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AN EVALUATION OF BLACK POLYETHYLENE AS A SKIN SIMULANT
UNDER FABRICS EXPOSED TO THERMAL RADIANT ENERGY

by:

George Mixer, Jr.
Thomas P. Davis

Division: Special Programs

Division Head: H. A. Blair

Section: Flash Burns

Section Head: H. D. Kingsley

Submitted by: Henry A. Blair,
Director

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An Evaluation of Black Polyethylene as a Skin Simulant
Under Fabrics Exposed to Thermal Radiant Energy

By

George Mixter, Jr.
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ABSTRACT

Use of maximal temperature attainment in black polyethylene was tested as a substitute for living skin of pigs in the assessment of protection from radiant thermal energy by certain fabrics. This method failed to indicate the actual skin responses in live Chester White pigs with the required degree of accuracy.

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.

Fig. 1. Semi-diagrammatic sketch of water-cooled polyethylene block, approximately 3X actual size. Water flow approximately 500 cc. per mm.

INTRODUCTION

This laboratory is currently investigating the thermally protective qualities of fabrics as a function of their reflectivity. In the course of the study it was necessary to determine the approximate $2+ EE_{50}$ (the arc setting at which half the exposures would result in a 2+ burn or more) for four fabrics at seven exposure times, a total of 28 situations. Use of a suitable inanimate "burn indicator" might possibly result in a great saving of time and of experimental animals. Suitable irradiances could be set up by such pilot study to bracket the probable $2+ EE_{50}$ for later pig studies, thereby avoiding the necessity for performing pilot studies on the pigs themselves. Since such predicted exposures would in any case have to be checked eventually against the living pig, this would provide an opportunity to test the hypothesis that maximal temperature rise in the surface of a polyethylene block is a practicable substitute for living skin responses. The choice of this system as a burn indicator was suggested by its extensive use for this purpose by Naval Material Laboratory, U. S. Naval Shipyard, New York.

METHODS

The plastic block used in these studies is shown in diagrammatic form in Fig. 1. The actual thickness of black polyethylene (provided through the courtesy of Naval Material Laboratory) beneath the thermocouple was 3 mm. The butt-welded iron-constantan couple, .006" in diameter, was embedded in the face, and the protruding half of its thickness sanded down until the metal was flush with the plastic.

In order to bring the block down to the same starting temperature after each exposure, water at 36° C. was circulated at a constant rate from a thermostatically controlled source against the back face of the polyethylene. This reduced the cooling time satisfactorily without appreciably affecting the maximum temperature attained. The reference junction was immersed in the circulating water just before it impinged upon the polyethylene block.

The thermoelectric potential developed by these couples was amplified by a Perkin-Elmer model 53 DC breaker-amplifier, the output from which was fed through a filter to a Sanborn single-channel direct-writing recording unit. Suitable calibrations were introduced in series with the thermocouples prior to amplification.*

No attempt has been made to obtain an accurate calibration of the thermocouple. However, since the amplifier was adjusted to give a 20 mm. deflection of the recorder stylus for a 2 mv calibration signal, and since the thermoelectric EMF of iron-constantan is approximately 50 μ v/°C., the overall response of the system was approximately 2° C. per mm. deflection.

The source of radiant energy was a 24" carbon arc with modifications previously described (1). Chester White and Yorkshire White pigs of about 20 lbs. weight were anesthetized with Dial-urethane (65 mg/kg), and closely clipped prior to exposure. Among the 30 to 36 available areas, 1.7 cm. in diameter, on each side of each pig, were randomized groups of exposure

 * The author wishes to express his thanks to Mr. R. E. Roth for the development and construction of the calibrating circuit.

conditions, each involving 3 fabrics and one or two exposure times, with 5 irradiances for each combination, giving 1 to 2 replications per side of each animal. Burns were assessed the following day and graded on a scale in which the 2+ level is characterized by minimal spotty whiteness overlying basic erythema. No biopsies were taken in this study.

