ECSS-U-10 – Space sustainability – Space Debris

ESA Independent Safety Office (TEC-QI)

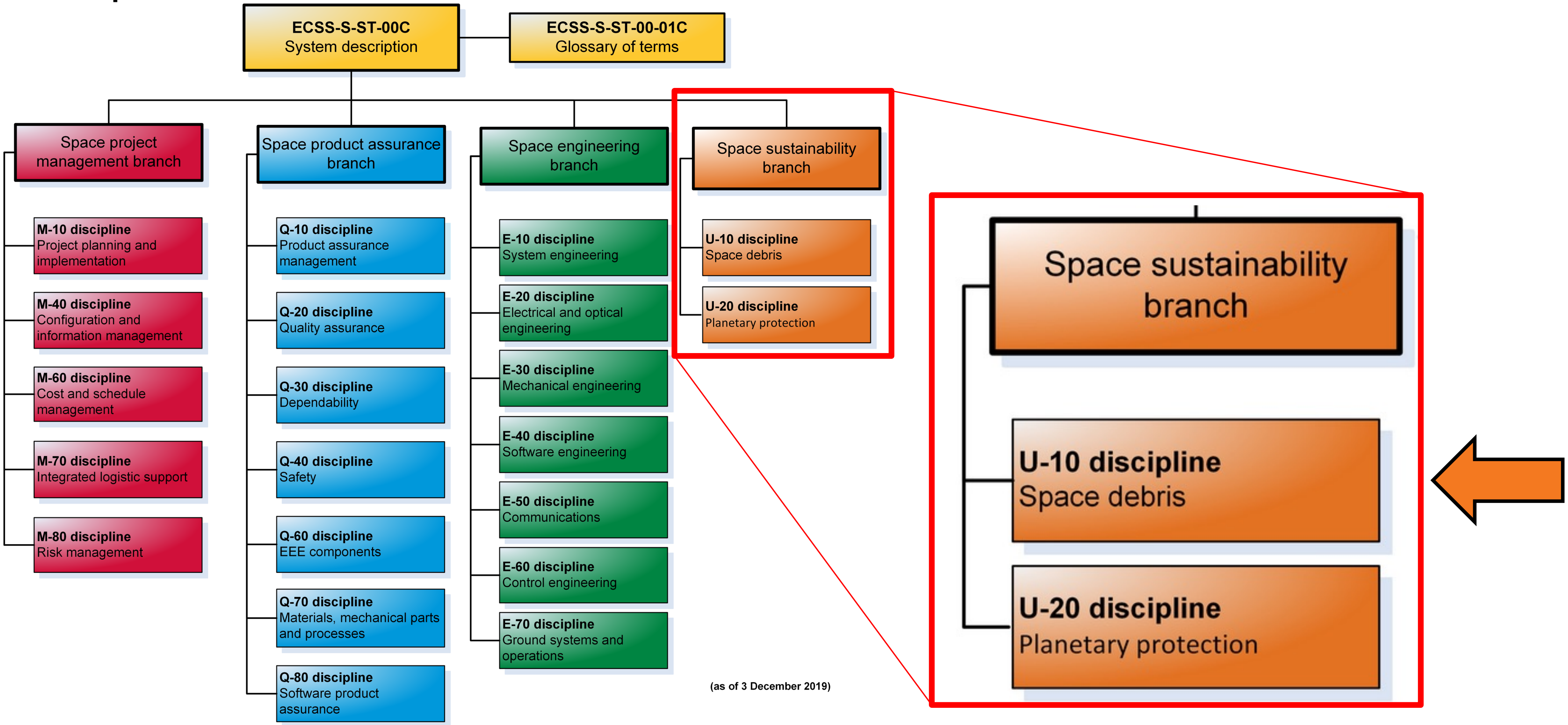
28th March 2023

Trainer's information: Sergio Ventura

- Sergio Ventura works as Space Debris Mitigation and Re-entry Safety Engineer at the ESA Independent Safety Office (TEC-QI), ESTEC, The Netherlands, since 2011.
- Sergio Ventura's main duties comprise:
  - supervision and assurance of the compliance of all ESA space missions with the ESA Space Debris Mitigation and Re-entry Safety policy and requirements;
  - assessment of the technical adequacy of the Space Debris Mitigation Plans and Reports;
  - performance of independent assessments;
  - coordination, preparation and maintenance of ESA standards and handbooks on Space Debris Mitigation and Re-entry Safety.
- Sergio Ventura graduated *Cum Laude* in Aerospace and Astronautical Engineering at the University of Naples "Federico II", Italy. He has a PhD in Aerospace Engineering, obtained in 2011 from the University of Naples "Federico II", Italy, in collaboration with the National Institute for Astrophysics (INAF), Italy, and the ESA ExoMars Programme.

Introduction

ECSS Disciplines



Topics

Definition of Space Debris Mitigation (SDM)

Organizations involved in the solution of the Space Debris problem

Definition of the Protected Regions

Rules and guidelines to preserve the Protected Regions

European Space Agency process for ensuring Space Debris Mitigation

National regulations and cooperation agreements on Space Debris Mitigation

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Space Debris Mitigation (SDM)

Space Debris
***man-made objects**, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are **non-functional**[1]*

Mitigation
the action of reducing the severity, seriousness, or painfulness of something[2]

Space Debris Mitigation
the action of reducing the severity, seriousness, or painfulness of space debris

Objectives

Space Sustainability
the ability to preserve and protect the outer space environment over long-term for use by future generations

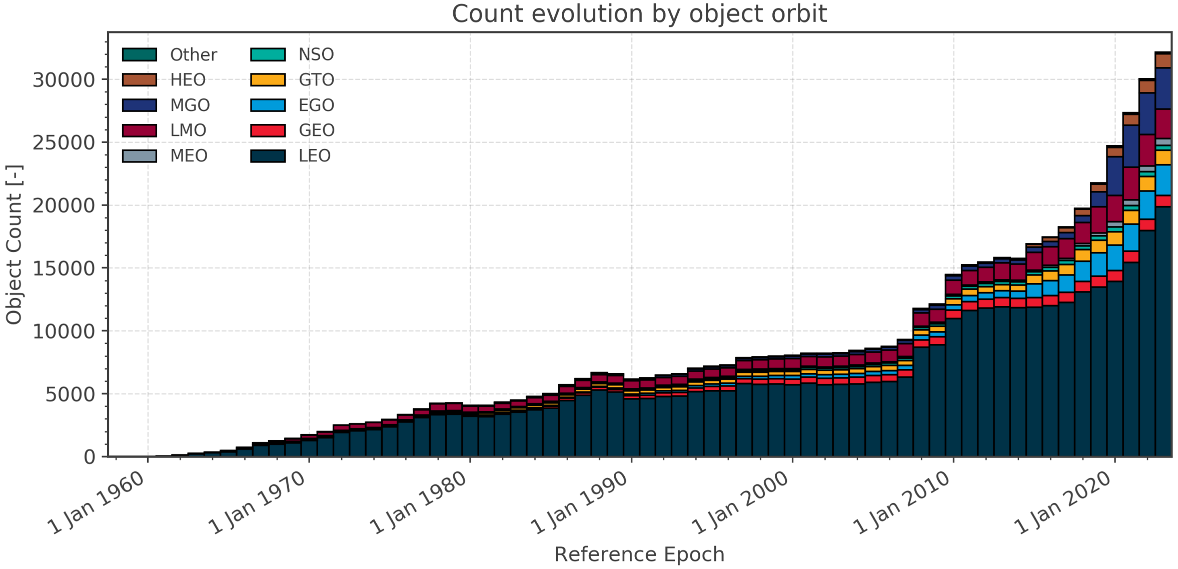
Targets:
- *To prevent the "**Kessler Syndrome**", i.e. global amount and density of space debris in Earth orbit growing to a point where random collisions occur between objects in space (cascade effect) making orbits not longer exploitable*

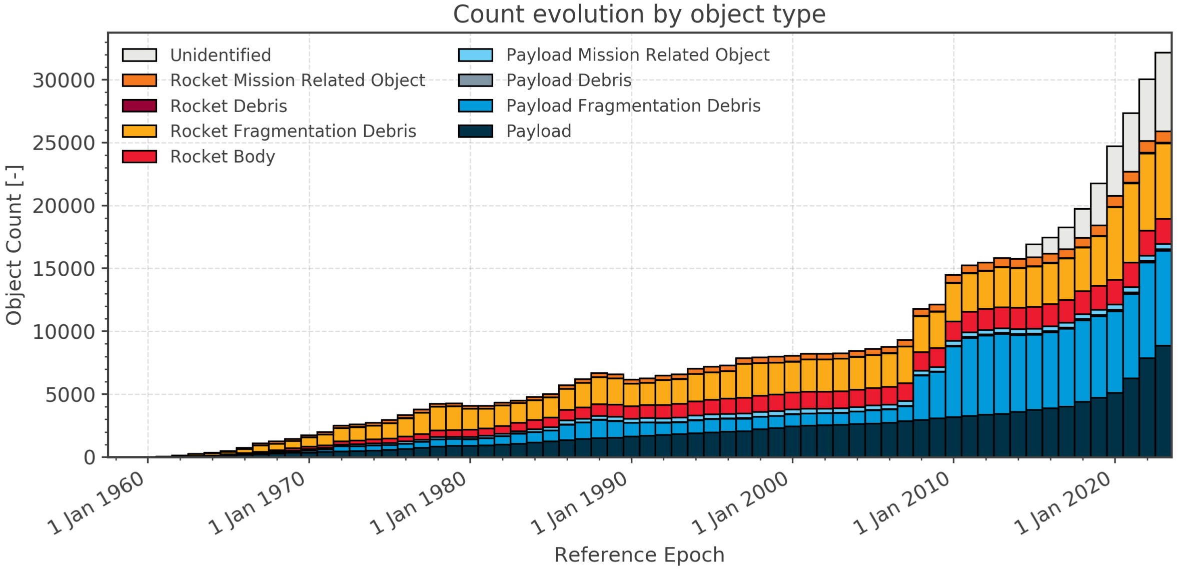
Risk limitation (on Earth and in Space)
For risk relates to:
- *fatality,*
- *injury or occupational illness,*
- *pollution of the environment,*
- *damage to public or private property.*

