Accessible Hot Surfaces & Burn Hazards

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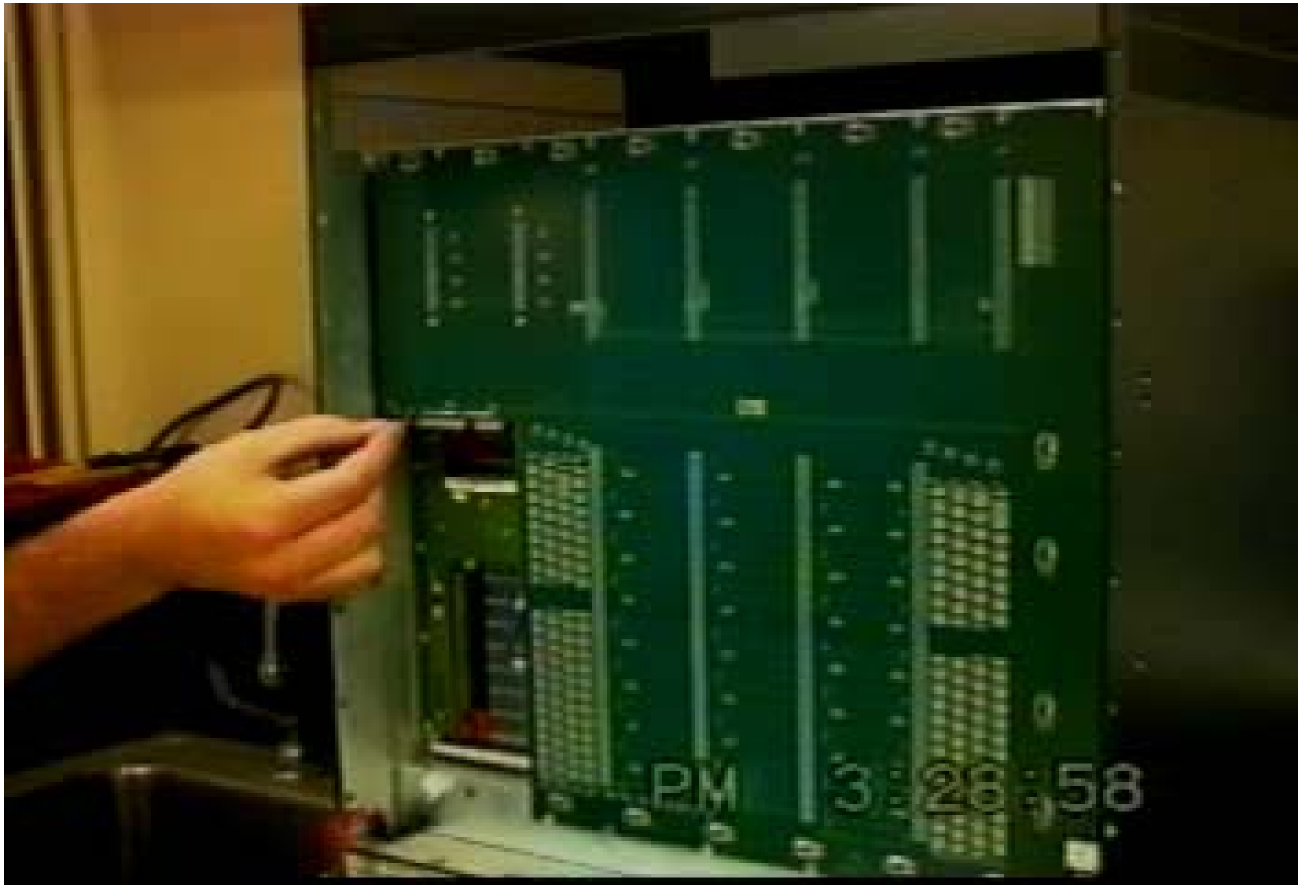
Agenda

- Why Characterize Burn Hazards?
- The Science of Burn Hazards
- Research & Experimental Analysis
- Industry Standards
- Mathematical Models
- Experimental technique: Thermesthesiometer
- Case Study #1
- Case Study #2
- Summary
- Questions

Potential Burn Hazard?



FOR IMMEDIATE RELEASE
September 10, 2008
Release #08-395

Firm's Recall Hotline: (800) 261-1193
CPSC Recall Hotline: (800) 638-2772
CPSC Media Contact: (301) 504-7908

Remote-Controlled Helicopter Toys Recalled by Protocol Due to Fire and Burn Hazards

WASHINGTON, D.C. - The U.S. Consumer Product Safety Commission, in cooperation with the firm named below, today announced a voluntary recall of the following consumer product. Consumers should stop using recalled products immediately unless otherwise instructed. It is illegal to resell or attempt to resell a recalled consumer product.

Name of Product: "Protocol" Remote-Controlled Mini Helicopter Toys

Units: About 78,000

Importer: Ashley Collection Inc., d.b.a. Protocol, of New York, N.Y.

Hazard: The rechargeable battery inside the helicopter can overheat. This can result in the helicopter's body melting, as well as a risk of fire or burns to consumers.

Gaming System Batteries and Recharging Station Recalled by LeapFrog Due to Burn Hazard

WASHINGTON, D.C. - The U.S. Consumer Product Safety Commission, in cooperation with the firm named below, today announced a voluntary recall of the following consumer product. Consumers should stop using recalled products immediately unless otherwise instructed. It is illegal to resell or attempt to resell a recalled consumer product.

Name of Product: Rechargeable Batteries and Recharging Station for Didj Custom Gaming System

Units: About 35,500

Manufacturer: LeapFrog Enterprises Inc., of Emeryville, Calif.

Hazard: The rechargeable batteries included with the Recharging Station can overheat if the gaming system is placed into the recharging base upside down, posing a burn hazard to consumers.

FOR IMMEDIATE RELEASE
April 30, 2010
Release #10-214

Firm's Recall Hotline: (877) 781-5186
CPSC Recall Hotline: (800) 638-2772
CPSC Media Contact: (301) 504-7908

Comarco Recalls Power Adapters for Laptops Due to Burn Hazard

WASHINGTON, D.C. - The U.S. Consumer Product Safety Commission, in cooperation with the firm named below, today announced a voluntary recall of the following consumer product. Consumers should stop using recalled products immediately unless otherwise instructed. It is illegal to resell or attempt to resell a recalled consumer product.

Name of Product: Targus Universal Wall Power Adapters for Laptops

Units: About 507,000

Manufacturer: Comarco Inc. of, Lake Forest, Calif.

Hazard: Faulty wiring can cause the connector tips to heat and melt the plastic encasing the connector tips, posing a burn hazard to consumers.

