NASA-STD-3001 Technical Brief

Physiological Effects of Touch Temperature

OCHMO-TB-009

Relevant Technical Requirements

NASA-STD-3001 Volume 1, Rev B
[V1 3004] In-Mission Medical Care
[V1 3009] Palliative Comfort Care
[V1 3015] Certification of Training Plans for Launch/Landing Medical Team

NASA-STD-3001 Volume 2, Rev C
[V2 9102] Skin/Tissue Damage Temperature Limits
[V2 9103] Pain/Non-Disabling Injury Skin Temperature Limits

Executive Summary

Exposure to either extreme heat or extreme cold, form whole-body exposure or contact with hot or cold surfaces, can be dangerous to crewmembers. Hot or cold surfaces are safety hazards due to the risk of touch exposure causing performance decrements and an inability to handle an object and/or numbness, ultimately leading to damage and illness (infection) of the skin/tissue. The sensation of the temperature of an object depends on the type of material that is touched and in some cases on the perception of injury by the human. An analysis utilizing test data can be preformed to determine the lag between the object temperature and skin temperature, which is one of the controls for both critical and catastrophic hazards related to touch temperature.

NASA Crewmember Serena Auñón-Chancellor conducting research inside the Microgravity Science Glovebox

Background

For spaceflight applications, it is important to protect humans from unintended extreme temperatures that may cause performance decrements and/or injury. NASA utilizes the following terminology:

Pain/Non-Disabling Injury Skin Temperature Limits

Defined as any condition which may cause pain and performance decrements. For these ranges (hot and cold) incidental contact (1 second) is allowed. For prolonged duration contact, testing and/or analysis is required to determine tolerance & performance.

Range/Limits Pain/Non-Disabling Injury/Possibly Resulting in Illness

Pain/Performance Decrements	Temperature Threshold Limit
High Temperature Range	$43°C \leq T_{skin} < 49°C$
Low Temperature Range	$0°C < T_{skin} \leq 15°C$

Skin Temperature Injury Limits

Defined as any condition that may cause a permanent or temporary disabling injury/illness or fatal injury/illness. For touch temperature, this condition is considered when tissue damage may be experienced.

Skin Temperature Injury Limits

Tissue Damage	Temperature Threshold Limit
High Temperature Limit	$\geq 49°C$
Low Temperature Limit	$\leq 0°C$

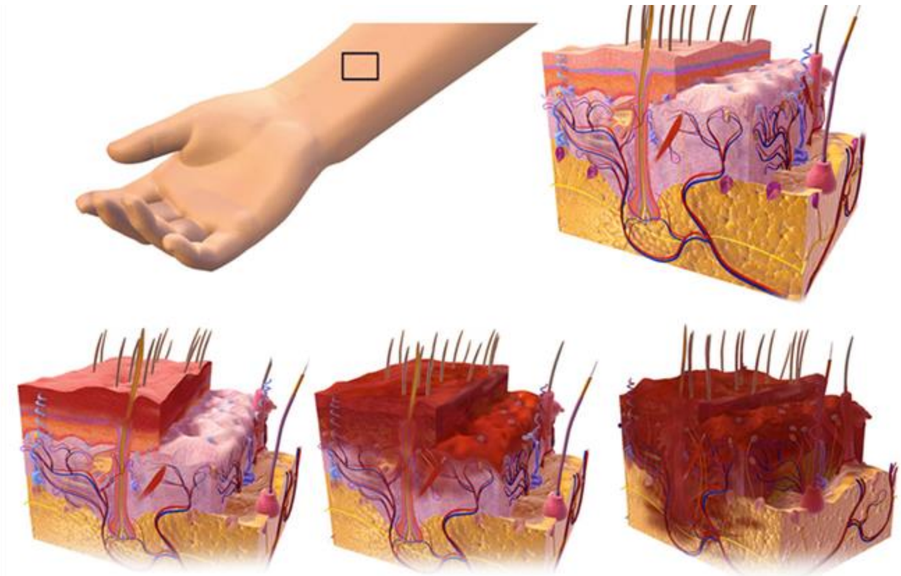
Summary Table of Bare Skin Exposure Temperature Ranges/Limits Standards

Nominal Thresholds No Controls Required Unlimited Contact	Sensation/Pain (Pain/Non-Disabling Injury/Possibly Resulting in Illness) [V2 9103]	Skin/Tissue Damage Controls required [V2 9102]
$15°C < T_{skin} < 43°C$	$43°C \leq T_{skin} < 49°C$ or $0°C < T_{skin} \leq 15°C$	$T_{skin} \geq 49°C$ or $T_{skin} \leq 0°C$

Note: There is a time lag between the object temperature and the skin temperature. An analysis can be performed to determine the time allowed before the skin temperature will exceed the acceptable, non-hazardous temperature range of 15℃ to 43℃. This can be used as a control. See page 9 for calculation methods.