Targets:
- *To minimize fatalities/casualties/damages associated to **re-entry***
- *To prevent fatalities/casualties/damages due to **in-orbit collisions***

References:
(1) IADC
(2) Oxford dictionary

Space environment





Space objects and debris: numbers
(as of 22 December 2022)

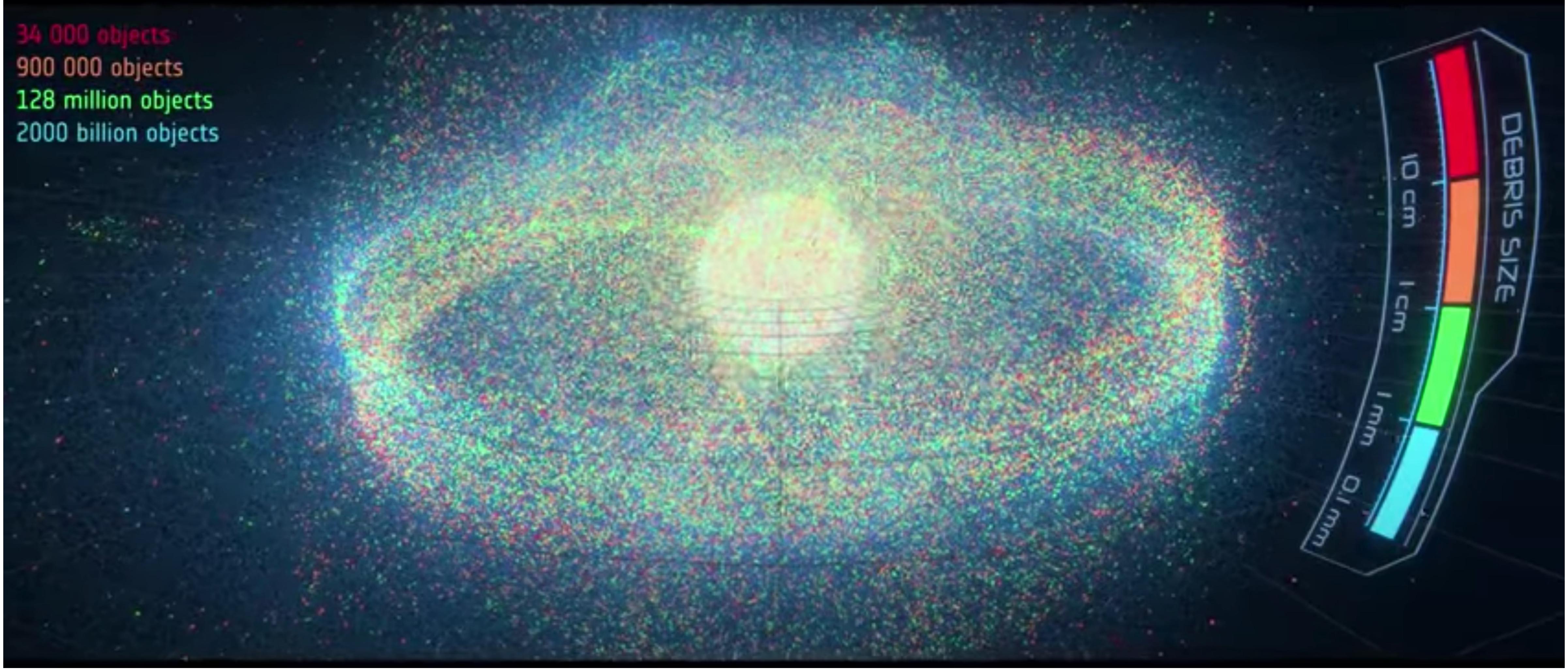
- Launched rocket (excl. failures): > 6370
- Launched spacecraft: > 15070
- On-orbit spacecraft: ~ 9790
- Functioning spacecraft: ~ 7200
- Tracked/catalogued space objects: ~ 32300
- Estimated break-ups events: > 640
- Space objects mass in Earth orbit: > 10,700 *t*

Source: ESA, 22-Apr-2022

https://sdup.esoc.esa.int/discosweb/statistics/

Space environment

Source: ESA, https://www.esa.int/ESA_Multimedia/Videos/2021/04/Time_to_Act



Worst historical space debris generation events

On-orbit break-up events by catalogued debris

(as of 31 January 2023)

Rank	International Designator	Common Name	Year of Breakup	Apogee Altitude (km)	Perigee Altitude (km)	Debris Cataloged	Debris in Orbit	Assessed Cause of Breakup
1	1999-025A	Fengyun-1C	2007	865	845	3532	2793	Anti-satellite (ASAT) test
2	1982-092A	Cosmos 1408	2021	490	465	1785	364	ASAT test
3	1993-036A	Cosmos 2251	2009	800	775	1715	1021	Accidental collision (with Iridium 33)
4	1994-029B	STEP II upper stage	1996	820	585	754	76	Accidental explosion
5	1997-051C	Iridium 33	2009	780	775	657	300	Accidental collision (with Cosmos 2251)
6	2022-151B	CZ-6A upper stage	2022	847	813	533	529	Accidental explosion
7	2006-026A	Cosmos 2421	2008	420	400	509	0	Unknown
8	1986-019C	SPOT 1 upper stage	1986	835	805	498	30	Accidental explosion
9	1981-053A	Cosmos 1275	1981	1015	960	479	418	Accidental explosion
10	1965-082DM	Titan 3C-4 transtage	1965	790	710	473	32	Accidental explosion

NASA “Orbital Debris Quartely News” March 2023

SDM historical background

- **1957:** First spacecraft in orbit (Sputnik 1)
- **1978:** First studies on the space debris problem (Kessler syndrome theory formulation)
- **1990s:** First draft of Space Debris Mitigation Standards, Guidelines and handbooks issued by national and international organizations and space agencies
- **1993:** Inter-Agency Debris Coordination Committee (IADC) established
- **2002:** First "IADC Space Debris Mitigation Guidelines" published by IADC (updated in 2007)
- **2007:** United Nations (UN) "Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space – 22/12/2007" approved by 63 Member Nations
- **2010:** First edition of the International Organization for Standardization (ISO) standard ISO 24113:2010 – Space Systems – Space Debris Mitigation Requirements published

Relevant Organizations: UN COPUOS

<u>What is it?</u>

- **United Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS)**, part of the UN Office for Outer Space Affairs (UNOOSA)
- Intergovernmental organization
- Ref. http://www.unoosa.org

<u>What does it do?</u>

- Produces resolutions and high-level guidelines for the exploration and use of space
- Receives technical inputs/recommendations from IADC regarding to SDM

<u>Membership</u>

- 95 Member States (from **UN Member States**)
- Observers: other intergovernmental or non-governmental organizations, e.g. ESA in scientific and technical sub-committee on space sustainability, and Safety Framework for Nuclear Power Source Applications

<u>Documents related to SDM</u>

- *UN Treaties and Principles on Outer Space*
- *UN Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space – 22/12/2007*
- *Guidelines for the long-term sustainability of outer space activities – 17/07/2018*

Relevant Organizations: IADC

What is it?

- **Inter-Agency Space Debris Coordination Committee (IADC)**
- Intergovernmental forum
- Ref. http://www.iadc-online.org

What does it do?

- Produces technical guidelines for SDM
- Suggest technical inputs/recommendations to UN COPUOS regarding to SDM

Membership

- **ASI** (Agenzia Spaziale Italiana – Italy), **CNES** (Centre National d'Etudes Spatiales – France), **CNSA** (China National Space Administration – China), **CSA** (Canadian Space Agency – Canada), **DLR** (German Aerospace Center – Germany), **ESA** (European Space Agency – 22 Member States), **ISRO** (Indian Space Research Organization – India), **JAXA** (Japan Aerospace Exploration Agency – Japan), **KARI** (Korea Aerospace Research Institute – South Korea), **NASA** (National Aeronautics and Space Administration – USA), **ROSCOSMOS** (State Space Corporation – Russia), **SSAU** (State Space Agency of Ukraine – Ukraine), **UKSA** (UK Space Agency – United Kingdom)

Documents related to SDM

- *IADC Space Debris Mitigation Guidelines – 2007 (2020)*
- *IADC-15-03 – IADC Statement on Large Constellations of Satellites in Low Earth Orbit – 09/2017*

Relevant Organizations: ISO

What is it?
- **International Organization for Standardization (ISO)**
- International non-governmental independent organization for unification of industrial standards
- Ref. http://www.iso.org

What does it do?
- Produces technical standards (requirements) for several disciplines and applications, including SDM in the frame of the Technical Committee ISO/TC20 (Aircraft and space vehicles) / Subcommittee SC14 – Space Systems and Operations

Membership
- 163 Member States
- Observers: other intergovernmental or non-governmental organizations, e.g. ESA in ISO/TC20/SC14 Working Group 7 on SDM

Documents related to SDM
- ~~*ISO 24113:2011 – Space Systems – Space Debris Mitigation Requirements (2nd edition)*~~
- *ISO 24113:2019 – Space Systems – Space Debris Mitigation Requirements (3rd edition)*

Relevant Organizations: ECSS

What is it?

