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THERMAL CONDUCTION EFFECTS IN HUMAN SKIN:
III. INFLUENCE OF EPIDERMAL THICKNESS AND EXPOSURE TIME

A.M. Stoll, J.R. Piergallini and M.A. Chianta
Aircraft and Crew Systems Technology Directorate
NAVAL AIR DEVELOPMENT CENTER
Warminster, Pennsylvania 18974

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Thermally safe material selection

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

Empirical data relating temperatures and thermal properties of materials to pain and blister end points have provided graphs and equations for predicting safe temperatures for any material in contact with bare skin for 1 to 5 seconds solely from a knowledge of its thermal properties. Conversely. the thermal inertia (kρc) of the optimal material for a specific use, and safe skin contact, can be predicted from a knowledge of the maximum material temperature and the length of contact time anticipated. (Continued)

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20. Increasing epidermal thickness causes an orderly elevation of the material temperature at pain threshold at fixed contact times, or lengthened contact times at fixed material temperatures, as indicated in the graphs and equations.

The data base and procedures described provide a simple means of evaluating the thermal safety of materials in contact with bare skin and pre-determining the kρc required for such safety in selecting suitable materials in myriad construction and manufacturing applications.

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INTRODUCTION Parts I and II presented the method of acquisition and partial analysis of the experimental data, the experimental validation of the concept that material temperatures which produce blisters on contact can be predicted from pain threshold measurements, and application of the data pertinent to minimal epidermal thickness in selection of safe materials. The present report encompasses the total body of data, its analysis in terms of effects of epidermal thickness and exposure time on maximum permissible temperature and its use in bioengineering applications.

EXPERIMENTAL DATA AND ANALYSIS After study of the minimal epidermal thickness data, the total body of information was reduced first manually and then by computer analysis. The observations used in deriving the correlations are the measured material temperatures for skin contact times of 1, 2, 3, 4 and 5 seconds. Using the coordinates of material temperature and material thermal properties described by Wu (1), the parameters defined by the threshold pain sensation resulted in families of curves for the different exposure times and various epidermal thicknesses.

Figure 1 illustrates the effect of exposure time on the material temperature at pain threshold (TmPT). These data were obtained from the ring finger pads of two subjects where epidermal thickness had been determined in an independent study (2) to be approximately the same, i.e., 0.249 and 0.259 mm. For graphic clarity, only the data for 1, 2 and 4 seconds are shown, the 3 second data, of course, lie between that of 2 and 4, and the 5 second data, slightly below the 4. The lines represent the best linear least squares solution for the respective data, having coefficients of determination between 0.990 and 0.999 throughout the entire range of data. The data range indicators show the extremes of variation from the mean of individual measurements of

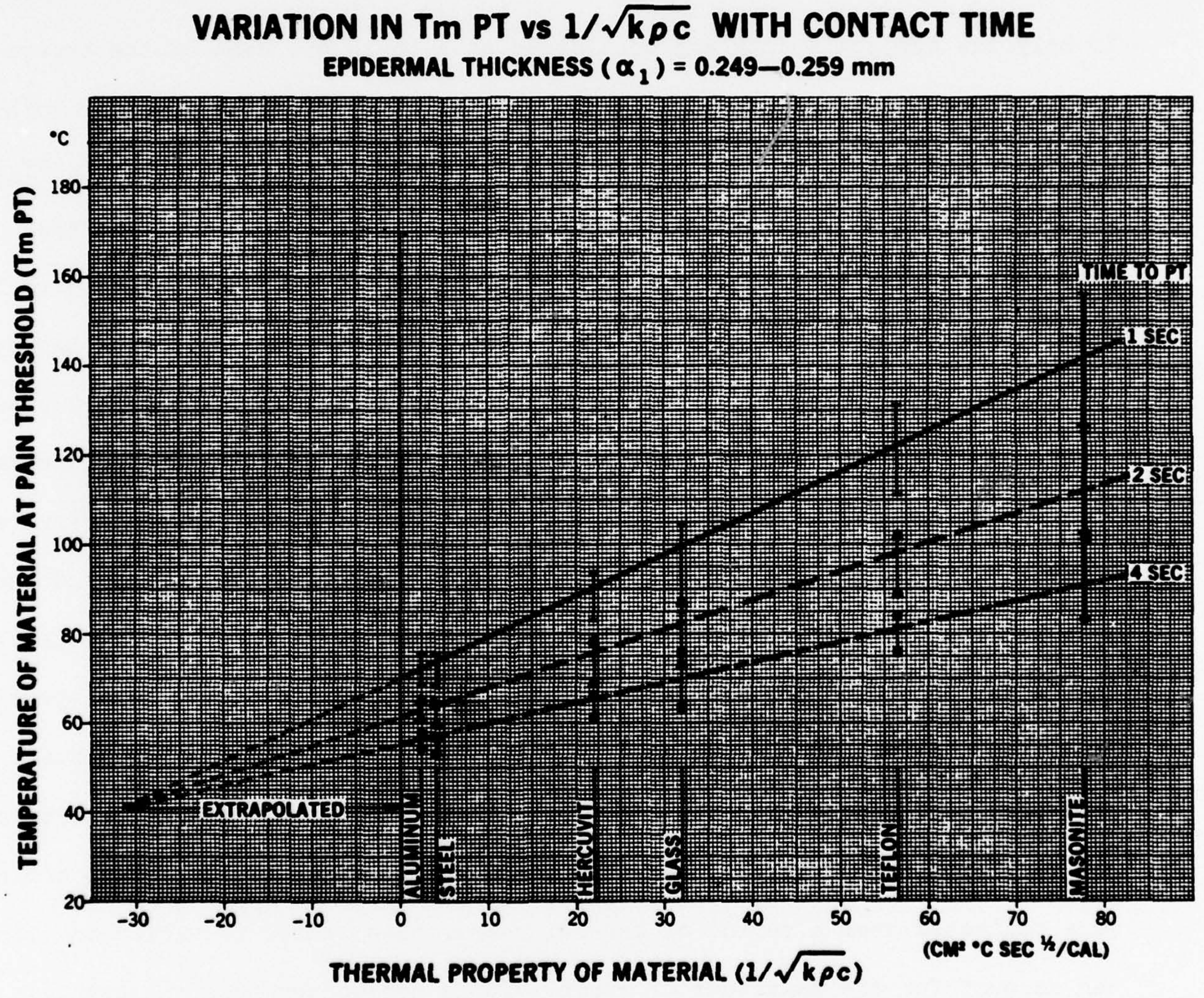


FIGURE 1 - Temperature and thermal inertia (kρc) as functions of pain threshold parameter for materials in contact with skin or given epidermal thickness (0.249 to 0.259mm) at three contact times (1, 2 and 4 seconds).

TmPT for each material at each exposure time for both subjects taken together. As seen in Table I where the graphic data for Figure 1 are tabulated, averaging the deviation from the mean at each of the six observation points throughout the range of material properties results in a variation of ±10.4% for the one second data for both subjects with a maximum of ± 11.2% and a minimum ±6.8%. The 2 and 4 second data are similar with somewhat smaller average deviations. If only one subject's data are considered at a time, the mean of the experimental observations falls slightly above or below that of the mean for both subjects depending upon whether α_1 is above or below the mean shown in Figure 1. As shown in Table I, Subject A and Subject B data, the variation from the individual's mean is smaller as would be expected. Again, the 1 second variation is greater than that for the longer times. However, considering the sources and magnitudes of experimental error inherent in these data, an overall standard deviation of ±10% is well within reasonable expectations. Even though instrumentation errors are of the order of ±1% and conditions of blood flow and resultant conductivity changes are minimized by strict control of surroundings and initial skin temperatures, there still exist the errors inherent in subjective data. The latter depend on the set point for the sensory perception, general physical condition and mood of the subject, reaction time and no doubt other subtle, undefined, influences with the net result that responses of trained subjects may vary from day to day as much as 5 to 10% (3). Since the data reported here were collected over a period of several years, this source of variation alone can account for the magnitude of error. It is noteworthy that the greatest error occurs in the 1 second data (Table I) both in the combined data and in the individual. This effect reflects the asymptotic nature of the material temperature vs contact time curves, e.g., Part I, Figures 2, 3 and 4 and is typical of all the data.