Background

Degrees of Skin Burns



A first-degree burn is one that affects only the epidermis, the top layer of the skin. This is the least serious type of burn.

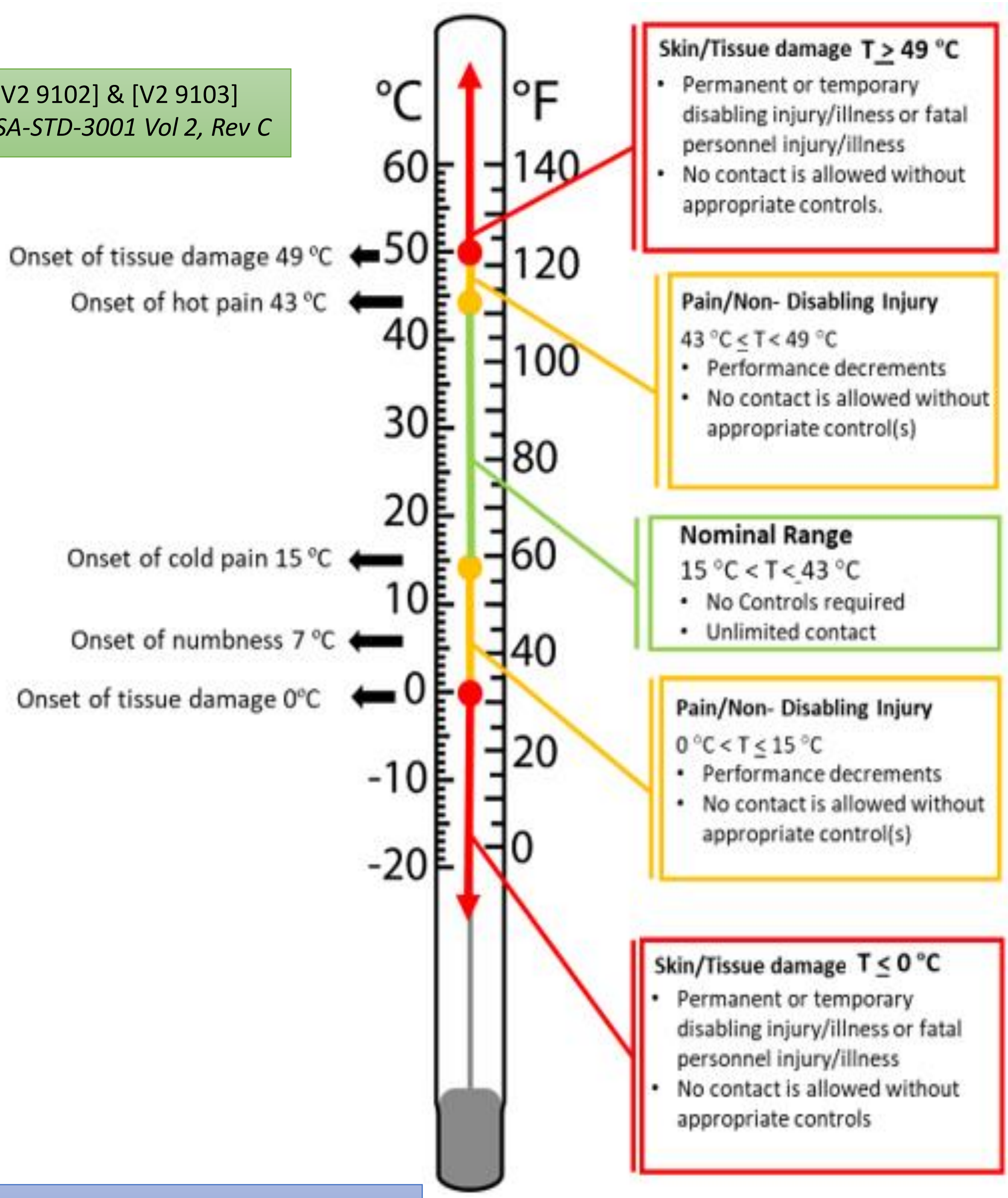
A second-degree burn is one that involves the epidermis and part of the dermis layer of skin.

