Evolution of ISO's Space Debris Mitigation Standards

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ABSTRACT

Since 2010 the International Organization for Standardization (ISO) has been publishing a comprehensive set of international standards on space debris mitigation based on guidelines and best practices from the IADC and other bodies. This paper describes the structure and content of the ISO debris standards and how they are evolving to address the needs of space environment sustainability within the context of a rapidly changing space industry. Particular emphasis is placed on ISO 24113 (Space systems – Space debris mitigation requirements), which was published as a third edition during July 2019. The new requirements are compared with those in the previous edition and the rationale for the various changes is discussed. Most notably, the requirement for a spacecraft or orbital stage to exceed a specified threshold for its probability of successful disposal has been made more demanding. With the launch of numerous small spacecraft into LEO and the imminent launch of constellation systems comprising thousands of satellites, it is likely that the ISO debris standards will have to implement even stricter requirements in the future. The challenge is to do this in a way that is fair and reasonable for the entire space industry.

1 INTRODUCTION

Shortly after the publication of the first edition of the Inter-Agency Space Debris Coordination Committee (IADC) Space Debris Mitigation Guidelines in 2002, the International Organization for Standardization (ISO) set up a Working Group (now identified as TC20/SC14/WG7) to transform guidelines and best practices from the IADC, the United Nations, spacecraft operators and regulatory bodies into a comprehensive set of international standards on space debris mitigation. The first of these standards was published in 2010, and since then ten more have been issued. It is worth noting that the standards have already been used to guide a number of countries in their space activities [1], and so they now represent an important contribution in global efforts to address the space debris problem.

The standards are organized in a hierarchical structure. All of the high-level debris mitigation requirements are contained in a top-level standard, ISO 24113 (Space systems – Space debris mitigation requirements). This is the most important debris standard. Below ISO 24113 in the hierarchy the remaining lower-level standards describe detailed requirements and implementation measures to comply with ISO 24113. These documents address all of the important aspects of debris mitigation for spacecraft and orbital stages, including post-mission disposal, preventing on-orbit break-ups, estimating orbit lifetime, limiting re-entry risk, and assessing survivability against impacts.

In this paper we describe the structure and content of the ISO debris standards and how they are evolving to address the needs of space environment sustainability within the context of a rapidly changing space industry. Particular emphasis is placed on ISO 24113, which was published as a third edition in July 2019. The new edition contains significant changes to several of the high-level debris mitigation requirements. These have become necessary in the face of mounting data about the projected growth of orbital debris in the LEO and GEO Protected Regions. In the paper we compare the new requirements with those in the previous edition and discuss the main changes and motivations. Most notably, the requirement for a spacecraft or orbital stage to exceed a specified threshold for its probability of successful disposal has been made more demanding. It is clear from long-term debris environment studies that space objects must now be disposed of with a very high degree of likelihood during their post-mission phase. Widespread adoption of measures such as these should go a long way towards mitigating the growth in orbital debris.

Whilst the new edition of ISO 24113 provides a much-needed upgrade to the set of high-level debris mitigation requirements, and is the foundation for improved organization of the standards hierarchy, members of WG7 will continue to review and amend the document to make sure it remains relevant. This is essential given the rapid increase in the size of the global space industry over the past decade. The launch of numerous small spacecraft into LEO and the imminent launch of constellation systems comprising thousands of satellites pose enormous challenges. On the one hand these systems offer huge economic and societal benefits today, but on the other hand we must be careful to protect the precious region around the Earth for the generations to come. ISO's debris mitigation standards will strive to maintain the delicate balance between these competing needs. As a consequence, the standards will likely continue to evolve as our use of space increases and as we learn more about the space debris population.

2 ISO BACKGROUND

The International Organization for Standardization, or ISO, is an independent, non-governmental organization made up of members from National Standards Bodies (or NSBs) of 163 countries. It was established over 70 years ago to promote standards for international trade, communications and manufacturing. The development of a standard typically takes place within one of ISO's Technical Committees (TCs) and/or Sub-Committees (SCs). TC20/SC14 is the ISO committee tasked with developing international standards that capture best practices for space systems and operations. Figure 1 illustrates the structure of SC14, which is divided into seven working groups, each one responsible for a major discipline. WG7 (formerly known as the Orbital Debris Coordination Working Group) was set up in 2003 to oversee the development of a set of spacecraft engineering standards aimed at mitigating space debris. The group comprises members from the civil and commercial space industry, government organizations, national space agencies, academic institutions, and the European Cooperation for Space Standardization (ECSS).

