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TECHNICAL REPORT

colour inside

Process management for avionics – Atmospheric radiation effects – Part 8: Proton, electron, pion, muon, alpha-ray fluxes and single event effects in avionics electronic equipment – Awareness guidelines

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IEC TR 62396-8, which is a Technical Report, has been prepared by IEC technical committee 107: Process management for avionics.

The text of this Technical Report is based on the following documents:

Draft TR	Report on voting
107/355/DTR	107/365/RVDTR

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all the parts in the IEC 62396 series, published under the general title *Process management for avionics – Atmospheric radiation effects,* can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Atmospheric radiation can be responsible for causing single event effects (SEEs) in electronic equipment. Beside neutrons and protons, there are other atmospheric radiation sources (for example electrons, pions and muons), which are currently regarded as minor sources, which can also affect electronics in avionics and terrestrial applications. This is currently a new emerging topic with a limited amount of test data and supporting information.

This document, as part of the IEC 62396 series, provides awareness on this new emerging topic in order to inform avionics systems designers, electronic equipment manufacturers and component manufacturers and their customers of the kind of ionising radiation environment that their electronic devices can be subjected to in aircraft and the potential effects this radiation environment can have on those electronic devices.

This awareness is unavoidable due to the aggressive scaling of electronic semiconductor devices to smaller and smaller transistor feature sizes where the impact of these radiation sources can become visible or even significant in the future. For example, some evidence of muon effects has appeared in the literature, in which the impact of muons seems to be negligible at present. This document gives a comprehensive survey on the nature of these particles, atmospheric spectra, induced phenomena and possible testing facilities with their radiation sources; it also provides orientation in order to prepare avionics in the future.

PROCESS MANAGEMENT FOR AVIONICS – ATMOSPHERIC RADIATION EFFECTS –

Part 8: Proton, electron, pion, muon, alpha-ray fluxes and single event effects in avionics electronic equipment – Awareness guidelines

1 Scope

This part of IEC 62396 is intended to provide awareness and guidance with regard to the effects of small particles (that is, protons, electrons, pions and muon fluxes) and single event effects on avionics electronics used in aircraft operating at altitudes up to 60 000 feet (18 300 m). This is an emerging topic and lacks substantive supporting data. This document is intended to help aerospace or ground level electronic equipment manufacturers and designers by providing awareness guidance for this new emerging topic.

Details of the radiation environment are provided together with identification of potential problems caused as a result of the atmospheric radiation received. Appropriate methods are given for quantifying single event effect (SEE) rates in electronic components.

NOTE 1 The overall system safety methodology is usually expanded to accommodate the single event effects rates and to demonstrate the suitability of the electronics for application at the electronic component, electronic equipment and system level.

NOTE 2 For the purposes of this document the terms "electronic device" and "electronic component" are used interchangeably.

Although developed for the avionics industry, this document can be used by other industrial sectors at their discretion.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 62396-1:2016, *Process management for avionics – Atmospheric radiation effects – Part 1: Accommodation of atmospheric radiation effects via single event effects within avionics electronic equipment*

3 Terms, definitions, abbreviated terms and acronyms

For the purposes of this document, the terms, definitions, abbreviated terms and acronyms given in IEC 62396-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1 Terms and definitions

3.1.1
AND
logic gate which produces, in digital electronics, an output that is true (1) if both inputs are true (1) and an output false (0) if neither or only one input is true (1)

3.1.2
bipolar action
phenomenon whereby some electrons or holes stay in the bulk of the semiconductor and switch on the parasitic transistor to change the data states in memory elements

3.1.3
charge collection
part of electrons or holes pairs collected into storage nodes

Note 1 to entry: Electrons or holes are generated along with the trajectory of high-energy charged particles. This phenomenon is called charge deposition.

3.1.4
linear energy transfer
LET
rate of decrease with distance of the kinetic energy of an ionizing particle, due to the ionization caused by that particle

Note 1 to entry: LET describes the action of radiation into matter. It is related to stopping power which in nuclear physics is defined as the retarding force acting on charged particles, typically alpha and beta particles, due to interaction with matter, resulting in loss of particle energy.

Note 2 to entry: LET is typically quantified in units of $MeV \cdot cm^2 \cdot mg^{-1}$, to account for the density of the material through which the particle travels.

