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THERMAL CONDUCTION EFFECTS IN HUMAN SKIN: I. EXPERIMENTAL DATA ACQUISITION

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To determine the maximum permissible temperature any material may attain without causing pain or burn on contact with bare skin, over 2000 observations were made of pain threshold during contact with materials at elevated temperatures. Six materials were used representing the full range of thermal properties of good conductors to good insulators. Initial specimen and skin temperatures, interface (material-skin) temperatures throughout contact, and time to pain threshold were noted. An orderly relationship was found between

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20. pain threshold and material temperature, either longer exposures or higher specimen temperatures being associated with better insulative properties. Variations in thickness of the epidermis affect these times and temperatures so that families of curves are generated from data obtained at sites of increasing thickness. On the basis of the relationship demonstrated between pain sensation and thermal properties the material temperature which will cause a blister on contact may be predicted.

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TABLE OF CONTENTS

INTRODUCTION Excessive heating occurs in cockpit materials such as display and control consoles due to proliferation of avionics and in fuselage walls in VSTOL aircraft due to ducting of hot gases past the cockpit. The high temperatures generated constitute a thermal hazard to the crewman, subjecting him to the risk of pain and burns on contact between bare skin and materials. The present study was undertaken to eliminate such hazard by enabling preselection of thermally safe construction materials during the engineering design phase. It establishes the biophysical data base and engineering guidelines for prediction of the highest permissible temperature specific materials may attain without causing pain or burn on contact.

METHOD The method for accomplishing this prediction entails four steps: (Step 1) experimental determination of pain threshold time at various temperatures of materials ranging in thermal properties from good conductors (metals) to good insulators (e.g., Masonite); (Step 2) calculation (from relationships obtained in earlier work) of time to minimal blister for each of these materials; (Step 3) extrapolation of the calculated data to the material temperature which will produce a blister on 0.3 sec contact with bare skin of minimal epidermal thickness, and (Step 4) establishment of curves for all materials studied relating material temperature, contact time to pain and to blister and thermal inertia (i.e., the product of thermal conductivity k, density ρ, and specific heat c).

In the first step it was necessary to establish, before collection of experimental data, that the subjects, two females and two males, had normal pain thresholds. The pricking pain threshold of each subject was measured in a standard manner (1) by exposing the volar surface of the forearm (a site chosen because it represents a uniformly thin area in the epidermis (2) to a radiant energy source, a commercially available Dolorimeter in which the shutter was modified to provide a truly square-wave pulse over a small area (1.3 cm diameter). The radiant flux required to produce the pain threshold in 3 seconds in all subjects was 300 $\pm$8% mcal/cm^{2}sec at an initial skin temperature of 32.5°C, the normal value at this initial temperature (2). In a similar manner pain threshold measurements were made on each of the three "test" fingers of each subject for use in estimating the thickness of the epidermis (3) in these areas.

In the experimental procedure six representative materials were heated to a given temperature (45°C to 195°C); the initial skin temperature of the finger, maintained at 32.5 $\pm$0.5°C, was measured radiometrically by the subject just before contact with the heated material; simultaneously, the temperature of the sample was measured radiometrically on a blackened corner of the specimen by an operator; contact was made at time zero and maintained until pain threshold was reached; the interface temperature was recorded throughout by a fine wire thermocouple attached to the finger (Figures 1, and 2).

In the second step pain threshold times measured in each material are converted to time to threshold blister on the basis of a relationship previously established (4) wherein the pain and blister parameters are virtually parallel (Figure 3). The procedure then consists of multiplying time to pain threshold by a factor of 2.5 to obtain time to threshold blister.