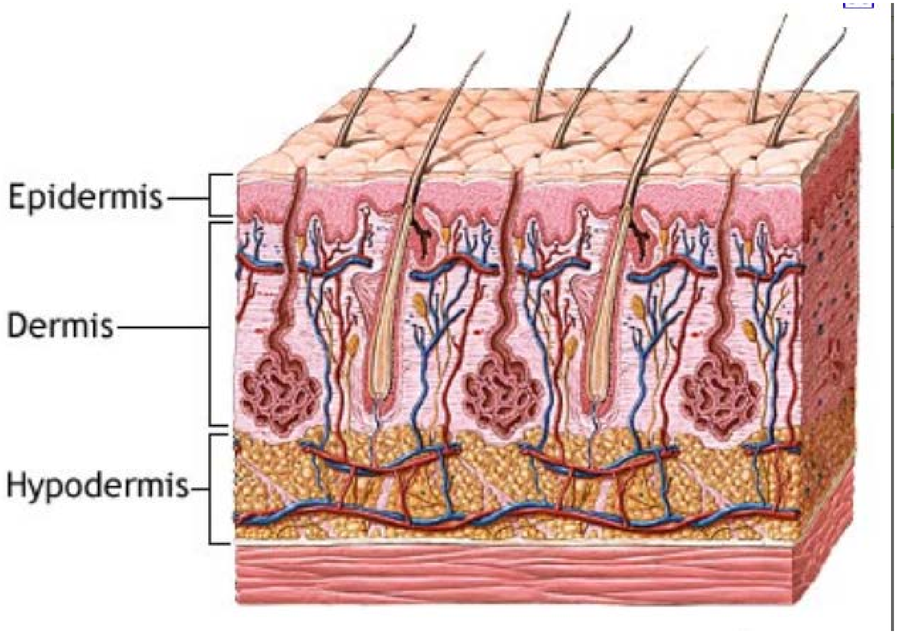
Incidents/Injuries: The firm has received 518 incidents of the connector tips heating, 53 of which resulted in the melting of the plastic casings. Eight consumers have reported a finger tip or hand burn. No reports of medical attention were received.

Nomenclature

- EPIDERMIS
  - Outermost layer of skin cells
  - No vascular or nerve cells
  - Protects skin layers
  - Thickness ~ 0.08 mm
- DERMIS
  - Second layer of skin tissue
  - Contains blood vessels and nerve endings
  - Thickness ~ 2 mm

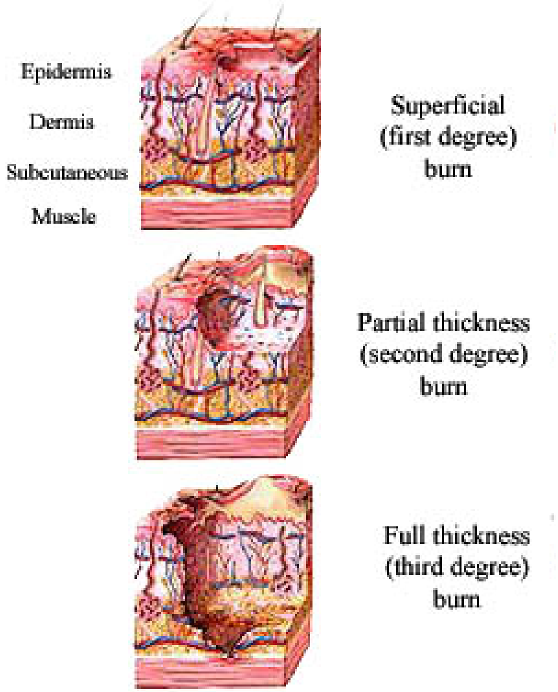
Nomenclature

- **NECROSIS**
  - **Localized death of cells**
  - **Permanent damage to skin layer occurs**



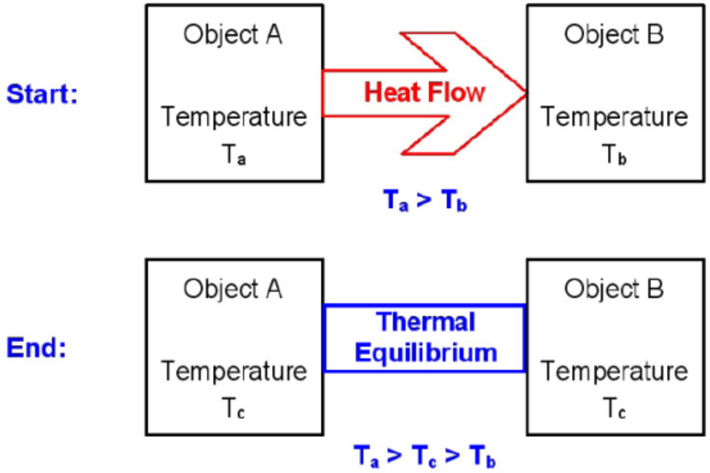
Burns

- **First degree burns**
  - **Exposure insufficient to cause necrosis of the epidermis**
  - **i.e. does not lead to death of skin cells**
- **Second degree burns**
  - **Causes necrosis of the epidermis but no significant damage to dermis**
  - **i.e. death of outermost layer of skin cells only**
- **Third degree burns**
  - **Dermal necrosis occurs**
  - **i.e. death of second layer of skin cells (generally 75% destruction of dermis)**



Burns

- **Burning occurs as a complex non-steady heat transfer between contacted medium and surface of skin**
- **Rate of heating depends on:**
  - **Temperature and heating capacity of the source**
  - **Heat capacity and thermal conductivity of the skin layers**
  - **Flow of blood**
  - **Physiological changes in skin properties as damaged zone traverses the outer skin layers**



Principals of Thermally-caused Injury, Richard Nute, IEEE PSES Product Safety Engineering Newsletter, Vol. 3 No. 3, Page 6 -12

Burns

- **Complexity arises due to**
  - **Site variations with respect to the thickness of different skin layers**
  - **Variations of initial conditions within the skin with respect to time, position and physical condition of the subject**
  - **Unknown rate of blood flow through the skin layers and variations within the skin layers**
  - **The appearance of watery fluids in variable quantities upon exposure that changes the characteristics of the skin (such as skin density, heat capacity, thermal conductivity etc.)**
- **First set of experiments used direct contact water bath**
  - **Indicated that for time/temperatures of interest**
    - **blood flow could be neglected**
    - **both the skin and contacted surfaces can be treated as semi-infinite**

