Certification Memorandum

Single Event Effects (SEE) Caused by Atmospheric Radiation

Certification Considerations and an Analysis Method to Demonstrate the Acceptability of Effects on Aircraft, Engine, APU and Propeller Systems and Equipment, caused by Atmospheric Radiation

EASA CM No.: CM–AS-004 Issue 01 issued 08 January 2018

Regulatory requirement(s): **CS-23, CS-25, CS-27, CS-29, CS-E, CS-P and CS-APU**

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Log of issues

Issue	Issue date	Change description
01	08.01.2018	First issue.

Table of Contents

1. Introduction

1.1. Purpose and scope

Atmospheric radiation is a generic term which refers to all types of ionizing radiation, including neutrons, penetrating or generated within the earth's atmosphere. The main contributors to atmospheric radiation are solar and galactic radiation. Solar radiation is emitted from the sun and galactic radiation originates from outside our solar system. Both types of radiation can be affected (distorted or bent) by the earth's magnetic field.

Note: *Throughout this Certification Memorandum, any reference to 'aircraft systems' also includes electronic controls of Engines, APUs and Propeller Systems.*

The applicant should demonstrate that aircraft systems, whose failure could contribute to a failure condition classified as hazardous or catastrophic, are adequately mitigated against SEE. Such mitigation can be achieved through architectural system considerations, equipment design and/or electronic device selection.

This Certification Memorandum provides complementary information and guidance for compliance demonstration with current standards when considering the effects of SEE on systems and equipment and is applicable to aircraft, engines, propellers and auxiliary power units certified in accordance with, but not limited to, CS-23, CS-25, CS-27, CS-29, CS-E, CS-P and CS-APU (and their associated AMCs).

EASA has also issued a Safety Information Bulletin (SIB) No. 2012-10 *Single Event Effects (SEE) on Aircraft Systems caused by Cosmic Rays* which informs aircraft operators, aircraft manufacturers, avionic system designers, electronic equipment and electronic device manufacturers of the fault conditions that could be caused by SEE.

Appendix B provides background information regarding the effects of atmospheric radiation on aircraft systems.

1.2. References

It is intended that the following reference materials be used in conjunction with this Certification Memorandum:

Reference	Title	Code	Issue	Date
SAE ARP 4761	Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment.	---	---	01/12/1996
CS 2x.1301* CS 23.2500	Function and Installation	CS-23 CS-25 CS-27 CS-29	---	---
CS 2x.1309* CS 23.2510	Equipment, system and installations	CS-23** CS-25 CS-27 CS-29	---	---
CS-E 50	Engine Control System	CS-E	---	---

Reference	Title	Code	Issue	Date
CS-E 210 CS-E 510	Failure Analysis Failure Analysis			
CS-P 150	Safety Analysis	CS-P	---	---
CS-APU 90 CS-APU 210	APU Control System Safety Analysis	CS-APU	---	---
ED-79A SAE ARP 4754A	Guidelines for Development of Civil Aircraft and Systems	---		December 2010
IEC 62396-1	Process management for avionics - Atmospheric radiation effects NOTE: Additional parts IEC 62396-2 to IEC 62396-5 have been issued with additional information.	---	Ed 1.0	23/05/2012
---	Extreme Space Weather: Impacts on Engineered Systems and Infrastructure. Royal Academy of Engineering - Summary report	---	---	February 2013
EASA Safety Information Bulletin SIB No. 2012-09	Effects of Space Weather on Aviation	---	---	23/05/2012
EASA Safety Information Bulletin SIB No. 2012-10	Single Event Effects (SEE) on Aircraft Systems caused by Cosmic Rays	---	---	23/05/2012

* Associated Acceptable Means of Compliance and Guidance Material where applicable.