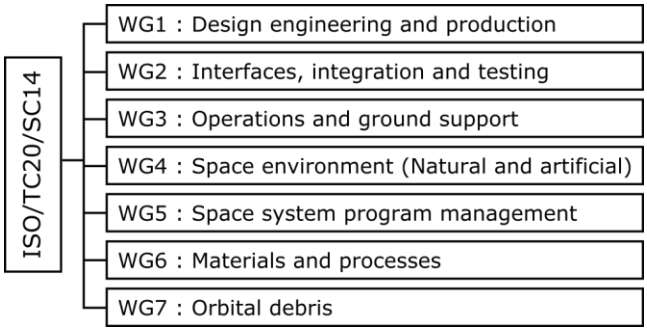

Fig. 1. Structure of ISO TC20/SC14

3 EVOLUTION OF THE FRAMEWORK OF ISO SPACE DEBRIS MITIGATION STANDARDS

3.1 Original Framework

There is international consensus that space activities need to be carefully managed to minimize the generation of space debris and its associated risks. This consensus is embodied in space debris mitigation guidelines published by

organizations such as the International Telecommunication Union (ITU) [2], the Inter-Agency Space Debris Coordination Committee (IADC) [3][4] and the United Nations (UN) [5]. The transformation of these guidelines into engineering practice is a key objective of the space debris mitigation standards developed by ISO TC20/SC14.

In 2010, SC14 began publishing the first of its debris mitigation standards. The aim of the documents was to specify measures which when implemented in the design, operation and disposal of a spacecraft or launch vehicle orbital stage would prevent the generation of space debris. This framework of documents has a hierarchical structure, as shown in Fig. 2.

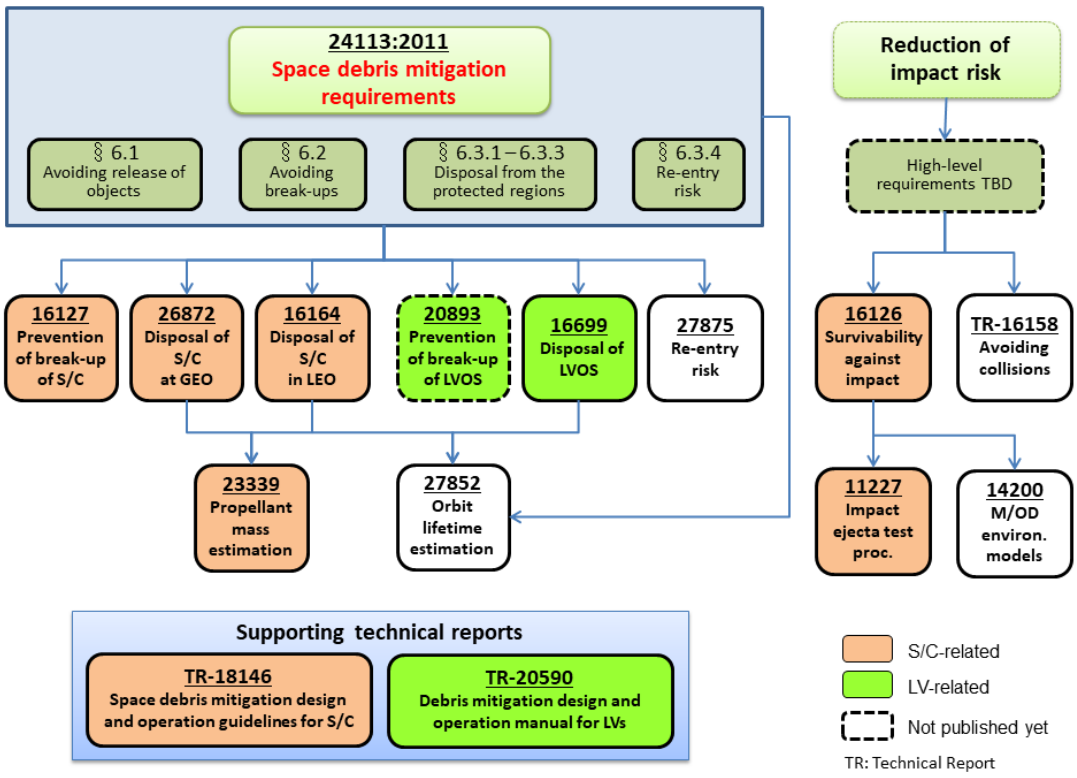

Fig. 2. Original framework of the ISO space debris mitigation standards

The top-level International Standard, ISO 24113, is perhaps the most important document. It 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 first edition of ISO 24113 was published in 2010 and was followed a year later by a slightly amended second edition.

