NBSIR 76-1097

Illustrative Generic Standard for the Control of Thermal Burn Hazards in Household Appliances

Robert G. Hendrickson
Elizabeth M. Robertson
Rudolph V. Kelly

Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

August 1976

Final

Prepared for
Consumer Product Safety Commission
5401 Westbard Avenue
Bethesda, Maryland 20207

NBSIR 76-1097

ILLUSTRATIVE GENERIC STANDARD FOR THE CONTROL OF THERMAL BURN HAZARDS IN HOUSEHOLD APPLIANCES

Robert G. Hendrickson
Elizabeth M. Robertson
Rudolph V. Kelly

Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

August 1976

Final

Prepared for
Consumer Product Safety Commission
5401 Westbard Avenue
Bethesda, Maryland 20207

U.S. DEPARTMENT OF COMMERCE, Elliot L. Richardson, ***Secretary***

Edward O. Vetter, ***Under Secretary***

Dr. Betsy Ancker-Johnson, ***Assistant Secretary for Science and Technology***

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Acting Director***

TABLE OF CONTENTS

Page

I. INTRODUCTION.. 1

II. BACKGROUND.. 3

III. STATEMENT OF PROBLEM.. 5

IV. APPROACH.. 6

Summary.. 6

V. ILLUSTRATIVE STANDARD.. 8

A. Scope.. 8

B. Exclusions.. 8

C. Maximum Temperature Levels.. 8

D. Test Accessibility Probes.. 9

E. Test Method..10

1. Determination of Accessible Contact Surfaces..........10

2. Test Conditions..10

3. Test Measure..11

Discussion..11

APPENDIX A. TECHNICAL APPROACH..A-1

A. Clustering and Fault-Tree Analysis..A-2

NEISS Data Source..A-2

Empirical Data..A-4

Fault-Tree Analysis..A-5

B. Heat-Flow Factors and Equations..A-10

Thermal Inertia and Diffusivity..A-11

Basic Concepts..A-11

TABLE OF CONTENTS (continued)

Page

C. Determination of Surface Temperature Levels....................A-13

Current Surface Temperature Limits........................A-13

Revised Temperature Levels................................A-19

D. Countermeasures.......................................A-22

E. Test Method...A-22

APPENDIX B. CONSUMER PRODUCTS ASSOCIATED WITH THERMAL BURNS: NEISS CLASSIFICATION..................................B-1

REFERENCES

Figures:

Figure A-1: Fault-Tree Diagram for Electric Ranges................A-6

Figure A-2: Fault-Tree Diagram for Electric Irons.................A-7

Figure A-3: Fault-Tree Diagram for Electric Coffee Makers.........A-9

Figure A-4: Fault-Tree Diagram for Electric Broilers..............A-10

Figure A-5: Surface Temperatures by Thermal Inertia for Selected Contact Temperatures....................................A-14

Figure A-6: Physiological Response Curve..........................A-15

Figure A-7: Plot of Current Temperature Limits....................A-17

Tables:

Table A-1: Basic Product-Type Cluster.............................A-3

Table A-2: Temperature-Contact Time Relationships.................A-13

Table A-3: Maximum Acceptable Temperature Limits..................A-16

Table A-4: Revised Maximum Surface Temperature Limits.............A-20

Table A-5: Revised Maximum Acceptable Temperature Limits..........A-23

I. INTRODUCTION

The objective of this work was to develop an illustrative example of a generic standard for a large number of household, consumer product-types having a common, explicit burn hazard. The concept of generic regulation implies that for a large number of product-types it is possible to define a countermeasure for the perceived hazard and to provide a satisfactory test method for compliance. In this report, the process of analysis, modeling, deriving the countermeasures, and specifying appropriate performance levels for hot surfaces, are presented.

The body of the report is in four parts, the Background (II), Statement of the Problem (III), Approach (IV) and the Illustrative Standard (V). The Background suggests the underlying interest in thermal burns as a serious national problem; the Statement of the Problem defines the scope of the perceived hazard addressed by the investigation of this study; the Approach summarizes the evaluations which are given in detail in the Appendix A; and Part V is a statement of the illustrative standard for nonfunctional hot surfaces.

The principal work on which the illustrative standard is based is presented in Appendix A, which contains descriptions of the technical rationale for product-hazard evaluation, measuring heat flow, and formulating the basic table of maximum surface-temperature levels. Appendix B lists the products in the NEISS data base associated with thermal burns.

There is no suggestion in this work that the illustrative standard is complete, nor that it has been developed or refined by review or consensus. Specific items not fully developed or which remain uncertain in the report or in the illustrative standard are: (1) the specifications for the articulated access probes (adult and child), (2) the specification for the articulated measuring probe, (3) the procedures for using the measuring probes (articulated and non-articulated), (4) a precise determination of values of thermal inertia, and (5) the details needed to specify the test conditions more clearly. Also needed are additional research on the physiological response curves for adults and children, and on possible operational design changes in the thermesthesiometer to obtain greater flexibility of use.

All conclusions should be viewed as tentative, and the revised maximum temperature limits should not be taken as final or authoritative. The data and information developed in this report are intended only to demonstrate the generic method and to provide a reasonable basis for the illustrative standard. It is not intended that any value in this report should be construed as a position by the National Bureau of Standards or the Consumer Product Safety Commission. The intent is to show by example that the concept of a generic standard can contribute efficiency and simplicity to an otherwise lengthy and complex process.

II. BACKGROUND

The NEISS* data system indicates a high incidence of thermal burns among the consumer population in 1975. A thermal burn is one in which the source of the burn is heat as opposed to other sources, such as chemicals. These burns range over approximately 240 product categories and produce severity of injury great enough to result in 4,900 visits to the 119 hospital emergency rooms reporting under NEISS. Of these 4,900 burn accidents, about 45% involved customary household appliances.

Of the 240 product categories, only about 19 possess appropriate characteristics as subjects for the illustrative standard. These 19, though less than 10% of the total number of categories, were responsible for or are involved in about 1,350 emergency room visits during 1975; which, if projected on a national basis, was about one burn accident per 53,000 households. Although there are no supporting data, the incidence of "nuisance" burns must be many times this figure.

A study of product-hazard combinations of these 19 product-types shows that burn accidents result from contact with accessible hot surface elements of the product. Despite the diversity of product-types, the hazard, and its manifestation, are common to all of the 19 product-types, where personal carelessness is not a factor in the accident sequence.

Current voluntary, industrial standards should not be judged or evaluated in the manner of generic standards, however if they are taken as a group, it is apparent that the primary emphasis is on the protection

---

*National Electronic Injury Surveillance System: a data collection system based on accident-injury reports from approximately 119 hospital emergency rooms.

of components of appliances from excessive heat rather than on the protection of the user against burns. The few standards which contain surface temperature limits could afford better protection of consumers from burn accidents. The inadequacies of present standards are in the inclusion of only a few surface materials used in appliances, in the consideration of contact times, and in the consideration of physiological response factors.

The concept of generic safety regulation is, in principle, only an extension of the product-specific idea applied to many products having a common hazard to be controlled. The extension to many products is based on the ability to provide appropriate countermeasures and a test method which are unambiguous and clearly applicable to all products covered. Reference 1 describes the elements in standards development and examines the relationship between the product-specific standard and the generic standard.

The recent development of a heat conduction model (Reference 2) and an instrument (thermesthesiometer) which measures physiological response (Reference 3) provide a theoretical and practical basis for generating criteria for the control of thermal burns associated with common household appliances.

III. STATEMENT OF PROBLEM

The cumulative evidence of the NEISS system, the discussion of burn accidents in the literature, the limited experimental data developed in the course of this effort, and the fault-tree analysis of product types lead to the inevitable conclusion that "nuisance" burns are a prevalent hazard of household appliances, and these burn-accidents may be agents in more severe accident situations.

It is also perceived that the correction of thermal hazards in household appliances is within the state of the art, and both theoretical and practicable methods are available to establish criteria and procedures for improved standards.

IV. APPROACH

This section summarizes the development of the data and information used to specify the countermeasures for the perceived thermal burn hazard and the test methodology for product compliance. The content and conclusions stated in the following Summary are supported by the technical detail given in Appendix A.

The technical approach to the development of an illustrative generic standard is based on a progression of analyses which begins with existing statistical evidence, clusters product types, evaluates product-hazard combinations, describes the theoretical and experimental models and applications, and ends with a determination of countermeasures and requirements for compliance. The sole objective of these efforts is to provide the basis for the content of the illustrative standard. All conclusions and data are to be considered as tentative and for illustrative purposes only.

Summary

In order to study the involvement of certain household consumer products with thermal burn accidents, it was first necessary to: (1) group the products according to certain characteristics pertaining to the perceived hazard, (2) establish the basis for selecting appropriate surface and product element temperature levels, by material and contact-time, and (3) mold these results into a specific statement of countermeasure and test methodology.

Using available statistical evidence and certain criteria of selection, 19 product-types from a total of 240 product categories (listed in Appendix B) were selected as subjects. These 19 possessed a common hazard for which countermeasures (design, insulation, or surrogate materials) could be identified and a single test method specified to obtain compliance.