A third-degree burn is one that destroy the epidermis and the dermis. Third-degree burns may extend deeper than the dermis into the subcutis – the deepest layer of skin; consists of collagen fat cells.

Background

Summary of Bare Skin Exposure Standards Temperature Ranges

[V2 9102] & [V2 9103]
NASA-STD-3001 Vol 2, Rev C



See reference data on page 5 for details on the origin of these values.

Reference Data

Data/evidence to determine the physiological thresholds for touch temperature are derived from the following:

Hot temperatures references/research data:

Greene, L.C., et al. (1958) on human tolerance to heat pain showed that the pain threshold is reached at 43.7℃ skin temperature.

Lloyd-Smith, D.L., and Mendelssohn, K. (1948) found the pain threshold to be 44.6℃.

Defrin & Peretz (2006) found the pain threshold to be between 43-46℃ (see graph in reference data).

Moritz & Henriques (1946) found damage to porcine skin at 49℃.

Based on testing, it takes approximately 8 minutes to achieve 3rd degree burns at 49℃. One minute was chosen for contact time to minimize injury but allow flexibility for design applications. *From Havenith et al., 1992*

Cold temperatures references/research data:

Hand dysfunction and the associated safety risk during occupational practices in the cold increases with decreasing skin temperature. Onset of cold pain has been reported to occur between 23℃ and 14℃ during cold contact (Havenith et al., 1992).

A marked deterioration in tactile discrimination occurs at finger skin temperatures <8℃ with numbness found in one-third of subjects at 7℃ (Provins & Morton, 1960).

Risk of frostbite occurs at 0℃ (Havenith et al. 1992).

"Overall, the reduction in sensitivity and/or manual performance seems to have occurred most clearly between 15 ℃ and 20 ℃, which coincided with the sensations of slightly painful and uncomfortably cool in the present experiment." From Havenith et al., 1992

Summary of levels chosen for hot touch temperatures:

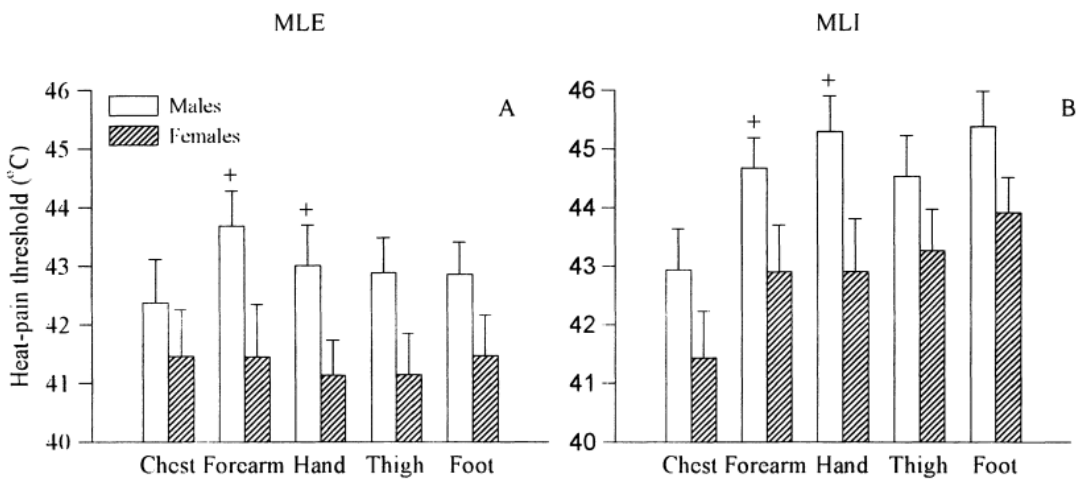
Onset of hot pain (T skin = 43℃) Reference Defrin & Peretz (2006)
Onset of tissue damage (T skin = 49℃) Reference Moritz & Henriques (1946)

