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Standard Guide for Heated System Surface Conditions that Produce Contact Burn Injuries¹

This standard is issued under the fixed designation C1055; 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.

1. Scope

1.1 This guide covers a process for the determination of acceptable surface operating conditions for heated systems. The human burn hazard is defined, and methods are presented for use in the design or evaluation of heated systems to prevent serious injury from contact with the exposed surfaces.

1.2 The maximum acceptable temperature for a particular surface is derived from an estimate of the possible or probable contact time, the surface system configuration, and the level of injury deemed acceptable for a particular situation.

1.3 For design purposes, the probable contact time for industrial situations has been established at 5 s. For consumer products, a longer (60-s) contact time has been proposed by Wu (1)² and others to reflect the slower reaction times for children, the elderly, or the infirm.

1.4 The maximum level of injury recommended here is that causing first degree burns on the *average* subject. This type of injury is reversible and causes no permanent tissue damage. For cases where more severe conditions are mandated (by space, economic, exposure probability, or other outside considerations), this guide ~~may be is~~ used to establish a second, less desirable injury level (second degree burns), where some permanent tissue damage ~~can be is~~ permitted. At no time, however, are conditions that produce third degree burns recommended.

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

1.6 A bibliography of human burn evaluation studies and surface hazard measurement is provided in the list of references at the end of this guide (1-16).

1.7 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.8 *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~~ safety, health, and ~~health~~ environmental practices and determine the applicability of regulatory limitations prior to its use.*

1.9 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*³

C680 Practice for Estimate of the Heat Gain or Loss and the Surface Temperatures of Insulated Flat, Cylindrical, and Spherical Systems by Use of Computer Programs

C1057 Practice for Determination of Skin Contact Temperature from Heated Surfaces Using a Mathematical Model and Thermesthesiometer

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

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.

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 skin:

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

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

3.1.4 *necrosis*—localized death of living cells. A clinical term that defines when permanent damage to a skin layer has occurred.

3.1.5 burns:

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

3.1.7 *second degree burn*—the reaction to an exposure where the intensity and duration is sufficient to cause complete necrosis of the epidermis but no significant damage to the dermis. The normal response to this exposure is blistering of the epidermis.

3.1.8 *third degree burn*—the reaction to an exposure where significant dermal necrosis occurs. Significant dermal necrosis has been defined in the literature (3) as 75% destruction of the dermis. The normal response to this exposure is open sores that leave permanent scar tissue upon healing.

3.1.9 *contact exposure*—the process by which the surface of skin makes intimate contact with a heated surface such that no insulating layer, film, moisture, etc., interferes with the rapid transfer of available energy.

3.1.10 *insulation system*—the combination of an insulation material or jacket, or both that forms a barrier to the rapid loss of energy from a heated surface. The insulation system ~~may involve~~ potentially involves a broad range of types and configurations of materials.

3.1.11 *jacket*—the protective barrier placed on the exposed side of an insulation to protect the insulation from deterioration or abuse. The jacket material ~~can be~~ potentially made of paper, plastic, metal, canvas cloth, or combinations of the above or similar materials.

3.1.12 *thermesthesiometer*—a probe device developed by Marzetta (13) that simulates the thermal physical response of the human finger to contact with heated surfaces.

4. Summary of Guide

4.1 This guide establishes a means by which the engineer, designer, or operator ~~can~~ determine the acceptable surface temperature of an existing system where skin ~~contact may be made with~~ potentially contacts a heated surface.

4.2 The process used in the analysis follows the outline listed below:

4.2.1 The user must first establish the acceptable contact exposure time and the level of acceptable injury for the particular system in question.

4.2.2 Secondly, the user determines the maximum operating surface temperature. This determination is made either by direct measurement (if possible) or by use of a calculation at design conditions using a method conforming to Practice C680.

4.2.3 Next, utilizing the contact time (4.2.1), the maximum surface temperature (4.2.2), and the graph, Fig. 1, the user determines the potential injury level. If the operating point falls below the injury level specified (4.2.1), then no further analysis is required. (See Note 1.)

