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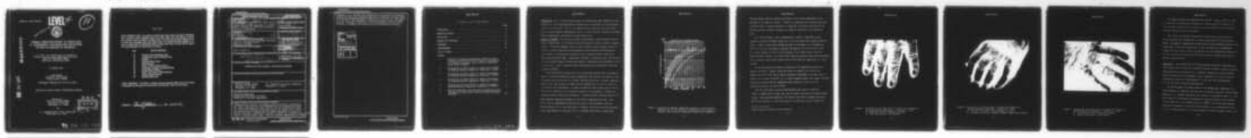

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THERMAL CONDUCTION EFFECTS IN HUMAN SKIN: II. EXPERIMENTAL VALIDATION AND APPLICATION OF DATA IN SELECTION OF MATERIALS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

Experimental production of threshold blisters at material temperatures and contact times predicted from measurements of pain thresholds validated the concept underlying this study, that is, that the relationship between pain and blister thresholds established earlier for radiant and for convective heating could be extended into the region appropriate to conductive heating to provide a simple factor by which to convert pain threshold contact times to threshold blister times. From the successful demonstration of this

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20. thesis, it is concluded that extrapolation of converted pain threshold temperature-time values determined empirically constitutes a reliable means of predicting maximum permissible temperature of materials for safe contact with bare skin. The information so derived pertinent to areas of minimal epidermal thickness is presented in chart form suitable for use in pre-selection of thermally safe construction and manufacturing materials.

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INTRODUCTION Part I of this study provided the experimental data required for the prediction of the maximum permissible temperature of any material for non-injurious contact with bare skin. Part II, the present report, describes the use of these data to predict material temperatures which will cause blisters virtually on contact and the experimental verification of these predictions.

METHOD AND RESULTS The raw data obtained by measurement of pain threshold time at various temperatures of each material used were plotted as shown in Part I, Figures 4 and 5. From these averaged, best-fit pain threshold curves, similar curves for threshold blister temperature-time parameters were calculated by multiplying by the constant 2.5 relating pain threshold time to threshold blister time at the same energy absorption rate. These data, converted to reciprocal time, were plotted on semi-log paper against corresponding material temperature and extrapolated to the 0.3 sec level. Figure 1 presents these extrapolations for the subject having the thinnest epidermis.

Since the predicted values were now two operations removed from the observed data, to verify the predicted blister temperature, each material was heated to the indicated level and the back of a finger (representing minimal epidermal thickness, approx. 80 μ) was brought in contact with the specimen for 0.3 sec as closely as the subject could approximate. As might be expected, some contacts were too short and some too long but for all practical purposes it was possible to bracket the threshold blister value quite accurately. A minimal blister occuring within 24 hr after exposure indicated attainment of the correct temperature and time. Only four of the six experimental materials were used in this procedure; steel was omitted because of its close similarity to aluminum, and Teflon was omitted because at the high temperature required (177°C) it expanded excessively, bulging away

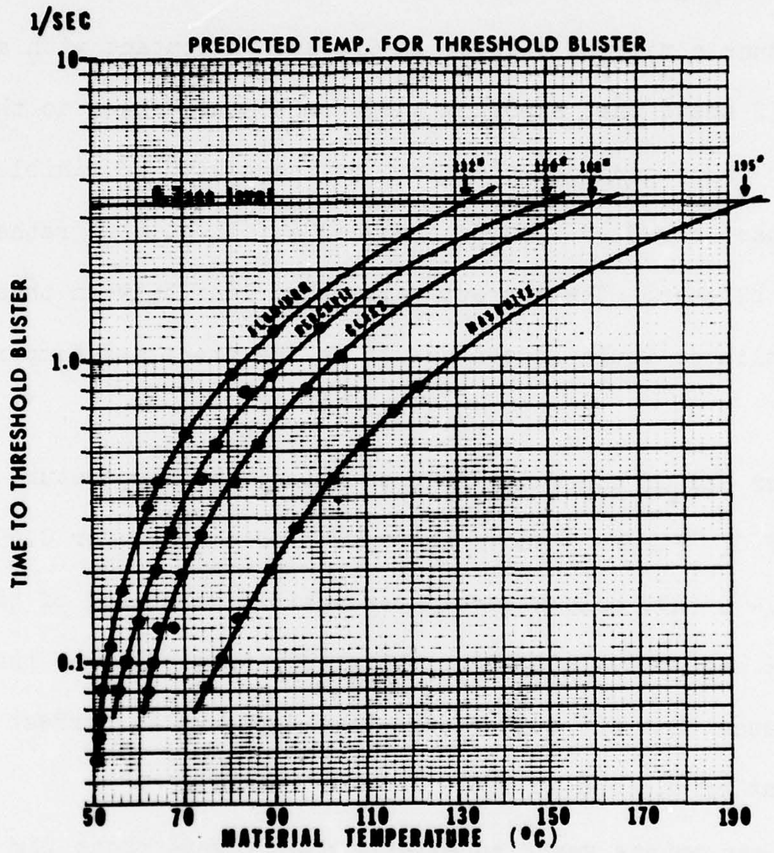

FIGURE 1 - Prediction of material temperature required to cause threshold blisters from 0.3 sec contact by extrapolation of reciprocal of exposure time vs material temperature along blister parameter.

from the heater plate and causing uncertainty in the actual temperature of the specimen at the moment of contact. However, the remaining four materials provided sufficient span in thermal properties to establish the blister end points at the extremes and key locations throughout the range of properties of the materials used.