TABLE I

Deviation from the mean for data in Figure 1.

Contact Time	Deviation from the mean (±%)								
	Both Subjects (α_1*= 0.254mm)			Subj A (α_1 = 0.249mm)			Subj B (α_1 = 0.259mm)		
(sec)	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.
1	10.4	11.2	6.8	6.1	13.6	2.4	6.0	11.1	3.5
2	8.8	14.0	4.9	5.0	9.0	0.5	3.5	9.5	0.2
4	7.2	12.1	3.7	3.5	6.6	1.2	3.8	6.7	1.3

*** α_1 = epidermal thickness**

Figure 2 shows the mean and the experimental variations from the mean for 3 second exposures at different values of α_1. Table II shows numerically the average full range deviations from the mean and the extremes of these values.

The deviations are not remarkable. Figure 2 indicates that a four-fold increase in epidermal thickness results in an increase in TmPT of as much as 40°C at the insulator end of the material property range.

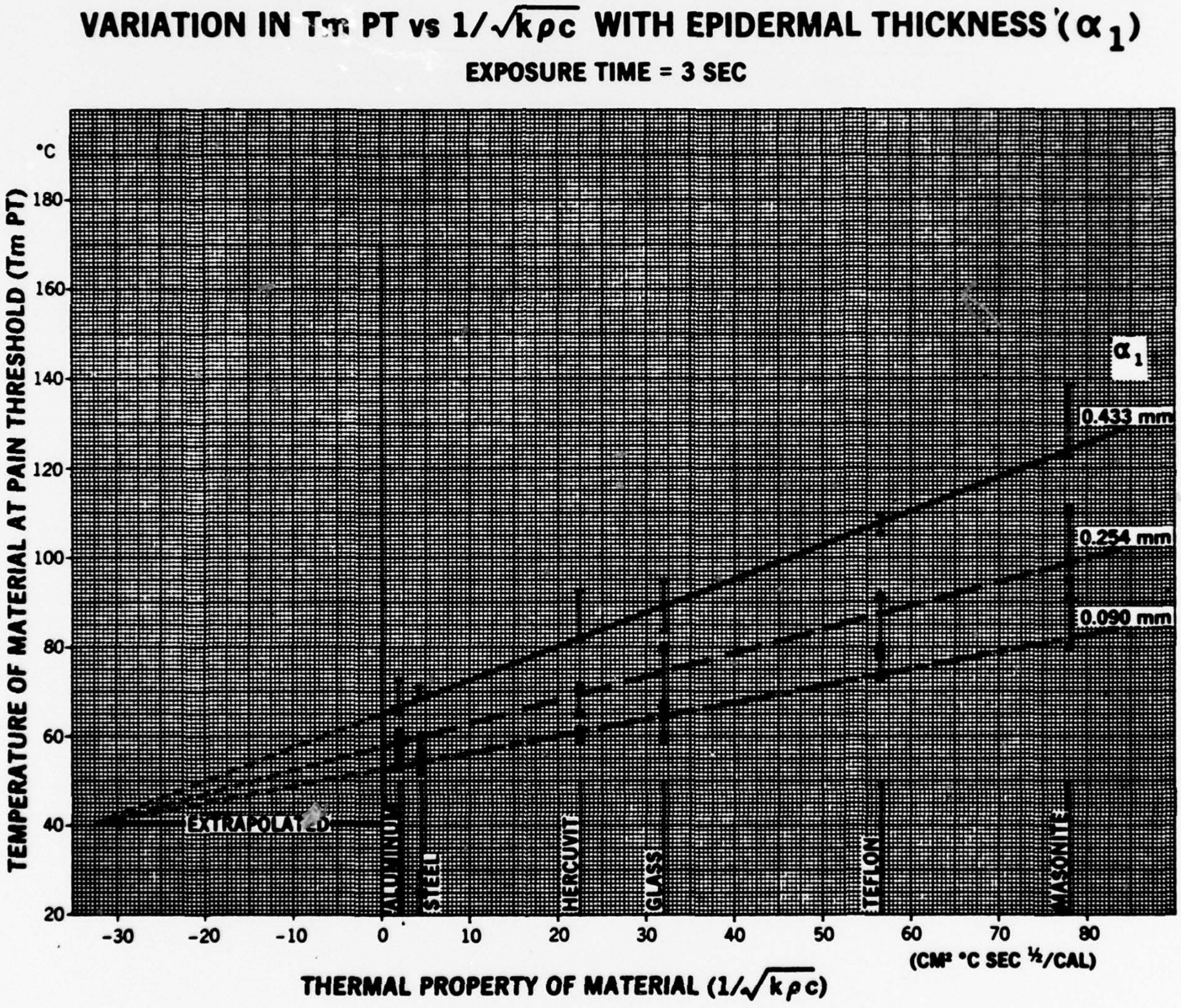
The linearity of the relationships shown in Figures 1 and 2 held throughout the entire body of observed data. Furthermore, in both instances, on extrapolation the lines converge at a point having the same coordinates, 41°C and -31.5 $cm^2\ ^oC\ sec^{\frac{1}{2}}/cal$. Because of the complex nature of the expression for thermal properties, $1/\sqrt{k\rho c}$, the biophysical significance of this fact is not immediately apparent. True, one might expect convergence at a temperature around 43°C, the firing temperature of the pain receptors inferred in an earlier study (4) since this occurence could be correlated with spontaneous pain, but the meaning of $1/\sqrt{k\rho c} = -31.5$ remains obscure. This point will be considered more fully in the discussion later. However, the mathematical convenience occasioned by this convergence greatly simplifies the identification of TmPTs as seen in the derivations to follow.

On realization that the data did indeed describe straight lines, they were analyzed by computer for linear least squares fit and the slope determined for each exposure time from 1 to 5 seconds at each α_1, using the slope intercept equation:

$$y = mx + b \qquad \text{Eq. 1}$$

where y = TmPT

m = slope



VARIATION IN Tm PT vs $1/\sqrt{k\rho c}$ WITH EPIDERMAL THICKNESS (α_1)

EXPOSURE TIME = 3 SEC

FIGURE 2 - Temperature and thermal inertia (kρc) as functions of pain threshold parameter for materials in contact with skin at a given contact time (3 seconds) at three epidermal thicknesses (0.090, 0.254 and 0.433mm).

TABLE II

Deviation from the mean for data in Figure 2.

Epidermal Thickness (mm)	Deviation from mean (±%)		
	Av.	Max.	Min.
0.090	3.9	6.6	1.5
0.254	6.1	12.8	2.3
0.433	6.5	8.9	1.8

$x = (1/\sqrt{k\rho c} + 31.5)$

$b = 41$ (intercept at translated x axis above).

The slopes so obtained were then plotted against the appropriate epidermal thicknesses and yielded the family of curves shown in Figure 3. It is seen that a semi-log correlation exists for each thickness at each exposure time. The equation of these curves is again the slope-intercept form of a straight line, this time in semi-log form:

$$\log yI = mx + \log b \qquad \text{Eq. 2}$$

where yI = slope of (TmPT vs $1/\sqrt{k\rho c}$) vs α_1

$x = \alpha_1$ (mm)

b = y intercept

Given the contact time and the epidermal thickness, the slope of any original data curve (TmPT vs $1/\sqrt{k\rho c}$) may be read from Figure 3 and applied in Equation 1 to find the applicable TmPT. However, to further simplify the process, the slopes and y intercepts of the curves in Figure 3 were plotted against the appropriate exposure times and yielded the correlations shown in Figure 4, straight lines in log-log coordinates. The mathematical expression descriptive of such lines is the power curve equation:

$$y = ax^{b} \qquad \text{Eq. 3}$$

where in one instance yII = slope of Figure 3 curves vs time

and in the other instance $yIII$ = intercept Figure 3 curves vs time

a = constant appropriate to data

b = constant appropriate to data

x = time (sec)

With these equations and the appropriate constants (a and b) it is possible to regenerate the original values of temperature at pain threshold for any material of known $k\rho c$ in a series of computations without recourse to the graphical data.

