NASA-STD-3001 Technical Brief

Non-Ionizing Radiation

OCHMO-TB-045

Relevant Technical Requirements

NASA-STD-3001 Volume 2, Rev D

[V2 6102] RF Non-Ionizing Radiation Exposure Limits

[V2 6103] Laser Exposure Limits

[V2 6104] Natural Sunlight Exposure Limits

[V2 6117] Artificial Light Exposure Limits

Executive Summary

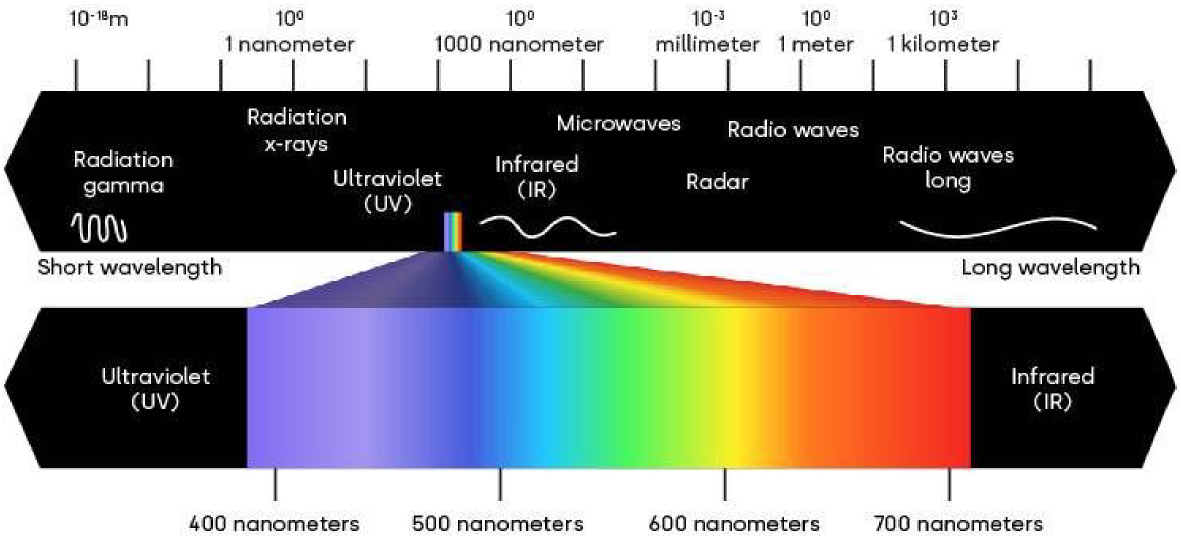
Non-ionizing radiation (NIR) is one of the health risks that astronauts face in spaceflight. Sources of NIR that are monitored in an effort to protect crew include radiofrequency (RF) emitters, natural and artificial incoherent light sources, and lasers. As research and development activities on the International Space Station (ISS) have progressed, NIR sources have expanded to include the use of stronger lasers and more powerful antennas for improved communication capabilities. Current NIR safety requirements are based on terrestrial guidelines, however the spaceflight environment has unique challenges that require a proactive, flexible, and highly adaptive risk management approach that is unique when compared to terrestrially-based NIR safety processes. Hardware design and controls, health countermeasures, and operational controls are all used as part of the NASA's NIR hazard mitigation strategy.

The Space Radiation Analysis Group (SRAG) NIR SMEs are the agency's focal point of expertise for NIR hazard requirements regarding space crew protection and are responsible for ensuring that the NIR exposure received by astronauts in space remains below established safety limits; and they will continue evaluation of the NIR hazards to ensure mission success and safe human exploration on ISS, outside low-Earth orbit, in cis-lunar space and on future missions.

For additional information, see *Human Space Exploration: Mitigating the Non-Ionizing Radiation Risks* in The Lifetime Surveillance of Astronaut Health October 2023 Newsletter (Vol 28 Issue 2)

Background

Non-ionizing radiation is any type of electromagnetic radiation that does not carry enough energy per quantum to ionize atoms or molecules directly. Unlike ionizing radiation, shielding from NIR sources can be done easily if proper protocol is followed.



