**ISO TC 20/SC 14**

Date: 2005-12-01

**ISO/DIS 21348**

ISO TC 20/SC 14/WG 4

Secretariat: ANSI

# Space environment (natural and artificial) — Process for determining solar irradiances

*Environment spatial (naturel et artificiel) — Procédé de déterminatio de i'irradiance solaire*



Document type: International Standard
Document subtype:
Document stage: (40) Enquiry
Document language: E

Europa:SpaceEnvironmentTechnologies:Projects:Standards:ISO:DIS21348:ISO_DIS_21348_(E)_revB.doc STD Version 2.1c2

# Contents

Page



**Figures**



**Tables**

# Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

This International Standard was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

## Introduction

This International Standard provides guidelines for specifying the process of determining solar irradiances. Solar irradiances are reported through products such as measurement sets, reference spectra, empirical models, theoretical models, and solar irradiance proxies or indices. These products are used in scientific and engineering applications to characterize solar irradiances within the natural space environment that are relevant to space systems and materials.

Examples of applications using input solar irradiance energy include the determination of atmospheric densities for spacecraft orbit determination, attitude control, and re-entry calculations and as well as for debris mitigation and collision avoidance activity. Direct and indirect pressure from solar irradiance upon spacecraft surfaces also affects attitude control separately from atmospheric density effects. Solar irradiances are used to provide inputs for calculations of ionospheric parameters, for photon-induced radiation effects, and for radiative transfer modeling of planetary atmospheres. Input solar irradiance energy is used to characterize material properties related to spacecraft thermal control including surface temperatures, reflectivity, absorption, and degradation. Solar energy applications requiring a standard process for determining solar irradiance energy include solar cell power simulation, material degradation, and the development of lamps and filters for terrestrial solar simulators.

A solar irradiance product certifies compliance with this process-based standard by following compliance criteria that are described in this document. The compliance criteria in clause 7 are based upon solar irradiance product types that are described in clause 5 and solar irradiance spectral categories described in clause 6. The method for certifying compliance of a solar irradiance product with this standard is provided in clause 8.

# Space environment (natural and artificial) — Process for determining solar irradiances

## 1 Scope

This International Standard specifies the process for determining solar irradiances and is applicable to measurement sets, reference spectra, empirical models, theoretical models, and solar irradiance proxies or indices that provide solar irradiance products representing parts or all of the solar electromagnetic spectrum. Its purpose is to create a standard method for specifying all solar irradiances for use by space systems and materials users.

## 2 Terms and definitions

For the purposes of this International Standard, the following terms and definitions apply.

**2.1**
**astronomical unit**
**ua**
also accepted nomenclature, AU, is a unit of length approximately equal to the mean distance between the Sun and Earth with a currently accepted value of (149 597 870 691 ±3) m [1,2]

NOTE Distances between objects within the solar system are frequently expressed in terms of ua. The ua or AU is a non-SI unit accepted for use with the International System and whose value in SI units is obtained experimentally. Its value is such that, when used to describe the motion of bodies in the solar system, the heliocentric gravitation constant is $(0.017\ 202\ 098\ 95)^2$ $ua^3\ d^{-2}$ where one day, d, is 86 400 s [3]. One AU is slightly less than the average distance between the Earth and the Sun since an AU is based on the radius of a Keplerian circular orbit of a point-mass having an orbital period in days of $2\pi/k$ (k is the Gaussian gravitational constant and is $(0.01720209895\ AU^3\ d^{-2})^{1/2}$). The most current published authoritative source for the value of 1 ua is from the Jet Propulsion Laboratory (JPL) Planetary and Lunar Ephemerides, DE405/LE405 [2].

**2.2**
**solar irradiance**
the Sun's radiation integrated over the full disk and expressed in SI units of power through a unit of area, $W\ m^{-2}$

NOTE The commonly used term "full disk" includes all of the Sun's irradiance coming from the solar photosphere and temperature regimes at higher altitudes, including the chromosphere, transition region, and corona. Some users refer to these composite irradiances as "whole Sun." Solar irradiance is more precisely synonymous with "total solar irradiance" while spectral solar irradiance is the derivative of irradiance with respect to wavelength and can be expressed in SI units of $W\ m^{-3}$; an acceptable SI submultiple unit description is $W\ m^{-2}\ nm^{-1}$. Mixed spectral solar irradiance units, for example quanta $cm^{-2}\ s^{-1}\ nm^{-1}$, photons $cm^{-2}\ s^{-1}\ Å^{-1}$, and ergs $cm^{-2}\ s^{-1}\ nm^{-1}$, can be useful as an addition to, but not as a replacement for, SI unit reporting.

Solar radiances, or the emergent energy from a spatial area that is less than the full disk of the Sun, are not explicitly covered by this standard at the present time unless the radiances are integrated across the full disk to represent an irradiance.