Summary of levels chosen for cold touch temperatures:

Onset of cold pain (T skin = 15℃)
Onset of numbness (T skin = 7℃)
Onset of skin freezing (T skin = 0℃)

Reference Data

Hot Touch Temperatures – Pain Thresholds



Temperature in °C.	Time: Minutes	Time: Seconds	Number of experiments	Sub-threshold exposures, 1° reactions, Hyperemia only: Mild	Sub-threshold exposures, 1° reactions, Hyperemia only: Severe	Sub-threshold exposures, 1° reactions, Focal epidermal necrosis: Scaling	Sub-threshold exposures, 1° reactions, Focal epidermal necrosis: Small ulcers	Threshold and supra-threshold exposures, 2° and 3° reactions, Complete epidermal necrosis: Red burn	Threshold and supra-threshold exposures, 2° and 3° reactions, Complete epidermal necrosis: Pale burn
44	420		1					x	
45	150		1	x					
	180		1					x	
46	45		1	x					
	60		1		x				
	90		1					x	
46.5	45		1	x					
	60		1					x	
47	35		1	x					
	45		1					x	
	50		1					x	
	60		1					x	
48	10		3	x					
	12		1		x				
	14		2			x			
	14		1					x	
	15		2					x	
	16		1		x				
	18		1					x	
	20		1					x	

Heat-pain threshold (HPT) and warm sensation threshold (WST) of males and females measured with the method of Levels (MLE) (A, C, respectively) and method of Limits (MLI) (B, D, respectively). The overall effect of sex on HPT and WST was not significant, although the thresholds of males were borderline higher than those of females; HPT, in the forearm and hand (+P = 0.0829 and +P = 0.0566) (A, B) and WST, in the chest, hand, and foot (^P = 0.087, ^P = 0.0798, ^P = 0.0793) (C, D). Bars denote group mean 6 SE. *From Defrin & Peretz (2006)*

Time-Surface Temperature Thresholds for Thermal Injury of Porcine Skin (left)
Human testing shows that the threshold for pain the hand between 41℃ to 43℃ depending on the method utilized. 43℃ was chosen based on the MLI method/data for women and low risk of tissue damage based on porcine testing. *From Moritz & Henriques (1946)*

Reference Data

Hot Touch Temperatures – Pain & Tissue Damage Thresholds

Time-Surface Temperature Thresholds for Thermal Injury of Porcine Skin

Based on porcine testing, onset of significant tissue damage (complete epidermal necrosis) occurs at 49℃. *From Moritz & Henriques (1946)*

Temperature in °C.	Time: Minutes	Time: Seconds	Number of experiments	Sub-threshold exposures, 1° reactions, Hyperemia only: Mild	Sub-threshold exposures, 1° reactions, Hyperemia only: Severe	Sub-threshold exposures, 1° reactions, Focal epidermal necrosis: Scaling	Sub-threshold exposures, 1° reactions, Focal epidermal necrosis: Small ulcers	Threshold and supra-threshold exposures, 2° and 3° reactions, Complete epidermal necrosis: Red burn	Threshold and supra-threshold exposures, 2° and 3° reactions, Complete epidermal necrosis: Pale burn
49	3		4	x					
	4		5	x					
	5		2	x					
	6		5		x				
	6		2			x			
	6		2				x		
	7		2		x				
	7		1			x			
	7		1				x		
	8		4			x			
	8		1				x		
	8		2					x	
	9		11					x	
	10		5					x	
50	1		1	x					
	2		1	x					
	4		1			x			
	5		1		x				
	5		3			x			
	5		2				x		
	5		2					x	
	6		2					x	
	6	30	2					x	
51		45	2	x					
	1		2	x					
	1	30	2	x					
	2		1			x			
	3		2		x				
	3		2			x			
	3		2					x	
	4		2					x	
	5		1				x		
	5		1					x	
	10		2					x	
52		30	1	x					
		45	1		x				
	1	30	1					x	

Application

- For items with exposed surface temperature that are outside the standard limit due to item functionality, bare skin contact shall be prevented through the use of controls.
  - This applies to items that are intentionally designed to be outside of the acceptable, non-hazardous temperature range of 15°C to 43°C due to the purpose of the item. This includes items that are specifically designed to function as freezers or heaters.

