TECHNICAL REPORT

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Space systems — Space debris mitigation design and operation manual for launch vehicle orbital stages

Systèmes spatiaux — Lignes directrices de conception et de manœuvre des étages orbitaux de lanceurs pour réduire les 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).

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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 second edition cancels and replaces the first edition (ISO/TR 20590:2017), which has been technically revised.

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

— text has been updated to be aligned with ISO 24113:2019;

— information has been added that the total number of structural elements and orbital stages is limited according to the number of payloads;

— information has been added that the ejection of slag debris from solid rocket motors is limited newly in low Earth orbit in addition to GEO previously;

— information relating to collision avoidance against catalogued space objects has been improved;

— corresponding to the new requirement limiting the total probability of successful disposal to be at least 0,9, the state of the art to confirm the compliance with that taken in the world space industries and national agencies has been added;

— other information relating to the changes in ISO 24113 has been added.

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

Coping with debris is essential to preventing the deterioration of the orbital environment and ensuring the sustainability of space activities. Effective actions can also be taken to ensure the safety of those on the ground from re-entering objects that were disposed of from Earth orbit.

Recently, the orbital environment has become so deteriorated by debris that it is necessary to take actions to mitigate the generation of orbital debris in design and operation of both spacecraft and the launch vehicle orbital stages.

ISO 24113 and other ISO documents, introduced in Bibliography, were developed to encourage debris mitigation activities.

In Clause 5, information about the major space debris mitigation requirements is provided.

In Clause 6, information about life-cycle implementation of space-debris-mitigation-related activities is provided.

In Clause 7, the system level aspects stemming from the space debris mitigation requirements are highlighted; while in Clause 8, the impacts at subsystem and component levels are detailed.

This document provides comprehensive information on the requirements and recommendations from ISO documents for the design and operation of the launch vehicles.

Space systems — Space debris mitigation design and operation manual for launch vehicle orbital stages

1 Scope

This document contains information on the design and operational practices for launch vehicle orbital stages for mitigating space debris.

This document provides information to engineers on the requirements and recommendations in the space debris mitigation standards to reduce the growth of space debris by ensuring that launch vehicle orbital stages are designed, operated, and disposed of in a manner that prevents them from generating debris throughout their orbital lifetime.

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.

ISO 24113:2019, *Space systems — Space debris mitigation requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 24113 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/

4 Symbols and abbreviated terms

CDR	critical design review
CNES	Centre National d'Études Spatiales
COPUOS	Committee on the Peaceful Uses of Outer Space
CSpOC	Combined Space Operations Center (USA)
DAS	debris assessment software (NASA)
DRAMA	debris risk assessment and mitigation analysis (ESA)
E_c	expected number of casualties
EOMDP	end-of-mission (operation) disposal plan
EOL	end-of-life
ESA	European Space Agency

FDIR	failure detection, isolation and recovery
FMEA	failure mode and effect analysis
GEO	geostationary Earth orbit
GTO	geosynchronous transfer orbit
IADC	Inter-Agency Space Debris Coordination Committee
JAXA	Japan Aerospace Exploration Agency
LEO	low Earth orbit
LV	launch vehicle
NOTAM	notice to airmen and notice to mariners
NM	notice to mariners
PDR	preliminary design review
QA	quality assurance
QR	qualification review
S/C	spacecraft
SDMP	space-debris-mitigation plan
SRR	system requirement definition review
STELA	semi-analytic tool for end of life analysis (CNES)
UN	United Nations

5 System-level activities

5.1 General

To accomplish comprehensive activities for debris mitigation work, the following steps are considered:

a) Identifying debris related requirements, recommendations, and best practices.

b) Determining how to comply with requirements, recommendations, and best practices.

c) Applying debris mitigation measures early and throughout development and manufacturing to assure sound debris mitigation capability in the final product.

d) Applying appropriate QA and qualification programs to ensure compliance with debris mitigation requirements.

e) Applying appropriate procedures during operation/utilisation and disposal to implement proper space debris mitigation.

This clause provides information useful for taking comprehensive action at the system level. More detailed information for action at the subsystem and component levels is provided in Clause 8. The following specific subjects are emphasized:

— limiting the release of objects into the Earth orbit;

— preventing fragmentation in orbit;

— proper disposal at the end of operation;

— minimization of hazards on the ground from re-entering debris;

— collision avoidance during launch at least for inhabited systems;

— quality, safety, and reliability assurance.

5.2 Design for limiting the release of objects

5.2.1 Intents of requirements in ISO 24113

ISO 24113:2019, 6.1, requires avoiding the intentional release of space debris into Earth orbit during normal operations, including general objects such as fasteners, fragments (larger than 1 mm) from pyrotechnics, slag (larger than 1 mm) from solid rocket motors, etc.

The following objects are concerned:

a) objects released according to the mission requirements (not directly indicated in ISO 24113:2019, 6.1.1.1, though);

b) mission-related objects, such as yo-yo de-spinners, fasteners and other parts (ISO 24113:2019, 6.1.1.1);

c) total number of structural elements in multi-payloads launches and orbital stages. (ISO 24113:2019, 6.1.1.2);

d) fragments and combustion products from pyrotechnic devices (ISO 24113:2019, 6.1.2.1);

e) slag from solid motors (ISO 24113:2019, 6.1.2.2).

ISO 24113 implies that if objects are unavoidably released despite the requirements, the orbital lifetime of such objects in LEO and the interference with GEO is limited as described in ISO 24113:2019, 6.1.1.3 (a typical example is the support structure utilized in a multiple payloads mission).

5.2.2 Work breakdown

Table 1 shows the work breakdown as delineated in ISO 24113 to prevent the release of debris.

Table 1 — Work breakdown for preventing the release of debris

Process	Subjects	Major work
Preventive measures	Identification of released objects and design measures	a) Take preventive design to avoid releasing objects that would turn into space debris. b) Minimise the total number of structural elements in multi-payloads launches, orbital stages, etc. c) If release is unavoidable, designers estimate the orbital lifetime of released objects and check compliance with ISO 24113:2019, 6.1.1.3. d) Apply pyrotechnic device which doesn't eject fragments or combustion product. e) When applying the solid motors, the possibility of generation of slag and its risk posed to environment will be assessed.

Table 1 *(continued)*

Process	Subjects	Major work
Corrective actions	Trouble shooting	Reference: If an object would be released unexpectedly, it is investigated and taken appropriate action to avoid repeating the release in the following missions.

