant ratio between the effectiveness of a and t, and this ratio is the same for mild burns as it is for more severe ones. The ratio is time dependent, however, and K decreases as exposure time increases.

We might be able to explain some of the experimental findings by thinking of the energy absorbed by the paint as being "held" on the surface and therefore producing a condition similar to a contact burn. At the shortest exposure time the small amount of energy which white paint absorbs seems to be so effective in producing injury that the paint, despite its high reflectance, really offers little protection. As exposure time increases, the

temperature of the paint approaches equilibrium with the skin. With very long exposure times one might expect energy absorbed by the paint and that transmitted through the paint to be nearly equally effective in producing a burn. Then K would approach unity as it seems to be doing with the longer exposure times used in this experiment.

Generally, protective creams so far developed have aimed at a high reflectance. Since 100% reflectance is impossible to achieve with any cream, we believe a second desirable quality is that such a cream absorb very little of the energy which it does not reflect. The data in this experiment indicate that a surface additive which absorbs an appreciable amount of the incident energy is detrimental, particularly at very short exposure times.

This work suggests a relationship between the effectiveness of energy absorbed by a paint on the skin and energy transmitted through that paint. The ratio seems to be constant for any one exposure time and to decrease as exposure time increases. Further work will be needed to determine whether or not precise values can be assigned to this ratio under other conditions. This concept should be of prime importance in subsequent work to develop a cream for protection against radiant thermal burns.

SUMMARY AND CONCLUSIONS

1. The effects of radiant thermal energy on bare, blackened and whitened pig skin were compared by both surface and microscopic criteria. Exposure times of 0.3, 3.0 and 30.0 seconds were used.
2. The median effective radiant exposures for two grades of burn assessed by surface appearance and for two depths of skin damage were calculated. An increase in the exposure time required an increase in the amount of energy delivered to produce equivalent burns.

3. The white paint offered little or no protection at the 0.3 seconds exposure but did at longer exposure times. On the other hand, the black paint decreased the median effective exposure particularly at the shortest exposure time.
4. These results could not be explained by differences in energy reflected from the surface.
5. The quantity of energy absorbed by the paint film and that transmitted through the paint film were calculated. The data indicate that the energy absorbed by the paint is more effective in producing a burn than is that transmitted through the paint. This difference is greatest at short exposure times.
6. A high reflectance is desirable for a protective film, but this quality may be nullified by high absorptance. Such a concept should be of prime importance in developing a cream for protection against radiant thermal burns.

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APPENDIX 1

DOSE RESPONSE (SURFACE) FOR BARE AND PAINTED PIG SKIN

Exposure Time (sec)	Surface	Radiant Exposure (cal/cm ²)	0	1+		2+			3+
				Mild	Sev	Mild	Mod	Sev	
0.3	Black	0.80		2	1	2			
		0.98		1	1	3	1	3	
		1.1		2		1	1	6	
		1.2	1	1		1	8	3	1
		1.3				2	3	3	
	Bare	2.8		3	7	2		2	
		3.1			4	5	3	2	
		3.5	1		1	6	6		
		3.8			2	1	3	8	
	White	3.1		5	5	2		1	1
		3.5		2	4	4	4		
		3.8		2	2	3	1	5	
		4.3			2	4	3	4	1
3.0	Black	1.8	1	2	4	3		1	
		2.0			2	6		5	
		2.2		1	1	2	1	3	1
		2.5			1	1	6	4	1
		2.8					1	2	
	Bare	3.8		4	5	1	1		
		4.2		3	3	4	4		
		4.7			2	5	2	3	2
		5.2			1	2	2	4	5
		5.8					1		1
	White	5.2	2	3	2	4	2	1	
		5.8		3		6	2	3	
		6.4		4		1	4	5	
		7.1		1	2	2	1	6	2
30.0	Black	3.4	3	6		2			
		3.7	1	4	1	2	2		1
		4.1		3	1	5	2	3	
		4.6				2	4	3	5
	Bare	5.7		4	5	2			
		6.3		6	4	2	2		
		7.0			5	4	3	1	1
		7.8				3	3	5	3
	White	8.7	7	4		2	1		
		9.6	4	2	1	1	2	1	3
		10.7	4	3	1	3			3
		11.9	1	2			1		10