- **European Cooperation for Space Standardization (ECSS)**
- European organization within the European space sector
- Ref. http://www.ecss.nl

What does it?

- Produces technical standards (requirements) for space project management, space engineering, space product assurance, and space sustainability (including SDM)

Which are the Members?

- **ESA** (European Space Agency – 22 Member States), **Eurospace** (55 space industries from 14 European States), **ASI** (Agenzia Spaziale Italiana – Italy), **CNES** (Centre National d'Etudes Spatiales – France), **CSA** (Canadian Space Agency – Canada), **DLR** (German Aerospace Center – Germany), **NSO** (Netherlands Space Office – The Netherlands), **UKSA** (United Kingdom Space Agency – United Kingdom)
- Observers: **Eumetsat**, **CEN** (European Committee for Standardization), **EDA** (European Defense Agency)

Documents related to SDM

- ~~*ECSS-U-AS-10C - Space sustainability - Adoption Notice of ISO 24113, 10/02/2012*~~
- *ECSS-U-AS-10C, Rev. 1 - Space sustainability - Adoption Notice of ISO 24113, 03/12/2019*

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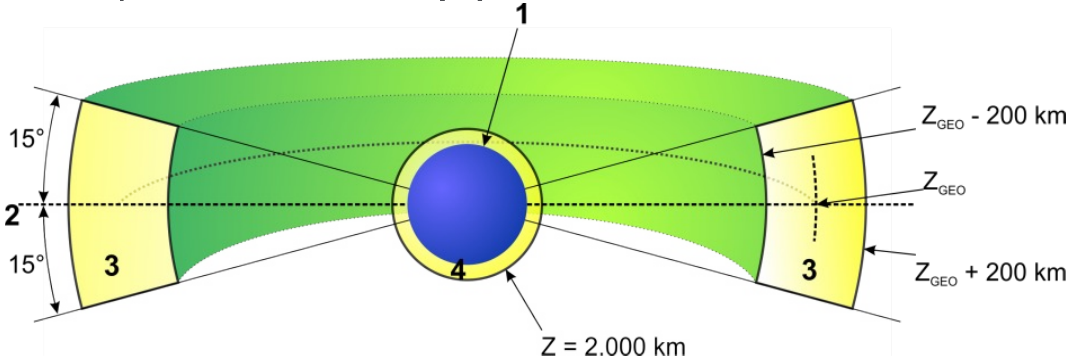
Protected Regions

- As priority for space sustainability, 2 Protected Regions in Earth orbit were identified in the frame of IADC, followed as well by the UN COPUOS guidelines and ECSS and ISO standards:

1. LEO Protected Region

Low Earth Orbit Protected Region is a shell that extends from the surface of a spherical Earth with an equatorial radius of 6378 km up to an altitude (Z) of 2000 km

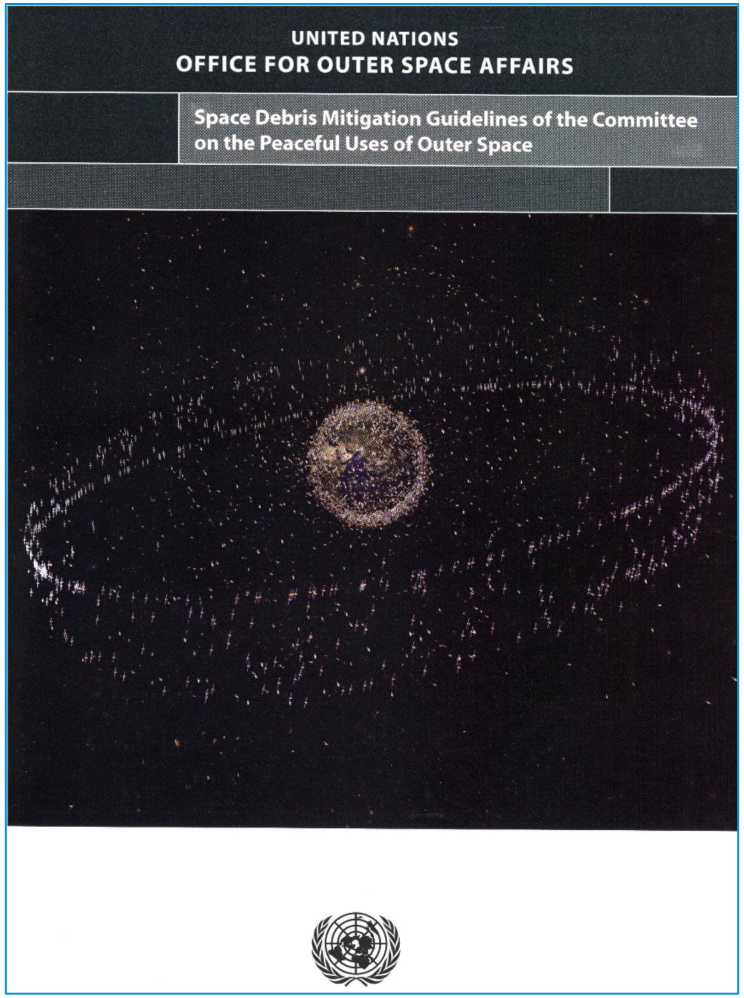


2. GEO Protected Region

Geostationary Earth Orbit Protected Region is a segment of a spherical shell defined by:

- lower altitude boundary = geostationary altitude minus 200 km
- upper altitude boundary = geostationary altitude plus 200 km
- latitude sector: 15° South ≤ latitude ≤ 15° North
- geostationary altitude (Z_{GEO}) = 35786 km (wrt the spherical Earth with an equatorial radius of 6378 km)

UN SDM Guidelines



States and International Organizations have:

- adopted the *"UN Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space – 22/12/2007"*, a
- generated own regulations and standards for the implementation of these guidelines.

Guideline 1:	Limit debris released during normal operations
Guideline 2:	Minimize the potential for break-ups during operational phases
Guideline 3:	Limit the probability of accidental collision in orbit
Guideline 4:	Avoid intentional destruction and other harmful activities
Guideline 5:	Minimize potential for post-mission break-ups resulting from stored energy
Guideline 6:	Limit the long-term presence of spacecraft and launch vehicle orbital stages in the low-Earth orbit (LEO) region after the end of their mission
Guideline 7:	Limit the long-term interference of spacecraft and launch vehicle orbital stages with the geosynchronous Earth orbit (GEO) region after the end of their mission

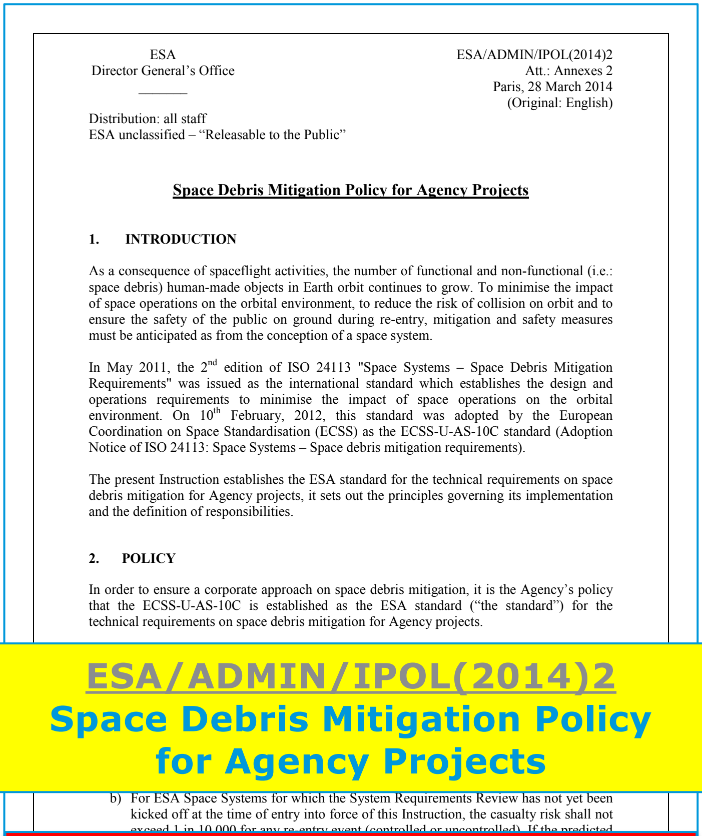
ESA SDM milestones

- **2004:** **European Code of Conduct for Space Debris Mitigation** signed by ESA, ASI (Italy), BNSC (UK), CNES (France) and DLR (Germany)
- **2008:** **ESA/ADMIN/IPOL(2008)2 - Space Debris Mitigation Policy for Agency Projects** released
- **2011:** **ISO 24113:2011 – Space Systems – Space Debris Mitigation Requirements** published
- **2012:** **ECSS-U-AS-10C – Adoption Notice of ISO 24113: Space Systems – Space Debris Mitigation Requirements** published
- **2014:** **ESA/ADMIN/IPOL(2014)2 – Space Debris Mitigation Policy for Agency Projects** released
- **2015:** **ESSB-HB-U-002, Issue 1 - ESA Space Debris Mitigation Compliance Verification Guidelines** published
- **2017:** **ESSB-ST-U-004 – ESA Re-entry Safety Requirements** published
- **2019:** **ISO 24113:2019 - Space Systems – Space Debris Mitigation Requirements** and **ECSS-U-AS-10C, Rev. 1 – Adoption Notice of ISO 24113: Space Systems – Space Debris Mitigation Requirements** published
- **2023:** **ESSB-HB-U-002, Issue 2 - ESA Space Debris Mitigation Compliance Verification Guidelines** published

