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Space systems — Space debris mitigation requirements

Systèmes spatiaux — Exigences de mitigation des débris spatiaux

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

This third edition cancels and replaces the second edition (ISO 24113:2011), which has been technically revised.

The main changes compared to the previous edition are as follows:

— many of the existing requirements and terminology definitions have been modified, and new requirements have been added for the purpose of:

  — limiting the total number of launch vehicle orbital stages and space debris objects left in Earth orbit by a launch vehicle during normal operations,

  — limiting the ejection of slag debris from solid rocket motors in low Earth orbit,

  — avoiding accidental break-up caused by a collision, and

  — limiting the total probability of successful disposal of a spacecraft or launch vehicle orbital stage to be at least 0,9;

— a note has also been added advising of the existence of a commonly-used threshold for the expected number of casualties during a re-entry.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Space debris comprises all objects of human origin in Earth orbit or re-entering the atmosphere, including fragments and elements thereof, that no longer serve a useful purpose. The growing population of these objects poses an increasing hazard to mankind's use of space. In response to this problem, there is international consensus that space activities need to be managed to minimize collision risks among space objects and casualty risks associated with atmospheric re-entry. This consensus is embodied in space debris mitigation guidelines published by organizations such as the International Telecommunication Union (ITU)[1], the Inter-Agency Space Debris Coordination Committee (IADC)[2] [3] and the United Nations (UN)[4]. The transformation of debris mitigation guidelines into engineering practice is a key purpose of this document.

The importance of this document can be seen within the context of four UN treaties[5] that were established under the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) to govern the involvement of nations in space activities. These are the *Outer Space Treaty*, the *Liability Convention*, the *Registration Convention* and the *Rescue Agreement*. Through some of these treaties, a Launching State has total liability for damage caused by its spacecraft or launch vehicle orbital stages (or any parts thereof) on the surface of the Earth or to aircraft in flight, as well as in outer space where fault can be proven.

All countries are encouraged to abide by these international agreements in order not to endanger or constrain existing and future activities in space. A Launching State can choose to appoint licensing or regulatory authorities to administer its approach for complying with the above-mentioned UN treaties. In several Launching States, these authorities have implemented national legislation to enforce the UN treaties. Such legislation can include the mitigation of space debris. Some Launching States meet their obligations by appointing non-regulatory government bodies, such as national space agencies, to provide the necessary guidelines or requirements, including those for space debris mitigation.

The general aim of space debris mitigation is to reduce the growth of space debris by ensuring that spacecraft and launch vehicle orbital stages are designed, operated and disposed of in a manner that prevents them from generating debris throughout their orbit lifetime. Another aim of space debris mitigation is to ensure that space objects re-entering the Earth's atmosphere cause no harm. These aims are achieved by the following actions:

a) avoiding the intentional release of space debris into Earth orbit during normal operations;

b) avoiding break-ups in Earth orbit;

c) removing spacecraft and launch vehicle orbital stages from protected orbital regions after the end of mission;

d) performing the necessary actions to minimize the risk of collision with other space objects;

e) reducing the risks associated with re-entry, e.g. to people, property and the Earth's environment.

Such actions are especially important for a spacecraft or launch vehicle orbital stage that has one or more of the following characteristics:

— has a large collision cross-section;

— remains in orbit for many years;

— operates near manned mission orbital regions;

— operates in highly utilized regions, such as protected regions;

— operates in regions of high debris population.

This document transforms these objectives into a set of high-level debris mitigation requirements. Methods and processes to enable conformance with these requirements are provided in a series of lower-level implementation standards.

Space systems — Space debris mitigation requirements

1 Scope

This document defines the primary space debris mitigation requirements applicable to all elements of unmanned systems launched into, or passing through, near-Earth space, including launch vehicle orbital stages, operating spacecraft and any objects released as part of normal operations.

The requirements contained in this document are intended to reduce the growth of space debris by ensuring that spacecraft and launch vehicle orbital stages are designed, operated and disposed of in a manner that prevents them from generating debris throughout their orbit lifetime. The requirements are also intended to reduce the casualty risk on ground associated with atmospheric re-entry of space objects.