The physical and technical details of the product-hazard combinations were studied in several ways. A theoretical heat flow model contributed general knowledge of heat-flow phenomena; fault-tree analysis provided a method for analyzing causes and effects; a measuring instrument called the thermesthesiometer was used to provide empirical data on hot surfaces; and physical properties of surface materials were studied with regard to the role of thermal inertial properties and composite surfaces in heat-flow problems. The heat flow model served as a basis (1) for the calculation of contact temperatures, (2) for certain conclusions about thin insulating surfaces, and (3) for providing an explanation of heat flow phenomena over short periods of time. The thermesthesiometer provided the capability for measuring contact temperatures for any surface of interest and for estimating the thermal inertia for such surfaces in lieu of complex theoretical calculations. The fault-tree analysis was instrumental in identifying safe or unsafe features of product-type characteristics and in deriving the choices for reducing or eliminating the hazard.

These investigations provided the basis for developing a table of acceptable surface temperature levels, which are based on a selected time of contact and the thermal inertia of the hot surface or product elements. This table is given in Appendix A and in the illustrative standard (Part V).

V. ILLUSTRATIVE STANDARD

A. Scope

1. This standard shall apply to all household consumer products containing a heat source which can have, as a result of anticipated use, an accessible, nonfunctional hot surface. A hot surface is defined as a surface whose temperature exceeds an equivalent human contact temperature of 50°C for a three-second contact time. A nonfunctional surface is a surface whose location, position, or function is not integral to the heat or radiative output of the product.

B. Exclusions

1. Functional hot surfaces except those surfaces which act as heat or light shields, collimators, or focusing structures.

2. Surfaces that cannot be contacted after installation.

3. Surfaces that cannot be contacted by the articulated probes described in Section D, below.

4. Vent openings and surfaces immediately adjacent to such openings.

5. Certain portions of a self-cleaning oven as prescribed in UL858, Section 34.2.G., September 30, 1975.

C. Maximum Temperature Levels

1. All products included under Section A and not excluded by Section B shall comply with the following maximum surface-temperature levels.

*Maximum Acceptable Temperature Limits**

A. Surface Material[1/]	Surface Temperatures (T_s), °C
Painted metal	50
Porcelain enamel	55
Glass	55
Plastics	80
Aluminum	60
Stainless steel	50
Carbon steel (1%)	50
Zinc	50
Copper	50
Chrome	50
B. Handles and Knobs	**°C**
Bare or painted metal[2/]	50
Glass[2/]	55
Plastic	75
Decorative/indicator metal strips[3/]	50

*The data in this table are for illustrative purposes only and should not be taken as final or authoritative.

[1/] Surfaces include open corners, decorator strips, portions of the product which may be used as a work area. There is no exclusion by height from floor or type of installation.

[2/] These temperatures apply for those elements of the product in which a heat conduction path is provided by direct contact with a heat source.

[3/] Thin metal strips on knobs are excellent heat sinks; if these are not insulated from heat flow they become a severe hot spot.

D. Test Accessibility Probes

1. An articulated test probe will be used to determine accessibility by an adult hand to remote portions of the product. The probe will approximate the maximum reach of an adult hand in straight or bent attitudes.

2. An articulated test probe will be used to determine accessibility by a child's hand to remote portions of the product. The probe will approximate the maximum reach of a child's hand in straight or bent attitudes.

E. Test Method

1. Determination of accessible contact surfaces

(a) The subject product will be examined for all accessible nonfunctional or included surfaces. These surfaces are designated as test surfaces.

(b) The articulated probes will be used to determine accessibility to remote surfaces.

2. Test conditions

(a) The product will be activated in an operating mode which reflects its normal performance result.

(b) Each test surface will be measured for its surface temperature by a thermocouple probe and recorded.

(c) This test will be repeated for each designed mode of operation of the product and for all of its normal cycles, range of settings, and performance results.

(d) A thermesthesiometer may be used instead of a thermocouple to obtain a direct measurement of contact temperature if the test conditions are satisfied.

3. Test measure

(a) Each recorded surface temperature will be converted to an equivalent human contact temperature (T_c) based on a three-second contact time and the thermal inertia of the test surface. A four-second contact time is permitted for handles or knobs unless the test surface has a thermal inertia greater than 0.07.

(b) If a thermesthesiometer is used, step 3 (a) is omitted.

(c) All recorded T_c values are compared against the maximum temperature levels, given in Section C, for compliance to the standard.

Discussion

Some of the minor burn problems could be corrected by the adoption and observance of good manufacturing practices. These practices include using appropriate materials of low thermal inertia, insulation, or coatings on surfaces; using good design procedures which will reduce heat flow to particular areas of the product; and using good quality control procedures to test product performance.

A number of additional features, which could be promulgated as good manufacturing practice or guidelines and would serve as effective countermeasures, are warning signal displays of dangerous temperature levels, interlock arrangements, cut-off devices adjusted to improper use, etc. These require research and development, but they represent ways and means of reducing burn accidents and should be considered as items of interest for product safety.

The illustrative standard which appears above is not intended to be complete, but rather to suggest the tone and content for the control of hot surfaces associated with some household appliances. This attempt has not had the benefit of the normal process of examination and consensus usually associated with the development of a voluntary industry standard. There are a number of technical matters that need additional study before data and conclusions can be taken as authoritative.

Appendix A.

Technical Approach

A. Clustering and Fault-Tree Analysis

In order to determine how many product-types will be covered by the illustrative standard, and in order to determine appropriate countermeasures to the hazard, the product-types are (1) clustered according to certain attributes, and (2) analyzed to determine the precise nature of the product-hazard factors. The first process, clustering, is intended to group together these product-types which have similar hazard characteristics. The second process, fault-tree analysis, is used to confirm or reject the initial assignment to the cluster by examining, in critical detail, each product-hazard factor for the causes of the hazard and the choices for corrective action. A product-type may be dropped from the cluster if the character of the hazard is significantly different from the rest of the product-types or if the countermeasure is peculiar to the product-type and not common to the group. By studying the hazard as it relates to the product-types and evaluating the information gained from the fault-tree diagrams, a final determination can be made for each product-type about its inclusion under the standard. The details of this development are given in the following sections.

NEISS Data Source

The NEISS data base lists approximately 240 product categories associated with thermal-burn injuries (see Appendix B). Many of these injuries are associated more with behavioral patterns than with product use, and many of the product categories are not appropriate candidates for inclusion under our illustrative standard because of their special characteristics.

Of these 240 product categories, we eliminate those whose special characteristics make them inappropriate for inclusion under our illustrative standard. Categories such as torches, charcoal grills, welding equipment, etc.; products which are not typically associated with household appliance use such as firearms, vehicles, foods, fireworks, etc., are also excluded. This screening results in reducing the list of 240 to 19 product categories of interest for our hypothetical regulation. This list is given in Table A-1:

Table A-1: Basic Product-Type Cluster

Product	Frequency*	Product	Frequency*
Ranges	261	Space Heaters, Electric	30
Irons	258	Fry Pans	28
Ovens	195	Heating Pads, Electric	25
Stoves	180	Hot Plates, Electric	24
Broilers, Electric	68	Steam Iron	20
Cookware, Metal	46	Pressure Cookers	20
Cooking Stoves	40	Toasters	19
Space Heaters	40	Coffee Makers	19
Gas Room Heaters	31	Table Stoves	18
Gas Space Heaters	30		

*1975 data, based on 119 hospitals reporting under the NEISS.

These 19 product categories are involved in about 45% of all burns recorded by the NEISS for 1975. Since the NEISS system reports only emergency room cases for those hospitals reporting under the NEISS structure, the total frequency is not necessarily indicative of the assumed widespread hazard of "nuisance" burns which are not reported or are reported under different circumstances, such as at burn treatment centers.