ESA SDM Policy

- An **ESA Policy** is an official document, signed by the Director General, which defines principles, procedures and responsibilities regarding to the management of specific Agency's relevant activities or strategies.
- The ESA Space Debris Mitigation Policy "ESA/ADMIN/IPOL(2014)2" is the **Instruction** setting out the principles governing the implementation and the definition of responsibility for Space Debris Mitigation.
- The ESA Space Debris Mitigation Policy establishes "ECSS-U-AS-10C – Adoption Notice of ISO 24113: Space Systems – Space debris mitigation requirements" as the **Standard** containing **technical requirements**, which applies to:
  - Procurement of ESA Space Systems (e.g. launchers, satellites, inhabited or robotic vehicles);
  - Operations under the responsibility of ESA, of any given Space System;
  - Procurement of launch services for ESA Space Systems on a *best effort* basis.

ESA SDM Policy, Standards, and Requirements



ESA
Director General's Office
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ESA/ADMIN/IPOL(2014)2
Att.: Annexes 2
Paris, 28 March 2014
(Original: English)

Distribution: all staff
ESA unclassified – "Releasable to the Public"

Space Debris Mitigation Policy for Agency Projects

1. INTRODUCTION

As a consequence of spaceflight activities, the number of functional and non-functional (i.e.: space debris) human-made objects in Earth orbit continues to grow. To minimise the impact of space operations on the orbital environment, to reduce the risk of collision on orbit and to ensure the safety of the public on ground during re-entry, mitigation and safety measures must be anticipated as from the conception of a space system.

In May 2011, the 2nd edition of ISO 24113 "Space Systems – Space Debris Mitigation Requirements" was issued as the international standard which establishes the design and operations requirements to minimise the impact of space operations on the orbital environment. On 10th February, 2012, this standard was adopted by the European Coordination on Space Standardisation (ECSS) as the ECSS-U-AS-10C standard (Adoption Notice of ISO 24113: Space Systems – Space debris mitigation requirements).

The present Instruction establishes the ESA standard for the technical requirements on space debris mitigation for Agency projects, it sets out the principles governing its implementation and the definition of responsibilities.

2. POLICY

In order to ensure a corporate approach on space debris mitigation, it is the Agency's policy that the ECSS-U-AS-10C is established as the ESA standard ("the standard") for the technical requirements on space debris mitigation for Agency projects.

b) For ESA Space Systems for which the System Requirements Review has not yet been kicked off at the time of entry into force of this Instruction, the casualty risk shall not

ESA/ADMIN/IPOL(2014)2
Space Debris Mitigation Policy for Agency Projects

ESA Policy applicable
to all ESA Projects

Extended until 31/12/2023

ECSS-U-AS-10C Rev.1
3 December 2019

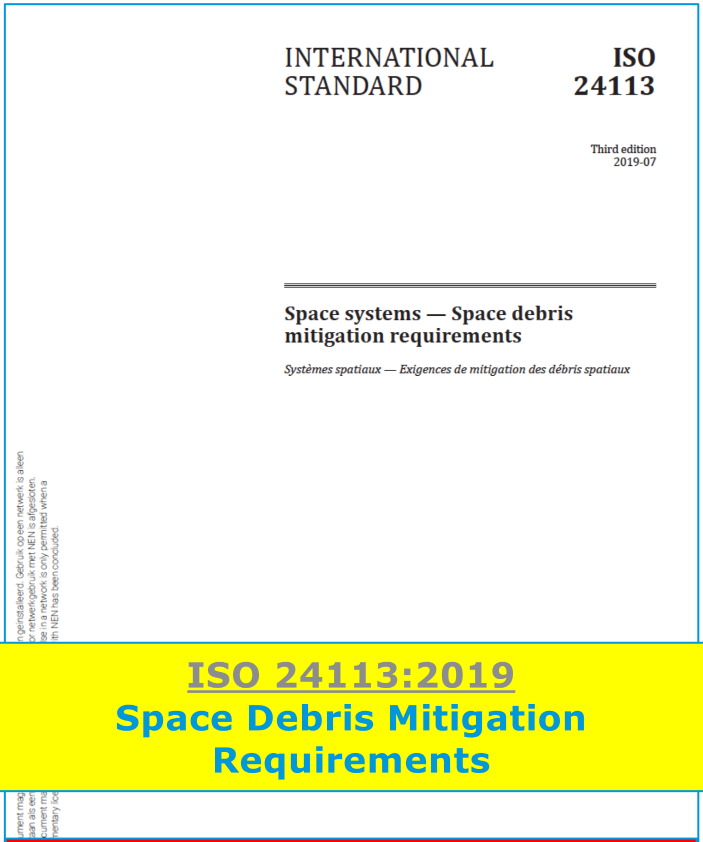
EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space sustainability

Adoption Notice of ISO 24113: Space systems - Space debris mitigation requirements

ECSS-U-AS-10C, Rev. 1
Space sustainability - Adoption Notice of ISO 24113

ECSS Standard,
adopting ISO 24113:2019,
applicable to Prime Contractors



INTERNATIONAL STANDARD

ISO
24113

Third edition
2019-07

Space systems — Space debris mitigation requirements

Systèmes spatiaux — Exigences de mitigation des débris spatiaux

ISO 24113:2019
Space Debris Mitigation Requirements

ISO Standard,
adopted by ECSS-U-AS-10C,
providing technical requirements

ESA Policy and Standards maintenance

Document Reference	Type of Document	Document Management and Change/Update Process
ESA/ADMIN/IPOL(2014)2	**ESA policy**	• Head of the ESA Department of Product Assurance and Safety (TEC-Q) is in charge of the management. • ESA Independent Safety Office (TEC-QI) in charge of the maintenance. • Effective for 4 years after publication and subject to revocation or revision by the ESA Director General. • Reviewed for extension, modification, or revocation 6 months before the validity period.
ECSS-U-AS-10C	**ECSS standard**	• Prepared by the ECSS Space Debris Working Group (SDWG). • Change Requests (CRs) can be proposed with a rationale at any time. • CRs shall be submitted to ECSS Executive Secretariat. • CRs shall be assessed by the ECSS Technical Authority for approval.
ESSB-U-ST-004 ESSB-HB-U-002	**ESA standard and handbook**	• Prepared by the ESA Space Debris Mitigation (SDM) / Re-entry Safety (RS) Working Group. • Approved by the ESA ESSB, ESB and QSB (standardisation boards). • Change Requests (CRs) can be proposed by anyone in ESA with a rationale. • CRs shall be processed by the ESSB Secretariat. • CRs shall be assessed by the ESA SDM/RS WG and through an ESA internal review for approval.
ISO 24113	**ISO standard**	• Prepared by ISO Technical Committee ISO/TC20 (Aircraft and space vehicles), subcommittee SC 14 (Space systems and operations), Working Group 7. • Proposed changes can be submitted to ISO TC20/SC14 WG7 for assessment/screening/review. • Proposed changes shall be submitted by the ISO TC20/SC14 WG7 to the ISO member bodies for voting.

SDM technical requirements

The Space Debris Mitigation (SDM) technical requirements, adopted by ESA, are defined in the standards ECSS-U-AS-10C / ISO 24113.

