INTERNATIONAL STANDARD

ISO 24113

Second edition
2011-05-15

Space systems — Space debris mitigation requirements

Systèmes spatiaux — Exigences de mitigation des débris spatiaux

Reference number
ISO 24113:2011(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 24113 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

This second edition cancels and replaces the first edition (ISO 24113:2010), of which it constitutes a minor revision.

Introduction

Space debris comprises all non-functional, man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the Earth's atmosphere. The growing population of these objects poses an increasing hazard to missions. In response to this problem, there is international consensus that space activities need to be managed to minimize debris generation and risk. 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 International Standard.

The importance of this International Standard 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 space missions. 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 orbital lifetime. This is 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 end of mission;

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

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

— 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 International Standard transforms these objectives into a set of high-level debris mitigation requirements. Methods and processes to enable compliance with these requirements are provided in a series of lower-level implementation standards.

Space systems — Space debris mitigation requirements

1 Scope

This International Standard 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 or disposal actions.

The requirements contained in this International Standard 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 orbital lifetime.

This International Standard is the top-level standard in a family of standards addressing debris mitigation. It will be the main interface for the user, bridging between the primary debris mitigation requirements and the lower-level implementation standards that will ensure compliance.

This International Standard does not cover launch phase safety for which specific rules are defined elsewhere.

2 Normative references

The following referenced documents are indispensable for the application 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.

ISO 9000:2005, *Quality management systems — Fundamentals and vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 9000:2005 and the following apply.

3.1
approving agent
entity from whom approval is sought for the implementation of space debris mitigation requirements with respect to the procurement of a spacecraft, or its launch, or its operations in space, or a combination of those activities

EXAMPLE Regulatory or licensing authorities; national or international space agencies.

3.2
break-up
event that destroys an object and generates fragments that are released into space

3.3
casualty risk
probability that a person is killed or seriously injured

3.4
disposal
actions performed by a spacecraft or launch vehicle orbital stage to permanently reduce its chance of accidental break-up and to achieve its required long-term clearance of the protected regions

3.5
disposal phase
interval during which a spacecraft or launch vehicle orbital stage completes its disposal actions

3.6
end of life
instant when a spacecraft or launch vehicle orbital stage is permanently turned off, nominally as it completes its disposal phase, or when it re-enters, or when the operator can no longer control it

3.7
end of mission
instant when a spacecraft or launch vehicle orbital stage completes the tasks or functions for which it has been designed, or when it becomes non-functional or permanently halted because of a failure or because of a voluntary decision

3.8
geostationary Earth orbit
GEO
Earth orbit having zero inclination and zero eccentricity, whose orbital period is equal to the Earth's sidereal rotation period

3.9
launch vehicle orbital stage
stage of a launch vehicle that is designed to achieve orbit

3.10
Launching State
State that launches or procures the launching of a spacecraft, or a State from whose territory or facility a spacecraft is launched

NOTE This definition is consistent with the definition in the UN Liability Convention[5] and Resolution 59/115[6] of 10 December 2004 on the notion of the Launching State.

3.11
normal operations
planned tasks or functions performed by a spacecraft or launch vehicle orbital stage prior to its disposal

3.12
orbital lifetime
period of time from when a spacecraft or launch vehicle orbital stage achieves Earth orbit to when it commences re-entry

3.13
probability of successful disposal
probability of successfully disposing of a spacecraft or launch vehicle orbital stage, evaluated as a conditional probability weighted on the mission success at the time disposal is executed

NOTE See Annex A.

3.14
protected region
region in space that is protected with regard to the generation of space debris to ensure its safe and sustainable use in the future

3.15
re-entry
process in which atmospheric drag cascades deceleration of a spacecraft or launch vehicle orbital stage (or any part thereof), leading to its destruction or return to Earth

NOTE For operational purposes, this is when the period of the mean orbit is 89 min or less.