1.3. Abbreviations

AFM	Aircraft Flight Manual
AIR	Aerospace Information Report
AMC	Acceptable Means of Compliance
APU	Auxiliary Power Unit
ARP	Aerospace Recommended Practice
DDP	Declaration of Design and Performance
EASA	European Aviation Safety Agency

ETSO	European Technical Standard Order
FAA	Federal Aviation Administration
FADEC	Full Authority Digital Engine Control
FHA	Functional Hazard Assessment
FPGA	Field-programmable Gate Array
HF	High Frequency
IEC	International Electrotechnical Commission
IC	Integrated Circuit
MBU	Multiple Bit Upset
PSSA	Preliminary System Safety Assessment
SAE	Society of Automotive Engineers
SEB	Single Event Burn-out
SEE	Single Event Effects
SEFI	Single Event Functional Interrupt
SEGR	Single Event Gate Rupture
SEL	Single Event Latch-up
SEU	Single Event Upset
SRAM	Static Random-Access Memory
SSA	System Safety Assessment
TC	Type Certificate
VHF	Very High Frequency

1.4. Description of SEE types

Single Event Upset	Occurs in a semiconductor device when the radiation absorbed by the device is sufficient to change a cell's logic state.
Multiple Bit Upset	Occurs when the energy deposited in the silicon of an electronic device, by a single ionizing particle, causes upset to more than one bit in the same logical word.
Multiple Cell Upset	Occurs when the energy deposited in the silicon of an electronic device, by a single ionizing particle, induces several bit upset in an IC to fail at one time.

Single Event Latch-up	Occurs in a four or more layer semiconductor device (typically a CMOS device) when the radiation absorbed by the device is sufficient to cause a node within the powered semiconductor device to be held in a fixed state whatever input is applied until the device is de-powered, such latch up may be destructive or non-destructive. *
Single Event Gate Rupture	Occurs in the gate of a powered insulated gate component when the radiation charge absorbed by the device is sufficient to cause gate rupture, which is destructive.
Single Event Burnout	Occurs when a powered electronic device or part thereof is burnt out as a result of the energy absorption triggered by an individual radiation event.
Single Event Transient	A spurious signal or voltage induced by the deposition of charge by a single particle that can propagate through the circuit path during one clock cycle.
Single Event Functional Interrupt	An interaction between a radiation particle and a semiconductor device that results in an interruption of the device functionality (potentially requiring a reset) for example due to corruption of the internal control path of a complex device such as a micro-processor. *

The definitions in the above table (except the ones marked by *) are taken with permission from the IEC 62396-1.

2. Background

2.1. Applicability

Typically, aircraft systems installed on large transport, commuter and business aircraft should consider SEE. This does not exclude other aircraft which could be affected by SEE due to their type of operations or architecture.

2.2. Discussion

This Certification Memorandum is intended for use by designers of aircraft, engines, APUs, propellers, systems and equipment, requesting an approval from the Agency, hereafter referred to as the applicant.

Applicants will be responsible for demonstrating, to the Agency, that SEE are adequately addressed in a system (or equipment) and that the effects (if any) at aircraft/engine level are acceptable. Part of this responsibility may require an assessment of the equipment supplier to ensure adequate procedures are in place, and are/were followed, to address SEE.

An Equipment Supplier may also wish to use this Certification Memorandum to demonstrate the equipment robustness to SEE, independently of a request from an Aircraft Manufacturer, Engine/APU Manufacturer, Propeller Manufacturer or a System Designer. Although not currently specifically mentioned in ETSO 'approval standards', a SEE analysis may be referenced in certification documentation provided to the Agency for obtaining an equipment ETSO authorisation.

The IEC 62396 Parts 1 to 5 provide useful information relating to atmospheric radiation effects, testing, and accommodation of SEE by optimisation of system design.

The applicant is requested to consider the relevant paragraphs of this Certification Memorandum when addressing SEE. Note that this Certification Memorandum provides a means of compliance which would be acceptable to the Agency, however, the applicant may propose an alternative means of compliance.

2.3. Effects of atmospheric radiation on systems and equipment in aircraft, engines, APUs or propellers

The impact of a SEE on aircraft systems can vary and may be transitory or permanent. Noticeable functional effects might or might not be produced. Occasionally the effect(s) may cause the loss or malfunctioning of a system. Although the crew may report the system loss or malfunction, the subsequent re-test on the ground or in the air may not reproduce the effect. This results in a 'no fault found' entry in the aircraft technical log. The system/equipment may continue, thereafter, to operate correctly with no further system loss or malfunction. It is also possible that the malfunction may not be detected/detectable and could contribute to misleading information presented to the crew.