For the calibration of ground-based instruments (pyrheliometers) measuring total solar irradiance (TSI) the World Radiometric Reference (WRR) was introduced in 1980 by the World Meteorological Organisation (WMO) as a primary standard to ensure world-wide homogeneity of solar radiation measurements. The WRR is created through an ensemble of absolute cavity radiometers called the World Standard Group (WSG) located and maintained at the World Radiation Center by the Physikalisch-Meteorologisches Observatorium Davos in Switzerland. The uncertainty of the WRR is 0.3%. The comparison of the WRR with the SI-scale that is represented by cryogenic radiometers and based on radiance measurements agrees within the quoted uncertainties of the two scales [4,5]. The transfer of the WRR to space has been done but, because the resulting uncertainty is large compared to the variations of the solar constant, a non-mandatory Space Absolute Radiation Reference (SARR) has been introduced [6].

 

**2.3**
**solar constant**
**S**
the total solar irradiance at normal incidence to the top of the Earth's atmosphere through a unit surface and at 1 ua with a mean value of 1366 W $m^{-2}$ [7]

NOTE The solar constant, a historical term, is not constant. It varies geometrically with the Earth's distance from the Sun and physically with the Sun's magnetic field activity on short to long timescales as well as with the observer's heliocentric latitude. The value of 1366 W $m^{-2}$ is the measurement community's current agreement expressed through a TSI space-based composite dataset that is normalized to an arbitrarily selected set of missions defining the SARR [6]. A range of measured values extends from SORCE/TIM 2003-2004(+?) values (~1362 W $m^{-2}$) to NIMBUS-7/HF 1978-1993 values (~1372 W $m^{-2}$) but also includes SMM/ACRIM I 1980-1989 (~1368 W $m^{-2}$), ERBS/ERBE 1984-2003 (~1365 W $m^{-2}$), UARS/ACRIM II 1991-2001 (~1364 W $m^{-2}$), EURECA/SOVA2 1992-1993 (~1367 W $m^{-2}$), SOHO/VIRGO 1996-2004(+?) (~1366 W $m^{-2}$), and ACRIMSAT/ACRIM III 2000-2004(+?) (~1364 W $m^{-2}$) measurements. The SARR reduces all solar constant space measurements to a single ensemble dataset. The currently measured 1-sigma variation in the composite dataset is approximately 0.6 W $m^{-2}$ and there is a long-term (yearly) smoothed solar cycle minimum to maximum relative variation about the mean value of approximately 1.4 W $m^{-2}$ [7].

# 3 Symbols and abbreviated terms

$\lambda$ designates the spectral wavelength of solar irradiance and is given in units of length, nm

# 4 General concept and assumptions

## 4.1 Solar irradiance representation

Solar irradiance products that are frequently reported to space systems users are derived from measurements and/or models. Examples of solar irradiance products include, but are not limited to, spectral and time series intensities, surrogates or substitutes (proxies), and activity indicators (indices) that are intended to represent solar irradiances, and solar images containing full-disk spectral information. Because knowledge of solar irradiance spectral and temporal characteristics is fundamental to the understanding of a wide variety of physical and technical processes, and because solar irradiances have been reported and are used in a variety of formats, it is recognized that the standardization of the process for determining solar irradiances is important. A standardized process for determining solar irradiances enables suppliers and users of these products to exchange information with a common, understandable language.

## 4.2 Robustness of standard

The implementation of this solar irradiance standard assumes that there will continue to be technical improvements in the accuracy and precision of measurements because ground-based and space-based instrumentation use new detectors, filters, and computer hardware/software algorithms and because there is improved understanding of the Sun's physical processes. There is also the expectation of continual improvements in the reporting and calculation of reference spectra, empirical models, first-principles models, and solar irradiance proxies or indices. It is likely that there will be an evolving solar standard user community. Given the continual change in these areas, this solar irradiance standard is designed as a robust document in scope and format so as to support and encourage these changes.

## 4.3 Process-based standard

This solar irradiance standard does not specify one measurement set, one reference spectrum, one solar model, or one solar irradiance proxy/index as a single standard. In order to encourage continual improvements in solar irradiance products, this solar irradiance standard is a process-based standard for determining solar irradiances. A solar irradiance product, after its development, may follow the process described in clause 7 to certify compliance with the standard.

 

### 4.4 Process-ownership of standard development

The process owner for developing this standard is ISO Technical Committee 20 (Aircraft and space vehicles), Sub Committee 14 (Space systems and operations) Working Group 4 (Space environment (natural and artificial)) or its successor(s). The participants in this process are the delegates and technical experts to ISO TC20/SC14/WG4. The expertise of the international solar science and material science communities was utilized in the development of this standard.

### 4.5 Parallel activity of certification to standard

Coincident with and subsequent to the publication of this standard, ISO TC20/SC14/WG4 participants expect solar irradiance product providers to supply measurement sets, reference spectra, models, and solar irradiance proxies or indices that certify compliance with this standard [8]. Solar irradiance products that are compliant will be so designated for international space systems and materials users.

## 5 Solar irradiance product types

### 5.1 Rationale

Solar irradiance product types are established so that the suppliers and users have a common, easy-to-recognize method of identifying standard-compliant solar irradiance products.

