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Space systems — Space environment — Simulation guidelines for radiation exposure of non-metallic materials

Systèmes spatiaux — Environnement spatial — Lignes directrices de simulation pour l'exposition aux radiations des matériaux non métalliques

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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.

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ISO 15856 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

The purpose of this International Standard is to establish guidelines for designing space systems that are highly reliable and will have long mission life spans. It is impossible to reproduce the space environment for ground testing of space system elements because of the variety and complexity of the environments and the effects on materials. The reliability of the test results depends on simulating the critical effects of the space environments for a particular mission. The main objectives of the simulation are to get test results that are satisfactory for the material behaviour in a space environment and to use existing radiation sources and methods available in the test laboratory.

Non-metallic materials used in space systems are affected by electrons and protons in a broad energy interval, electromagnetic solar radiation (both the near and the far ultraviolet radiation) and X-ray radiation. The response of non-metallic materials to radiation depends on the type of radiation and energy that defines the ionization losses density, and the radiation response of materials depends on these losses. The radiation spectrum and chemical composition of materials define the absorbed dose distribution, especially in the near-the-surface layers.

During the design of the space system, it is necessary to simulate long mission time in reasonable ground time. For this reason, it is necessary to perform accelerated radiation tests requiring the use of dose rates that may be of an order of magnitude greater than in the natural space environment. These high dose rates can influence the effects on the properties of materials. Therefore, the main requirement for the correct simulation in radiation tests involves simulating the correct effects of materials in space by considering the type, spectrum (energy), and absorbed dose rate of the radiation. Simulation is complex because the various properties of materials may respond differently to the approximations of the natural space environment used for testing. In addition, various materials may respond differently to the same simulated space radiation environment. This is valid for different classes of materials such as polymeric and semiconductor materials.

The space engineering materials in space environment are exposed not only to charged particles and electromagnetic solar radiation but also to a number of other environmental factors, e.g. atomic oxygen, deep vacuum, thermocycling, etc. Synergistic interactions can significantly increase the material degradation, i.e. decrease the time of operation, but in certain cases (like solar absorptance variation under UV and protons) synergistic interaction can decrease the degradation. These effects are not well understood and have to be simulated as far as possible. Space environment simulation at the combined exposure is a much more complicated procedure than the simulation of each factor separately. Development of corresponding standards, both for different factors and different classes of materials, will be provided in the following stages of the standard set preparation for space environment simulation at on-ground tests of materials.

This International Standard contains normative statements, recommended practices and informative parts. The term “shall” indicates a normative statement.

Space systems — Space environment — Simulation guidelines for radiation exposure of non-metallic materials

IMPORTANT — The electronic file of this document contains colours which are considered to be useful for the correct understanding of the document. Users should therefore consider printing this document using a colour printer.

1 Scope

This International Standard is the first part of a series on space environment simulation for on-ground tests of materials used in space. This International Standard covers the testing of non-metallic materials exposed to simulated space radiation. Non-metallic materials include glasses, ceramics and polymer-metal composite materials such as metal matrix composites and laminated materials. This International Standard does not cover semiconductor materials used for electronic components. The types of simulated radiation include charged particles (electrons and protons), solar ultraviolet radiation and soft X-radiation of solar flares. Synergistic interactions of the radiation environment are covered only for these natural, and some induced, environmental effects.

This International Standard outlines the recommended methodology and practices for the simulation of space radiation effects on materials. Simulation methods are used to reproduce the effects of the space radiation environment on materials that are located on surfaces of space vehicles and behind shielding.

This methodology involves:

a) the definition of the environment to be simulated using commonly accepted space environment models;

b) the definition of the material properties under test or of concern in accordance with the specificity of degradation in the space environment, satellite-specific constraints determination, temperature conditions (constant values or cycled temperature mode), mechanical stress, charging, contamination, etc.;

c) the selection of laboratory radiation simulation sources, energies and fluences that will be used to reproduce the kind of orbital radiation and mimic the orbital dose profiles;

d) the exposure techniques and procedures used to perform the laboratory simulation including contamination control, acceleration factors (dose rates), temperature control, vacuum levels and atmospheric effects.

An alternative method using standard spacecraft orbits and environments is included.

This International Standard does not specify the design of material specimens, methods of measuring the properties of materials and characteristics of radiation sources, the design of vacuum systems and the preparation of test reports. The user should select designs and measurement methods based on the state of the art and the requirements of specific space systems and contracts.