Below ISO 24113 in the framework's hierarchy there are several lower-level International Standards and Technical Reports which describe detailed requirements and implementation measures designed to enable compliance with the high-level requirements in ISO 24113. These documents address all of the important aspects of debris mitigation for spacecraft and orbital stages, including post-mission disposal, preventing on-orbit break-ups, estimating orbit lifetime, limiting re-entry risk, avoiding collisions and assessing survivability against debris impacts.

At the lowest level in the framework's hierarchy there are two supporting Technical Reports which contain non-normative information to guide space system engineers in the application of the aforementioned standards.

Tables 1 to 3 summarize the scope of the most important standards depicted in Fig. 2 that have been published to date. The standards can be applied in a variety of ways. For example, they can be adopted voluntarily by a spacecraft manufacturer or operator, or brought into effect through a commercial contract between a customer and supplier, or used as the basis for establishing a set of national regulations on space debris mitigation.

Tab. 1. Scope of ISO debris standards in the original framework (applicable to spacecraft and orbital stages)

ISO No.	Title	Scope (abridged version)
24113:2011 (replaced by 24113:2019 in new framework)	Space systems — Space debris mitigation requirements	ISO 24113 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. It is the top-level standard in a family of standards addressing debris mitigation.
27852:2016	Space systems — Estimation of orbit lifetime	ISO 27852 describes a process for the estimation of orbit lifetime for spacecraft, launch vehicles, upper stages and associated debris in LEO-crossing orbits. It also clarifies modelling approaches and resources for solar and geomagnetic activity modelling, resources for atmosphere model selection, and approaches for spacecraft ballistic coefficient estimation.
27875:2019	Space systems — Re-entry risk management for unmanned spacecraft and launch vehicle orbital stages	ISO 27875 provides a framework with which to assess, reduce, and control the potential risks that spacecraft and launch vehicle orbital stages pose when they re-enter the Earth's atmosphere and impact the Earth's surface.

Tab. 2. Scope of ISO debris standards in the original framework (applicable to spacecraft only)

ISO No.	Title	Scope (abridged version)
16126:2014	Space systems — Assessment of survivability of unmanned spacecraft against space debris and meteoroid impacts to ensure successful post-mission disposal	ISO 16126 defines requirements and a procedure for assessing the survivability of an unmanned spacecraft against space debris and meteoroid impacts to ensure the survival of critical components required to perform post-mission disposal. It also describes two impact risk analysis procedures that can be used to satisfy the requirements.
16127:2014	Space systems — Prevention of break-up of unmanned spacecraft	ISO 16127 defines the requirements to reduce the risk of in-orbit break-up of unmanned spacecraft, both during and after their operational lives. The aim would be met by reducing the possibility of a break-up caused by an unplanned internally caused event and by depleting to a safe level all the sources of stored energy at the end of a spacecraft's life.
16164:2015	Space systems — Disposal of satellites operating in or crossing Low Earth Orbit	ISO 16164 specifies requirements for: planning the disposal and passivation of a spacecraft operating in LEO, selecting a disposal orbit that is compliant with ISO 24113, and estimating, prior to launch, the probability of executing the disposal maneuver.
26872:2019	Space systems — Disposal of satellites operating at geosynchronous altitude	ISO 26872 specifies requirements for: planning the disposal of a spacecraft operating at geosynchronous altitude, selecting a final disposal orbit that is compliant with ISO 24113, executing the disposal maneuver successfully, and depleting all energy sources on board the spacecraft before the end of its life.

Tab. 3. Scope of ISO debris standards in the original framework (applicable to orbital stages only)

ISO No.	Title	Scope (abridged version)
16699:2015	Space systems — Disposal of orbital launch stages	ISO 16699 specifies techniques for planning and executing the disposal of orbital launch stages that are consistent with ISO 24113 requirements, reflect current internationally accepted guidelines, and consider current operational procedures and best practices.