All systems containing semiconductor devices could be affected to varying degrees. It is not expected, however, that the **normal** levels of atmospheric radiation activity could affect several systems simultaneously. SEE are random and independent events and their effects do not introduce any new common cause of failure.

3. EASA Certification Policy

3.1. Certification process

The applicant should have a procedure to address SEE. This procedure may be incorporated into an 'existing' overall design process.

3.1.1. The Certification Programme should address the recommendations introduced by this certification guidance.

3.1.2. The certification specifications which could be applicable are, but not limited to, CS-23, CS-25, CS 27, CS 29, CS-E, CS-P and CS-APU (and their associated AMCs). The following certification requirements are considered applicable within the context of this Certification Memorandum:

i. CS 23.1301/CS 23.2500, CS 23.1309/CS 23.2510(see Note 1)

ii. CS 25.1301, CS 25.1309,

iii. CS 27.1301, CS 27.1309

iv. CS 29.1301, CS 29.1309

v. CS-E 50, CS-E 210, CS-E 510,

vi. CS-P 150,

vii. CS-APU 90, CS-APU 210.

3.1.3. The failure conditions, introduced by the system or equipment operation (or major change/modification), should be identified and classified in accordance with the applicable AMC to CS 2x-1309, CS 23.2510 or CS-E 510, or CS-P 150 or CS-APU 210 and considered in the related Functional Hazard Assessment (FHA).

Note 1: Where the certification basis is CS-23 Amendment 5, the applicant should consult the Agency for related Acceptable Means of Compliance and Guidance Material (not currently available at the issue date of this CM).

Note 2: *The applicant may refer to SAE ARP 4761 for guidance of how to produce a Functional Hazard Assessment.*

The susceptibility to SEE for each system, piece of equipment or hardware device contributing to Catastrophic or Hazardous failure conditions should be considered.

Equipment, Engine, APU and Propeller System designers need to consider the effect of functional failures of the equipment, Engine, APU or Propeller System at equipment-level, system-level and aircraft level. The assessment of the effect at aircraft level could require coordination with the aircraft manufacturer. When the applicant cannot establish the failure effect at aircraft level, an assumption should be made and stated in a certification document such as a Certification Programme and/or a Declaration of Design and Performance (DDP).

Note 3: *The susceptibility to SEE of systems or equipment contributing only to Major, Minor or No Safety Effect failure conditions may be addressed on a voluntary basis.*

3.1.5. Mitigation against the impact of SEE, on a device, within a system or piece of equipment may be achieved by taking into account the architectural system design (e.g. dual systems, dual channels, error detection and correction, etc.), equipment design and/or electronic device selection. These architectural or design features, and any supporting assumptions, should be documented in a PSSA, SSA, or similar document (e.g. Safety Analysis Report) following standard practices.

3.1.6. The applicant should produce a summary document describing the tasks accomplished to meet the objectives of this guidance. The summary document should include references to the Safety Analysis Report and any other reports where qualitative or quantitative SEE analysis is documented. Alternatively the method used to meet the objectives of this guidance could be provided in other documents within the safety assessment.

3.2. SEE analysis method to assess the safety of systems and equipment in aircraft, engines, APUs or propellers

This section describes a method to assess the potential contribution of Atmospheric Radiation effects, as an aspect of the overall system safety assessment process. This contribution could be used together with the other safety aspects identified by classical safety analyses (FMEA, FHA, SSA etc.). This method is acceptable to the Agency, but should not be considered as the only method. A flow diagram is provided in **Appendix A** to assist in understanding the SEE analysis method.

3.2.1. Initial assessment

Functional hazard assessments (FHAs) for the aircraft, engine, APU or propeller and their associated systems should be reviewed (see **Section 3.1.4**). For each system or function with one or more failure conditions classified as Catastrophic or Hazardous, all contributing pieces of equipment should be identified and evaluated as described in **Section 3.2.2**. Qualitative Assessment Process.

3.2.1.1. An analysis should be performed for each equipment, which contributes to a Catastrophic or Hazardous failure condition. Resulting from this, a parts list should be produced to identify the electronic devices contributing to Catastrophic or Hazardous failure conditions.

