

BS EN 16603-10-12:2014



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Space engineering — Method for the calculation of radiation received and its effects, and a policy for design margins

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee ACE/68, Space systems and operations.

A list of organizations represented on this committee can be obtained on request to its secretary.

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English version

Space engineering - Method for the calculation of radiation received and its effects, and a policy for design margins

Ingénierie spatiale - Procédé pour le calcul de rayonnement reçue et ses effets, et une politique de marges de conception

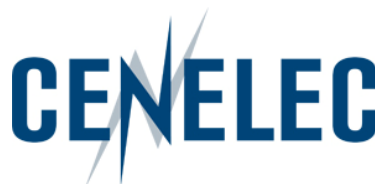
Raumfahrttechnik - Methoden zur Berechnung von Strahlungsdosis, -wirkung und Leitfaden für Toleranzen im Entwurf

This European Standard was approved by CEN on 9 February 2014.

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Foreword

This document (EN 16603-10-12:2014) has been prepared by Technical Committee CEN/CLC/TC 5 "Space", the secretariat of which is held by DIN.

This standard (EN 16603-10-12:2014) originates from ECSS-E-ST-10-12C.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2015, and conflicting national standards shall be withdrawn at the latest by January 2015.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been developed to cover specifically space systems and has therefore precedence over any EN covering the same scope but with a wider domain of applicability (e.g. : aerospace).

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1

Scope

This standard is a part of the System Engineering branch of the ECSS engineering standards and covers the methods for the calculation of radiation received and its effects, and a policy for design margins. Both natural and man-made sources of radiation (*e.g.* radioisotope thermoelectric generators, or RTGs) are considered in the standard.

This standard applies to the evaluation of radiation effects on all space systems.

This standard applies to all product types which exist or operate in space, as well as to crews of manned space missions. The standard aims to implement a space system engineering process that ensures common understanding by participants in the development and operation process (including Agencies, customers, suppliers, and developers) and use of common methods in evaluation of radiation effects.

This standard is complemented by ECSS-E-HB-10-12 “Radiation received and its effects and margin policy handbook”.

This standard may be tailored for the specific characteristic and constraints of a space project in conformance with ECSS-S-ST-00.

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Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revision of any of these publications do not apply. However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the more recent editions of the normative documents indicated below. For undated references, the latest edition of the publication referred to applies.

EN reference	Reference in text	Title
EN 16601-00-01	ECSS-S-ST-00-01	ECSS system – Glossary of terms
EN 16603-10-04	ECSS-E-ST-10-04	Space engineering – Space environment
EN 16603-10-09	ECSS-E-ST-10-09	Space engineering – Reference coordinate system
EN 16602-30	ECSS-Q-ST-30	Space product assurance – Dependability
EN 16602-60	ECSS-Q-ST-60	Space product assurance – Electrical, electronic and electromechanical (EEE) components

Terms, definitions and abbreviated terms

3.1 Terms from other standards

For the purpose of this Standard, the terms and definitions from ECSS-ST-00-01 apply, in particular for the following terms:

derating
subsystem

3.2 Terms specific to the present standard

3.2.1 absorbed dose

energy absorbed locally per unit mass as a result of radiation exposure which is transferred through ionisation, displacement damage and excitation and is the sum of the ionising dose and non-ionising dose

NOTE 1 It is normally represented by D , and in accordance with the definition, it can be calculated as the quotient of the energy imparted due to radiation in the matter in a volume element and the mass of the matter in that volume element. It is measured in units of gray, Gy ($1 \text{ Gy} = 1 \text{ J kg}^{-1} (= 100 \text{ rad})$).

NOTE 2 The absorbed dose is the basic physical quantity that measures radiation exposure.

3.2.2 air kerma

energy of charged particles released by photons per unit mass of dry air

NOTE It is normally represented by K .

3.2.3 ambient dose equivalent, $H^*(d)$

dose at a point equivalent to the one produced by the corresponding expanded and aligned radiation field in the ICRU sphere at a specific depth on the radius opposing the direction of the aligned field

NOTE 1 It is normally represented by $H^*(d)$, where d is the specific depth used in its definition, in mm.

NOTE 2 $H^*(d)$ is relevant to strongly penetrating radiation. The value normally used is 10 mm,

but dose equivalent at other depths can be used when the dose equivalent at 10 mm provides an unacceptable underestimate of the effective dose.

3.2.4 bremsstrahlung

high energy electromagnetic radiation in the X-ray energy range emitted by charged particles slowing down by scattering off atomic nuclei

NOTE The primary particle is ultimately absorbed while the bremsstrahlung can be highly penetrating. In space the most common source of bremsstrahlung is electron scattering.