### 5.2 Type designation

A solar irradiance product can be a measurement set, reference spectrum, empirical model, first-principles model, or solar irradiance proxy/index. A solar irradiance product has the characteristics of only one type.

**Type 1.** Type 1 is a measurement set product. Solar irradiances are measured by space- or ground-based instrumentation (including balloons and rockets) at specified wavelengths, with an identifiable wavelength bandpass, having a quantifiable value based upon a calibrated reference source, integrated over an identified spatial area, and reported through a specified time interval.

**Type 2.** Type 2 is a reference spectrum product. Reference spectra can be derived from single and/or multiple measurement sets and can be incorporated into models. Reference spectra represent generalized characteristics of solar irradiances for identified solar activity conditions or unique dates.

**Type 3.** Type 3 is an empirical model product. An empirical solar irradiance model is derived from space- or ground-based measurement sets (including balloons and rockets). It uses proxies to represent solar irradiances at specified wavelengths and produces irradiances with an identifiable wavelength bandpass, having a quantifiable value related to the measurements, integrated over an identified spatial area, and reported through a specified time interval. A hybrid model can combine empirical methods, data assimilation, or physics-based algorithms and is included in this type.

**Type 4.** Type 4 is a first-principles or theoretical model product. A first-principles solar irradiance model is derived from the fundamental physics describing energy, momentum, and/or mass conservation, transfer, and state changes. It produces solar irradiances at specified wavelengths, with an identifiable wavelength bandpass, having a quantifiable value related to the physical processes, integrated over an identified spatial area, and reported through a specified time interval.

**Type 5.** Type 5 is a surrogate solar irradiance product, also called a proxy or index. There is not yet consensus regarding common definitions of proxies and indices; often the terms are used interchangeably. An evolving usage of the term solar irradiance proxy is a measured or modeled data type that can be used as a substitute for solar spectral irradiances at different specified wavelengths or over a wavelength bandpass; it may be only empirically related. Alternatively, an evolving usage of the term solar irradiance index is a measured or modeled data type that is an indicator, or expresses an activity level, of solar irradiances and can represent a specified wavelength or integrated irradiances over a wavelength bandpass. Proxies and indices can represent other irradiance-related solar features including irradiance deficit from sunspots or sunspot numbers. Examples also exist where both terms may apply to the same measurement when used in different circumstances. A solar measurement at one wavelength is an index of activity for the regime of solar temperatures that creates the solar emission; yet, a generalization of the same measurement to a broader wavelength bandpass encompassing other solar temperature regimes would be considered a proxy. The intent of this International Standard is to encourage developers and users of proxies or indices to clearly specify their origins and applications. Proxies and indices have a quantifiable value related to physical solar processes and can be reported through a specified time interval.

# 6 Solar irradiance spectral categories

## 6.1 General

Definitions of solar irradiance spectral categories are based on recommendations or usages by provider and user communities. There can be differing or overlapping definitions used by separate communities and these definitions are collected in this clause. This standard does not recommend one definition over another in cases of ambiguity or overlap. It is also anticipated that these definitions will change or evolve as convention dictates. The information in clauses 6.2 through 6.9 are summarized below in tabular format (Table 1) and graphical format (Figure 1).

The common wavelength unit used in this clause is the SI derived submultiple unit nanometer, nm, where 1 nm = $1\times10^{-9}$ m and where the meter, m, is the SI base unit for length. The clause also refers to other SI derived, community-recognized units where appropriate. These include microns or micrometers (1 $\mu$m = $1\times10^{-6}$ m), millimetres (1 mm = $1\times10^{-3}$ m), centimetres (1 cm = $1\times10^{-2}$ m), and Hertz ($s^{-1}$).

## 6.2 Total Solar Irradiance

The Total Solar Irradiance (TSI) is the full-disk (whole Sun) solar irradiance at 1 ua integrated across all wavelengths and is reported in units of W $m^{-2}$ (clauses 2.1, 2.2, and 7.2). The solar constant, as described in clause 2.3, is the mean value of the TSI.

## 6.3 Gamma-rays

**Gamma-rays**. Gamma-ray irradiances are defined as the wavelength range of ($0.00001 \le \lambda < 0.001$) nm.

NOTE This definition is commonly used by data providers for this spectral category.

## 6.4 X-rays

**Hard X-rays**. Hard X-ray irradiances are defined as the wavelength range of ($0.001 \le \lambda < 0.1$) nm.

NOTE This definition is commonly used by data providers for this spectral category.

**Soft X-rays.** Soft X-ray irradiances, also called the XUV or SXR, are defined as the wavelength range of ($0.1 \le \lambda < 10$) nm.

NOTE This definition is commonly used by data providers of this spectral category. As a less common practice, some aeronomers consider soft X-rays to extend to 30 nm.

## 6.5 Ultraviolet

**Ultraviolet.** Ultraviolet or UV irradiances are defined as the wavelength range of ($100 \le \lambda < 400$) nm.

NOTE This definition is given by the Global Solar UV Index (UVI) designation [9,10].

 

**Vacuum Ultraviolet.** Vacuum Ultraviolet or VUV irradiances are defined as the wavelength range of ($10 \le \lambda < 200$) nm.