ELECTRIC RANGES

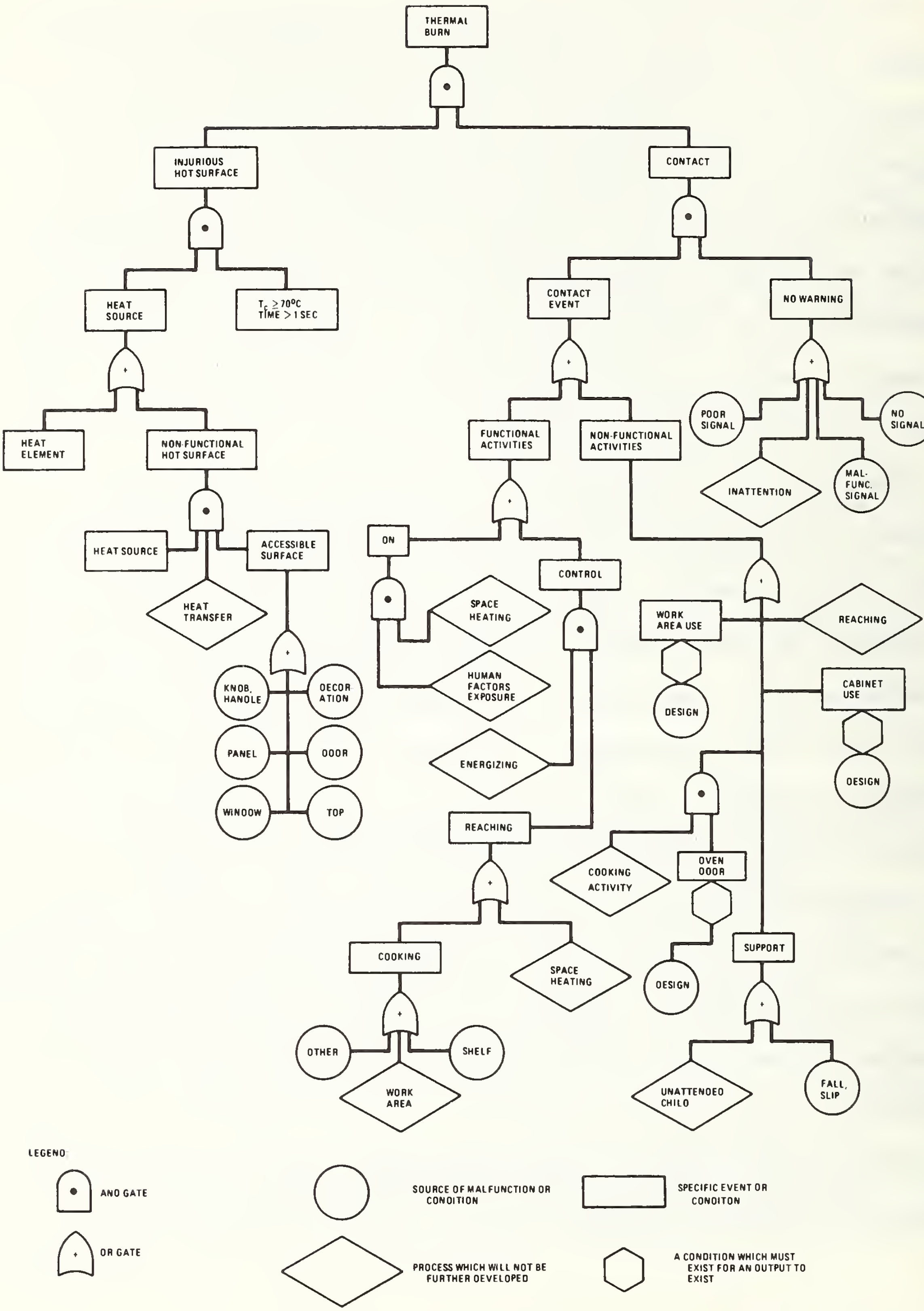

FIGURE A-1 FAULT TREE DIAGRAM FOR ELECTRIC RANGES

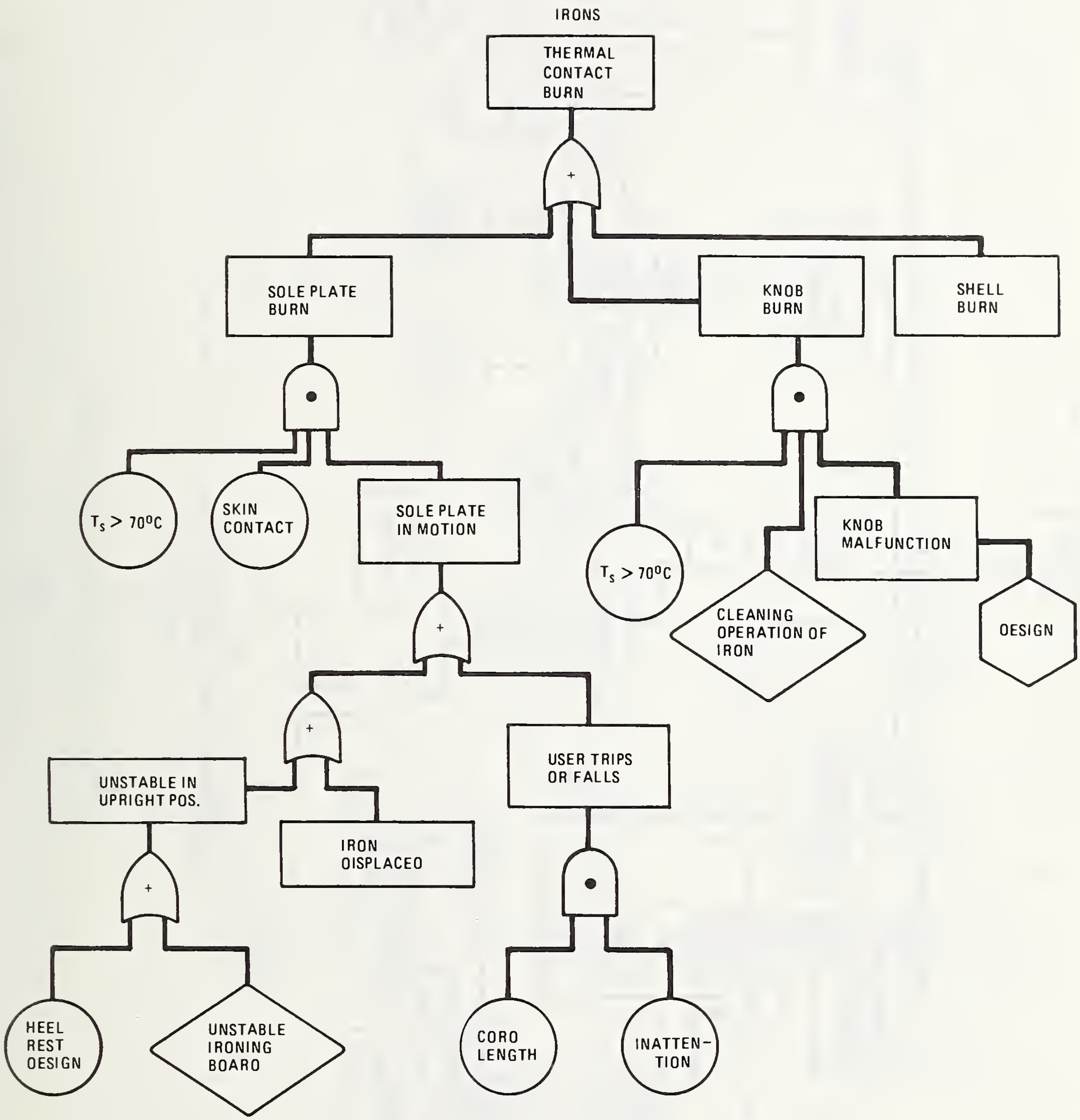

FIGURE A-2 FAULT-TREE DIAGRAM FOR ELECTRIC IRONS

ELECTRIC BROILERS

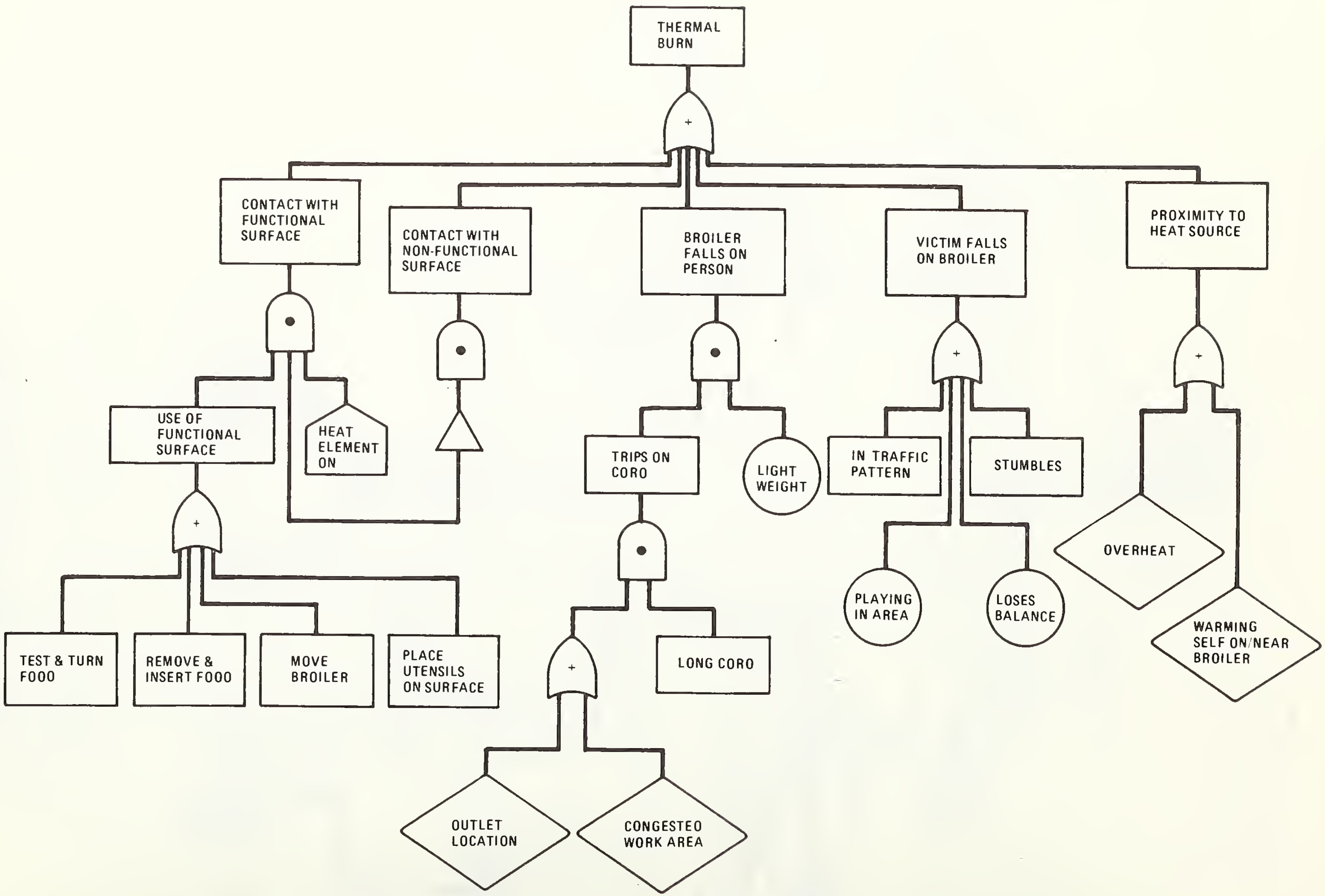

Figure A–3 FAULT-TREE OIAGRAM FOR ELECTRIC BROILERS

ELECTRIC COFFEE MAKER – ORIP PERCOLATOR

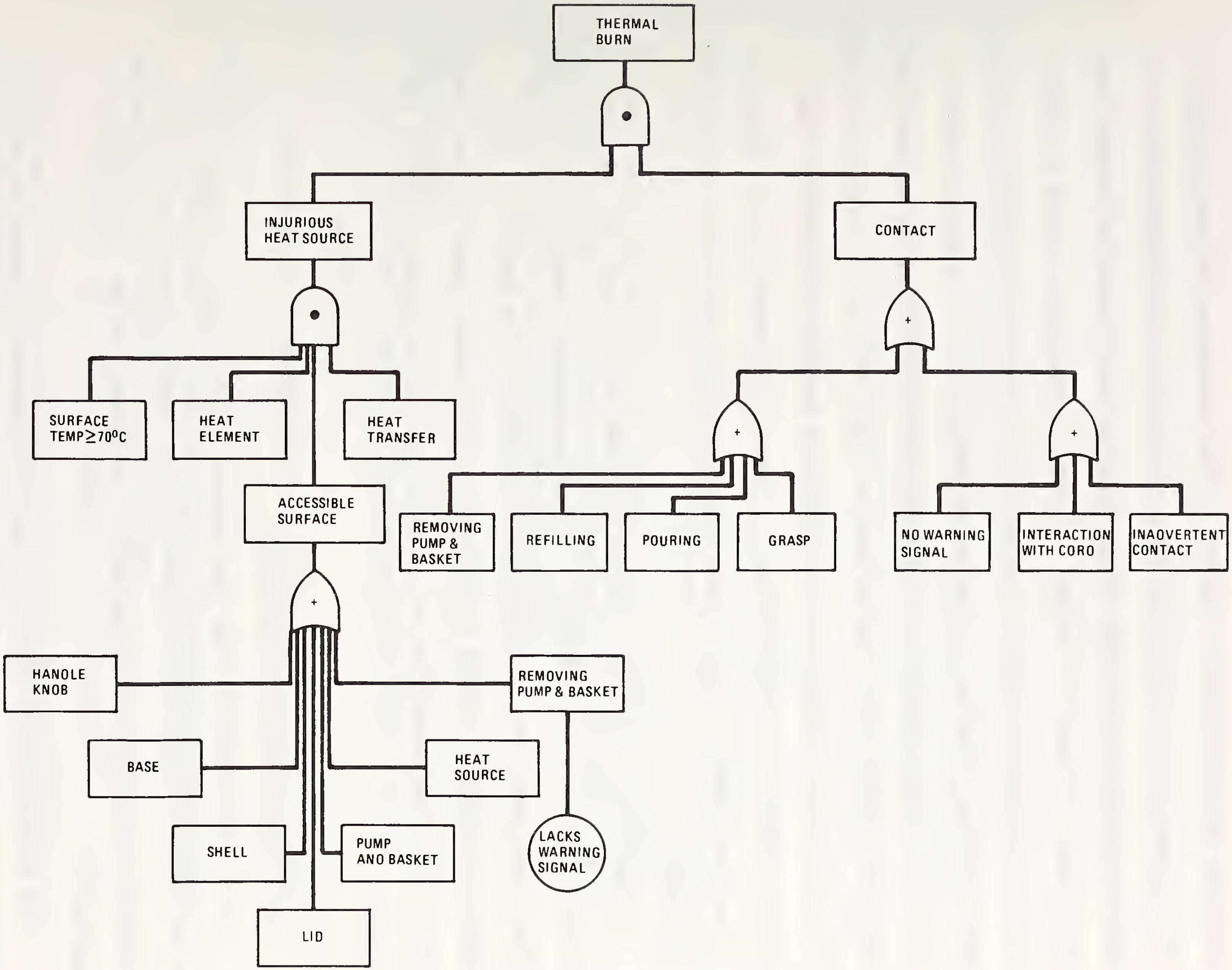

Figure A–4 FAULT-TREE OIAGRAM FOR ELECTRIC COFFEE MAKERS important use of fault-tree analysis is the development of what is called the "minimum-cut set." The minimum-cut set is the set of basic events which can produce the failure or accident, but which cannot be reduced and still cause the hazard or failure. Minimum-cut sets can be used to study a variety of safety problems. One of the most important of these is the identification of factors or conditions common to all or some of the paths in the fault-tree diagram. If appropriate countermeasures can be specified for certain conditions in the minimum-cut set, then the correction or reduction of the failure or accident can be obtained in an efficient manner. This process amounts to an optimization, in that if countermeasures are applied to a minimum number of basic events, then a maximum reduction of the hazard is realized.

Although the minimum-cut set is not shown in the fault-tree diagrams, the concept was used to identify the countermeasures. Based on the analysis, it was concluded that the illustrative standard will be generic in scope because the hazard is shown to be common to the product-types in the cluster, and a single test method can be specified for all the product-types in the cluster.

B. Heat-Flow Factors and Equations

It is not appropriate for the purposes of this report to digress into an extensive review of heat conductivity, but certain aspects of heat-flow phenomena are relevant as background to the content of the illustrative standard.

The material which follows on heat-flow phenomena is based on the work contained in References 2 and 3, and has been paraphrased for the purposes of this report. The need for including selected portions of theory is to provide a foundation for selecting effective countermeasures and to understand the physical limitations and consequences of choices for this standard.

Thermal Inertia and Diffusivity

Thermal inertia ($\sqrt{\lambda}$) is defined as the square root of the product of thermal conductivity (k), specific heat (c), and density (ρ):

$$\sqrt{\lambda} = \sqrt{kc\rho} \quad . \tag{1}$$

Diffusivity (α) is defined as

$$\alpha = \frac{k}{c\rho} \quad . \tag{2}$$