3.2.5 component

device that performs a function and consists of one or more elements joined together and which cannot be disassembled without destruction

3.2.6 continuous slowing down approximation range (CSDA)

integral pathlength travelled by charged particles in a material assuming no stochastic variations between different particles of the same energy, and no angular deflections of the particles

3.2.7 COTS

commercial electronic component readily available off-the-shelf, and not manufactured, inspected or tested in accordance with military or space standards

3.2.8 critical charge

minimum amount of charge collected at a sensitive node due to a charged particle strike that results in a SEE

3.2.9 cross-section

<single event phenomena> probability of a single event effect occurring per unit incident particle fluence

NOTE This is experimentally measured as the number of events recorded per unit fluence.

3.2.10 cross-section

<nuclear or electromagnetic physics> probability of a particle interaction per unit incident particle fluence

NOTE It is sometimes referred to as the *microscopic cross-section*. Other related definition is the macroscopic cross section, defines as the probability of an interaction per unit path-length of the particle in a material.

3.2.11 directional dose equivalent

dose at a point equivalent to the one produced by the corresponding expanded radiation field in the ICRU sphere at a specific depth d on a radius on a specified direction

NOTE 1 It is normally expressed as $H'(d, \Omega)$, where d is the specific depth used in its definition, in mm, and Ω is the direction.

NOTE 2 $H'(d, \Omega)$, is relevant to weakly-penetrating radiation where a reference depth of 0,07 mm is usually used and the quantity denoted $H'(0,07, \Omega)$.

3.2.12 displacement damage

crystal structure damage caused when particles lose energy by elastic or inelastic collisions in a material

3.2.13 dose

quantity of radiation delivered at a position

NOTE 1 In its broadest sense this can include the flux of particles, but in the context of space energetic particle radiation effects, it usually refers to the energy absorbed locally per unit mass as a result of radiation exposure.

NOTE 2 If “dose” is used unqualified, it refers to both ionising and non-ionising dose. Non-ionising dose can be quantified either through energy deposition via displacement damage or damage-equivalent fluence (see Clause 8).

3.2.14 dose equivalent

absorbed dose at a point in tissue which is weighted by quality factors which are related to the LET distribution of the radiation at that point

3.2.15 dose rate

rate at which radiation is delivered per unit time

3.2.16 effective dose

sum of the equivalent doses for all irradiated tissues or organs, each weighted by its own value of tissue weighting factor

NOTE 1 It is normally represented by E , and in accordance with the definition it is calculated with the equation below, and the w_T is specified in the ICRP-92 standard [RDH.22]:

$$E = \sum w_T \cdot H_T \quad (1)$$

For further discussion on E , see ECSS-E-HB-10-12 Section 10.2.2.

NOTE 2 Effective dose, like organ equivalent dose, is measured in units of sievert, Sv. Occasionally this use of the same unit for different quantities can give rise to confusion.

3.2.17 energetic particle

particle which, in the context of space systems radiation effects, can penetrate outer surfaces of spacecraft

3.2.18 equivalent dose

See 3.2.41 (organ equivalent dose)

3.2.19 equivalent fluence

quantity which represents the damage at different energies and from different species by a fluence of monoenergetic particles of a single species

NOTE 1 These are usually derived through testing.

NOTE 2 Damage coefficients are used to scale the effect caused by particles to the damage caused by a standard particle and energy.

3.2.20 extrapolated range

range determined by extrapolating the line of maximum gradient in the intensity curve until it reaches zero intensity

3.2.21 Firsov scattering

the reflection of fast ions from a dense medium at glancing angles

NOTE See references [2].

3.2.22 fluence

time-integration of flux

NOTE It is normally represented by Φ .

3.2.23 flux

<unidirectional incident particles> number of particles crossing a surface at right angles to the particle direction, per unit area per unit time

3.2.24 flux

<arbitrary angular distributions> number of particles crossing a sphere of unit cross-sectional area (i.e. of radius $1/\sqrt{\pi}$) per unit time

NOTE 1 For arbitrary angular distributions, it is normally known as omnidirectional flux.

NOTE 2 Flux is often expressed in “integral form” as particles per unit time (e.g. electrons $\text{cm}^{-2} \text{s}^{-1}$) above a certain energy threshold.

NOTE 3 The directional flux is the differential with respect to solid angle (e.g. particles- cm^{-2} steradian $^{-1}\text{s}^{-1}$) while the “differential” flux is

differential with respect to energy (e.g. particles-cm⁻²MeV⁻¹s⁻¹). In some cases fluxes are treated as a differential with respect to linear energy transfer rather than energy.

3.2.25 ICRU sphere

sphere of 30 cm diameter made of ICRU soft tissue

NOTE This definition is provided by the International Commission of Radiation Units and Measurements Report 33 [12].

3.2.26 ICRU Soft Tissue

tissue equivalent material with a density of 1 g/cm³ and a mass composition of 76,2 % oxygen, 11,1 % carbon, 10,1 % hydrogen and 2,6 % nitrogen.

NOTE This definition is provided in the ICRU Report 33 [12].