APPENDIX I (Continued)

Exposure Time (sec)	Surface	Radiant Exposure (cal/cm ²)	2+	3+		4+			5+
				Mild	Sev	Mild	Mod	Sev	
0.3	Black	2.3	1	4	3	3			3
		2.5	3		2	3		1	5
		2.8	2	1	1	3	1		6
		3.1		1	2	1	1		9
	Bare	6.5	2	8	2	2			
		7.2	1	5	5	2		1	
		8.0		6	4	1	2		1
		8.9	1	2		5	2		4
	White	6.5	2	1					
		7.2	7	3	2	2			
		8.0	5	4	3	1			1
		8.9	2	6	1	2			
		9.9	3	2		2	2		2
3.0	Black	4.7		4	7				
		5.2		3	7	3	1		
		5.8			6	2			6
		6.4		1	1		3	2	8
		7.1				1		1	1
	Bare	12.0	1	4	5	4			
		13.4			6	4	3		1
		14.9			2	5	4	3	
		16.6			1	2	3	3	5
	White	13.4	1	6	1		1		
		14.9		4	6	3			1
		16.6		2	3	3	4	1	1
		18.4		2	2	5		1	4
		20.4			2	1	1		1
30.0	Black	8.7	1		5	3			
		9.6			7	6	1		
		10.7			3	5	5	1	
		11.9			2	3	9	2	
		12.3				1	2		
	Bare	14.7			8	1	1		
		16.3			7	2	5		
		18.1			5	5	4		
		20.1			2	2	8	1	1
		22.3				2	1		
	White	20.1		4	5	3	1		1
		22.3		1	6	5	1	1	
		24.8		1	8	3	3	1	
		27.6		1	5	1	6	1	

APPENDIX 2

DOSE-RESPONSE (DEPTH OF DAMAGE) FOR BLACKENED PIG SKIN

Exposure Time (sec)	Q (cal/cm ²)	*P.E.D.	*C.E.D.	*0-.1	*.1-.2	*.2-.3	*.3-.4	*.4-.5	*.5-.6	*.6-.7	*.7-.8	*.8-.9
0.3	0.88	1	4									
	0.98		1	4	1	3						
	1.1		2	3	3	2					1	
	1.2	1		6	5	1						
	1.3			3	3	1						
	1.5			2	2			1				
	1.7			1	2							
	2.3	1			2	5	3	2				
	2.5				1	3	6	3		1		
	2.8			1		6	4	2				
3.0	3.1			1		2	7	3			1	
	1.8	1	4	5	1							
	2.0	1	3	3	5		1	1				
	2.2	1	1	5	4		3					
	2.5		1	5	4	1			1			
	2.8			1	2							
	4.7			1		1	1	3	2	2		
	5.2					3	1		2	2	3	
	5.8					1			7	1	2	2
	6.4							3	3	5		1
30.0	7.1								2	2		
	3.4	8	1			1		1				
	3.7	6	1	2		1			1			
	4.1	4	3	5	1		1					
	4.6		4	5	1	1	2					
	5.1			1	1		1					
	5.6			1			1					
	8.7							3		1		
	9.6			1			1		2	1	2	
	10.7						1		1		1	1
	11.9							1				
	12.3											

- * P.E.D. - Partial Epidermal Damage
 * C.E.D. - Complete Epidermal Damage
 * 0-.1 - Dermal Damage in Millimeters

APPENDIX 2 (Continued)

.9- 1.0	1.0- 1.1	1.1- 1.2	1.2- 1.3	1.3- 1.4	1.4- 1.5	1.5- 1.6	1.6- 1.7	1.7- 1.8	1.8- 1.9	1.9- 2.0	2.0- 3.0	3.0-
									1			
1 1		1				1						1
2 1 1	1 2 2	1 2	3 2 1	1 1	1	1	1 1	1	1	1	1 2 1 2	1 1