- Incidental and intentional contact with exposed surfaces should be prevented through failure tolerance or design for minimal risk (DFMR).
  - DFMR is a hazard reduction process where if an identified hazard cannot be eliminated, the design is modified to reduce the risk to an acceptable level. High reliability vs. redundancy is considered as part of this process.

- Controls that may be utilized to protect crew.
  - **Personal Protective Equipment (PPE)** – High reliability/quality barriers
    - Hands and fingers are the most likely body parts of the body to be used for grasping and manipulation of objects.
    - When utilizing gloves, not only the hands but the arms should be considered for protection, especially when accessing hardware in “deep” freezer and ovens.
  - **Limit contact time (with margin)** – with an item of specific material to ensure that the skin will not exceed a temperature limit. See the following pages for techniques/data to determine appropriate contact time to ensure that skin temperatures do not exceed the limits in these standards.
  - **Delayed crew access to the object** – analysis to determine the time required for the object/material to reach non-hazardous Touch Temperature range.

- Another factor to be considered for ease of implementation is to institute a max permissible material temperature to be used across the vehicle, as opposed to allowing different control/contact times for each hardware that is accessible by the crew.

Bare skin Touch Temperature limits depend on contact thermal conductance, which is a function of an end item’s material properties, initial temperature, and skin contact time.

Application

Hot Temperature Calculations

The following information is provided to aid designers in determining the duration of contact allowed for different materials before the skin exceeds the temperature limits.

In order to calculate the material thermal inertia, use documented thermophysical property resources. The Inverse Thermal Inertia for Commonly Used Materials table provides Inverse thermal Inertia for Commonly Used Materials.

For high (43°C, 49°C) or low (0°C, 15°C) temperatures, use the subsequent figures and tables to determine the permissible material temperature (TPM) for the expected time of contact.

Inverse Thermal Inertia for Commonly Used Materials

Material	Inverse Thermal Inertia a/Ö(k r c) (m^2 $s^{0.5}$ K/J)*
Aluminum 6061 T-6	5.24×10^{-5}
316 Stainless Steel	1.420×10^{-4}
Glass	6.61×10^{-4}
Teflon(R)	1.430×10^{-3}
Nylon Hook Velcro	1.400×10^{-2}
The unit of measure for thermal inertia is (m^2 $s^{0.5}$ K/J)* * Analysis performed by E. Ungar	

Application

Hot Temperature Calculations

Determining Material Temperature and Duration of Contact for 49℃

To determine the maximum permissible material temperature (T_{PM}) and the allowable time of contact to ensure the skin temperature does not exceed the limits:

- Use either the equation and constants from Table 24, High-Temperature Constants: 49℃, and perform the appropriate calculations.

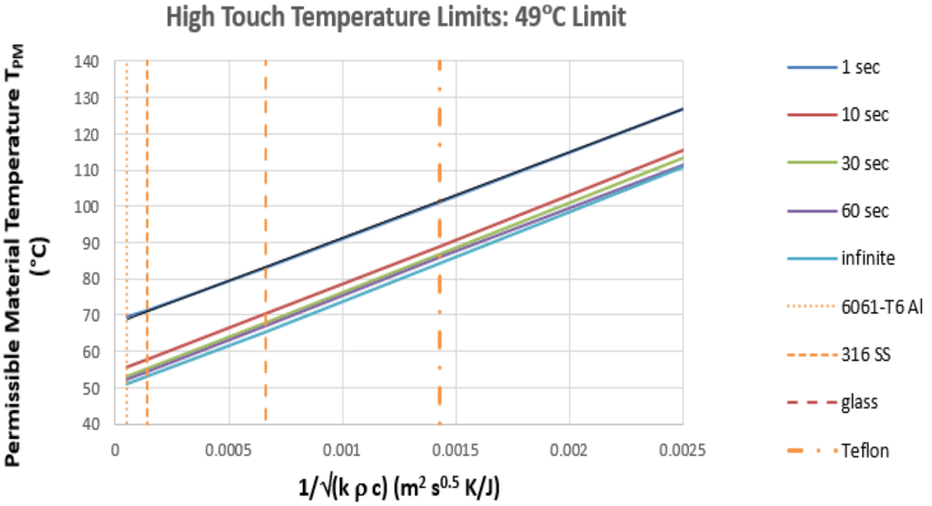
or

- Utilize the calculated and graphed values in Figure 15, High T_{PM} for Incidental and Intentional (Planned) Contact for 49℃.