Four 9 oz. cotton sateen fabrics were studied, in contact with skin only. Three of these ("LG", "MG" and "DG") were an especially prepared series of light to dark grey cloth; the fourth was a regular olive green ("OG").

The 2+ EE_{50} 's at 0.5 sec. exposures for these fabrics in contact with pig's skin were first determined; the approximate probit method of Litchfield and Wilcoxon (2) was used to estimate this exposure from the dose-response tables, together with the 95% confidence limits about the estimates.

The temperature response of the plastic block was next determined under each fabric at, above and below the critical energy (Q_c), as defined by the 2+ EE_{50} estimate in pigs. This defined, for each fabric, a characteristic mean temperature maximum in the polyethylene block.

Each fabric was next tested over the polyethylene block at various other exposure times, from 0.25 to 5.0 sec. The "up-and-down" method of Anderson, McCarthy, and Tukey (3) was used, the attainment or exceeding of the previously defined ΔT_{max} constituting a positive result. Twenty-five to fifty exposures were made for each combination of time and fabric, and the EE_{50} 's required to produce this temperature rise calculated by the formulas given, together with the 95% confidence intervals about these estimates.

Fig. 2. Temperature response of black polyethylene block in contact with 9 oz. sateens (light, medium and dark grey, and olive green) at $2+EE_{50}$ dosage levels. 1 mm. deflection approximately equals 2°C . Vertical brackets give 95% confidence intervals.

Finally, each combination of exposure time and fabric was tested on the pigs to determine the $2+ EE_{50}$ estimates, together with the 95% confidence intervals about them. It will be noted that the "OG" fabric was discarded from the final test of the hypothesis, because of its different origin, preparation and physical properties.

RESULTS

The $2+ EE_{50}$'s in pigs at exposure times of 0.5 sec. were estimated as 8.1, 5.6, 3.8 and 6.0 cal/cm² for the light grey, medium grey, dark grey, and olive green, respectively, in contact with skin.

These data, plus the critical temperature response (in terms of mm. deflection) in polyethylene (ΔT_c) for these exposures, are shown in Fig. 2. The 95% confidence limits for the ΔT_c of the members of the grey series do not overlap, indicating that for each fabric there is a statistically different temperature response in the plastic block, at these caloric levels. The variation of response to exposures above and below the critical exposure is shown in Fig. 3. It will be noted that, if any single temperature response be chosen as characteristic of all the fabrics (e.g. 23.5 mm.), the attainment of that temperature by any other fabric will occur in response to exposures at least 20% higher or lower than critical. Such an error was not acceptable for the purposes of our study.

If, however, the characteristic temperature rise for any one fabric were to remain the same for a wide range of exposure times, the plastic block would still have considerable utility. As described above, predictions of pig response at various times were then made on the polyethylene, and finally the actual responses of the pig were determined. These are

Fig. 3. Sensitivity of polyethylene block to doses above and below critical ($Q_c = 2+EE_{50}$ radiant exposure): note the large error introduced by assuming any single T_{max} as characteristic of all four fabrics.

given in the form of dose-response tables (tables 1 - 3) in the Appendix. Figs. 4, 5 and 6 present a summary of the results for each of the grey fabrics. The calculated confidence intervals, represented by vertical lines about the EE_{50} estimates, overlap in each case of 0.5 sec., since this exposure was chosen to define the ΔT_c . Of the twelve other combinations of time and fabric studied, there was failure of overlap in nine, and in no instance was the EE_{50} in pigs the same as predicted by the inanimate system. In one instance the predicted energy level was 40% higher than the observed.

DISCUSSION

Data from Naval Material Laboratory (4) indicate that the ΔT max response of a solid block of black polyethylene, under various fabric systems, to a critical dose ($2+ EE_{50}$ level) of radiant energy, may vary from 34° to 63° C. This clearly indicates that, from one fabric system to another, a single ΔT max is not a reliable indication for the attainment of a 2+ burn in pigs.