This document is the top-level standard in a family of standards addressing space debris mitigation. It is the main interface for the user, bridging between the primary space debris mitigation objectives and a set of lower level standards and technical reports that support conformance. The lower level documents contain detailed requirements and implementation measures associated with the high-level requirements in this document.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
approving agent
entity from whom approval is sought for the implementation of *space debris* (3.23) mitigation requirements with respect to the procurement of a *spacecraft* (3.25), or its launch, or its operations in outer space or its safe *re-entry* (3.22), or a combination of those activities

EXAMPLE Regulatory or licensing authorities; national or international space agencies; other delegated organizations.

3.2
break-up
event that completely or partially destroys an object and generates *space debris* (3.23)

3.3
casualty risk
expected number of casualties
situation expressed by the probability that at least one person is killed or seriously injured as a consequence of an event

Note 1 to entry: The medical profession has defined a number of different injury scoring systems to distinguish the severity of an injury. Broadly, a serious injury is one of such severity that hospitalisation is required.

Note 2 to entry: The *re-entry* (3.22) of a *spacecraft* (3.25) is an example of an event.

3.4
controlled re-entry
type of *re-entry* (3.22) where the time of re-entry is sufficiently controlled so that the impact of any surviving debris on the surface of the Earth is confined to a designated area

Note 1 to entry: The designated area is usually an uninhabited region such as an ocean.

3.5
disposal
actions performed by a *spacecraft* (3.25) or *launch vehicle orbital stage* (3.13) to permanently reduce its chance of accidental *break-up* (3.2) and to achieve its required long-term clearance of the *protected regions* (3.21)

Note 1 to entry: Actions can include removing stored energy and performing post-mission orbital manoeuvres.

3.6
disposal manoeuvre
action of moving a *spacecraft* (3.25) or *launch vehicle orbital stage* (3.13) to a different orbit as part of its *disposal* (3.5)

3.7
disposal phase
interval during which a *spacecraft* (3.25) or *launch vehicle orbital stage* (3.13) performs its *disposal* (3.5)

3.8
Earth orbit
bounded or unbounded Keplerian orbit with Earth at a focal point, or Lagrange point orbit which includes Earth as one of the two main bodies

Note 1 to entry: For the purposes of this document, it is not necessary to consider *space objects* (3.24) in unbounded Keplerian orbits if their probability of interference with the LEO and *GEO* (3.11) *protected regions* (3.21) is negligible.

3.9
end of life
instant when a *spacecraft* (3.25) or *launch vehicle orbital stage* (3.13):

a) is permanently turned off (nominally as it completes its *disposal phase* (3.7)),

b) re-enters the Earth's atmosphere, or

c) can no longer be controlled by the operator

Note 1 to entry: See Annex A.

3.10
end of mission
instant when a *spacecraft* (3.25) or *launch vehicle orbital stage* (3.13):

a) completes the tasks or functions for which it has been designed, other than its *disposal* (3.5),

b) becomes non-functional as a consequence of a failure, or

c) is permanently halted through a voluntary decision

Note 1 to entry: See Annex A.

3.11
geostationary Earth orbit
GEO
Earth orbit (3.8) having zero inclination, zero eccentricity, and an orbital period equal to the Earth's sidereal rotation period

3.12
launch vehicle
DEPRECATED: launcher
system designed to transport one or more payloads into outer space

3.13
launch vehicle orbital stage
complete element of a *launch vehicle* (3.12) that is designed to deliver a defined thrust during a dedicated phase of the launch vehicle's operation and achieve orbit

Note 1 to entry: Non-propulsive elements of a launch vehicle, such as jettisonable tanks, multiple payload structures or dispensers, are considered to be part of a launch vehicle orbital stage while they are attached.

3.14
Launching State
State that launches or procures the launching of a *spacecraft* (3.25), or State from whose territory or facility a spacecraft is launched

Note 1 to entry: This definition is consistent with the definition in the UN Liability Convention[5] and the UN General Assembly's Resolution 59/115 on the notion of the Launching State[6].