NOTE This definition is commonly used by data providers of this spectral category as well as by the materials sciences community.

**Extreme Ultraviolet.** Extreme Ultraviolet or EUV irradiances are defined as the wavelength range of ($10 \le \lambda < 121$) nm.

NOTE This definition is commonly used by data providers of this spectral category. Sometimes aeronomers use a less common definition of 30 nm as the shorter wavelength cut-off. The longer wavelength cut-off includes, for example, the ionization potential for $O_2$ at 102.7 nm, the edge of crystal window transmission for $MgF_2$ at 115 nm, and is shortward of the H I Lyman-$\alpha$ emission at 121.6 nm.

**Lyman-alpha.** Lyman-alpha or Lyman-$\alpha$ irradiances are defined as the wavelength range of ($121 \le \lambda < 122$) nm.

NOTE The hydrogen Lyman-alpha line is the most prominent single emission in this part of the spectrum and originates from the solar transition region (line center) and chromosphere (line wings). The emission corresponds to the $1s^2S\text{-}2p^{2p0}$ resonance transition of hydrogen at 121.5668 and 121.5674 nm. The line center and wing emissions span the range of 121.4 to 121.8 nm and are important throughout the solar system; for example, terrestrial D-region ionization, planetary and cometary hydrogen corona, and interstellar hydrogen entering the heliosphere are affected by these irradiances.

**Far Ultraviolet.** Far Ultraviolet or FUV irradiances are defined as the wavelength range of ($122 \le \lambda < 200$) nm.

NOTE This definition is commonly used by data providers of this spectral category.

**Ultraviolet C.** Ultraviolet C or UVC irradiances are defined as the wavelength range of ($100 \le \lambda < 280$) nm.

NOTE This definition is given by the Global Solar UV Index (UVI) designation [9,10].

**Middle Ultraviolet.** Middle Ultraviolet or MUV irradiances are defined as the wavelength range of ($200 \le \lambda < 300$) nm.

NOTE This definition is commonly used by the aeronomy community.

**Ultraviolet B.** Ultraviolet B or UVB irradiances are defined as the wavelength range of ($280 \le \lambda < 315$) nm.

NOTE This definition is given by the Global Solar UV Index (UVI) designation [9,10].

**Near Ultraviolet.** Near Ultraviolet or NUV irradiances are defined as the wavelength range of ($300 \le \lambda < 400$) nm.

NOTE This definition is commonly used by the aeronomy community.

**Ultraviolet A.** Ultraviolet A or UVA irradiances are defined as the wavelength range of ($315 \le \lambda < 400$) nm.

NOTE This definition is given by the Global Solar UV Index (UVI) designation [9,10].

## 6.6 Visible

**Visible.** Visible, optical, or VIS irradiances are defined as the wavelength range of ($380 \le \lambda < 760$) nm [11].

NOTE Solar visible irradiances are defined with respect to the part of the electromagnetic spectrum that stimulates the human retinal cones, i.e., photopic vision. Human sensitivity to light varies between individuals and most human visual perception is between 380 nm to 760 nm. However, some people have visual perception out to 830 nm. The term “light” only applies to the visible part of the electromagnetic spectrum.

**Purple.** Purple irradiances are defined as the wavelength range of ($360 \le \lambda < 450$) nm.

**Blue.** Blue irradiances are defined as the wavelength range of ($450 \le \lambda < 500$) nm.

**Green.** Green irradiances are defined as the wavelength range of $(500 \leq \lambda < 570)$ nm.

**Yellow.** Yellow irradiances are defined as the wavelength range of $(570 \leq \lambda < 591)$ nm.

**Orange.** Orange irradiances are defined as the wavelength range of $(591 \leq \lambda < 610)$ nm.

**Red.** Red irradiances are defined as the wavelength range of $(610 \leq \lambda < 760)$ nm.

## 6.7 Infrared

**Infrared.** Infrared or IR irradiances are defined as the wavelength range of $(760 \leq \lambda < 1\,000\,000)$ nm.

NOTE 760 nm is 0.76 μm and 1 000 000 nm is 1 mm. Infrared is often divided into 3 spectral categories, i.e., the near, middle and far-infrared.

**Near Infrared.** Near infrared or IR-A irradiances are defined as the wavelength range of $(760 \leq \lambda < 1\,400)$ nm.

NOTE 760 nm is 0.76 μm and 1 400 nm is 1.4 μm.

**Middle Infrared.** Middle infrared or IR-B irradiances are defined as the wavelength range of $(1\,400 \leq \lambda < 3\,000)$ nm.

NOTE 1 400 nm is 1.4 μm and 3 000 nm is 3 μm.

**Far infrared.** Far infrared or IR-C irradiances, also sometimes called submillimetric irradiances, are defined as the wavelength range of $(3\,000 \leq \lambda < 1\,000\,000)$ nm.

NOTE 3 000 nm is 3 μm and 1 000 000 nm is 1 mm.

## 6.8 Microwave

Microwave irradiances are defined as the wavelength range of $(1\,000\,000 \leq \lambda < 15\,000\,000)$ nm.