This International Standard does not include a list of hazards and safety precautions. The users are responsible for providing safe conditions based on national and local regulations.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60544-2, *Guide for determining the effects of ionizing radiation on insulating materials — Part 2: Procedures for irradiation and test*

ASTM E490, *Standard Solar Constant and Zero Air Mass Solar Spectral Irradiance Tables*

ASTM E512, *Standard Practice for Combined, Simulated Space Environment Testing of Thermal Control Materials with Electromagnetic and Particulate Radiation*

3 Terms, definitions, abbreviated terms and acronyms

3.1 Terms and definitions

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

3.1.1
absorbed dose
D
amount of energy imparted by ionizing radiation per unit mass of irradiated matter

NOTE 1 The quotient of $\mathrm{d}\bar{\varepsilon}$ by $\mathrm{d}m$, where $\mathrm{d}\bar{\varepsilon}$ is the mean energy imparted by ionizing radiation to matter of mass $\mathrm{d}m$, is

$$D = \frac{\mathrm{d}\bar{\varepsilon}}{\mathrm{d}m}$$

NOTE 2 The special name of the unit for absorbed dose is the gray (Gy). 1 Gy = 1 J·kg^{-1}.

3.1.2
acceleration factor
ratio of dose rate between simulation and expectation at space application for the same type of radiation

3.1.3
bremsstrahlung
brake radiation
photon radiation, continuously distributed in energy up to the energy of the incident particle radiation, emitted from a material due to deceleration of incident particle radiation within the material, mainly due to electrons

3.1.4
depth distribution criterion of absorbed dose
ratio of the exponent index, μ, of the absorbed dose depth profile curve to the material density, ρ

NOTE The depth distribution criterion of absorbed dose is measured in square centimetres per gram.

3.1.5
depth dose profile
distribution of the absorbed dose through the depth of material

3.1.6
energy fluence
total energy of ionizing radiation per unit area of the irradiated surface

NOTE Energy fluence is measured in joules per square metre.

3.1.7
galactic cosmic rays
GCR
high-energy-charged particle fluxes penetrating the heliosphere from local interstellar space

[ISO 15390, definition 2.1]

3.1.8
heliosphere
region surrounding the sun where the solar wind dominates the interstellar medium

NOTE Also known as solar cavity.

3.1.9
ionizing radiation
any type of radiation consisting of charged particles or uncharged particles or both, that, as a result of physical interaction, creates ions of opposite signs by either primary or secondary processes

NOTE Charged particles could be positive or negative electrons, protons or other heavy ions, and uncharged particles could be X-rays, gamma rays, or neutrons.

3.1.10
linear energy transfer
LET
energy delivered by a charged particle passing through a substance and locally absorbed per unit length of path

NOTE It is measured in joules per metre. Other dimensions are $keV{\cdot}\mu m^{-1}$, $J{\cdot}m^2{\cdot}kg^{-1}$, $MeV{\cdot}cm^2{\cdot}g^{-1}$, $MeV{\cdot}cm^2{\cdot}mg^{-1}$.

3.1.11
mean free path
average distance that a subatomic particle, ion, atom or molecule travels between successive collisions with ions, atoms or molecules

3.1.12
natural space environment
environment that exists in space without a spacecraft system present

NOTE This includes radiation, vacuum, residual atmosphere, plasmas, magnetic fields and meteoroids.

3.1.13
near ultraviolet radiation
NUV radiation
solar electromagnetic radiation with a wavelength in the range of 300 nm to 400 nm

3.1.14
radiation action measure
energetic characteristic of radiation action on a material

NOTE The radiation action measure for non-metallic materials is an absorbed dose or energy fluence.

3.1.15
radiation belt
electrons and protons trapped by the geomagnetic (planetary magnetic) field

3.1.16
radiation scale effect
dependence of the material degradation on the thickness ratio of irradiated and unirradiated layers

3.1.17
surface properties
properties of a material which are defined by the physico-chemical and morphological structure of its surface

NOTE The depth or thickness that constitutes surface properties depends upon the type of material and particular property.

3.1.18
synchrotron radiation
continuous radiation created by the acceleration of relativistic charged particles, as in a synchrotron or storage ring

NOTE Synchrotron radiation is a practical energy source of photons.

3.1.19
volume properties
bulk properties
properties that are determined by characteristics averaged through the volume of a product

3.1.20
irradiance
⟨at a point on a surface⟩ quotient of the radiant flux incident on an element of the surface containing the point, by the area of that element

3.1.21
vacuum ultraviolet radiation
VUV radiation
solar electromagnetic radiation with a wavelength in the range from 10 nm to 200 nm

3.1.22
X-rays
irradiances with a wavelength in the range from 0,001 nm and 10 nm

3.2 Abbreviated terms and acronyms

Al	aluminium
ASTM	(now ASTM International) American Society for Testing and Materials
ECSS	European Cooperation for Space Standardization
ESA	European Space Agency
EUV	extreme ultraviolet
FEP	fluorinated ethylene propylene
VUV	vacuum ultraviolet
GCR	galactic cosmic rays
GEO	Geosynchronous orbit
GLON	GLONASS navigation spacecraft (Russian Federation)
GOST R	Federal Agency on Technical Regulating and Metrology (Russian Federation)
GPS	Global Positioning Satellite (U.S.A.)
HEO	highly elliptical orbit

ISS International Space Station

LEO low Earth orbit

LET linear energy transfer

MeV megaelectronvolt

Mg magnesium

MUV middle ultraviolet

NUV near ultraviolet

POL Standard polar orbit

PTFE polytetrafluoroethylene

4 Space environment radiation characteristics

4.1 Sources of radiation in space

The main sources of radiation in space are galactic and solar particle radiation (solar wind), solar X-radiation in the 1 nm to 10 nm wavelength band, vacuum ultraviolet radiation and trapped charged particles of low energy in radiation belts around the planets (e.g. Earth, Jupiter and Saturn).

