



NSAI
Standards

Irish Standard Recommendation
S.R. CEN/CLC/TR 17603-10-12:2021

Space engineering - Calculation of radiation and its effects and margin policy handbook

S.R. CEN/CLC/TR 17603-10-12:2021

Incorporating amendments/corrigenda/National Annexes issued since publication:

The National Standards Authority of Ireland (NSAI) produces the following categories of formal documents:

I.S. xxx: Irish Standard — national specification based on the consensus of an expert panel and subject to public consultation.

S.R. xxx: Standard Recommendation — recommendation based on the consensus of an expert panel and subject to public consultation.

SWiFT xxx: A rapidly developed recommendatory document based on the consensus of the participants of an NSAI workshop.

This document replaces/revises/consolidates the NSAI adoption of the document(s) indicated on the CEN/CENELEC cover/Foreword and the following National document(s):

NOTE: The date of any NSAI previous adoption may not match the date of its original CEN/CENELEC document.

This document is based on:

CEN/CLC/TR 17603-10-12:2021

Published:

2021-09-29

This document was published under the authority of the NSAI and comes into effect on:

2021-10-18

ICS number:

49.140

NOTE: If blank see CEN/CENELEC cover page

NSAI
1 Swift Square,
Northwood, Santry
Dublin 9

T +353 1 807 3800
F +353 1 807 3838
E standards@nsai.ie
W NSAI.ie

Sales:
T +353 1 857 6730
F +353 1 857 6729
W standards.ie

Údarás um Chaighdeáin Náisiúnta na hÉireann

National Foreword

S.R. CEN/CLC/TR 17603-10-12:2021 is the adopted Irish version of the European Document CEN/CLC/TR 17603-10-12:2021, Space engineering - Calculation of radiation and its effects and margin policy handbook

This document does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

For relationships with other publications refer to the NSAI web store.

Compliance with this document does not of itself confer immunity from legal obligations.

In line with international standards practice the decimal point is shown as a comma (,) throughout this document.

This page is intentionally left blank

TECHNICAL REPORT
RAPPORT TECHNIQUE
TECHNISCHER BERICHT

**CEN/CLC/TR 17603-10-
12**

September 2021

ICS 49.140

English version

**Space engineering - Calculation of radiation and its effects
and margin policy handbook**

Ingénierie spatiale - Manuel de calcul du transport des
radiations et de leurs effets, et politique des marges

Raumfahrttechnik - Handbuch zur Berechnung von
Strahlung, Strahlungseffekten und Marginregeln

This Technical Report was approved by CEN on 19 March 2021. It has been drawn up by the Technical Committee CEN/CLC/JTC 5.

CEN and CENELEC members are the national standards bodies and national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.



**CEN-CENELEC Management Centre:
Rue de la Science 23, B-1040 Brussels**

Table of contents

European Foreword	9
1 Scope	10
2 Terms, definitions and abbreviated terms	11
2.1 Terms from other documents	11
2.2 Terms specific to the present handbook	11
2.3 Abbreviated terms.....	11
3 Compendium of radiation effects.....	12
3.1 Purpose	12
3.2 Effects on electronic and electrical systems.....	14
3.2.1 Total ionising dose	14
3.2.2 Displacement damage	14
3.2.3 Single event effects.....	15
3.3 Effects on materials	16
3.4 Payload-specific radiation effects.....	16
3.5 Biological effects.....	17
3.6 Spacecraft charging.....	17
3.7 References	17
4 Margin	19
4.1 Introduction.....	19
4.1.1 Application of margins.....	19
4.2 Environment uncertainty	20
4.3 Effects parameters' uncertainty.....	21
4.3.1 Overview.....	21
4.3.2 Shielding	21
4.3.3 Ionising dose calculation	22
4.3.4 Non-ionising dose (NIEL, displacement damage).....	22
4.3.5 Single event effects.....	22
4.3.6 Effects on sensors.....	23
4.4 Testing-related uncertainties.....	23

4.4.1	Overview	23
4.4.2	Beam characteristics	23
4.4.3	Radioactive sources	23
4.4.4	Packaging	24
4.4.5	Penetration	24
4.4.6	Representativeness	24
4.5	Procurement processes and device reproducibility	24
4.6	Project management decisions	25
4.7	Relationship with derating	25
4.8	Typical design margins	25
4.9	References	25
5	Radiation shielding	26
5.1	Introduction	26
5.2	Radiation transport processes	26
5.2.1	Overview	26
5.2.2	Electrons	26
5.2.3	Protons and other heavy particles	28
5.2.4	Electromagnetic radiation – bremsstrahlung	32
5.3	Ionising dose enhancement	33
5.4	Material selection	33
5.5	Equipment design practice	33
5.5.1	Overview	33
5.5.2	The importance of layout	34
5.5.3	Add-on shielding	34
5.6	Shielding calculation methods and tools – Decision on using deterministic radiation calculations, detailed Monte Carlo simulations, or sector shielding analysis	36
5.7	Example detailed radiation transport and shielding codes	45
5.8	Uncertainties	45
5.9	References	46
6	Total ionising dose	48
6.1	Introduction	48
6.2	Definition	48
6.3	Technologies sensitive to total ionising dose	48
6.4	Total ionising dose calculation	50
6.5	Uncertainties	50