Research & Experimental Analysis

- **Subsequent experiments indicated that**
  - **Pain reaction to prolonged hyperthermia exposure first occurs as a stinging sensation at between 47.5^{0}C and 48.5^{0}C.**
  - **Lowest temperature at which epidermis damage occurs is 44 ^{0}C when sustained for 6 hours**
  - **Extrapolation shows that longer exposures may cause damages at temperatures below 44^{0}C**
  - **As temperature of contact increases above 44^{0}C, the time to damage is shortened by approximately 50% for each 1^{0}C rise in temperature up to about 51^{0}C**
  - **At temperatures above 70^{0}C, the rate of injury from a high capacity surface exceeds the body reaction time**

Research & Experimental Analysis

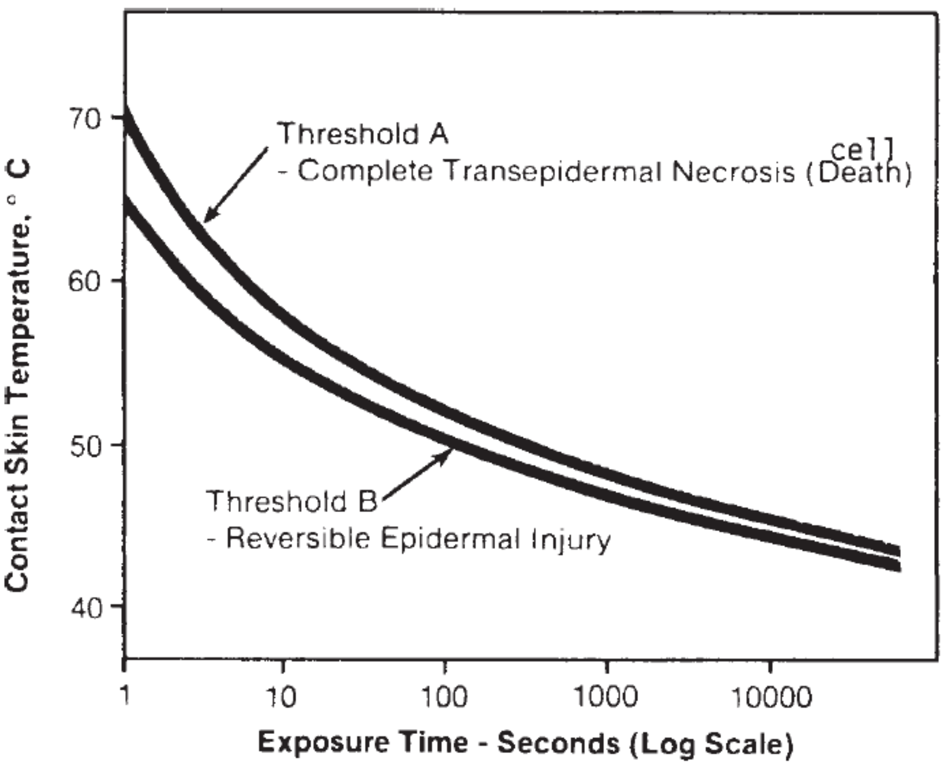
<table>
<tr><th rowspan="2">Sensation</th><th rowspan="2">Skin Color</th><th colspan="2">Tissue Temperature</th><th rowspan="2">Process</th><th rowspan="2">Injury</th></tr>
<tr><th>°C</th><th>°F</th></tr>
<tr><td rowspan="2">Numbness</td><td>White</td><td>68-72</td><td>154-162</td><td>Protein Coagulation</td><td>Irreversible</td></tr>
<tr><td>Mottled Red & White</td><td>60-64</td><td>140 - 147</td><td rowspan="4">Thermal inactivation of Tissue Contents</td><td>Possibly Reversible</td></tr>
<tr><td>Maximum Pain</td><td>Bright Red</td><td>52-56</td><td>126-133</td><td rowspan="3">Reversible</td></tr>
<tr><td>Severe Pain</td><td rowspan="2">Light Red</td><td>48</td><td>118</td></tr>
<tr><td>Threshold Pain</td><td>40-44</td><td>104-111</td></tr>
<tr><td>Hot</td><td rowspan="2">Flushed</td><td rowspan="2">36-40</td><td rowspan="2">97-104</td><td rowspan="2">Normal metabolism</td><td rowspan="2">None</td></tr>
<tr><td>Warm</td></tr>
</table>

ASTM C 1055-03, Standard Guide for Heated System Surface Conditions that Produce Contact Burn Injuries, page 6

Research & Experimental Analysis

$$T_A = 15.005 + 0.51907 \times Ln(time \times 1000) + \frac{352.97}{(Ln(time \times 1000))}$$

$$T_B = 39.468 - 0.41352 \times Ln(time \times 1000) + \frac{190.6}{(Ln(time \times 1000))}$$



- **T_A**
  - critical contact temperature for complete transepidermal necrosis, °C
- **T_B**
  - critical contact temperature for reversible epidermal injury
- **Time**
  - elapsed contact time (seconds)
- **Ln**
  - natural logarithm

ASTM C 1055-03, Standard Guide for Heated System Surface Conditions that Produce Contact Burn Injuries, page 6

Research & Experimental Analysis

- **Surface Temperature**
  - **< 44°C**
    - **No short term (<6 hrs) hazard exists**
  - **> 70°C**
    - **Metallic surface**
      - **hazard regardless of contact duration**
    - **Non-metallic surface**
      - **skins may be safe for limited exposure. Exposure time can be determined from plot and acceptable criteria**

Limitations

- Data and plots valid for the “average” person
- Actual subject response depends on physical condition, age, ambient conditions etc.
- Data and plots found to agree for a panel of subjects within approximately 10%

INDUSTRY STANDARDS

Industry Standards

- Temperature limits specified in safety standards for surface temperatures that may be touched
- Surface which may be touched continuously
  - 50°C (122°F) – plastic adapter enclosure
- Surface which may be touched intermittently
  - 95°C (203°F) – touchable plastic parts