3.16
regulatory authority
governmental entity, national or international, that bears responsibility for implementing space debris mitigation policy or law with respect to the procurement of a spacecraft, or its launch, or its operations in space, or a combination of those activities

3.17
space debris
orbital debris
man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional

3.18
spacecraft
system designed to perform specific tasks or functions in space

NOTE A spacecraft that can no longer fulfil its intended mission is considered non-functional. Spacecraft in reserve or standby modes awaiting possible reactivation are considered functional.

4 Symbols and abbreviated terms

4.1 Symbols

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

C_R solar radiation pressure coefficient ($0 < C_\mathrm{R} < 2$)

$P(D|M)$ probability that disposal, D, will be successful given that the nominal mission, M, has been completed

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

Z_GEO altitude of the geostationary orbit with respect to a spherical Earth whose radius is 6 378 km

ΔH change in altitude

4.2 Abbreviated terms

GEO geostationary earth orbit

LEO low earth orbit

LV launch vehicle

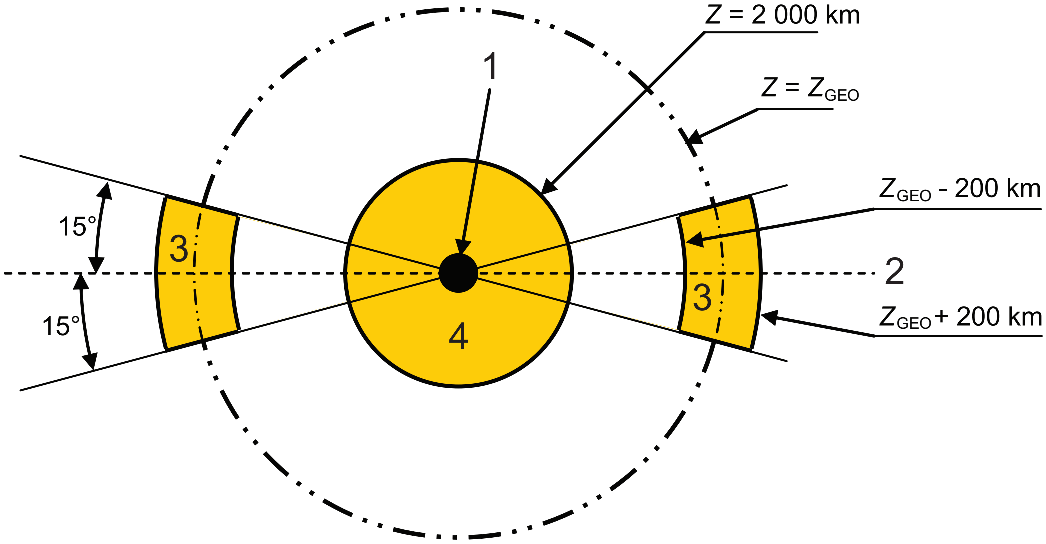
S/C spacecraft

SDMP space debris mitigation plan

5 Protected regions

5.1 General

Due to their operational interest and unique nature, the LEO and GEO regions are considered as protected regions with regard to space debris (see Figure 1).



Key

1 Earth

2 equator

3 GEO region

4 LEO region

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

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

NOTE The dimensions in the figure are not to scale.

Figure 1 — View in the equatorial plane of Earth and the protected regions

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 $\leqslant$ latitude $\leqslant$ 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 and launch vehicle orbital stages shall be designed so as not to release space debris into Earth orbit during normal operations.

6.1.1.2 Space debris released into Earth orbit as part of normal operations, other than as covered by 6.1.2, shall remain outside the GEO protected region, and its presence in the LEO protected region shall be limited to a maximum of 25 years after release.

6.1.2 Combustion-related products

6.1.2.1 Pyrotechnic devices shall be designed so as to avoid the release into Earth orbit of products larger than 1 mm in their largest dimension.

6.1.2.2 Solid rocket motors shall be designed and operated so as to avoid releasing solid combustion products into the GEO protected region.

6.1.2.3 In the design and operation of solid rocket motors, methods to avoid the release of solid combustion products that might contaminate the LEO protected region shall be considered.