NOTE 1 000 000 nm is 1 mm and 15 000 000 nm is 1.5 cm.

Solar microwave irradiances can create interference or noise for radio communications and navigation frequencies. Frequency bands of interference that also overlap into the radio wavelengths include [12]:

*W:* $(100.0 \geq \nu > 56.0)$ GHz or $(3.00\times10^6 \leq \lambda < 5.35\times10^6)$ nm;

*V:* $(56.0 \geq \nu > 46.0)$ GHz or $(5.35\times10^6 \leq \lambda < 6.52\times10^6)$ nm;

*Q:* $(46.0 \geq \nu > 36.0)$ GHz or $(6.52\times10^6 \leq \lambda < 8.33\times10^6)$ nm;

*K:* $(36.00 \geq \nu > 10.90)$ GHz or $(8.33\times10^6 \leq \lambda < 2.75\times10^7)$ nm;

*X:* $(10.90 \geq \nu > 5.20)$ GHz or $(2.75\times10^7 \leq \lambda < 5.77\times10^7)$ nm;

*C:* $(6.20 \geq \nu > 3.90)$ GHz or $(4.84\times10^7 \leq \lambda < 7.69\times10^7)$ nm;

*S:* $(5.20 \geq \nu > 1.55)$ GHz or $(5.77\times10^7 \leq \lambda < 1.93\times10^8)$ nm;

*L:* $(1.550 \geq \nu > 0.390)$ GHz or $(1.93\times10^8 \leq \lambda < 7.69\times10^8)$ nm; and

*P:* $(0.390 \geq \nu > 0.225)$ GHz or $(7.69\times10^8 \leq \lambda < 1.33\times10^9)$ nm.

### 6.9 Radio

Solar radio irradiances can be defined as the wavelength range of (100 000 ≤ λ < 100 000 000 000) nm although most reports of solar measurements range from (1 000 000 ≤ λ < 10 000 000 000) nm.

NOTE 100 000 nm is 0.1 mm or approximately 3000 GHz and 100 000 000 000 nm is 100 m or approximately 3000 kHz; 1 000 000 nm is 1 mm or approximately 300 GHz and 10 000 000 000 nm is 10 m or approximately 30 MHz

Solar radio irradiances can create interference or noise for radio communications and navigation frequencies. Frequency bands of interference include [12]:

Extremely High Frequency (EHF): (300 ≥ $\nu$ > 30) GHz or ($1.00\times10^6$ ≤ λ < $1.00\times10^7$) nm;

Super-High Frequency (SHF): (30 ≥ $\nu$ > 3) GHz or ($1.00\times10^7$ ≤ λ < $1.00\times10^8$) nm;

Ultra-High Frequency (UHF): (3000 ≥ $\nu$ > 300) MHz or ($1.00\times10^8$ ≤ λ < $1.00\times10^9$) nm;

Very-High Frequency (VHF): (300 ≥ $\nu$ > 30) MHz or ($1.00\times10^9$ ≤ λ < $1.00\times10^{10}$) nm; and

High Frequency (HF): (30 ≥ $\nu$ > 3) MHz or ($1.00\times10^{10}$ ≤ λ < $1.00\times10^{11}$) nm.

The calculation of Hertz in frequency units, $\nu$, is $\nu = c/\lambda$, where *c,* the speed of light in a vacuum, is defined as (299 792 458) m $s^{-1}$ and λ is the wavelength of interest in meters. For example, the 10.7 cm solar radio flux can be converted to frequency in Hz: (299 792 458 m $s^{-1}$)/(0.107 m) = 2 801.799 MHz. Note that 1 kHz = $1\times10^3$ Hz, 1 MHz = $1\times10^6$ Hz, and 1 GHz = $1\times10^9$ Hz.

## 7 Compliance criteria

### 7.1 Rationale

The compliance criteria for this standard consist of activities that are common to solar irradiance product types (clause 5) and solar irradiance spectral categories (clause 6). These criteria specify a compliance process for the determination of solar irradiances that includes the reporting, documenting, publishing, and archiving of solar irradiance products.

### 7.2 Reporting

Solar irradiances shall be reported in SI units, W $m^{-2}$ and solar spectral irradiances shall be reported in SI units, W $m^{-3}$. The conversion to other appropriate conventional units such as W $m^{-2}$ $nm^{-1}$ can be additionally applied. The reported irradiances shall be described as to whether or not they are corrected to 1 ua. It is recommended, though not required, that reported irradiances are corrected to 1 ua. If applicable, the wavelength bins (spectral sampling) and spectral resolution (bandpass) shall be reported for solar irradiance products.

### 7.3 Documenting

The method of determining solar irradiances shall be documented and, as appropriate, shall include data collection, retrieval, processing, calibration, validation, verification, accuracy, and precision methodology and/or algorithms, as well as archiving information.

