TECHNICAL REPORT

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Space systems — Space debris mitigation design and operation guidelines for spacecraft

Systèmes spatiaux — Conception de mitigation des débris spatiaux et lignes directrices de manoeuvre de la navette

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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. www.iso.org/directives

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

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

Recently, the orbital environment has become so deteriorated by debris that action must be taken to prevent damage due to the impact. Collision avoidance manoeuvres should be taken to avoid large debris (larger than 10 cm, for example), which can be observed from the ground. Spacecraft design should protect against micro-debris (even smaller than 1 mm) that can cause critical damage to vulnerable components.

The following ISO standards and technical reports cover these issues: ISO 24113, *Space systems — Space debris mitigation requirements*; ISO/TR 16158, *Space systems — Avoiding collisions with orbiting objects*; ISO 16126, *Space systems — Assessment of the survivability of unmanned spacecraft against space debris and meteoroid impacts to ensure successful post-mission disposal*. Other ISO documents, introduced in Clause 2, are currently being developed to encourage debris mitigation and protection from debris impact. Table 1 shows those requirements together with the recommendations in the United Nations Space Debris Mitigation Guidelines and the Inter-Agency Space Debris Coordination Committee (IADC) space debris guidelines referred to in the UN guidelines.

Reliability and quality shortfalls have resulted in fragmentation events that generated thousands of fragments. ISO 24113 and other debris-mitigation guidelines make the assumption that space hardware quality and reliability issues have been addressed by other management programs. But for low-cost or low-criticality missions, spacecraft of reduced quality have been developed. The failure of such spacecraft may not pose critical damage to their owners but they may adversely affect the environment and impair the sustainability of space activities. This Technical Report suggests activities that can improve reliability and quality sufficiently to avoid this problem. This aspect of space-debris mitigation is particularly important for micro-satellites developed by universities and newcomers to space activities.

Space systems — Space debris mitigation design and operation guidelines for spacecraft

1 Scope

This Technical Report contains non-normative information on spacecraft design and operational practices for mitigating space debris.

This Technical Report is a supporting document to the family of international standards addressing space debris mitigation (see 2.2). The purpose of these standards is to minimize the creation of additional space debris by ensuring that spacecraft and launch vehicle orbital stages are designed, operated and disposed of in a manner that prevents them from generating debris throughout their orbital lifetime.

This Technical Report can be used to guide spacecraft engineers in the application of these space debris mitigation standards. Table 1 lists the main debris mitigation requirements defined in the standards and compares them to equivalent recommendations published by the United Nations and the Inter-Agency Space Debris Coordination Committee.

In Clause 3, the main space debris mitigation requirements are reported and discussed. Clause 4 provides guidance for life-cycle implementation of space debris mitigation related activities.

In Clause 5, the system level aspects stemming from the space debris mitigation requirements are highlighted, while in Clause 6, the impacts at subsystem and component levels are detailed.

Where it is not directly required by existing ISO standards but considered relevant to spacecraft operations, design and debris mitigation, content in this Technical Report is labelled as such with "[information]".

Table 1 — Comparison of ISO debris-related documents with UN and IADC space debris mitigation Guidelines

	Measures	ISO International Standards (or Technical Reports)	UN Guidelines	IADC Guidelines
Released objects	General measures for avoiding the release of objects	ISO 24113, 6.1.1	Recommendation-1	5.1
	Operational debris	Included in above	Included in above	5.1
	Slag from solid motors	ISO 24113, 6.1.2.2, 6.1.2.3	--	--
	Combustion products from pyrotechnics	ISO 24113, 6.1.2.1 (Combustion Products < 1 mm)	--	--
On-orbital break-ups	Intentional destruction	ISO 24113, 6.2.1	Recommendation-4	5.2.3
	Accident during operation	ISO 24113, 6.2.2 (Probability < 10^{-3})	Recommendation-2	5.2.2 (Monitoring)
	Post-mission break-up (Passivation, etc.)	ISO 24113, 6.2.2.3 **(Detailed in** ISO 16127**)**	Recommendation-5	5.2.1
Disposal at end of operation **GEO**	Reorbit at EOL	ISO 24113, 6.3.2 **(Detailed in** ISO 26872**)** 6.3.2.1: General Requirement. 6.3.2.2: 235 km+ (1000·Cr·A/m), e < 0,003 6.3.1: Success Probability > 0,9	Recommendation-7 (No quantitative requirements) Note: ITU-R S.1003-1 recommends; 235 km + 1000 *Cr*A/M* Here, A[m^2], M[kg], Cr[-]	5.3.1 235 km+ (1000·Cr·A/m), e < 0,003
Disposal at end of operation **LEO**	Reduction of orbital lifetime	ISO 24113, 6.3.3 **(Detailed in** ISO 16164**)** 6.3.3.1: EOL Lifetime < 25 years 6.3.1: Success Probability > 0,9	Recommendation-6 (No quantitative requirements)	5.3.2 (Recommend 25 years)
	Transfer to graveyard	ISO 24113, 6.3.3.2 **(f)** (guarantee 100 years' non-interference)	Mentioned in recommendation-6	5.3.2
	Other options	ISO 24113, 6.3.3.2 **(a) ~ (e)**	--	5.3.2
Re-entry	Avoidance of ground casualties	ISO 24113, 6.3.4 **(Detailed in** ISO 27875**)**	Included in Recommendation-6	5.3.2
Collision avoidance for large debris		ISO/TR 16158 **(for assessment)**	Recommendation-3	5.4
Protection from the impact of micro-debris		ISO 16126 **(for assessment)**	--	5.4