3.2 New Framework

Following the publication of the debris mitigation standards, the ISO working group responsible for overseeing their development – ISO TC20/SC14/WG7 – considered a number of options for improving the documents. Feedback from industry was particularly important in this respect. As a consequence, WG7 has constructed a new framework with the aim of consolidating the lower-level standards into a more concise and coherent set of documents. The

documents will retain all of the key debris mitigation requirements that have been published to date, but do so in a form that improves their usability and maintainability. The new framework is illustrated in Fig. 3.

As before, the top-level standard is ISO 24113. When ISO 24113 was published in 2011, it was not possible to include high-level requirements pertaining to collision avoidance or survivability against small debris and meteoroid impacts. This resulted in a disconnect between ISO 24113 and some of the mid-level debris documents, such as ISO 16126 and ISO/TR 16158, as shown in the original framework in Fig. 2. However, changes in the industry since 2011 have allowed such requirements to be included in the 2019 edition of ISO 24113. In particular, clauses have been added which require spacecraft collision risk to be actively managed and, where appropriate, avoidance maneuvers to be performed. There is also a new requirement for debris/meteoroid impact risk to be assessed during the design of a spacecraft. These changes to ISO 24113 mean that it is fully connected to all of the lower-level standards, as illustrated in Fig. 3.

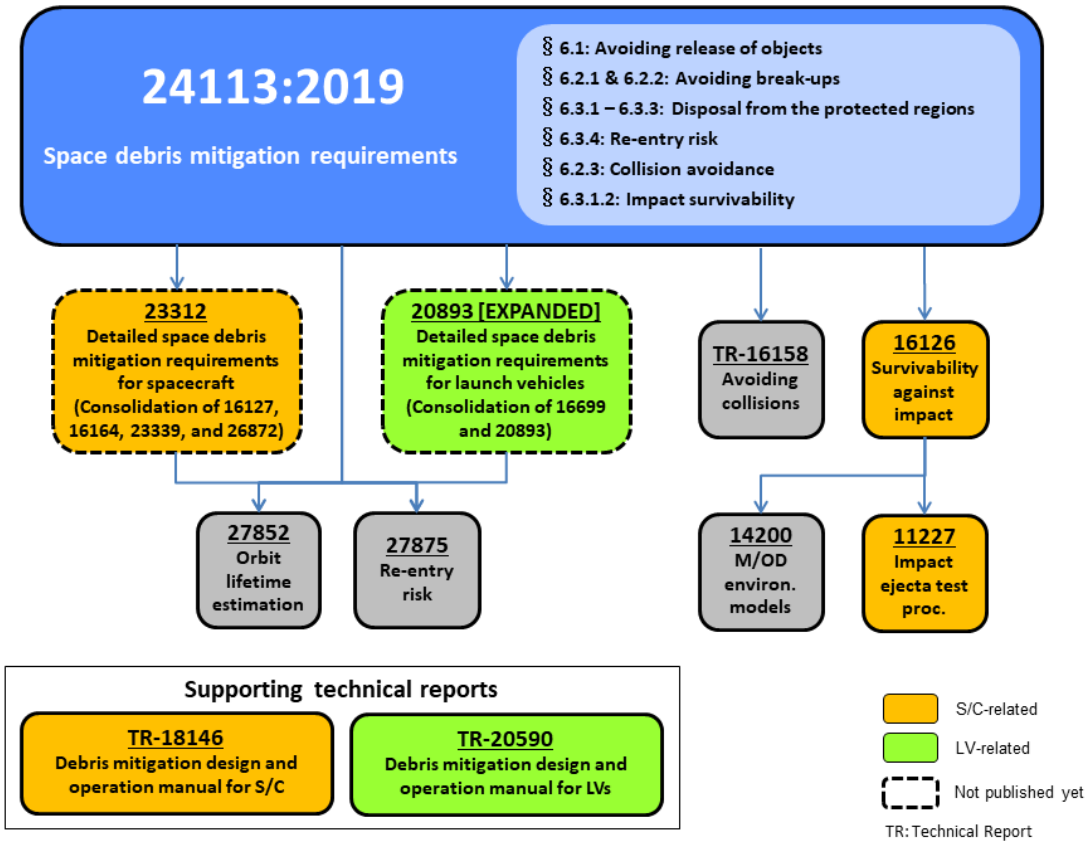

Fig. 3. New framework of the ISO space debris mitigation standards

The new framework contains several other important changes, mainly to the mid-level documents. Firstly, the four spacecraft-related debris mitigation standards will be combined. That is, the content of ISO 16127, ISO 16164, ISO 23339 and ISO 26872 will be merged into one document with the number ISO 23312 and the title “Space systems — Detailed space debris mitigation requirements for spacecraft”. ISO 23312 will define detailed planning, design, verification, operation and disposal requirements for unmanned spacecraft to comply with ISO 24113. Once this document is published, the four spacecraft-related standards – ISO 16127, ISO 16164, ISO 23339 and ISO 26872 – will be cancelled.

Secondly, the content of the two launch vehicle-related standards, ISO 16699, which concerns the disposal of orbital stages, and ISO 20893, which originally focused on the prevention of break-up of orbital stages, will be combined into one standard. Since ISO 20893 is not yet published, this newly-merged document will be developed under the

ISO five-digit number, 20893, and the title modified to reflect the expanded content. The new title will be "Space systems — Detailed space debris mitigation requirements for launch vehicle orbital stages". When ISO 20893 is ready for publication ISO 16699 will then be cancelled.

4 EVOLUTION OF ISO 24113

4.1 The Second Edition (2011)