**Table 1 — Definitions of solar irradiance spectral categories**

| Spectral category | Spectral sub-category | Wavelength range (nm) | Wavelength range (SI prefixes from Table 2) | Notes |
|---|---|---|---|---|
| Total Solar Irradiance | | | | full-disk, 1 ua solar irradiance integrated across all λ |
| Gamma-rays | | 0.00001 ≤ λ < 0.001 | 10 fm ≤ λ < 1 pm | |
| X-rays | | 0.001 ≤ λ < 0.1 | 1 pm ≤ λ < 0.10 nm | Hard X-rays |
| | XUV | 0.1 ≤ λ < 10 | 0.10 nm ≤ λ < 10 nm | Soft X-rays |
| Ultraviolet | UV | 100 ≤ λ < 400 | 100 nm ≤ λ < 400 nm | Ultraviolet |
| | VUV | 10 ≤ λ < 200 | 10 nm ≤ λ < 200 nm | Vacuum Ultraviolet |
| | EUV | 10 ≤ λ < 121 | 10 nm ≤ λ < 121 nm | Extreme Ultraviolet |
| | H Lyman-α | 121 ≤ λ < 122 | 121 nm ≤ λ < 122 nm | Hydrogen Lyman-alpha |
| | FUV | 122 ≤ λ < 200 | 122 nm ≤ λ < 200 nm | Far Ultraviolet |
| | UVC | 100 ≤ λ < 280 | 100 nm ≤ λ < 280 nm | Ultraviolet C |
| | MUV | 200 ≤ λ < 300 | 200 nm ≤ λ < 300 nm | Middle Ultraviolet |
| | UVB | 280 ≤ λ < 315 | 280 nm ≤ λ < 315 nm | Ultraviolet B |
| | NUV | 300 ≤ λ < 400 | 300 nm ≤ λ < 400 nm | Near Ultraviolet |
| | UVA | 315 ≤ λ < 400 | 315 nm ≤ λ < 400 nm | Ultraviolet A |
| Visible | VIS | 380 ≤ λ < 760 | 380 nm ≤ λ < 760 nm | optical |
| | | 360 ≤ λ < 450 | 360 nm ≤ λ < 450 nm | purple |
| | | 450 ≤ λ < 500 | 450 nm ≤ λ < 500 nm | blue |
| | | 500 ≤ λ < 570 | 500 nm ≤ λ < 570 nm | green |
| | | 570 ≤ λ < 591 | 570 nm ≤ λ < 591 nm | yellow |
| | | 591 ≤ λ < 610 | 591 nm ≤ λ < 610 nm | orange |
| | | 610 ≤ λ < 760 | 610 nm ≤ λ < 760 nm | red |
| Infrared | IR | 760 ≤ λ < 1 000 000 | 760 nm ≤ λ < 1.00 mm | |
| | IR-A | 760 ≤ λ < 1 400 | 760 nm ≤ λ < 1.40 μm | Near Infrared |
| | IR-B | 1 400 ≤ λ < 3 000 | 1.40 μm ≤ λ < 3.00 μm | Middle Infrared |
| | IR-C | 3 000 ≤ λ < 1 000 000 | 3.00 μm ≤ λ < 1.00 mm | Far infrared |
| Microwave | | 1 000 000 ≤ λ < 15 000 000 | 1.00 mm ≤ λ < 15.00 mm | |
| | W | $3.00\times10^6 \le \lambda < 5.35\times10^6$ | 3.00 mm ≤ λ < 5.35 mm | (100.0 ≥ $\nu$ > 56.0) GHz |
| | V | $5.35\times10^6 \le \lambda < 6.52\times10^6$ | 5.35 mm ≤ λ < 6.52 mm | (56.0 ≥ $\nu$ > 46.0) GHz |
| | Q | $6.52\times10^6 \le \lambda < 8.33\times10^6$ | 6.52 mm ≤ λ < 8.33 mm | (46.0 ≥ $\nu$ > 36.0) GHz |
| | K | $8.33\times10^6 \le \lambda < 2.75\times10^7$ | 8.33 mm ≤ λ < 27.5 mm | (36.00 ≥ $\nu$ > 10.90) GHz |
| | X | $2.75\times10^7 \le \lambda < 5.77\times10^7$ | 27.50 mm ≤ λ < 57.70 mm | (10.90 ≥ $\nu$ > 5.20) GHz |
| | C | $4.84\times10^7 \le \lambda < 7.69\times10^7$ | 48.40 mm ≤ λ < 76.90 mm | (6.20 ≥ $\nu$ > 3.90) GHz |
| | S | $5.77\times10^7 \le \lambda < 1.93\times10^8$ | 57.70 mm ≤ λ < 193.00 mm | (5.20 ≥ $\nu$ > 1.55) GHz |
| | L | $1.93\times10^8 \le \lambda < 7.69\times10^8$ | 193.00 mm ≤ λ < 769.00 mm | (1.550 ≥ $\nu$ > 0.390) GHz |
| | P | $7.69\times10^8 \le \lambda < 1.33\times10^9$ | 769.00 mm ≤ λ < 1.33 m | (0.390 ≥ $\nu$ > 0.225) GHz |
| Radio | | 100 000 ≤ λ < 100 000 000 000 | 0.10 mm ≤ λ < 100 m | measurements: (1 000 000 ≤ λ < 10 000 000 000) nm |
| | EHF | $1.00\times10^6 \le \lambda < 1.00\times10^7$ | 1.00 mm ≤ λ < 10.00 mm | Extremely High Frequency (300 ≥ $\nu$ > 30) GHz |
| | SHF | $1.00\times10^7 \le \lambda < 1.00\times10^8$ | 10.00 mm ≤ λ < 100.00 mm | Super-High Frequency (30 ≥ $\nu$ > 3) GHz |
| | UHF | $1.00\times10^8 \le \lambda < 1.00\times10^9$ | 100.00 mm ≤ λ < 1.00 m | Ultra-High Frequency (3000 ≥ $\nu$ > 300) MHz |
| | VHF | $1.00\times10^9 \le \lambda < 1.00\times10^{10}$ | 1.00 m ≤ λ < 10.00 m | Very-High Frequency (300 ≥ $\nu$ > 30) MHz |
| | HF | $1.00\times10^{10} \le \lambda < 1.00\times10^{11}$ | 10.00 m ≤ λ < 100.00 m | High Frequency (30 ≥ $\nu$ > 3) MHz |