5.2.3 Identification of released objects and design measures

a) Mission-related objects

The following objects are concerned (ISO 24113:2019, 6.1.1.1):

1) nozzle closures for propulsion devices and certain types of igniters for solid motors, which are ejected into space after ignition (particularly if their orbital lifetimes are longer than 25 years);

2) clamp bands that tie the S/C and launch vehicles;

3) structural elements used in multi-payloads launches, fragments and combustion products from pyrotechnic devices, and slag from solid motors are excluded from ISO24113:2019, 6.1.1.1, but are mentioned in ISO24113:2019, 6.1.1.2 and 6.1.2.

b) Structural elements in multi-payloads launches, orbital stages, etc. (ISO 24113:2019, 6.1.1.2)

ISO 24113:2019, 6.1.1.2 requires limiting the total number of orbital stages and “space objects” to one for the launch of a single spacecraft and two for the launch of multiple spacecraft. Generally, “space objects” means structural elements such as payload adaptors.

This requirement seems to prohibit to inject multiple stages in any instance. However, considering the ultimate objective to minimize the number and mass of orbital objects, this requirement can be understood in a slightly different way. For example, in the case that a three-stage LV is designed to leave two stages in orbit during the launch of a single spacecraft, if the second stage has a very short decay life, the third stage is relatively small, and that the total in-orbit collision risk and the total re-entry casualty risk are demonstrably lower compared to the option of leaving one stage in orbit, it is an option worth studying. Careful analysis is needed to confirm the benefit before applying this requirement.

c) Fragments and combustion products from pyrotechnic devices (ISO 24113:2019, 6.1.2.1)

Adequately designed devices are selected to avoid the release of fragments or combustion products. It is possible to apply parts that trap all fragments and combustion products larger than 1 mm inside for segregation.

d) Combustion products from solid motors (ISO 24113:2019, 6.1.2.1)

1) It is preferable not to use an upper-stage with solid propulsion potentially leaving debris in orbit (slag, throat elements), especially if the altitude of the orbit is higher than that of inhabited systems, and if the solid propulsion system conception includes a dead-zone where recirculating gases can concentrate some metalized slag which can be ejected in orbit.

2) It is taken into consideration that if a solid motor is fired to decrease the velocity of the orbital object, to deorbit it for instance, as the particles velocity would increase with that of the orbital object, leading to an increase in apogee of the particles.

e) Estimation of orbital lifetime (ISO 24113:2019, 6.1.1.3)

The orbital lifetime of released objects is assessed as specified in ISO 27852. ISO 27852 designates acceptable analysis methodologies the user employs dependent upon the orbit regime. The available simplified tools that are admissible to estimate the long-term orbital lifetime are introduced in 5.4.3.1.

5.2.4 Monitoring during operation

The released objects, if they are large enough to be detected from the ground, can be confirmed by ground-based space tracking facilities to ensure that they are released as expected and that their orbital lifetimes are sufficiently short. The Space Situation Report provided by the US Combined Space Operations Center (CSpOC https://www.space-track.org/auth/login) provides a good reference.

5.2.5 Preventing failure

If objects are released unexpectedly, the origin of the objects can be identified to help prevent recurrence in future missions. Because such phenomena can indicate a malfunction, the situation is reviewed carefully, and appropriate action is taken to prevent further abnormal conditions.

5.3 Break-up prevention

5.3.1 Break-up caused by intentional behaviour, or stored energy

5.3.1.1 Intents of requirements in ISO 24113

ISO 24113:2019, 6.2 requires the prevention of break-ups caused by intentional behaviour, stored energy, collision with large objects, and impact of tiny debris or meteoroid. This subclause introduces the result of study for the break-ups due to the intentional behaviour, and the stored energy.

While ISO 16127 addresses the prevention of break-ups of S/C, it also provides useful information to the launch vehicle.

5.3.1.2 Work breakdown

Table 2 shows the work breakdown as delineated in ISO 24113 to prevent orbital break-up.

Table 2 — Work breakdown for preventing orbital break-ups

Process	Subjects	Major work
Preventive measures	Identification of sources of breakup	Identify components that can cause fragmentation during or after operation.
	Design measures	1) Preventive designs to limit the probability of accidental break-up during operation no greater than 10^{-3}. Confirm it with FMEA. 2) Providing functions to prevent break-ups after disposal. 3) Preventive design to avoid an unintentional destruction of a self-destruct system caused by miss-command or solar heating.
Risk detection	Monitoring for successful disposal	1) Providing functions to monitor the health of vehicle at the critical events particularly for the decision to proceed to the controlled re-entry. 2) In the case of controlled re-entry, the critical parameters to decide the initiation of re-entry action are monitored. 3) All the cases including the non-controlled re-entry, some parameters to identify the successful execution of critical operation, such as re-ignition, separation of payload, passivation, etc. are being monitored.
Actions in operation phase	Preventive measures for break-up	Energy sources for break-up are removed (residual propellants, high-pressure gas, etc.) or designed to assure safety so as not to cause break-ups after the end of operation.

5.3.1.3 Identification of the sources of break-up

The following launch vehicle subsystem or elements can be potential causes of break-ups:

a) propulsion subsystems and associated components (rocket engines and solid motors, tanks, tank pressurizing systems, valves, piping, etc.);

b) electrical batteries;

c) pressure vessels and other equipment (such as pneumatic control systems);

d) self-destruct systems for range safety.

5.3.1.4 Design measures

Nowadays, the following aspects are incorporated into the design of launch vehicles.

a) Avoiding accidental break-ups during operation

Per ISO 24113, the probability of accidental break-up is no greater than 10^{-3} until its EOL.

ISO 16127 is designed to apply to the S/C, but ISO 16127:2014, Annex A provides adequate instructions to engineers on coping with complicated subsystems such as liquid rocket engines.

To prevent the unintentional explosion of self-destruct charges, the command destruct receivers are turned off after passing through the range safety areas to prevent explosion due to miss-command.

b) Preventing break-ups that occur after the end of operation

The following items are the typical measures to prevent fragmentation for each of the items identified in 5.3.1.3. More detailed information for each subsystem or component is described in Clause 8.

1) Residual propellants in the propulsion systems and associated components

— burning residual propellants to depletion;

— venting residual propellant until its amount is insufficient to cause a break-up by ignition or pressure increase from tanks and lines;

— adequate design of tank. (Historically, some explosion events of the orbital stages and the assist modules were caused by a type of propellant tank design combined fuel and oxygen tanks, separating them only by a common bulkhead.)

2) High pressure fluids

— venting pressurized systems.

3) Range safety systems

— prevention from inadvertent commands, thermal heating, or radio frequency interference.

5.3.1.5 Preventive measures for break-up after mission completion

After separation of payloads, the major sources of break-ups (examples listed in 5.3.1.3) are mitigated (vented or operated in safe mode) according to ISO 16127:2014, 4.4.

Residual propellants and other fluids, such as pressure gasses, are depleted as thoroughly as possible, by either depletion burns or venting, to prevent accidental breakups by over pressurization or chemical reaction. Opening fluid vessels and lines to the space environment, directly or indirectly, at the conclusion of EOM passivation, is one way to reduce the possibility of a later explosion or rupturing, especially if the stage thermal configuration and solar aspect angle allow for a vaporisation of the remaining propellant.

The passivation actions are usually monitored to confirm the successful disposal.