2 Related documents and abbreviated terms and symbols

2.1 Overview of ISO debris-related standards

The requirements, recommendations, and best practices for mitigating debris generation and preventing other debris related problems are now examined.

Figure 1 shows a general diagram of major ISO documents relevant to debris.

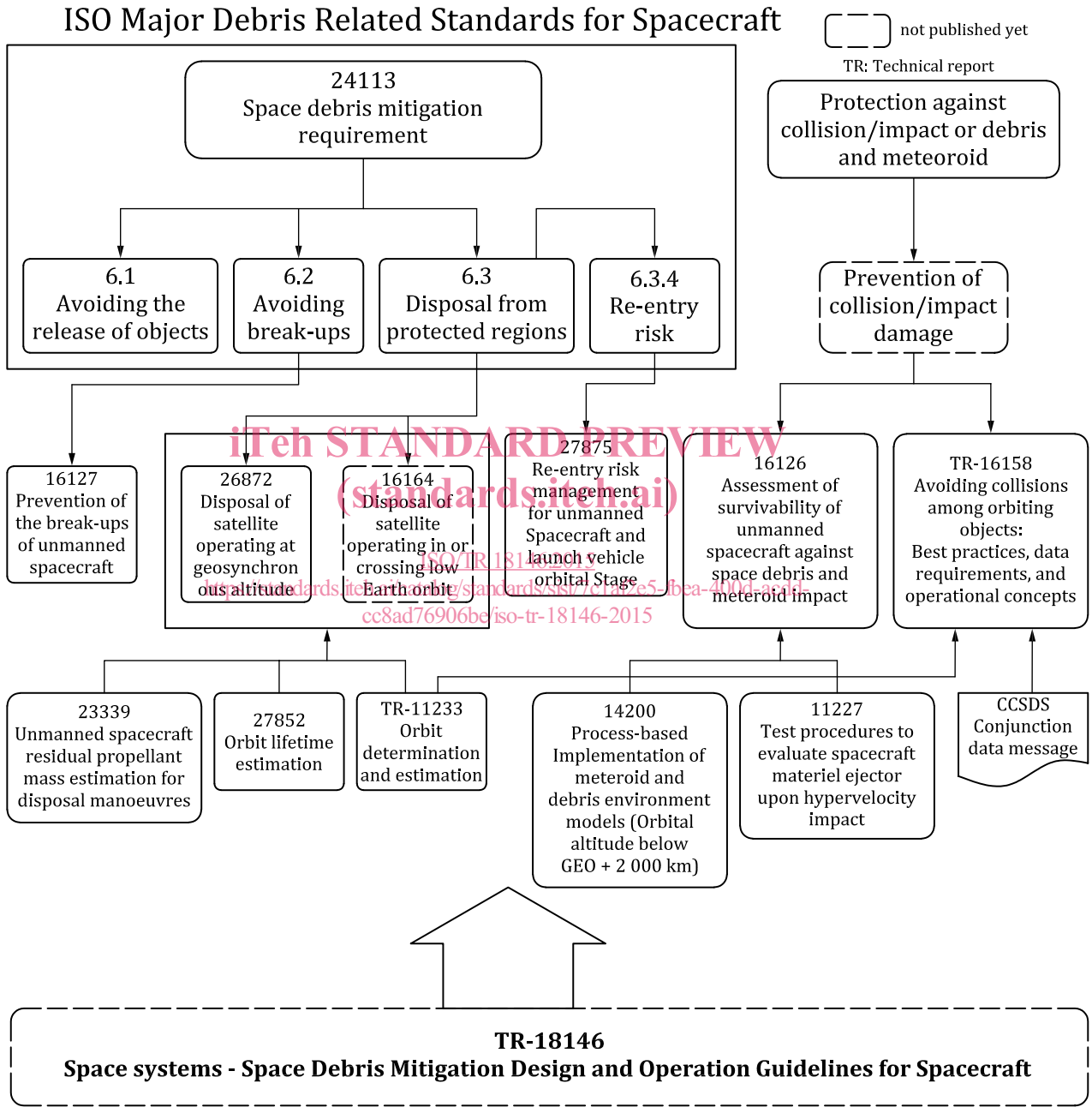

Figure 1 — Structure of major ISO debris-related standards

2.2 ISO debris-related standards as of February 2015

The following ISO standards have been published to address space debris mitigation:

(1) ISO 11227:2012, *Space systems — Test procedures to evaluate spacecraft material ejector upon hypervelocity impact*

(2) ISO 14200:2012, *Space environment (natural and artificial) — Guide to process-based implementation of meteoroid and debris environmental models (orbital altitude below GEO + 200 km)*

(3) ISO 16126:2014, *Space systems — Assessment of survivability of unmanned spacecraft against space debris and meteoroid impacts to ensure successful post-mission disposal*

(4) ISO 16127:2014, *Space systems — Prevention of break-up of unmanned spacecraft*

(5) ISO 16164:2015, *Space systems — Disposal of satellites operating in or crossing Low Earth Orbit*

(6) ISO 23339:2010, *Space systems — Unmanned spacecraft residual propellant mass estimation for disposal manoeuvres*

(7) ISO 24113:2011, *Space systems — Space debris mitigation requirements*

(8) ISO 26872:2010, *Space systems — Disposal of satellites operating at geosynchronous altitude*

(9) ISO 27852:2011, *Space systems — Estimation of orbit lifetime*

(10) ISO 27875:2010, *Space systems — Re-entry safety control for unmanned spacecraft and launch vehicle orbital stages*

