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TECHNICAL REPORT

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Process management for avionics – Atmospheric radiation effects – Part 6: Extreme space weather – Potential impact on the avionics environment and electronics

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FOREWORD

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IEC TR 62396-6, which is a technical report, has been prepared by IEC technical committee 107: Process management for avionics.

This first edition cancels and replaces the first edition of IEC PAS 62396-6 published in 2014. This edition constitutes a technical revision. The technical changes with respect to the previous edition are the contents of the present document.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
107/298/DTR	107/305/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 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- withdrawn,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.

A bilingual version of this publication may be issued at a later date.

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

This document provides information intended to improve the understanding of extreme space weather events.

Rarely occurring natural hazards can have a high impact to society and national economies. Natural events have no respect for national boundaries and the whole world can suffer. The April 2010 Icelandic (Eyjafjallajökull) volcano eruption and resulting ash cloud and the March 2011 Japanese earthquake and tsunami demonstrated how devastating rarely occurring natural events can be.

In 2011 the UK recognised “extreme space weather” (ESW) events (also referred to as solar super storms and sometimes simply as super storms) as one of these rare, but high impact, hazards. There is evidence of the impact of ESW events in the past. During an event in February 1956, which was monitored at ground level, a rise in radiation flux of more than 2 orders of magnitude was derived for aircraft environments.

The document does not consider high altitude nuclear explosions or any other man-made modifications of space weather.

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PROCESS MANAGEMENT FOR AVIONICS – ATMOSPHERIC RADIATION EFFECTS –

Part 6: Extreme space weather – Potential impact on the avionics environment and electronics

1 Scope

This part of IEC 62396, which is a technical report, provides information intended to improve the understanding of extreme space weather events; it details the mechanisms and conditions that produce "extreme space weather" (ESW) as a result of a large increase in the activity on the surface of the sun and it discusses the potential radiation environment based on projection of previous recorded ESW.

This document does not detail the solutions with regard to the ESW events whose occurrence is extremely rare. As the stakes related to ESW environment go widely beyond the electronics issues and there are a lot of other elements in consideration (human concern for example), this document does not detail potential specific provisions or mitigations.

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 and definitions

For the purposes of this document, the terms and definitions 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
Carrington event
largest solar storm on record, which took place from 1 to 3 September 1859, and is named after British astronomer Richard Carrington

3.2
coronal mass ejection
CME
large burst of solar wind plasma ejected into space

3.3
extreme space weather
ESW
solar activity leading to the endangerment of engineered systems or human health and safety

3.4
geo-effective
storm causing

3.5
geomagnetic storm
worldwide disturbance of the Earth's magnetic field induced by a solar storm

3.6
single event effect
SEE
response of a component caused by the impact of a single particle (for example galactic cosmic rays, solar energetic particles, energetic neutrons and protons)

Note 1 to entry: The range of responses can include both non-destructive (for example upset) and destructive (for latch-up or gate rupture) phenomena.

[SOURCE: IEC 62396-1:2016, 3.53]

3.7
solar energetic particles
SEP
high-energy particles coming from the sun

3.8
AD774
large ground level enhancement (GLE) implied by radiocarbon-dating of tree rings to have occurred in AD774-775

4 Abbreviated terms and acronyms

ATC	air traffic control
CAA	Civil Aviation Authority
CME	coronal mass ejection
ConOps	concept of operation
EDAC	error detection and correction
ESW	extreme space weather
FAA	Federal Aviation Administration
GCR	galactic cosmic rays
GEO	geostationary orbit
GLE	ground level enhancement
GLNM	ground level neutron monitor
GNSS	global navigation satellite systems
GPS	global positioning system
GRB	gamma ray burst
HF	high frequency
IAVWOPSG	International Airways Volcano Watch Operations Group

ICAO	International Civil Aviation Organization
ICRP	International Commission on Radiological Protection
LF	low frequency
MBU	multiple bit upset
NATS	National Air Traffic Control Service
NOAA	National Oceanic and Atmospheric Administration
QARM	Quotid Atmospheric Radiation Model
RAE	Royal Academy of Engineering
SEB	single event burnout
SEE	single event effects
SEIEG	Space Environment Impact Expert Group
SEPE	solar energetic particle event
SEU	single event upset
SRAM	static random access memory

5 Extreme space weather (ESW)

5.1 General

Space weather is defined in the 2013 report by the Royal Academy of Engineering as "variations in the Sun, solar wind, magnetosphere, ionosphere, and thermosphere, which can influence the performance and reliability of a variety of space-borne and ground-based technological systems and can also endanger human health and safety" [1][1]. A great deal of additional information on the many different varieties of both space weather environments and effects is provided in the report. The probability of occurrence of extreme space weather events is very difficult to determine, especially for the types of events most relevant to avionics. There are approximately seventy years' worth of direct measurements of events affecting the atmospheric radiation environment. Recently this record has been partially supplemented by solar events not directed at the Earth, for example the large solar eruption in July 2012 that was measured by the Stereo A spacecraft [2]. However, it is still the case that the upper limit for the severity of extreme space weather is unknown, and ultimately estimates should be made based on various assumptions.