6.2 Avoiding break-ups in Earth orbit

6.2.1 Intentional break-ups

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

6.2.2 Accidental break-ups

6.2.2.1 The probability of accidental break-up of a spacecraft or launch vehicle orbital stage shall be no greater 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, excluding those from external sources such as impacts with space debris and meteoroids.

6.2.2.3 During the disposal phase, a spacecraft or launch vehicle orbital stage shall permanently deplete or make safe all remaining on-board sources of stored energy in a controlled sequence.

6.3 Removing a spacecraft or launch vehicle orbital stage from the protected regions after end of mission

6.3.1 Probability of 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 at the time disposal is executed.

6.3.1.2 The probability of successful disposal, as discussed in Annex A, shall be evaluated as conditional probability weighted on the mission success, i.e. $P(D|M)$.

6.3.1.3 The start and end of the disposal phase, as illustrated in Annex B, shall be chosen so that all disposal actions are completed within a period of time that ensures compliance with 6.3.1.1.

6.3.2 GEO disposal manoeuvres

6.3.2.1 A spacecraft or launch vehicle orbital stage operating in the GEO protected region, with either a permanent or periodic presence, shall be manoeuvred in a controlled manner during the disposal phase to an orbit that lies entirely outside the GEO protected region.

6.3.2.2 A spacecraft operating within the GEO protected region shall, after completion of its GEO disposal manoeuvres, have an orbital state that satisfies at least one of the following two 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 Equation (1):

$$\Delta H = 235 + \left(1\,000 \times C_{\mathrm{R}} \times A/m\right) \qquad (1)$$

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.

6.3.3 LEO disposal manoeuvres

6.3.3.1 A spacecraft or launch vehicle orbital stage operating in the LEO protected region, with either a permanent or periodic presence, shall limit its post-mission presence in the LEO protected region to a maximum of 25 years from the end of mission.

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

a) retrieving it and performing a controlled re-entry to recover it safely on the Earth, or

b) manoeuvring it in a controlled manner into a targeted re-entry with a well-defined impact footprint on the surface of the Earth to limit the possibility of human casualty, or

c) manoeuvring it in a controlled manner to an orbit with a shorter orbital lifetime that is compliant with 6.3.3.1, or

d) augmenting its orbital decay by deploying a device so that the remaining orbital lifetime is compliant with 6.3.3.1, or

e) allowing its orbit to decay naturally so that the remaining orbital lifetime is compliant with 6.3.3.1, or

f) manoeuvring it in a controlled manner to an orbit with a perigee altitude sufficiently above the LEO protected region that long-term perturbation forces do not cause it to re-enter the LEO protected region within 100 years.

6.3.4 Re-entry

6.3.4.1 For the re-entry of a spacecraft or launch vehicle orbital stage (or any part thereof), the maximum acceptable casualty risk shall be set in accordance with norms issued by approving agents.

6.3.4.2 The re-entry of a spacecraft or launch vehicle orbital stage (or any part thereof) shall comply with the maximum acceptable casualty risk according to 6.3.4.1.

7 Space debris mitigation plan

7.1 The provider of a spacecraft or launch vehicle shall prepare a space debris mitigation plan (SDMP).

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

a) the applicable space debris mitigation requirements;

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

c) a compliance matrix;

d) justifications for non-compliance.

7.3 The SDMP shall be approved by approving agents.

Annex A
(informative)

Probability of successful disposal

A.1 General

If the orbital scenario of a spacecraft or launch vehicle orbital stage is constituted by the following two main phases,

— nominal mission, M,

— disposal phase, D,

then the conditional probability theorem allows us to state

$$P\left(M \cap D\right) = P\left(M\right) \times P\left(D \middle| M\right) \quad \text{(A.1)}$$

It follows that

$$P\left(D \middle| M\right) = \frac{P\left(M \cap D\right)}{P\left(M\right)} \quad \text{(A.2)}$$

Therefore, the probability, $P\left(D \middle| M\right)$, of successfully performing the disposal once the nominal mission has been completed may be estimated on the basis of the following:

a) $P(M)$: mission success probability (normally evaluated within the framework of the dependability programme to verify the compliance of the developed design with regard to the applicable mission reliability requirement), which can exclude consideration of the payload, and

b) $P\left(M \cap D\right)$: probability of correctly performing both mission and disposal phases [this is generally an extension of the $P(M)$ model].