NOTE 1—The following equations have been developed from the original data used to generate Fig. 1 for easier use of this figure.

$$T_A = 15.005 + 0.51907 \times \ln(\text{time} \times 1000) + 352.97 / (\ln(\text{time} \times 1000)) \quad (1)$$

$$T_B = 39.468 - 0.41352 \times \ln(\text{time} \times 1000) + 190.60 / (\ln(\text{time} \times 1000)) \quad (2)$$

where:

T_A = critical contact temperature for complete transepidermal necrosis, °C.

T_B = critical contact temperature for reversible epidermal injury, °C.

time = elapsed contact time, s.

\ln = natural logarithm.

4.2.4 If the injury level exceeds that specified, further analysis of the system is required using either the thermesthesiometer (a direct method) or an additional calculation. Both methods are described in Practice C1057.

4.2.5 If after this additional analysis the system still exceeds the injury level criterion, then the system is unacceptable for the criterion specified and the design ~~should~~ shall be revised.

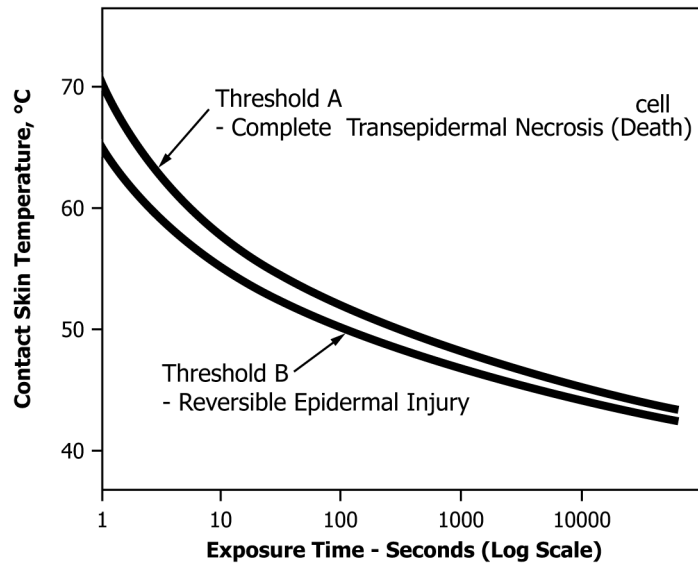


FIG. 1 Temperature-Time Relationship for Burns

5. Significance and Use

5.1 Most heated apparatus in industrial, commercial, and residential service are insulated, unless thermal insulation would interfere-interferes with their function; for example, it is inappropriate to insulate the bottom surface of a flatiron. However, surface temperatures of insulated equipment and appliances may still be are potentially high enough to cause burns from contact exposure under certain conditions.

5.2 This guide has been developed to standardize the determination of acceptable surface operating conditions for heated systems. Current practice for this determination is widely varied. The intent of this guide is to tie together the existing practices into a consensus standard based upon scientific understanding of the thermal physics involved. Flexibility is retained within this guide for the designer, regulator, or consumer to establish specific burn hazard criteria. Most generally, the regulated criterion will be the length of time of contact exposure.

5.3 It is beyond the scope of this guide to establish appropriate contact times and acceptable levels of injury for particular situations, or determine what surface temperature is "safe." Clearly, quite different criteria may be are justified for cases as diverse as those involving infants and domestic appliances, and experienced adults and industrial equipment. In the first case, no more than first degree burns in 60 s might be desirable. In the second case, second degree burns in 5 s might be acceptable.

NOTE 2—An overview of the medical research leading to the development of this guide was presented at the ASTM Conference on Thermal Insulation, Materials and Systems on Dec. 7, 1984 (14).

5.4 This guide is meant to serve only as an estimation of the exposure to which an average individual might be subjected. Unusual conditions of exposure, physical health variations, or nonstandard ambients all serve to modify the results.

5.5 This guide is limited to contact exposure to heated surfaces only. It should be is noted that conditions of personal exposure to periods of high ambient temperature or high radiant fluxes may potentially cause human injury with no direct contact.

5.6 This guide is not intended to cover hazards for cold temperature exposure, that is, refrigeration or cryogenic applications.

5.7 The procedure found in this guide has been described in the literature as applicable to all heated surfaces. For extremely high-temperature metallic surfaces (>70°C), damage occurs almost instantaneously upon contact.