3.2.1.2. Information from relevant electronic device data and/or test data should be used to determine the level of susceptibility to SEE for each electronic device. Where the available data does not contain sufficient information regarding susceptibility to SEE, a conservative determination of SEE susceptibility should be made based on the ‘type’ of technology used within the electronic device (i.e., logic device, memory device, FPGA, or other types of semiconductor devices which are susceptible to SEE). IEC 62396-1 and IEC 62396-2 contain guidance regarding conservative values of generic SEE data based on the electronic device basic technology. A component list (hereafter referred to as **Parts List A**) should be produced for those remaining electronic devices which could be susceptible to SEE should

3.2.2. Qualitative Assessment Process

A qualitative assessment should be performed for the electronic devices which were identified, in **Section 3.2.1.2**, as potentially affected by SEE. These electronic devices should be reviewed and any mitigations, as a result of architecture or system design, should be identified and recorded. Certain electronic devices, for which there exists sufficient qualitative mitigation may be exempt from the subsequent quantitative assessment. A component list (hereafter referred to as **Parts List B**) should be produced for those electronic devices which are susceptible to SEE for which there is no, or incomplete, mitigation in the design.

3.2.3. Quantitative Assessment Process

3.2.3.1 A quantitative assessment should be performed for the remaining electronic devices (**Parts List B**), where sufficient qualitative mitigation against the effects of SEE, cannot be demonstrated.

IEC 62396-1 introduces a mean neutron flux of 6000 n/cm^2/h for Energy > 10 MeV (which is equivalent to a typical flight envelope of 40,000 feet and latitude of 45 degrees). This figure of 6000 n/cm^2/h should be used as a minimum value when determining the effect of SEE on an electronic device. Use of a lower value should be justified by the applicant to the Agency. Deviations should be stated in a Declaration of Design and Performance (DDP) document and any resulting operational limitations should be stated in the Aircraft Flight Manual (AFM) or, for Engines and Propellers, it should be stated in the respective manuals as required by CS-E 20 and CS-P 30.

IEC 62396-5 introduces the effects on electronic devices caused by Thermal Neutrons (see Note 1 below). An assessment should include the possible effects on electronic devices, equipment and systems caused by Thermal Neutrons. IEC 62396-5 provides a method, but not the only method, for determining the effect of Thermal Neutrons on electronic devices, equipment and systems inside an aircraft.

Note 1: *Thermal Neutrons are the result of neutrons, with initially much higher energies, which have encountered sufficient number of collisions within the surrounding medium to form a thermal equilibrium with the molecules (or atoms) of the medium in which they are present. The thermal neutron flux inside the aircraft is usually higher than the thermal neutrons outside of the airplane because of the presence of all of the hydrogenous materials within it (fuel, plastic structures, baggage, people, etc.). The presence of thermal neutrons may also lead to SEE.*

3.2.3.2 The quantitative assessment should use the available electronic device SEE rates (from electronic device or test data) or, if not available, a conservative SEE rate should be used. Note that the SEE rate is a product of the SEE cross section (cm^2 per device) and flux density. The SEE cross-section can be derived by reference to IEC 62396 or verified data relating to the electronic device.

The quantitative assessment should evaluate the probability of occurrence of the SEE event and indicate its impact on the availability and on the integrity of the function. These assessments should be integrated in an SSA (e.g. Fault Tree Analysis).

3.2.3.3 When the quantitative assessment indicates an unacceptably high probability that the electronic device (and therefore the equipment/system) could be affected by SEE, compared to the classification of the failure, the following options should be considered:

i. a re-design of the electronic device, use of a different electronic device (different specification or technology) or use of partitions (hardware or software) may provide mitigation for the effects of SEE **or**

ii. architecture re-design to include additional mitigation(s)

Note: *At this stage, an architecture or system design change may provide mitigation thus removing the need to perform a quantitative assessment.*

or

iii. radiation testing of the electronic device to confirm the SEE rate (see **Section 3.2.4**).

Note: *Previously obtained radiation testing data, for the electronic device may also be used if this data was shown to be relevant. This would negate the need to repeat radiation testing for this electronic device.*

3.2.4. Electronic Device radiation testing

Radiation testing to determine the SEE rate should be performed when the quantitative assessment indicates an unacceptably high probability that the electronic device could be affected by SEE, compared to the classification of the failure, and a re-design of the electronic device (or use of a different electronic device) or an architecture re-design to include additional mitigation(s) is not practical (refer to IEC 62396-2 for further details regarding radiation testing). During the radiation testing, all the used function of the electronic device(s) should be carefully monitored to reflect the performance of the device under radiations.