CEN/CLC/TR 17603-10-12:2021 (E)

7 Displacement damage	51
7.1 Introduction.....	51
7.2 Definition	51
7.3 Physical processes and modelling	51
7.4 Technologies susceptible to displacement damage	55
7.4.1 Overview.....	55
7.4.2 Bipolar.....	56
7.4.3 Charge-coupled devices (CCD).....	57
7.4.4 Active pixel sensors (APS).....	57
7.4.5 Photodiodes.....	58
7.4.6 Laser diodes	58
7.4.7 Light emitting diode (LED).....	58
7.4.8 Optocouplers.....	58
7.4.9 Solar cells	59
7.4.10 Germanium detectors.....	59
7.4.11 Glasses and optical components.....	60
7.5 Radiation damage assessment.....	60
7.5.1 Equivalent fluence calculation	60
7.5.2 Calculation approach	60
7.5.3 3-D Monte Carlo analysis.....	60
7.5.4 Displacement damage testing	60
7.6 NIEL rates for different particles and materials	61
7.7 Uncertainties.....	68
7.8 References	68
8 Single event effects	70
8.1 Introduction.....	70
8.2 Modelling	71
8.2.1 Overview.....	71
8.2.2 Notion of LET (for heavy ions).....	71
8.2.3 Concept of cross section.....	71
8.2.4 Concept of sensitive volume, critical charge and effective LET	72
8.3 Technologies susceptible to single event effects	73
8.4 Test methods.....	73
8.4.1 Overview.....	73
8.4.2 Heavy ion beam testing.....	73

8.4.3	Proton and neutron beam testing	74
8.4.4	Experimental measurement of SEE sensitivity	74
8.4.5	Influence of testing conditions	75
8.5	Hardness assurance	77
8.5.1	Rate prediction	77
8.5.2	Prediction of SEE rates for ions	77
8.5.3	Improvements	79
8.5.4	Method synthesis	80
8.5.5	Prediction of SEE rates of protons and neutrons	80
8.5.6	Method synthesis	82
8.5.7	Calculation toolkit	82
8.5.8	Applicable derating and mitigating techniques	82
8.5.9	Analysis at system level	82
8.6	Destructive SEE	83
8.6.1	Single event latch-up (SEL) and single event snapback (SESB)	83
8.6.2	Single event gate rupture (SEGR) and single event dielectric rupture (SEDR)	85
8.6.3	Single event burnout (SEB)	86
8.7	Non-destructive SEE	87
8.7.1	Single event upset (SEU)	87
8.7.2	Multiple-cell upset (MCU) and single word multiple-bit upset (SMU)	87
8.7.3	Single event functional interrupt (SEFI)	89
8.7.4	Single event hard error (SEHE)	90
8.7.5	Single event transient (SET) and single event disturb (SED)	91
8.8	References	92
9	Radiation-induced sensor backgrounds	96
9.1	Introduction	96
9.2	Background in ultraviolet, optical and infrared imaging sensors	96
9.3	Background in charged particle detectors	100
9.4	Background in X-ray CCDs	100
9.5	Radiation background in gamma-ray instruments	101
9.6	Photomultiplier tubes and microchannel plates	104
9.7	Radiation-induced noise in gravity-wave detectors	105
9.8	Other problems common to detectors	105
9.9	References	106
10	Effects in biological material	108
10.1	Introduction	108

CEN/CLC/TR 17603-10-12:2021 (E)

10.2	Quantities used in radiation protection work.....	108
10.2.1	Overview.....	108
10.2.2	Protection quantities.....	109
10.2.3	Operational quantities	111
10.3	Radiation effects in biological systems.....	113
10.3.1	Overview.....	113
10.3.2	Source of data.....	114
10.3.3	Early effects	114
10.3.4	Late effects	115
10.4	Radiation protection limits in space.....	117
10.4.1	Overview.....	117
10.4.2	International agreements.....	117
10.4.3	Other considerations in calculating crew exposure.....	118
10.4.4	Radiation limits used by the space agencies of the partners of the International Space Station (ISS)	118
10.5	Uncertainties.....	122
10.5.1	Overview.....	122
10.5.2	Spacecraft shielding interactions.....	122
10.5.3	The unique effects of heavy ions.....	122
10.5.4	Extrapolation from high-dose effects to low-dose effects.....	123
10.5.5	Variability in composition, space and time.....	123
10.5.6	Effects of depth-dose distribution	123
10.5.7	Influence of spaceflight environment.....	123
10.5.8	Uncertainties summary	125
10.6	References	125