The third step required extrapolation of calculated blister time data to the material temperature which will produce a threshold blister instantaneously. This extrapolation cannot be made directly from the experimental curve because it tends to become asymptotic. Therefore, the calculated blister times were

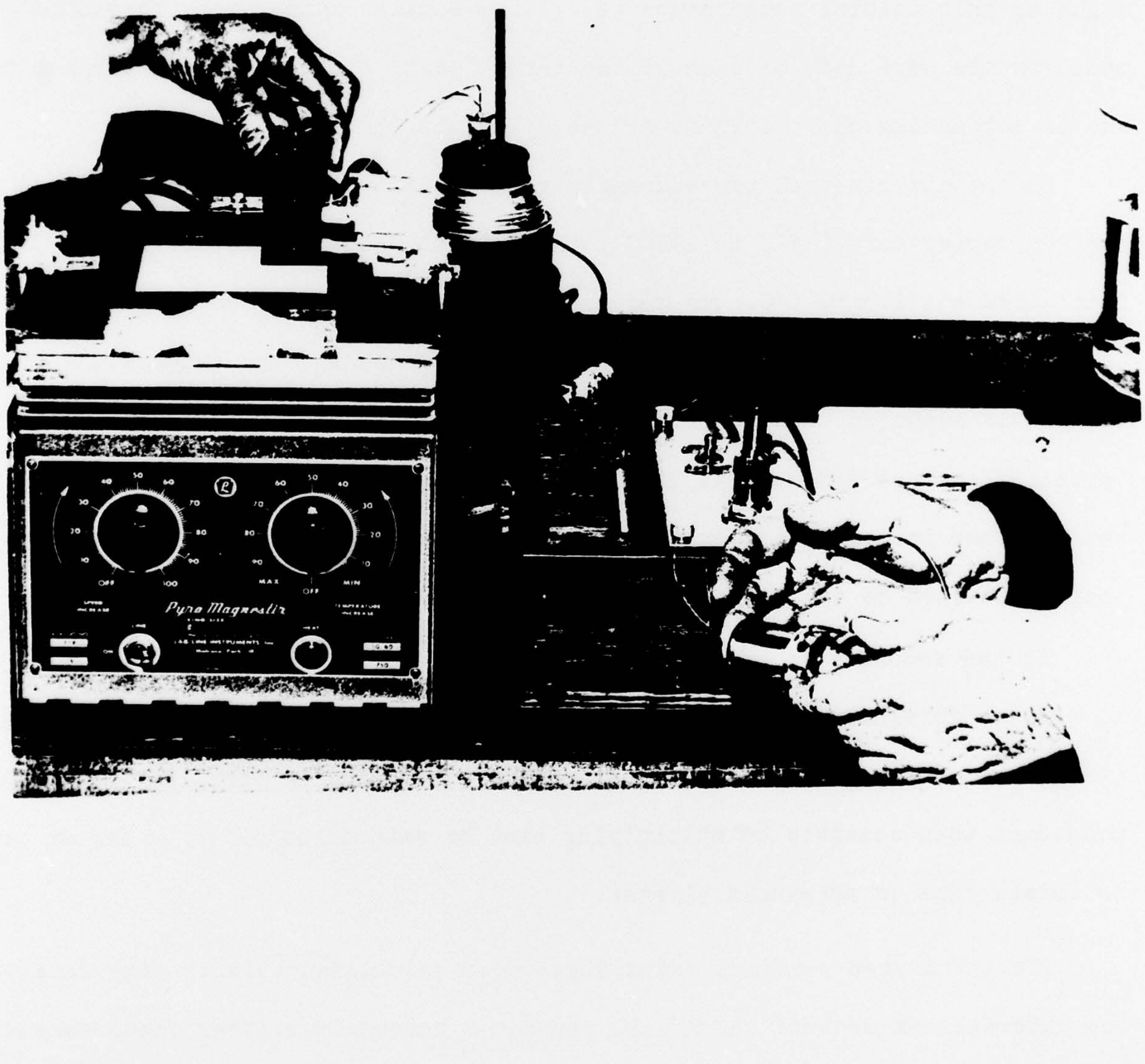

FIGURE 1 - Radiometric measurement of initial temperature of specimen and skin site.