3.2.27 ionising dose

amount of energy per unit mass transferred by particles to a target material in the form of ionisation and excitation

3.2.28 ionising radiation

transfer of energy by means of particles where the particle has sufficient energy to remove electrons, or undergo elastic or inelastic interactions with nuclei (including displacement of atoms), and in the context of this standard includes photons in the X-ray energy band and above

3.2.29 isotropic

property of a distribution of particles where the flux is constant over all directions

3.2.30 L or L-shell

parameter of the geomagnetic field often used to describe positions in near-Earth space

NOTE L or L-shell has a complicated derivation based on an invariant of the motion of charged particles in the terrestrial magnetic field. However it is useful in defining plasma regimes within the magnetosphere because, for a dipole magnetic field, it is equal to the geocentric altitude in Earth-radii of the local magnetic field line where it crosses the equator.

3.2.31 linear energy transfer (LET)

rate of energy deposited through ionisation from a slowing energetic particle with distance travelled in matter, the energy being imparted to the material

NOTE 1 LET is normally used to describe the ionisation track caused due to the passage of an ion. LET

is material dependent and is also a function of particle energy and charge. For ions involved in space radiation effects, it increases with decreasing energy (it also increases at high energies, beyond the minimum ionising energy). LET allows different ions to be considered together by simply representing the ion environment as the summation of the fluxes of all ions as functions of their LETs. This simplifies single-event upset calculation. The rate of energy loss of a particle, which also includes emitted secondary radiations, is the stopping power.

NOTE 2 LET is not equal to (but is often approximated to) particle electronic stopping power, which is the energy loss due to ionisation and excitation per unit pathlength.

3.2.32 LET Threshold

minimum LET that a particle should have to cause a SEE in a circuit when going through a device sensitive volume

3.2.33 margin

factor or difference between the design environment specification for a device or product and the environment at which unacceptable behaviour occurs

3.2.34 mean organ absorbed dose

energy absorbed by an organ due to ionising radiation divided by its mass

NOTE It is normally represented by DT, and in accordance with the definition, it is calculated with the equation (35) in ECSS-E-HB-10-12 Section 10.2.2. The unit is the gray (Gy), being $1 \text{ Gy} = 1 \text{ joule / kg}$.

3.2.35 mean range

integral pathlength travelled by particles in a material after which the intensity is reduced by a factor of $e \approx 2,7183$

NOTE In accordance with the above definition, it is not the range at which all particles are stopped.

3.2.36 multiple bit upset (MBU)

set of bits corrupted in a digital element that have been caused by direct ionisation from a single traversing particle or by recoiling nuclei and/or secondary products from a nuclear interaction

NOTE MCU and SMU are special cases of MBU.

3.2.37 multiple cell upset (MCU)

set of physically adjacent bits corrupted in a digital element that have been caused by direct ionisation from a single traversing particle or by recoiling nuclei from a nuclear interaction

3.2.38 (total) non-ionising dose, (T)NID, or non-ionising energy loss (NIEL) dose

energy absorption per unit mass of material which results in damage to the lattice structure of solids through displacement of atoms

NOTE Although the SI unit of TNID or NIEL dose is the gray (see definition 3.2.34), for spacecraft radiation effects, MeV/g(material) is more commonly used in order to avoid confusion with ionising energy deposition, *e.g.* MeV/g(Si) for TNID in silicon.

3.2.39 NIEL or NIEL rate or NIEL coefficient

rate of energy loss in a material by a particle due to displacement damage per unit pathlength

3.2.40 omnidirectional flux

scalar integral of the flux over all directions

NOTE This implies that no consideration is taken of the directional distribution of the particles which can be non-isotropic. The flux at a point is the number of particles crossing a sphere of unit cross-sectional surface area (i.e. of radius $1/\sqrt{\pi}$) per unit time. An omnidirectional flux is not to be confused with an isotropic flux.

3.2.41 organ equivalent dose

sum of each contribution of the absorbed dose by a tissue or an organ exposed to several radiation types, weighted by the each radiation weighting factor for the radiations impinging on the body

NOTE 1 The organ equivalent dose, an ICRP-60 [11] defined quantity, is normally represented by H_T , and usually shortened to **equivalent dose**. In accordance with the definition, it is calculated with the equation below (for further discussion, see ECSS-E-HB-10-12 Section 10.2.2):

$$H_T = \sum w_R \cdot D_{T,R} \quad (2)$$

NOTE 2 The organ equivalent dose is measured in units of sievert, Sv, where $1 \text{ Sv} = 1 \text{ J/kg}$. The unit rem (roentgen equivalent man) is still used, where $1 \text{ Sv} = 100 \text{ rem}$.

3.2.42 personal dose equivalent (individual dose equivalent)

dose equivalent in ICRU soft tissue at a depth in the body

NOTE 1 The personal dose equivalent, and ICRU quantity, is normally represented by $H_p(d)$ for strongly penetrating radiation at a depth d in millimetres that is appropriate for strongly penetrating radiation. A reference depth of 10 mm is usually used. It varies both as a function of individuals and location and is appropriate for organs and tissues deeply situated in the body.