Figures

Figure 1:	CSDA range of electrons in example low- and high-Z materials as a function of electron energy	27
Figure 2:	Total stopping powers for electrons in example low- and high-Z materials	28
Figure 3:	Intensity of mono-energetic protons in a beam as a function of integral pathlength,	29
Figure 4:	Projected range of protons in example low- and high-Z materials as a function of proton energy.....	30
Figure 5:	Total stopping powers for protons in example low- and high-Z materials.....	30
Figure 6:	Stopping power for electrons from collisions with atomic electrons and bremsstrahlung production, and from bremsstrahlung production alone.....	32

Figure 12: Five electric effects due to defects in the semiconductor band gap [RDE.4]	56
Figure 13: SEE initial mechanisms by direct ionisation (for heavy ions) and nuclear interactions (for protons and neutrons).....	70
Figure 22: ISOCAM images for quiet conditions (top) and during solar flare event of November 1997.....	98
Figure 23: Predicted and measured background spectra observed in OSSE instrument on Compton Gamma-Ray Observatory 419 days after launch [RDG.10].....	102
Figure 25: Relationship of quantities for radiological protection.	113

Tables

Table 1: Summary of radiation effects parameters, units and examples.....	12
Table 2: Summary of radiation effects and cross-references to other chapters (part 1 of 2)	13
Table 2: Summary of radiation effects and cross-references to other chapters (part 2 of 2)	14
Table 3: Description of physics models (part 1 of 4)	37
Table 3: Description of physics models (part 2 of 4)	38
Table 3: Description of physics models (part 3 of 4)	39
Table 3: Description of physics models (part 4 of 4)	40
Table 4: Example radiation transport simulation programs which are applicable to shielding and effects analysis.....	44
Table 5: NIEL rates for electrons incident on Si (from Summers <i>et al</i> based on Si threshold of 21 eV [RDE.11]).....	61
Table 6: NIEL rates for protons incident on Si (part 1 of 2). This is a subset of NIEL data from Huhtinen and Aarnio [RDE.12].	62
Table 6: NIEL rates for protons incident on Si (part 2 of 2). This is a subset of NIEL data from Huhtinen and Aarnio [RDE.12].	63
Table 7: NIEL rates for neutrons incident on Si (part 1 of 2). This is a subset of NIEL from Griffin <i>et al</i> [RDE.13].	64
Table 7: NIEL rates for neutrons incident on Si (part 2 of 3). These data are from Konobeyev <i>et al</i> [RDE.14].	65
Table 7: NIEL rates for neutrons incident on Si (part 3 of 3). This is a subset of NIEL from Huhtinen and Aarnio [RDE.12].	66
Table 8: NIEL rates for electrons in Si and GaAs (Akkerman <i>et al</i> [RDE.15])	67
Table 9: NIEL rates for protons in Si.....	67
Table 10: NIEL rates for protons in GaAs.	68
Table 11: Typical materials for UV, visible and IR sensors, with band-gap and electron-hole production energies (e-h production energy for MCT is based on Klein semi-empirical formula.	97
Table 12: Lifetime mortality in a population of all ages from specific cancer after exposure to low doses.....	116
Table 13: Estimates of the thresholds for deterministic effects in the adult human testes, ovaries, lens and bone marrow.	116

CEN/CLC/TR 17603-10-12:2021 (E)

Table 14: CSA career ionising radiation exposure limits.....	119
Table 15: ESA ionising radiation exposure limits.....	119
Table 16: NCRP-132 recommended RBEs.....	119
Table 17: NCRP-132 Deterministic dose limits for all ages and genders (Gy-Eq.).....	120
Table 18: NCRP-132 career ionising radiation exposure limits.....	120
Table 19: NCRP-132 career effective dose limits for age and gender specific ionising radiation exposure for 10-year careers.....	120
Table 20: JAXA short-term ionising exposure limits.....	120
Table 21: JAXA career ionising radiation exposure limits (Sv).....	121
Table 22: JAXA current career exposure limits by age and gender.....	121
Table 23: RSA short-term ionising exposure limits.....	121
Table 24: Russian career ionising radiation exposure limits.....	122

European Foreword

This document (CEN/CLC/TR 17603-10-12:2021) has been prepared by Technical Committee CEN/CLC/JTC 5 “Space”, the secretariat of which is held by DIN.

It is highlighted that this technical report does not contain any requirement but only collection of data or descriptions and guidelines about how to organize and perform the work in support of EN 16603-10-12.

This Technical report (CEN/CLC/TR 17603-10-12:2021) originates from ECSS-E-HB-10-12A.

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 prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

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

1 Scope

This handbook is a part of the System Engineering branch 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 handbook.

This handbook can be applied to the evaluation of radiation effects on all space systems.

This handbook can be applied to all product types which exist or operate in space, as well as to crews of on manned space missions.

This handbook complements to EN 16603-10-12 “Methods for the calculation of radiation received and its effects and a policy for the design margin”.

This is a free preview. Purchase the entire publication at the link below:

[Product Page](#)

-
- [Looking for additional Standards? Visit Intertek Inform Infostore](#)
 - [Learn about LexConnect, All Jurisdictions, Standards referenced in Australian legislation](#)
-