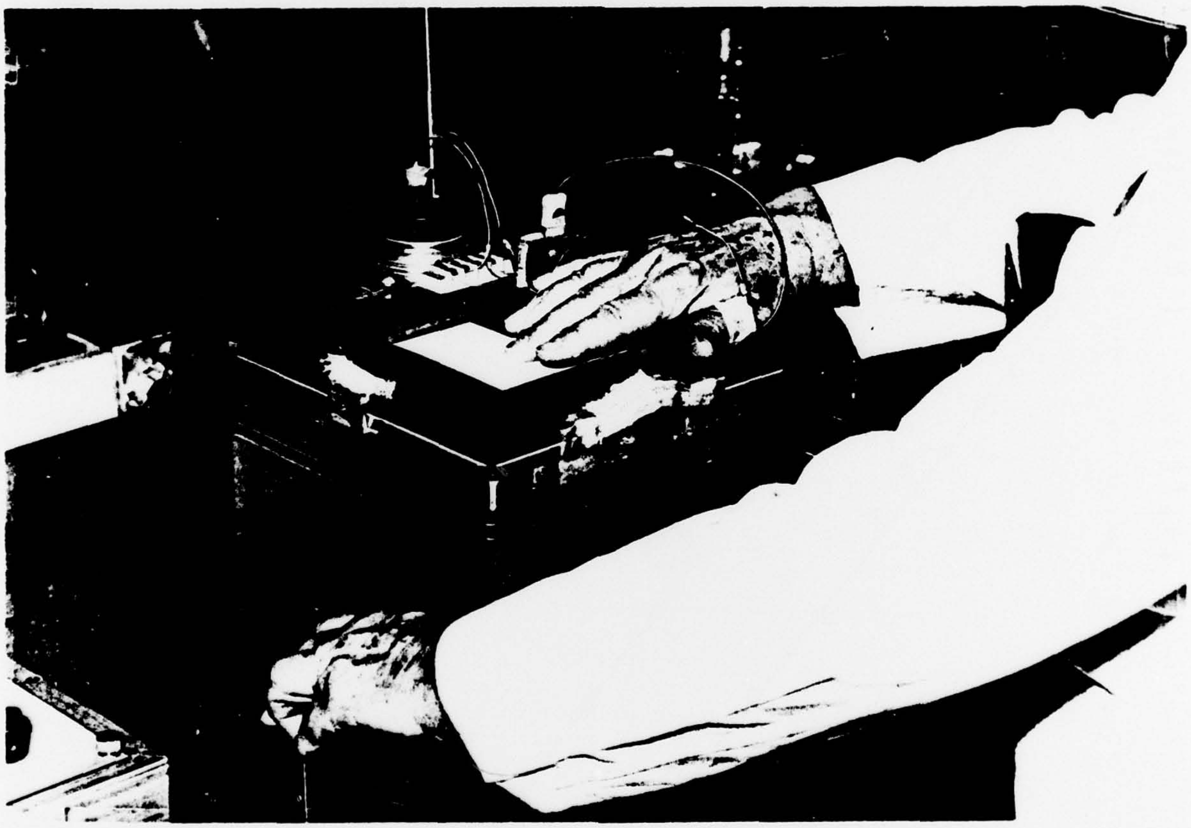

FIGURE 2 - Interface temperature recorded during contact to pain threshold end point.