From: Lena Lighting - The spectrum of visible light, the wavelength of the light

Sources of Non-Ionizing Radiation

<u>Radiofrequency (RF) Emitters</u>

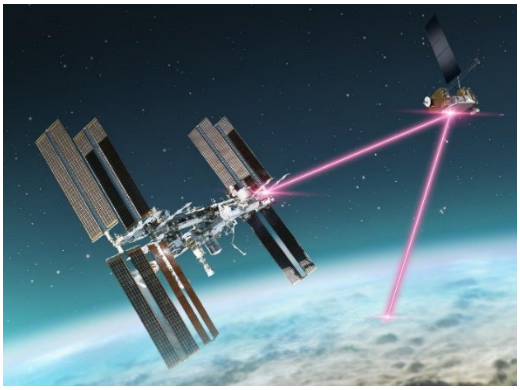
- Ranging from antennas, wireless systems, satellites, and radiofrequency identifier systems

<u>Natural and Artificial Incoherent Light Sources</u>

- Sunlight (UV, visible, near-IR and IR)
- Artificial Incoherent Light Sources:
    - Ultraviolet (UV) (180-400 nm): Produced in welding and carbon arcs, blacklights, sun lamps, germicidal lamps, and low/high pressure gas discharge lamps
    - Visible (380 – 3000 nm): LEDs, lamps, cabin lighting, display screens
    - Near-Infrared and Infrared (770-3000 nm): IR LEDs, heat lamps, IR saunas

<u>Lasers</u>

- Continuous wave or pulsed lasers (UV, visible, near-IR and IR)
- Internal or External to ISS, docking lasers, research lasers



NASA's ILLUMA-T payload communicating with Laser Communications Relay Demonstration (LCRD) over laser signals.
Source: NASA/Dave Ryan

Reference Data

Radiofrequency (RF) Emitters

- A large number of low-power transmitters and high-power antennas are used on the International Space Station. The two main areas of concern regarding RF emitters on the ISS are hardware interference or damage and crew injury or illness.
- RF exposure can lead to shocks or burns, heating pain or tissue burns, behavioral disruption, heat exhaustion or stroke.
- NASA-STD-3001 Volume 2 establishes limits for RF non-ionizing radiation exposure.

[V2 6102] RF Non-Ionizing Radiation Exposure Limits The system shall maintain the crew exposure to RF electromagnetic fields to or below the limits stated in Table 6.8-2—Maximum Permissible Exposure (MPE) to RF Electromagnetic Fields and shown graphically in Figure 6.8-1—RF Electromagnetic Field Exposure Limits. *From: NASA-STD-3001 Volume 2*

Table 6.8-2—Maximum Permissible Exposure (MPE) to RF Electromagnetic Fields (modified from IEEE C95.1-2005, lower tier)

Frequency Range (MHz)	RMS Electric Field Strength (E)[a] (V/m)	RMS Magnetic Field Strength (H)[a] (A/m)	RMS Power Density (S) E–Field, H–Field (W/m^2)	Averaging Time[b] $\lvert E\rvert^2$, $\lvert H\rvert^2$, or S (min)	
0.1 – 1.34	614	$16.3/f_M$	$(1{,}000,\ 100{,}000/f_M^2)$[c]	6	6
1.34 – 3	$823.8/f_M$	$16.3/f_M$	$(1{,}800/f_M^2,\ 100{,}000/f_M^2)$	$f_M^2/0.3$	6
3 – 30	$823.8/f_M$	$16.3/f_M$	$(1{,}800/f_M^2,\ 100{,}000/f_M^2)$	30	6
30 – 100	27.5	$158.3/f_M^{1.668}$	$(2,\ 9{,}400{,}000/f_M^{3.336})$	30	$0.0636 f_M^{1.337}$
100 – 300	27.5	0.0729	2	30	30
300 - 5000	–	–	$f/150$	30	
5000 - 15000	–	–	$f/150$	$150/f_G$	
15000 – 30,000	–	–	100	$150/f_G$	
30,000 – 100,000	–	–	100	$25.24/f_G^{0.476}$	
100,000 – 300,000	–	–	100	$5048/[(9f_G-700)f_G^{0.476}]$	

Note: f_M is the frequency in MHz; f_G is the frequency in GHz.