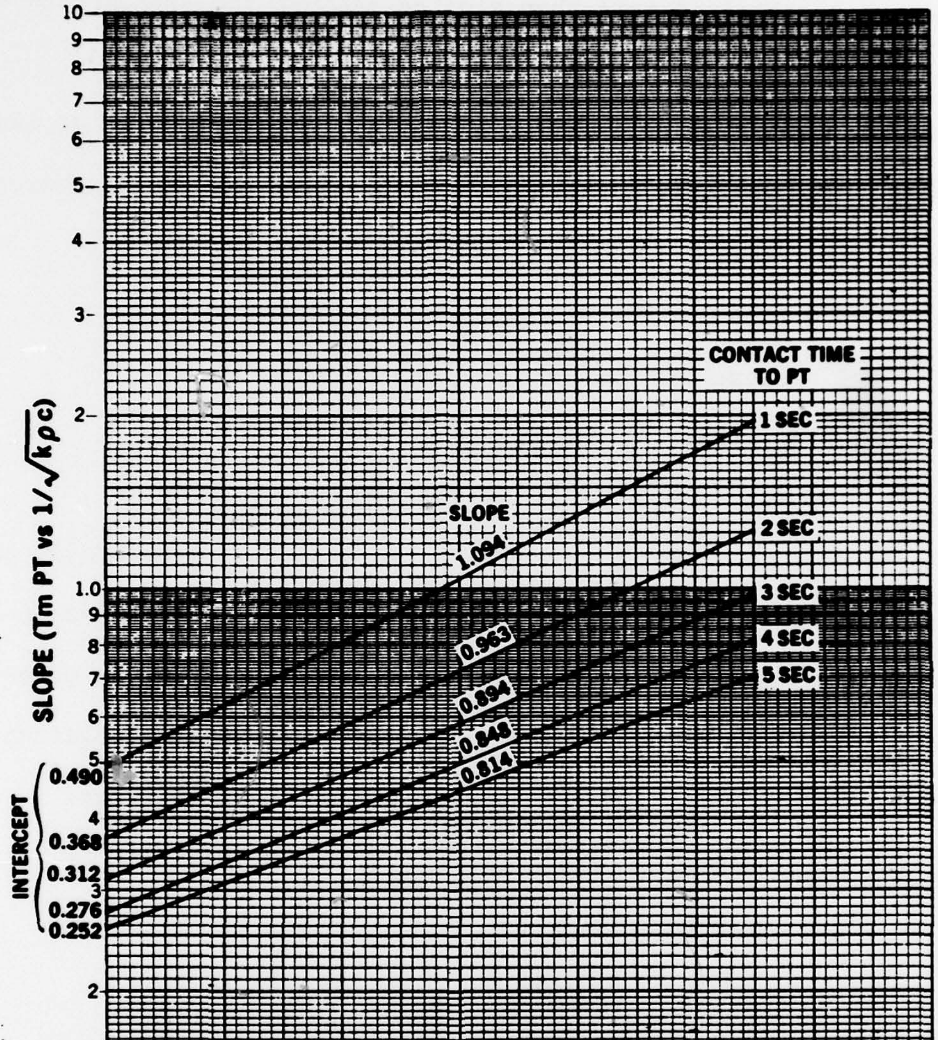


FIGURE 3 - Slope of (TmPT vs $1/\sqrt{k\rho c}$) vs epidermal thickness (0.5mm) at given contact times (1, 2, 3, 4 and 5 seconds).

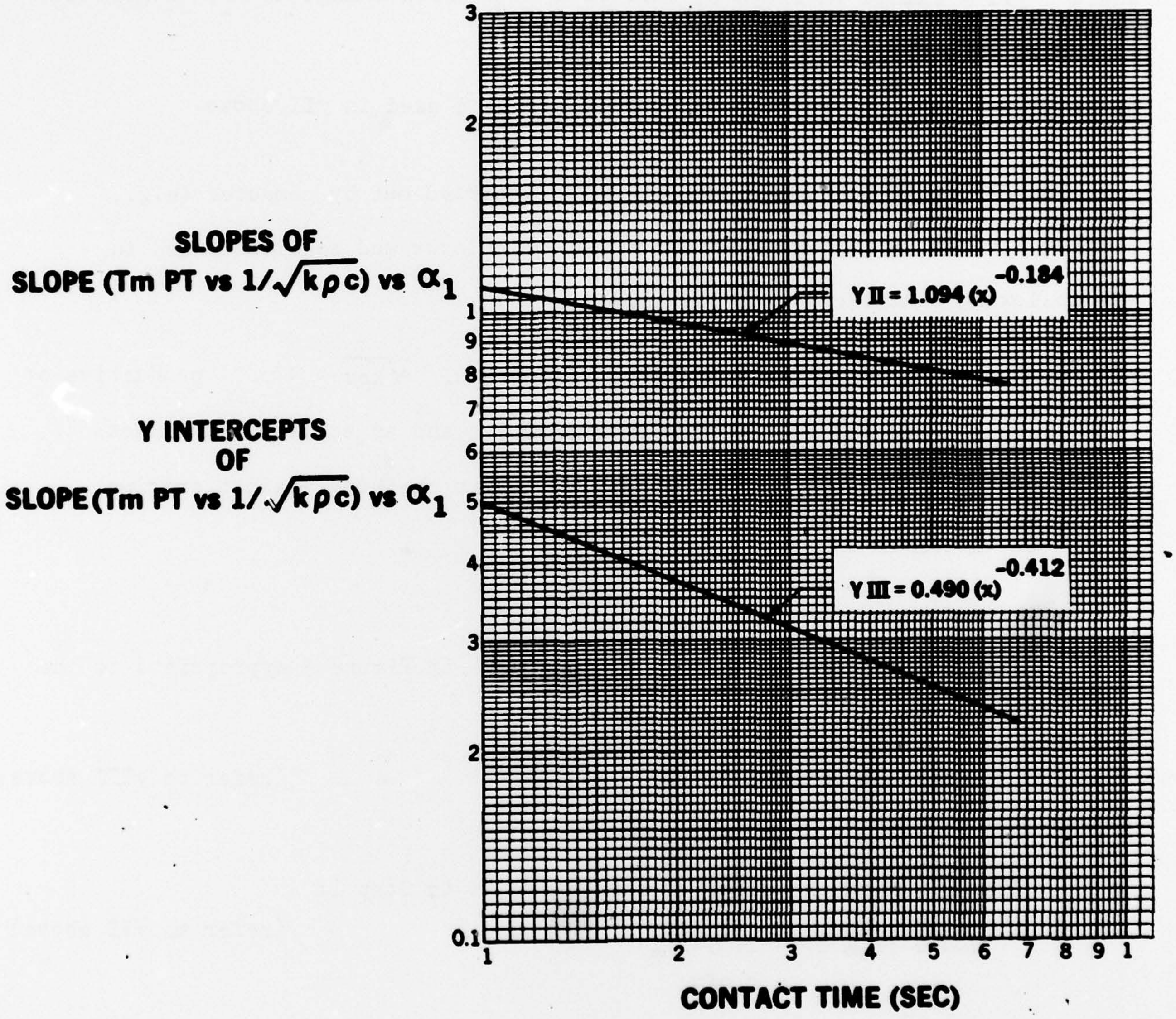


FIGURE 4 - Slopes (1.094 to 0.814) and y intercepts (0.490 to 0.252) of slope of (TmPT vs 1/$\sqrt{k\rho c}$)vs α_1 at contact times of 1 to 5 seconds.