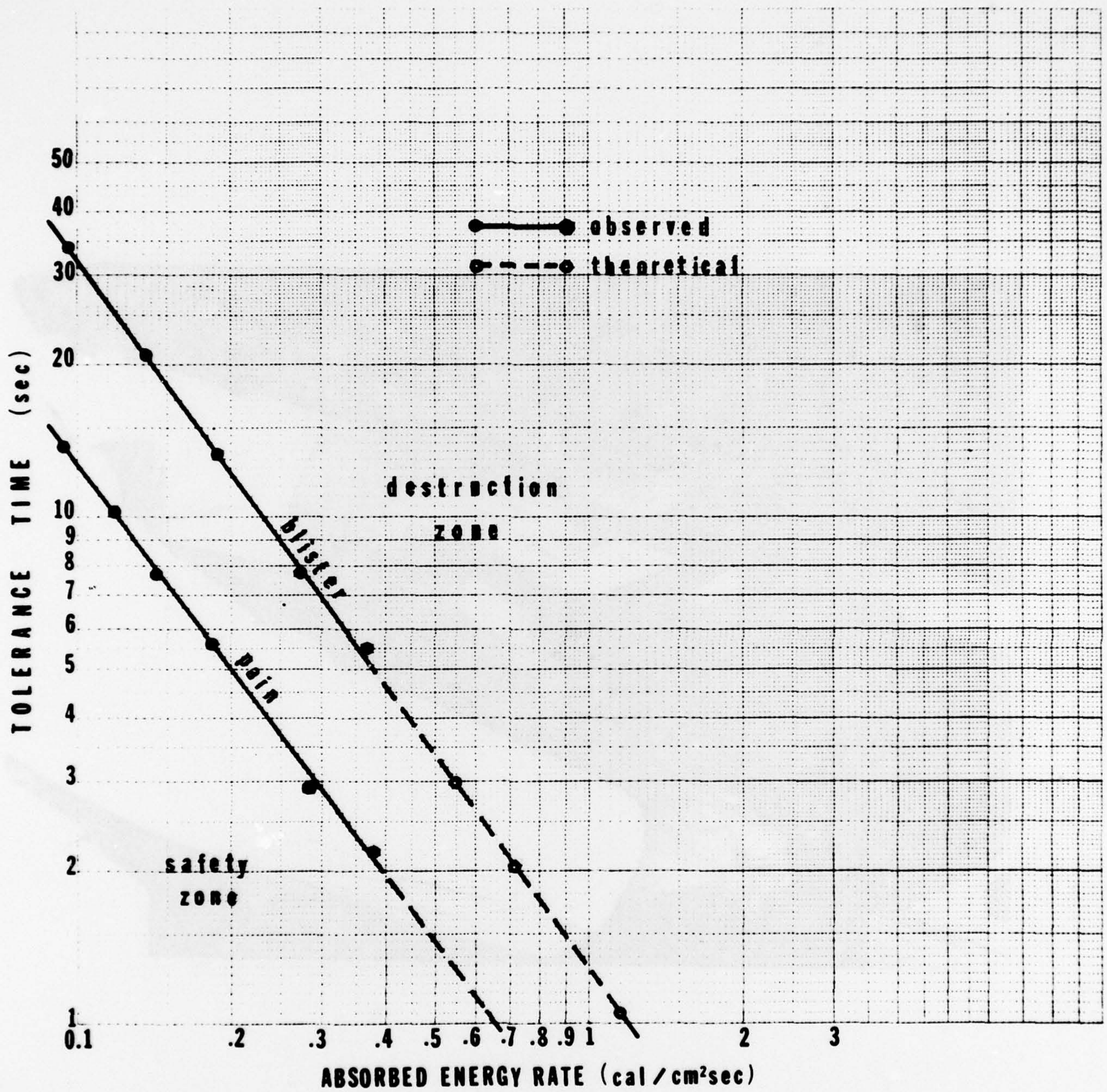

FIGURE 3 - Threshold pain and blister parameters, tolerance time vs energy absorption rate.

converted to reciprocals and this curve extrapolated to the material temperature corresponding to a contact time of 0.3 second, allowing 0.2 second for reaction time and an additional 0.1 second to ensure good contact.

Step four concerns the application of the observed data to selection of safe materials.

RESULTS AND DISCUSSION In all, over 2000 observations were made on the skin sites of four normal subjects exposed to six heated materials representing a wide range of thermal properties as shown in Table I.

In any one series of exposures, i.e., one material at different levels of temperature, the pain threshold end point was quite precisely identified so that, in most instances, smooth curves with very little scatter of individual points resulted (Figures 4, 5 and 6). However, the variation in end point from day to day within any one individual was sometimes as much as ±10% as might be expected with this method (1). Thus, the overall accuracy for one individual became about ±6.5%.