2.3 Other relevant ISO standards

The following ISO standards are not specific to space debris mitigation but are considered relevant:

(1) ISO/TR 11225:2012, *Space environment (natural and artificial) — Guide to reference and standard atmosphere models*

(2) ISO/TR 11233:2014, *Space systems — Orbit determination and estimation — Process for describing techniques*

(3) ISO 14300-1:2011, *Space systems — Programme management — Part 1: Structuring of a project*

(4) ISO 14623:2003, *Space systems — Pressure vessels and pressurized structures — Design and operation*

(5) ISO/TR 16158:2013, *Space systems — Avoiding collisions among orbiting objects: Best practices, data requirements, and operational concepts*

(6) ISO 16404:2013, *Space systems — Programme management — Requirements management*

(7) ISO 27025:2010, *Program management — Quality assurance requirements*

2.4 Other documents

The following relevant documents are listed to provide the reader with additional background of the above ISO standards:

(1) UN, *Space Debris Mitigation Guidelines of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space*, Annex IV of A/AC.105/890, 6 March 2007, endorsed by the United Nations General Assembly under Resolution A/RES/62/217

(2) *IADC Space Debris Mitigation Guidelines*, IADC-02-01, Revision 1, September 2007, available at http://www.iadc-online.org/index.cgi?item=docs_pub

(3) *Support Document to the IADC Space Debris Mitigation Guidelines*, IADC-04-06, Issue 1, 5 October 2004, available at http://www.iadc-online.org/index.cgi?item=docs_pub

(4) *ITU Recommendation on GEO Disposal*, ITU-R S.1003, January 2004

(5) IADC-08-03 Sensor system to detect impact on spacecraft (http://www.iadc-online.org/)