For this purpose the least squares fit for yII and yIII curves in Figure 4 were generated and the constants determined as follows (Figure 5):

$$yII = 1.094\ x^{-0.184}$$

where yII = change in slope of TmPT vs $1/\sqrt{k\rho c}$ with change in α_1, (Figure 3);

$$yIII = 0.490\ x^{-0.412}$$

where yIII = intercepts of the curves in Figure 3 used in yII above.

The procedure for computing TmPT may be carried out by computer (e.g., Fortran Program, Appendix A), or on a hand calculator and is illustrated in the following example:

Problem: Find the temperature of Masonite ($1/\sqrt{k\rho c} = 77.80$) productive of threshold pain at an exposure time of 2 sec and an epidermal thickness of 0.254 mm. (Note: t and α_1, chosen to permit checking against original data in Figure 1).

Procedure:

Step 1 - Find the intercept of the curve in Figure 3 appropriate to the given exposure time:

$$\text{Intercept (Fig 3)} = 0.490\ (2)^{-0.412} \qquad \text{(refer to yIII above)}$$
$$= 0.368$$

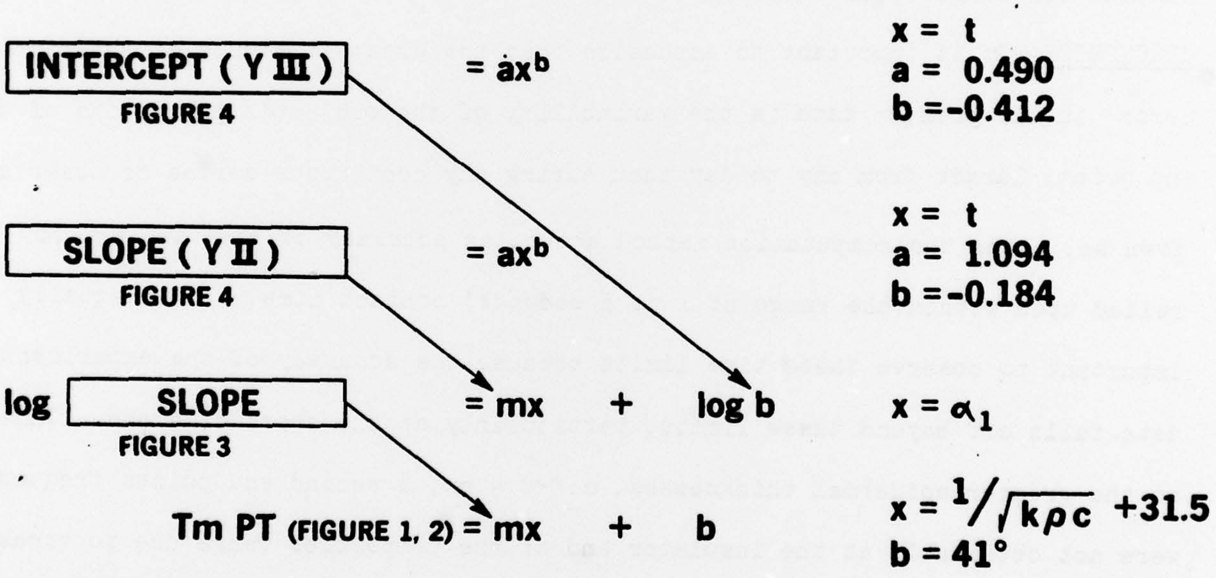
Step 2 - Find the slope of same curve as in Step 1:

$$\text{Slope (Fig 3)} = 1.094\ (2)^{-0.184} \qquad \text{(refer to yII above)}$$
$$= 0.963$$

Step 3 - Insert values from Steps 1 and 2 into equation of line in Figure 3 to find slope of appropriate curve in Figure 1:

$$\log \text{Slope (Fig 1)} = 0.963\ (0.254) + \log 0.368 \qquad \text{(refer to yI above)}$$
$$\text{Slope} = 0.647$$

MATERIAL TEMPERATURE AT PAIN THRESHOLD (TmPT) AT GIVEN CONTACT TIME (t = 1 to 5 SEC) AND EPIDERMAL THICKNESS ($\alpha_1 = 0.09$ to 0.50 mm)



INTERCEPT (Y III) FIGURE 4 $= ax^b$

$x = t$
$a = 0.490$
$b = -0.412$

SLOPE (Y II) FIGURE 4 $= ax^b$

$x = t$
$a = 1.094$
$b = -0.184$

log **SLOPE** FIGURE 3 $= mx + \log b$

$x = \alpha_1$

Tm PT (FIGURE 1, 2) $= mx + b$

$x = 1/\sqrt{k\rho c} + 31.5$
$b = 41^\circ$

FIGURE 5 - Equations for calculating any material temperature at pain threshold within the range of experimental data.

Step 4 - Find TmPT using slope from Step 3:

TmPT = 0.647 (77.80 + 31.5) + 41 (refer to y above)

= 111.7°C Ans.

(check against Figure 1)

Figure 6 presents an additional example in which t = 3 sec and α_1 = 0.09mm for contact with the same material (Masonite) to check against data in Figure 2.

In this manner the TmPT for each material at each given t and α_1, was retrieved and verified by the observed data throughout the experimental range of material properties from 2.09 to 77.80 $cm^2\ {}^{\circ}C\ sec^{\frac{1}{2}}/cal$, contact times from 1 to 5 seconds, and epidermal thickness from minimal, about 0.09 mm, to approximately 0.50 mm, maximum for finger pads measured.

DISCUSSION It is important to emphasize that the greatest source of experimental error in the present data is the variability of the subject's perception of the end point, larger from day to day than during any continuous series of observations. Even so, using the computation method above, an accuracy of $\pm 10\%$ in TmPT may be relied upon within the range of 1 to 5 seconds' contact time. It is equally important to observe these time limits because the accuracy of the experimental data falls off beyond these limits, particularly at the short time end. Indeed, at the greater epidermal thicknesses, $\alpha_1 \sim 0.4$ mm, 1 second end points frequently were not obtainable at the insulator end of the properties range due to breakdown of the specimen at the high material temperatures required (sometimes $> 200^{\circ}C$), and also, the development of soreness of the finger pads before reaching the pricking pain threshold. It is possible that at the high heat transfer rates associated with these contact times the superficial layers of the skin are dessicated almost instantaneously to some depth short of the pain receptors, changing the $k\rho c$ and disrupting the heat flow pattern characteristic of the

CALCULATE TmPT

where: $t = 3 \text{ sec}, \quad \alpha_1 = 0.09 \text{ mm}, \text{ and } 1/\sqrt{k\rho c} = 77.80 \text{ cm}^2\ ^\circ\text{C sec}^{1/2}/\text{cal}$

$$\begin{aligned} \text{Intercept (Y III)} &= ax^b \\ &= 0.490\ (3)^{-0.412} \\ &= 0.3116 \end{aligned}$$

$$\begin{aligned} \text{Slope (Y II)} &= ax^b \\ &= 1.094\ (3)^{-0.184} \\ &= 0.8938 \end{aligned}$$

$$\begin{aligned} \log \text{Slope (TmPT)} &= mx \quad + \quad \log b \\ &= 0.894\ (0.090) + (-0.5064) \end{aligned}$$

$$\begin{aligned} \log \text{Slope} &= -0.4259 \\ \text{Slope} &= 0.375 \end{aligned}$$

$$\begin{aligned} \text{TmPT} &= mx \quad + \quad b \\ &= 0.375\ (77.8 + 31.5) + 41 \\ &= 82.0\ ^\circ\text{C} \end{aligned}$$

FIGURE 6 - Procedure for calculating TmPT at any point within the range of experimental data.

region in contacts over 1 second long. At the opposite limit, 5 seconds, little difficulty is experienced. Beyond 5 seconds large differences in PT time may be observed at a given material temperature with occasional failure to reach the pain end point because of a burning sensation cycling just short of the pain threshold level. These occurrences are probably attributable to changes in blood flow brought on by relatively gentle warming of the skin resulting in large changes in $k\rho c$ (5). The cyclic burning sensation may be associated with periodic dissipation of heat from the locale of the pain receptors which then do not quite reach firing temperature.