In general terms, thermal inertia is a way of describing the capability of a material to move heat from itself to another material. Diffusivity is a measure of how quickly heat moves from one point to another. Both $\sqrt{\lambda}$ and α are used in the discussions which follow.

Basic Concepts

The basic ideas of heat-flow theory that are relevant to the illustrative standard are:

(1) the relative temperature distribution is a function of thermal inertia,

(2) if the time of contact is large, the temperature distribution behaves as if the interface were not present,

(3) the time required for temperature to reach a particular value is proportional to the square of the distance and inversely proportional to the thermal diffusivity.

(4) given an interval of contact time, the thickness of the material influences whether the maximum rate of dissipation occurs during that interval or occurs at a time greater than that interval.

The significance of this is that under certain conditions of contact between human tissue and a hot surface, the influence of a protecting layer is meaningful only when the contact time is reasonably short.

A basic steady-state equation obtained from the theory, which relates surface temperature (T_s) to skin-contact temperature (T_c) and the thermal inertia of the material ($\sqrt{\lambda}$), is:

$$T_s = T_c + \frac{0.035\ (T_c - T_\rho)}{\sqrt{\lambda}} \qquad (3)$$

where T_ρ is the assumed temperature of the skin. A device called the thermesthesiometer has been constructed to measure surface temperatures as they are perceived by human tissue (T_c). This work is described in Reference 3. T_ρ may be taken as 33°C, so equation (3) becomes

$$T_s = T_c + \frac{0.035\ (T_c - 33)}{\sqrt{\lambda}} \qquad (4)$$

Equation (4) shows that as the thermal inertia becomes large the contact temperature approaches the surface temperature.

Figure A-5 shows the relation between T_s and T_c for a range of values of $R = 28.6\ \sqrt{\lambda}$, where R is the ratio of the thermal inertia of the material to the thermal inertia of skin. The thermal inertia of skin is 0.035, whose inverse is 28.6. Also shown are various materials according to their value of R. Figure A-6 shows the physiological response, contact-time data. A contact time greater than 2 seconds is considered to be a steady-state condition for which equation (3) is valid. From Figure A-6 we construct Table A-2, which gives the pain response temperature for various contact times; included also are the corresponding temperatures for the lower limit of reversible burn injury (shown as Lower Reversible in Table A-2).