5.3.2 Avoidance of collision

There are no definite requirements for collision avoidance of the launch vehicles in ISO 24113. However, the UNCOPUOS Space Debris Mitigation Guidelines[3] address that "the probability of accidental collision with known objects during the systems' launch phase and orbital lifetime should be estimated and limited. And if available orbital data indicate a potential collision, adjustment of the launch time or an orbital avoidance manoeuvre should be considered".

For the launch vehicle, the only way to avoid collision is to coordinate the lift-off time so as not to collide with known objects and ensure no collisions until a space surveillance network, e.g. CSpOC, determines the orbital characteristics of orbital stages and other released objects.

However, since the dispersion of flight trajectories complicates the avoidance of collision with all known objects at later times, the best practice is at least to avoid collision with inhabited systems whose operational plan is disclosed (ISS, etc.), primarily for safety reasons. When it is obvious that lift-off times or flight trajectories conflict with known objects, it is desirable to avoid these lift-off times or flight trajectories.

The criteria and procedures for collision avoidance have not been globally defined yet. The basic concept is that a launch service provider assures that each stage of the launch vehicle, payload, and other objects separated from the stages would not collide for a few days (two days, for example) after lift-off until a space surveillance network, e.g. CSpOC, determines the orbital characteristics of orbital stages and all the objects separated from them.

5.4 Disposal manoeuvres at the end of operation

5.4.1 Intents of requirements in ISO 24113

ISO 24113:2019, 6.3 addresses the disposal of a spacecraft or launch vehicle orbital stage at end-of-mission and requires that probability of successful disposal (PSD) be larger than 0,9. This requirement is based on the research conducted by IADC that, to keep the LEO environment stable, LEO space system is removed from the LEO protected orbital region within 25 years, on the condition that the 90 % of the space systems are disposed properly.

The probability is evaluated based on mainly the inherent reliabilities of disposal function. However, since such probability is dependent on several other factors which are identified in ISO 24113, and some of them are unmeasurable factors, there is no method to demonstrate perfectly the compliance with this requirement quantitively. These factors are:

a) the uncertainties in the availability of resources, such as propellant;

b) the inherent reliabilities of subsystems, monitoring of those subsystems, and operational remediation of any observed subsystem degradation or failure;

c) the risk that a space debris or meteoroid impact prevent the disposal (not mandatory).

In the case of spacecraft, the compliance is assessed with comprehensive design and operation measures and procedures. In the case of the launch vehicle, the reliability at the end of mission is assessed with a normal procedure; and the resources for disposal maneuverer is assured. The matters of the probability of impact with debris and meteoroid, or the effect of life extension, are not concerned.

ISO 26872 provides more detailed requirements and procedures for the disposal of GEO missions (the mission of direct injection of GES) to comply with the high-level requirements stated in ISO 24113; and ISO 16699 provides more detailed requirements and procedures for the disposal of launch vehicle orbital stages in LEO missions.

5.4.2 Work breakdown

Table 3 shows the work breakdown as delineated in ISO 24113 to protect orbital regions.

Table 3 — Work breakdown for the preservation of the LEO-protected region

Process	Subjects	Major work
Preventive measures	Estimate the orbital lifetime and define a disposal plan	Estimate the orbital lifetime after payload separation and define a disposal manoeuvre plan.
	Disposal planning	One of the following methods is applied. (ISO 24113:2019, 6.3.3.2): a) retrieving it safely to Earth, as per ISO 24113:2019, 6.3.3.2, a), or b) performing a controlled re-entry with a well-defined impact footprint on the surface of the Earth, or c) allowing its orbit to decay naturally in accordance with the specified 25-year limit for orbit lifetime, or d) manoeuvring it to reduce the remaining time to comply with the specified 25-year limit, or e) augmenting its orbital decay by deploying a device to reduce the remaining time to comply with the specified 25-year limit. The option to manoeuvre a perigee altitude to above the LEO protected region was deleted in ISO 24113:2019.
	Disposal function and resources	Functions and resources are provided to remove orbital stages (e.g. restart function of main engine, secondary propulsion systems, or independent thrusters) from the protected orbital region.
	Reliability of disposal function	Design the reliability of disposal function in development life cycle or confirm it in the production life cycle.
Action in operation phase	Disposal sequence	Disposal operations are executed in the proper sequence.

5.4.3 LEO mission

5.4.3.1 Estimate the orbital lifetime and define a disposal plan

For LEO missions, ISO 16699:2015, 5.3 shows the planning and documentation for a disposal manoeuvre. ISO 27852 shows the steps and tools to estimate the orbital lifetime in more detail. The precision of analysis is dependent on the algorithm; and using high-precision algorithms, it takes several hours to complete the analysis, which is not adequate for use in the early phases when the exact operation plan has not been fixed. Tools are selected during the design phase.

There are several tools available to calculate the orbital lifetime, for instance:

a) ISO 27852 introduces "STELA" available via the CNES freeware server. As of October 2020, the latest version is 3.3, and it can be downloaded from https://logiciels.cnes.fr/content/stela?language=en.

NASA is releasing "DAS (debris assessment software)" (since October 2020, latest version is v 3.0.1), which has functions to analyse various debris related matters comprehensively, including the orbital lifetime analysis (https://orbitaldebris.jsc.nasa.gov/mitigation/debris-assessment-software.html).

b) ESA provides the DRAMA tool available at https://sdup.esoc.esa.int/.

c) Other viable commercial off-the-shelf (COTS) toolkits exist to determine orbit lifetime.

5.4.3.2 Disposal planning

ISO 16699 provides more detailed requirements and guidance for the orbital stages. An EOMDP is required. The process of developing it is described in detail in ISO 16699:2015, Clause 7.

5.4.3.3 Disposal function and resources to transition to disposal orbit

a) It is thought to be better to provide liquid propellant engines with a re-start function to perform a disposal manoeuvre after payload separation.

b) In some cases, other propulsion devices, including attitude control thrusters, can be used.

c) Drag-enhancement, solar radiation pressure, or other devices can also be used.

5.4.3.4 Probability of successful disposal

In the case of S/C, since it is not easy to comply with requirement of the probability, ISO 24113:2019, 3.20, Note 2 to entry states: "The calculation of this probability can include 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". However, in the case of launch vehicle, achieving compliance is usually considered easier, since the mission duration is so short that there is no need to be conscious about the degradation of reliability, limit of the useful lifetime, degradation of components, probability of debris impact, etc.

ISO 24113:2019, 6.3.1.3 requires spacecraft to decide on initiating the disposal action in adequate conditions to assure a successful disposal. However, for the launch vehicle orbital stage, it is applied to just the case of controlled re-entry and requires developing a specific criterion to allow initiating the re-entry operation and if met, consequent actions are executed. This requirement intends to minimize the re-entry risk due to the unsuccessful controlled re-entry.