In any event, the region of confidence, 1 to 5 seconds' contact time, must represent a region of stable $k\rho c$ reflective of the normal condition of the skin, i.e., neither dessicated nor vasodilated. The convergence of the extrapolated parameters, TmPT vs $1/\sqrt{k\rho c}$, at the point of 41°C and -31.5 cm^2 °C sec$^{1/2}$/cal suggests the possibility of a physical meaning of these coordinates. As mentioned earlier, the temperature level for firing of the pain receptors associated with threshold pain, the end point by which each parameter is defined, has been calculated to be about 43°C (4). Also, the value -31.5 cm^2 °C sec$^{1/2}$/cal is equal to the reciprocal negative root of a $k\rho c$ of skin of 1 x 10^{-3} cal^2/cm^4 °C^{2}sec, a frequently observed value for superficial layers of living skin without blood flow interference (2, 5, 6 and 7). Theoretically, given infinite contact time, one would expect the pain threshold parameters to level off at a material temperature commensurate with a receptor temperature of 43°C and the convergence point for finite times to be this value with the corresponding material property ($1/\sqrt{k\rho c}$), the coordinate of this point. Perhaps, the location of the convergence point on the negative side of the abscissa represents a negative heat flow and the material temperature indicated is indeed below that of the receptors. On the other hand, given an accuracy of ±10% in the original data, the extrapolated temperature at convergence falls within the range of experimental error, i.e., 41° is -4.7% different from 43°; the property coordinate at 43° is -25 $\mathrm{cm}^2\ {}^\circ\mathrm{C}\ \mathrm{sec}^{1/2}/\mathrm{cal}$, equivalent to a $k\rho c$ of skin of 1.6×10^{-3}. Since the latter figure lies midway between the extremes of the widely ranging values of measured $k\rho c$ of skin, variously reported as 0.5 to 2.3 $\times 10^{-3}$ (7), the difference between the convergence temperature and receptor firing temperature may not be significant. With measured values of the material-skin interface temperatures now available, it is anticipated that the uncertainty in these values can be much reduced but this analysis has not yet been done, therefore, while attributing real significance to the convergence point coordinates is attractive, it must be considered to be entirely speculation at this time.

That the computational system does not apply at contact times shorter than 1 second is evidenced by significant discrepancies between calculated TmPTs and those predicted by graphic extrapolation of reciprocal time to blister described in Part II of this series. (E.g., TmPT for Masonite at 0.5 sec calculated by equations 1 through 3, Steps 1 through 4 for α_1 = 0.09 mm yields a value of 133°C whereas reference to Figure 1, Part II at time to threshold blister = 0.8 in reciprocal units ($\frac{1}{0.5 \times 2.5} = 0.8$) yields a value of TmPT = 121°C). Since the graphic system was shown by experiment to predict blistering temperatures at 0.3 sec correctly to within 1°C, the graphically predicted temperatures intermediate between 1 and 0.3 sec must also be correct. Again, one must consider changes in the physical properties of both the skin and the materials as contributing to the breakdown of the computational relationship in this region. Nevertheless, as a mathematical device, extrapolation to convergence is convenient and entirely reliable within the experimental limits of 1 to 5 seconds' contact time. Suitable expressions describing the region below 1 second are currently under consideration.

It is possible to determine "instantaneous" pain and burn temperatures for sites of epidermal thickness greater than minimal by following the same procedure as described in Part II for sites of minimal thickness. These too should be verified by production of blisters at the predicted temperatures, but it is doubtful whether this effort would be of particular value aside from academic interest. Judging from the fact that few insulating materials can sustain the temperatures required for instantaneous (0.3 sec) blistering of skin at minimal α_1 without deteriorating, even fewer would be expected to remain intact at the higher temperatures required at greater thicknesses. For instance, in minimal epidermal thickness exposures, polypropylene ($1/\sqrt{k\rho c} = 92.88$) sheets, 1/8" (0.32cm) thick*, softened and deformed before even pain threshold was obtained; Masonite sections blackened and charred after a number of elevations to blistering temperatures ($\sim 200^{\circ}C$); and Teflon buckled and bulged at temperatures below that required for blistering. Materials of intermediate thermal properties such as glass and ceramics could withstand the elevated temperatures, as could the metals at the conductor end of the range, although changes in their kρc values might occur due to significant thermal expansion at these high temperatures. Such property changes could be measured and accounted for in the blister predictions but it is dubious that the research effort would be worthwhile inasmuch as epidermal thicknesses for the population in general would not be available for application in specific instances. On the other hand, the data from the minimal thickness studies provide a safe baseline for applications within the aerospace community.

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* Samples prepared and supplied courtesy of Dupont Company.

It is noted that many of the insulative types of materials will disintegrate before they can inflict burns instantaneously or even in reasonably short contact times (< 1 sec) in the adult. Ceramics and metals, however, can be hazardous and in possible skin contact with these materials at temperatures above the appropriate TmPT-thermal property parameter consideration should be given to protective measures such as guards, coatings and insulative devices.

SUMMARY AND CONCLUSION Analysis of the total body of empirical data relating temperatures and thermal properties of materials to pain and blister end points has provided a graphic system and a mathematical formulation for predicting safe temperatures for any material in contact with bare skin for 1 to 5 seconds solely from a knowledge of its thermal properties. Conversely, the thermal inertia ($k\rho c$) of the optimal material for safe skin contact can be predicted from a knowledge of the maximum material temperature and the length of contact time anticipated.

The effect of increasing epidermal thickness is an orderly elevation of the material temperature at pain threshold at fixed contact times, or lengthened contact times at fixed material temperatures. This effect is taken into account in the graphic and mathematical formulations.

It is concluded that the data base and procedures described constitute a simple means of evaluating the thermal safety of materials in contact with bare skin and of pre-determining the $k\rho c$ required for such safety in selecting suitable materials in myriad construction and manufacturing applications. In addition, these data have important applicability in nondestructive measurement of skin thickness and correlations of thermal pain and burn effects in conductive heating.

REFERENCES

1. WU, Y-C. Material properties criteria for thermal safety. J of Materials JMLSA, Vol 7, #4, 573-579, Dec 1972.
2. Stoll, A.M. Thermal properties of human skin related to nondestructive measurement of epidermal thickness. J. Invest. Derm. 69:328-332, 1977.
3. Hardy, J.D., H.G. Wolff and H. Goodell. Pain Sensations and Reactions, pp 80-85, Williams and Wilkins, Baltimore, MD., 1952.
4. Stoll, A.M. and L.C. Greene. Relationship between pain and tissue damage due to thermal radiation. J. Appl. Physiol. 14:373-382, 1959.
5. Lipkin, M. and J.D. Hardy. Measurement of some thermal properties of human tissues. J. Appl. Physiol. 7:212, 1954.
6. Kraning, K.K. Heat conduction in blackened skin accompanying pulsatile heating with a xenon flash lamp. J. Appl. Physiol. 35:281-287, 1973.
7. Chato, J.C. A survey of thermal conductivity and diffusivity data on biological materials ASME Paper No. 66-WA/HT-37, 1966.