It is seen in Figure 1 that a temperature of 132°C is indicated as that required to produce a minimal blister in 0.3 sec in contact with aluminum (6061-T6 alloy). Figure 2 shows that exposing the back of the finger to the aluminum at 132° for 0.2 sec (A) produced a transient erythema with no visible effect after 24 hr while contact for 0.45 sec (B) produced a full blister rather than the desired minimal blister. The correct value then lies between these times indicating that a minimal blister would indeed result at the predicted temperature on 0.3 sec contact.

At the other end of the range of properties, the temperature indicated for Masonite was 195°C. Figure 3 shows the effect of contact for 0.29 sec with Masonite at 194.4°C (A), only a barely perceptible darkening of the skin, and in contact for 0.35 sec at 194.6°C (B), a blister slightly larger than minimal resulted, again good evidence that the temperature-time exposure is correct for the desired end point of 0.3 sec at 195°C.

The two other points verified experimentally were those for Hercuvit (106)*, a ceramic used in range tops, and for glass, and these too yielded similar results: The predicted temperature for Hercuvit was 149°C; erythema resulted at 149.3°C and 0.20 sec (A), and full blister at 149.6°C and 0.29 sec contact (B).

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*Sample supplied courtesy of PPG Industries.

FIGURE 2 - Verification of blister effect in contact with aluminum at predicted material temperature. Predicted T = 132°C
A. 132°C for 0.20 sec = Transient erythema
B. 132°C for 0.45 sec = Full blister

FIGURE 3 - Verification of blister effect in contact with Masonite at predicted material temperature. Predicted T = 195°C
A. 194.4°C for 0.29 sec = discoloration, no blister
B. 194.6°C for 0.35 sec = blister, slightly larger than threshold

FIGURE 4 - Verification of blister effect in contact with Hercuvit at predicted material temperature. Predicted T = 149°C
A. 149.3°C for 0.20 sec = transient erythema
B. 149.6°C for 0.29 sec = full blister

For glass the predicted temperature was 159.6°C. Trials at 160° for 0.46 sec and 0.29 sec produced full blisters; at 0.26 sec and 157°C, Figure 5 (A), only erythema followed while at exactly 0.30 sec and 158°C (B) the definitive standard threshold blister was obtained.

This series of exposures indicates that the blister end point is quite precise and that the extrapolation is usually within about 1°C of the correct value. Furthermore, temperatures corresponding to blister-producing contact times longer than 0.3 sec can be predicted even more reliably as the extrapolated distances become shorter, thus it is expected that the temperatures predicted for 0.5 sec contact will be within 0.5°C of the true value although these were not verified experimentally.

<u>APPLICATION</u> The working chart for finding maximum premissible temperature for safe thermal contact with skin of minimal epidermal thickness is shown in Figure 6. Using coordinates described by Wu (1), material temperature is plotted against material properties to the parameter of pain threshold at 1.0 and 3.0 sec and extrapolated values for "instantaneous" (0.3 sec) pain and "instantaneous" (0.3 sec) blister as verified experimentally.

To use this chart for identification of the maximum safe temperature of a given material, the engineer need know only the thermal properties of the proposed material, i.e., thermal conductivity (k), density (ρ) and specific heat (c). One then locates on the abscissa the appropriate value calculated as the reciprocal of the square root of the thermal inertia, $1/\sqrt{k\rho c}$. The corresponding maximum permissible temperature is found as the coordinate on the instantaneous blister (0.3 sec) parameter minus 1°C for minimal safety, or more for greater safety, the

FIGURE 5 - Verification of blister effect in contact with glass at predicted material temperature. Predicted T = 159.6°C
A. 157°C for 0.26 sec = transient erythema
B. 158°C for 0.30 sec = threshold blister