NOTE 2 It is normally represented by $H_s(d)$ for weakly penetrating radiation (superficial) at a depth d in millimetres that is appropriate for weakly penetrating radiation. A reference depth of 0,07 mm is usually used. It varies both as a function of individuals and location and is appropriate for superficial organs and tissues which are going to be irradiated by both weakly and strongly penetrating radiation.

3.2.43 plasma

partly or wholly ionised gas whose particles exhibit collective response to magnetic or electric fields

NOTE The collective motion is brought about by the electrostatic Coulomb force between charged particles. This causes the particles to rearrange themselves to counteract electric fields within a distance of the order of the Debye length. On spatial scales larger than the Debye length plasmas are electrically neutral.

3.2.44 projected range

average depth of penetration of a particle measured along the initial direction of the particle

3.2.45 quality factor

factor accounting for the different biological efficiencies of ionising radiation with different LET, and used to convert the absorbed dose to operational parameters (ambient dose equivalent, directional dose equivalent and personal dose equivalent)

NOTE 1 Quality factor, normally represented by Q , are used (rather than radiation or tissue weighting factors) to convert the absorbed dose to dose equivalent quantities described above (ambient dose equivalent, directional dose equivalent and personal dose equivalent). Its actual values are given by ICRP-60 [11] (see 11.2.3.2).

NOTE 2 Prior to ICRP-60 [11], quality factors were synonymous to radiation weighting factors.

3.2.46 radiation

transfer of energy by means of a particle (including photons)

NOTE In the context of this Standard, electromagnetic radiation below the X-ray band is excluded. This therefore excludes UV, visible, thermal, microwave and radiowave radiation.

3.2.47 radiation design margin (RDM)

<cumulative process> ratio of the radiation tolerance or capability of the component, system or protection limit for astronaut, to the predicted radiation environment for the mission or phase of the mission

NOTE The component tolerance or capability, above which its performance becomes non-compliant, is project-defined.

3.2.48 radiation design margin (RDM)

<non-destructive single event> ratio of the design SEE tolerance to the predicted SEE rate for the environment

NOTE The design SSE tolerance is the acceptable SEE rate which the equipment or mission can experience while still meeting the equipment reliability and availability requirements.

3.2.49 radiation design margin (RDM)

<destructive single event> ratio of the acceptable probability of component failure by the SEE mechanism to the calculated probability of failure

NOTE the acceptable probability of component failure is based on the equipment reliability and availability specifications.

3.2.50 radiation design margin (RDM)

<biological effect> ratio of the protection limits defined by the project for the mission to the predicted exposure for the crew

3.2.51 radiation weighting factor

factor accounting for the different levels of radiation effects in biological material for different radiations at the same absorbed dose

NOTE It is normally represented by w_R . Its value is defined by ICRP (see clause 11.2.2.2).

3.2.52 relative biological effectiveness (RBE)

inverse ratio of the absorbed dose from one radiation type to that of a reference radiation that produces the same radiation effect

NOTE 1 The radiation type is usually ^{60}Co or 200-250 keV X-rays.

NOTE 2 In contrast to the weighting or quality factors, RBE is an empirically founded measurable quantity. For additional information on RBE, see ECSS-E-HB-10-12 Section 10.2.2.

3.2.53 sensitive volume (SV)

charge collection region of a device

3.2.54 single event burnout (SEB)

destructive triggering of a vertical n-channel transistor or power NPN transistor accompanied by regenerative feedback

3.2.55 single event dielectric rupture (SEDR)

formation of a conducting path triggered by a single ionising particle in a high-field region of a dielectric

NOTE For example, in linear devices, or in FPGAs.

3.2.56 single event disturb (SED)

momentary voltage excursion (voltage spike) at a node in an integrated circuit, originally formed by the electric field separation of the charge generated by an ion passing through or near a junction

NOTE SED is similar to SET, but used to refer to such events in digital microelectronics.

3.2.57 single event effect (SEE)

effect caused either by direct ionisation from a single traversing particle or by recoiling nuclei emitted from a nuclear interaction

3.2.58 single event functional interrupt (SEFI)

interrupt caused by a single particle strike which leads to a temporary non-functionality (or interruption of normal operation) of the affected device

3.2.59 single event gate rupture (SEGR)

formation of a conducting path triggered by a single ionising particle in a high-field region of a gate oxide

3.2.60 single event hard error (SEHE)

unalterable change of state associated with semi-permanent damage to a memory cell from a single ion track

3.2.61 single event latch-up (SEL)

potentially destructive triggering of a parasitic PNPN thyristor structure in a device

3.2.62 single event snapback (SESB)

event that occurs when the parasitic bipolar transistor that exists between the drain and source of a MOS transistor amplifies the avalanche current that results from a heavy ion

3.2.63 single event transient (SET)

momentary voltage excursion (voltage spike) at a node in an integrated circuit, originally formed by the electric field separation of the charge generated by an ion passing through or near a junction

3.2.64 single event upset (SEU)

single bit flip in a digital element that has been caused either by direct ionisation from a traversing particle or by recoiling nuclei emitted from a nuclear interaction

3.2.65 single word multiple bit upset (SMU)

set of logically adjacent bits corrupted in a digital element caused by direct ionisation from a single traversing particle or by recoiling nuclei from a nuclear interaction

NOTE SMU are multiple bit upsets within a single data word.