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APPENDIX A

PRØGRAM TMPT

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00100 PRØGRAM TMPT(INPUT,ØUTPUT)
00110 PRINT 1
00120 1 FØRMAT(2X,36HMATERIAL PRØPERTY (1/SQRT(K*RH*C)) =)
00130 READ 2,XX
00140 2 FØRMAT(F15.0)
00150 X=XX+31.5
00160 PRINT 3
00170 3 FØRMAT(2X,*THICKNESS ØF SKIN IN MM =*)
00180 READ 2,THICK
00190 PRINT 4
00200 4 FØRMAT(2X,*TIME IN SEC =*)
00210 READ 2,TIME
00220 A3=1.094
00230 B3=-0.184
00240 Y3=A3*(TIME**B3)
00250 A2=0.490
00260 B2=-0.412
00270 Y2=A2*(TIME**B2)
00280 Y1=10.0**((Y3*THICK)+ALØG10(Y2))
00290 Y=(Y1*X)+41.0
00300 PRINT 5,Y
00310 5 FØRMAT(2X,*TMPT = *,F15.2)
00320 END
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THERMAL CONDUCTION EFFECTS IN HUMAN SKIN. III. INFLUENCE OF EPI--ETC(U)
JAN 79 A M STOLL, J R PIERGALLINI CPSC-77-0091
UNCLASSIFIED NADC-79035-60 NL

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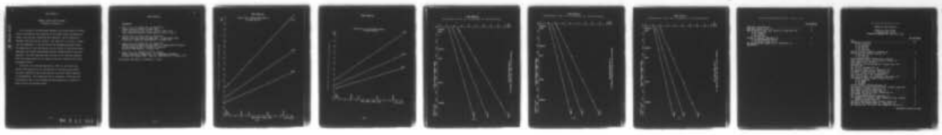
INFORMATION



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THERMAL CONTACT SAFETY CRITERIA
(Addendum to Reference 4)

At the request of aircraft design engineers the present series of working charts is provided for the evaluation of the thermal hazard of materials on contact with bare skin (touch-pain and touch-burn), and for selection of thermally safe materials for cockpits. The charts are to be used in conjunction with References 1-4 and are suitable for engineering guidance during the design phase of new constructions and for retrofit in applications where experience has revealed unsatisfactory thermal characteristics of existing materials. The lines represent exact solutions of the pertinent equations while the plotted points are the computer print-outs rounded to the nearest even-number values.

In practice, the indicated temperatures (TmPT) for safe short-time contacts with materials at the insulator end of the abscissa may exceed the actual temperatures which some materials may attain without degrading or disintegrating. This eventuality must be considered in selecting suitable materials with a view to permitting high temperatures to prevail because of their low pain/burn hazard.

REFERENCES:

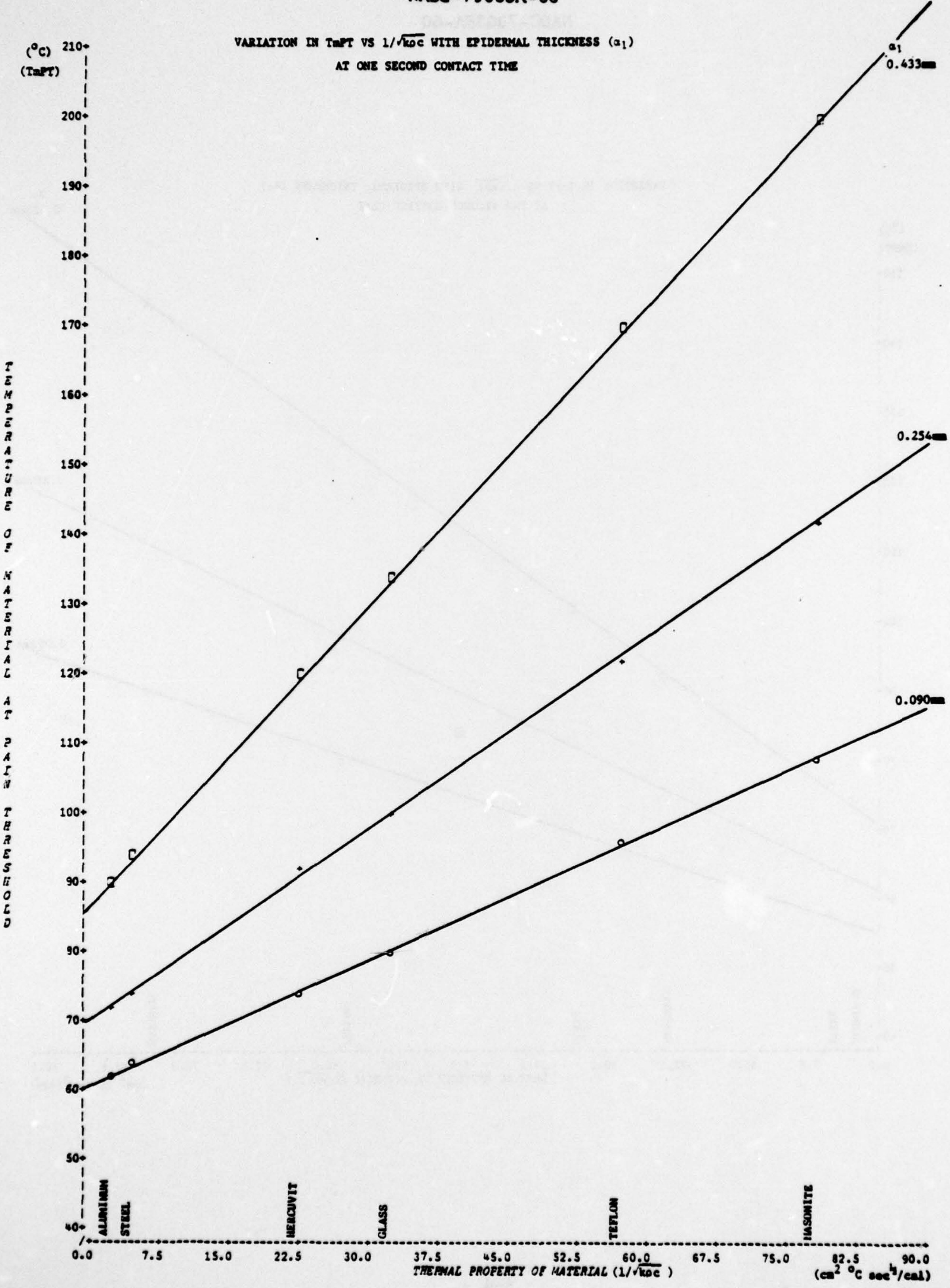
1. Stoll, A.M., M.A. Chianta and J.R. Piergallini.
Thermal Conduction Effects in Human Skin.
Aviat. Space Environ. Med. 50 (8): 778-787, August 1979.
(Open literature synopsis of NADC reports in ref 2, 3 and 4).

2. Chianta, M.A., A.M. Stoll and J.R. Piergallini.
Thermal Conduction Effects in Human Skin: I. Experimental Data Acquisition. Report No. NADC-79033-60, 15 January 1979.

3. Stoll, A.M., M.A. Chianta and J.R. Piergallini.
Thermal Conduction Effects in Human Skin: II. Experimental Validation and Application of Data in Selection of Materials.
Report No. NADC-79034-60, 15 January 1979.