ISO 24113 is by far the most important of the ISO space debris mitigation standards. The high-level requirements in ISO 24113 are intended to reduce the growth of space debris by ensuring that spacecraft (S/C) and launch vehicle orbital stages (LVOS) are designed, operated and disposed of in a manner that prevents them from generating debris throughout their orbital lifetime. In other words, the aim of ISO 24113 is to specify the actions necessary for sustainable space activities. These are especially important for a space system with the following characteristics:

- Has a large total mass and collision cross-section.
- Remains in orbit for many years.
- Operates near manned mission orbital regions, highly utilized regions such as the LEO and GEO protected regions, or regions of high debris population.

The left column of Tables 4 to 7 lists some of the technical measures specified in the second edition of ISO 24113 published in 2011. The technical requirements were grouped into four major categories, as follows:

1. Avoid the intentional release of space debris into Earth orbit during normal operations.
2. Avoid break-ups in Earth orbit.
3. Remove spacecraft and launch vehicle orbital stages from the protected orbital regions after end of mission.
4. Control the risk to the human population from space objects re-entering the Earth's atmosphere.

In the standard a particular effort was made to include quantitative requirements as these would provide the industry with clear, measureable and verifiable targets. Thus, the document contained probability thresholds for accidental break-up and successful disposal, a 25-year limit for post-mission disposal in LEO, and a minimum re-orbit altitude for disposing in the graveyard region above GEO.

Once ISO 24113:2011 had been published, ISO TC20/SC14/WG7 monitored the standard to identify how well it was being adopted by the industry and any potential implementation difficulties. Sales figures revealed that it was one of SC14's most requested space standards. Feedback from industry was largely positive with specific recommendations about possible improvements that could be made in the next edition. Within Europe, ISO 24113:2011 was adopted by the ECSS and subsequently by the European Space Agency. In countries such as China, Japan and Russia the document became the basis for equivalent national standards [1]. Therefore, ISO 24113 will have influenced a variety of the world's spacecraft since 2011.

Tab. 4. Summary of selected changes between the second and third editions of ISO 24113: Avoiding the intentional release of space debris into Earth orbit during normal operations

Selected high-level requirements in ISO 24113:2011 (paraphrased)	Selected high-level requirements in ISO 24113:2019 (paraphrased)	Summary of changes
	Number of LVOS / debris objects left in Earth orbit by a LV is limited to one for the launch of a single S/C and two for the launch of multiple S/C.	New requirement added to limit the number of objects (debris and orbital stages) that a LV can release.
SRMs are not to release solid combustion products into GEO, and are to avoid contaminating LEO.	SRMs are not to release debris > 1 mm into LEO or GEO.	Limit placed on the size of slag debris that can be released. Restriction extended to LEO as well as GEO.