3.15
mission
set of tasks or functions to be accomplished by a *spacecraft* (3.25) or *launch vehicle orbital stage* (3.13), other than its *disposal* (3.5)

3.16
mission lifetime extension
postponement of the previously defined *end of mission* (3.10)

3.17
normal operations
execution of the planned tasks or functions for which a *spacecraft* (3.25) or *launch vehicle orbital stage* (3.13) was designed

Note 1 to entry: Normal operations include the *disposal phase* (3.7).

3.18
orbit lifetime
elapsed time between an orbiting *space object's* (3.24) initial or reference position and its *re-entry* (3.22)

Note 1 to entry: Examples of "initial position" are the injection into orbit of a *spacecraft* (3.25) or *launch vehicle orbital stage* (3.13), or the instant when *space debris* (3.23) is generated. An example of a "reference position" is the orbit of a spacecraft or launch vehicle orbital stage at the *end of mission* (3.10).

3.19
passivate
<space debris mitigation> act of permanently depleting, irreversibly deactivating, or making safe all on-board sources of stored energy capable of causing an accidental *break-up* (3.2)

Note 1 to entry: Passivation reduces the chance of an accidental explosion that could generate *space debris* (3.23).

Note 2 to entry: Residual propellants, batteries, high-pressure vessels, self-destruct devices, flywheels and momentum wheels are examples of on-board sources of stored energy capable of causing an accidental break-up.

3.20
probability of successful disposal
probability that a *spacecraft* (3.25) or *launch vehicle orbital stage* (3.13) is able to complete all of the actions associated with its *disposal* (3.5)

Note 1 to entry: The calculation of this probability includes consideration of uncertainties in the availability of resources, such as propellant, required for the disposal.

Note 2 to entry: The calculation of this probability can include consideration of the inherent reliabilities of subsystems that are necessary to conduct the disposal, monitoring of those subsystems, and operational remediation of any observed subsystem degradation or failure.

Note 3 to entry: The calculation of this probability can include an assessment of the risk that a *space debris* (3.23) or meteoroid impact will prevent the disposal, but this is not mandatory.

Note 4 to entry: In the previous edition of this document, ISO 24113:2011, the probability of successful disposal was defined as a conditional probability, i.e. the probability of successfully performing a disposal given that the nominal *mission* (3.15) had been completed. In this document the probability is no longer conditional.

3.21
protected region
region in outer space that is protected with regard to the generation of *space debris* (3.23) to ensure its safe and sustainable use in the future

3.22
re-entry
permanent return of a *space object* (3.24) into the Earth's atmosphere

Note 1 to entry: Several alternative definitions are available for the delineation of a boundary between the Earth's atmosphere and outer space.

3.23
space debris
DEPRECATED: orbital debris
objects of human origin in *Earth orbit* (3.8) or re-entering the atmosphere, including fragments and elements thereof, that no longer serve a useful purpose

Note 1 to entry: *Spacecraft* (3.25) in reserve or standby modes awaiting possible reactivation are considered to serve a useful purpose.

3.24
space object
object of human origin which has reached outer space

3.25
spacecraft
system designed to perform a set of tasks or functions in outer space, excluding *launch vehicle* (3.12)

4 Symbols and abbreviated terms

4.1 Symbols

A/m aspect area to dry mass ratio (m^2kg^{-1})

C_R solar radiation pressure coefficient ($0 < C_R < 2$)

Z altitude measured with respect to a spherical Earth whose radius is 6 378 km

Z_{GEO} altitude of the geostationary Earth orbit with respect to a spherical Earth whose radius is 6 378 km

ΔH change in altitude (km)