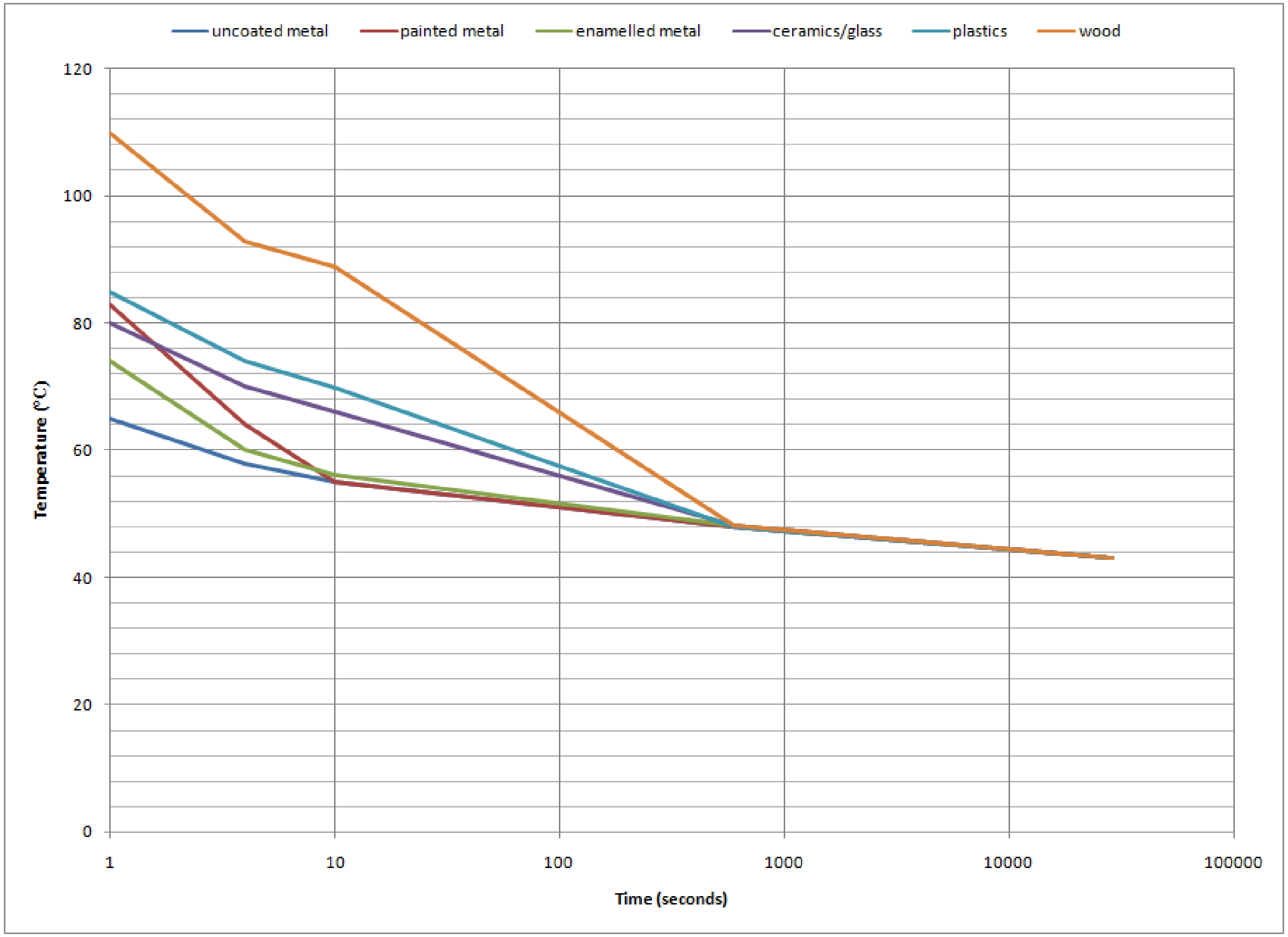
Industry Standards – BS EN 13202:2000

Time (s)	Contact	Part
1	Accidental contact	Oven doors, toaster sides
4	Parts held for short period of time	Knobs, switches
10	Parts continuously held in normal use	Handles
600	Prolonged use	Handles
>1000	Prolonged use	Handles

Industry Standards – BS EN 13202:2000

Material	Time-temperature (°C)				
	1 s	4 s	10 s	600 s	>1000 s
Uncoated metal	65	58	55	48	43
Painted metal	83	64	55	48	43
Enamelled metals	74	60	56	48	43
Ceramics, glass, stones	80	70	66	48	43
Plastics	85	74	70	48	43
Wood	110	93	89	48	43

Industry Standards – BS EN 13202:2000



Determining Burn Hazards

- Look-up tables can be used when material of contact surface is known
- However, in a lot of cases, surface material is either unknown or may contain additives
- Procedure needed to determine risk of burn hazards and whether additional insulation layers are needed for surfaces exposed to a user
- Two methods may be used
  - Mathematical Model
  - Experimental Analysis

MATHEMATICAL MODEL

Inputs for Model

- System description
  - Geometry, location, accessibility
- Operating conditions
  - Duty cycle, operating temperature etc.
- System/surface data
  - Insulation type and thickness, surface properties such as emissivity and condition, shiny, painted, dirty, corroded etc.
- Ambient conditions
  - Dry bulb temperature, local air velocity etc.

Pain Threshold Equation: Stoll et al

- Experiment performed to characterize pain thresholds
- Equation is a curve fit of experimental data
- Equation only valid for contact times from 1 to 5 seconds

$$T_{object} = Y1[(k\rho c)_{object}^{\frac{-1}{2}} + 31.5] + 41$$

$$Y1 = anti\log_{10}[Y2(a1) + \log(Y3)]$$

$$Y2 = 1.094t^{-0.184}$$

$$Y3 = 0.490t^{-0.412}$$

kρc = thermal inertia of hot material
k = thermal conductivity
ρ = density
c = specific heat
a1 = epidermal thickness (0.25 -0.255 mm)
T = exposure time in seconds

Mathematical Model – Valid for contact times > 5 seconds*

Model converges in 5-10 iterations

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

and:

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

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

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

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

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

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

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

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

$$\alpha_1 = K_1/\rho_1 \cdot C_1$$

$$\alpha_2 = K_2/\rho_2 \cdot C_2$$

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, $W/m \cdot K$, and
- C_i = specific heat of material i, $J/kg \cdot K$.

*ASTM C 1055-03, Standard Guide for Heated System Surface Conditions that Produce Contact Burn Injuries, page 6

Mathematical Models

- Mathematical models are complex and rely on a set of inputs to determine burn hazards
- Model output is only as good as the set of inputs provided
- Careful analysis of system geometry, operating temperatures, air flow measurements etc needed
- Various researchers have developed different models all of which provide similar results

THERMESTHESIOMETER

An instrument for measuring the human sensibility to heat

Theory

- **Contact temperature between two masses brought into contacted is predicted by heat flow theory to be:**