(a) For exposures that are uniform over the dimensions of the body such as certain far-field plane-wave exposures, the exposure field strengths and power densities are compared with the MPEs in the table. For non-uniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the squares of the field strengths or averaging the power densities over an area equivalent to the vertical cross section of the human body (projected area) or a smaller area, depending on the frequency, are compared with the MPEs in the table. For further details, see IEEE C95.1-2005, notes to Table 8 and Table 9.

(b) The left column is the averaging time for $\lvert E\rvert^2$; the right column is the averaging time for $\lvert H\rvert^2$. For frequencies greater than 400 MHz, the averaging time is for power density (S).

(c) These plane-wave equivalent power density values are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.

Reference Data

Natural and Artificial Incoherent Light

- Natural Incoherent Light (Sunlight) – There are many windows on the ISS that provide viewing and sunlight exposure to the crew. Sunlight includes UV, visible and IR radiation some of the ISS windows (e.g., Cupola) attenuate sunlight to safe levels.
- Exposure to natural and artificial incoherent light sources can lead to retinal thermal damage, macular degeneration, and photochemical effects such as corneal sunburn and skin damage.
- Exposure to visible light sources whose luminance does not exceed 10,000 Nits is safe (1 Nit = 1 Candela per meter squared; 1 Nit = 1cd/m2). Exposure to visible light sources whose luminance exceeds 10,000 Nits and is below 10,000,000 Nits is considered of marginal severity. Therefore, the ACGIH limits for visible light are required only for artificial sources exceeding 10,000,000 Nits as per Table 6.8-4—ACGIH Requirements Applicability.

Reference OCHMO-TB-026 Lighting Design for additional information on light sources and considerations.

[V2 6117] Artificial Light Exposure Limits
The system shall limit crew exposure from Visible, Infrared (IR), near-IR and Ultraviolet (UV) artificial light sources (180 nm to 3000 nm) at or below the threshold limit value (TLV) as calculated per ACGIH version 2022 or later.
From: NASA-STD-3001 Volume 2

Astronaut Andrew Morgan waters plants in the Veg-04B experiment on the space station. This space botany research is one of several studies into how to provide fresh food for crews on long-term space missions. Source: NASA

Table 6.8-4—ACGIH Requirements Applicability

Requirement/ Damage Mechanism	Luminance Value (Nits)	ACGIH Calculations Applicability
Visible Light (380-770 nm) *Retina: Thermal* **Visible Light (305-700 nm)** *Lens, Retina: Photo-chemical*	$<10^4$ Nits Eye safe	N/A
	$<10^7$ Nits Marginal Hazard	N/A
	$\geq 10^7$ Nits Critical or Catastrophic Hazard	ACGIH calculations needed
IR/Near-IR Light (770-3000 nm) *Cornea, Retina: Thermal*	N/A	ACGIH calculations needed
Ultraviolet (180-400 nm) *Cornea, Lens, Retina, Skin*	N/A	Full Containment or ACGIH calculations needed

Reference Data

The ACGIH requirement compliance and pass criteria are summarized in Table 6.8-5—ACGIH Requirement Compliance and Pass Criteria. Although not explicitly stated in ACGIH, the assumed viewing distance is 10 cm since this is the minimum focus length of the human eye and thus the largest optical power/hazard potential on to the retina. ACGIH pass criteria for visible light account for the 0.25 seconds human aversion response (i.e., time to look away and/or blink). However, the protection offered by the aversion response will not occur if the light intensity is great enough to produce damage in less than 0.25 seconds, as explained in the ACGIH. Note: Older than 2014 versions of the ACGIH TLVs cannot be utilized due to substantial differences in hazard functions.