The SDM requirements covers:

- Avoidance of mission-related objects release
- Avoidance of particles release
- In-orbit break-up risk mitigation
- Collision risk management
- End of mission passivation
- Clearance of the LEO Protected Region
- Clearance of the GEO Protected Region
- Assurance of successful disposal
- Re-entry casualty risk mitigation

SDM constantly evolving

ECSS-U-AS-10C / ISO 24113 periodically reviewed/updated

ECSS-U-AS-10C, Rev. 1 / ISO 24113:2019: requirements

Requirement	Requirement subject	Synthetic requirement content
6.1.1.1	Debris release limitation – Spacecraft	No release of debris in Earth orbit
6.1.1.2	Debris release limitation – Launch vehicle	≤ 1 object for single payload launch; ≤ 2 objects for multiple payload launch
6.1.1.3	Debris release limitation – Launch vehicle elements in-orbit presence	Launch vehicle debris > 100 yrs outside GEO and ≤ 25 yrs in LEO
6.1.2.1	Particles limitation – Pyrotechnic devices	No particles ≥ 1 mm
6.1.2.2	Particles limitation – Solid rocket motors	No particles ≥ 1 mm
6.2.1	Intentionally-caused break-up control – Avoidance	No intentional break-ups allowed
6.2.2.1	Internally-caused break-up control – Probability threshold	Probability of accidental break-up < 10^{-3}
6.2.2.2	Internally-caused break-up control – Probability computation	Probability of accidental break-up to be assessed (by analysis/test)
6.2.2.3	Internally-caused break-up control – Passivation	Passivation implementation mandatory for end of mission (excl. spacecraft controlled re-entry)
6.2.2.4	Internally-caused break-up control – Passivation for launch vehicle	Passivation implementation mandatory by design for launch vehicles
6.2.2.5	Internally-caused break-up control – Health monitoring	Periodical system/units monitoring to be perfomed
6.2.2.6	Internally-caused break-up control – Contingency plan	Contingency plan to be prepared to cope with flight anomalies
6.2.3.1	Externally-caused break-up control – Collision avoidance capability for GEO	Collision avoidance manouvrability mandatory for GEO spacecraft
6.2.3.2	Externally-caused break-up control – Collision avoidance duties	Collision avoidance manoeuvres to be performed for spacecraft with propulsion capability
6.2.3.3	Externally-caused break-up control – Collision risk mitigation	Collision risk to be assessed and below the Approving Agent's threshold
6.2.3.4	Externally-caused break-up control – Vulnerability assessment	Collision risk / Vulnerability with space debris or meteoroids to be assessed

Part 1/2: See ISO 24113:2019 for full standard / requirements text

ECSS-U-AS-10C, Rev. 1 / ISO 24113:2019: requirements

Requirement	Requirement subject	Synthetic requirement content
6.3.1.1	Successful disposal assurance – Probability threshold	Probability of successful disposal ≥ 0.90 until end of mission
6.3.1.2	Successful disposal assurance – Vulnerability assessment	Collision risk / Vulnerability with space debris or meteoroids to be assessed
6.3.1.3	Successful disposal assurance – Disposal criteria	Criteria for disposal to be defined/monitored during Development/Operation Phase
6.3.1.4	Successful disposal assurance – Health monitoring	Periodical system/units monitoring to be performed
6.3.1.5	Successful disposal assurance – Continency plan	Contingency plan to be prepared to cope with flight anomalies
6.3.1.6	Successful disposal assurance – Mission extension conditions	Probability of successful disposal ≥ 0.90 until end of extended mission
6.3.2.1	GEO clearance – Disposal conditions	No return to GEO for > 100 years
6.3.2.2	GEO clearance – Disposal execution for continuous presence	Orbit altitude increase higher than IADC formula ($\Delta H=235+(1000 \cdot C_r \cdot A/m)$, $e<0.003$)
6.3.2.3	GEO clearance – Disposal execution for periodical presence	No return to GEO for > 100 years
6.3.3.1	LEO clearance – Disposal conditions	≤ 25 yrs n LEO allowed from time of no collision avoidance manoeuvrability
6.3.3.2	LEO clearance – Disposal execution	Active or passive disposal options to ensure LEO clearance in ≤ 25 yrs
6.3.4.1	Re-entry – Safety requirements	ESSB-ST-U-004 - ESA Re-entry Safety Requirements
6.3.4.2	Re-entry – Risks threshold	Re-entry casualty risk < 10^{-4}

NOTE:

1) The requirements are applicable to any **Earth orbit**, i.e. bounded or unbounded Keplerian orbit with Earth at a focal point, or Lagrange point orbit which includes Earth as one of the two main bodies.

2) The requirements are not considered for space objects in an unbounded Earth orbit if the assessed risk of a space object interference with the LEO and GEO Protected Regions or re-entry for at least 100 years after the space objects enter the unbounded Earth orbit is less or equal to the corresponding threshold set by the Approving Agent.

Part 2/2: See ISO 24113:2019 for full standard / requirements text

Avoidance of mission-related objects

Requirement(s)	ECSS-U-AS-10C, Rev .1 / ISO 24113:2019 6.1.1.1-6.1.1.3
Objective	**Space system designed such that during launch and operations no debris are released**

Guidelines for compliance:

1. No release of objects in orbits crossing the LEO and GEO Protected Regions.

2. Avoidance release of items (i.e. retainment by design) from:
   a. launch vehicle,
      e.g. connectors, fasteners (separation bolts, clamp bands), fairings, adapters for launching multiple payloads, etc..
   b. spacecraft,
      e.g. covers (e.g. nozzles closures, lens caps, cooler covers), tethers, yo-yo weights and lines, etc..

3. For launch operations (allowance):
   maximum number of debris released by the launch vehicle to 1 for single spacecraft launch, and
   2 for multi-spacecraft launch (max 25 years in LEO, and outside GEO for at least 100 years).

Verification Method(s)	Review of design

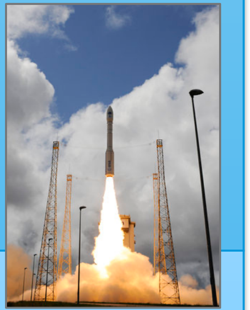
Avoidance of release of particles

Requirement(s)	ECSS-U-AS-10C, Rev. 1 / ISO 24113:2019 6.1.2.1-6.1.2.2
Objective	**Space system designed such that during operations no particles > 1 mm are released in Earth orbit**

<u>Guidelines for compliance:</u>

1. No generation/ release of particles larger than 1 mm in Earth orbit, especially LEO/GEO Protected Regions.
3. For **pyrotechnic devices**:
   (e.g. as pyrotechnic release bolts, pyrotechnic cable cutters and pyrotechnic valves):
   - Possible particulate released during operations, if not contained, to be characterized (during qualification), and verified by review of design (off-the-shelf devices) or by test (new developments.)
   - Select only products fulfilling the requirement.
3. For **Solid Rocket Motors (SRMs)**:
   - Avoid the use of SRMs for orbital operations by preferring liquid propulsion systems or metal-free propellants.

   NOTE: Although the several particles released by SRMs are typically smaller than 1 mm diameter (5-50 µm), during tail-off large amounts of slag and amalgamated combustion products up to 5 cm in diameter may be released.
3. Containment for particles generated by devices.
4. Use of materials and technologies able to be resistant to environmental degradation.



Verification Method(s)	Review of design

In-orbit break-up risk mitigation

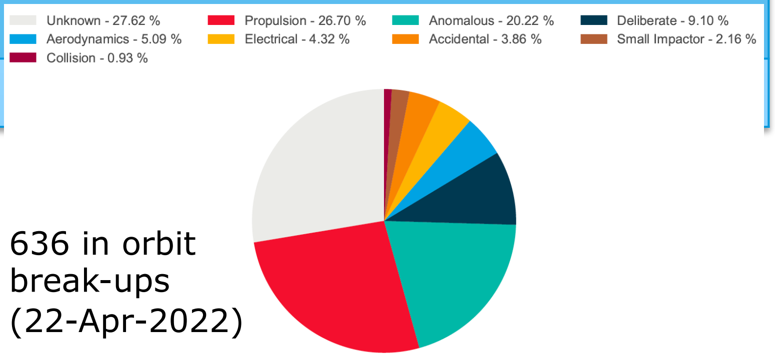
Requirement(s)	ECSS-U-AS-10C, Rev. 1 / ISO 24113:2019 6.2.1, 6.2.2.1-6.2.2.6
Objective	**No intentional in-orbit break-ups** **Accidental in-orbit break-up risk < 10^{-3} until end of life**

Guidelines for compliance:

1. No intentional fragmentation of the space system.
2. Quantitative assessment of the in-orbit break-up risk based on **Failure Mode and Effects Critical Analysis (FMECA)** for each critical component storing energy.
3. Risk assessment, if no passivation measures are implemented at end of mission (risk inversely proportional to in-orbit presence).
4. For example, assurance that:
   a. Battery cells implement adequate safety devices, e.g. PTC (Positive Temperature Coefficient polyswitch), CID (Current Interrupt Device), leak-before-burst device; are traceable and procured from a well-reputed manufacturer; successfully passed qualification tests, lot acceptance tests, and flight acceptance tests.
   b. Pressure vessels (e.g. propulsion tanks) are qualified (e.g. ECSS-E-ST-32-02C, ECSS-E-ST-10-04C, ANSI/AIAA S-081A-2006, ANSI/AIAA S-080-1988), the thermal/environmental effects up to EOL is assessed, propellant dissociation does not lead to accidental explosions before the end of life.

Verification Method(s)	Analysis and/or Test

- **End of life** is the instant when a space system has ensured clearance of the Protected Regions and has permanently minimized its chances of break-up (if re-entry is not expected), or is the re-entry time (if re-entry is expected or planned).



https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf

End of mission passivation

Requirement(s)	ECSS-U-AS-10C, Rev. 1 / ISO 24113:2019 6.2.2.3-6.2.2.4
Objective	**Removal of stored energy to prevent debris generation after end of mission**

<u>Guidelines for compliance:</u>

1. Implementation of measures for depleting the stored energy in the space system at end of mission (e.g. residual energy in propulsion tanks, batteries, etc.).
2. Risk assessment for components that cannot be fully depleted of their energy (versus the worst-case expected environmental conditions).
3. No unpredictable attitude or orbit dynamics resulting from passivation operations.