NOTE ISO 24113:2019, 6.3.1.3 supports an on-board Go/NoGo criterion and computation to determine whether a controlled re-entry is to be pursued or not, in real time. This criterion considers the status of on-board avionics, remaining propellant, etc.

5.4.4 GEO missions and other high-elliptical orbit missions

5.4.4.1 General

Detailed requirements and procedures for GEO S/C are defined in ISO 26872. The concept of disposal methods of launch vehicle orbital stages for the mission of direct injection of GES, is similar to those for the GEO S/C.

There are several methods to launch a GEO S/C; and the typical methods are the following:

a) High elliptical GTO: this is the most typical case in which the perigee altitude is within or close to the LEO protected region, and the apogee altitude is near GEO. The S/C is transferred to GEO by firing its apogee kick propulsion system.

b) Direct injection: the orbital stages reach the circular orbit near GEO. The S/C is transferred to GEO with the S/C control function.

c) Another elliptical orbit: the apogee altitude is higher than GEO; and the perigee altitude is inside or near the LEO protected region.

5.4.4.2 High elliptical GTO

In the case of the high elliptical GTO mentioned in 5.4.4.1, a), orbital stages left in GTO after payload injection generally pose a risk to both GEO and LEO protected regions.

It is desirable to place the perigee altitude as low as possible to limit orbital lifetime to shorter than 25 years. However, as explained in ISO 27852:2016, 5.6, since it is difficult to estimate lifetime in GTO with a specific value due to the perturbation caused by the solar reflection and the gravities of sun and moon, it is better to provide the maximum lifetime corresponding to the planned perigee altitude while indicating its probability (e.g. If the perigee will be sent to 200 km, the lifetime will be shorter than 25 years, with a probability of 0,9). This probability can be counted outside the probability of successful disposal. If the right ascension of the ascending node (RAAN) can be controlled well by adequately selecting the lift-off time, the orbital lifetime can be greatly reduced.

If the orbital stages have a re-start function in the main engine, the decreasing of either apogee altitude or perigee altitude is possible. Lowering the apogee altitude immediately precludes interference with the GEO protected region, but orbital lifetime cannot be shortened significantly. On the other hand, lowering the perigee altitude takes longer time to avoid interference with GEO; but it is more efficient at reducing the orbital lifetime.

In some missions, perigee altitude can be as high as a few thousand kilometres; and natural forces are not available to decay the orbit. In this case, the apogee altitude is placed 200 km lower than the GEO altitude.

5.4.4.3 Direct injection

In the case of direct injection, the orbital stage and payloads are typically sent directly into or near the GEO protected region. Then, the payloads perform manoeuvres to move to the planned operation orbit in GEO; and the orbital stage is left outside the GEO protected region.

5.4.4.4 Other elliptical orbits

There are missions which are not GEO missions but inject payloads in an elliptical orbit. ISO 24113 requires the same measures for such missions as for GTO missions. This means that the following are required:

a) Elliptic orbit: if apogee altitude is lower than the GEO area, and the perigee altitude is above the LEO area. If there will be no risk to the GEO and LEO protected regions for at least 100 years, there will be no suggestions for those objects.

b) Very high elliptic orbit: if the apogee altitude is higher than the GEO area, and circularization above the GEO altitude is not reachable, such orbit will be avoided where possible.

5.5 Ground safety from re-entering objects

5.5.1 Intents of requirements in ISO 24113

ISO 24113:2019, 6.3.4 requires ensuring ground safety from re-entering objects.

5.5.2 Work breakdown

ISO 27875 indicates the risk assessment procedure. Table 4 shows the work breakdown as delineated in ISO 24113 to assure ground safety from re-entry.

Table 4 — Work breakdown related to ground safety from re-entry

Process	Subjects	Major work
Preventive measures	Identification of requirements	Identify the re-entry safety requirements imposed contractually, voluntarily, or by national or international authorities.
	Hazard analysis to estimate the casualties	Hazard analysis is conducted to estimate the expected number of casualties and the pollution on the ground.
	Design measures	(1) During design phase, the casualty risk is limited in accordance with norms issued by approving agents. (2) Prevent environmental pollution on the ground. (3) If the expected number of casualties is larger than the requirement, a controlled re-entry is planned (ISO 27875). (4) If the casualty risk is small enough comparing to the criteria imposed by the authority, and effective and practical measures were taken to reduce it, the uncontrolled re-entry is selected.
Risk detection	Notification of impact	For controlled re-entry, notifications are sent to all countries that can be affected or will be sent through the NOTAM and NMs systems.
Action in operation phase	Conduct controlled re-entry and Monitoring	(1) Conduct controlled re-entry as planned. (2) Monitor the re-entry procedure and take adequate action in abnormal situations.

5.5.3 Preventive measures

5.5.3.1 Identification of requirements

The first step is identification of re-entry safety requirements imposed contractually, voluntarily, or by national or international authorities. ISO 27875 indicates the risk assessment procedure without mandating quantitative requirements.

ISO 27875 provides procedures for assessing, reducing, and controlling the potential risks that the re-entering launch vehicle orbital stages pose to people and the environment, but does not show quantitative criteria even for the risk of expected number of casualties (E_c), which is defined by appropriate regulatory bodies. ISO 24113 mentions a quantitative threshold of 10^{-4} as a common example.

Note ISO 24113:2019, 6.3.4 mentions "casualty risk", but, as ISO 27875 points out, there are another risk including environmental pollutions. Therefore "re-entry risk" is understood as comprehensive risk defined by approving agents.

5.5.3.2 Hazard analysis

As specified in ISO 27875:2019, 5.2 and 5.5, safety requirements are identified; and the hazard risks are estimated using approved processes, methods, tools, models, and data. Then, the estimated risk is assessed to determine the necessity of risk reduction measures.

If the expected number of casualties exceeds the criteria, despite the design improvement (see 5.5.3.3, or ISO 27875:2019, 6.2), the impact area is controlled according to ISO 27875:2019, 6.3. Because the system concept can be affected significantly depending on whether the controlled re-entry will be applied, the decision is made early enough to reflect it in the system specifications.

NOTE 1 At present, there is no consensus on the standard analysis tools or algorithms, analysis conditions, thermal properties of materials, distribution model of human population with prediction models for the future, or even formulae to calculate casualties from the size of object impacts. These factors depend on the technical judgment or management decisions of organizations.

NOTE 2 Several national agencies have developed re-entry survivability analysis tools for their own use. For rough estimation, there are several analysis tools available in the world, such as DAS (debris assessment software) provided by NASA (available at https://orbitaldebris.jsc.nasa.gov/mitigation/debris-assessment-software.html) and the DRAMA tool by ESA (available at https://sdup.esoc.esa.int/web/csdtf/home). However, both tools are used to obtain very rough estimations; therefore, the official value is estimated with the tool officially authorized by the responsible organization.

5.5.3.3 Design measures

5.5.3.3.1 Design for demise

Even in the case of a controlled re-entry, since the risk of re-entry on the ground is assessed by the product of the failure rate of related functions and the expected number of casualties in the case of natural re-entry, it is better to design as much as possible for objects are easily demised.