High Temperature Constants: 49°C

$$T_{obj} = a/\sqrt{(k\ \rho\ c)}+b$$

time (s)	a	b
1	23,600	68.2
10	24,400	54.3
30	24,400	51.9
60	24,400	51.0
¥	24,400	49.6



High T_{PM} for Incidental and Intentional (Planned) Contact (49°C)

Application

Hot Temperature Calculations

<u>Determining Material Temperature and Duration of Contact for 43℃</u>
To determine the maximum permissible material temperature (T_{PM}) and the allowable time of contact to ensure the skin temperature does not exceed the limits:

- Use either the equation and constants from Table 25, High Temperature Constants: 43℃, and perform the appropriate calculations.

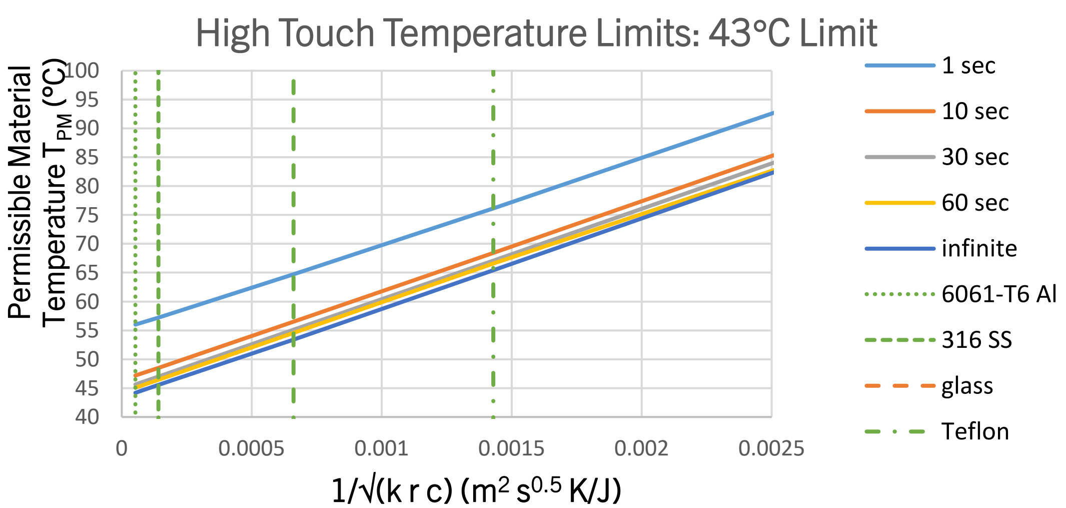
or

- Utilize the calculated and graphed values in Figure 16, High T_{PM} for Incidental and Intentional (Planned) Contact for 43℃.

High Temperature Constants: 43°C

$$T_{obj} = a/\sqrt{(k\ \rho\ c)}+b$$

time (s)	a	b
1	15,500	55.2
10	15,500	46.4
30	15,500	44.8
60	15,500	44.3
¥	15,500	43.4



High T_{PM} for Incidental and Intentional (Planned) Contact (43°C)

Application

Cold Temperature Calculations

<u>Determining Material Temperature and Duration of Contact for 15℃</u>

To determine the maximum permissible material temperature (T_{PM}) and the allowable time of contact to ensure the skin temperature does not exceed the limits:

- Use either the equation and constants from Table 26, Low Temperature Constants: 15℃, and perform the appropriate calculations.