**Table 2 — SI prefixes and symbols for multiples and submultiples [13]**

| Submultiple | Prefix | Symbol | Multiple | Prefix | Symbol |
|---|---|---|---|---|---|
| $10^{-1}$ | deci | d | 10 | deca | da |
| $10^{-2}$ | centi | c | $10^{2}$ | hecto | h |
| $10^{-3}$ | milli | m | $10^{3}$ | kilo | k |
| $10^{-6}$ | micro | µ | $10^{6}$ | mega | M |
| $10^{-9}$ | nano | n | $10^{9}$ | giga | G |
| $10^{-12}$ | pico | p | $10^{12}$ | tera | T |
| $10^{-15}$ | femto | f | $10^{15}$ | peta | P |
| $10^{-18}$ | atto | a | $10^{18}$ | exa | E |

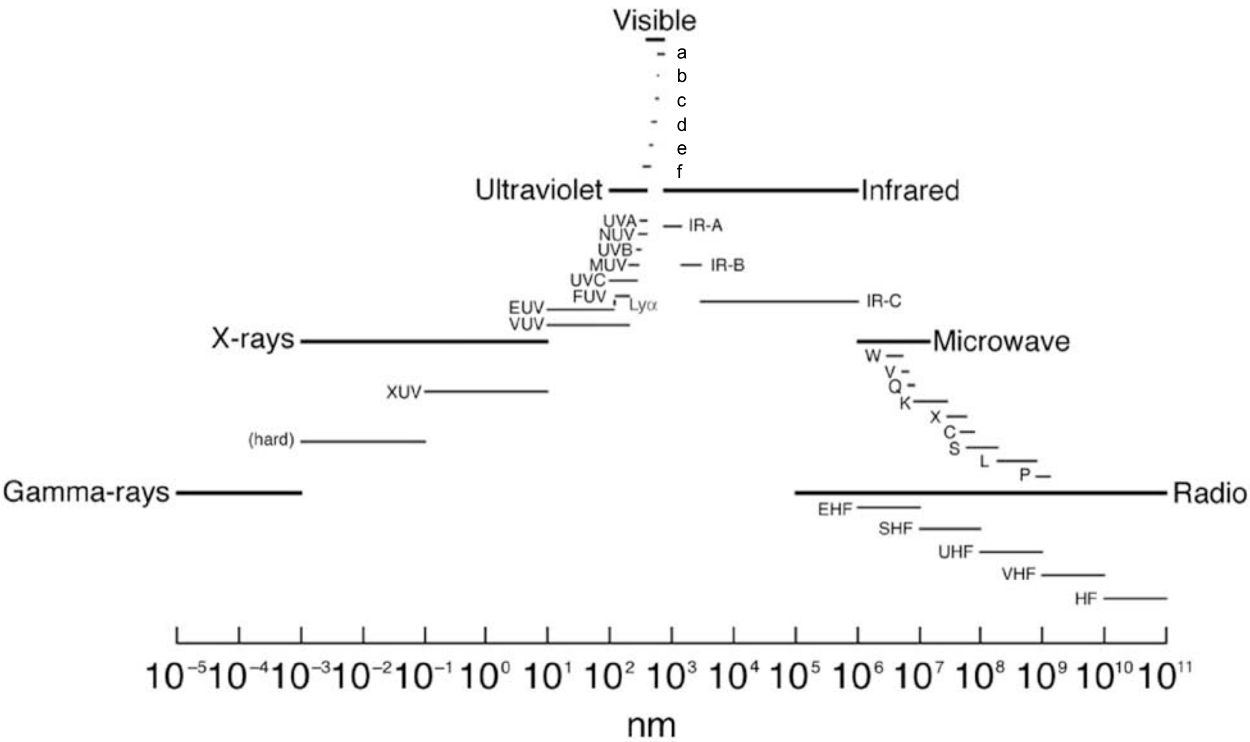


**Figure 1 — Solar irradiance spectral categories from gamma-rays through radio wavelengths. Visible light annotation is a) red, b) orange, c) yellow, d) green, e) blue, and f) purple.**

**Measurements**. For measurements, including spacecraft observations, rocket experiment datasets, and ground-based observations (including balloons), a description of the responsible agent or institution and the instrumentation used to collect and retrieve the irradiances shall be provided. The data processing algorithms, the instrument calibration techniques and heritage, the method of determining accuracy and precision, the validation and verification methodology, as well as the archival processes shall be documented.