Evidence is presented here to demonstrate that, in addition, a) from one shade of fabric to another, and b) from one exposure time to another, the ΔT max response of black polyethylene did not give suitably accurate burn prediction. From a practical standpoint, it was not sufficiently reliable to function as a pilot method for the establishment of a suitable range of exposures about the $2+ EE_{50}$, subsequently to be tested on the pig.

Many possible reasons for this failure can be advanced, among which certainly the foremost is the difference between skin and black polyethylene,

Fig. 4. Energy requirements to produce "critical" temperature rise as determined at 0.5 sec. in polyethylene block ("predicted"), as compared with energies required to produce 2+ EE₅₀ in pigs ("actual"). Dark grey 9 oz. sateens, contact.

2+ EE₅₀S UNDER 9-OZ. SATEEN (CONTACT)

Fig. 5. Energy requirements to produce "critical" temperature rise as determined at 0.5 sec. in polyethylene block ("predicted"), as compared with energies required to produce 2+ EE₅₀ in pigs ("actual"). Medium grey 9 oz. sateens, contact.

2+ EE₅₀ S UNDER 9-OZ. SATEEN (CONTACT)LIGHT GRAY

Fig. 6. Energy requirements to produce "critical" temperature rise as determined at 0.5 sec. in polyethylene block ("predicted"), as compared with energies required to produce 2+ EE₅₀ in pigs ("actual"). Light grey 9 oz. sateens, contact.

in terms of its thermal and optical characteristics: conductivity, density, thermal capacity, reflectivity and diathermancy. Also to be considered are the possibilities that a) some function of time and temperature must be used as a "burn" criterion; and b) temperature criteria should be studied, not at the surface, but at some small but finite depth within the block.

CONCLUSIONS

1) That maximal temperature rise in the surface of black polyethylene, in our hands and for our purposes, was not a reliable burn predictor in the study of sub-fabric burns.

2) That there are a number of possible reasons for this failure, which require further investigation.

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Table 1

Dose vs. Response, Light Grey Fabric in Contact with Pig's Skin

Exposure Time (sec)	Dose (Q) (cal/cm ²)	Response						
		0	1+ Mild	1+ Sev	2+ Mild	2+ Mod	2+ Sev	3+
.25	5.4		5	3				
	6.0		2	5	1			
	6.6		1	5	1	1		
	7.2		2	1	2	1	1	1
	8.0		1	0	1	1	4	1
.5	6.0		1					
	7.0			1				
	7.5	2	3	3	2			
	8.0		2	3	4	2		
	8.5		2	3	3	1		
	9.0			2	5	2	2	
	9.5						1	
	10.0						1	
1.0	6.0		4	4				
	6.6		3	1	3	1		
	7.3		1	1	5	1		
	8.0			2	4	2		
	8.8				1	4	2	1
2.0	6.4	4	5	2	1			
	7.0	2	6	3	2			
	7.7		2	3	4	3		
	8.6		2	2	3	1	4	
	9.5	1	1	0	2	7	1	
	10.4					1	1	
5.0	6.5	1	1					
	7.25	6	6	0	1			
	8.0	1	7	4	1			
	9.0		4	3	3	2		
	10.0		1	1	2	6	2	
	11.0			1	3	4	4	

Table 2

Dose vs. Response, Medium Grey Fabric in Contact with Pig's Skin

Exposure Time (sec)	Dose (Q) (cal/cm ²)	Response						
		0	1+ Mild	1+ Sev	2+ Mild	2+ Mod	2+ Sev	3+
.25	4.1		3	3	2			
	4.5			3	3	2		
	4.9				2	4	2	
	5.4				4	3	1	
	6.0			1	1	2	3	1
.5	4.64	4	6	13	1			
	5.1		6	8	6	3	1	
	5.6	1	1	2	7	5	9	
	5.9		1	7	7	5	4	
	6.2		3	3	13	14	14	1
	6.5			6	8	3	7	
	6.8		1	4	9	9	21	4
	7.15			4	4	6	8	2
	7.5				5	3	11	5
	7.9				2	4	8	10
1.0	4.1	1	2	5				
	4.5		2	2	3	1		
	4.95			4	1	2	1	
	5.45	1	1	0	1	3	2	
	6.0				3	0	4	1
2.0	4.4	2	5	2	1			
	4.8		3	4	5			
	5.3	1	4	2	3	2		
	5.8				8	3	2	
	6.4				3	3	5	1
	7.0				0	0	1	3
5.0	5.0		2					
	5.5	3	3	3	1			
	6.0	2	4	4	2			
	6.5		3	4	3	2		
	7.25	1	0	3	3	3	1	
	8.0			1	4	4	2	1
	8.8				1	0	0	1