4.2 Radiation levels for Earth orbits

4.2.1 General

The specified radiation levels for the various standard orbits are based on generally accepted, published models that are, in turn, based on measurements. Work is in progress for improving and standardizing the models. Space Environment Information System (SPENVIS) provides standardized access to models of the hazardous space environment through the following website: http:/www.spenvis.oma.be/spenvis/.

4.2.2 Electron irradiation

The electron irradiation environment is based on the best available model to date, the AE-8 model. The AE-8 model describes spectra of electrons with minimal energy 40 keV (see Clause A.1 and Reference [23]).

There are no similar models for lower-energy electrons. Energy characteristics of low-energy particles for a geosynchronous orbit are presented in References [25] and [28].

For the LEO and POL orbits, the energy ranges are 40 keV to 5 MeV for electrons. For the GEO, GLON and HEO orbits, the energy ranges are 1 keV to 5 MeV for electrons.

4.2.3 Proton irradiation

The proton irradiation environment is based on the best AP-8 model available now. The AP-8 model describes spectra of protons with minimal energy 100 keV (see Clause A.1 and Reference [24]).

There are no similar models for low-energy protons. Energy characteristics of such particles for a geosynchronous orbit are presented in Reference [26].

For the LEO (ISS) and POL orbits, the energy ranges are 100 keV to 200 MeV for protons. For the GEO, GLON and HEO orbits, the energy ranges are 1 keV to 100 MeV for protons.

4.2.4 X-radiation

The main part of the solar X-ray radiation in the energy range of 0,1 keV to 10 keV corresponds to the solar flares. See Reference [29]. The predominant energy contribution comes from photons with energies between 1 keV and 3 keV.

4.2.5 Bremsstrahlung (brake radiation)

Bremsstrahlung is produced from the deceleration of particulate radiation inside matter. Bremsstrahlung contributes to the radiation damage in materials with thicknesses greater than several grams per square centimetre or in shielded materials.

4.2.6 Ultraviolet radiation

Solar spectral irradiances in the VUV and NUV are specified in ASTM E490.

Irradiance of the VUV in low Earth orbits is about 0,1 W·m^{-2} or 0,007 % of the total solar electromagnetic irradiance. Irradiance of the NUV for the same conditions is about 118 W·m^{-2} or 8,7 % of the total solar electromagnetic irradiance.

The VUV energy spectrum with wavelength lower than 50 nm is specified in ASTM E512.

4.3 Methods for charged particle and photon irradiation

Use the dose and energy fluence calculation made for a typical mission (for specific environmental conditions and place of the material on the spacecraft, taking into account all the shielding effects). Examples of the most commonly used codes are presented in Clause A2.

An alternative method to obtain such information is based on the standard spacecraft orbits and environments (see Clause 8).

Take into account that the contribution of each type of space radiation into the total absorbed dose depends on the shielding depth (see, for example, Table A.1). Sometimes the space radiation (i.e. Bremsstrahlung, high-energy electrons) may be simulated by ^{60}Co gamma rays (see References [14], [15] and [18] for simulation methods). See ASTM E512 and Reference [21] for UV radiation simulation methods.

5 Properties of spacecraft materials

5.1 General

Various regions of radiation spectra are responsible for the degradation of different properties when materials are irradiated in the space environment. The properties are divided into surface properties and volume (bulk) properties.

5.2 Surface properties

Surface properties are determined by the nature of the material at or near the surface. The surface of a material is defined as that part of the material exposed directly to the space environment in the spacecraft application. “Near the surface” is considered to be approximately 4 mg·cm^{-2} or less (see Figures B.1 to B.3). The surface properties include surface electrical conductivity, optical properties (reflectance, absorptance, emittance), adhesive properties (adhesion, adhesive strength), tribotechnical characteristics (coefficient of friction, friction durability, wear resistance) and surface electrical charging.

The low-energy part of the corpuscular radiation spectrum (no more than 50 keV for electrons and 1,0 MeV for protons) and VUV are primarily responsible for the degradation of surface properties.

The whole spectrum of the solar X-radiation and UV affect the surface properties of non-metallic materials. Most materials have a high absorption of VUV, and some materials will be affected by near UV-radiation depending on absorption characteristics and energies required to break molecular bonds.