APPENDIX 3

DOSE-RESPONSE (DEPTH OF DAMAGE) FOR BARE PIG SKIN

Exposure Time (sec)	Q (cal/cm ²)	*P.E.D.	*C.E.D.	*0-.1	.1-.2	.2-.3	.3-.4	.4-.5	.5-.6	.6-.7	.7-.8	.8-.9
0.3	2.8	1	6	3	2	2						
	3.1		2	7	3	1						
	3.5	1	1	6	3	1	1					
	3.8			5	6	2	1					
	6.5			3	2	5	1	2	1			
	7.2				1	5	4	1	2			
	8.0					2	6	4	1	1		
	8.9	1			1	2	4	2	1	1		
3.0	3.8	1	7	1	2							
	4.2	2	5	4	2							
	4.7		4	3		2	2	2				
	5.2		3	6	3		1					
	5.8				1							
	12.0					1	2			2	2	3
	13.4			1						1	1	2
	14.9				1				1		1	1
	16.6									1		
30.0	5.7	3	6		1							
	6.3	4	7	2		1						
	7.0	2	7	3	2							
	7.8	1	6	4	1		1	1				
	8.7			1	1							
	14.7					1		1	1	2	2	
	16.3						2	1	1			
	18.1							1	3			
	20.1				1						2	2
	22.3											1

* P.E.D. - Partial Epidermal Damage

* C.E.D. - Complete Epidermal Damage

* 0-.1 - Dermal Damage in Millimeters

APPENDIX 3 (Continued)

.9- 1.0	1.0- 1.1	1.1- 1.2	1.2- 1.3	1.3- 1.4	1.4- 1.5	1.5- 1.6	1.6- 1.7	1.7- 1.8	1.8- 1.9	1.9- 2.0	2.0- 3.0	3.0-
		1									1	
				1								
2 1 2	1 1 3	1 1 1	1 3	1 2 2	1	1 1	1	1 1	1 1		1 1	1
						1						
1 3 1 1	1	1 1	1 1	1 2		1	1 2 1		1	1 1	1 1 2 2	2

APPENDIX 4

DOSE-RESPONSE (DEPTH OF DAMAGE) FOR WHITENED PIG SKIN

Exposure Time (sec)	Q (cal/cm ²)	*P.E.D.	*C.E.D.	*0-.1	.1-.2	.2-.3	.3-.4	.4-.5	.5-.6	.6-.7	.7-.8	.8-.9
0.3	3.1 3.5 3.8 4.3	2	4 2 4 1	4 7 3 9	1 3 4 2	2 1	1 1 1	1				
	6.5 7.2 8.0 8.9 9.9	1	1	1	2 4 4 6 3	1 4 2 2 2	3 3 1 1	1 2 1 2	1 3			
3.0	5.2 5.8 6.4 7.1	4 1 1 1	4 2 5 1	3 4 5 5	1 4 3 4	2 2	2	1				
	13.4 14.9 16.6 18.4 20.4					1 1 1	1 2 3 3 1	3 1 3 1	1 4 1	1 3 4 2	1 1	2 1
30.0	8.7 9.6 10.7 11.9	9 8 6 3	2 2 4 1	1 1 1 2	2 1 3	1 1 1	1 1 1	1	1	2		
	20.1 22.3 24.8 27.6			1	2	1 1 1	1 1 2 1	3 1 1 3	1 1 3	1 2	1 1	1 1

*P.E.D. - Partial Epidermal Damage

*C.E.D. - Complete Epidermal Damage

*0-.1 - Dermal Damage in Millimeters

APPENDIX 4 (Continued)

.9- 1.0	1.0- 1.1	1.1- 1.2	1.2- 1.3	1.3- 1.4	1.4- 1.5	1.5- 1.6	1.6- 1.7	1.7- 1.8	1.8- 1.9	1.9- 2.0	2.0- 3.0	3.0-
						1						
1 1 1	2 2 2			1		2						
	1											
3 1 2	1 2	1 1 1	1		1	2 1 2	1 1		1 1 1	1 1	1 1	