4.2 Abbreviated terms

GEO geostationary Earth orbit

LEO low Earth orbit

LV launch vehicle

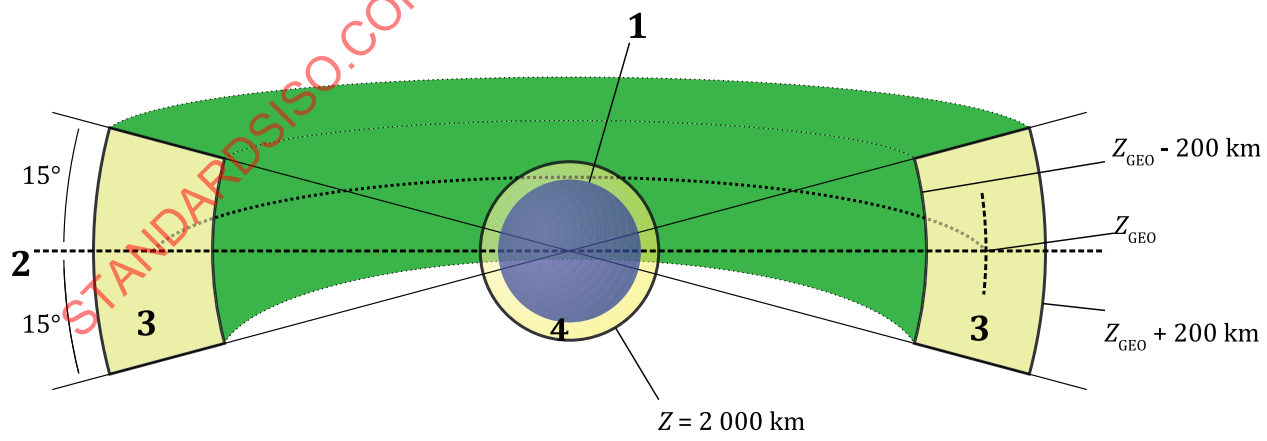
S/C spacecraft

SDMP space debris mitigation plan

5 Protected regions

5.1 General

The LEO and GEO regions are considered as protected regions with regard to the generation of space debris (see Figure 1). This is necessary to ensure their safe and sustainable use in the future.



Key

1 Earth

2 equatorial plane

3 GEO protected region

4 LEO protected region

NOTE The dimensions in the figure are not to scale.

Figure 1 — Three-dimensional view of the protected regions around the Earth

5.2 LEO protected region

The LEO protected region, as defined by the IADC[2] and illustrated in Figure 1, is a shell that extends from the surface of a spherical Earth with an equatorial radius of 6 378 km up to an altitude, Z, of 2 000 km.

5.3 GEO protected region

The GEO protected region, as defined by the IADC[2] and illustrated in Figure 1, is a segment of a spherical shell with the following characteristics:

a) lower altitude: geostationary altitude minus 200 km;

b) upper altitude: geostationary altitude plus 200 km;

c) latitude sector: 15° South ≤ latitude ≤ 15° North,

where geostationary altitude (Z_{GEO}) is approximately 35 786 km, i.e. the altitude of the geostationary Earth orbit above a spherical Earth with an equatorial radius of 6 378 km.

6 Technical requirements

6.1 Avoiding the intentional release of space debris into Earth orbit during normal operations

6.1.1 General

6.1.1.1 Spacecraft shall be designed so as not to release space debris into Earth orbit during normal operations, other than space debris from pyrotechnics and solid rocket motors.

6.1.1.2 The total number of launch vehicle orbital stages and space debris objects left in Earth orbit by a launch vehicle during normal operations, other than space debris from pyrotechnics and solid rocket motors, shall be limited to one for the launch of a single spacecraft and two for the launch of multiple spacecraft.

6.1.1.3 Space debris left in Earth orbit by a launch vehicle after normal operations, other than space debris from pyrotechnics and solid rocket motors, shall satisfy the following conditions:

a) remain outside the GEO protected region for at least 100 years, and

b) have an orbit lifetime of not more than 25 years if released into an orbit that lies within or crosses the LEO protected region.

6.1.2 Space debris from pyrotechnics and solid rocket motors

6.1.2.1 Pyrotechnic devices shall be designed so as not to release space debris larger than 1 mm in their largest dimension into Earth orbit.

6.1.2.2 Solid rocket motors shall be designed and operated so as not to release space debris larger than 1 mm in their largest dimension into the LEO and GEO protected regions.