Table 6.8-5—ACGIH Requirement Compliance and Pass Criteria

Requirement/ Damage Mechanism	Parameter/ Units	ACGIH 2022 Section/Equation	ACGIH 2022 Pass Criteria
Visible Light (380-770 nm) *Retina: Thermal*	Total Effective Radiance $W \cdot cm^{-2} \cdot sr^{-1}$	Section 4 [10, 12b[1,2], 13a[1,2]]	$T_{max} \geq 0.25$ sec If a>0.1 rad: $LR \leq 45\ W \cdot cm^{-2} \cdot sr^{-1}$ If α<0.1 rad: $LR \leq 4.5 \cdot \alpha^{-1}\ W \cdot cm^{-2} \cdot sr^{-1}$
Visible Light (305-700nm) *Lens, Retina: Photo-chemical*	Effective Radiance $W \cdot cm^{-2} \cdot sr^{-1}$	Section 1 [1, 2a[1], 3[2], 4a[1, 2]]	$T_{max} \geq 0.25$ sec If α>0.011 rad: $L_B \leq 400\ W \cdot cm^{-2}$ If α<0.011 rad: $E_B \leq 0.04\ W \cdot cm^{-2}$
IR and Near-IR Light (770-3000 nm) *Cornea, Lens: Thermal*	Total Infrared Irradiance $W \cdot cm^{-2}$	*Section 2* [6, 7b]	$E_{IR\text{-}only} \leq 0.01\ W \cdot cm^{-2}$
IR and Near-IR Light (770-3000 nm) *Retina: Thermal*	Total Effective Radiance $W \cdot cm^{-2} \cdot sr^{-1}$	*Section 2, 3* [8, 9b[2]]	$L_{Near\text{-}IR} \leq 0.6 \cdot \alpha^{-1}$ $W \cdot cm^{-2} \cdot sr^{-1}$
Ultraviolet (180-400 nm) *Cornea Lens, Retina: Photochemical*	Effective Radiance over 8 hours $J \cdot m^{-2}$	*Section "UV Radiation"* [1, 2, 4-7]	See ACGIH Table 1 in this section for all TLVs (delineated per UV wavelength)
Ultraviolet (180-300 nm) *Skin (only)*	Effective Radiance $J \cdot m^{-2}$	*Section "UV Radiation"* [1, 3]	See ACGIH Table 2 in this section for all TLVs (delineated per UV wavelength)

Note: Refer to ACGIH 2022 for all equations referenced in this table.
[1] Assume a 0.25 second aversion response time or calculate T_{max}.
[2] Dependent on angular subtense, a. See Equation 11 in Section 4.

Reference Data

[V2 6104] Natural Sunlight Exposure Limits The system shall maintain the crew exposure to natural sunlight for spectral radiance or irradiance (as applicable) within wavelengths between 180 nm and 3000 nm, as noted in Table 6.8-3—Natural Sunlight Exposure Limits for Different Damage Mechanisms.
From: NASA-STD-3001 Volume 2

Table 6.8-3—Natural Sunlight Exposure Limits for Different Damage Mechanisms

Requirement	ACGIH 2014 – TLVs Equations in the Optical Radiation Section	Units	Pass Criteria	Damage Mechanism
Visible and Near-Infrared Radiation 380-3000 nm (relaxed 2x)	Equations 4a, 4b (Section 1)*	Seconds (Eq. 4a) Factors over allowable irradiance (Eq. 4b)	$T_{max} \geq 0.25$s (Eq. 4a) Weighted irradiance divided by TLV ratio ≤1 (Eq. 4b)	Retinal Thermal
Visible Radiation 305-700 nm (relaxed 5x)	Equation 8b (Small Source) (Section 2)*	Seconds (Eq. 8b)	$T_{max} \geq 0.25$ sec (Eq. 8b)	Retinal Photochemical
Ultraviolet Exposure 180-400 nm (not relaxed)	Equations 3, 4 (Ultraviolet Radiation)*	Minutes (Eq. 3, Eq. 4)	$T_{max} \geq 480$ min (Eq. 3) $T_{max} \geq 17$ min (Eq. 4)	Corneal, Skin