Generally, the following are taken in the design phase; but some of them can be limited to the orbital stages.

a) Selection of adequate materials

Whenever possible, materials with a high melting temperature, specific heat, and heat of fusion, such as titanium or beryllium, are replaced by other materials with thermal characteristics that encourage demise. Generally, propellant tanks and high-pressure bottles made of titanium have been found on the ground after surviving a re-entry. There are tanks made of aluminium alloy, which seems to be better in terms of thermal characteristics that encourage demise.

b) Multiple materials, thinner wall thickness, etc.

Sometimes, a material that does not undergo demise can be replaced by multiple materials that do undergo demise and still maintain structural integrity. For example, a dummy mass or balance weight can be designed as a set of multiple metal plates instead of one thick, solid mass.

If there is enough structural margin, and if it is possible to reduce wall thickness without changing the dimensions, the material can undergo demise more readily.

c) Exposure to the ablation environment

Components that will be exposed to the ablation environment can undergo demise more readily. If propellant tanks or high-pressure bottles are located so that they are exposed to the atmosphere during re-entry, they can undergo demise more readily. However, this exposure to the atmosphere incurs disadvantages during the orbit phase in terms of protection from the thermal effects and debris impact.

5.5.3.3.2 Prevention of environmental pollution on the ground

Efforts are also be made to avoid polluting the environment with toxic substances (including radioactive materials) as required in ISO 27875:2019, 5.6.

5.5.3.3.3 Specific design for controlled re-entry in subsystem level

Subsystem engineers, who are involved in controlled re-entry from the aspects of not only propulsion subsystem but also power, guidance, and communication subsystems, consider specific functions and performance, as well as support of the ground station. It is also necessary to define uninhabited regions, such as broad ocean areas, which accept the footprint of survived fragments. For these reasons, the decision to use a controlled re-entry is made early in the design and development cycle, before system specifications are set.

For example, a controlled re-entry can take a longer operation time to complete and result in a longer exposure to the radiation environment. Therefore, all systems are qualified for this additional lifetime and required to meet radiation hardness design requirements.

5.5.4 Risk detection: notification

ISO 27875:2019, 7.5 defines the notifications in case of a planned re-entry event.

5.5.5 Countermeasures: controlled re-entry and monitoring

In the case that controlled re-entry is planned, it is thought to be better to monitor the progress and confirm the consequences.

5.6 Reliability and QA

It is important to ensure enough reliability and quality. ISO 16127:2014, 5.1 contains the requirements for reliability and quality control to prevent failures that can lead to a break-up event.

The methodology for assessing break-up probability and the probability of successful disposal is provided in ISO 24113:2019, 6.2.2 and 6.3.1.

The trade-off between cost reduction and quality/reliability always exists in the development of space systems. Levelling QA according to the importance of a mission is typically conducted during project management. However, note that orbital stages with low quality can become debris in orbit and pose a risk to other space operators.

ISO 27025 provides the quality assurance system and a wider scope consisting of product assurance, quality assurance; and ISO 23460 provides dependability assurance.

6 Debris-related work in the development life cycle

6.1 General

A typical phased planning of the development life cycle is illustrated in Figure 1, according to ISO 14300-1

From an early phase in the life cycle of the orbital stages, the preservation of the orbital environment is considered when creating a system concept and is realized throughout the development and operation.

6.2 Concept of debris-related work in each phase

The following debris-related activities are considered in each phase (see Table 5):

a) The mission requirement analysis phase (pre-phase A) consists of an initial definition of launch performance according to the strategy of launch service business. The debris mitigation requirements are identified as a part of the requirements, such as design requirements and regulatory constraints.

b) The feasibility phase (phase A) consists of exploring the various possible concepts so as to meet the defined objectives (performance, cost, and schedule), as defined in ISO 14300-1:2011, 8.2.3. The major debris related specifications are determined and reflected in a functional specification and a technical specification, which are drafted in this phase. Examples are the re-entry control function and design reliability, which affect system design and cost.

c) The definition phase (phase B) consists of a general concept of the launch vehicle system as defined at the end of the feasibility phase, as defined in ISO 14300-1:2011, 8.2.4. All the major debris mitigation concepts that impact functions, performance, allocation of resources, and reliability are reflected in the system level technical specification.

d) The development phase (phase C) consists of creating a detailed study of the proposal selected upon completion of the definition phase, as defined in ISO 14300-1:2011, 8.2.5.3.1. The purpose of this phase is to obtain a qualified design for the mass production of deliverable products required for system operation and support. All the debris mitigation design and operation procedures are defined.

e) The production phase (phase D) consists of manufacturing and delivery to the customer (typical example is a launch service provider). Qualification of the product design and production procedures marks the end of the production phase.

NOTE In the routine production flow after qualification, a pre-shipment review is conducted to confirm the configuration and quality to proceed to launch site operations. This means that the detailed configuration and mission profile of the vehicle have been defined for each launch mission according to the mission analysis. Flight trajectory, propellant allocation, disposal sequence, etc. are confirmed.

f) During the utilization phase (phase E), at the final launch preparation at the launch site, lift-off time is confirmed, ensuring to avoid collision risks between inhabited mission systems if required, followed by lift-off.

g) During the disposal phase (phase F), after injection of payload, disposal manoeuvres and break-up prevention procedures are conducted.

In all the above phases, debris-related characteristics are identified and realized in design and implemented by the completion of disposal. The output of each phase is reviewed at the end of each phase.

Debris-related measures that have an impact on design and options for solutions are described in Clause 5. Subsystems and component-level information is provided in Clause 8. A typical phased planning of the development life cycle can be illustrated as depicted in Figure 1, according to ISO 14300-1.