Table A-2: Temperature-Contact Time Relationships

Contact Time (seconds)	Threshold of Pain (°C)	Lower Reversible (°C)
0.5	70	70
1	62	65
2	54	61
4	48*	58
8	46*	56
16	44*	54

*Extrapolated estimates.

The data of Figures A-5 and A-6, and Table A-2 provide a basis for evaluating surface temperature standards as they appear in some current voluntary standards; this evaluation follows.

C. Determination of Surface Temperature Levels

Current Surface Temperature Limits

The following Table, A-3, of maximum acceptable temperature limits is extracted from a current, voluntary standard for kitchen ranges.

SURFACE TEMPERATURES BY THERMAL INERTIA FOR SELECTED CONTACT TEMPERATURES

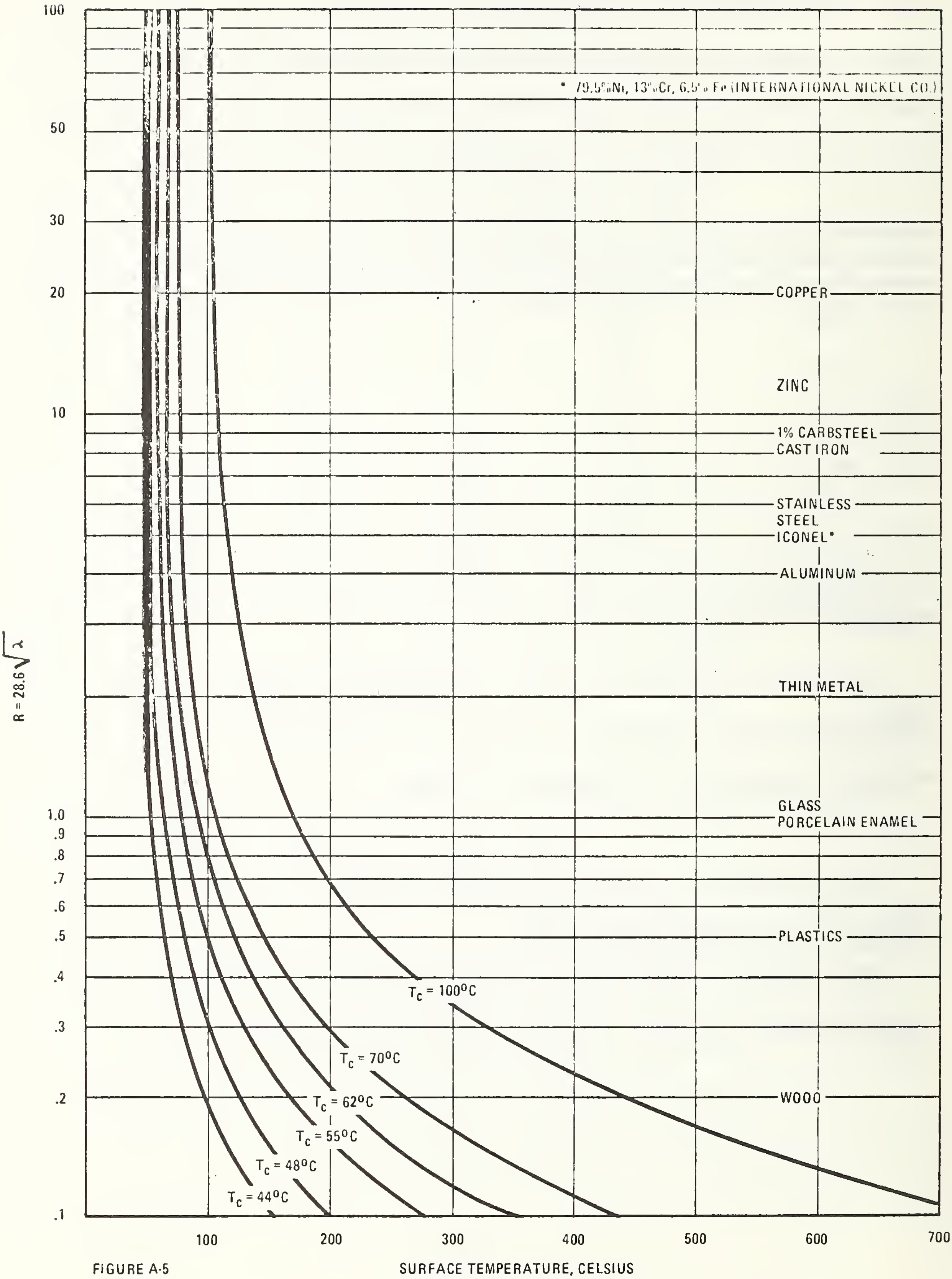

FIGURE A-5

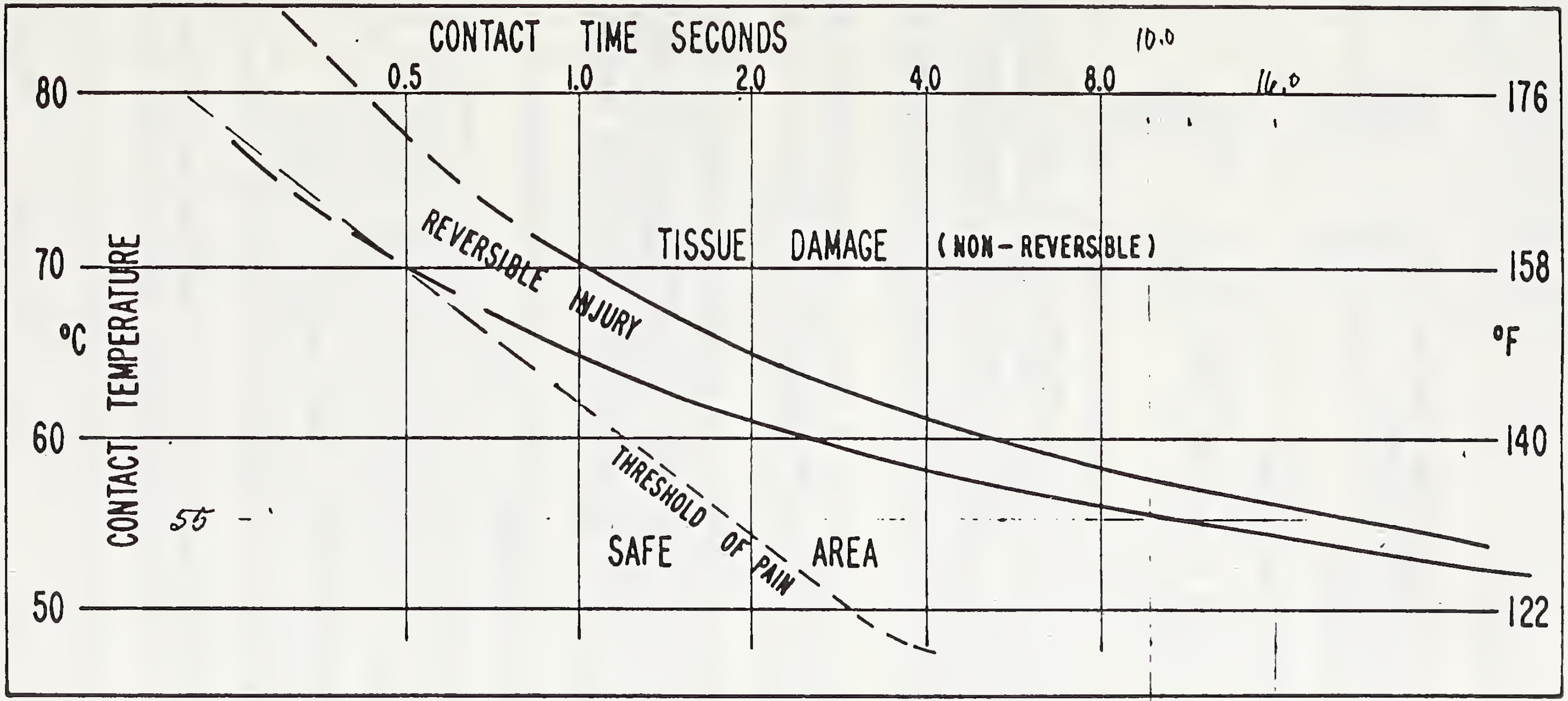

Figure A--6 : Physiological Response Curve

Table A-3. Maximum Acceptable Temperature Limits*

	°C	°F
A. Surfaces[a]		
(1) Bare or painted metal	67	152
(2) Porcelain enamel	71	160
(3) Glass	78	172
(4) Plastic[b]	83	182
B. Handles and knobs[c]		
(1) Bare or painted metal	55	131
(2) Glass	65	149
(3) Plastic[b]	75	167

[a]Temperature limits are increased 17°C (31°F) for areas that will be more than 3 feet above floor level as installed. A cabinet-supported, counter-mounted, or wall-mounted appliance is to be installed in accordance with the manufacturer's instructions to determine which areas are 3 feet above floor level.

[b]Includes plastic with a metal plating not more than 0.005-inch thick; and metal with a plastic or vinyl covering not less than 0.005-inch thick.

[c]For a self-cleaning or a continuous-cleaning oven, these temperature limits apply only during the time an oven door can be opened. At cleaning temperatures when the door is locked, the temperature limits for handles and knobs are the same as given for surfaces.