The data on any one subject in contact with a specific material yielded a different curve for each of three fingers of the same hand because of differences in the thickness of the epidermal layer (Figure 4). Since the effective depth of the pain receptors lies in the dermal layer, an increased thickness of the epidermis lengthens the heat transfer pathway to the receptors, changes the total conductivity and increases the time to pain perception. Figure 5 shows similar data for all four subjects using the right ring finger of each. At the longer pain threshold times there is little difference in the specimen temperature required to produce the end point, but at the shorter times, where the insulative properties of the epidermal layer exert the greatest effect, the difference in specimen temperature for the same pain threshold time between the

TABLE I

THERMAL PROPERTIES OF EXPERIMENTAL MATERIALS

Material	$k \times 10^{-3}$ $\frac{cal}{sec\,^{\circ}C\,cm}$	ρ $\frac{gm}{cc}$	c $\frac{cal}{gm\,^{\circ}C}$	$k\rho c \times 10^{-3}$ $\frac{cal^2}{cm^4\,^{\circ}C^2\,sec}$	$\frac{1}{\sqrt{k\rho c}}$
Aluminum	370	2.70	0.23	230	2.09
Steel	103	7.84	0.067	54	4.30
Hercuvit	4	2.50	0.20	2.00	22.36
Glass	1.94	2.50	0.20	0.97	32.11
Teflon	0.58	2.15	0.25	0.31	56.64
Masonite	0.413	1.00	0.40	0.165	77.80

k = thermal conductivity, ρ = density,

c = specific heat, $k\rho c$ = thermal inertia

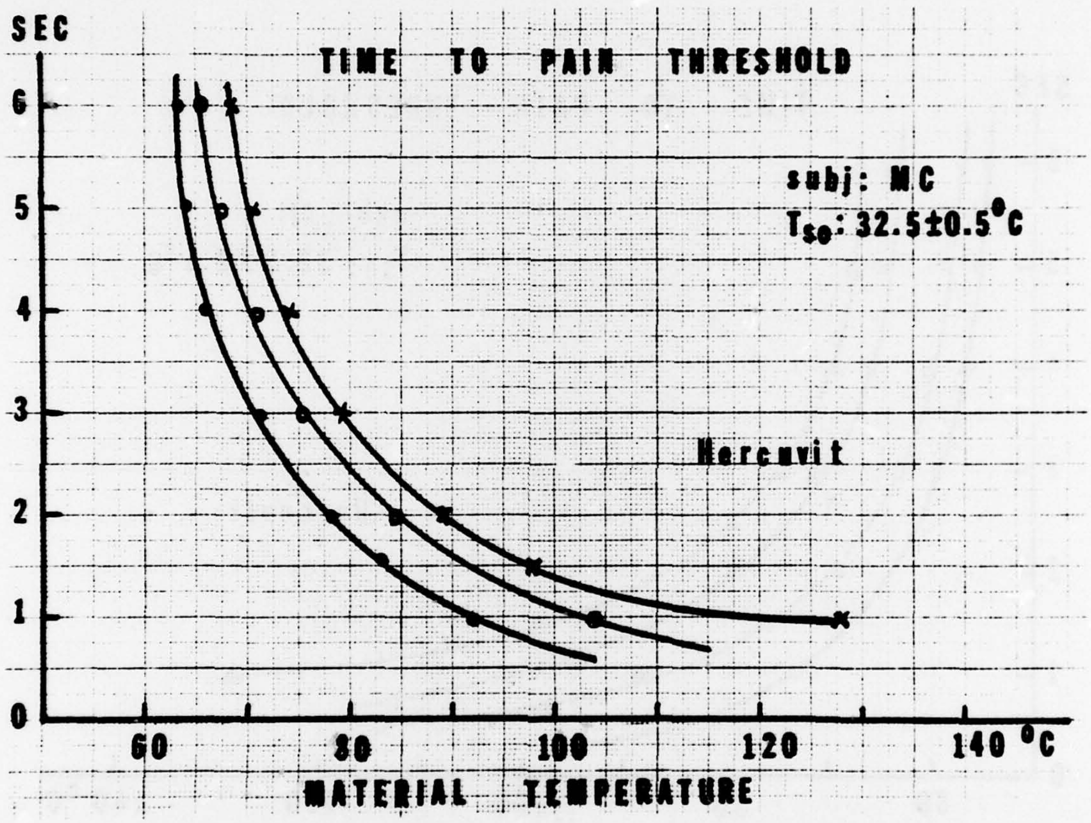

FIGURE 4 - Pain threshold time vs material temperature, three fingers of same hand, one material.