6. Procedure

6.1 This procedure requires the user to make several decisions that are based upon the results obtained. Careful documentation of the rationale for each decision and intermediate result is an important part of this evaluation process.

6.2 The first phase in the use of this guide is to establish the acceptable limits for contact exposure time and the acceptable level of injury for the system in question. Where no available standards for these limits are prescribed, the following limits are recommended based upon a survey of the existing medical literature.

6.2.1 *Acceptable Contact Times:*

6.2.1.1 *Industrial Process*—5 s.

6.2.1.2 *Consumer Items*—60 s.

6.2.2 *Acceptable Injury Levels*—The acceptable injury level is that of first degree burns as defined in 3.1.6 and is the limit represented by the bottom curve in Fig. 1.

6.3 The next phase in the process is to establish the maximum operating surface temperature under worst case conditions. This evaluation ~~may be~~ is made either by direct measurement (but only at worst case conditions) or by using a calculation approximation. The steps required for determining the maximum surface temperature are as follows:

6.3.1 The initial step is to establish the operating system parameters. This step provides input information to the analysis and ~~may will~~ preclude any further work concerning burn hazard. The items that need to be identified and recorded are as follows:

6.3.1.1 *System Description*—Shape, size, materials, including jacket material, thickness, and surface emittance.

6.3.1.2 *Operation Conditions*—Temperatures of heated system, times of year, cycle, etc.

6.3.1.3 *Ambient Conditions*—Worst case design temperature for burn hazards ~~would be~~ typically is at summer design dry bulb. Or, for inside conditions, the maximum expected room ambient air temperature. Include the ambient air velocity, if known.

NOTE 3—Design conditions for burn hazard evaluation may be different from those used for heat loss analysis. For example, the highest ambient is used for burn hazard analysis versus the lowest for heat loss.

6.3.2 The second step is to determine the temperature of the system surface at the *worst* design condition by one of the following methods.

6.3.2.1 Insert the system dimensions, material properties, and operating conditions into an analysis technique conforming to Practice C680. This technique ~~should be~~ is used during design or where the system surface temperatures cannot be physically measured at *worst case* conditions.

6.3.2.2 Direct contact thermometry (thermocouple or resistance device) or infrared, noncontact thermometry.

NOTE 4—(1) Care should be used in attaching measurement devices on hot systems since burns can result; and (2) Proper installation techniques must be used with direct contact thermometry to prevent heat sinking of the surface and obtaining incorrect temperature readings.

6.4 In many situations, surface temperatures exceed the range of applicability of this guide and thus the evaluation is made through interpretation of the surface temperature data and the system properties. The limiting conditions below ~~should~~ shall first be examined to see if further analysis is required.

6.4.1 If the surface temperature is below 44°C, no short term (that is, less than 6 h) hazard exists and the remaining sections ~~can be~~ are ignored.

6.4.2 If the surface temperature exceeds 70°C and the surface is metallic, it ~~may will~~ likely present a hazard regardless of contact duration. Attempts ~~should~~ shall be made to lower the surface temperature below 70°C. ~~Nonmetallic skins may be~~ 70°C as a first step in protection. Nonmetallic skins are potentially safe for limited exposure at temperatures above 70°C. In these cases, as with all cases between ~~44°C~~ 44 and 70°C, the analysis ~~should~~ shall be completed.

6.5 With the measurement or estimation of surface temperature for the system in question, utilize the graph (Fig. 1) and check if the intersection of the operating surface temperature and the selected time of contact falls below the threshold temperature.

NOTE 5—The threshold temperature used will depend on the limits of acceptable burn chosen in 6.2.2. If the burn level is first degree, use threshold line B in Fig. 1. If second degree burns are acceptable, use threshold line A in Fig. 1.

6.6 If the operating surface temperature and time are below the threshold (line B) curve, then the system meets the selected criteria.

6.7 If, however, the point falls above the curve, it is feasible that the system ~~may will~~ meet the selected criterion only if certain combinations of insulation or jacketing, or both, are used. Analysis procedures for the jacketing/insulation effects are outlined in Practice C1057. Two methods provided in Practice C1057 are briefly described below.