3.2.66 solar energetic particle event (SEPE)

emission of energetic protons or heavier nuclei from the Sun within a short space of time (hours to days) leading to particle flux enhancement

NOTE SEPE are usually associated with solar flares (with accompanying photon emission in optical, UV and X-Ray) or coronal mass ejections.

3.2.67 stopping power

average rate of energy-loss by a given particle per unit pathlength traversed through a given material

NOTE The following are consequence of the above definition:

- **collision stopping power:** (electrons and positrons) average energy loss per unit pathlength due to inelastic Coulomb collisions with bound atomic electrons resulting in ionisation and excitation.
- **radiative stopping power:** (electrons and positrons) average energy loss power unit pathlength due to emission of bremsstrahlung in the electric field of the atomic nucleus and of the atomic electrons.
- **electronic stopping power:** (particles heavier than electrons) average energy loss

per unit pathlength due to inelastic Coulomb collisions with atomic electrons resulting in ionisation and excitation.

- **nuclear stopping power:** (particles heavier than electrons) average energy loss per unit pathlength due to inelastic and elastic Coulomb collisions with atomic nuclei in the material.

3.2.68 tissue weighting factor

factor that accounts for the different sensitivity of organs or tissue in expressing radiation effects to the same equivalent dose

NOTE It is normally represented by w_T , and its actual values are defined by ICRP (see clause 11.2.2.3).

3.2.69 total ionising dose

energy deposited per unit mass of material as a result of ionisation

NOTE The SI unit is the gray (see definition 3.2.34). However, the deprecated unit rad (radiation absorbed dose) is still used frequently (1 rad = 1 cGy).

3.3 Abbreviated terms

For the purpose of this Standard, the abbreviated terms from ECSS-S-ST-00-01 and the following apply:

Abbreviation	Meaning
ADC	analogue-to-digital converter
ALARA	as low as reasonably achievable
APS	active pixel sensor
ASIC	application specific integrated circuit
BFO	blood-forming organ
BiCMOS	bipolar complementary metal oxide semiconductor
BJT	bipolar junction transistor
BRYNTRN	Baryon transport model
BTE	Boltzmann transport equation
CAM/CAF	computerized anatomical man/male / computerized anatomical female
CCD	charge coupled device
CCE	charge collection efficiency
CDR	critical design review

CEPXS/ONELD	One-dimensional Coupled Electron-Photon Multigroup Discrete Coordinates Code System
CERN	European Organisation for Nuclear Research
CGRO	Compton Gamma Ray Observatory
CID	charge injection device
CMOS	complementary metal oxide semiconductor
COMPTEL	CGRO Compton Telescope
COTS	commercial off-the-shelf
CREAM	Cosmic Radiation Effects and Activation Monitor (Space Shuttle experiment)
CEASE	compact environmental anomaly sensor
CREME	cosmic ray effects on microelectronics
CSA	Canadian Space Agency
CSDA	continuous slowing down approximation range
CTE	charge transfer efficiency
CTI	charge transfer inefficiency
CTR	current transfer ratio
CZT	cadmium zinc telluride (semiconductor material)
DAC	digital-to-analogue converter
DD	displacement damage
DDEF	displacement damage equivalent fluence
DDREF	dose and dose rate effectiveness factor
DNA	deoxyribonucleic acid
DOSRAD	software to predict space radiation dose at system and equipment level
DRAM	dynamic random access memory
DSP	digital signal processing
DUT	device under test
EEE	electrical and electronic engineering
EEPROM	electrically erasable programmable read only memory
EGS	Electron Gamma Shower Monte Carlo radiation transport code
ELDRS	enhanced low dose-rate sensitivity
EM	engineering model
EPIC	European Photon Imaging Camera on the ESA X-ray Multi-Mirror (XMM) mission
EPROM	erasable programmable read only memory

ESA	European Space Agency
ESABASE	engineering tool to support spacecraft mission and spacecraft platform design
ESD	electrostatic discharge
EVA	extravehicular activity
FASTRAD	sectoring analysis software for space radiation effects
FLUKA	Fluktuierende Kaskade (Fluctuating Cascade) Monte Carlo radiation transport code
FPGA	field programmable gate array
FM	flight model
GEANT	Geometry and Tracking Monte Carlo radiation transport code
GEO	geostationary Earth orbit
GOES	Geostationary Operational Environment Satellite
GRAS	Geant4 Radiation Analysis for Space
HERMES	3-D Monte Carlo radiation transport simulation code developed by Institut für Kernphysik Forschungszentrum Jülich GmbH
HETC	High Energy Transport Code
hFE	current gain of a bipolar transistor in common-emitter configuration
HPGe	high-purity germanium
HZE	particle of high atomic mass and high energy
IBIS	Imager on Board the INTEGRAL Satellite
IC	integrated circuit
ICRP	International Commission on Radiobiological Protection
ICRU	International Commission on Radiation Units and Measurements
IGBT	insulated gate bipolar transistor
IML1	International Microgravity Laboratory 1
INTEGRAL	International Gamma Ray Astrophysical Laboratory
IR	infrared
IRPP	integrated rectangular parallelepiped
IRTS	Integrated Radiation Transport Suite
ISO	Infrared Space Observatory
ISOCAM	ISO infrared Camera
ISS	International Space Station