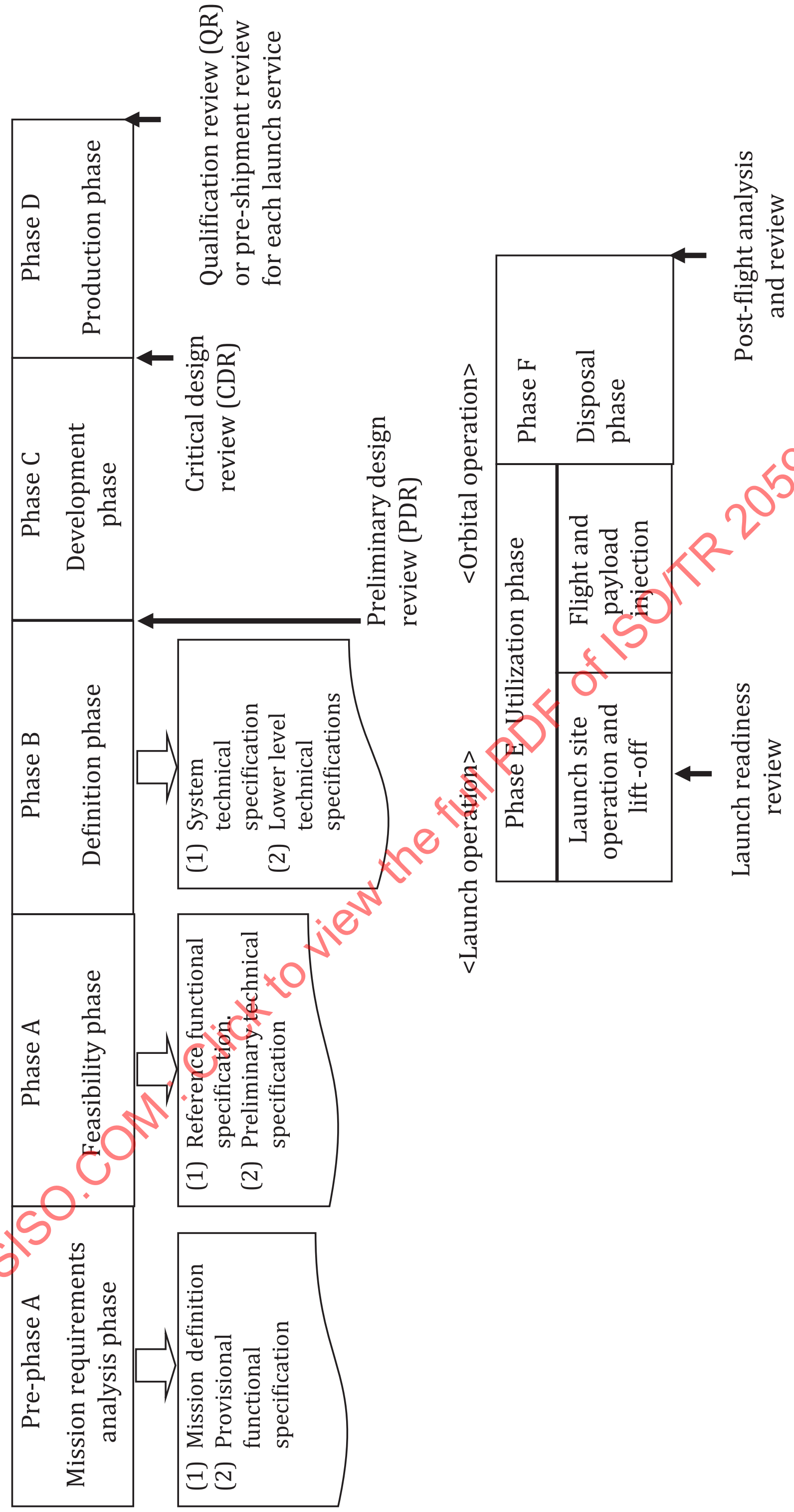

Figure 1 — Typical phased planning of the development life cycle

Table 5 — Major works related to debris in each phase

Phase Subjects	Pre-phase A: Mission requirements analysis phase Phase A: Feasibility phase	Phase B: Definition phase Phase C: Development phase Phase D: Production phase	Phase E: Utilization phase	Phase F: Disposal phase
System-level work	a) Input debris related requirements[d] b) Clarify debris related design philosophy and input into the system requirements and specification[d]	a) Mass and Propellant allocation[d] (including that for disposal manoeuvre, controlled re-entry, etc.)	a) Transfer debris-mitigation plan to operators[a] b) Fix the procedure to terminate the operation[a] (with guarantee the propellant for disposal)	a) Disposal action, which is conducted automatically[a] (including disposal manoeuvre, break-up prevention, controlled re-entry)
Quality assurance	a) Clarify QA design philosophy[d] b) Define QA program including parts program[d]	a) Confirm the probabilities for successful disposal and non-break-up and other probabilities required for the launching state or the mission requirements[a]		
Limiting of debris generation **(ISO 24113:2019**, 6.1**)**	a) Clarify debris-mitigation design philosophy[a]	a) Fix the design to limit releasing objects, limit their orbital lifetime, etc.[a] b) Identify the energy sources of break-up and design to prevent them[a]	a) Monitor critical parameters to check symptoms of critical malfunctions[d]	a) Vent residual energy[a] b) Terminate operation in the proper sequence[a]
Disposal **(ISO 24113:2019**, 6.3**)**	a) Clarify disposal concept[a] b) Estimate propellant for disposal[a]	a) Design a propulsion subsystem for the planned disposal manoeuvre[a]		a) Remove orbital stages to avoid interference with protected regions[a]

[a] Complying with the requirement of ISO standards (ISO 24113, ISO 27875, etc.), or recommendations induced from them.

[b] Best practices recommended by UN Guidelines[3] (and IADC Guidelines[9] referenced by the UN Guidelines[3]).

[c] Instructions given by the authorities, which are addressed in ISO standards.

[d] Management work conducted according to general project management, reliability and QA program, safety program, etc.

Table 5 *(continued)*

Phase **Subjects**	**Pre-phase A: Mission requirements analysis phase** **Phase A: Feasibility phase**	**Phase B: Definition phase** **Phase C: Development phase** **Phase D: Production phase**	**Phase E: Utilization phase**	**Phase F: Disposal phase**
Re-entry safety **(ISO 24113:2019**, 6.3.4**)**	a) Clarify re-entry safety concept[c] b) Define re-entry survivability analysis method[c] c) Determine whether to apply controlled re-entry or not[c]	a) Design a propulsion subsystem and attitude control system for controlled re-entry, if needed[a]		a) Conduct controlled re-entry[a]

[a] Complying with the requirement of ISO standards (ISO 24113, ISO 27875, etc.), or recommendations induced from them.

[b] Best practices recommended by UN Guidelines[3] (and IADC Guidelines[9] referenced by the UN Guidelines[3]).

[c] Instructions given by the authorities, which are addressed in ISO standards.

[d] Management work conducted according to general project management, reliability and QA program, safety program, etc.

6.3 Mission requirements analysis phase (pre-phase A)

6.3.1 General

The main purpose of this phase is to identify the concept of a launch vehicle. From the point of view of debris-related issues, the following items are conducted during this phase:

a) identifying the debris-mitigation requirements in ISO standards, national regulations, etc.;

b) identifying safety, reliability, and quality requirements to ensure the ability to conduct debris-mitigation measures, including prevention of the fragmentation caused by malfunctions, etc.

6.3.2 Debris-related works

Debris-mitigation requirements reported in ISO 24113 are identified. If there are other applicable debris-related regional and national regulations, they are also considered, and the final set of requirements is identified.

ISO 24113 (as of 2016) presented requirements only for mitigating the generation of debris. It does not address collision avoidance, but the UN Space Debris Mitigation Guidelines[3] recommends estimating and limiting the probability of accidental collision with known objects during the systems' launch phase, and considers adjustment of the launch time, if available orbital data indicates a potential collision. See UN Space Debris Mitigation Guidelines[3] 4.5 (1).