3.1.5
multi-node transient
MNT
multiple transients (SETs) produced along with a high-energy charged particle or in an area affected by bipolar action

3.1.6
negative-AND
NAND
logic gate which produces, in digital electronics, an output that is false (0) only if all its inputs are true (1) and an output true (1) if one or both inputs are false (0)

[SOURCE: IEC 62239-1:2018, 3.1.22]

3.1.7
negative-OR
NOR
logic gate which produces, in digital electronics, an output that is true (1) if both the inputs are false (0) and an output false (0) if one or both inputs are true (1)

[SOURCE: IEC 62239-1:2018, 3.1.23]

3.1.8
OR
logic gate which produces, in digital electronics, an output that is true (1) if one of both inputs is true (1) and an output false (0) if neither input is true (1)

3.1.9
soft error rate
SER
rate at which a device or system encounters or is predicted to encounter soft errors

Note 1 to entry: Usually, this is expressed as either the number of failures-in-time (FIT) or mean time between failures (MTBF). The unit adopted for quantifying failures in time is called FIT, which is equivalent to one error per billion hours of device operation. MTBF is usually given in years of device operation; to put it into perspective, one FIT equals approximately 1 000 000 000 / (24 × 365,25) = 114 077 times more than one-year MTBF.

3.1.10
radiation induced leakage current
RILC
cumulative effect of ion-induced defects in capacitors with ultra-thin oxides

Note 1 to entry: This phenomenon can be noted in floating gate memory with thin oxide layers; data is stored depending on the number of electrons in the floating gate. When a high-energy charged particle passes through the tunnel oxide between the floating gate and source-drain channel underneath, a conduction path is created along the path and stored electrons flow away, resulting in V_{th} shift or SEU.

3.1.11
(quasi-) monoenergetic neutron
neutron from a well-defined distribution of energies obtained by bombarding high-energy charged particles at a thin metallic target

Note 1 to entry: Monoenergetic neutron beams have a single narrow flux peak at a particular neutron energy. All the neutrons in the beam have energies at or close to the nominal energy.

Note 2 to entry: Quasi-monoenergetic neutron beams have a narrow flux peak at a nominal neutron energy and a tail covering a broad range of energies below the nominal energy. Typically, about half the neutrons have energy close to the nominal energy and about half are in the low-energy tail.

3.2 Abbreviated terms and acronyms

ANITA	Atmospheric-like Neutrons from thick Target
BNCT	boron neutron capture therapy
BNL	Brookhaven National Laboratory (USA)
BOX	buried oxide
BPSG	boron phosphorus silicate glass (also named borophosphosilicate glass)
CAM	content addressable memory
CEA / CVA	Atomic Energy Commission / Centre of Valduc (France)
CEA / DIF	Atomic Energy Commission / “Direction” of military applications Ile de France (France)
CMOS	complementary metal oxide semiconductor
CMOSFET	complementary metal oxide semiconductor field effect transistor
CMP	chemical mechanical polishing
CNL	Crocker Nuclear Laboratory (USA)
CNRF	Cold Neutron Research Facility
CPU	central processing unit
CYRIC	CYclotron and RadioIsotope Center (Tohoku University, Japan)
DD	displacement damage
DICE	dual interlocked storage cell
DMR	double modular redundancy
DRAM	dynamic random access memory
DUT	device under test

ECC	error correction code / error checking and correction
ECU	electronic control unit
EEPROM	electrically erasable programmable read-only memory
EMI	electro-magnetic interference
FD	fully depleted
FET	field effect transistor
FF	flip-flop
FIT	failure in time
FNL	Fast Neutron Laboratory (Tohoku University, Japan)
FPGA	field-programmable gate array
GPU	graphic processing unit
HKMG	high-k metal gate
HLA	hyper low alpha
IGBT	insulated gate bipolar transistor
INC	intra nuclear cascade
IUCF	Indiana University Cyclotron Facility (USA)
J-PARC	Japan Proton Accelerator Research Complex (Japan)
L1 / L2	level 1 / level 2 (related to microprocessor cache memories, "level 1" cache memory being usually built onto the microprocessor device itself, “level 2” cache memory being usually on a separate device or expansion card) [SOURCE: IEC TR 62396-7:2017, 3.2]
L3	level 3 (related to, “level 3” cache memory being usually built onto the CPU module or motherboard and working together with L1 and L2 cache memories for improving processing performance
LANSCE	Los Alamos National Science Center (USA)
LAMPF	Los Alamos Meson Physics Facility (USA)
LBNL	Lawrence Berkeley National Laboratory (USA)
LENS	low-energy neutron source (university-based pulsed neutron source at IUCF)
LET	linear energy transfer
MBU	multiple bit upset
MCU	multiple cell upset
MCBI	multi-coupled bipolar interaction
MF	masking factor
MNT	multi-node transient
MOSFET	metal oxide semiconductor field effect transistor
MTBF	mean time between failures
NAND	negative-AND
NIST	National Institute of Standards and Technology (USA)
NMIJ	National Metrology Institute (Japan)
NOR	negative-OR
NPL	National Physical Laboratory (UK)
NYC	New York City
PCB	printed circuit board
PD	partially depleted
PDSOI	partially depleted SOI