Cases 1 to 3 below are presented to clarify the application of Equation (A.2). Other cases are also possible.

A.2 Case 1

The end-of-mission disposal is performed making use of “all” subsystems involved in the nominal mission, as illustrated in the Venn diagram shown in Figure A.1.

In this way, the reliability model defined for the nominal mission (0; T_{mission}) is extended to cover both phases (0; $T_{\text{mission}} + T_{\text{disposal}}$).

$$P(D|M) = \frac{R_{\text{system}}(T_{\text{mission}} + T_{\text{disposal}})}{R_{\text{system}}(T_{\text{mission}})} \times P_{\text{propellant}} \quad \text{(A.3)}$$

where R_{system} is the reliability of all the subsystems used for normal operations and $P_{\text{propellant}}$ is the probability of there being sufficient propellant to perform a successful transfer to, and injection into, the final disposal orbit. For spacecraft that do not have a propulsion subsystem, this term is not applicable.

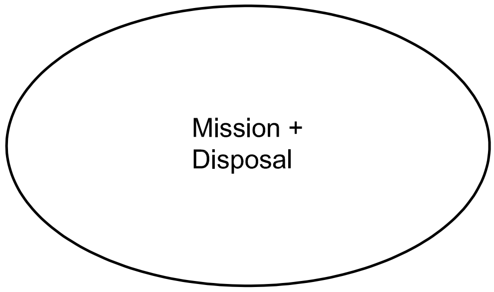


Figure A.1 — All subsystems involved in the nominal mission required for disposal

A.3 Case 2

The end-of-mission disposal is performed making use of “some” subsystems involved in the nominal mission, as illustrated in the Venn diagram shown in Figure A.2.

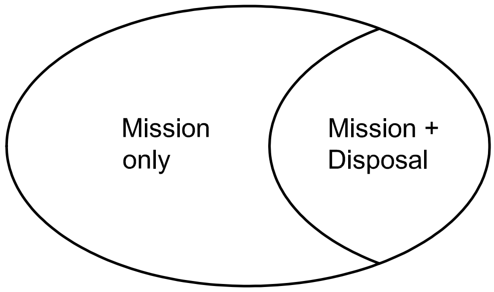


Figure A.2 — Some subsystems involved in the nominal mission are used for disposal

In this case, the function $R'_{\text{system}}(t)$ includes the reliability of the subsystems used for disposal estimated over the interval (0; $T_{\text{mission}} + T_{\text{disposal}}$). For the remaining subsystems, the interval (0; T_{mission}) is considered. For all subsystems, the reliability models defined for mission success may be used, even if with different time durations.

The reliability function $R_{\text{system}}(t)$ refers to the nominal mission (as presented in Case 1).

$$P(D|M) = \frac{R'_{\text{system}}(T_{\text{mission}} + T_{\text{disposal}})}{R_{\text{system}}(T_{\text{mission}})} \times P_{\text{propellant}} \tag{A.4}$$

A.4 Case 3

The end-of-mission disposal is performed making use of dedicated equipment and “some” subsystems involved in the nominal mission, as illustrated in the Venn diagram shown in Figure A.3.