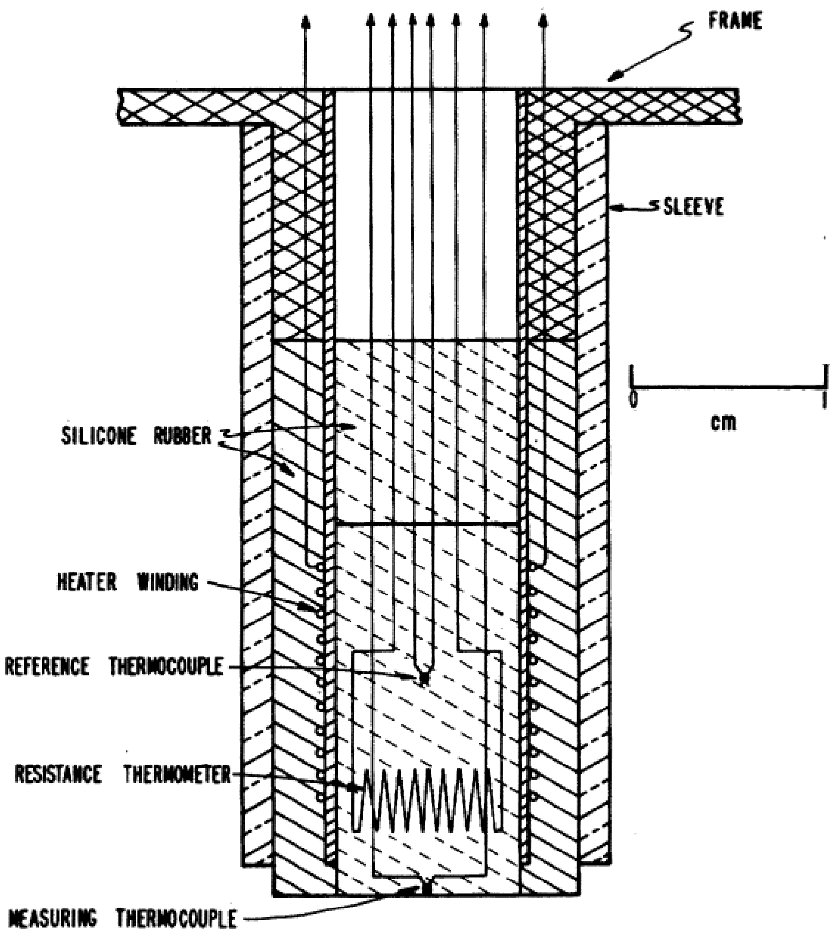
$$T_C = T_h - \frac{T_h - T_p}{1 + \left(\frac{\lambda_h}{\lambda_p}\right)^{\frac{1}{2}}}$$

- T_c: contact temperature
- T_h: heated surface temperature
- T_p: probe or finger temperature
- λ_h: thermal inertia of heated surface
- λ_p: thermal inertia of probe/finger

Thermal inertia = thermal conductivity x specific heat x density

Requirements for probe:
- selection of probe material with thermal inertia equivalent to human finger
- regulation of probe temperature to finger tissue temperature

Probe



- Silicone rubber
    - Eccosil 4952
- Heater wire and resistance thermometer maintain probe assembly at 33°C (finger tissue temperature)
- Measuring thermocouple element positioned 100 µm (skin depth) beneath outer surface of the probe face
- Effect of temperature regulator on contact temperature measurement is negligible for involved contact time

Marzetta A. Louis, A Thermesthesiometer – An Instrument for Burn Hazard Measurement, IEEE Transactions on Biomedical Engineering, September 1974, pp 425-427

Processing Circuit

- Analog section
  - Amplifies low-level signal from measuring thermocouple
  - Temperature controller circuitry
- Digital section
  - Timing
  - Output display – converts thermocouple output to a reading in degrees Celsius

Thermesthesiometer

- Duplicates tissue temperature that would be experienced if human contact is made with a hot surface, regardless of surface composition
- However!
  - Does not take into consideration the ability of human skin to deform about a device
  - Measurements not accurate if surface is uneven, rough or too small for the probe to contact fully
  - Readings can be affected by the pressure applied to the surface of the heated contact area

TEST METHOD

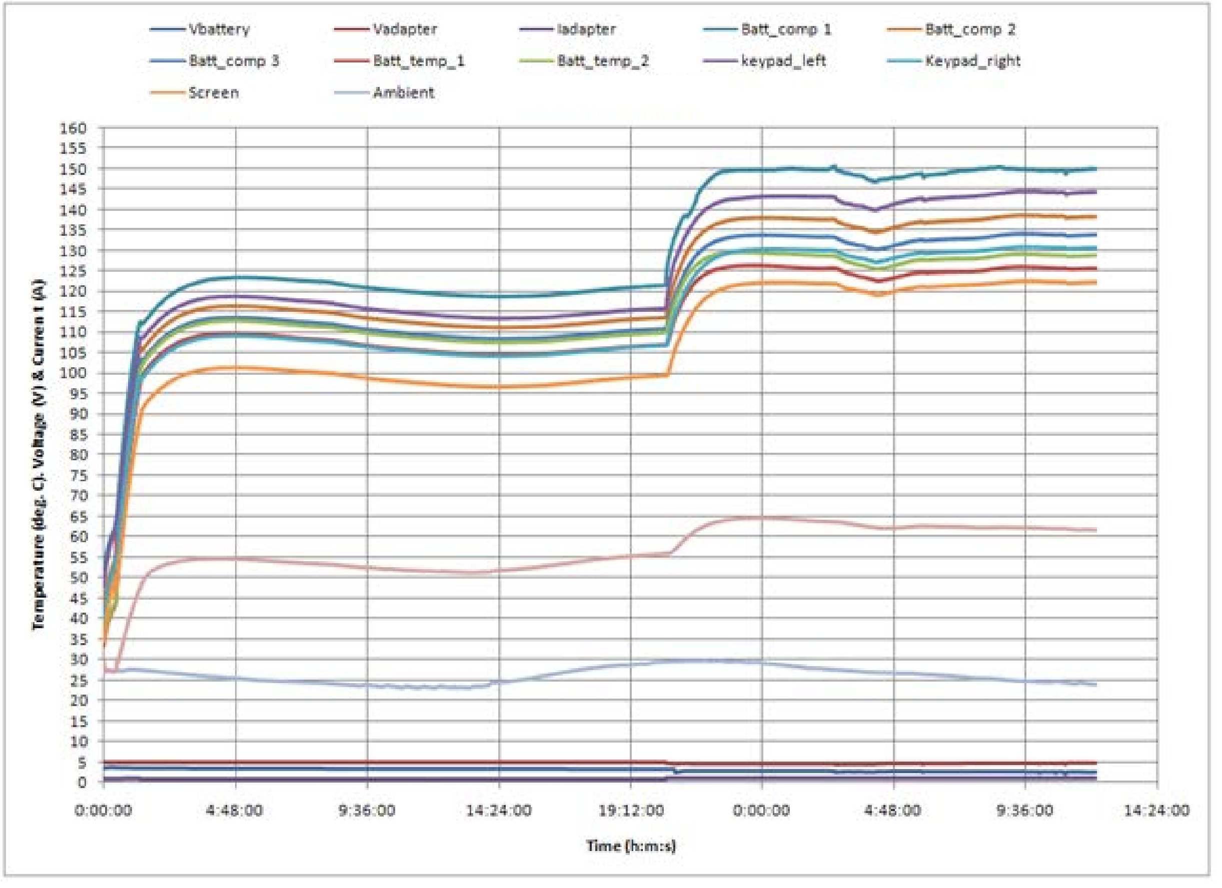
Test Method for Determining Burn Hazards from Hotspots