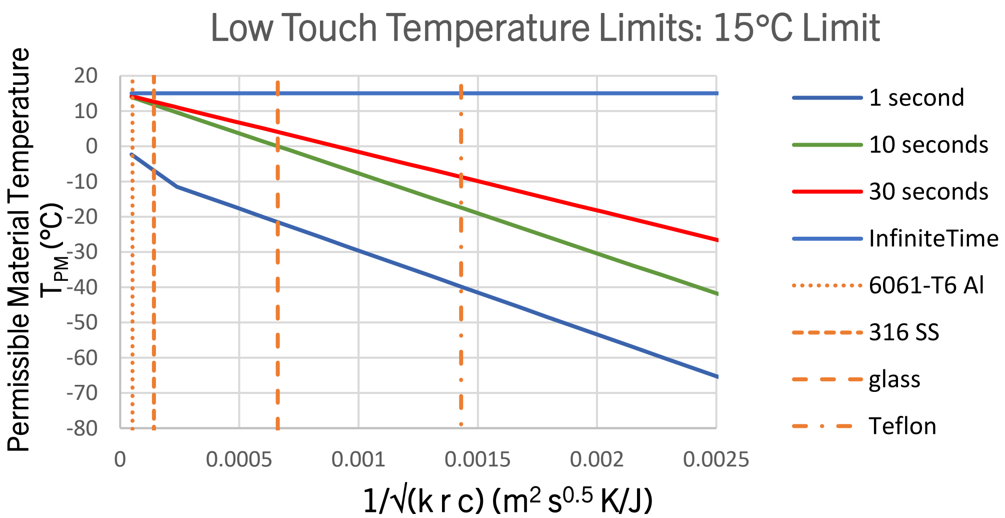
or

- Utilize the calculated and graphed values in Figure 17, Low T_{PM} for Incidental and Intentional (Planned) Contact for 15℃.

Low Temperature Constants: 15°C

$$T_{obj} = a/\sqrt{(k\ \rho\ c)} + b$$

time (s)	a	b
1s for $a/\sqrt{(k\ \rho\ c)} < 2.34X10^{-4}$	-48,600	0
1s for $a/\sqrt{(k\ \rho\ c)} \geq 2.34X10^{-4}$	-23,800	-5.8
10	-22,700	15
30	-16,600	15
∞	0	15



Low T_{PM} for Incidental and Intentional (Planned) Contact (15°C)

Application

Cold Temperature Calculations

<u>Determining Material Temperature and Duration of Contact for 0℃</u>

To determine the maximum permissible material temperature (T_{PM}) and the allowable time of contact to ensure the skin temperature does not exceed the limits:

- Use either the equation and constants from Table 27, Low Temperature Constants: 0℃, and perform the appropriate calculations.

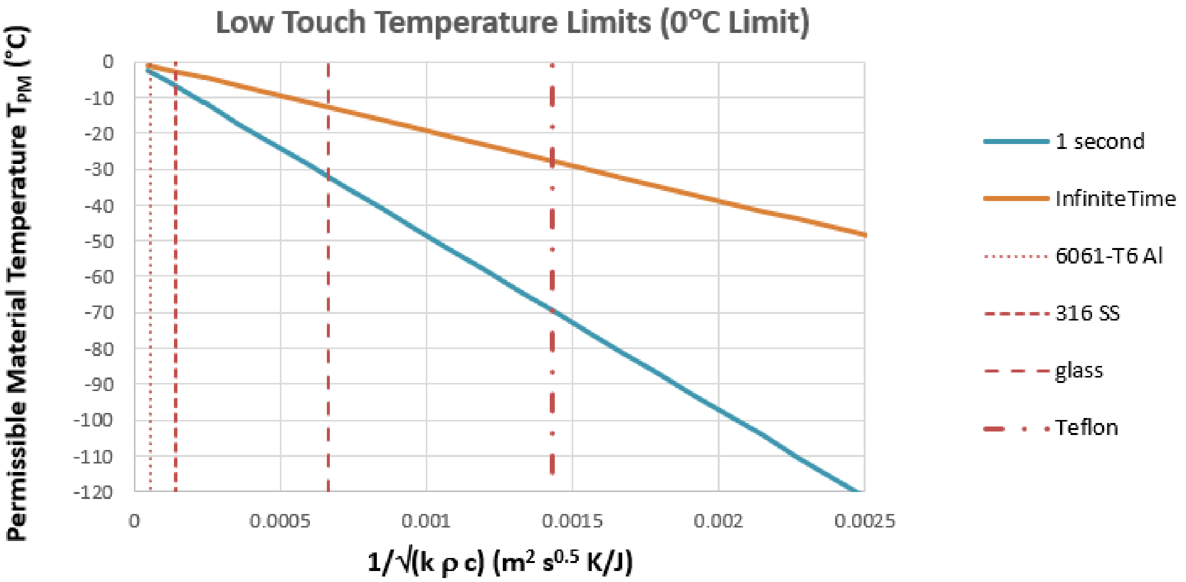
or

- Utilize the calculated and graphed values in Figure 18, Low T_{PM} for Incidental and Intentional (Planned) Contact for 0℃.