**Injury TLVs from visible light presume a dark-adapted pupil with additional factors of safety applied. A minimum safety factor of 2 in the spectral radiance L_λ source terms has been included in the ACGIH standard. A minimum safety factor of 5 in the spectral irradiance E_λ source terms has been included in the ACGIH standard. To eliminate this excess conservatism, the requirement should relax the spectral radiance L_λ by multiplying it by a factor of 1/2 and the spectral irradiance E_λ by multiplying it by a factor of 1/5. Thus, Equations 4a and 4b are subjected to the 2x relaxation factor, while Equation 8b is subjected to the 5x relaxation factor. This reduction does not apply to ultraviolet radiation. Thus, Equations 3 and 4 are not subjected to any relaxation factors.*
These limits do not apply to laser exposure (see laser exposure limits). Older versions of the ACGIH TLVs should not be utilized due to substantial differences in hazard functions. These limits do not account for forced chronic solar viewing.
NOTE: Refer to ACGIH 2014 for all equations referenced in this table.

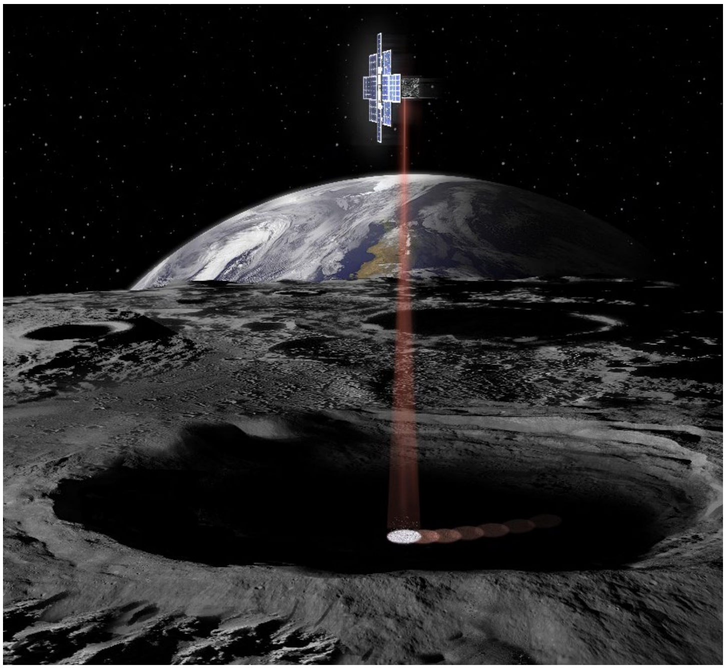
Expedition 51 Flight Crew wearing protective sunglasses inside the ISS Cupola. The windows inside the Cupola are constructed of materials to protect crewmembers from UV light exposure. Source: NASA

Reference Data

Lasers

- Spaceflight programs rely on lasers for a variety of operational and research applications, including vehicle docking, optical communications, Light Detection & Ranging (LIDAR), Laser Communications Relay Demonstration (LCRD) systems, environmental gas monitoring, fluorescent stimulation, extravehicular activities (EVAs), extraterrestrial surface transport vehicles (ESTVs), and intravehicular laser science payloads.
- Extravehicular lasers are hazardous to crewmembers conducting EVAs, to crewmembers inside the vehicle through windows, and to visiting vehicles that may be approaching to dock. They also pose a small risk to the uncontrolled general population through potential use of magnifying optics viewing from the ground.
- Acute exposure to certain powers of laser wavelengths can cause burns to the cornea and/or retina. Chronic excessive exposure levels to the eye can lead to the development of cataracts and damage to the retina. High amounts of optical radiation in lasers can also lead to skin burns. Additionally, the system components of a laser may contain dangerous substances that are flammable and hazardous to human health; and create high voltages that could be lethal in unintentional exposure.
- NASA-STD-3001 established a technical requirement to limit crew ocular and dermal exposure to both continuous and pulsed lasers to protect against eye and skin injury. The limits are adopted from the Laser Institute of America's (LIA) publication ANSI Z136.1, 2014. The term *laser system* includes the laser, its housing, and controls. This requirement applies to laser systems utilized both internal and external to the vehicle. In addition, this requirement limits uncontrolled ground population ocular exposure to space lasers. The limits are adopted from ANSI Z136.1, 2014. ANSI Z136.6, 2015, which may be used for guidance on laser hazard analysis methodology.