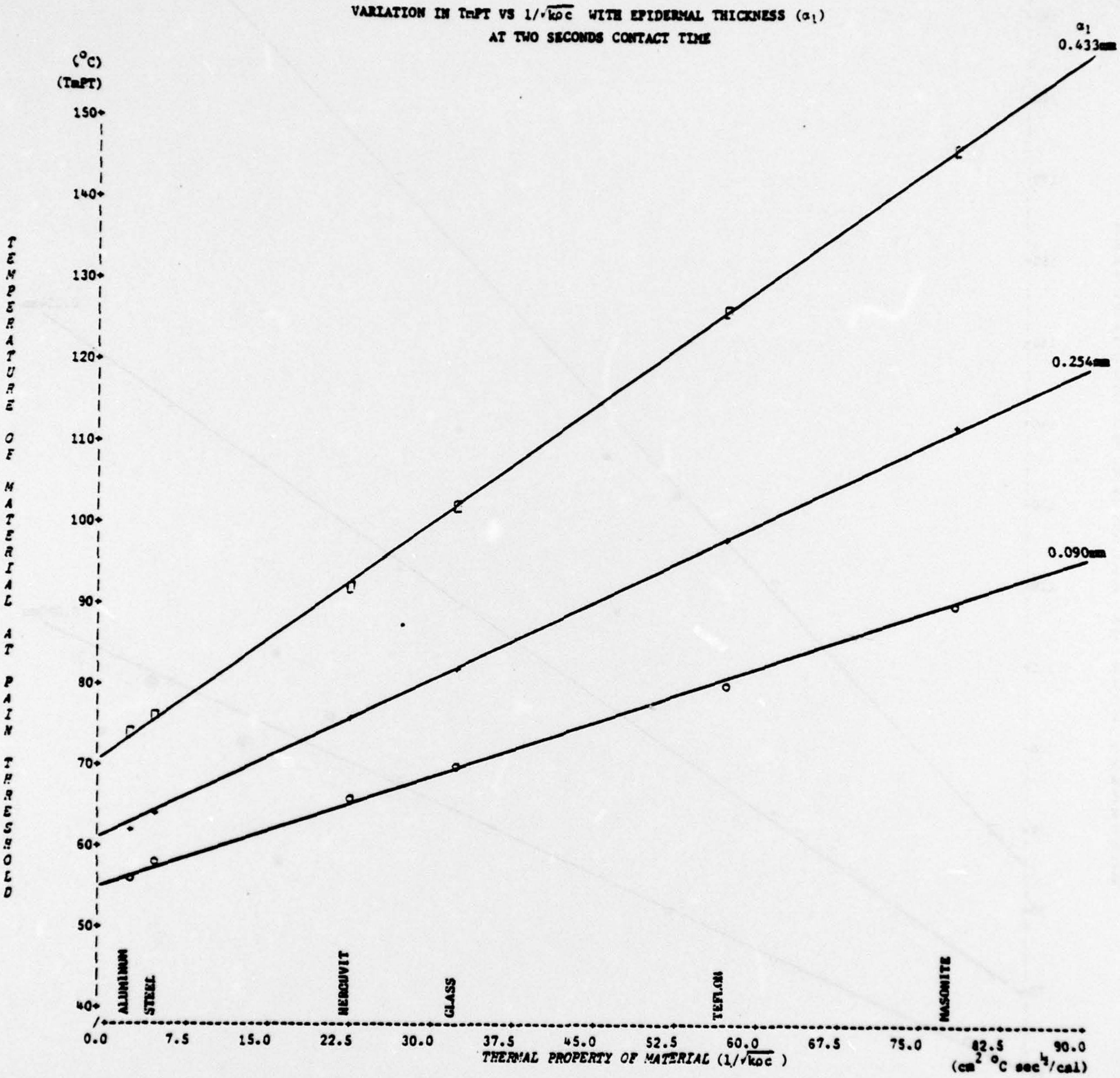
4. Stoll, A.M., J.R. Piergallini and M.A. Chianta.
Thermal Conduction in Human Skin: III. Influence of Epidermal Thickness and Exposure Time. Report No. NADC-79035-60, 15 January 1979.

Distribution list same as in reference 2, 3 and 4.



VARIATION IN TmPT VS $1/\sqrt{k\rho c}$ WITH EPIDERMAL THICKNESS (a_1)
AT ONE SECOND CONTACT TIME

VARIATION IN TmPT VS $1/\sqrt{koc}$ WITH EPIDERMAL THICKNESS (α_1)
AT TWO SECONDS CONTACT TIME



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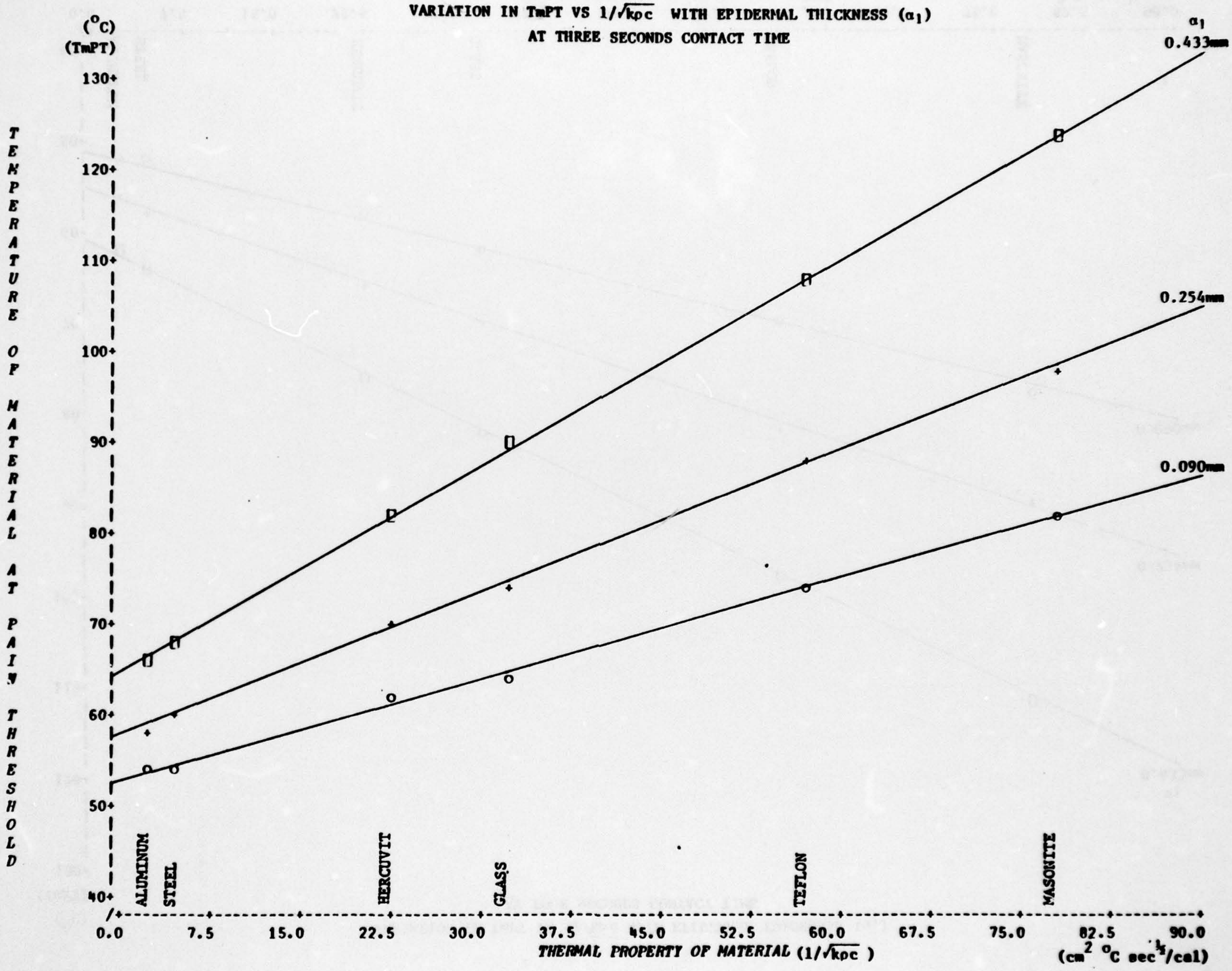