Low Temperature Constants: 0°C

$$T_{obj} = a/\sqrt{(k\ \rho\ c)}+b$$

time (s)	a	b
1	-48,600	0
∞	-19,400	0



Low T_{PM} for Incidental and Intentional (Planned) Contact (0°C)

Back-Up

Referenced Technical Requirements

NASA-STD-3001 Volume 1 Revision B
[V1 3004] In-Mission Medical Care All programs shall provide training, in-mission medical capabilities, and resources to diagnose and treat potential medical conditions based on epidemiological evidence-based PRA, clinical practice guidelines and expertise, historical review, mission parameters, and vehicle derived limitations. These analyses should consider the needs and limitations of each specific DRM and vehicles. The term “in-mission” covers all phases of the mission, from launch, through landing on a planetary body and all surface activities entailed, up to landing back on Earth. In mission capabilities (including hardware and software), resources (including consumables), and training to enable in-mission medical care, are to include, but are not limited to:

[V1 3009] Palliative Comfort Care In medical scenarios where onboard medical resources have been exhausted, a timely return to Earth or another location of higher medical capability is not feasible, and survival of the crewmember has been determined to be impossible, palliative comfort care shall be provided.

[V1 3015] Certification of Training Plans for Launch/Landing Medical Team The organization responsible for astronaut health shall certify training plans for EMS personnel who work launch/landing and concur on training plans for organizations that have a specific EMS training plan in support of a NASA space flight program. Training includes but is not limited to: a. Physiological changes occurring as a result of prolonged launch body posture. b. Space flight physiology. c. Injuries resulting from launch and landing contingencies (such as trauma, burns, hypoxia, and hypothermia). d. Hazards of exposure to space vehicle-associated toxic chemicals such as propellant, fuels, oxidizers, thermal control fluids, off gassed products, and their unique treatments and responses. e. Launch/landing suit, helmet, and equipment configuration and safe removal.

NASA-STD-3001 Volume 2 Revision C
[V2 9102] Skin/Tissue Damage Temperature Limits Any surface to which the bare skin of the crew is exposed shall not cause skin temperature to exceed the injury limits in Table 21, Skin Temperature Injury Limits.

[V2 9103] Pain/Non-Disabling Injury Skin Temperature Limits Any surface to which the bare skin of the crew is exposed shall not cause skin temperature to exceed the injury limits in Table 22, Range/Limits Pain/Non-Disabling Injury/Possibly Resulting in Illness.

Reference List

1. NASA Touch Temperature Calculation Tool, May 2020.
2. Human Integration Design Handbook (HIDH), NASA/SP-2010-3407/rev1, 06-05-2014.
3. Eugene Ungar & Kenneth Stroud. *New Approach to Defining Human Touch Temperature Standards.* NASA/Johnson Space Center. Available at: https://ntrs.nasa.gov/api/citations/20100020960/downloads/20100020960.pdf
4. Defrin, R., Shachal-Shiffer, M., Hadgadg, M., Peretz, C. (2006). Quantitative Somatosensory Testing of Warm and Heat-Pain Thresholds: The Effect of Body Region and Testing Method*. Clinical Journal of Pain*, *22*(2), pp. 130-136.
5. Greene, L.C., Alden, J.C., and Hardy, J.D. (1958). Adaptation to Pain. *Federation Proc. 17*: 60.
6. Havenith, G., van de Linde, E.J.G., Heus, R. (1992). Pain, thermal sensation and cooling rates of hands while touching cold materials. *European Journal of Applied Physiology; 65*: 43–51.
7. Moritz, A.R., and Henriques, F.C. (1947). Studies in Thermal Injury II. The Relative Importance of Time and Air Surface Temperatures in the Causation of Cutaneous Burns. *American Journal of Pathology, 23*: 695-720.
8. Lloyd-Smith, D.L., and Mendelssohn, K. (1948). Tolerance limits to radiant heat. *British Medical Journal*, p. 975.
9. Provins, K.A., and Morton, R. (1960). Tactile discrimination and skin temperature. *Journal of Applied Physiology; 15*: 155–60.