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

UR-355

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 ON FLASH BURNS:

THE INFLUENCE OF EXPOSURE TIME AND IRRADIANCE ON THE
THERMAL PROTECTIVE QUALITIES OF TWO FABRIC ASSEMBLIES

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Date Completed: 9/1/54

Date of Issue: 11/16/54

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THE INFLUENCE OF EXPOSURE TIME AND IRRADIANCE ON THE
THERMAL PROTECTIVE QUALITIES OF TWO FABRIC ASSEMBLIES.

By

George Mixter, Jr., M. D.
Herman E. Pearse, M. D.ABSTRACT

The protective qualities of two types of fabric barrier against radiant energy burns in pigs have been studied over a wide range of exposure time and irradiance. The most notable characteristic of these barriers is the complexity of their protective patterns at the higher irradiances. A 3-dimensional graphic method is used to express this bizarre behavior. The studies reveal the marked increase of protection by separation of fabric from skin, and the significance of post-exposure flame in the production of burns. In the case of heavier fabric ensembles, it is demonstrated that the cloth itself can act as a thermal reservoir, but that at high irradiances the rapid destruction of this reservoir operates to increase the protection to the underlying skin.

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

Attention is drawn to the fact that all calorie levels in this paper should be multiplied by a factor of 0.85, in order to correct them to the energy levels shown by recent recalibration to be correct.

INTRODUCTION

This laboratory has published data on the susceptibility of the unprotected skin of Chester White pigs to radiant thermal energy which demonstrated that the median effective exposure is a function of exposure time, as well as total dose (1, 2). Previous reports on protective qualities of fabrics (3, 4) have been concerned primarily with studies limited to a single exposure time. Since it appeared that a systematic investigation of fabric protection as a function of exposure time was necessary, the present experiments were carried out.

The puzzling character of burn response beneath one of the systems studied suggested the use of an inanimate physical analogue to explain the mechanisms involved. An apparatus was devised for this purpose and is presented as a subsidiary experiment to demonstrate a mechanism of thermal transfer.

METHODS

Equipment

The source of high-intensity radiant energy employed was a modified 24" carbon arc (5), delivering a maximal irradiance of $37.5 \text{ cal/cm}^2/\text{sec}$ to a circular, water-cooled exposure port 1.6 cm in diameter. Carefully clipped Yorkshire and Chester White pigs, anesthetized with Dial-urethane, 65-70 mg/Kg intraperitoneally, were used. Twenty-seven to 36 exposures were made on each side of each animal. Exposures were randomized as to exposure time and irradiance among these areas.

Fabric was held in contact with the pig's skin by gentle pressure only; separation was maintained where necessary by a machined and polished aluminum ring. Burns were observed after 24 hours for their gross appearance

RESULTS

The salient characteristic of these studies is the irregular protective pattern of two widely differing fabric systems under high irradiances at short times, as shown by the exposure-response data (tables 1 and 2).

With the introduction of the time-variable into the study, the number of treatment combinations was greatly increased, and it was necessary to reduce the number of replications of each treatment lest the experiments become too unwieldy. This made the establishment of 2+ median effective exposures by a probit analysis quite unsatisfactory, and it was found convenient to use a simple "scoring" system to give numerical values to various degrees of burn.

Table 3 shows the numerical values used:

Table 3

Burn Degree	Score
0	0
1+ mild	1
1+ severe	2
2+ mild	3
2+ moderate	4
2+ severe	5
3+	6

While arbitrary, and not necessarily linear, such a system possesses the advantage that, for small groups of replications at a given exposure, an arithmetic mean of the burn "score" may be taken as an approximate indication of the "average response".

2 LAYERS (HW) AT 0.5 CM SEPARATION FROM SKIN
AV. SCORE FOR $T = 1.0$ SEC.

2 LAYERS (HW) AT 0.5 CM SEPARATION FROM SKIN
AV. SCORE FOR $H = 24$ CAL/CM²/SEC.

Figs. 3 and 4. Plane intercepts of fig. 1 at constant exposure time (1.0 sec, fig. 3) and at constant irradiance (24 cal/cm²/sec, fig. 4). Note decrease of burn severity at higher exposures in both cases.