- Identification of hot spot locations
  - Temperature measurements
  - Infrared imaging
- Thermesthesiometer calibration
- Recreation of failure mode to generate hot spot locations
- Thermesthesiometer measurements
- Verification of measurement results

CASE STUDY #1

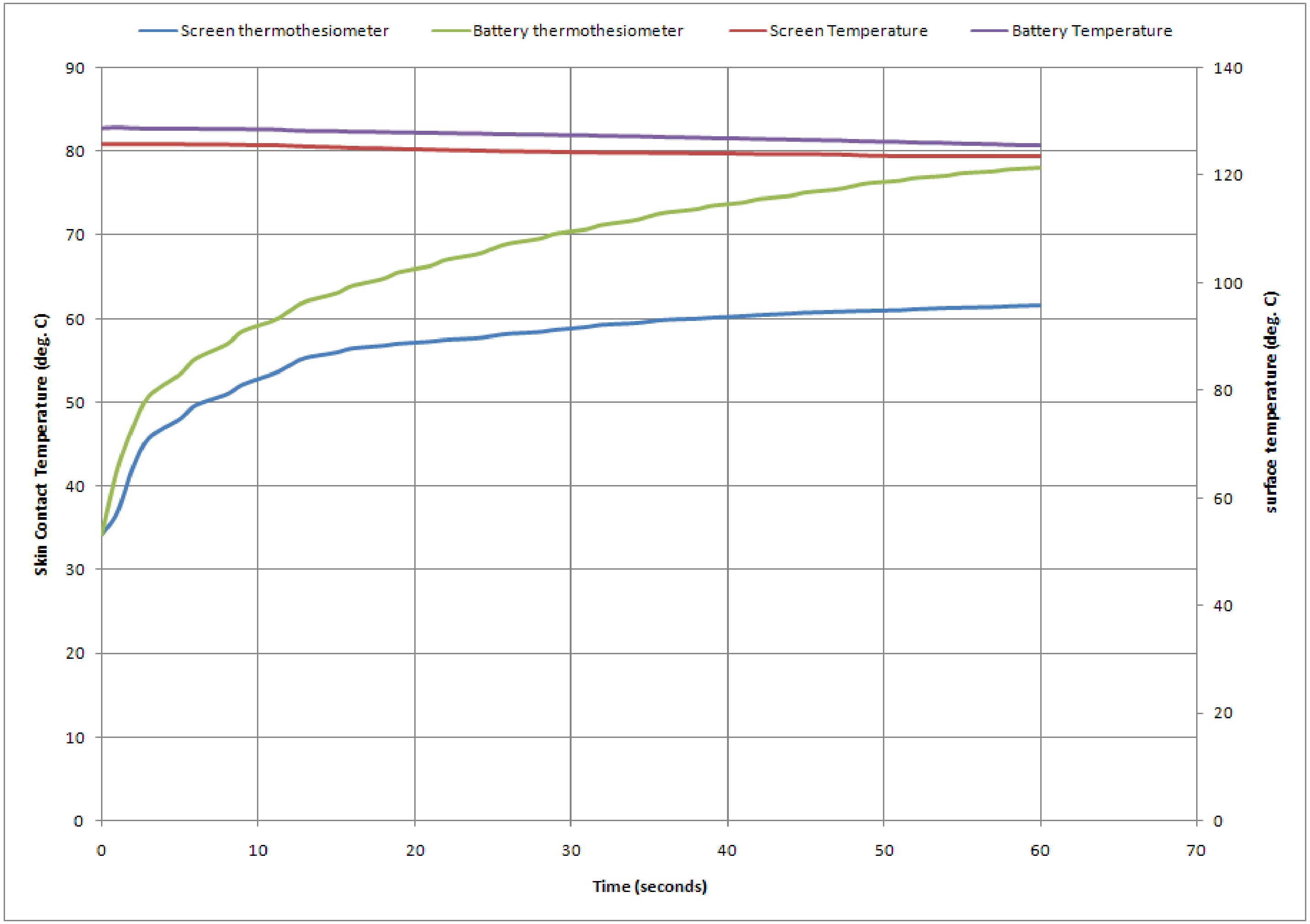
Background

- Failures in the field of a consumer electronics device resulted in damage to the device's battery pack and also the device LCD screen
- Aim of the investigation was to identify the failure mode and to determine whether failure mode resulted in a burn hazard