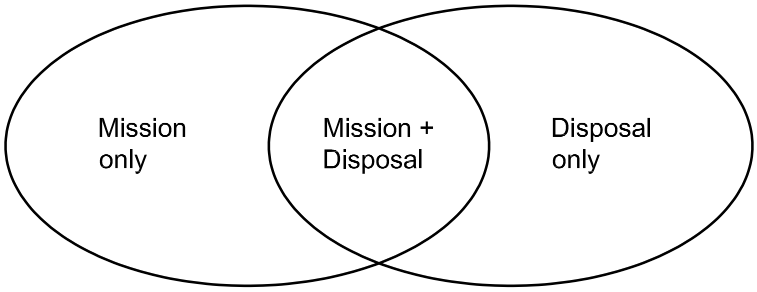


Figure A.3 — Disposal requires some systems used for normal operations plus some systems specifically used for disposal only

In this extension of Case 2, the $R''_{\text{system}}(t)$ function includes the contribution of the equipment for disposal, which is considered in active or passive mode (as applicable) in the interval (0; T_{mission}) and in active mode in the interval (T_{mission}; $T_{\text{mission}} + T_{\text{disposal}}$).

The reliability function $R_{\text{system}}(t)$ refers to the nominal mission (as presented in Case 1).

$$P(D|M) = \frac{R''_{\text{system}}(T_{\text{mission}} + T_{\text{disposal}})}{R_{\text{system}}(T_{\text{mission}})} \times P_{\text{propellant}} \quad \text{(A.5)}$$

Annex B
(informative)

Post-launch life cycle phases of a launch vehicle or spacecraft

The post-launch life cycle phases of an Earth-orbiting launch vehicle and spacecraft are shown in Figures B.1 and B.2, respectively. The length of each phase and its relationship to other phases are shown for illustrative purposes only.

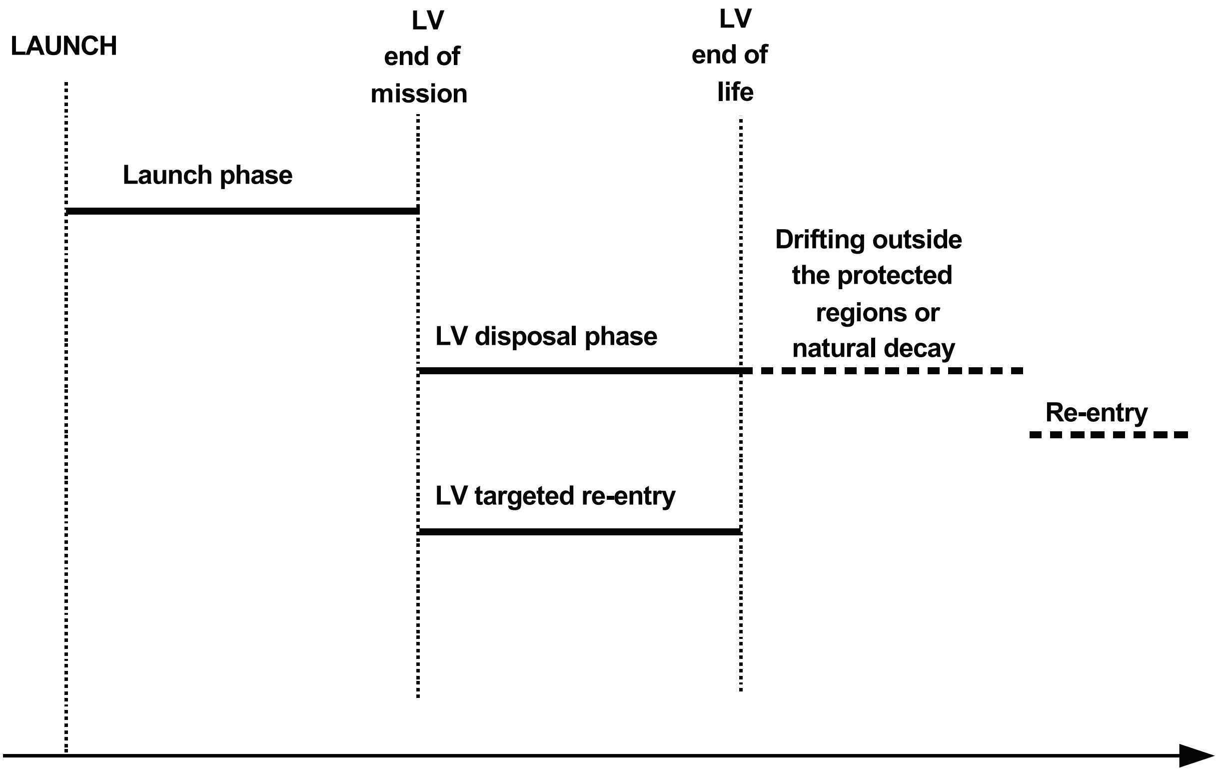


Figure B.1 — Post-launch life cycle phases of an Earth-orbiting launch vehicle (LV)