5.2 Space weather relevant to avionics

The vast majority of space weather phenomena are not directly relevant to avionics. Some, for example ionospheric disturbances that potentially affect GPS navigation and radio communication, are relevant to aviation generally but not to avionics specifically. This document concerns itself solely with solar energetic particle events (SEPEs), as these pose the primary hazard to electronic components within aircraft. Like galactic cosmic rays (GCR), SEPEs are comprised of highly energetic protons and ions that interact with molecules in the upper atmosphere and produce cascades of secondary particles, of which neutrons are of primary interest in this context. The secondary neutrons are able to penetrate the atmosphere at aviation altitudes and below, where they can pose a threat to avionics through single event effects (SEEs) in sensitive components. Much more detail on this general SEE phenomenon is given in IEC 62396-1 and more background on the threat of ESW to aviation and other infrastructure is given in the RAE report. [1]

Knowledge of the SEPE environment is dependent on measurements and thus uncertainties increase substantially with more historical events. In the space era (1960s onwards) there are relatively good measurements from space-borne instruments of SEPE proton fluxes at the

1 Numbers in square brackets refer to the Bibliography.

lower end of the relevant spectral energy range (i.e. a few hundred MeV and below). These data provide an effect characterisation of such events on satellites where lower energy protons dominate single event effects rates. For terrestrial effects, including the aviation environment, it is crucial to supplement these data with measurements pertaining to the higher energy part of the proton spectra. Protons need a minimum energy of around 300 MeV to instigate secondary cascades that can penetrate to aircraft altitudes. At low latitudes, even higher energies are required for primary particles to penetrate the shielding provided by the Earth's magnetic field. Indeed, it is this geomagnetic shielding that effectively enables knowledge of the higher energy end of the proton spectrum to be obtained. A global network of ground level neutron monitor (GLMN) stations provides continuous measurement of high energy neutron fluxes at the Earth's surface over a broad range of latitudes. These record not only the background GCR-induced neutron flux that varies with an eleven-year period in anti-phase with the solar cycle, but also the infrequent and transient enhancements caused by the most powerful SEPEs. A minority of SEPEs produce a sufficient number of very high energy (~GeV and above) protons to cause measurable neutron flux increases over a range of latitudes within the GLNM network. During these ground level enhancements (GLEs) the geomagnetic field effectively acts as a giant spectrometer, providing proxy information on the incident proton spectrum via relative neutron flux increases at different vertical cut-off rigidities. Vertical cut-off rigidity is the ratio of momentum to charge required by a charged particle (e.g. a proton) to reach the upper atmosphere at a certain point within the magnetosphere. It is a function of both latitude and longitude. If a number of neutron monitors at similar rigidities show differing levels of neutron flux increase, this is a measure of the anisotropy of the event. Tylka and Dietrich [3] have used a combination of neutron monitor data and satellite instrument data to fit proton spectra for 53 of the 67 GLEs recorded since 1956.

5.3 Examples of proton spectra for GLEs

Comparison plots from Tylka and Dietrich [3] of the 23 February 1956 event and the 19 October 1989 ground level events, both of which were large solar events, are given below; these are based on ground level radiation monitoring of the event.

A significant difference between the spectra is that the 1956 spectrum contains more (over an order of magnitude) high energy protons (above 1 000 MeV) than the 1989 event. The events have been termed ground level events because there has been a large increase in atmospheric radiation at ground level which has been monitored. The radiation levels monitored at ground level were significantly higher for the February 1956 event than the October 1989 event. Radiation ground level monitoring has only been available in modern times for about the last 100 years and the February 1956 event can be considered a nominal ESW event. At that time during the 1950s electronics was in its infancy with most systems based on thermionic valves and less prone to influence from atmospheric radiation.

The 23 February 1956 and 19 October 1989 solar proton spectra are given as examples of the different fitting methods in Figure 1 and Figure 2 respectively. It should be noted that only the fits are shown in these plots (symbols do not represent data). The band spectral form, comprised of a double power-law, was deemed to be the best fit to data.