PLL	phase locked loop
QMN	quasi-monoenergetic
RAM	random access memory
RCNP	Research Center for Nuclear Physics (Japan)
RILC	radiation induced leakage current
ROM	read only memory
SBU	single bit upset
SEB	single event burnout
SEE	single-event effect
SEFI	single event functional interrupts
SEGR	single event gate rupture
SEL	single event latch-up
SER	soft error rate
SET	single event transient
SEU	single event upset
SIMS	secondary ion mass spectrometry
SOI	silicon on insulator
SRAM	static random access memory
SRIM	stopping and range of ions in matter (related to a collection of softwarepackages
STI	shallow trench insulator
TAMU	Texas A&M University (USA)
TID	total ionization dose
TMR	triple modular redundancy
TSL	The Svedberg Laboratory (Uppsala university, Sweden)
ULSI	ultra large scale integration

4 Technical awareness

4.1 Basic knowledge of atmospheric secondary particles

Primary cosmic rays, which are ionizing particles with extremely high energies, come from the galactic core and the sun to the atmosphere of Earth, where they generate secondary cosmic radiation. The atmospheric radiation environment under normal conditions is described in IEC 62396-1; extreme space weather conditions, which can occur at times of high solar activity, are described in IEC TR 62396-6. Here, an abbreviated description is given, based on terrestrial radiation effects in ULSI electronic components and electronic systems, see [1][1].

Primary cosmic rays in outer space consist mainly of protons. Cosmic rays are charged particles so that they twine around lines of geomagnetic or heliomagnetic forces as illustrated by Figure 1. Some are trapped by geomagnetic force to form the Van Allen radiation belt. Cosmic rays with energies less than a geomagnetic rigidity cut-off tend to be deflected before entering the atmosphere. Some are, on the other hand, attracted into geomagnetic poles along with lines of geomagnetic force sometimes accompanied by aurorae. Cosmic rays are deflected rather strongly near the equator since the lines of geomagnetic force are roughly parallel to the surface of Earth. Therefore, the strength of cosmic rays that reach the atmosphere differs depending on geomagnetic latitude.

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1 Numbers in square brackets refer to the Bibliography.

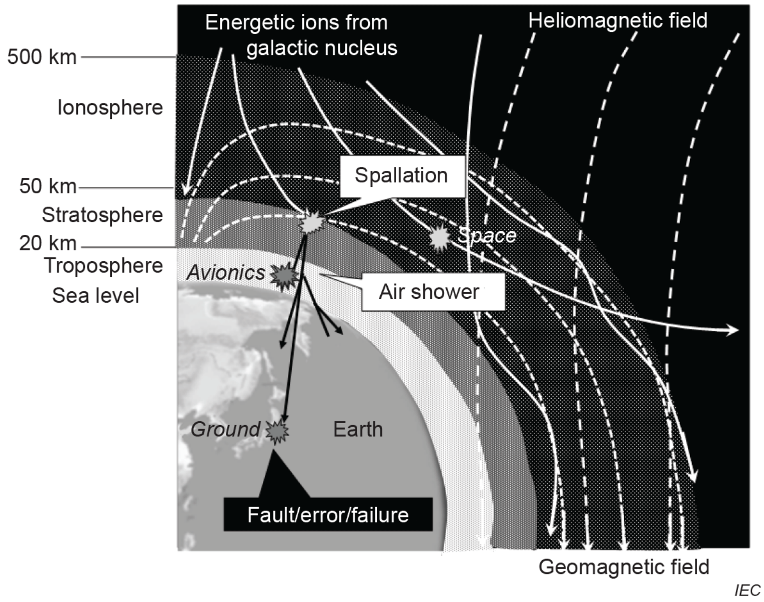

Figure 1 – Cosmic rays as origin of single event effects

When primary cosmic rays enter the atmosphere (troposphere and stratosphere) of Earth, some particles induce spallation reaction in nuclei in the atmosphere (mainly nitrogen and oxygen nuclei) to produce a number of secondary particles including electrons, muons, pions, protons and neutrons as illustrated by Figure 2. Since secondary neutrons in the atmosphere have a longer range than protons, they can cause cascades of spallation reactions in the atmosphere to make air showers that can reach the surface of Earth. Figure 3 shows an estimated differential neutron spectrum at the NYC sea level based on the measured data in JEDEC JESD89 [2]. As the air can shield neutrons, the strength (flux and energy) of neutrons depends upon altitude with a slight dependency on atmospheric pressure [3].

As cosmic rays are also deflected by the heliomagnetic field, which is affected by cyclic solar activity for a period of around eleven years, the strength of neutrons on the ground also has an eleven-year cycle as illustrated by Figure 4. At solar maximum, neutron intensity on the ground is weakest, while it is the strongest at the solar minimum. Under normal activity, the sun emits a large quantity of protons but their energies are relatively low, as shown in Figure 5 for solar maximum conditions, as protons from the sun do not cause air showers on the ground. However, when big flares take place on the sun's surface, a much larger quantity of protons is emitted with comparable energies to galactic protons and can cause air showers.