6.7.1 The calculation technique provided in Practice C1057 uses system geometry, material properties, and temperature conditions to estimate the maximum contact temperature used in Fig. 1 when the heat capacity effects of the surface are to be considered. Once this maximum contact temperature is determined, the user returns to steps 6.5 – 6.7 for the refined analysis.

6.7.2 An alternative to calculation of the contact temperature is available for those systems that are already operating. The thermesthesiometer (13) provides an analogue measurement of the same phenomenon as the computer method models (6.7.1). Care ~~should be used~~ is necessary in applying the thermesthesiometer since it must be applied at *worst case* conditions if the hazard potential is to be evaluated. Practice C1057 outlines the correct procedures for use of this device for surface hazard evaluation. The output from the thermesthesiometer is the maximum contact temperature of the skin that ~~can be~~ are related to Fig. 1 with no corrections for surface type needed.

6.8 If, after analysis using Practice C1057, the system temperature still fails to meet the selected criterion, then increasing insulation, changing jacketing, or other means must be used to lower the surface temperature. Practice C680 will be helpful in determining the levels required.

6.9 Once a new level of jacket and insulation is determined, the analysis above ~~should be~~ is repeated to confirm safe operating conditions.

7. Report

- 7.1 Any report citing the use of this guide ~~should~~shall include the following information:
- 7.1.1 System description,
 - 7.1.2 System operating conditions (either measured or design),
 - 7.1.3 Ambient conditions (either measured or design),
 - 7.1.4 Method of surface temperature evaluation used, calculation or measurement,
 - 7.1.5 Method of analysis of hazard potential, calculation, thermesthesiometer, contact time, and hazard level selected, and
 - 7.1.6 Statement of analysis of results and conclusions.

8. Precision and Bias

8.1 As stated in the Scope, this procedure is valid for the *average* person. Individuals ~~may be~~potentially tolerant or sensitive to burns depending upon physical condition, age, ambient conditions, emotional state, etc. The literature (1, 4, 5) has shown, however, agreement on pain response and tissue damage for a panel of subjects to within approximately 10 %.

9. Keywords

9.1 burns; epidermal injury; heat; injuries; skin contact temperatures; thermal insulation

APPENDIX

(Nonmandatory Information)

X1. RATIONALE

X1.1 Background—General

X1.1.1 Man has faced the potential of skin burns from touching hot surfaces since the discovery of fire in prehistoric times. He was concerned more with treatment of the injury than with the development of some means to prevent its occurrence. As civilization advanced, man developed crude insulation forms to control the extremes of heat to which he was exposed. The greatest improvement to these systems came since the industrial revolution where the use of high temperature power and process systems dictated the development of modern insulation systems, that not only conserve energy but also protect process products during manufacture. As technology expanded to include higher temperatures, more complex processes, and thus more worker exposure situations, worker organizations and later governmental agencies demanded the increased use of insulation for personal protection.

X1.1.2 At the same time that the workplace was becoming more hazardous, the increased development of consumer products that heated, steamed, or cooked increased the potential hazards found in consumer products and forced the use of more insulation and protection for the operator. Personal protection now is required everywhere for consumer products. Examples include curling irons, ranges, irons, dryers, dishwashers, light fixtures, and furnace and heating fixtures.

X1.1.3 The obvious solution is to simply insulate the heated part and thus isolate the hazard from the user. Unfortunately, the random application of insulation without detailed analysis can sometimes disrupt the process (that is, overheating where some loss is desired) or be an economic handicap to the overall cost of the project. Most applications of insulation to heated process systems are made on the basis of trade-offs between the cost of the installed insulation and the cost of the energy lost. Using this criteria or the more common rule-of-thumb approach, that is, “put on about an inch like we always do,” can create exposed surface temperatures that exceed even the shortest term human exposure limits. Thus, to protect both operators and casual visitors in an area, an analysis of the exposed surfaces must be undertaken to identify those having temperatures capable of causing burns.

X1.1.4 When consumer product and industrial system designers recognized the need to design for personnel safety, they established what they felt were safe operating limits for exposed surfaces. Since limited research data was available before 1950, many industries chose to establish their own standards for maximum surface temperatures based upon combinations of available research results and personal experience. This remains as the current method for the evaluation of surface hazards.