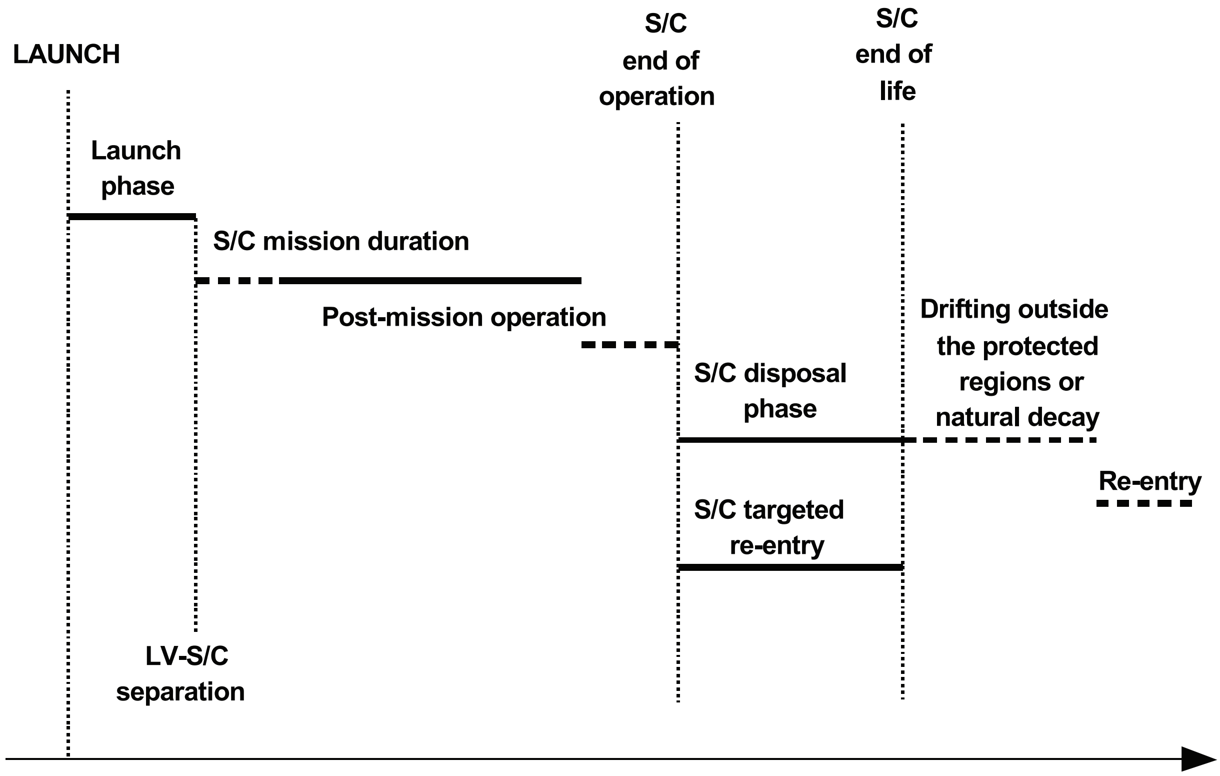


Figure B.2 — Post-launch life cycle phases of an Earth-orbiting spacecraft (S/C)

The end of the disposal phase is the point in time, T_{disposal}, at which all disposal actions are completed. Nominally, this is at end of life. For launch vehicles, it should be noted that the disposal phase will end after a short period of time as this is usually limited by battery life.

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ICS 49.140

Price based on 13 pages