Designation: C 1057 – 92 (Reapproved 1998)$^{\epsilon 1}$

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Standard Practice for Determination of Skin Contact Temperature from Heated Surfaces Using ~~A~~ a Mathematical Model and Thermesthesiometer[1]

This standard is issued under the fixed designation C 1057; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

~~ϵ^1 Note—Keywords were added editorially in July 1998.~~

1. Scope

1.1 This practice ~~establishes~~ covers a procedure for evaluating the skin contact temperature for heated surfaces. Two complimentary procedures are presented. The first is a purely mathematical approximation that can be used during design or for worst case evaluation. The second method describes the thermesthesiometer, an instrument that analogues the human sensory mechanism and can be used only on operating systems.

Note 1—Both procedures listed herein are intended for use with Guide C 1055. When used in conjunction with that guide, these procedures can determine the burn hazard potential for a heated surface.

1.2 A bibliography of human burn evaluation studies and surface hazard measurement is provided in the References at the end of Guide C 1055. Thermesthesiometer and mathematical modeling references are provided in the References at the end of this ~~standard~~ practice **(1-5)**~~.~~.[2]

1.3 This practice addresses the skin contact temperature determination for passive heated surfaces only. The analysis procedures contained herein are not applicable to chemical, electrical, or other similar hazards that provide a heat generation source at the location of contact.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C 680 Practice for ~~Determination~~ Estimate of the Heat Gain or Loss and the Surface Temperatures of Insulated ~~Pipe~~ Flat, Cylindrical, and ~~Equipment~~ Spherical Systems by Use of ~~a~~ Computer Programs

C 1055 Guide for Heated System Surface Conditions That Produce Contact Burn Injuries

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *acceptable contact time*—the limit of time of contact for the heated surface and the exposed skin. Practice has suggested limits of 5 s for industrial processes and up to 60 s for consumer items.

3.1.2 *burns*:

3.1.2.1 *first degree burn*—the reaction to an exposure where the intensity and duration is insufficient to cause complete necrosis of the epidermal layer. The normal response to this level of exposure is dilation of the superficial blood vessels (reddening of the skin).

3.1.2.2 *second degree burn*—the reaction to an exposure where the intensity and duration is sufficient to cause complete

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[1] This practice is under the jurisdiction of ASTM Committee C~~-~~16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.30 on Thermal Measurement.

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[2] The boldface numbers in parentheses refer to the list of references at the end of this practice.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

necrosis of the epidermis but no significant damage to the dermis. The normal response to this exposure is blistering of the epidermis.

3.1.2.3 *third degree burns*—the reaction to an exposure where significant dermal necrosis occurs. Significant dermal necrosis has been defined in the literature as a 75 % destruction of the dermis thickness. The normal response to this exposure is open sores that leave permanent scar tissue upon healing.

3.1.3 *skin*:

3.1.3.1 *epidermis*—the outermost layer of skin cells. This layer contains no vascular or nerve cells and acts to protect the outer skin layers. The thickness of this layer averages 0.08 mm.

3.1.3.2 *dermis*—the second layer of skin tissue. This layer contains blood vessels and nerve endings. The thickness of this layer is about 2 mm.

3.1.3.3 *necrosis*—localized death of living cells. This is a clinical term that defines when damage to the skin layer has occurred.

3.1.4 *skin contact temperature*—the temperature of the skin at a depth of 0.08 mm reached after contact with a heated surface for a specified time.

3.1.5 *thermesthesiometer*—an electromechanical device developed by L. A. Marzetta at National Institute of Standards and Technology to analogue the touch response of the human skin when it contacts a heated surface. This measurement concept holds U.S. Patent No. 3,878,728 dated April 22, 1975, and was assigned to the USA as represented by the Department of Health and Welfare. No known restriction exists to limit the development of units based upon this principle.

4. Summary of Practice

4.1 This practice provides two procedures for evaluation of the skin contact temperature from heated surfaces. Either of the two methods, a mathematical model and a physical measurement, can be used depending upon the availability of the system (that is, is it built and operating or is it in the design state) and the operating conditions. The first step in using this practice is to determine which procedure is to be used. Unless the system of interest is operating at design "worst case" conditions, such as high system temperatures and high ambient temperature, the calculational procedure is recommended. On the other hand, if the question is safety at the present conditions, the thermesthesiometer provides a quick measurement with no auxiliary calculations. ~~Sections~~ Paragraphs 4.2 and 4.3 outline the two alternative procedures available.