*Effective September 30, 1975

Our interest in this table concerns the protection it provides against severe burns, the diversity of surface materials of interest, and the extent to which it adequately deals with composite surfaces.

In order to understand the temperature limits for surfaces, handles, and knobs in a more concrete way we plot the temperatures of the table on the *surface-temperature versus R* graph. This plot is given in Figure A-7. The limits for surfaces fall on or to the left of the 55°C threshold line. At this temperature a safe contact time is two seconds or less. The point for plastics is safer, giving about a three-second contact time. The plots for handles and knobs lie consistently close to the 48°C threshold line, which provides protection for a contact time of four seconds or less.

A concern is whether it is adequate to try to cover all metals with one temperature limit, i.e., 67°C. From Figure A-5 it can be seen that if products are made from alloys or materials with high values of R, the contact temperature will be very close to the surface temperature. At 67°C surface temperature, no more than a one-second contact time can be tolerated, and this is getting close to non-reversible tissue damage if longer contact-times occur.

A last point concerns the problem of composite surfaces. On a theoretical basis, composite surfaces are difficult to model because the assumptions needed to solve the heat conduction equation are difficult to reproduce experimentally. Consequently, theoretical solutions may be unsatisfactory to establish useful, operational criteria. Data on composite surface heat-flow phenomena may have to be developed experimentally to provide industry with guidelines. The table cited above provides composite-surface data for only plastic coating and porcelain enamel. Painted metal and bare metal have the same temperature limit.

It should be noted that the temperature-limit table, A-3, was intended to apply to kitchen ranges and was not necessarily intended as a generic standard for temperature limits for all product-types of a similar nature.

PLOT OF CURRENT TEMPERATURE LIMITS

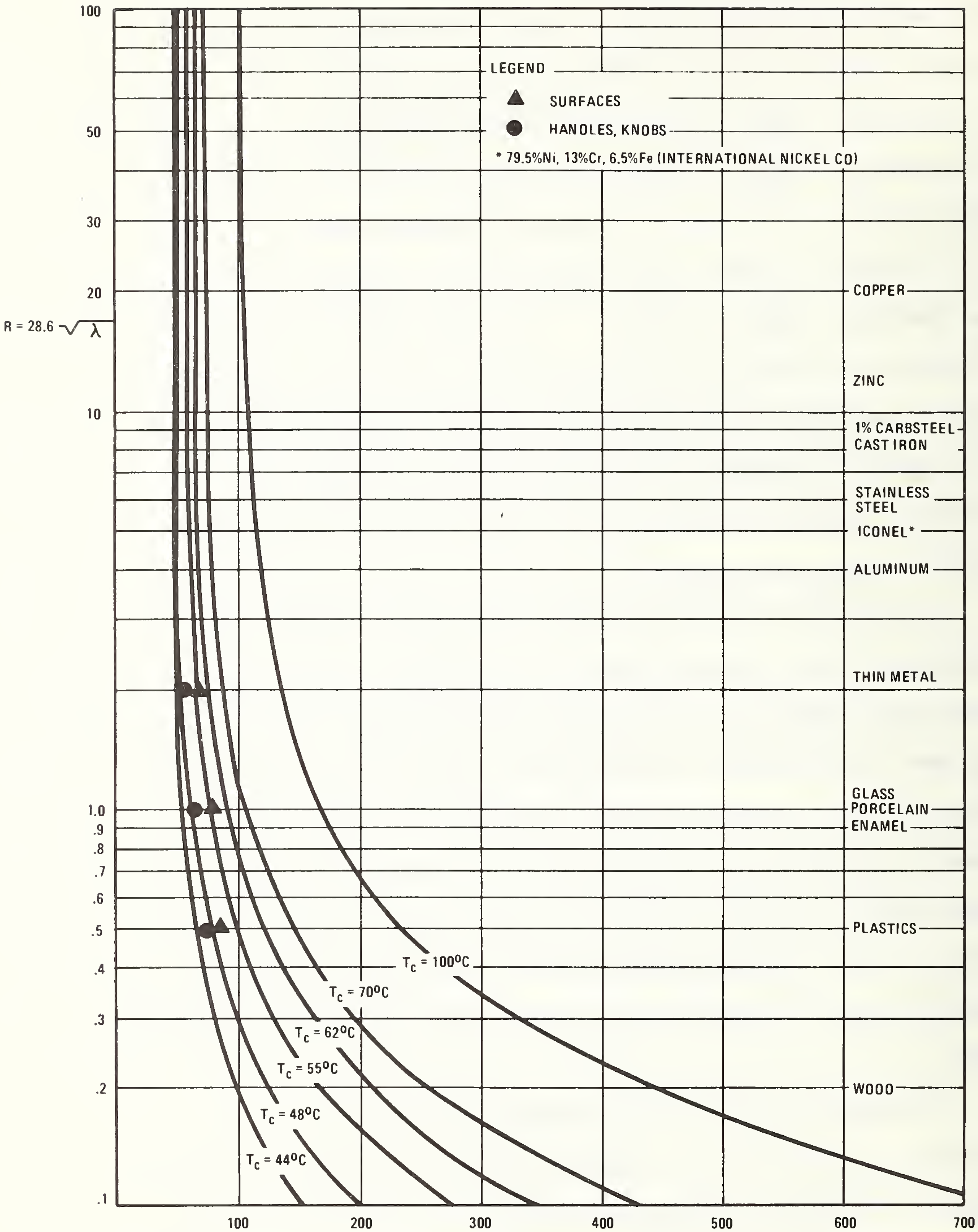

FIGURE A-7

SURFACE TEMPERATURE, CELSIUS

Ranges and other similar products do, nevertheless, create a potential for severe burns, not so much from hot surfaces as from hot spots, which in some standards are excluded from the standard temperature limits or not addressed at all. The results of our analysis of the heat-flow problem and the points raised on current standards provide a basis for a revised table of temperature limits.

Revised Temperature Limits

If a reasonable contact time can be ascertained, then the temperature limit standards follow directly. The selection of a reasonable contact time, however, is based on a difficult accommodation of providing safety to the user and feasibility to the manufacturer. Determining the level of safety and achieving that level involves a number of issues, some of which may be more a matter of opinion or interpretation than a matter of fact. Different assumptions about safety requirements lead to different standards for contact times and surface temperature limits. For the purposes of illustrating the generic method a conservative decision was made to use 50°C as the contact temperature and three seconds as the maximum contact time.

The selections of a contact time of three seconds and a contact temperature of 50°C are founded on the following points:

(1) A contact time greater than three seconds would probably occur in situations other than in the normal use of the product; therefore, if the contact time is greater than three seconds, then it is likely that the situation is abnormal, and protection should be provided;

(2) Hot spots are often more hazardous than hot surfaces, and a three-second contact time is probably the maximum allowable contact time if the thermal inertia of the spot surface is greater than 0.07;

(3) A contact time greater than three seconds and a contact temperature greater than 50°-55°C produces pain and may cause injury.

(4) A combination of a four-second contact time and a contact temperature of 55°C may be a contributing factor in non-burn kitchen accidents because of sudden, involuntary reaction to the pain;

(5) If a contact time greater than three seconds is experienced by a user, but the contact temperature is not greater than 50°C, then the injury severity is held below the lower reversible damage curve. This conclusion is based on the admittedly uncertain reliability of the response curves of Figure A-6. Until these data are improved, however, the conclusion is not unreasonable.

Therefore, until the physiological response data can be improved, the three-second contact time and the 50°C contact temperature have been chosen as conservative limits for the illustrative standard.

Taking 50°C as a compromise contact temperature the maximum acceptable surface temperature-limit table would become:

Table A-4: Revised Maximum Surface Temperature Limits

Surface Material	Maximum Surface Temp. (°C)
(1) Bare or painted metal	50
(2) Porcelain enamel	55
(3) Glass	55
(4) Plastic	82

The values for the first three surface types differ markedly from those in current use. For handles and knobs, the plots shown in Figure A-7 lie in the region of a four-second contact time. For normal use of the range this contact time is reasonable, but the hazard may be associated with an accessory to the handle or knob rather than the handle itself. An accessory would be a rivet, a support, a bolt, or a structure attaching the handle to a surface of the appliance. These accessories are usually made of metal for structural integrity; if this is so, then their heat conduction properties should conform to safe limits. Our limited, empirical data on hot spots show, however, that the contact temperature ranged from 10% to 145% above the average contact temperature of nearby surfaces, although not all measured temperatures were considered hazardous. All of these hot spots were readily accessible to contact and were located in the "business" part of the appliance. The temperature limits of current standards do not cover these hot spots directly because they are not always located on surfaces nor are they classified as handles or knobs. A typical hot spot on a range is a small metal disc or strip fastened into the face of a knob. This strip is usually in a direct line of heat flow from the interior of the range by virtue of being in contact with or contiguous to a knob stem, which is usually made of highly conductive material. Other hot spots, hot corners, or local hot areas on large surfaces occur because the configuration of the appliance concentrates the heat in particular areas.

In order to correct these hazards it is suggested that the maximum acceptable temperature limits be amended to apply to hot spots and hot strips; be based on contact times no greater than three seconds for surfaces and four seconds for handles and knobs, as qualified by thermal inertia; and include a wide range of surface materials. Table A-5 gives the revised temperature limits as developed for the illustrative standard.