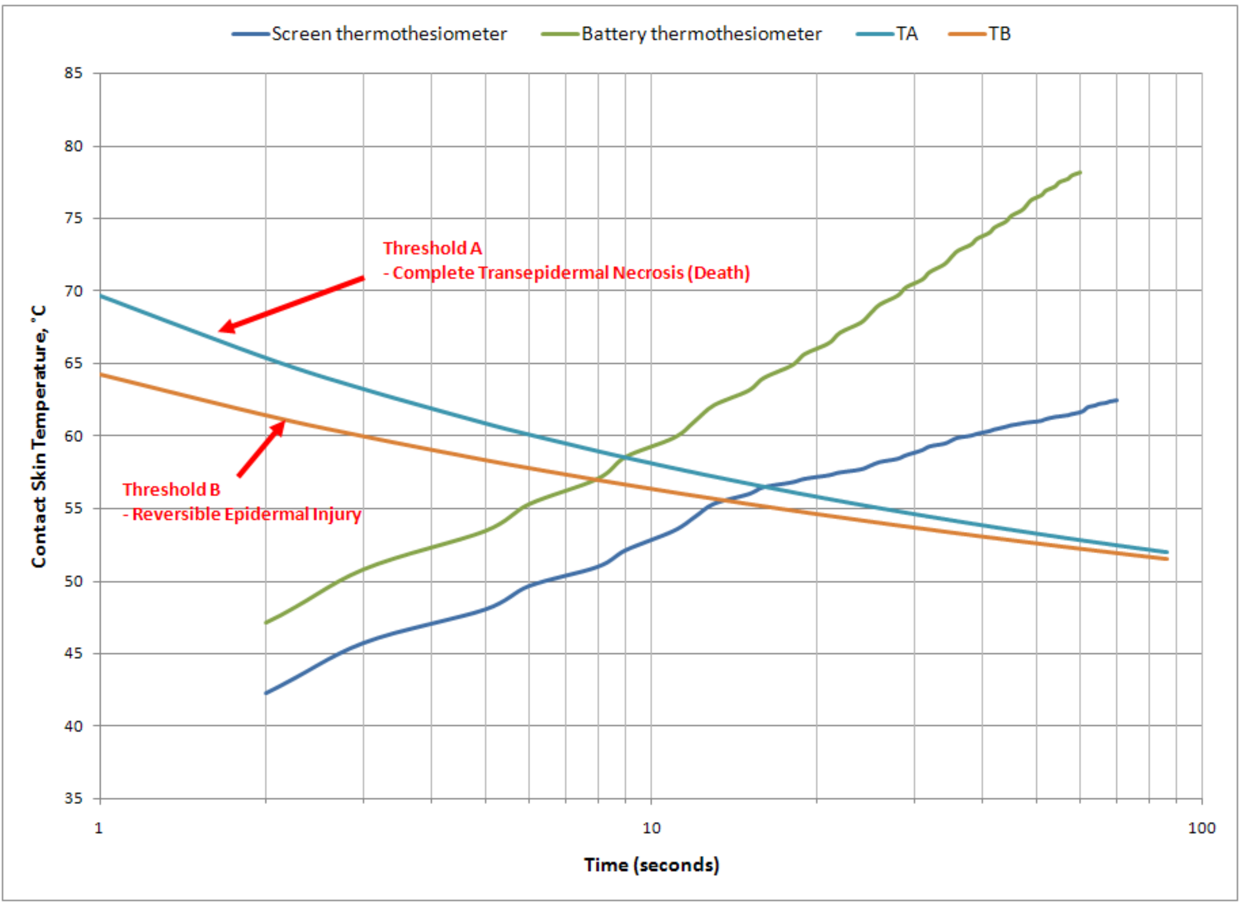


- Failures attributed to design of product's input voltage circuit
- Under certain conditions a failure of this circuit could cause elevated temperatures.
- Temperatures on the surface of the product measured in excess of 150°C.

Surface Temperature vs. Contact Temperature



Burn Hazard

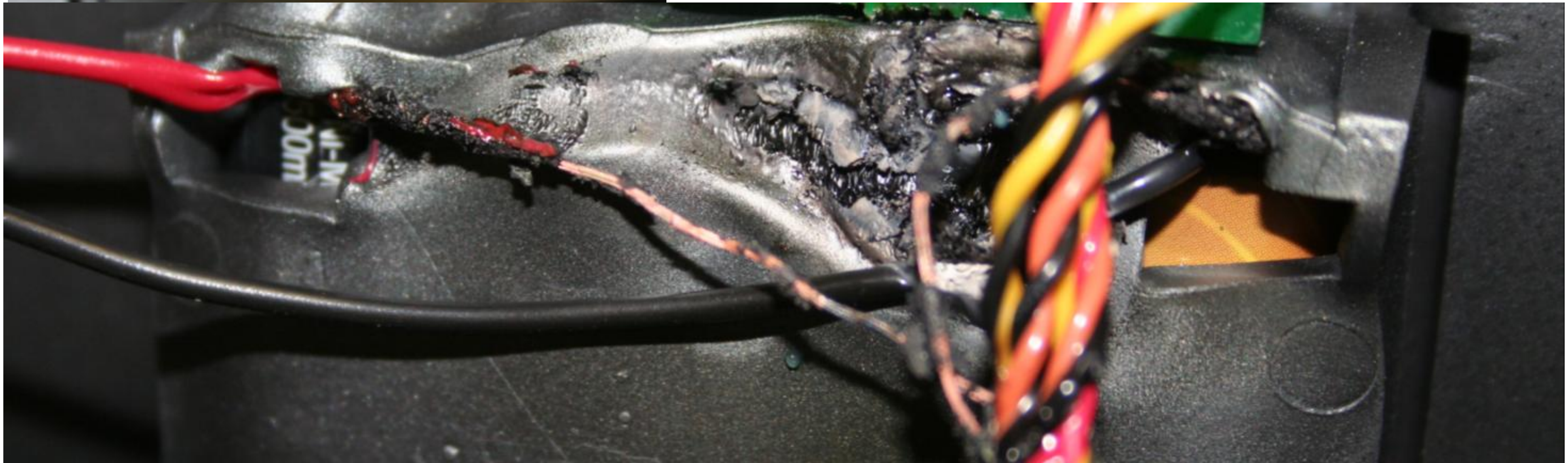


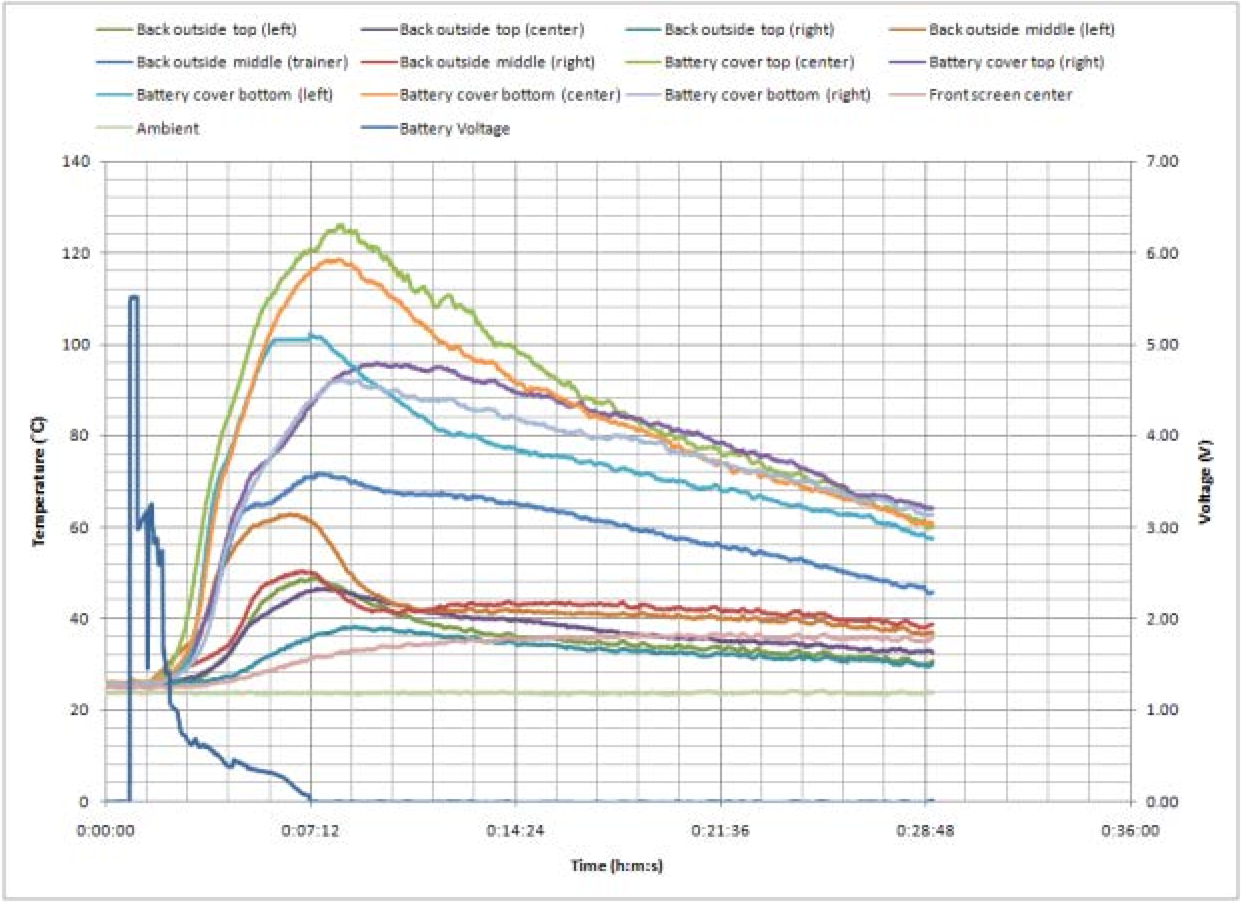
Testing indicated that no irreversible epidermal injury should occur if a user releases the over-heated battery pack within 8 seconds or releases the over-heated screen within approximately 10 seconds or less