4.2 *Calculational Procedure, Method A*—First the surface temperature of the insulated system is determined by either a direct measurement, using either thermocouples, thermistors, or infrared noncontact techniques, or by modeling of the system using Practice C 680. Once the surface temperature is known, the designer uses the equation set to estimate the maximum epidermal contact temperature for the acceptable contact time. This temperature is a function of surface temperature, time of contact, and composition of both the surface material and substrate. The designer then refers to Guide C 1055 to determine the burn hazard potential of the surface.

4.3 *Thermesthesiometer, Method B*—The operator places the calibrated sensor probe face firmly against the heated surface for the acceptable contact time. The device directly reads the contact temperature from the probe. The maximum temperature is used in conjunction with the Guide C 1055 to determine the burn hazard potential of the surface.

5. Significance and Use

5.1 The procedures in this practice support the determination of the burn hazard potential for a heated surface. These procedures provide an estimate of the maximum skin contact temperature and must be used in conjunction with Guide C 1055 to evaluate the surface hazard potential.

5.2 The two procedures outlined herein are both based upon the same heat transfer principles. Method A uses a mathematical model to predict the contact temperature, while Method B uses a plastic rubber probe having similar heat transfer characteristics to the human finger to "measure" the contact temperature on real systems.

5.3 These procedures serve as an estimate for the skin contact temperatures which might occur for the "average" individual. Unusual conditions of exposure, incorrect design assumptions, subject health conditions, or unforeseen operating conditions may negate the validity of the estimations.

5.4 These procedures are limited to direct contact exposure only. Conditions of personal exposure to periods of high ambient temperatures, direct flame exposure, or high radiant fluxes may cause human injury in periods other than determined herein. Evaluation of exposures other than direct contact are beyond the scope of this practice.

5.5 *Cold Surface Exposure*—No consensus criteria exists for the destruction of skin cells by freezing. If, at some future time, such criteria are developed, extrapolation of the techniques presented here will serve as a basis for cold surface exposure evaluation.

6. Method A—Use of the Mathematical Model

6.1 This modeling approach is for use when the system is being designed or, if for some reason, it cannot be operated at design conditions. The model approximates the transient heat flow phenomena of the skin contacting a hot surface using the equation set described by Dussan **(1)** and Wu **(5).** The user is required to make certain definitions of system geometry and materials, the system operating conditions, and the allowable time of exposure. After definition of the input values, the equation set yields an estimate of the skin contact temperature needed for the hazard evaluation. The user must realize that as with all mathematical approximations, the estimate is only as good as the input data. Where some input parameter is known only within some range of values, a sensitivity analysis about that range is recommended.

6.2 The first step in estimating the effective skin contact temperature is to identify and record the following information describing the system as input for the model:

6.2.1 *System Description*—Geometry, location, accessibility.

6.2.2 *Present/Design Operating Conditions* —Duty cycle, operating temperatures of equipment.

6.2.3 *System/Surface Data* (as appropriate)—Substrate (insulation) type and thickness, jacket type and thickness, surface properties, such as emissivity and condition, shiny, painted, dirty, corroded.

6.2.4 *Ambient Conditions*, including dry bulb temperature and local wind velocity.

NOTE 2—The design temperatures should be at the worst case (generally high operating and high ambient) conditions. Care should be used in the selection of design conditions since the hazard design conditions are different from the heat loss design conditions.

6.3 Using Practice C 680 or a compatible program and the information gathered in 6.2, calculate the maximum operating surface temperature. This temperature is an input to the model for the contact temperature.

6.3.1 Where the system is operating at design conditions, direct measurement can be used to determine the surface temperature. Thermocouples, resistance thermometers, or other means can be used; however, proper application techniques are required for accurate results. Caution must be observed since the surface temperature may be high and the surface could constitute a burn hazard.

6.4 Calculate the expected skin contact temperature versus time history using the procedure below based upon the hot surface temperature, time of contact, and system properties. The development of the equations below is taken from Dussan **(1).** A more detailed derivation of the equation set used is included in the papers by Dussan **(1)** and Wu **(5).** See Fig. 1.