D. Countermeasures

The perceived hazard of thermal burns may be effectively reduced by the following actions: (1) tightening the maximum acceptable temperature limits to correspond to a three-second contact time for surfaces and a four-second contact time for handles and knobs; (2) using a probe for access determinations which more closely approximates the dimensions of an adult's or child's hand; (3) controlling the temperature level of surfaces of appliances likely to be used as work areas; and (4) including in the surface elements of the maximum-acceptable-temperature-limits table the variety of materials likely to be used in the manufacture of appliances whose thermal inertial values are in excess of 0.07. (This value corresponds to R=2 in Figures A-5 and A-7.)

Depending on the product-type and the manifestation of the hazard, the ways in which temperature levels are controlled will be through use of either design changes, new or surrogate materials, coating surfaces with materials having low thermal inertial properties, or insulation. Which one is used will depend on a cost-benefit evaluation and the attitude toward compliance.

E. Test Method

The test procedure for the countermeasures includes a table of maximum-acceptable-temperature-limits (MATL) for actions (1), (3) and

(4), general specifications for an access probe for action (2), and a method for obtaining contact temperatures of human response from surface temperature measurements. These are discussed separately:

(1) Based on the foregoing analysis, the table of maximum-temperature limits is revised as follows:

Table A-5. Revised Maximum Acceptable Temperature Limits*

A. Surface Material[1/]	Surface Temperatures (T_s), °C
Painted metal	50
Porcelain enamel	55
Glass	55
Plastics	80
Aluminum	60
Stainless steel	50
Carbon steel (1%)	50
Zinc	50
Copper	50
Chrome	50
B. Handles and Knobs	**°C**
Bare or painted metal[2/]	50
Glass[2/]	55
Plastic	75
Decorative/indicator metal strips[3/]	50

*The data in this table are for illustrative purposes only and should not be taken as final or authoritative.

[1/] Surfaces include open corners, decorator strips, portions of the product which may be used as a work area. There is no exclusion by height from floor or type of installation.

[2/] These temperatures apply for those elements of the product in which a heat conduction path is provided by direct contact with a heat source.

[3/] Thin metal strips on knobs are excellent heat sinks; if these are not insulated from heat flow they become a severe hot spot.

(2) The access probe prescribed in certain current voluntary standards is not appropriate for simulating the human finger. Its dimensions do not approximate those of the finger nor is it designed for articulation.

The articulated probe described in UL 1026 possesses most of the necessary features for good hand or finger simulation. Its dimensions approximate the adult hand; however, a probe representing juvenile hand characteristics is necessary.

(3) Compliance with the temperature levels given above requires measuring product-element temperatures (T_s), according to test procedures, and converting these temperatures to equivalent contact temperatures for humans (T_c).

A test procedure prescribes the orientation or use of the product, important human factors at play in the product's use, and includes in the measurements to be made the appropriate combinations of variables and conditions. It is important to include the anticipated uses of the appliance, such as using its top surfaces as a work area, in the test scenarios.

(4) There are two methods to obtain measurements of T_c, one based on a measuring instrument called the thermesthesiometer, the other is the conversion of a measured surface-temperature to its equivalent T_c value.

The thermesthesiometer is a thermocouple probe designed to simulate the heat conduction properties of human skin. It measures the temperature of a hot surface as the skin would measure it, as a function of the length of time of contact. These data are used to make a theoretical determination of skin damage or the severity of the injury.

Although the thermesthesiometer has been able to verify theoretical models of heat conduction in which human tissue is a subject, has provided a device which bypasses the need to estimate thermal inertial values for composite services, and has dramatized the importance of contact times in burn accidents, it is not recommended for extended use in its present configuration in a quality control, production line context.

An alternative procedure is to measure test surface temperatures in the usual manner by employing a standard thermocouple probe, regular or articulated, according to the test procedures of the illustrative standard or their equivalent, then convert this temperature to an equivalent human-response temperature. This method requires knowing the thermal inertia of the surface, and this can be obtained by using the thermesthesiometer under a strict experimental regimen. It would combine measuring T_s by a standard thermocouple and T_c by the thermesthesiometer and computing $\sqrt{\lambda}$ from equation (3). The value of T_ρ would have to be stabilized for each experiment, for large variations in either T_c or T_ρ, or both, would produce corresponding variations in $\sqrt{\lambda}$. The final estimate, in theory, of $\sqrt{\lambda}$ would be given as an interval estimate. From experiments made over many surface types a table of thermal inertial values could be developed which when entered with a measured T_s would yield the proper value of T_c. If a thermesthesiometer is to be used directly, in place of the method given above, then it should be designed to meet the requirements of the measuring probes as implied in the illustrative standard.

Appendix B.

Consumer Products Associated with

Thermal Burns: NEISS Classification

The following list of 240 product categories are based on the NEISS for 1975.

Ranges, Not Otherwise Specified
Irons, Not Otherwise Specified
Motor Vehicles, Except Two-Wheeled Vehicles
Gasoline
Sun Lamps
Matches
Cigarettes, Cigars and Pipes
Ovens, Not Otherwise Specified
Stove/Range, With Oven, Gas
Licensed Two-Wheeled Vehicles, Motorcycles, Etc.
Home Structures, Not Otherwise Specified
Heating Systems, Not Otherwise Specified
Foods
Fireworks
Cigarette/Pipe/Cigar Lighters
Charcoal
Cookware, Not Otherwise Specified
Radiators, Home
Lighter Fluid
Welding Equipment, Not Otherwise Specified
Furnaces, Not Otherwise Specified
Day Wear
Home Elect. Wiring, Outlets, Fuses, Fuseboxes
Cookware, Metal
Floor Furnaces, Not Otherwise Specified
Torches, Soldering, Cutting, Welding, Unpowered
Gas Furnaces - Excluding Wall, Room, Unit, Duct, Floor Heater
Stove/Range, With Oven, Electric
Irons With Dry Heat
Wires/Cords, Not Otherwise Specified
Portable Gasoline Cooking Stoves/Grills
Space Heaters, Not Otherwise Specified
Outdoor Grills, Not Specified
Light Bulbs
Radiators, Not Otherwise Specified
Heaters, Room, Gas, Floor Type
Clothing
Space Heaters, Gas, Not Otherwise Specified
Ovens, Separate From Ranges, Gas
Electric Fry Pans and Skillets
Fire Arms
Grills, Charcoal, Not Otherwise Specified
Range and Oven Accessories - E.G. Racks, Broiler Pans
Electric Heating Pads
Water Heaters, Not Otherwise Specified
Electric Hot Plates
Lawn Mowers, Not Otherwise Specified
Nightwear
Extension Cords

Motor Scooters, Minibikes, Etc., (2 or 3 Wheels)
Gas Water Heaters
Pressure Cookers and Canners
Steam Irons
Toasters
Coffeemakers/Teapots, Not Otherwise Specified
Table Stoves, Open Flame
Wax Candles/Paraffin
Electric Space Heaters, Not Otherwise Specified
Metal Pieces, Not Otherwise Specified
Power Mowers, Not Specified
Charcoal Igniters, Chemical
Gasoline, Kerosene and Propane Lanterns and Lamps
Hot Water Pipes
Fireplaces, Not Otherwise Specified
Space Heaters, Electric, Portable
Portable Grills, Charcoal
Appliance and Lamp Cords, Not Attached
Heaters, Wall, Gas
Tableware, Including Insulated Designs
Electric Broilers and Grills
Plastic Products, Not Otherwise Specified
Welding Equipment, Electric
Paper Wrapping Products, Paper Objects
Pressurized Containers
Hair Curlers, Electric, Without Steam
Lamp/Light Fixtures, Lanterns, Not Otherwise Specified
Propane (LP) and Butane Gas Tanks and Fittings
Pipes, Not Otherwise Specified
Ductwork for Heating/Cooling Systems, Registers
Steam Pipes
Bathtowels/Cloths, Beach Towels, Dishtowels/Cloths
Mattresses, Not Otherwise Specified
Incinerators, Not Otherwise Specified
Electric Corn Popper
Fireplaces, Factory Built, Wood Burning
Beds, Not Otherwise Specified
Hair Dryers
Emergency Flares, Signal Flares
Bicycle and Bicycle Equipment
Bedding, Mattresses, Box Springs, Matt. Covers, Pad
Kerosene
Heat Lamps
Outer Wear
Drapes, Curtains, Inc. Plastic and Shower Curtains
Electric Comb
Gas (LP) Heating Stoves