**Reference spectra**. For reference spectra, including the mean of spectra over several solar cycles or spectra for a variety of solar activity conditions, the rationale for specifying a spectrum as a reference shall be described. The measurement set(s) used to derive the reference spectrum, the method of resolving discrepancies between multiple datasets, the data processing algorithms, the method of determining accuracy and precision, the validation and verification methodology, as well as the archival processes shall be documented.

**Empirical models**. For empirical models, including those based on one or many space- or ground-based measurement sets, or for hybrid models, a description of the rationale for developing the model, its areas of application, and the rationale for selecting proxies or indices shall be described. The measurement datasets used in the derivation, the mathematical formulation of the model, the method of resolving discrepancies between multiple datasets, the derivation algorithms, the method of determining accuracy and precision, the validation and verification methodology, as well as the archival processes shall be documented.

**Theoretical models**. For first-principles or theoretical models of solar processes, a description of the physical principles that are used as the basis of the model, the rationale for developing the model, and its areas of application shall be described. The numerical algorithms that produce solar irradiances, the mathematical formulation of the model, the method of determining accuracy and precision, the validation and verification methodology, as well as the archival processes shall be documented.

**Solar irradiance proxies or indices**. For solar irradiance proxies or indices, a description of the rationale for developing the proxy or index and its areas of application shall be described. Where appropriate, the datasets used in the derivation, the mathematical formulation of the proxy or index, the method of resolving discrepancies between multiple datasets, the derivation algorithms, the method of determining accuracy and precision, the validation and verification methodology, as well as the archival processes shall be documented.

### 7.4 Publishing

The documented solar irradiance product shall be published in an internationally-accessible journal which uses scientific or discipline-area peer review in the publication process. For any irradiance product, the published article may point to a permanent electronic archival location where the archived measurements, spectra, models, or proxies/indices can be found, accessed, or recreated by an international community.

### 7.5 Archiving

The documented and published solar irradiance product shall be archived in a method consistent with any contemporary technology that ensures long-term international accessibility.

## 8 Certification

Certification of compliance with this standard shall be achieved by complying with the criteria listed in clause 7. Self-declaration of compliance in an archival publication as part of clause 7.4 can be accomplished by using the statement “The process used for determining solar irradiances reported herein is compliant with ISO International Standard 21348: Space environment (natural and artificial) – process for determining solar irradiances." The type designation (clause 5) and the solar irradiance spectral category (clause 6) shall be identified as part of the self-declaration of compliance.

## Bibliography


[1] The International System of Units (SI), Bureau International des Poids et Mesures (BIPM) (1998).

[2] The JPL Planetary and Lunar Ephemerides, DE405/LE405 located at http://ssd.jpl.nasa.gov/iau-comm4/de405iom/.

[3] National Institute of Standards and Technology (NIST), Special Publication 330 (2001).

[4] Romero, J., N.P. Fox, and C. Fröhlich, "1st comparison of the solar and an SI radiometric scale," *Metrologia,* Vol. 28, pp. 125-128, 1990.

[5] Romero, J., N.P. Fox, and C. Fröhlich, "Improved comparison of the World Radiometric Reference and the SI radiometric scale," *Metrologia,* Vol. 32, No. 6, pp. 523-524, 1995.

[6] Crommelynck, D., A. Fichot, R.B. Lee, III, and J. Romero, "First realisation of the Space Absolute Radiometric Reference (SARR) during the ATLAS 2 flight period," *Adv. Space Res.,* Vol. 16, No. 8, pp. 17-23, 1995.

[7] E 490 – 00a, Standard Solar Constant and Zero Air Mass Solar Spectral Irradiance Tables, © ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959 (2000).

[8] Tobiska, W.K. and A.A. Nusinov, "Status of the draft ISO Solar Irradiance Standard," *Phys. Chem. Earth* (C), Vol. 25, No. 5-6, pp. 387-388, 2000.

[9] World Health Organization (WHO) *Global Solar UV Index: A Practical Guide* 2002.

[10] Joint ISO/CIE Standard: ISO 17166:1999/CIE S007-1998, Erythema Reference Action Spectrum and Standard Erythema Dose.

[11] Commision Internationale de l'Eclairage. International Lighting Vocabulary, 4th ed., Publication No. 17.4 (joint IEC/CIE publication 1987).

[12] Reference Data for Radio Engineers, Howard W. Sams & Co., Inc., ITT (1982).

[13] Wilkinson, G.A., "IAU Style Manual," Comm. 5, IAU Transactions XXB (1987).


 