NOTE: Spacecraft performing controlled re-entry are not required to perform passivation.

Verification Method(s)	Review of design / Analysis / Test

Credits: GomSpace

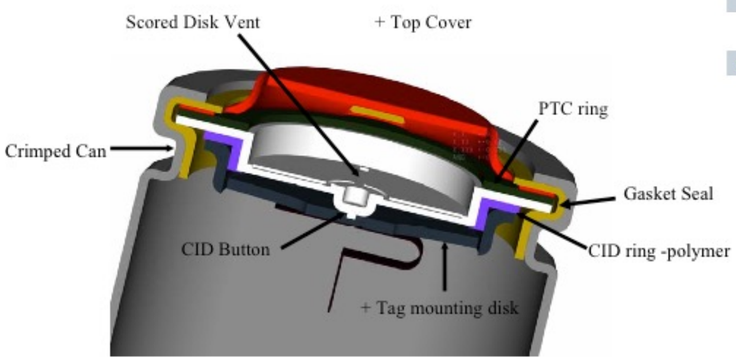
- **Passivation** is the permanent depletion or making safe of all on-board sources of stored energy able of causing break-ups

End of mission passivation: power subsystem

Subsystem	Component	Passivation Measures
Power	**Batteries**	1. Discharge 2. Disconnect from solar array, power bus or any charging source
Power	**Fuel Cells**	1. Discharge 2. Disconnect from solar array, power bus or any charging source
Power	**Solar Array**	1. Disconnect from power bus or batteries 2. Short-circuit

In-orbit break-up risk mitigation: battery hazard control

Li-ion battery cells failure can cause thermal runaways leading to explosions or bursts which can damage the space system and generate debris in orbit



- Cell failure modes that can lead to cell explosion:
  1. Overcharge
  2. Overdischarge
  3. Overpressure (vent/burst)
  4. Overtemperature
  5. External short-circuit
  6. Internal short-circuit
- Cell manufacturing defects that can lead to cell explosion:
  1. Dendrites formation
  2. Counterfeits

Typical safety devices that can be found in a battery cells (cylindrical cells 18650):

- Current Interrupt Device (CID), including also a burst disk, to protect against overcharge and overpressure inside the cell;
- Positive Temperature Coefficient device (PTC) to protect against short-circuit external to the cell and overcurrent inside the cell;
- Leak-Before-Burst (LBB) device to mitigate the burst of the cell.

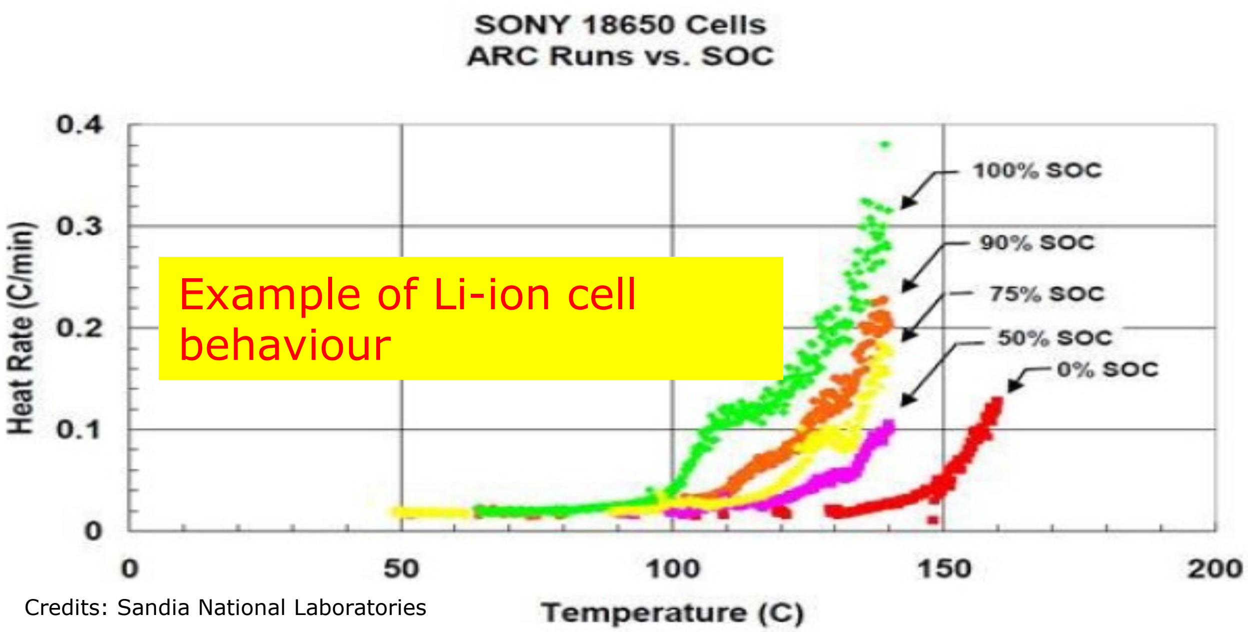
End of mission passivation: battery hazard control

a. Assure minimum State of Charge of the battery cells after the end of mission, e.g. by disconnecting the battery from the solar array at end of mission, etc.

b. Use battery cells implementing adequate safety devices, e.g. PTC (Positive Temperature Coefficient polyswitch), CID (Current Interrupt Device), leak-before-burst device.

c. Assure traceability, procurement from a well-reputed manufacturer, and successfully passed qualification tests, lot acceptance tests, and flight acceptance tests for the battery cells.

d. Check withstanding with the worst-case space environment conditions, e.g. maximum exposure temperature (Sun illumination), radiation level, micrometeoroid and debris impact, until re-entry.



Credits: Sandia National Laboratories

The onset temperature of self-generating heating (thermal runaway) decreases with increasing State of Charge (SoC)

Warning:
Alone cell safety devices are not proven to be always fully reliable in all battery assembly configurations, for all type of cells, and in all space environement conditions.
Control measures (passivation) are also required to mitigate the effect of thermal runaway propagation.

End of mission passivation: propulsion subsystem

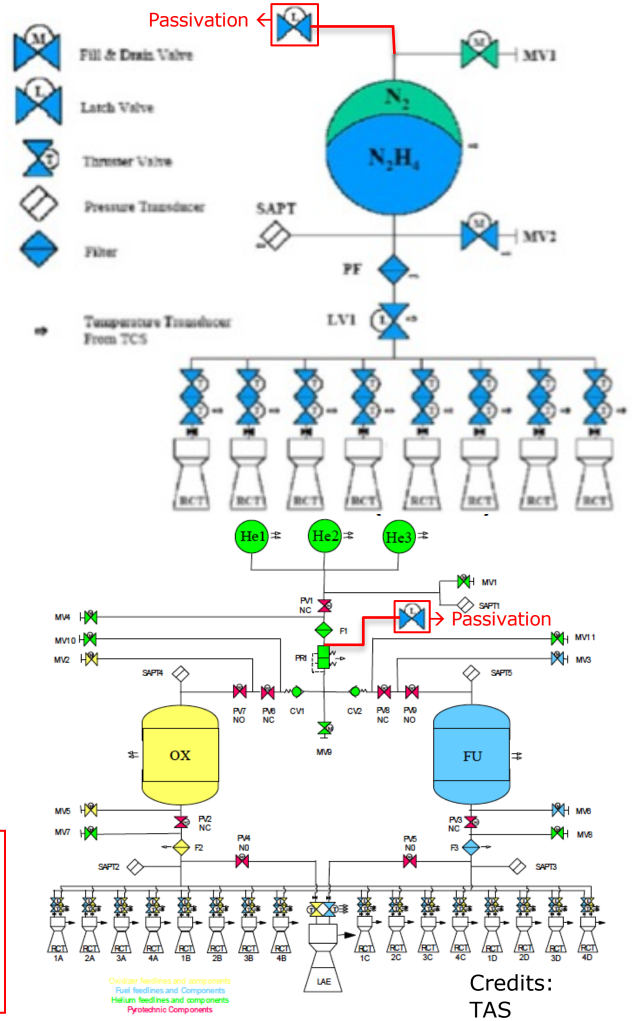
Subsystem	Component	Passivation Measures
Propulsion	**Pressurant Gas Tank**	1. Venting (as far as possible) 2. Depressurization at least down to a level such that no bursts can occur due over-pressure, over-temperature, or hyper velocity impacts (with debris or meteoroids)
Propulsion	**Propellant Tank**	1. Venting (as far as possible) 2. Depletion burn(s) 3. Depressurization at least down to a level such that no bursts can occur due over-pressure, over-temperature, or hyper velocity impacts (with debris or meteoroids)

End of mission passivation: tank hazard control

- **Mono-propellant (hydrazine) blow-down mode systems (common LEO spacecraft):**
  - ➢ < 5 bar pressurant tank pressure (if pressurant tank is applicable)
  - ➢ < 5.5-6 bar propellant tank pressure
  - ➢ Propellant residual volume limited to maximum 1% of the tank maximum capacity
- **Bi-propellant, pressure regulated systems (common GEO spacecraft):**
  - ➢ < 5 bar pressurant tank pressure
  - ➢ < 3 bar propellant tank pressure
  - ➢ Propellant residuals volume ≤ 1% of the tank usable volume plus the feedlines volume and each propellant component isolated from the other by minimum 2 barriers