If the radiation testing results confirm an unacceptably high electronic device SEE rate then a system/equipment redesign, or use of different electronic device(s), will be necessary

3.3. Management and control of parts

The applicant should ensure that a plan is in place to address SEE issues in the initial parts selection and also in continued airworthiness of the system, equipment and/or electronic device. A process should be in place to ensure that new parts, selected to replace obsolescent parts, are analysed to ensure that the original SEE mitigation remains valid.

3.4. Ground and flight testing

No ground or flight testing is required unless the applicant wishes to take certification credit for additional SEE testing. Note, ground testing refers to testing at aircraft level to complement electronic device and/or system/equipment level testing.

3.5. Whom this Certification Memorandum affects

This Certification Memorandum is intended for use by designers of aircraft, engines, APUs, propellers, systems and equipment. Also see section 2.1

4. Remarks

1. Suggestions for amendment(s) to this EASA Certification Memorandum should be referred to the Certification Policy and Safety Information Department, Certification Directorate, EASA. E-mail CM@easa.europa.eu.

2. For any question concerning the technical content of this EASA Certification Memorandum, please contact:

   Name, First Name: Hallworth, Kevin

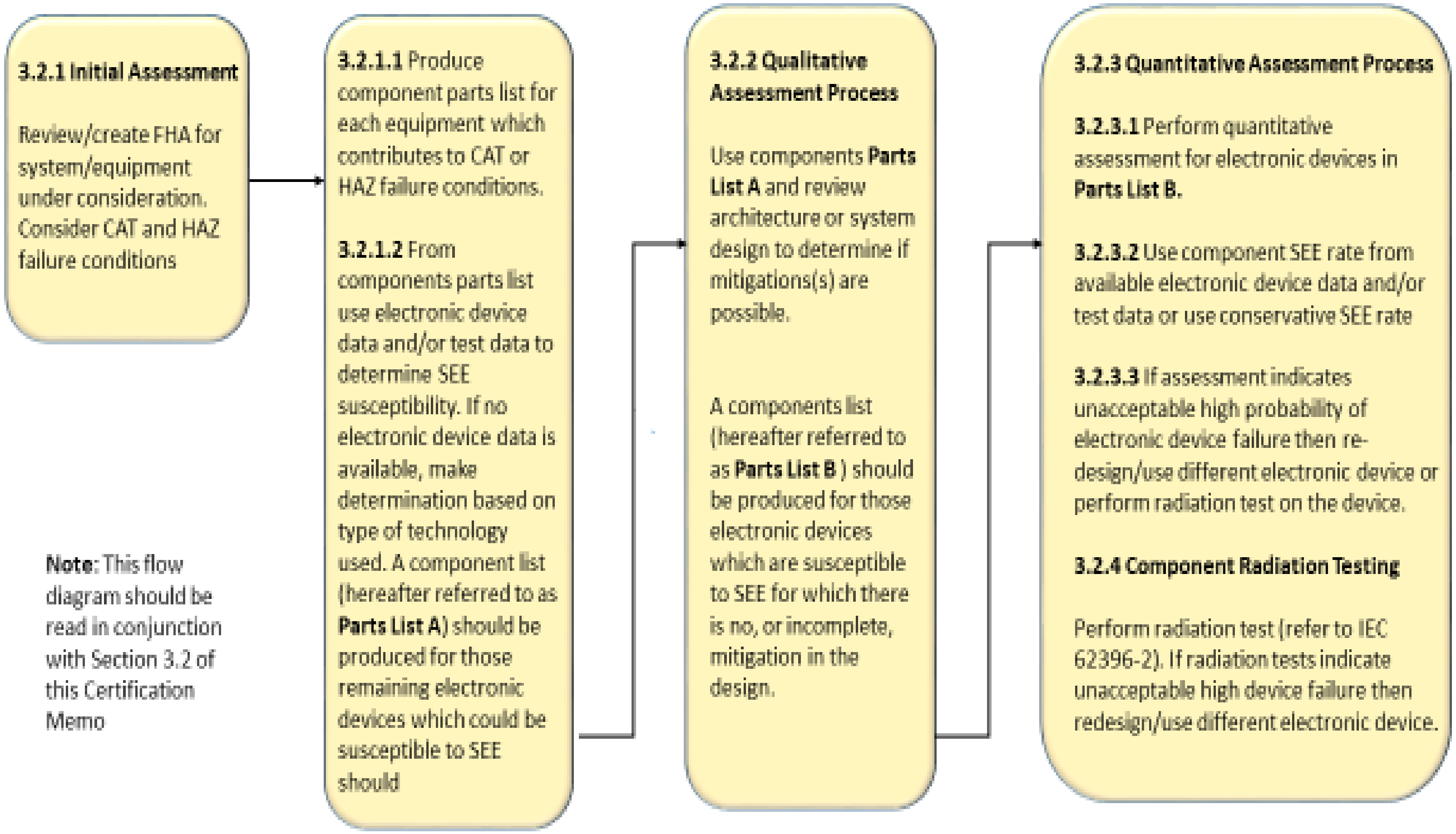
   Function: Avionics Systems Expert

   Phone: +49 (0)221 89990 4050

E-mail: kevin.hallworth@easa.europa.eu

Appendix A

SEE Analysis Method to Assess the Safety of Systems and Equipment in Aircraft, Engines, APUs or Propeller Systems (Flow Diagram)



Note: This flow diagram should be read in conjunction with Section 3.2 of this Certification Memo

Appendix B

Background Information - Effects of Atmospheric Radiation on Aircraft Systems.

Single Event Effects (SEE) occur when atmospheric radiation, comprising high energy particles, collide with specific locations on semiconductor devices contained in aircraft systems. SEE can also occur when low energy neutrons interact with boron 10 isotope, which can also be present in semiconductors devices. Memory devices, microprocessors and FPGAs are most susceptible to SEE. In addition high voltage (power) transistors and diodes may also be affected by SEE.

Some examples of these types of effects are Single Event Upset (SEU), Multiple Bit Upset (MBU), Single Event Latch-up (SEL), Single Event Functional Interrupt (SEFI), Single Event Gate Rupture (SEGR) and Single Event Burnout (SEB). However, SEU and MBU are two of the most frequent examples of SEE which affect aircraft systems (see **Section 1.4** for description of SEE types).