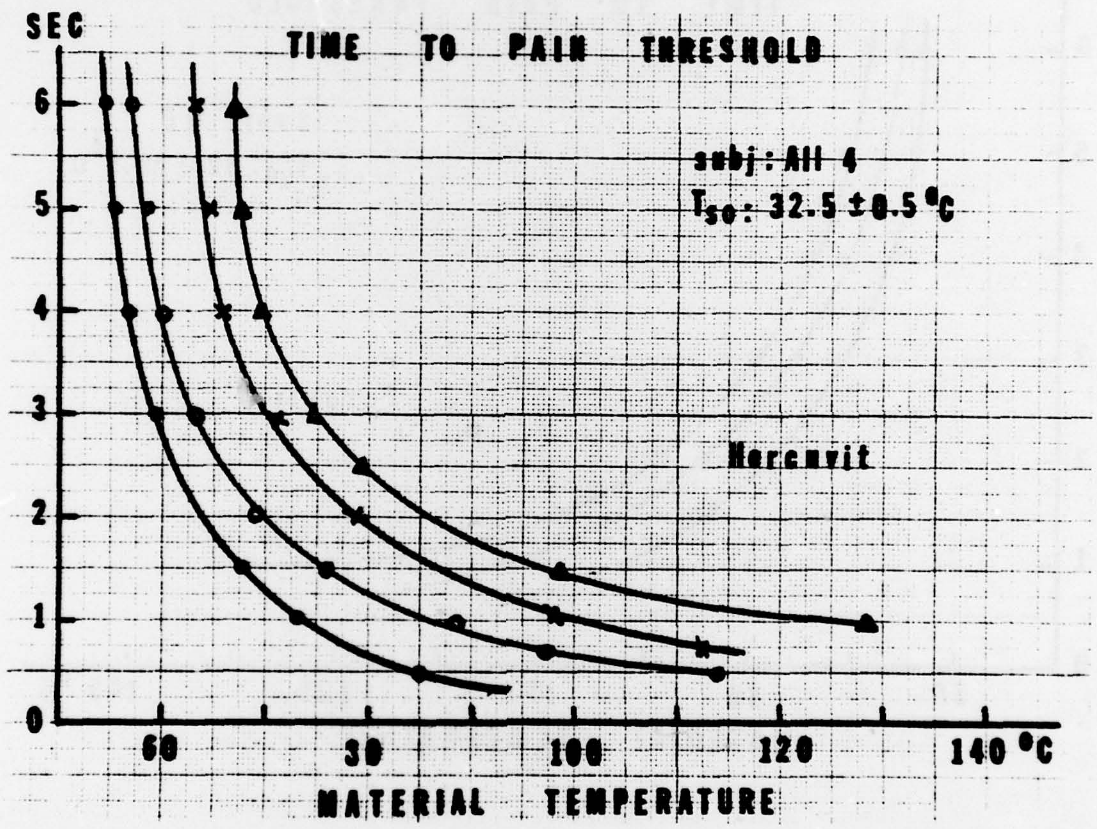

FIGURE 5 - Pain threshold time vs material temperature, ring finger of four subjects, one material.