Example

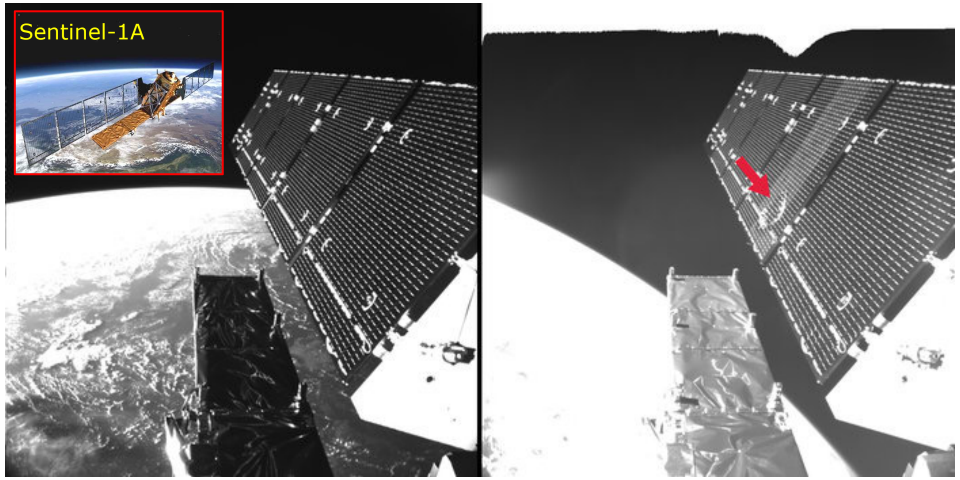
The current pressure limits are a compromise between what is needed and what is feasible or verifiable (state of art); the limits can be improved in future with the help of consolidated design concepts and technology.

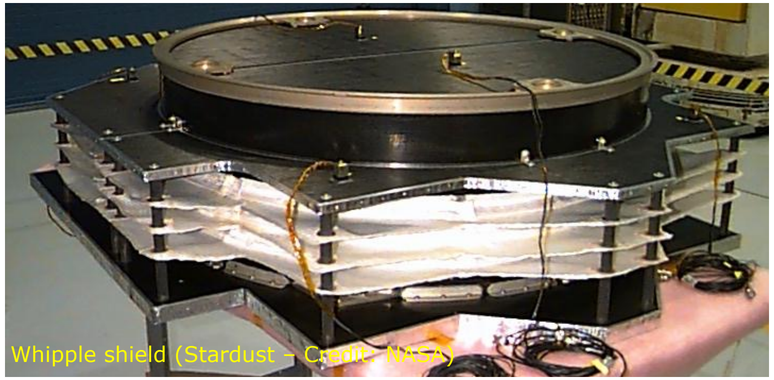


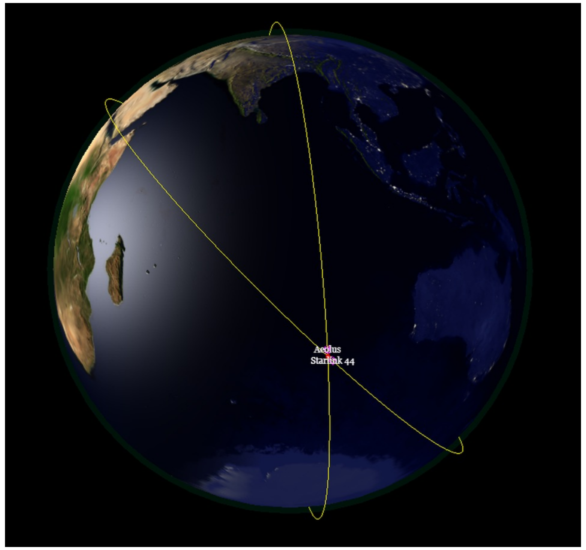
Credits: TAS

Collision risk management

Requirement(s)	ECSS-U-AS-10C, Rev. 1 / ISO 24113:2019 6.2.3.1-6.2.3.4
Objective	**Minimization of collision risk (probability x effects)**
<u>Guidelines for compliance:</u> 1. Implementation of recurrent **manouevre capability**. 2. Performance of collision avoiadance manouevres when a **risk threshold** (set by Approving Agent) is exceed (for trackable objects). 3. Performance of **collision risk / vulnerability analysis** during the space system development phase. 4. Improvement of the space system design against impacts with space debris and meteoroids (e.g. **shielding**).	
Verification Method(s)	Review-of-Design, Analysis




Whipple shield (Stardust – Credit: NASA)



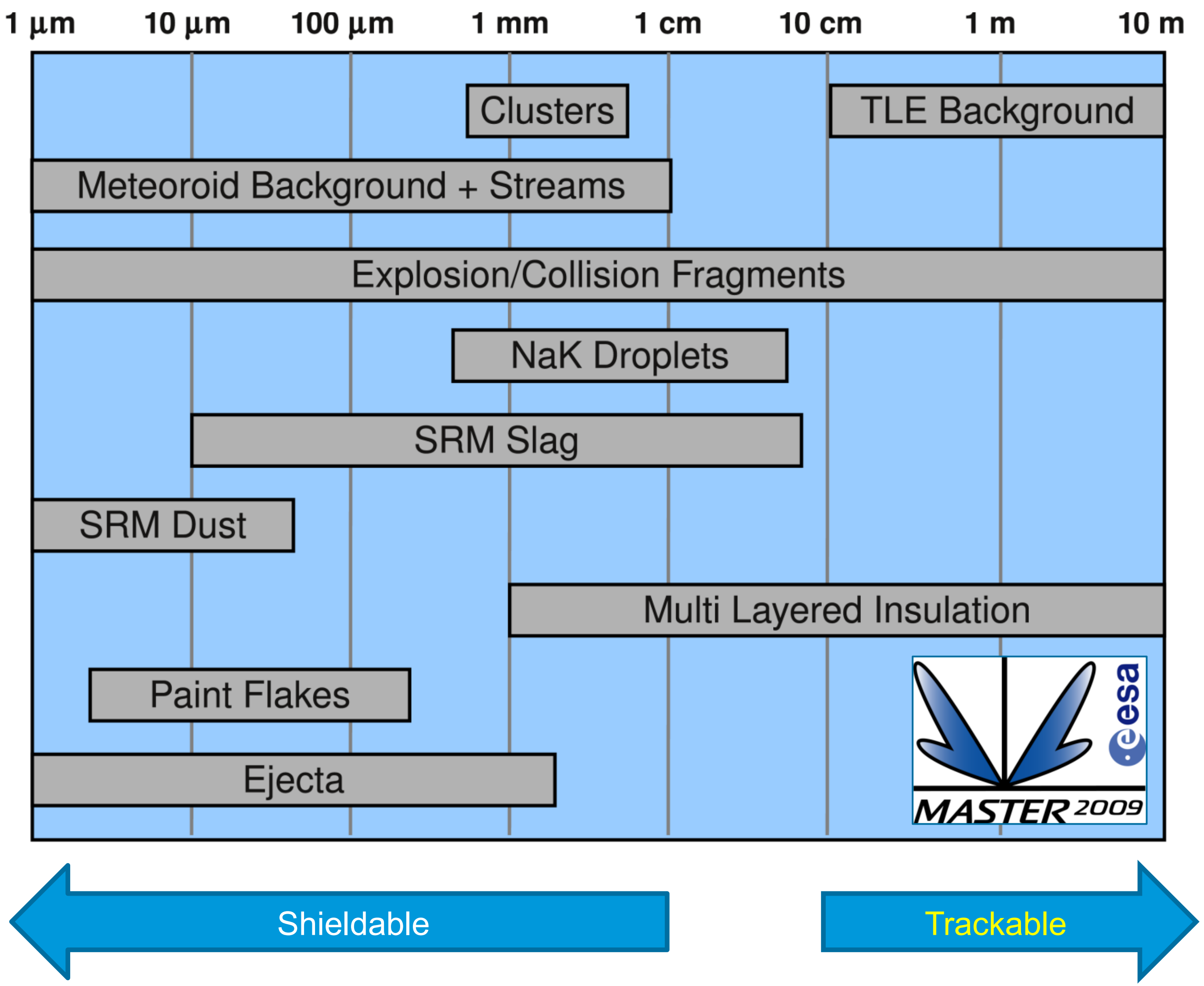
ESA reference tool for collision risk and vulnerability analysis: DRAMA/ARES/MIDAS

ESA DRAMA: https://sdup.esoc.esa.int/drama/downloads

ARES

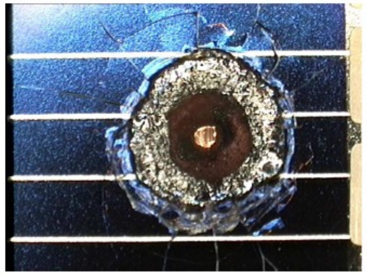
MIDAS

Hypervelocity impacts



Hubble Space Telescope (HST)

Impact on HST Solar Cell
Crater size: 3.5 mm;
Hole size: 0.5 mm

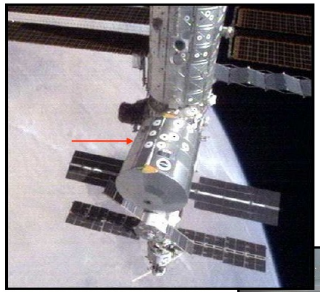


Impact on HST MLI
Outer damage size: 5 mm;
Hole size: 464 um

Hypervelocity impact test

Al sphere, 12 mm diameter,
Impact velocity: 6.8 km/s

More than 26 impacts reported on MPLM over the first 5 missions

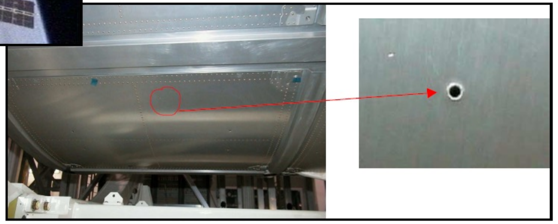


MPLM Leonardo, mission STS-102/5A.1 (March 2001), 3 MMOD impacts.