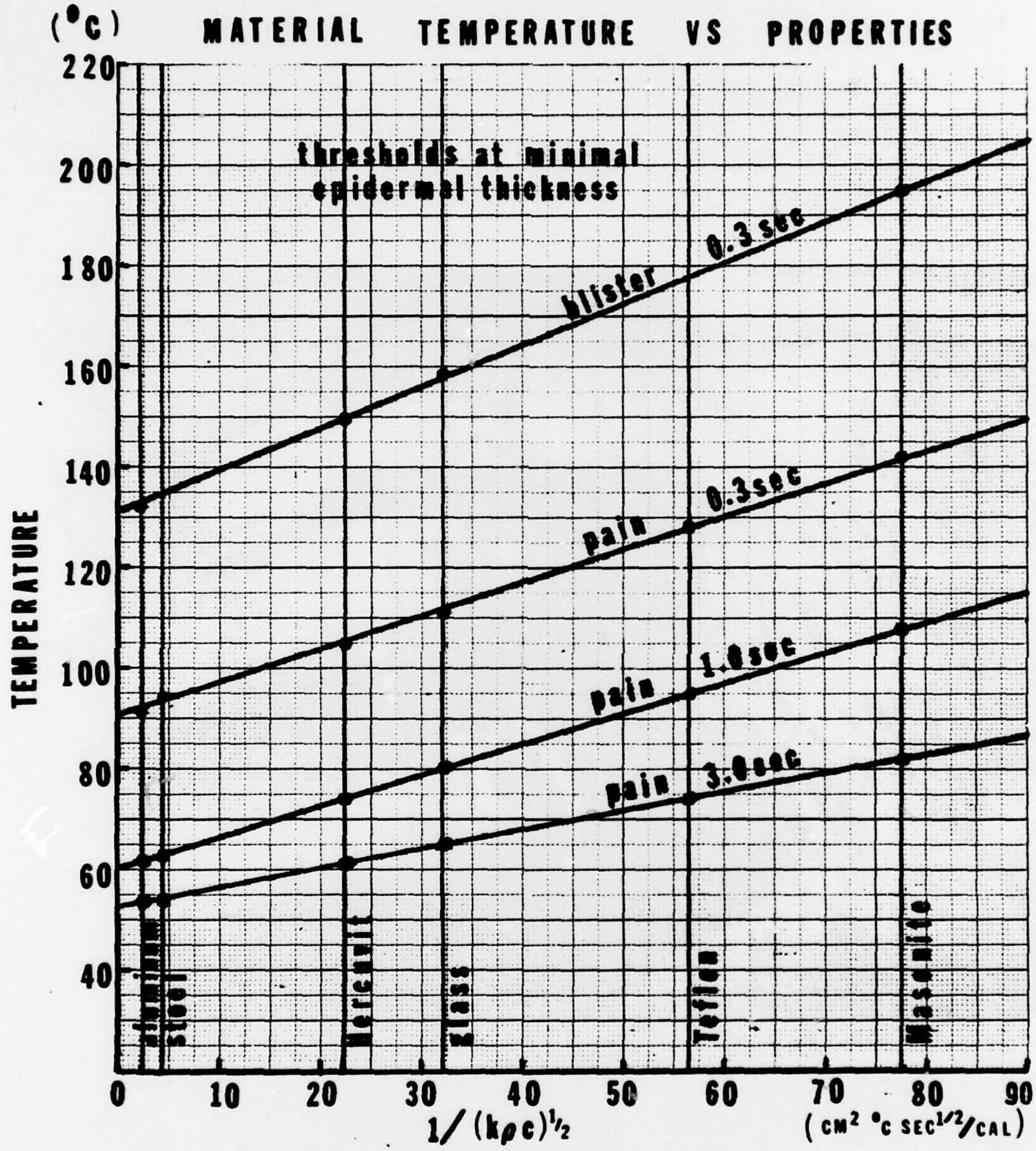

FIGURE 6 - Material temperatures and properties as functions of pain and blister at given contact times and minimal epidermal thickness.

latter margin at the discretion of the engineer. In considering the safety margin, it should be borne in mind that the accuracy of these data as applied generally should not be expected to be better than ±10%, the limits of the original data.

Should it be desirable to use the chart for selection of a safe material, the procedure is used in reverse order, i.e., the maximum anticipated temperature plus the safety margin is located on the ordinate, the coordinate found on the blister line and the corresponding thermal property value read off the abscissa. A search may then be made to identify a suitable material having the proper thermal inertia.

Additionally, if the material is mandated by the function it must perform, e.g., a metal for strength, and it is not possible to hold the temperature below the indicated injurious level, it is possible to select an insulative coating material to provide a safe surface. The thickness of the coating can be calculated from the thermal properties of both materials by use of heat flow equations for two-layer walls (2) and the "safe" temperature of the composite determined from the present chart. Trial specimens may be made up and tested for efficacy by means of the pain threshold determination technique described in Part I.

SUMMARY AND CONCLUSION Experimental production of threshold blisters at material temperatures and contact times predicted from measurements of pain thresholds validated the concept underlying this study, that is, that the relationship between pain and blister thresholds established earlier for radiant (3) and for convective (4) heating could be extended into the region appropriate to conductive heating to provide a simple factor by which to convert pain threshold contact times to threshold blister times. From the successful demonstration of this thesis, it is concluded that extrapolation of converted pain threshold temperature-time values determined empirically constitutes a reliable means of predicting maximum permissible temperatures of materials for safe contact with bare skin. The information so derived pertinent to areas of minimal epidermal thickness is presented in chart form suitable for use in preselection of thermally safe construction and manufacturing materials.

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