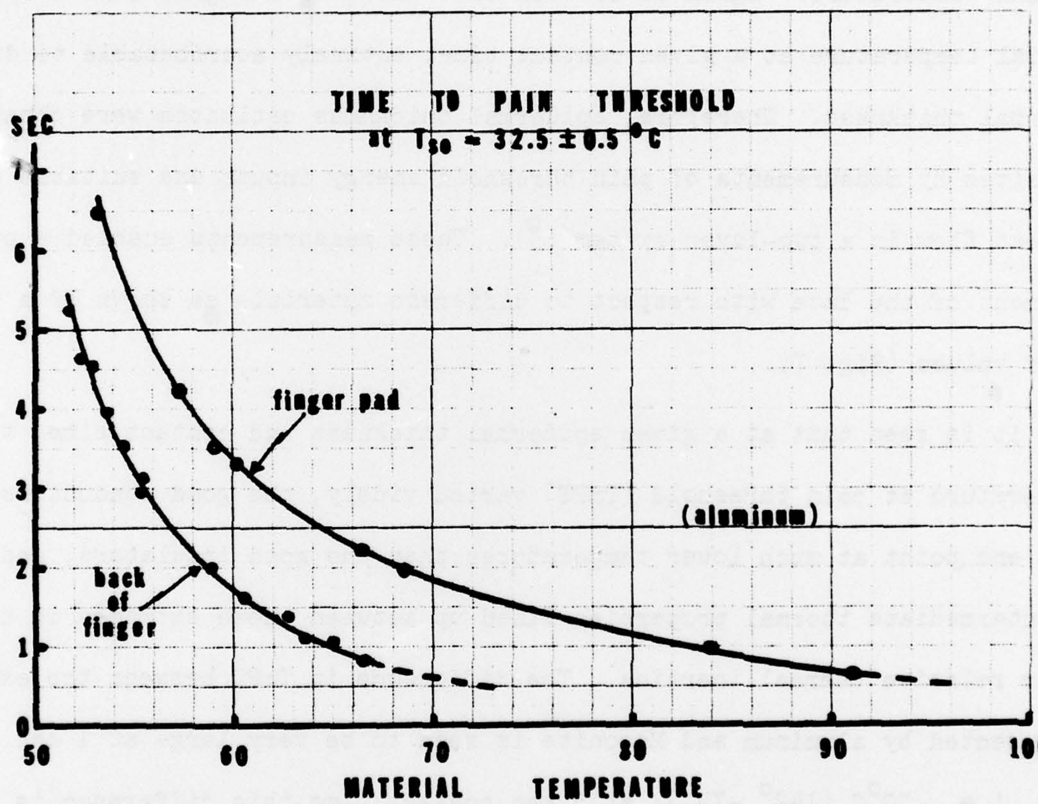

FIGURE 6 - Pain threshold time vs material temperature finger pad and back of same finger, one material.

subjects having the thinnest and the thickest epidermis is significant, in this instance 55°C at the 1 second level. To further illustrate the effect of epidermal thickness, data from exposures of the finger pad and the back of the same finger are shown in Figure 6.

Under this experimental condition there can be no question of individual differences in conductivity or other thermal properties accounting for the increase in time or material temperature. Again it is seen that there is a significant difference in material temperature at a given contact time, entirely attributable to difference in epidermal thickness. Therefore, epidermal thickness estimates were obtained on all test sites by measurements of pain threshold energy inputs and suitable equations for heat flow in a two-layer system (3). These measurements enabled a systematic treatment of the data with respect to different materials as shown by a typical set of values (Fig. 7).

Here it is seen that at a given epidermal thickness and contact time, the material temperature at pain threshold (TmPT) varied widely, the good conductors producing this end point at much lower temperatures than the good insulators, and materials of intermediate thermal properties lined up between these extremes in the order of their relative thermal inertias. The difference in TmPT between the extremes represented by aluminum and Masonite is seen to be very large at 1 sec contact time, i.e., 70°C (142° -72°); at 5 sec contact time this difference is reduced to 31° (85° -54°); still a very appreciable amount. Similar families of curves can be drawn for different epidermal thicknesses. These curves shift to higher temperatures at greater thicknesses and lower temperatures at lesser thicknesses but always arranged in the same relative positions with respect to the thermal properties of the materials. Such differences across the whole spectrum of properties points up the thermal safety advantages to be gained by careful selection of materials designed for use in specific applications.