X1.1.5 In 1983, Committee C16 undertook the study of a proposal to establish a *standard* criteria for evaluating burn hazard potential. This standard was to be well documented and easily used. As an adjunct to this effort, a second standard was proposed to establish a means for evaluating existing or proposed systems for hazard level by either physical measurement or mathematical modeling.

X1.2 Background—Physiological Mechanism of a Burn

X1.2.1 Previous to World War II, little research has been performed in developing an understanding of the physiology of burns to the human body. With the increased destruction potential of more powerful weapons, burn injuries became a common battle problem and the military began to support research to study the relationships between burn damage and the severity of exposure. At that time, little was known about the mechanism by which hyperthermia (high temperature exposure) leads to irreversible damage. The chemical reactions occurring within the skin cells upon exposure and the relationships between exposure temperature and duration on the transfer of heat into the skin were also subjects of research.

X1.2.2 The first significant research on the subject was conducted by Henriques and Moritz at the Harvard Medical School (2, 3, 8, 9, 10, 11). The results were released for publication in 1946 through 1948. This research, performed primarily on swine (which happen to have similar skin properties to humans), with some human subjects added later, helped define the significant parameters controlling the flow of heat into the skin. Later, the relationship between temperature and duration of exposure to the extent of damage observed was established to serve as a guide for future work. Some of the significant results of this initial work (2) are:

X1.2.2.1 The burning of human skin occurs as a complex, nonsteady heat transfer between a contacted medium, that is, a hot surface, and the surface of the skin. The rate of heating depends upon the temperature and heating capacity of the source and the heat capacity and thermal conductivity of the skin layers (see Fig. X1.1). Neglected in these studies were the flow of blood to carry heat away and the physiological changes in skin properties as the damaged zone traverses the outer skin layers.

X1.2.2.2 Factors that cause increased complexity of the problem include: (1) site variations with respect to the thickness of the different skin layers; (2) variations of initial conditions within the skin with respect to time, position, and physical condition of the subject; (3) the unknown average rate of blood flow through the skin layers and variations within the layers with respect to location and ambient temperatures (warm ambient causes increased flow near surface and cold ambient results in less flow near surface); and (4) the appearance of watery fluids in variable quantities upon exposure that result in alterations of skin density, heat capacity, thickness, and thermal conductivity.

X1.2.2.3 Analysis of the experimental results showed that it was possible to assume average conditions and to develop an approximate first order Fourier's law equation to describe the transient heat flow in the contact problem. The modeling work by Henriques neglected the influence of contact resistance and blood flow and assumed that both the skin and touched surface could be treated as semi-infinite. Succeeding experiments showed that the assumption of semi-infinite solids and neglecting blood flow were valid for the time/temperature conditions of interest. The experiments performed at Harvard used a direct contact water bath which avoided the issue of contact resistance.

X1.2.3 After their initial work was complete, Moritz and Henriques extended their work to include the effects on human skin of hyperthermia of varying duration and varying degrees of intensity. These studies (3) led to a clearer definition of the degree of burning. Several additional conclusions were forthcoming from that research and are outlined as follows:

X1.2.3.1 The pain reaction to prolonged hyperthermia exposure first occurs as a stinging sensation at between 47.5° and 48.5°C. The level of discomfort does not always correlate with the level of damage sustained or with intensity between subjects or the same subject on different days.

X1.2.3.2 The lowest temperature where epidermis (outside skin layer) damage occurs is approximately 44°C when it is sustained for approximately 6 h. It is possible to extrapolate this result to conclude that longer exposures might cause damages at temperatures below 44°C.

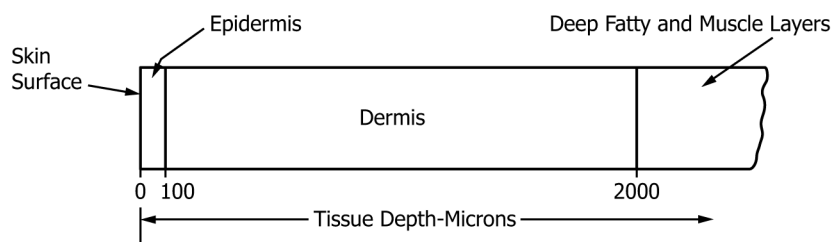


FIG. X1.1 Cross Section of Human Tissue