NOTE The main aim of this requirement is to limit the generation of slag debris ejected into Earth orbit during the final phase of combustion. Slag debris is potentially hazardous to current and future space operations due to its size, number and orbital lifetime. This is particularly the case when slag debris is ejected into a high orbital region where it can pose an impact risk for a long period of time.

6.2 Avoiding break-ups in Earth orbit

6.2.1 Intentional break-up

In Earth orbit, intentional break-up of a spacecraft or launch vehicle orbital stage shall be avoided.

6.2.2 Accidental break-up caused by an on-board source of energy

6.2.2.1 The probability of accidental break-up of a spacecraft or launch vehicle orbital stage in Earth orbit shall be less than 10^{-3} until its end of life.

6.2.2.2 The determination of accidental break-up probability shall quantitatively consider all known failure modes for the release of stored energy, capable of causing an accidental break-up, excluding those from external sources such as impacts with space debris and meteoroids.

6.2.2.3 A spacecraft or launch vehicle orbital stage, for which a controlled re-entry has not been planned, shall be passivated in a safe and controlled manner before the end of life.

6.2.2.4 If for any reason a launch vehicle orbital stage cannot perform a controlled re-entry as planned then it shall be passivated in a safe and controlled manner.

6.2.2.5 The condition of a spacecraft shall be monitored periodically during its operation to detect any anomalies that could lead to an accidental break-up.

6.2.2.6 During the operation of a spacecraft, if an anomaly is detected which could lead to an accidental break-up then a contingency plan shall be implemented to mitigate this risk.

6.2.3 Accidental break-up caused by a collision

6.2.3.1 A spacecraft that will operate in the GEO protected region shall have a recurrent manoeuvre capability.

6.2.3.2 A spacecraft that will operate in Earth orbit with a recurrent manoeuvre capability shall be designed and operated to actively manage collision risk until the end of life.

6.2.3.3 For a spacecraft with the capability to actively manage collision risk, if the risk of collision with other space objects is assessed to be above the corresponding risk threshold set by an approving agent then collision avoidance manoeuvres shall be conducted to reduce the risk of collision below the threshold.

6.2.3.4 During the design of a spacecraft an assessment shall be made of the risk that a space debris or meteoroid impact will cause the spacecraft to break-up before its end of life.

NOTE The aim of this assessment is to improve spacecraft design against impacts.

6.3 Disposal of a spacecraft or launch vehicle orbital stage after the end of mission so as to minimize interference with the protected regions

6.3.1 Provisions for successful disposal

6.3.1.1 The probability of successful disposal of a spacecraft or launch vehicle orbital stage shall be at least 0,9 through to the end of life.

6.3.1.2 During the design of a spacecraft for which a disposal manoeuvre has been planned, an assessment shall be made of the risk that a space debris or meteoroid impact will prevent the successful disposal.

6.3.1.3 Specific criteria for initiating the disposal of a spacecraft or launch vehicle orbital stage shall be developed, evaluated during the mission and, if met, consequent actions executed.

NOTE It is possible for disposal criteria to be programmed into a spacecraft or launch vehicle orbital stage prior to the launch, and for consequent actions to be executed automatically when the programmed criteria have been met.

6.3.1.4 The condition of a spacecraft shall be monitored periodically during its operation to detect any anomalies that could affect its successful disposal.

6.3.1.5 During the operation of a spacecraft, if an anomaly is detected which could affect its successful disposal then a contingency plan shall be developed and implemented to mitigate this risk.

6.3.1.6 In case the mission lifetime is to be extended, the capability of a spacecraft to perform successful disposal shall be reassessed considering the status of the spacecraft at the beginning of the mission lifetime extension.

6.3.2 Disposal to minimize interference with the GEO protected region

6.3.2.1 A launch vehicle orbital stage shall be disposed of in such a way that long-term perturbation forces do not cause it to enter the GEO protected region within 100 years after its end of life.