Table 3

Dose vs. Response, Dark Grey Fabric in Contact with Pig's Skin

Exposure Time (sec)	Dose (Q) (cal/cm ²)	Response						
		0	1+ Mild	1+ Sev	2+ Mild	2+ Mod	2+ Sev	3+
.25	3.0		6	2				
	3.35		5	4	5			
	3.7		7	1	3	3		
	4.1			6	6	2		
	4.5			1	6	3	2	2
	4.95				1	3	2	
.5	2.5		1					
	3.0	3	8	1				
	3.3	3	5	1				
	3.55	1	3	6	1			
	3.9	1	1	2	5			
	4.1			1	3	3	1	
	4.5				4	3	1	
	5.0				1	2	4	1
1.0	3.3		3	8	1			
	3.7		2	2	9	1		
	4.1		1	4	6	3		
	4.5		1	3	4	4	2	
	4.95			1	2	4	5	2
2.0	2.9	1	0	1				
	3.2	6	4					
	3.6	2	7	1	2			
	4.0		5	3	2	2		
	4.4	1	3	1	7			
	4.8		1	1	5	5		
	5.3				1	1	1	
5.0	3.65		2					
	4.05							
	4.5	1	3	2	4			
	5.0		2	8	2			
	5.5	1	3	4	4			
	6.0	1	1	3	4	3		
	6.5			2	1	3	4	
	7.25					1	2	

Table 4

Dose vs. Response, OG 9 Oz. Sateen in Contact with Pig's Skin

Exposure Time (sec)	Dose (Q) (cal/cm ²)	Response						
		0	1+ Mild	1+ Sev	2+ Mild	2+ Mod	2+ Sev	3+
.25	5.2	2	5	4	1			
	5.8		6	5	8	3	1	
	6.1	1	1	1	5	3	2	
	6.4		4	10	3	6		
	6.7		1	4	5	1	2	
	7.1		3	8	3	3	5	5
	7.8				3	3	6	
.5	4.5	5	5	1	1			
	5.0	3	7	6	8			
	5.5	8	2	4	6	3	1	
	6.0	2	3	7	6	5	1	
	6.5	2	4	5	6	6	1	
	7.0				2	4	6	
	8.0		1	0	1	2	6	2
	9.0				1	2	4	5
	10.0				1	1	2	8
1.0	5.6	1	6	3	2			
	6.2	1	6	6	8	1	1	
	6.5		2	5	5	1		
	6.8		3	6	8	4	3	
	7.15			2	2	5	3	
	7.5		1	4	7	9	2	1
	8.3			1	1	4	6	

Table 5

Temperature Response of Polyethylene Block, 0.5 Sec. Exposure
in Contact with Fabric at and about 2+ EE₅₀ Dose for Pigs.