6.4.1 Calculate the initial parameter constants, using Eq 4-11.

6.4.2 The contact temperature for the skin can now be determined using Eq 1, Eq 2, and Eq 3 together for the system in question. Note that the solution to this equation is a sum of an infinite series. The solution, however, converges quickly (five or six terms) and can be easily handled manually or by a small computer.

$$T_c = T_0 + A \sum_{N=0}^{\infty} I^N \, erfc\,(\theta_N) + B \sum_{N=0}^{\infty} I^N \, erfc\,(\theta'_N) \tag{1}$$

and:

$$\theta_N = \frac{X_1/\sqrt{\alpha_1} + 2 \cdot N \cdot l/\sqrt{\alpha_2}}{2\sqrt{t}} \tag{2}$$

$$\theta'_N = \frac{X_1/\sqrt{\alpha_1} + 2 \cdot (N+1) \cdot l/\sqrt{\alpha_2}}{2\sqrt{t}} \tag{3}$$

$$I = \frac{(P_2 - P_3) \cdot (P_2 - P_1)}{(P_2 + P_3) \cdot (P_2 + P_1)} \tag{4}$$

$$A = \frac{(T_i - T_0) \cdot P_2}{P_2 + P_1} \tag{5}$$

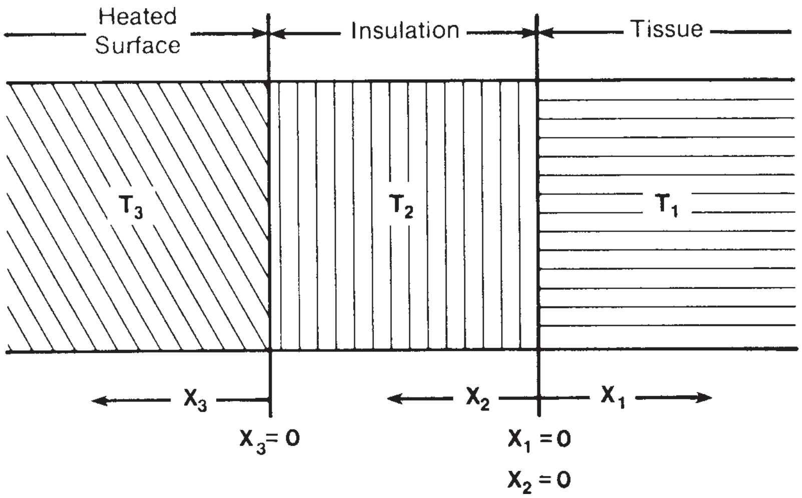

FIG. 1 Schematic of Heat Transfer Model

$$B = \frac{(T_i - T_0) \cdot (P_3 - P_2) \cdot P_2}{(P_2 + P_3) \cdot (P_2 + P_1)} \tag{6}$$

$$P_1 = (\rho_1 \cdot C_1 \cdot K_1)^{1/2} \tag{7}$$

$$P_2 = (\rho_2 \cdot C_2 \cdot K_2)^{1/2} \tag{8}$$

$$P_3 = (\rho_3 \cdot C_3 \cdot K_3)^{1/2} \tag{9}$$

$$\alpha_1 = K_1/\rho_1 \cdot C_1 \tag{10}$$

$$\alpha_2 = K_2/\rho_2 \cdot C_2 \tag{11}$$

where:

T_0 = initial tissue temperature, °C,
N = integral constant, $1 > \infty$,
X_1 = depth of tissue of interest, normally 8.0×10^{-5} m,
α_i = thermal diffusivity of layer *i*, m^2/s,
l = layer thickness of jacket material, m,
P = layer thermal inertia; $W \cdot m^{-2} \cdot K^{-1} \cdot \sqrt{s}$,
t = time of contact, s,
T_i = initial hot surface temperature, K,
T_c = contact skin temperature at depth X and at time (t) after contact, K,
$erfc(\theta)$ = complementary error function (a mathematical function),
ρ_i = density of material *i*, kg/m^3,
K_i = conductivity of material *i*, W/m · K, and
C_i = specific heat of material *i*, J/kg · K.

6.4.3 To obtain the skin contact temperature versus contact time history, repeat the calculation at one second intervals for times up to the maximum contact time exposure expected.

6.4.4 The maximum contact temperature used in the analysis of burn hazard (Guide C 1055) is the maximum contact temperature calculated for the contact period in step 6.4.3.