2 LAYERS 9 OZ. SATEEN (OG) IN CONTACT WITH SKIN
AV. SCORE FOR $T = 1.0$ SEC.

2 LAYERS 9 OZ. SATEEN (OG) IN CONTACT WITH SKIN
AV. SCORE FOR $H = 30$ CAL/CM²/SEC.

Figs. 5 and 6. Plane intercepts of fig. 2 at constant exposure time (1.0 sec, fig. 5) and constant irradiance (24 cal/cm²/sec, fig. 6). Note decrease of burn severity at higher exposures in both cases.

Fig. 7 shows the combinations of time and irradiance which caused ignition of the fabric and post-exposure flaming for 6 sec or longer. It will be noted that these coincide with the prominent "peaks" of Fig. 1. Almost all exposures at irradiances above $18 \text{ cal/cm}^2/\text{sec}$ caused a "flare" of brief duration (during exposure) to shoot out from the exposed fabric; but this incandescent material often failed to ignite the remaining fabric.

In every instance of short exposures in the region of 15 cal/cm^2 , (Fig. 1), there was a "punching out" of the outer layer, preservation of the inner layer and absence of flaming. Little or no cutaneous burn resulted from such exposures.

At slightly higher energy levels, the remaining light, porous inner layer obviously transmitted significant amounts of energy, permitting severe burns to be inflicted very rapidly.

Combination B (2 layers heavy sateen, contact with skin)

In the case of this combination (Fig. 2), a long "valley" of lesser burns occurred at a dosage of about 25 cal/cm^2 .

Examination of the fabric over these lesser burns showed that the outer layer was neatly "punched out", with little or no charring of the under layer, in a manner analogous to combination A. The phenomenon became less and less prominent as the exposure time was prolonged and irradiance became less, until at 2 sec it disappeared. At exposures longer than this, it is to be noted, the outer layer fails to be destroyed; in fact, at exposures of 20 sec and longer, no gross visible damage occurred to the fabric even when 3+ burns were sustained beneath it.

Post-exposure flaming, in this system, was very brief, lasting at most 4 sec, and was not associated with any increase in the severity of the

CUTANEOUS BURNS AS A RESULT OF SUSTAINED FLAMING OF FABRIC IN SEPARATIONS FROM SKIN

Fig. 7. Cross-hatched area: Time-irradiance combination at which post-exposure flaming of 6 sec. or longer was observed in more than 50% of exposures. Black dots: Burn scores of 2.5 or higher, corresponding to an average burn of 2+ mild or more. See text for complete discussion.

TEMPERATURE RESPONSE OF POLYETHYLENE BLOCK UNDER 2 LAYERS OF 9 OZ. SATEEN IN CONTACT

Fig. 8. Thermal response of polyethylene under Combination B to 1 sec exposures at increasing irradiance. Note lower response at 20 and 25 cal/cm²/sec. Complete discussion in text.

burn. It occurred only in a sharply limited exposure region, with irradiances at 38 to 36 cal/cm²/sec and exposure times of 0.5 to 0.7 sec. Under the conditions of this experiment it was not significant in burn production.

What, then is the nature of the thermal insult producing significant burns at 10-18 cal/cm²? The results of the thermocouple experiment described under "methods" are summarized in Fig. 8. These time-temperature curves indicate that for the lowest irradiance (7.5 cal/cm²/sec) there was a long, slow rise of temperature, with prolonged elevation beyond 16 sec. As the irradiance was increased, the rise became steeper and the peak higher; the elevation was also prolonged. This is an exposure which, in the pig, gives a 2+ severe response. Beginning at 20 cal/cm², however, the peak, though rapidly attained, was lower and the elevation less well maintained. This was the exposure level at which the outer layer of fabric has been partly destroyed, and the pig responded by a 2+ mild to 1+ severe burn. At 25 cal/cm² the temperature response was rapid but low, and dwindled rapidly; living skin sustained negligible damage. The outer layer of fabric in this instance was destroyed. At higher doses, the temperature rose very sharply to high levels, from which it fell rapidly. The pig's skin, under these circumstances, sustained at least a 2+ burn.

It appears from the above that the outer layer of fabric, after absorbing the incident energy, delivers it in the form of heat to the underlying receiver over a relatively long (> 15 sec) period of time. If, in absorbing energy at high irradiance, the cloth itself becomes destroyed, the energy is dissipated, the "thermal reservoir" is lost, and the underlying temperature drops sharply. If the outer layer be destroyed before the end of the energy pulse, there is a very sharp, high temperature rise in the polyethylene due

4. Definite progress has been made in the understanding of some specific causes of "bizarre" protection pattern by fabrics at high irradiances, but this is still not of a degree of accuracy to permit broad generalizations or extrapolations to other systems or higher irradiances.