6.3.2.2 A spacecraft operating in the GEO protected region with a continuous presence shall be disposed of in such a way that its orbital state, after disposal manoeuvres, satisfies at least one of the following conditions:

a) the orbit has an initial eccentricity less than 0,003 and a minimum perigee altitude ΔH (in km) above the geostationary altitude, in accordance with Formula (1):

$$\Delta H = 235 + \left(1\ 000 \times C_R \times A/m\right) \tag{1}$$

b) the orbit has a perigee altitude sufficiently above the geostationary altitude that long-term perturbation forces do not cause the spacecraft to enter the GEO protected region within 100 years after its end of life.

NOTE Formula (1) was derived to ensure that long-term perturbations will not cause a spacecraft to re-enter a protected zone of geostationary altitude plus 200 km.

6.3.2.3 A spacecraft operating in the GEO protected region with a periodic presence shall be disposed of in such a way that long-term perturbation forces do not cause it to enter the GEO protected region within 100 years after its end of life.

6.3.3 Disposal to minimize interference with the LEO protected region

6.3.3.1 The orbit lifetime of a spacecraft or launch vehicle orbital stage shall be less than 25 years starting from:

a) the orbit injection epoch, if the spacecraft or launch vehicle orbital stage operates continuously or periodically in the LEO protected region and has no capability to perform collision avoidance manoeuvres,

b) the end of mission epoch, if the spacecraft or launch vehicle orbital stage operates continuously or periodically in the LEO protected region and has the capability to perform collision avoidance manoeuvres, or

c) the epoch of first intersection of the orbit with the LEO protected region within 100 years after the end of life, if the spacecraft or launch vehicle orbital stage operates continuously outside of the LEO protected region.

6.3.3.2 The removal of a spacecraft or launch vehicle orbital stage from the LEO protected region shall be accomplished by one or more of the following means (in order of preference):

a) retrieving it safely to Earth,

b) performing a controlled re-entry with a well-defined impact footprint on the surface of the Earth to limit the possibility of human casualty,

c) allowing its orbit to decay naturally in accordance with the specified 25-year limit for orbit lifetime,

d) manoeuvring it in a controlled manner to reduce the remaining time in orbit so as to comply with the specified 25-year limit for orbit lifetime, or

e) augmenting its orbital decay by deploying a device to reduce the remaining time in orbit so as to comply with the specified 25-year limit for orbit lifetime.

NOTE In the previous edition of this document, ISO 24113:2011, an option f) was included which allowed a spacecraft or launch vehicle orbital stage to be disposed of above the LEO protected region. In this document, the option is no longer available.

6.3.4 Re-entry

6.3.4.1 Specific re-entry safety requirements imposed contractually, voluntarily or by national or international authorities shall be identified and applied.

NOTE Compliance with notification procedures defined by international civil aviation and maritime authorities is an important prerequisite for performing a controlled re-entry.

6.3.4.2 The quantifiable risks associated with a re-entry shall be less than or equal to the corresponding risk thresholds set by approving agents.

NOTE 1 There are several risks associated with a re-entry. Debris fragments that survive to reach the surface of the Earth represent an impact risk to people and property. Radioactive substances, toxic substances or any other hazardous materials that are released into the Earth's environment represent a pollution risk.

NOTE 2 A number of existing guidelines and regulations use 10^{-4} as the threshold for the re-entry casualty risk or the expected number of casualties, with the detailed method for risk assessment defined by the approving agent.

7 Planning requirements

7.1 General

Planning activities which define at a high level the space debris mitigation actions to be performed shall start during the mission design.

7.2 Space debris mitigation plan

7.2.1 A space debris mitigation plan (SDMP) that includes all phases of design, manufacturing, launch, operation and disposal shall be prepared.

7.2.2 As a minimum, the SDMP shall contain the following:

a) the applicable space debris mitigation requirements;

b) plans for addressing the applicable space debris mitigation requirements;

c) the verification and validation means to assess compliance with the applicable space debris mitigation requirements;

d) a compliance matrix;

e) justifications for non-compliance.

7.2.3 The SDMP shall be approved by approving agents.

7.2.4 The SDMP shall be reviewed, updated and implemented during the design, manufacturing, launch, operations and disposal phases.