Fabric	Q	% of 2+ EE ₅₀	mm Deflection	Mean
LG	7.3	90	26.5, 26.4, 26.0, 26.6, 26.8	26.3
	7.7	95	26.3, 28.2, 27.5, 27.8, 28.2	27.6
	8.1	100	26.6, 28.1, 29.0, 29.4, 27.1,	
			26.5, 28.0, 26.7, 27.8, 28.1	27.7
	8.5	105	28.6, 27.0, 30.0, 28.6, 27.0	28.0
	9.0	110	29.0, 31.0, 28.7, 27.8, 28.6	29.0
MG	4.55	80	22.6, 22.0, 21.3, 18.9, 19.9,	
			21.0, 20.2, 24.3, 20.0	21.2
	5.05	90	23.6, 21.0, 22.0, 21.2, 22.1,	
			22.4, 24.0, 22.3, 23.8, 22.5	22.5
	5.6	100	22.2, 24.9, 22.3, 22.1, 24.0,	
			24.1, 24.0, 25.1, 24.4, 25.0	23.8
	6.15	110	23.5, 25.7, 24.6, 20.0, 26.6,	
			23.1, 24.1, 25.1, 23.0, 24.6	24.0
	6.75	120	29.0, 29.0, 29.7, 25.3, 27.6,	
			27.0, 29.3, 26.2, 27.5, 25.9	27.7
DG	3.4	90	19.1, 20.6, 18.1, 17.9, 20.8	19.3
	3.6	95	19.9, 19.3, 20.7, 21.5, 20.5	20.4
	3.8	100	21.1, 21.8, 22.1, 23.3, 20.0,	
			22.1, 17.7, 24.0, 22.0, 17.0	21.1
	4.0	105	22.3, 19.8, 23.2, 19.8, 20.9	21.2
	4.2	110	19.6, 26.0, 22.6, 21.0, 21.2	22.1
OG	5.4	90	19.0, 18.0, 22.0, 20.8, 18.9,	
			23.1, 20.6, 20.5, 21.2, 22.8	21.6
	5.7	95	22.0, 18.0, 19.0, 20.1, 19.8,	
			22.1, 22.1, 22.0, 21.0, 22.1	21.9
	6.3	105	21.5, 23.7, 23.0, 21.3, 24.2,	
			21.4, 22.3, 22.3, 23.3, 23.1	22.5
	6.6	110	24.0, 23.1, 22.2, 23.2, 22.4,	
			23.7, 22.0, 24.4, 23.7, 23.2	23.0

Table 6

Dose Response Data - Polyethylene Block Studies

Exposure Time (sec)	Light Grey			Medium Grey			Dark Grey			Olive Green		
	Q	$\Delta T < \Delta T_c$	$\Delta T \geq \Delta T_c$	Q	$\Delta T < \Delta T_c$	$\Delta T \geq \Delta T_c$	Q	$\Delta T < \Delta T_c$	$\Delta T \geq \Delta T_c$	Q	$\Delta T < \Delta T_c$	$\Delta T \geq \Delta T_c$
.25	5.7 6.0 6.35 6.7 7.0 7.35	1 5 6 6 2 0	0 1 5 6 6 2	4.45 4.92 5.42 6.0	9 10 2 0	0 8 9 2	3.8 4.0 4.2 4.45 4.7 4.95	1 8 7 4 1 0	0 1 7 6 4 1	5.43 5.7 6.0 6.3 6.63 6.95 7.3	2 2 2 8 5 2 0	0 2 2 1 7 5 2
1.0	6.6 7.2 8.0 8.8 9.7	1 3 13 3 0	0 1 3 13 3	4.5 4.95 5.45 6.0 6.6	2 1 13 5 0	0 2 1 12 4	3.6 4.0 4.45 4.95 5.45	4 5 9 3 0	0 3 6 9 3	6.0 6.3 6.6 6.9 7.3 7.6 8.0	3 4 7 3 2 2 0	0 2 3 7 3 2 2
2.0	9.1 10.0 11.0 12.1	5 11 4 0	0 5 11 4	5.8 6.4 7.0 7.7	12 5 3 0	0 12 5 3	3.7 4.1 4.5 5.0	1 15 4 0	0 1 15 4	5.85 6.5 7.2 8.0	5 11 3 0	0 5 12 4
5.0	9.1 10.0 11.1 12.2	1 12 7 0	0 1 12 7	7.5 8.25 9.1	8 12 0	1 7 11	4.85 5.35 5.9 6.5 7.15	1 3 12 5 0	0 1 2 11 5	6.9 7.25 7.6 8.0 8.4	1 3 9 8 0	1 3 8 7