ISSP	International Space Station Program
ITS	Integrated Tiger Series coupled electron-photon radiation transport codes
JAXA	Japan Aerospace Exploration Agency
JFET	junction field effect transistor
LDEF	Long Duration Exposure Facility
LEO	low Earth orbit
LED	light emitting diode
LET	linear energy transfer
LHI	Light Heavy Ion Transport code
LISA	Laser Interferometer Space Antenna
LNT	linear no-threshold
LOCOS	local oxidation of silicon
LWIR	long-wavelength infrared
MCP	microchannel plate
MCNP	Monte Carlo N-Particle Transport Code
MCNPX	Monte Carlo N-Particle Extended Transport Code
MCT	mercury cadmium telluride
MCU	multiple-cell upset
MEMS	micro-electromechanical structure
MEO	medium (altitude) Earth orbit
MICAP	Monte Carlo Ionization Chamber Analysis Package
MMOP	Multilateral Medical Operations Panel
MORSE	Multigroup Oak Ridge Stochastic Experiment – coupled neutron- γ -ray Monte Carlo radiation transport code
MOS	metal oxide semiconductor
MOSFET	metal oxide semiconductor field effect transistor
MRHWG	Multilateral Radiation Health Working Group
MULASSIS	Multi-Layered Shielding Simulation Software
MWIR	medium-wavelength infrared
NASA	National Aeronautics and Space Administration
NCRP	National Council on Radiation Protection and Measurements
NID	non-ionising dose (identical to TNID)
NIEL	non-ionising energy loss
NMOS	N-channel metal oxide semiconductor
NOVICE	3-D Radiation transport simulation code developed

	by Experimental and Mathematical Physics Consultants, Gaithersburg, USA
NPN	bipolar junction transistor with P-type base
NUREG	Nuclear Regulatory Commission Regulation
OMERE	Radiation environment and effects code developed by TRAD with the support of CNES
OSSE	CGRO Oriented Scintillator Spectrometer Experiment
PCB	printed circuit board
PCC	part categorization criterion
PDR	preliminary design review
PIXIE	particle-induce X-ray emission
PLL	phase-locked loop
PMOS	P-channel metal oxide semiconductor
PMT	photomultiplier tube
PNP	bipolar junction transistor with N-type base
PNPN	deliberate or parasitic thyristor-like semiconductor structure (containing four, alternating P-type and N-type regions)
PPAC	parallel plate avalanche counter
PSR	Pacific-Sierra Research Corporation
PSTAR	stopping power and range tables for protons
PWM	pulse-width modulator
RBE	relative biological effectiveness
RC	resistor-capacitor
RDM	radiation design margin
RGS	reflection grating spectrometer
RHA	radiation hardness assurance
RPP	rectangular parallelepiped
RSA	Russian Space Agency
RTG	radio-isotope thermoelectric generator
RTS	random telegraph signal
SBD	surface barrier detector
SDRAM	synchronous dynamic random access memory
SHIELDOSE	space shielding radiation dose calculations
SEB	single event burnout
SED	single event disturb
SEDR	single event dielectric rupture
SEE	single event effect

SEFI	single event functional interrupt
SEGR	single event gate rupture
SEHE	single event hard error
SEL	single event latch-up
SEPE	solar energetic particle event
SESB	single event snapback
SET	single event transient
SEU	single event upset
SMART-1	Small Mission for Advanced Research and Technology
SMU	single word multiple-bit upset
SOHO	Solar and Heliospheric Observatory
SOI	silicon-on-insulator
SOS	silicon-on-sapphire
SPE	solar particle event
SPENVIS	Space Environment Information System
SPI	Spectrometer on INTEGRAL
SRAM	static random access memory
SREM	Standard Radiation Environment Monitor
SSAT	Sector Shielding Analysis Tool
STRV	Space Technology Research Vehicle
SV	sensitive volume
SWIR	short wavelength infrared
TID	total ionising dose
TNID	total non-ionising dose
UNSCEAR	United Nation's Scientific Committee on the Effects of Atomic Radiation
USAF	United States Air Force
UV	ultraviolet
VLSI	very large scale integration
WCA	worst-case analysis
XMM	X-ray Multi Mirror Mission (also known as Newton)

4

Principles

4.1 Radiation effects

This standard is applicable to all space systems. There is no space system in which radiation effects can be neglected.