6.4 Feasibility phase (phase A)

The output of this phase is reflected in the system requirements document (specifications). This document is reviewed during the system requirement definition review (SRR).

The various possible concepts are studied to meet the defined objectives. Mission requirements, debris-related requirements, and other regulatory rules are considered.

The following aspects are considered:

a) The requirements regarding not releasing objects provide normative content for the selection of types of propulsion systems (solid, hybrid, or liquid).

b) Break-up preventive requirements provide normative content for the safety design concept (impact on mass allocation due to tank design, safety factors, and margins, etc.) and reliability design.

c) Disposal requirements provide normative content for the basic configuration of staging structure and the allocation of function for each stage.

d) Re-entry safety requirements provide normative content for the design of associated subsystems related to controlled re-entry, including the radiation hardness design for avionics.

6.5 Definition phase (phase B)

6.5.1 Work in phase B

The output of this phase is reflected in the system specifications and subsystem specifications (draft). They are reviewed during the preliminary design review (PDR).

In this phase, the system requirements are defined in a reference functional specification and a preliminary technical specification at the system level as specified in ISO 14300-1.

NOTE The principal configurations, including physical, functional, and performance characteristics, as well as the operational concept, verification concept, and project resources (development regime, budget, and scheduling) are chosen in this phase. Therefore, the decision to implement a re-entry control function that can impose a heavy burden on the functional and performance characteristics is fixed no later than in this phase.

The concept to comply with ISO 24113 is defined in the space-debris-mitigation plan (SDMP) as defined in ISO 24113:2019, Clause 7.

6.5.2 Work procedure

a) Basic concept

Excessive low reliability is not only unfavourable on its own, but also undesirable, due to its effects on the orbital environment in case it causes a malfunction or fragmentation. Therefore, a mission assurance philosophy is developed.

b) Information of debris mitigation measures in system design

1) In the allocation of propellant, the propellant for disposal manoeuvres and controlled re-entry manoeuvres are considered.

2) In the allocation of reliability, the probability of break-up during operation is considered.

3) In planning the controlled re-entry, the manoeuvre sequence and the function and performance of the propulsion subsystem are studied by the end of this phase. Moreover, the total system, including the ground control and monitoring system, is studied by the end of this phase.

6.6 Development phase (phase C)

In this phase, the system specifications are allocated at the component and part levels. In the specifications, the functional and performance requirements are defined to satisfy the SDMP.

This phase includes the task necessary to complete the designed state of the system and of each of its components. The result is reviewed during the critical design review (CDR).

During the above procedure, the following are considered:

a) Reliability and QA

Again, reliability and QA for orbital stages are essential not only for mission completion, but also for the safety of the other operating S/C in orbit. See ISO 16127:2014, 5.1.

b) Break-up prevention and safety control

Major causes of break-up are explosion of the propulsion subsystem and the rupture of high-pressure vessels. To prevent those causes of break-up, appropriate design measures (prevention of the mixture of bi-propellants, robust structural design, etc.) are essential.

c) Prevent the release of parts

According to ISO 24113:2019, 6.1, orbital stages are designed so as not to release objects that will become orbital debris (such as clamp bands, nozzle closures, combustion-related products, igniters for solid motors) during normal operations.

d) Disposal after the end of operation

During the design phase, enough propellant is allocated to carry out the disposal manoeuvre.

e) Safety assurance from ground impact after re-entry

1) According to ISO 27875, the expected number of casualties is estimated and limited; and ground pollution is avoided.

2) If there is significant risk on the ground, a controlled re-entry is planned. Such a plan includes the design of a re-entry trajectory with control manoeuvres, error analysis, prediction of the footprint of surviving objects, etc. Controlled re-entry requires a propulsion subsystem satisfying such objectives, enough propellant, and specific designs for avionics (designing for

radiation hardness, etc.). These factors can require additional constraints for mass allocation. Other ground support systems are required, including ground tracking and control systems (See ISO 27875).

6.7 Production phase (phase D)

6.7.1 Work in phase D

There are no specific debris-related requirements for manufacturing and verification/validation if the production procedures are properly controlled under the reliability and QA program. The design and production procedures are qualified at the end of this phase (see 6.7.2).

6.7.2 Qualification review

In the qualification process, the final design and manufacturing procedures are verified through testing and design evaluation or demonstration.

The following items are reviewed at the QR:

a) list of parts that are designed to separate or be released;

b) list of sources of break-up energy;

c) a monitoring system for detecting critical malfunctions that can cause break-up as far as technically feasible;

d) a disposal operation plan and data that is transferred to the operation phase;

e) ground casualty expectations if the orbital stages are disposed of by orbit decay;

f) if controlled re-entry is planned, review of the operation plan;

g) plan for notifying air traffic and maritime traffic authorities, in the case of controlled re-entry.

6.7.3 Launch service

After qualification, the launch vehicles are applied to routine service. For each launch mission, corresponding to launch mission requirements, mission analysis is done; system configuration is defined; the hardware is validated and served to launch operation at the launch site.

6.8 Utilization phase (phase E)

Lift-off time is typically coordinated to ensure that orbital stages, payloads, and other released objects from the orbital stages do not put inhabited systems at risk.

Debris mitigation measures are conducted according to the programmed sequence of events.

6.9 Disposal phase (phase F)

Disposal actions are automatically conducted as follows:

a) At the end of operation, the planned disposal manoeuvres defined in the SDMP are conducted. If a controlled re-entry is planned, it is most likely conducted with ground support.

   Notification for controlled re-entry is given to the relevant nations, air traffic authorities, and maritime authorities.

b) After completion of disposal manoeuvres, residual energy (propellant, high pressure fluids, etc.) is removed (according to ISO 16127) unless mechanical strength is used to assure that a break-up will not occur until the residual fluids are depressurized to a safe level.

If there is potential risk that orbital stages can have interference with payloads by the venting force, the following item is considered:

For example, when venting of residual fluids is conducted, the effects of other devices (antennas, etc.), which are exposed to the venting streams, are assessed to ensure that they do not cause undesirable disturbances to the orbital stage.

7 System-level information

7.1 System design

Once the maximum mass of payloads is defined along their injection orbit, geodetic conditions of launching sites and tracking stations are identified; other conditions are defined; and the system concept of the launch vehicle is studied. Then the "debris mitigation design philosophy" effects on system concept are examined; for example:

a) Constitution of stages is defined to minimize interference with protected orbital regions, ground casualties, probability of break-ups, etc.

b) Orbital stages are given functions for disposal manoeuvres or controlled re-entry, if required, for missions that require such actions.

c) Solid propulsion systems, which generate slag, are not applied to the upper stages reaching not only GEO but also LEO mission. Otherwise, the propellant is altered so that it does not generate slag or change the nozzle design so that it does not have submerged nozzles.

d) Orbital stages, whose re-entry hazards do not comply with restrictions, are given functions for controlled re-entry.

e) ISO 24113:2019 added a requirement to limit the total number of objects released into orbit. (In the case of a single payload launching, it is limited to one object, typically only one orbital stage. In the case of multiple payload launching, it is limited to two objects, typically the orbital stage and support structure, but not limited to those.)