The rate of SEE are likely to be greater for aircraft systems flying at high altitudes and high geographic latitudes (North and South). This is for two reasons:

- the particle flux density generally increases with increasing altitude due to reduced atmospheric absorption,
- the particle flux density generally increases with latitude due to deflection of the atmospheric radiation towards the poles by the earth's magnetic field.

The high energy particles are randomly distributed at any given location. Due to this, the predicted SEE rates can be derived based on the characteristics of the aircraft equipment (number of vulnerable elements) and operating conditions (altitude, latitude).

The effect of atmospheric radiation is one factor that could contribute to equipment loss or malfunction. From a system safety perspective the standard methods described in SAE ARP 4761 (Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment) are an acceptable means for conducting a safety assessment. Note that an SAE AIR document is in preparation to include the possibility of performing a qualitative assessment in the case of SEE.

Extreme space weather includes the effects of solar flares, which can result in large bursts of solar particles arriving in the atmosphere creating an increase in atmospheric radiation of short duration (order of hours). During solar flare activity, the atmospheric radiation may rise to significantly higher levels than that normally expected and could increase by a factor of 300 or more (see document IEC62396-1, Section 5.6). This Certification Memorandum considers the **normal** atmospheric radiation levels, which are experienced during a typical flight, and not those which could be experienced during a solar flare.

Some prior notification of high solar activity, such as solar flares, may be available to the operator of an aircraft via solar weather information websites. This could result in operational limitations relating to the routing of the flight (e.g. avoiding high latitudes). In some circumstances, however, prior notification may not be available due to the short notice period. Further guidance may need to be developed to deal with exceptional conditions such as solar flares.

Information regarding extreme space weather can be found in the following report: *Extreme Space Weather – Impacts on Engineered Systems and Infrastructure. Royal Academy of Engineering – February 2013 and EASA Safety Information Bulletin SIB No. 2012-09 Effects of Space Weather on Aviation.*