In this clause the word “component” refers not only to electronic components but also to other fundamental constituents of space hardware units and sub-systems such as solar cells, optical materials, adhesives, and polymers.

Survival and successful operation of space systems in the space radiation environment, or the surface of other solar system bodies cannot be ensured without careful consideration of the effects of radiation. A comprehensive compendium of radiation effects is provided in ECSS-E-HB-10-12 Section 3. The corresponding engineering process, including design of units and sub-systems, involves several trade-offs, one of which is radiation susceptibility. Some radiation effects can be mission limiting where they lead to a prompt or accumulated degradation which results in subsystem or system failure, or catastrophic system anomalies. Examples are damage of electronic components due to total ionising dose, or damaging interaction of a single heavy ion (thermal failure following “latch-up”). Others effects can be a source of interference, degrading the efficiency of the mission. Examples are radiation “background” in sensors or corruption of electronic memories. Biological effects are also important for manned and some other missions where biological samples are flown.

The correct evaluation of radiation effects occurs as early as possible in the design of systems, and is repeated throughout the development phase. A radiation environment specification is established and maintained as a mandatory element of any procurement actions from the start of a project (Pre-Phase A or other orbit trade-off pre-studies). The specification is specific to the mission and takes account of the timing and duration of the mission, the nominal and transfer trajectories, and activities on non-terrestrial solar system bodies, employing the methods defined in ECSS-E-ST-10-04. Upon any update to the radiation environment specification (*e.g.* as a result of orbit changes), a complete re-evaluation of the radiation effects calculations arising from this standard is performed.

In order to make a radiation effects evaluation, test data are used, both to confirm the compatibility of the component with the environment it is intended to operate in, and to provide data for quantitative analysis of the radiation effect. In general there is one effects parameter for each radiation effect. Severe engineering, schedule and cost problems can result from inadequate

anticipation of space radiation effects and preparation of the engineering options and solutions.

In some cases, knowledge about the radiation effects on a particular component type can be found in the published literature or in databases on radiation effects. It is important to use these data with extreme caution since verifying that data are relevant to the actual component being employed is often very difficult. For example in evaluating electronic components, consideration is given to:

- variations in sensitivity between manufacturers' "batches";
- variations in sensitivity within a nominally identical manufacturing "batch";
- changes in manufacturing, processes, packaging;
- correlation of measurements made on the ground and in-flight experience is far from complete.

As a consequence, and to account for accumulated uncertainties in testing procedures, component-to-component variations and environmental uncertainties, margins are usually applied to the radiation effects parameters for the particular mission. This document also seeks to provide specification for when and how to apply such margins.

Application of margins can have important effects on the engineering. Too high a level, implying a severe environment, can imply change of components (leading to increased cost or degradation of performance), application of additional shielding or even orbit changes. On the other hand, too low a margin can result in compromised mission performance or premature failure.

4.2 Radiation effects evaluation activities

Table 4-1 summarises the activities to be undertaken during a project. Effects on electrical and electronic systems, and materials are considered in terms of total ionising dose (TID), displacement damage, and single event effects (SEE). For spacecraft sensors, whether as part of the platform or payload, radiation-enhanced background levels are also considered. The user can find a general description of these radiation effects in ECSS-E-HB-10-12 Section 3. Table 4-2 provides a summary, identifying the parameters used to quantify radiation effects, units and space radiation sources which induce those effects, whilst Table 4-3 identifies the effects as a function of component technology.

Table 4-1: Stages of a project and radiation effects analyses performed

Phase	Activity
Pre-phase A	Environment specification for each mission option; Preliminary assessment of sensitivities and availability of components
A	Environment specification for baseline mission and options where they are retained for consideration Preliminary assessment of sensitivities and availability of components
B	Environment specification update; Space radiation hardness assurance requirements including detailed analysis of component requirements and identification of availability of susceptibility data; Establishment and execution of component test plan
C & D	Accurate shielding and radiation effects analysis (including component-specific analysis) ^a Consolidation of test results; augmented testing
E	Investigation of radiation effects; consideration of radiation effects in anomaly investigation; feedback to engineering groups of lessons learned including <i>e.g.</i> radiation related anomalies.
^a If mission assumptions change in this phase, such as the proposed orbit, a complete re-evaluation of the radiation environment specification is performed.	