Tab. 5. Summary of selected changes between the second and third editions of ISO 24113: Avoiding break-ups in Earth orbit

Selected high-level requirements in ISO 24113:2011 (paraphrased)	Selected high-level requirements in ISO 24113:2019 (paraphrased)	Summary of changes
Avoid intentional break-ups.	Avoid intentional break-ups.	
Probability of accidental break-up < 10^{-3}.	Probability of accidental break-up < 10^{-3}.	
	A GEO S/C is to have a recurrent maneuver capability.	New requirement added to avoid orbital collisions with known objects.
	A S/C with a recurrent maneuver capability is to actively manage collision risk up to end of life.	New requirement added to avoid orbital collisions with known objects.
	A S/C capable of actively managing collision risk is to perform collision avoidance maneuvers if collision risk exceeds a predefined threshold.	New requirement added to avoid orbital collisions with known objects.
	Assess risk that an impact will cause a S/C to break-up before its end of life.	New requirement added. The probability assessment can include consideration of large object collisions as well as small debris impacts on propellant tanks, etc.

Tab. 6. Summary of selected changes between the second and third editions of ISO 24113: Removing spacecraft and launch vehicle orbital stages from the protected orbital regions after end of mission

Selected high-level requirements in ISO 24113:2011 (paraphrased)	Selected high-level requirements in ISO 24113:2019 (paraphrased)	Summary of changes
Probability of disposal > 0.9 (conditional probability weighted on mission success).	Probability of disposal > 0.9.(non-conditional probability).	Requirement made stricter. 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.
	Assess risk that an impact will prevent a S/C from being disposed of.	New requirement added.
A S/C or LVOS operating in LEO region is to remain there < 25 years after end of mission.	Orbit lifetime of a S/C or LVOS is to be < 25 years starting from: a) orbit injection, if the S/C or LVOS operates in LEO region and is unable to perform collision avoidance maneuvers, b) end of mission, if the S/C or LVOS operates in LEO region and is able to perform collision avoidance maneuvers, or c) epoch of first intersection of the orbit with the LEO region within 100 years after end of life, if the S/C or LVOS operates continuously outside of the LEO region.	Requirement made stricter.
Removal from LEO region is to be accomplished by: retrieval, controlled re-entry, shortening orbit lifetime (by maneuvering or drag augmentation), natural orbit decay, or raising the perigee above LEO.	Removal from LEO region is to be accomplished by: retrieval, controlled re-entry, natural orbit decay, shortening orbit lifetime (by maneuvering or drag augmentation).	Requirement made stricter. The disposal option of maneuvering to a higher orbit than the LEO region has been deleted.

Tab. 7. Summary of selected changes between the second and third editions of ISO 24113: Controlling the risk to the human population from space objects re-entering the Earth's atmosphere

Selected high-level requirements in ISO 24113:2011 (paraphrased)	Selected high-level requirements in ISO 24113:2019 (paraphrased)	Summary of changes
A S/C or LVOS must comply with the casualty risk threshold.	Re-entry risks are to be less than the corresponding risk thresholds set by approving agents.	A note has been added to this requirement advising that 10^{-4} is a commonly-used casualty risk threshold.

4.2 Background of Updating to a New Edition (2011 - 2019)

At the time of publication, the requirements in ISO 24113:2011 were considered sufficient to achieve a sustainable space environment. They emerged from international consensus based on extensive long-term debris environment studies performed by well-respected organizations, such as the IADC. However, when formulating the requirements for ISO 24113 two important caveats were assumed. Firstly, the requirements had to be adopted extensively throughout the industry and, secondly, the average annual volume of traffic launched into Earth orbit had not to increase significantly. Since 2011 it is clear that neither of these caveats has been met, especially for the LEO protected region. For example, despite the adoption of ISO 24113:2011 among several of the major spacefaring nations, there has been poor compliance globally with long-established, fundamental debris mitigation measures, such as the well-known "25-year rule" for post-mission disposal in LEO. The space industry has also undergone a period of rapid expansion and change in which a variety of new launchers has come into service, new types of spacecraft, such as CubeSats, have been placed into orbit in large numbers, and new concepts have emerged for satellite constellations comprising thousands of spacecraft in LEO.

Since 2011, in an effort to redress the balance, a variety of initiatives have been pursued. For example,

- Systems are being developed for improved space situational awareness.
- Technologies are being developed for debris remediation, including active removal of large debris objects.
- Rating metrics are being formulated to quantify the environmental impact of new space systems.
- New guidance has emerged from organizations such as the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) [6], IADC and industry / operator associations.
- Standardized procedures for space traffic coordination are under consideration.