[V2 6103] Laser Exposure Limits The system shall maintain the crew ocular and dermal exposure to laser systems and the ocular exposure of the uncontrolled ground population to space lasers to or below the limits specified in ANSI Z136.1, 2014, American National Standard for Safe Use of Lasers, Table 5 (ocular) and Table 7 (dermal) without Personal Protective Equipment.
From: NASA-STD-3001 Volume 2



Artist's concept showing the Lunar Flashlight spacecraft, a six-unit CubeSat designed to search for ice on the Moon's surface using special lasers. The spacecraft will use its near-infrared lasers to shine light into shaded polar regions on the Moon, while an onboard reflectometer will measure surface reflection and composition. Source: NASA

Application

Countermeasures

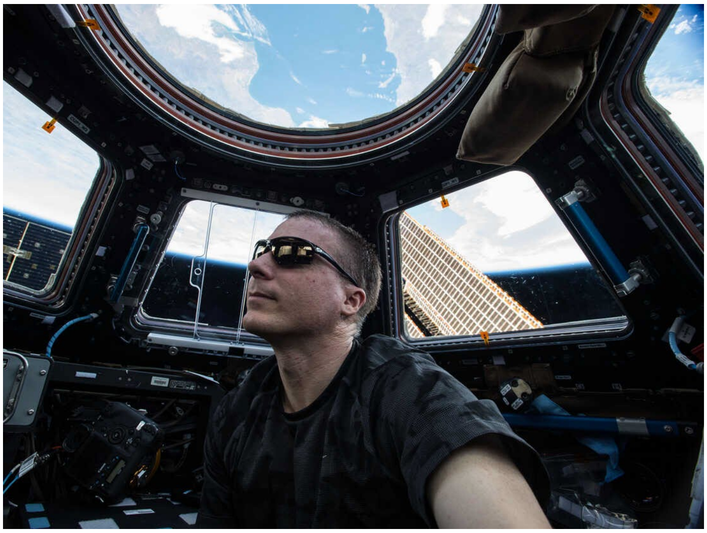
Due to the complexity of space environment operations, nominal terrestrial safety practices (e.g., turn laser off for maintenance and troubleshooting; no direct beam viewing for hazardous laser; minimize reflective surfaces) cannot be easily implemented.

Astronaut Andrew Feustel delivers the Wide Field Camera 3 to the Hubble Space Telescope. Major process improvements were made to supply optical filters for the cameras and other NASA imagers. Source: NASA

Full containment and/or applied shielding are acceptable methods of risk reduction; however, need to assume worst case hazard severity (Catastrophic) and corresponding fault-tolerance requirements. Containment examples include the use of light-tight structures and enclosures to fully contain the light at the source. The applied shielding must be placed between crewmember and the light source; examples include screens, optical filters, etc.

One mitigation technique for crew protection from RF exposure is to power down the RF source while the crewmembers are scheduled to execute daily activities near the RF emitter.

ESA astronaut Thomas Pesquet using the Amateur Radio on the ISS (ARISS). Source: NASA



Expedition 43 commander Terry Virts in the Cupola module. Source: NASA

Crewmembers are instructed to use NASA developed laser and sunlight protection glasses, which provide 100% of UV ray blocking and contain a special coating to block infrared radiation, during all window viewing activities. In addition, the crew must not use binoculars or the camera view finder when the sun is either in the field of view or anticipated to be in the field of view.

Back-Up

View the current versions of NASA-STD-3001 Volume 1 & Volume 2 on the OCHMO Standards website

Referenced Technical Requirements

NASA-STD-3001 Volume 2 Revision D

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Reference List

1. The Lifetime Surveillance of Astronaut Health Newsletter. October 2023 Volume 28, Issue 2. *National Aeronautics and Space Administration*. Available at: https://www.nasa.gov/wp-content/uploads/2023/10/lsah-newsletter-2023-vol28-issue2.pdf?emrc=65aea3d7666ff
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