5. The importance of fire-proofing of cotton fabric when separated from skin is evident.

6. The studies reveal the futility of using any single exposure time or irradiance to characterize the "protectivity" of a given fabric combination. Specific information must be obtained over a considerable range of time and irradiance in order to give a suitably complete picture.

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Table 1

Summary: Burn Response, Chester White Pigs Beneath Combination A

Time (sec)	H (cal/cm ² /sec)	Q (cal/cm ²)	0	1+		2+			3+	4+
				Mild	Sev	Mild	Mod	Sev		
.2	30	6	6							
	35	7	3				2	2		
.3	20	6	6							
	23.3	7	4				2			
	26.7	8	2				4			
	30	9	1		2		3			
	33.3	10	1		2	2	1			
	36.7	11	3	2		1				
.4	15	6	6							
	17.5	7	5					1		
	20	8	6							
	22.5	9	5		1					
	25	10	2	1	1		2			
	30	12	4	1				1		
	35	14	6							
	37.5	15	6							

Time (sec)	H (cal/cm ² /sec)	Q (cal/cm ²)	0	1+		2+			3+	4+
				Mild	Sev	Mild	Mod	Sev		
.5	14	7	8		1	1		1		
	16	8	14				1	2		
	18	9	3		1	1		6		
	20	10	4	1	1	2	7	3		
	22	11	4	4			2	1		
	24	12	12		2			2		
	28	14	9	3				1		
	30	15	11							
	32	16	9							
	36	18	8	2						
.6	11.3	7	6							
	13.3	8	6							
	15	9	4		2					
	16.7	10	3			2	1			
	18.3	11	3	1			2			
	20	12	4		2					
	25	15	6							

.6 Continued	26.7	16	2						
	30	18	6	1		1	1		
	33.3	20	2	5			3	3	1
	36.7	22	1			1	2	7	
.7	7.2	5	6						
	8.6	6	3				3		
	10	7	3			2	1		
	11.4	8	6						
	12.8	9	6				1		
	14.3	10	4		1		1		
	17.2	12	6						
	21.5	15	6						
	25.7	18	4	1			1		
	34.3	24				3	3		

2/

Time (sec)	H (cal/cm ² /sec)	Q (cal/cm ²)	0	1+		2+			3+	4+
				Mild	Sev	Mild	Mod	Sev		
.8	7.5	6	5		1					
	8.75	7				2	2	1	1	
	10	8	4				1	1		
	12.5	10	4	1		1				
	15	12	6							
	18.8	15	5	1						
	22.5	18	1	1	1	2	1			
	25	20				3	3			
	30	24				8	4	5		
	32.5	26				2	2	4	1	
	35	28						7	3	
	37.5	30					1	1	10	5
1.0	6	6	6							
	8	8				3	2	1		
	9	9				1				
	10	10		1	2	1	1	1		
	12	12	5		1					

1.0 Continued	15	15	4	1		1				
	18	18		1	3	2				
	20	20		1	2	2	1			
	24	24						1	5	
1.2	5	6	6							
	6.7	8				4	2			
	8.3	10			2	3	1			
	10	12	4	1			1			
	12.5	15	4			2				
	15	18		3	1		1	1		
	20	24						5	1	
	25	30							3	3
1.5	3.3	5	6							
	4.7	7	6							
	5.3	8	1		1		4			
	6.7	10			1		2	3		
	8	12	3		2		1			
	10	15		2	1	2	1			

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Table 1 (continued)

Time (sec)	H (cal/cm ² /sec)	Q (cal/cm ²)	0	1+		2+			3+	4+
				Mild	Sev	Mild	Mod	Sev		
1.5 Continu- ed	12	18		1	1	2	1	1		
	13.3	20		1	1	2			2	
	16	24						3	3	
2.0	4	8	6							
	6	12	1		2		2	1		
	9	18			1	1	1	3		