6.5 *Typical Input Data*—Table 1 contains typical values for the commonly used insulation and jacketing materials. Skin properties are also included. Nonstandard insulations or jacket material properties may be substituted for the table values in the calculation if they are known.

NOTE 3—Eq 1-11 work with any system of consistent units.

TABLE 1 Typical Properties (23°C)

Code	Material	Density, $kg/m^3 \cdot 10^3$	Specific Heat, J/kg $K \cdot 10^3$	Conductivity, W/m· K
1	steel	7.80	0.46	45.200
2	aluminum	2.70	0.96	154.800
3	brass	8.90	0.38	85.400
4	borosilicate glass	2.25	0.84	1.130
5	porcelain	2.20	0.84	1.210
6	concrete	2.47	0.92	2.430
7	brick	1.70	0.84	0.630
8	stone	2.30	0.84	0.920
9	plastics	1.28	1.55	0.250
10	phenolics	1.25	1.38	0.042
11	nylons	1.11	2.09	0.209
12	ABS resins	1.04	1.51	0.170
13	wood	0.66	1.72	0.130
14	paper	0.60	2.81	0.084
15	human tissue	0.90	4.60	0.544
16	water	1.00	4.19	0.602
17	cork	0.13	2.01	0.042
18	mineral wool	0.19	1.00	0.059
19	cal silicate	0.24	1.09	0.067
20	foam glass	0.13	0.76	0.071
21	organic foam	0.05	1.05	0.021
22	glass cloth	0.40	0.63	0.084
23	fiberglas-LD	0.10	1.00	0.046
24	TFE-fluorocarbon	2.15	1.05	0.243
25	masonite	1.00	1.67	0.173

6.6 *Example Calculation*—Using the equations listed in 6.4 and the following input data parameters, the following results were obtained for a simulated burn condition.

6.6.1 *Problem*—Assume a heated system is to be insulated with light density fib~~e~~rous glass. Jacketing material choices available include: (~~a~~1) *aluminum at 0.4 mm thickness and* (~~b~~2) *glass cloth at 1.0 mm thickness. Also assume that the skin depth of interest is 0.008 cm and the initial skin temperature is 33°C. The question is: What would be the maximum expected contact skin temperature for each jacket material at the desired depth for an exposure of 10 s, if the operating jacket surface temperature is 150°C~~.~~?*

6.6.2 *Result*—In 10 s of exposure the equations above predict a skin temperature at 0.008 cm of approximately ~~71.4°C~~ 50.2°C for the aluminum jacket and approximately ~~42.9°C~~ 40.3°C for the glass cloth jacket. See Fig. 2 for the time/temperature histories.

7. Method B—Use of the Thermethesiometer

7.1 The thermesthesiometer approach is for use where the system is operating at the desired design conditions or when evaluation of an existing condition is desired. The thermesthesiometer provides an electrical analogue of the finger's thermal response when placed against a heated surface. Since the use of this device requires some technique, the user should have some experience on known systems as practice before examining unknown surfaces. Repeating a procedure similar to the calibration on other surface geometries is one method of obtaining this needed training.

7.2 The initial step in the measurement of the effective skin contact temperature using the thermesthesiometer is to identify and record the following information describing the system to be analyzed:

7.2.1 *System Description*—Geometry, location, accessibility.

7.2.2 *Present Operational Conditions* —Duty cycle, system operating temperatures.

7.2.3 *System or Surface Data* (as appropriate)—Substrate (insulation) type and thickness, jacket type and thickness, surface condition, that is shiny, painted, dirty, corroded.

7.3 Next, measure and record the ambient conditions. This includes:

7.3.1 Dry bulb temperature of air,

7.3.2 Wet bulb temperature of air or relative humidity, and

7.3.3 Localized wind velocity.

7.4 After the system and ambient conditions are defined, locate on the surface several spots that will be measured with the probe. In cases of some geometries, points should be distributed over the surface to get representative areas. Where known variations exist