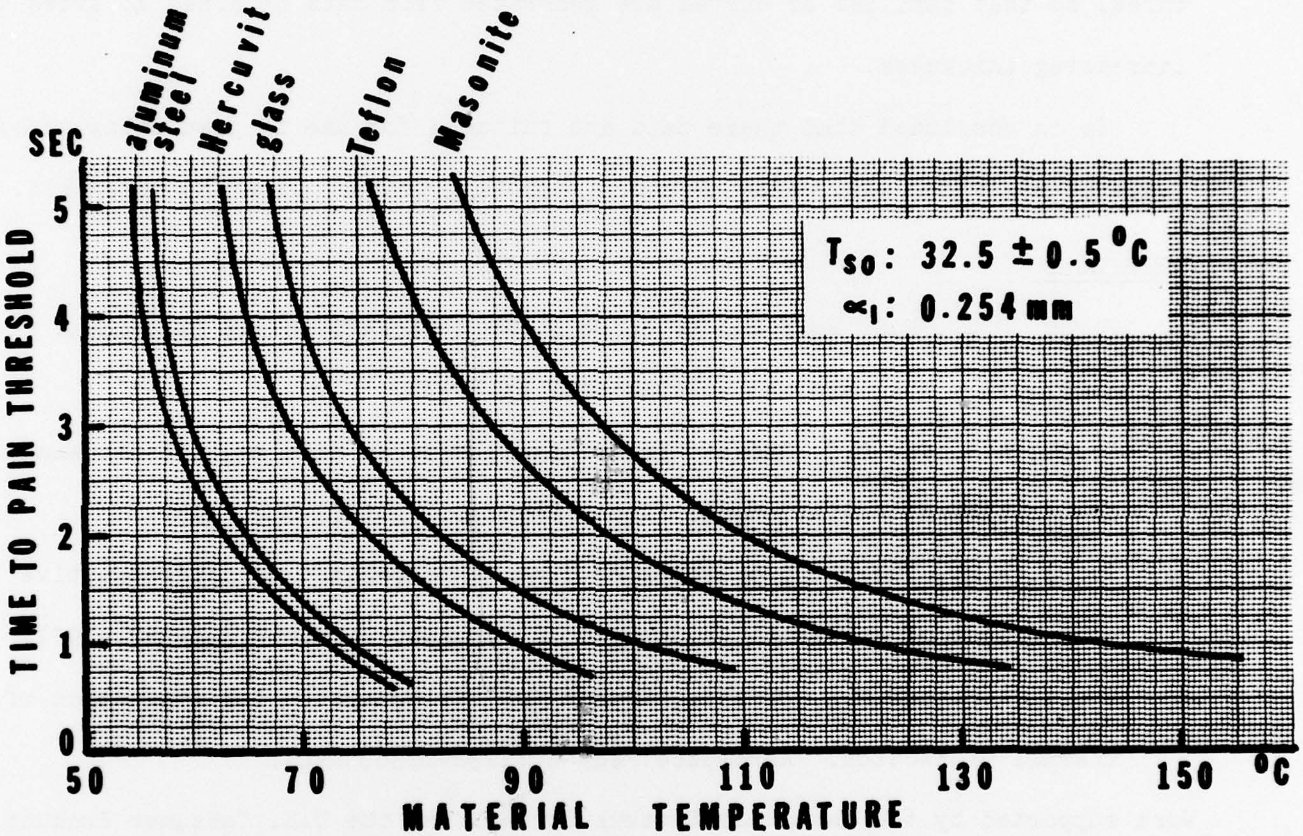

FIGURE 7 - Variations in time to pain threshold at given temperatures due to differences in thermal properties of materials.

CONCLUSIONS The results reveal an orderly relationship between pain threshold time and the temperature of each material, either long exposures or higher specimen temperatures being associated with better insulative properties. Variations in the thickness of the epidermis further affect these times and temperatures, so that families of curves are generated from data obtained at sites of increasing thickness.

It is concluded that these data are suitable for use in predicting material temperatures which will cause blisters following contact with the bare skin.

REFERENCES

1. Hardy, J.D., H.G. Wolf and H. Goodell, Pain Sensations and Reactions. Baltimore: Williams and Wilkins 1952 pp 80-85.

2. Stoll, A.M. and L.C. Greene, Relationship between pain and tissue damage due to thermal radiation. J. Appl. Physiol. 14:373-382, 1959.

3. Stoll, A.M., Thermal properties of human skin related to nondestructive measurement of epidermal thickness. J. Invest. Derm. 69:328-332, 1977.

4. Stoll, A.M. and M.A. Chianta, Method and rating system for evaluation of thermal protection. Aerospace Med. 40:1232-1238, 1969.

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