Table 4-2: Summary of radiation effects parameters, units and examples

Effect	Parameter	Typical units	Examples	Particles
Total ionising dose (TID)	Ionising dose in material	grays (material) (Gy(material)) or rad(material) 1 Gy = 100 rad	Threshold voltage shift and leakage currents in CMOS, linear bipolar (note dose-rate sensitivity)	Electrons, protons, bremsstrahlung
Displacement damage	Displacement damage equivalent dose (total non-ionising dose) Equivalent fluence of 10 MeV protons or 1 MeV electrons	MeV/g cm ⁻²	All photonics, e.g. CCD transfer efficiency, optocoupler transfer ratio Reduction in solar cell efficiency	Protons, electrons, neutrons, ions
Single event effects from direct ionisation	Events per unit fluence from linear energy transfer (LET) spectra & cross-section versus LET	cm ² versus MeV·cm ² /mg	Memories, microprocessors. Soft errors, latch-up, burn-out, gate rupture, transients in op-amps, comparators.	Ions Z>1
Single event effects from nuclear reactions	Events per unit fluence from energy spectra & cross-section versus particle energy	cm ² versus MeV	As above	Protons, neutrons, ions
Payload-specific radiation effects	Energy-loss spectra, charge-deposition spectra charging	counts s ⁻¹ MeV ⁻¹	False count rates in detectors, false images in CCDs Gravity proof-masses	Protons, electrons, neutrons, ions, induced radioactivity (α, β±, γ)
Biological damage	Dose equivalent = Dose(tissue) x Quality Factor; equivalent dose = Dose(tissue) x radiation weighting factor; Effective dose	sieverts (Sv) or rems 1 Sv = 100 rem	DNA rupture, mutation, cell death	Ions, neutrons, protons, electrons, γ-rays, X-rays
Charging	Charge	coulombs (C)	Phantom commands from ESD	Electrons

Table 4-3: Summary of radiation effects and cross-references to other chapters
(Part 1 of 2)

Sub-system or component	Technology	Effect	ECSS-E-ST-10-12 main clause cross-reference	ECSS-E-HB-10-12 Section cross-reference
Integrated circuits	Power MOS	TID	7	6
		SEGR	9.4.1.6	8.6.2
		SEB	9.4.1.6	8.6.3
	CMOS	TID	7	6
		SEE (generally)	9	8
	Bipolar	TNID	8	7.4.2
		SEU	9.4.1.2, 9.4.1.3	8.7.1
		SET	9.4.1.7	8.7.5
		TID	7	6
	BiCMOS	TID	7	6
		TNID	8	7.4.2
		SEE (generally)	9	8
Optoelectronics and sensors (1)	SOI	TID	7	6
		SEE (generally exc. SEL)	9	8
	MEMS ^a	TID	7	6
	CCD	TNID	8	7.4.3
		TID	7	6
		Enhanced background (SEE)	10.4.2, 10.4.3, 10.4.5	9.2, 9.4
	CMOS APS	TNID	8	7.4.4
		TID	7	6
		SEE (generally)	9	8
		Enhanced background	10.4.2, 10.4.3, 10.4.5	9.2, 9.4
	Photodiodes	TNID	8	7.4.5
		TID	7	6
		SET	9.4.1.7	8.7.5
	LEDs	TNID	8	7.4.7
		TID	7	6
	laser LEDs	TNID	8	7.4.7
		TID	7	6
	Opto-couplers	TNID	8	7.4.8
		TID	7	6
		SET	9.4.1.7	8.7.5

Table 4-3: Summary of radiation effects and cross-references to other chapters
(Part 2 of 2)

Sub-system or component	Technology	Effect	ECSS-E-ST-10-12 main clause Cross-reference	ECSS-E-HB-10-12 Cross-reference
Optoelectronics and sensors (2)	γ -ray or X-ray scintillator	TNID (alkali halides) Enhanced background	8 10.4.2, 10.4.3, 10.4.4	7.4.11 9.5
	γ -ray semiconductor ^b	TNID Enhanced background	8 10.4.2, 10.4.3, 10.4.4	7.4.10 9.5
	charged particle detectors	TNID (scintillator ^c & semiconductor)	8	9.5
		Enhanced background	10.4.2, 10.4.3	9.3
		TID (scintillator ^c & semiconductors)	7	6
	microchannel plates	Enhanced background	10.4.6	9.6
	photomultiplier tubes	Enhanced background	10.4.6	9.6
	Other imaging sensors (<i>e.g.</i> InSb, InGaAs, HgCdTe, GaAs and GaAlAs)	TNID Enhanced background	8 10.4.2, 10.4.3	7 9.3
Gravity wave sensors	Enhanced background	10.4.7	9.7	
Solar cells	Cover glass & bonding materials	TID	7	6
	Cell	TNID	8	7.4.9
Non-optical materials	Crystal oscillators	TID	7	6
	polymers	TID (radiolysis)	7	6
Optical materials	silica glasses	TID	7	6
	alkali halides	TID TNID	7 8	6 7.4.11
Radiobiological effects		Early effects	11	10.3.3, 10.4.4
		Stochastic effects	11	10.3.4, 10.4.4
		Deterministic late effects	11	10.3.4, 10.4.4
^a MEMS refers to the effects on the microelectromechanical structure only. Any surrounding microelectronics are also subject to other radiation effects identified in “Integrated circuits” row				
^b See Table 8-1, “Radiation Detectors” for examples of semiconductor materials that are susceptible to γ -rays.				
^c The effect on scintillators refers primarily to the detector material registering the radiation. The electronics needed for readout can need additional radiation assessment.				