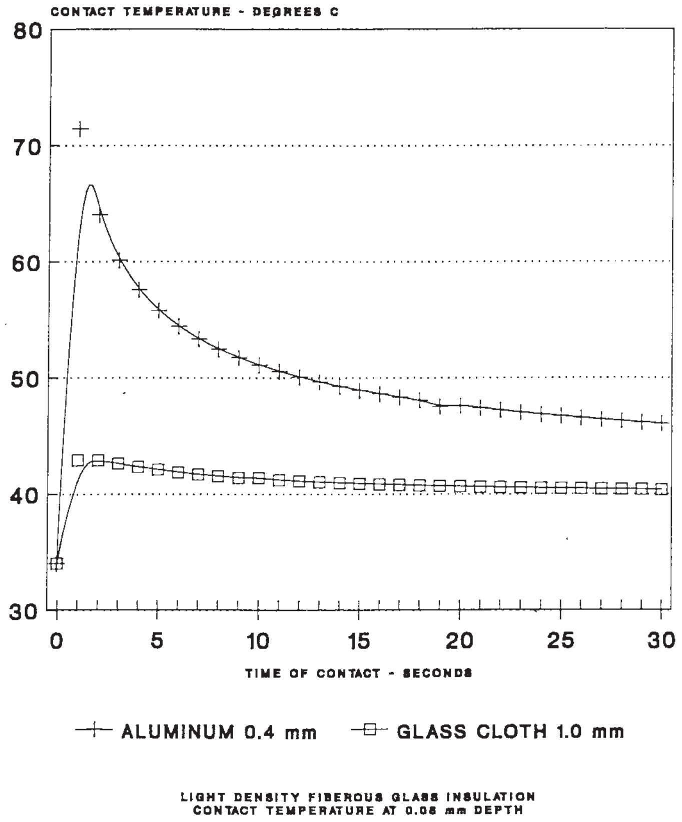

FIG. 2 Time-Contact Temperature History Heated Insulated Surface at 150°C Jacket Material Effects

in a system, those points should be considered; for example, for a pipe, location selection should include: top, sides, and bottom. Mark each point using a marking tool suitable for the surface by circling each point with a large zero. The test will be conducted at the center of each mark. Record on the data sheet the location of the points selected.

NOTE 4—Care should be observed when using the probe on curved surfaces. Surfaces having a diameter less than three times the probe diameter should not be measured.

7.5 Precondition the thermesthesiometer probe and readout by turning on the electronics and waiting at least 30 min for warm-up.

NOTE 5—Individual instructions will be different for each model used in the field. Therefore, consult the unit's operating instructions for the correct warm-up, calibration, and operating procedures.

7.6 Upon warm-up, adjust the probe temperature control until the readout reads 305 ± 2 K. Hold at that condition for five more minutes to ensure equilibrium.

NOTE 6—The temperature value of 305 K is selected to simulate the normal skin temperature.

7.7 Adjust the temperature control for the surface verification spot, usually provided as part of the unit, to control to a temperature of 343 ± 1 K or similar known value (if a commercial unit, see the manufacturer's instructions for this value).

7.8 Remove the probe from its storage position and place it in contact with the calibration spot for 4 ± 0.5 s. At that time, remove the probe from the calibration spot and allow it to return to below 303 K. Record the peak temperature achieved during contact with the calibration spot.

NOTE 7—Some units are equipped with a peak hold readout and time circuit to catch the peak at exactly 4 s after touching. A strip chart recorder with a fast response and chart speed would also be useful in this recording. The zero time of touch is defined for these units as that time when the contact temperature reaches 313 K.

NOTE 8—For rapid measurements at several points, quick cooldown can be accomplished by heat sinking the probe face to a metal surface at room temperature. Caution, however, must be used to precondition the probe, as in 7.6, prior to each new test.

7.9 The peak temperature recorded in 7.8 should be compared to the manufacturer's calibration data. If the recorded temperature deviates from this specification, repeat the calibration steps 7.5-7.8. If the unit still fails to operate properly, the probe or readout is probably defective and should be checked by the manufacturer.

7.10 Once calibration is complete, precondition the probe as stated in 7.6. No adjustment of the probe heater should be required.

7.11 At each point selected on the system, repeat the test sequence; contact for a time equal to the acceptable contact time, recording the peak temperature, cooling down below 303 K and reconditioning (7.5) until all points have been measured.

7.12 Determine the average peak temperature for the system and record.

7.13 The report shall include the highest peak temperature measured, the average peak temperature, the contact time used, the number of spots measured, and the information recorded in 7.1 and 7.2.