2.5 Abbreviated terms and symbols

A/m:	Area-to-mass
AOCS:	Attitude and Orbit Control System
CDR:	Critical Design Review
CFRP:	Carbon-Fiber-Reinforced Plastic
CNES:	Centre National d'Etudes Spatiales
COPUOS:	Committee on the Peaceful Uses of Outer Space
Cr:	Solar Radiation Pressure Coefficient
DAS:	Debris Assessment Software (NASA)
DIS:	Draft International Standard (drafting phase in the process in ISO for registration of new standard)
DoF:	Degrees-of-Freedom
COTS:	Commercial Off-The-Shelf
DRAMA:	Debris Risk Assessment and Mitigation Analysis (ESA)
e:	eccentricity
EOMDP:	End-of-Mission (Operation) Disposal Plan
EOL:	End of Life
ESA:	European Space Agency
FMEA:	Failure Mode and Effect Analysis
GEO:	Geosynchronous orbit
GPS:	Global Positioning System
GTO:	Geosynchronous transfer orbit
IADC:	Inter-Agency Space Debris Coordination Committee
IRU:	Inertial Reference Unit
ISO:	International Organization for Standardization
JAXA:	Japan Aerospace Exploration Agency
JSpOC:	Joint Space Operations Center (USA)
LEGEND:	LEO-to-GEO Environment Debris model
LEO:	Low Earth orbit
MASTER:	Meteoroid and Space Debris Terrestrial Environment Reference
MEO:	Medium Earth orbit

MMOD:	Micro-Meteoroid Orbital Debris
NOTAM:	Notice To Airmen and Notice to Mariners
NSS:	NASA Safety Standard
ORDEM:	Orbital Debris Engineering Model
ORSAT:	Object Re-entry Survival Analysis Tool
PDR:	Preliminary Design Review
PNF:	Probability of no Failures
QA:	Quality Assurance
QR:	Qualification Review
RAAN:	Right ascension of the ascending node
RCS:	Reaction Control System
S/C:	Spacecraft
SCARAB:	Space Craft Atmospheric Re-entry and Aerothermal Break-up
SDA:	Space Data Association
SDR:	System Definition Review
SDMP:	Space-Debris-Mitigation Plan
STELA:	Semi-analytic Tool for End of Life Analysis (CNES)
USSTRATCOM:	United States Strategic Command
STS:	Space Transportation System
TLE:	Two-Line Element Set
TR:	Technical Report (a type of ISO document)
TT&C:	Telemetry Tracking and Command
UN:	United Nations
UNCOPUOS:	United Nations Committee on the Peaceful Uses of Outer Space Scientific and Technical Subcommittee

3 Requirements in ISO standards and system-level methodologies for complying with them

3.1 General

To accomplish comprehensive activities for debris mitigation and protection work, the following steps are to be considered:

(1) Identifying debris-related requirements, recommendations and best practices.

(2) Determining how to comply with these requirements, recommendations, and best practices.

(3) Apply those methods early and throughout development and manufacturing to ensure sound debris mitigation capability in the final product.

(4) Apply appropriate quality assurance and qualification program to ensure compliance with debris mitigation requirements

This sub-clause provides methodologies for taking comprehensive action at the system level. More detailed information for action of subsystem and component levels is provided in Clause 6. The following specific subjects are emphasized:

(1) Limiting the release of objects in protected orbital regions.

(2) Preventing fragmentation in orbit.

(3) Proper disposal during the end of operation to preserve the environment in protected orbital regions.

(4) Minimization of hazard on the ground from re-entering debris.

(5) Collision avoidance for trackable known objects.

(6) Protection against the impact of micro-debris and meteoroid.

(7) Quality, safety and reliability assurance.

3.2 Design for limiting the release of objects

3.2.1 Requirements

ISO 24113, 6.1 requires avoiding the intentional release of space debris into Earth orbit during normal operations:

(1) For general objects:

a) Spacecraft and launch vehicle orbital stages shall be designed so as not to release space debris into Earth orbit during normal operations.

b) Space debris released into Earth orbit as part of normal operations, other than as covered by next (2), shall remain outside the GEO protected region, and its presence in the LEO protected region shall be limited to a maximum of 25 years after release.

(2) For the combustion-related products:

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

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

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

The following classes of released objects are of concern from an orbital debris mitigation standpoint:

(1) Objects released as directed by mission requirements (ISO 24113, 6.1.1).

(2) Mission-related objects, such as fasteners, under the responsibility of designers (ISO 24113, 6.1.1).

(3) Combustion products from pyrotechnic devices (ISO 24113, 6.1.2.1).

(4) Combustion products from solid motors (ISO 24113, 6.1.2.2).

ISO 24113, 6.1.1.2 states that if objects must unavoidably be released despite requirements in ISO 24113, 6.1.1.1, orbital lifetime of such objects in Low Earth Orbit (LEO) and interference with Geostationary