Wood Stoves
Radios, All Models
Coal Stoves
Patio Lights/Torches - Fuel Burning
Farm Tractor
Fuel Storage Tanks, Gas Cans
Batteries, Not Otherwise Specified
Soldering Guns and Irons
Mobile Homes and Related Equipment
Roofs and Roofing Materials
Heating Equipment, Portable, Not Otherwise Specified
Germicidal Lamps
Containers, Metal - Cans
Boats, Motors and Accessories for Recreational Use
Rope and String
Go-Carts, All-Terrain Vehicles, Etc., (4 or More Wheels)
Power Mower, Rotary, Gasoline
Hair Curlers, Hair Pins, Hair Clips, Etc.
Waste Containers
Gas Pipes, Fittings and Distribution Systems
Clothes Dryers, Not Otherwise Specified
Vacuum Cleaners
TV, Not Otherwise Specified
Microwave Ovens Separate from Ranges
Electric Deep Fryers
Floor Furnaces, Gas
Kerosene Space Heaters, Attached
Ovens, Separate from Ranges, Electric
Air Conditioners, Not Otherwise Specified
Flatware, Except Cutlery
Dishwashers
Fireplace Equipment
Other Kitchen Gadgets, Mix/Measuring Spoons/Cup
Ironers - an le
Alcohol, Not Otherwise Specified
Catalytic Heater (LP or Gasoline)
Hair Curlers, Electric, With Steam
Paint and Varnish Thinners
Paints, Varnish, Shellac, Rust Preventive, Etc.
Home First-Aid, Health Equip., Thermometers, Q-Tips, Etc.
Solvent Based Cleaning and Sanitizing Compounds
Exercise Equipment
Gasoline or Other Fuel-Powered Toys, Model Cars
Grills, Electric, Stationary, Built-in
Hair Brush/Combination - Not Powered
Hand Mowers
Alcohol, Beverage
Stationary Grills, Gas
Stationary Grills, Charcoal
Portable Gas Heating Equipment - LP

Football, Activity and Related Equipment
Containers, Plastic, Including Bottles, Bowls, Etc.
Camping Equipment Including Tents, Cots, and Sleeping Bags
Portable Gasoline Heating Equipment
Turpentine
Lubricants, Machine Oils, Engine Oil
Adhesives and Adhesive Products Including Glues
Respiratory Protection Devices
Other Construction Materials
Chain Saws
Snow Throwers, Blowers
Garden Tractors
Grills, Gas, Not Otherwise Specified
Liniments, Rubbing Compounds, Including Camphor, Etc.
Bricks, Concrete Blocks
Couches, Sofas, Davenport, Divan, Studio Couches
Electric Table Lamps & Floor Lamps
Step Stools
Beds, Springs, Frames, Not Mattresses/Box Springs
Blankets, Not Otherwise Specified
Fireplaces, Built-In
Rugs, Carpets, Not Otherwise Specified
Electric Kettles
Electric Coffeemakers and Teapots
Pillows
Plastic Parts or Pieces, Unknown Product Origin
Other Heating Systems, Including Heat Pumps
Chairs, Not Upholstered or Not Otherwise Specified
Floor Furnaces, Oil
Automotive Tools and Accessories
Cookware, Non-Metal Including Glass, Pottery and Ceramic
Cutlery, Unpowered
Sinks
Batteries, Wet Cell
Boilers
Electric Immersion Water Heaters
Bleaches and Dyes, Not Intended for Cosmetic Use
Space Heaters, Electric, Stationary
Waxes, Floor
Faucet Water Heaters
Potholders, Oven Mits, Hot Pads
Coffeemakers and Teapots, Unpowered
Garbage Disposers
Knives, Not Otherwise Specified
Candle Holders, Candlesticks
Sound Recording and Reproducing Equipment, E.G. Tape Recorders
Other Chemicals
Shoe Polish
Refrigerators, Not Otherwise Specified

Automotive Chemicals
Straw, Drinking
Coal Furnaces
Electric Fences
Bathtub and Shower Enclosures of Non-Glass Materials
Farm Materials Handling Equipment, Not Otherwise Specified
Cutting and Chopping Devices
Resealable Closures
Air Compressors, Separate
Sheets and Pillow Cases
Kerosene Heating Stoves, Not Attached
Cardboard Boxes, Cartons and Other Cardboard Products
Aluminum Foil Wrapping Products
Glass Bottles and Jars, Not Otherwise Specified
Separate Electric Motors
Coffee Grinders, Not Otherwise Specified
Stove, Combination Heating/Cooking
Oil Furnaces
Test Equipment, Voltage Testers
Glass Bathtub and Shower Enclosures
Heaters and Duct Heaters, Gas Unit, Suspended
Gas Ranges Without Ovens
Swimming Pools and Associated Equipment, Not Including Above Ground
Gas, Air and Spring Operated Guns
Slides
Electric Ranges Without Ovens
Blankets/Sheets, Electric
Bars and Bar Stools
Portable Grills, Kerosene
Glass, Unknown Origin
Portable Alcohol Heating Equipment
Electric Griddles
Power Drills
Billiards, Tables, Balls, Etc.
Fire Extinguishers
Charcoal Lighters, Not Otherwise Specified
Guns, Not Otherwise Specified
Thermometer, Cooking
Tennis, Badminton and Squash, Activity and Equipment
Toy Cars and Trucks, Non-Fly Planes, Boats-Not Models
Electric Waffle Irons
Toy Guns and Other Toy Weapons with Projectiles
Furniture, Not Otherwise Specified
Other Models and Their Construction Materials
Non-Heating Toy Home Equipment Including Stoves, Irons, Etc.
Caps and Cap Toys
Fuel for Model Cars, Airplanes, Etc.
Woodburning Kits
Molding Compounds (E.G., Clay, Play-Dough, Etc.)

Toys, Not Otherwise Specified
Plumbing Pipes
Blankets, Except Electric and Baby Blankets
Ice Cream Makers, Not Otherwise Specified
Floor Furnaces, Electric
Power Tillers and Cultivators
Outdoor Lighting Equipment, Electric
Electric Dryers Without Washing Machines Attached
Washing Machines with Wringers
Power Mowers, Rotary, Electric
Hatchets, Axes
Gas Lamps
Drinking Glasses, Glass
Bottle Warmers
Sterilizers
Night Lamps
Crib Mattress, Playpen Pad, Crib Bumper Pad, Etc.
Washing Machines, Not Otherwise Specified
Trays Including Folding TV Trays
Gas Incinerators
Electric Water Heaters
Massage Devices
Saunas Including Facial Saunas
Clothes Hangers of All Types
Sewing Machines
Electric Fans, Portable
Industrial Equipment
Wire, Not Electric, Hanging, Construction and Barbed Wire
Ash Trays
Elevators and Other Lifts
Outside Structures, Exterior Walls, Patios, Etc.
Insecticides, Fungicides and Rodenticides
Comb, Not Otherwise Specified
Hair Waving Preparations and Straighteners
Medical Therapeutic Equipment
Other Seasonal Decorations
Hair Curlers, Hair Pins, Etc., Not Otherwise Specified
Trains
Adult Games and Novelty Items
Christmas Tree Lights
Lumber, Boards, Paneling Pieces, Not Part of Structure

References

1. Hendrickson, R., Guidelines for the Determination and Development of Generic Safety Standards, NBSIR 76-1096, National Bureau of Standards, Washington, D.C., 1976, pp. A1-A8.

2. Wu, Y. C., "On the Control of Thermal Impact for Thermal Safety," AIAA Paper No. 75-713, AIAA 10th Thermosphysics Conference, Denver, May 1975.

3. Marzetta, L. A., "Engineering and Construction Manual for an Instrument to Make Burn Hazard Measurements in Consumer Products," NBS Technical Note 816, National Bureau of Standards, Washington, D.C., February 1974.

4. "Product Safety: Caveat Vendor," Materials Research and Standards, ASTM Vol. 12, No. 8, August 1972, pp. 12-17 et seq.

5. Hammer, W., Handbook of System and Product Safety, Prentice-Hall, Englewood Cliffs, N. J., 1972, pp. 225-250.

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 76-1097	2. Gov't Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE Illustrative Generic Standard for the Control of Thermal Burn Hazards in Household Appliances			5. Publication Date June 30, 1976
			6. Performing Organization Code 3053
7. AUTHOR(S) Robert G. Hendrickson, Elizabeth M. Robertston, Rudolph V. Kelly			8. Performing Organ. Report No.
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234			10. Project/Task/Work Unit No. 441.1432, 441.2432
			11. Contract/Grant No.
12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)* Consumer Product Safety Commission Washington, D.C. 20207			13. Type of Report & Period Covered Final
			14. Sponsoring Agency Code 118

15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This document reports on the development of an illustrative generic standard for controlling hot surfaces associated with certain categories of consumer products. The development includes evaluations of accident data, fault-tree diagrams, theoretical heat-flow phenomena, current standards, and application of the thermesthesiometer as a test instrument.

This work is a companion to the Guidelines for the Development of Generic Safety Standards, and as such, it applies the methods and techniques provided in the Guidelines. The principal tool of analysis is the fault-tree method. This method brings to safety problems a versatile and insightful way of depicting events, conditions, and causes associated with hazards and accidents.

The intent is to demonstrate the feasibility of the generic approach to controlling safety aspects of consumer products. Although the illustrative standard is based on a study of actual data, the conclusions are not to be construed as final or authoritative.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Burn hazards, household appliances; fault-tree diagrams; generic safety standards; household appliances; operations research; thermal burn hazards

18. AVAILABILITY	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
[x] Unlimited [ ] For Official Distribution. Do Not Release to NTIS	UNCLASSIFIED	47
[ ] Order From Sup. of Doc., U.S. Government Printing Office Washington, D.C. 20402, SD Cat. No. C13 [x] Order From National Technical Information Service (NTIS) Springfield, Virginia 22151	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. Price $4.00