NOTE 9—For continued reliable operation, the probe should not be used on surfaces hotter than 473 K as it is generally made of silicon rubber which exhibits property changes above that level.

NOTE 10—The appropriate method of applying the probe face to the test surface is shown in Fig. 3 and Fig. 4. The probe should be applied firmly and squarely to the surface in a continuous motion resulting in positive contact. Avoid rubbing or scraping the probe face across the test surface. The level of applied pressure is not critical within bounds. A force of four to five pounds has been found to be satisfactory and comfortable.

NOTE 11—This method assumes negligible surface resistance at the interface between the skin and hot surface. The contact resistance to heat flow at the interface appears to be negligibly small on normal, clean surfaces. Therefore, excessive surface moisture, dirt, or oils should be removed before testing begins.

8. Report

8.1 Report the following information:

8.1.1 Analysis procedure used, either Method A or B with justification.

8.1.2 System description as outlined in Sections 6 or 7.

8.1.3 The maximum hot surface temperature expected in Method A and its method of determination.

8.1.4 The design contact time of exposure.

8.1.5 The estimated skin contact temperature calculated by Method A or the average and maximum contact temperature measured by Method B.

9. Determination of Burn Hazard Potential

9.1 Once the skin contact temperature expected for the system has been determined, the user shall refer to Guide C 1055, in order to determine the relative hazard involved with the system in question.

10. Precision and Bias

10.1 The accuracy of the procedures included in this practice have been estimated by various researchers. Wu **(5)** estimates agreement between the modeling and the thermesthesiometer of approximately ±2 K. Application of these results to actual burning of the skin of an individual can vary widely due to thermophysical property variations between different people. Whenever possible, however, the conservative approach has been used to select the simplifying assumptions used herein.

FIG. 3 Applying the Thermesthesiometer to a Horizontal Surface

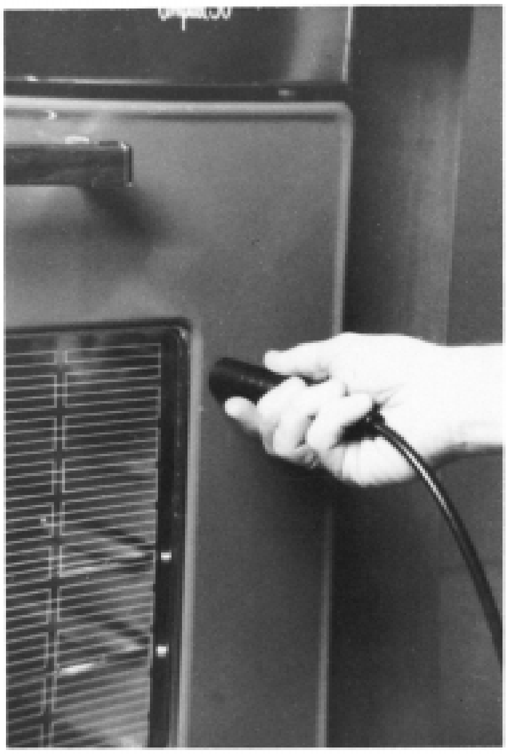

FIG. 4 Applying the Thermesthesiometer to a Vertical Surface

11. Keywords

11.1 burn potential; elevated temperature; health hazards; in- situ measurement; maximum temperature; temperature test; thermothesiometer; thermal contact

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(**1**) Dussan, B. I., and Weiner, R. I., "Study of Burn Hazard in Human Tissue and Its Implication on Consumer Product Design," presented at Winter Meeting Nov. 28–Dec. 2, 1971, Paper No. 71- *WA/HT-39, ASME Journal*, 1972.
(**2**) Marzetta, L. A., "A Thermesthesiometer—An Instrument for Burn Hazard Measurement," *IEEE Transactions on Biomedical Engineering*, September 1974, pp. 425–427.
(**3**) Marzetta, L. A., "Thermesthesiometer," *U.S. Patent No. 3,878,728*, dated April 22, 1975.
(**4**) Marzetta, L. A., "Engineering and Construction Manual for an Instrument to Make Burn Hazard Measurements in Consumer Products," *NBS Technical Note 816*, February 1974.
(**5**) Wu, Yung-Chi, "Control of Thermal Impact for Thermal Safety," *AIAA Journal*, Vol 15, No. 5, 1977, pp. 674–680.

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