7.2 Mission analysis for each launch mission

For each launch mission, mission analysis, which includes the following debris related items, is conducted and reviewed before the pre-shipment review.

a) re-confirmation of physical characteristics of payloads and their injection orbits;

b) disposal planning;

c) development of flight profile and sequence of events (debris mitigation measures, such as turning off the command destruct receivers; payload separation collision avoidance; orbit change manoeuvre for disposal; venting residual fluids; and controlled re-entry, if planned);

d) propellant allocation, including consumption for disposal manoeuvre or controlled re-entry.

8 Subsystem/Component design and operation

8.1 General

8.1.1 Scope

During the design related phases (Phases B, C, and D), the requirements defined in ISO 24113:2019, Clause 6 and other related standards are converted to design requirements and allocated to the design specifications for system, subsystems, or components. Those allocated specifications support engineers engaged in each subsystem design.

The following subsystems are mentioned in this clause:

a) propulsion subsystem;

b) guidance and control subsystem;

c) electric power-supply subsystem;

d) communication subsystem;

e) structure subsystem;

f) range safety subsystem (the same as the self-destruct subsystem).

8.1.2 Debris-mitigation measures and subsystem-level actions for realizing them

While ISO 24113:2019, Clause 3 introduced system-level design concepts, this subclause presents a more detailed allocation of functions and performance for each subsystem. Table 6 shows the relationships between the requirements in the ISO standards and the recommended actions for each subsystem.

Table 6 — Debris-related technology and design of affected subsystem

	Name of debris-related technology	Subsystem					
		Propulsion	Guidance and control	Power supply	Communication	Structure	Range safety
1	Releasing of parts, slags, etc.		-				
	(a) Fasteners, clamp bands, etc.					Yes	
	(b) Slag from solid motors	Yes					
	(c) Others						
	(d) Support structures for multi-payloads launching					Yes	
2	Prevention of fragmentation						
	(a) Explosion of engines, propellant tanks, etc.	Yes					
	(b) Rupturing of high-pressure vessels	Yes					
	(c) Rupturing of batteries			Yes			
	(d) Unintentional activation of self-destruct devices for range safety system						Yes
3	Disposal from protected regions	Yes	Yes	Yes	Yes		

Table 6 *(continued)*

	Name of debris-related technology	Subsystem					
		Propulsion	Guidance and control	Power supply	Communication	Structure	Range safety
4	Ground safety						
	(a) Re-entry control	Yes	Yes	Yes	Yes		
	(b) Improvement of demisability	Yes				Yes	
	(c) Avoidance of toxic material	Yes					

8.2 Propulsion subsystem

8.2.1 Debris-related design

This subclause applies to the main (and vernier) engines (motors), attitude control thrusters, ullage thrusters (or motors), etc.

The measures applied for the propulsion subsystem are shown in Table 7.

Table 7 — Debris-related measures in the propulsion subsystem

Mitigation measures	Propulsion subsystem	Major components				
		Liquid engine, Thrusters	Propellant tank	Pressure vessels	Valve, piping	Solid motor
Refrain from releasing objects	Yes	-	-	-	-	Yes (slag)
Break-up prevention	Yes	Yes	Yes	Yes	Yes	Yes
Disposal manoeuvre	Yes	Yes	Yes	-	-	-
Ground safety	Yes	-	Yes	Yes	-	-
Re-entry control	Yes	Yes	Yes	-	-	-

8.2.2 Information of propulsion subsystems

8.2.2.1 Refrain from releasing objects

To refrain from releasing objects, the following items are considered, per ISO 24113:

a) In the case of solid motors, igniters and nozzle closures are designed not to be released whenever possible, especially when they remain in orbit for a long time. Solid motors, which contain metal and have submerged nozzles, tend to generate and exhaust slag. They are not applied only to GTO mission or near GEO but also to LEO mission especially higher than inhabited mission altitude.

b) Auxiliary propulsion systems (ullage motors, retro motors, etc.) are not separated, especially when they are injected into a long-lived orbit.

8.2.2.2 Break-up prevention

ISO 24113 requires the probability of fragmentation during operation except for such external factors as collision with debris.

The following are typical modes of fragmentation relating to the propulsion subsystem:

a) failures of engine or thrusters (failures of combustion related elements, turbo-pumps, turbines, heaters of thrusters, etc.);

b) explosion caused by a mixture of the fuel and oxidizer (as a typical example, a propellant tank design combining the fuel and oxygen tanks, separating them only by a common bulkhead, has caused explosions, which are probably due to a defect of the bulkhead, or impact of debris which allowed the mixture of propellants);

c) rupture of highly pressurized tanks or vessels caused by defects of tank structure, failures of regulators, valves, etc.;

d) certain types of gas jet thrusters can cause fragmentation due to cold start induced by the failure of the heater for the catalyst bed;

After the EOM (injection of payloads), energy sources of break-up as the forms of residual propellants and high-pressure gasses are vented or relieved, according to ISO 24113:2019, 6.2, and ISO 16127. As addressed in 8.2.3.1, the function and performance for venting and relieving residual fluids are accomplished by coordinated work among related components, such as engines, tanks, pressure vessels, valves, piping, etc.

Complete depletion of fluids is sometimes impossible in complicated propulsion systems. ISO 16127:2014, 5.3.2.1 shows the tailoring guidance for such cases.

8.2.2.3 Disposal manoeuvre

In the case that disposal manoeuvres need stronger forces than can be obtained by passivation, re-start functions of the main engines or auxiliary propulsion systems, including independent devices attached specifically for such purposes, are needed.

The following characteristics are designed to comply with disposal manoeuvre requirements:

a) re-start functions of the main engines or auxiliary propulsion systems, which are available after payload separation, is designed;

b) mission is designed to keep an enough propellant for disposal manoeuvres;

c) tanks are designed to allow a safe and reliable re-start function of main engines or auxiliary propulsion systems;

d) electric power subsystem and other subsystems support disposal manoeuvres.

8.2.2.4 Ground safety and re-entry control

Propulsion subsystems have several elements that survive re-entry, including major components of liquid engines, propellant tanks made of stainless steel or titanium, pressure vessels made of titanium, large valves, motor cases, and nozzles of solid motors. Design efforts are applied to minimizing objects that survive re-entry, but if the total number of casualties still cannot be made smaller than the requirement, a controlled re-entry is planned.

When a controlled re-entry is planned:

a) The propulsion system used for the final burn is designed to have thrust level to provide enough delta velocity within a short period.

b) If controlled re-entry takes an extended amount of operation time, longer than a simple disposal operation, radiation hardness design is applied for electronic devices.