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Table 2

Summary: Burn Response in Chester White Pigs Beneath Combination B

Time (sec)	H (cal/cm ² /sec)	Q (cal/cm ²)	0	1+		2+			3+	4+
				Mild	Sev	Mild	Mod	Sev		
0.3	26.7	8	3	2	1					
	33.3	10	1	4	1					
0.4	20	8	1	3	1	1				
	25	10	2	1	2	1				
	35	14	1	2	1	2				
0.5	16	8	1	4	1					
	20	10		1	1	4				
	28	14		2	2	2				
	36	18			2	1	2	1		
0.6	13.3	8	1	4	1					
	16.7	10		2	0	3	1			
	23.4	14		3	1	2				
	30	18			4	0	2			

Table 2 (continued)

Time (sec)	H (cal/cm ² /sec)	Q (cal/cm ²)	0	1+		2+			3+	4+
				Mild	Sev	Mild	Mod	Sev		
0.7	11.4	8	2	2	2					
	14.3	10	1	2	2	1				
	20	14		2	1	1	2			
	25.7	18			3	2	1			
	34.3	24		3	2	0	0	1		
0.8	10	8	3	2	0	1				
	12.5	10		1	2	1	1	1		
	17.5	14			2	2	2			
	22.5	18			3	2	1			
	30	24	2	3	1					
	37.5	30		2	3	1				
0.9	9	8		3	2	1				
	11.4	10			2	0	2	2		
	15.6	14			2	1	0	3		
	20	18			2	3	1			
	26.7	24	3	1	2					
	33.3	30		3	1	1	1			

1.0	8	8		3	3					
	10	10		1	2	1	2			
	14	14			1	2	2	1		
	18	18			2	4				
	24	24		2	3	0	1			
	30	30		1	2	1	2			
	36	36				1	0	3	2	
1.2	6.7	8		4	0	2				
	8.3	10			1	2	2	1		
	11.4	14			1	1	1	3		
	15	18			1	3	2			
	20	24		2	1	1	1	1		
	25	30				3	1	3		
	30	36						1	5	
	35	42							6	

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Table 2 (continued)

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Time (sec)	H (cal/cm ² /sec)	Q (cal/cm ²)	0	1+		2+			3+	4+
				Mild	Sev	Mild	Mod	Sev		
1.5	5.3	8		5	1					
	6.7	10		1	0	0	5			
	9.3	14			2	1	0	3		
	12	18	1	0	2	0	1	1	1	
	16	24			2	2	1	1		
	20	30			1	2	0	3		
	24	36					1	0	5	
	28	42						1	5	
2.0	3.5	7	1	4	1					
	4.05	8.1	1	1	2	2				
	5	10		1	1	4	5	1		
	9	18				2	0	2	2	
	15	30				2	0	0	4	
3.0	2.1	6.3	5	0	1					
	2.6	7.8	1	3	2					
	3	9	1	0	4	1				
	3.5	10.5			2	2	1	0	1	
	4.05	12.1			1	1	0	1	3	

5.0	1.65	8.2	0	4	2					
	1.84	9.2		1	2	2	1			
	2.1	10.5			2	2	0	2		
	2.6	13			1	1	1	1	2	
7.0	1.08	7.6	1	1						
	1.3	9.1	0	2	4					
	1.65	11.5			2	1	2	1		
	1.84	12.9			1	2	1	2		
	2.1	14.7						1	3	
10.0	.86	8.6		5	2					
	1.08	10.8		1	4	0	1	0	1	
	1.3	13			1	0	3	1	1	
	1.65	16.5							6	
12.0	.6	7.2	4	2						
	.71	8.5		4	2					
	.86	10.3			1	4	0	1		
	1.08	13				2	0	3	1	
	1.3	15.6							2	

Table 2 (continued)

Time (sec)	(cal/cm ² /sec)	(cal/cm ²)	0	1+		2+			3+	4+
				Mild	Sev	Mild	Mod	Sev		
15.0	.51	7.7	2	3	1					
	.6	9	1	2	3					
	.71	10.7			1	0	2	2	1	
	.86	12.9					2	2	2	
20.0	.36	7.2	5	1						
	.41	8.2	2	2	2					
	.51	10.4		3	2	1	1			
	.6	12				1	2	1	2	
25.0	.35	7.8	3	2	1					
	.36	8.8		2	4					
	.41	9		3	0	3				
	.51	10.3				2	4			
30.0	.31	9.3	1	0	1					
	.35	10.5	1	1	4					
	.36	10.8			4	2				
	.41	12.3			3	1	1	0	1	
	.51	15.3						4		