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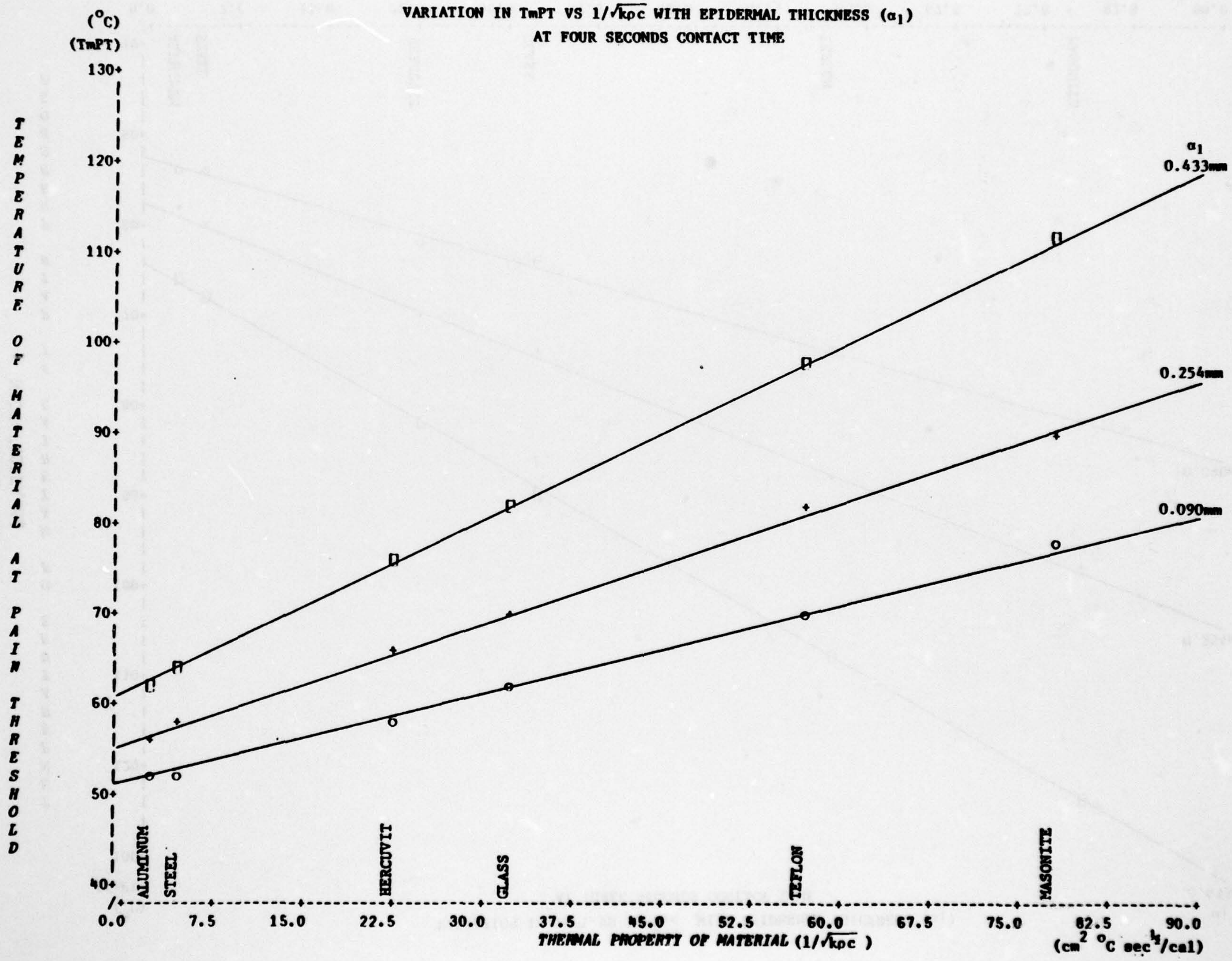
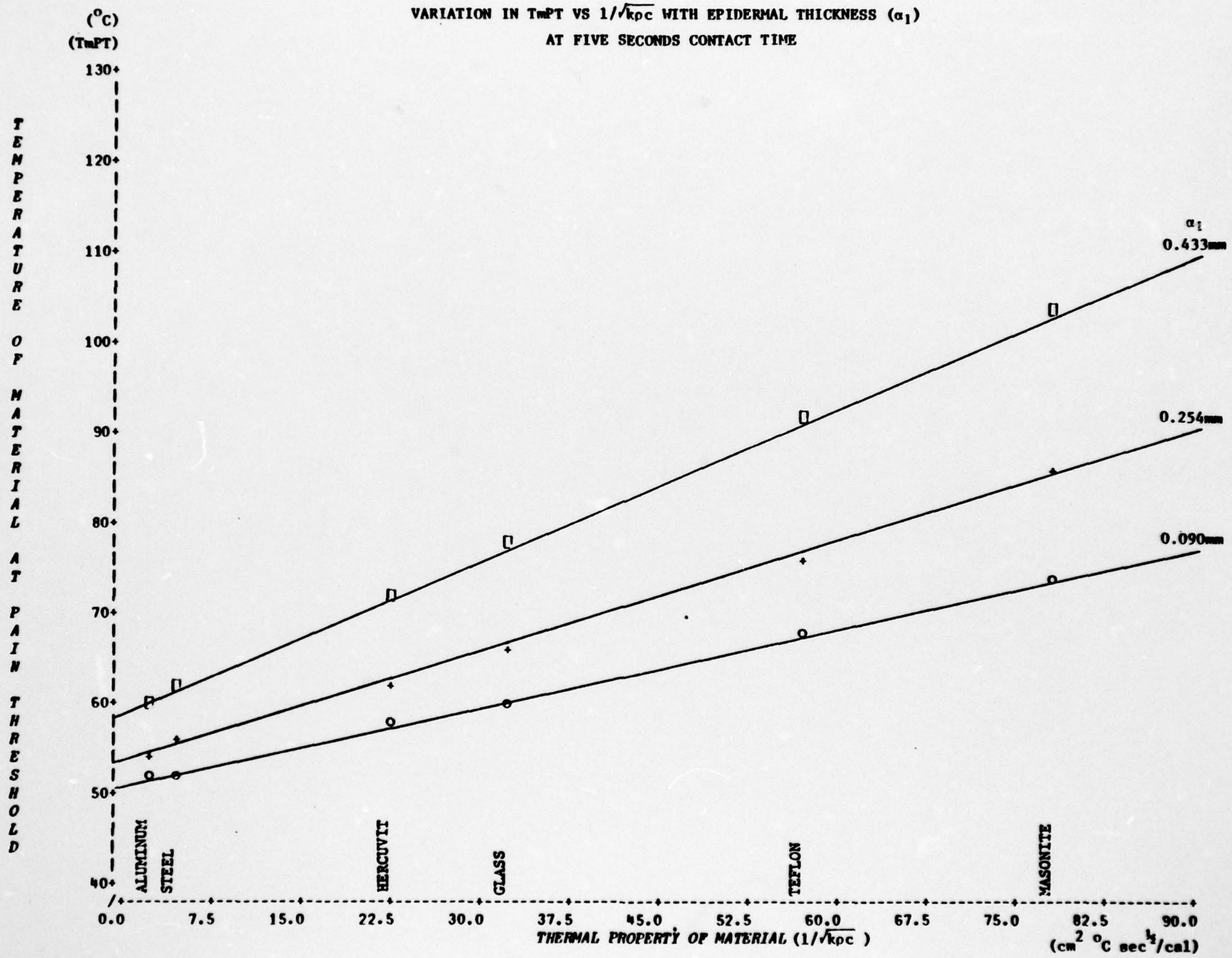
AT FOUR SECONDS CONTACT TIME



VARIATION IN TmPT VS $1/\sqrt{k\rho c}$ WITH EPIDERMAL THICKNESS (α_1)
AT FIVE SECONDS CONTACT TIME



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