Against this backdrop of change, ISO TC20/SC14/WG7 recognized that a major revision of ISO 24113 would also be necessary. This led to the development of the third edition published in 2019.

4.3 The Third Edition (2019)

The center column of Tables 4 to 7 shows how some of the technical measures specified in the 2011 edition of ISO 24113 have evolved in the 2019 edition. Several of the changes are intended to clarify requirements that were open to misinterpretation. Other changes are designed to make the requirements more effective at mitigating debris. In particular:

1. Limiting the ejection of slag from solid rocket motors. Solid rocket motors that eject slag, a result of motor design and chemistry, have been recognized as a major contributor to the orbital debris environment. The third edition limits the ejection of slag in the LEO protected region, in addition to the GEO region requirement in the second edition. This results in limiting the use of solid rocket orbital stages that release debris larger than 1 mm in size.
2. Probability of successful disposal. The '0.90' probability of successful disposal requirement, which was a conditional probability (weighted on the mission success) in the 2011 edition, is a non-conditional probability in the 2019 edition. Thus, a spacecraft must now demonstrate a high probability of successful disposal coupled with high reliability throughout its design lifetime. This means that critical parameters must also be monitored and adequate contingency actions put in place in case of abnormal situations. Furthermore, if an unplanned event occurs or a decision is made to extend the mission then a reassessment

must be performed. The intention of these requirements is mainly to encourage the proper disposal of LEO spacecraft, as statistical studies indicate that most LEO spacecraft do not comply with the 25-year rule. Clarifying notes within the standard explain that the probability can take into consideration operational remediation measures, such as periodically monitoring the health of disposal functions and taking immediate action if degradation or failure is detected.

3. Collision avoidance. Several requirements have been introduced to minimize the risk of a break-up by assessing and managing the risks associated with collisions. In the 2011 edition such requirements were not considered feasible because of the lack of available, accurate orbit data. Collision avoidance against known objects is now a mandatory requirement for all GEO spacecraft. For LEO spacecraft, it is required only of those that have a maneuvering capability. This recognizes that many small spacecraft currently do not have such a capability.
4. Impact risk assessment. The 2019 edition adds two requirements related to the assessment of debris and meteoroid impacts: probability of catastrophic break-up caused by impacts, and probability of non-catastrophic impact disabling hardware required for post-mission disposal.
5. Removal of a disposal option from LEO. Another tightening of the requirements concerns the option of disposing of a LEO spacecraft above the LEO region. In the 2019 edition this option has been deleted to avoid creating a potentially hazardous graveyard region in the future.
6. Definition of the start point for the 25-year rule. Additionally, the 25-year LEO disposal requirement has been modified so that a spacecraft or orbital stage which cannot by design perform collision avoidance maneuvers must be removed from LEO within 25 years of its injection into orbit. Previously, the 25-year clock began at end-of-mission for this type of space vehicle.
7. Limit the number of debris objects released by a launch vehicle. Finally, a requirement has been added restricting the number of orbital stages and debris objects that a launch vehicle is allowed to release.

The 2011 edition of ISO 24113 contained 21 distinct requirements. In the 2019 edition the total number of requirements is 34. This increase is clearly a reflection of the concerns that many in the industry now have about the growth in the volume of space traffic and the associated debris risks over the long-term.

5 THE WAY AHEAD

With the publication of the third edition of ISO 24113 the global space industry has access to a comprehensive set of high-level measures which, when implemented in the design and operation of any unmanned spacecraft or launch vehicle orbital stage, will contribute to a sustainable long-term future for the orbital environment around the Earth. Therefore, it is incumbent on every member of the industry – manufacturer, operator, space agency, launch licensing authority, and regulatory body – to play their part in observing standards such as ISO 24113.

The ISO debris standards will continue to evolve to reflect the enormous changes taking place throughout the industry and in orbit. For example, in the next edition of ISO 24113, it is anticipated that requirements could be added which are specific to satellite constellation systems. The exact nature of these requirements is still unclear but may involve the specification of separation zones between constellations, higher probability of successful disposal, and the inclusion of components on spacecraft to enhance their trackability [7].

Looking ahead, ISO TC20/SC14/WG7 welcomes greater industry participation in the further development of the ISO space debris mitigation standards. This is especially true for those organizations with plans to launch large numbers of spacecraft into orbit during the next few years.

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