CASE STUDY #2

Background

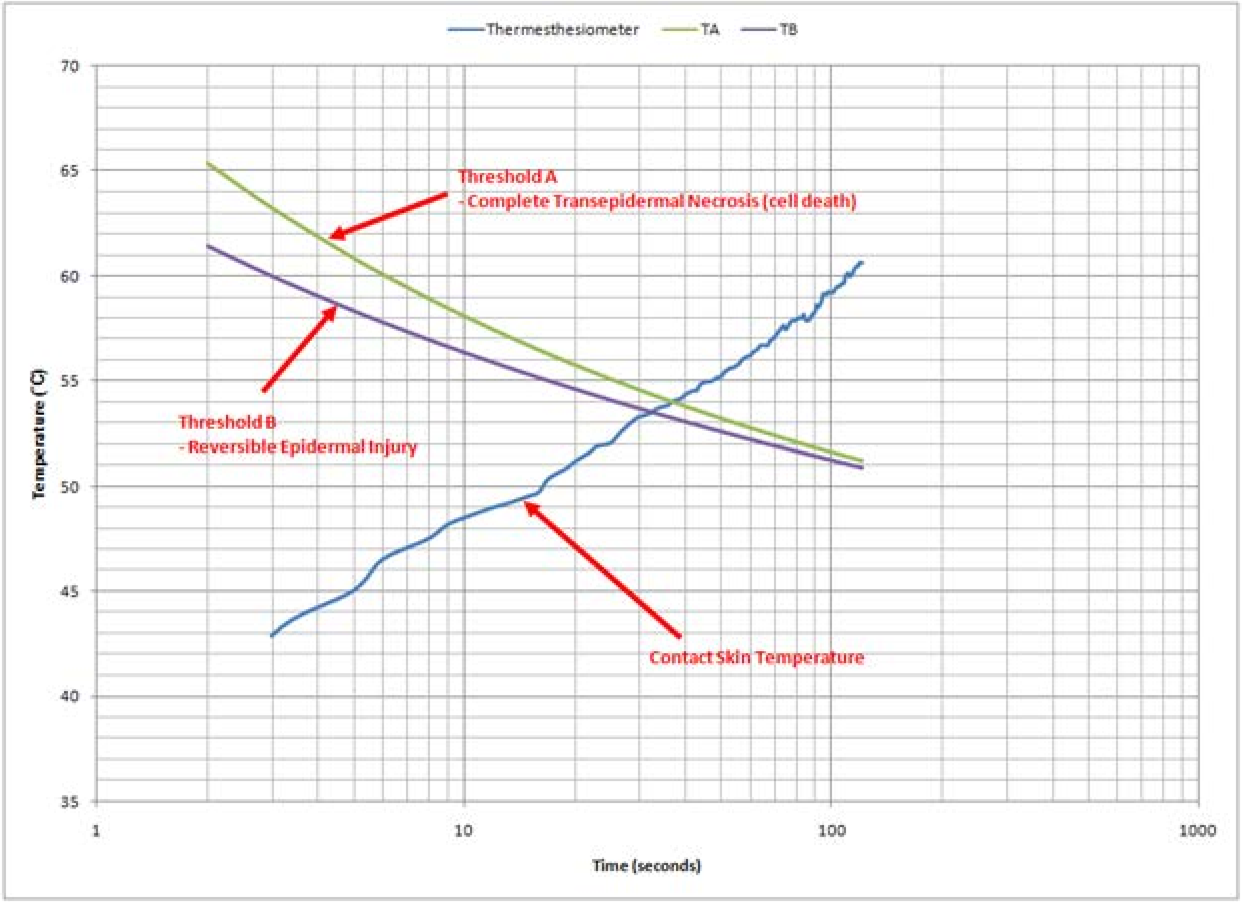
- Poor manufacturing and design controls caused short circuit of AA cells in a product
- Overheated cells resulted in thermal damage to device plastic enclosure
- Aim of the investigation was to identify the failure mode and to determine whether failure mode resulted in a burn hazard





- Failures attributed to poor manufacturing controls
- Under certain conditions a failure of this circuit could cause elevated temperatures.
- Temperatures on the surface of the product measured in excess of 125°C.

Burn Hazard



Measurements indicate that during this event no irreversible epidermal injury should occur if a user releases the controller within 32 seconds, which, is a reasonable scenario given the typical usage of this device

Summary

- The thermesthesiometer provides an experimental means of determining whether an exposed surface constitutes a burn hazard or not
- The experimental technique although straightforward involves making detailed accurate and precise measurements
- The readings from the thermesthesiometer along with the temperature-time relationship for burns plot provided in ASTM C 1055-03 can be used to characterize the risk of burn hazard and help with product recall issues

And Finally!

Questions?

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