Largest impact: through hole in bumper shield 1.2 mm diam. According to NASA impactor could be a paint flake about 0.46 mm diam.

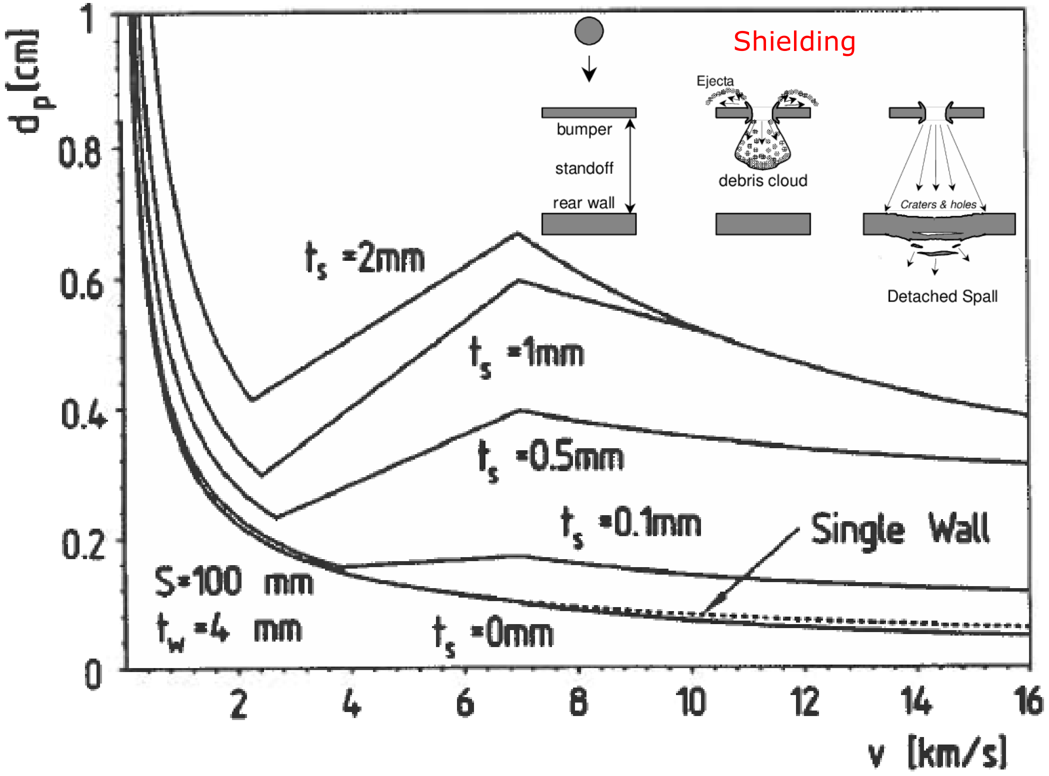
No damage to MLI underneath.

ISS
Multi-Porpuse
Logistic Module
(MPLM)



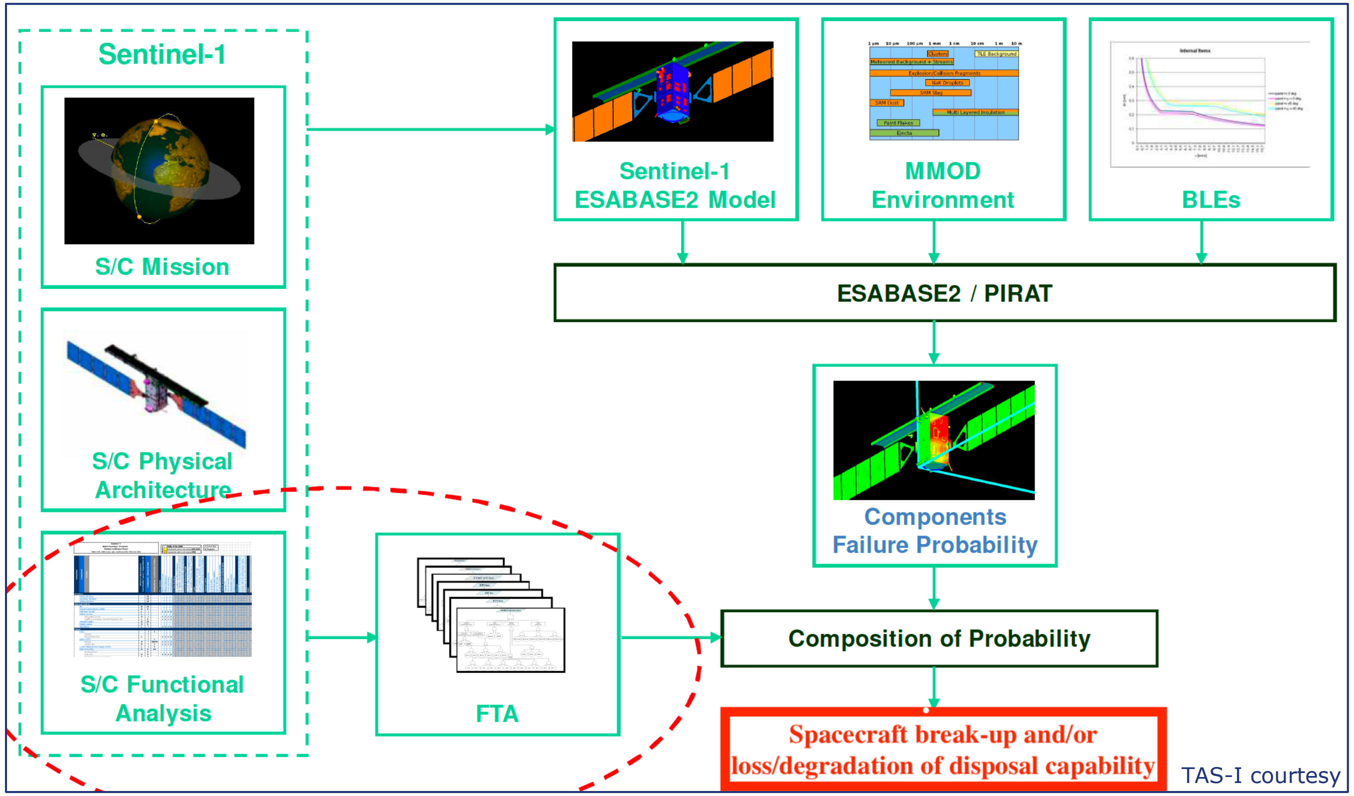
Hypervelocity impacts

Ballistic limit diameter



Impact velocity (v_p)		
$v_p \leq 3$ km/s	3 km/s $\leq v_p \leq 7$	$v_p > 7$ km/s
Impactor not shattered	Break-up starts	Efficiency reduces ($\sim v_p^{-2/3}$)

Example



TAS-I courtesy

Clearance of the LEO Protected Region

Requirement(s)	ECSS-U-AS-10C, Rev. 1 / ISO 24113:2019 6.3.3.1-6.3.3.2
Objective	**No space system left in LEO for more than 25 years after the end of mission**

Guidelines for compliance:

1. Space system able to clear (after the mission) the LEO Protected Region by **performing de-orbit operations,** e.g. to an orbit where natural orbital decay allows to re-enter in 25 years.
2. Performance of **orbit propagation analysis** to show that the selected orbit has sufficient low perigee and apogee altitudes to ensure re-entry in 25 years. For analysis accuracy:
   a. Consider both the average and worst-case cross-sectional area to cover attitude or configuration uncertainties;
   b. Use different solar cycle methods to get confidence on the prediction results;
   c. Run the latest release of the **ESA DRAMA tool**.
3. When de-orbit/deployed devices are used, if limited reliability data is available:
   release of the space system on an orbit from which natural orbital decay ensures re-entry in 25 years even in case of failure of these systems.
4. In case of orbits with non-zero probability of return to or crossing LEO:
   disposal on an orbit where natural perturbations lead to a permanent clearance of the LEO in less than 25 years
   (e.g. *Sun-Earth Lagrangian point 2* missions could be disposed into heliocentric orbits with no revisit closer than 1.5×10^6 km from Earth within 100 years).
5. Preference to operational orbits and operations minimizing the risk of debris generation and long-term presence.

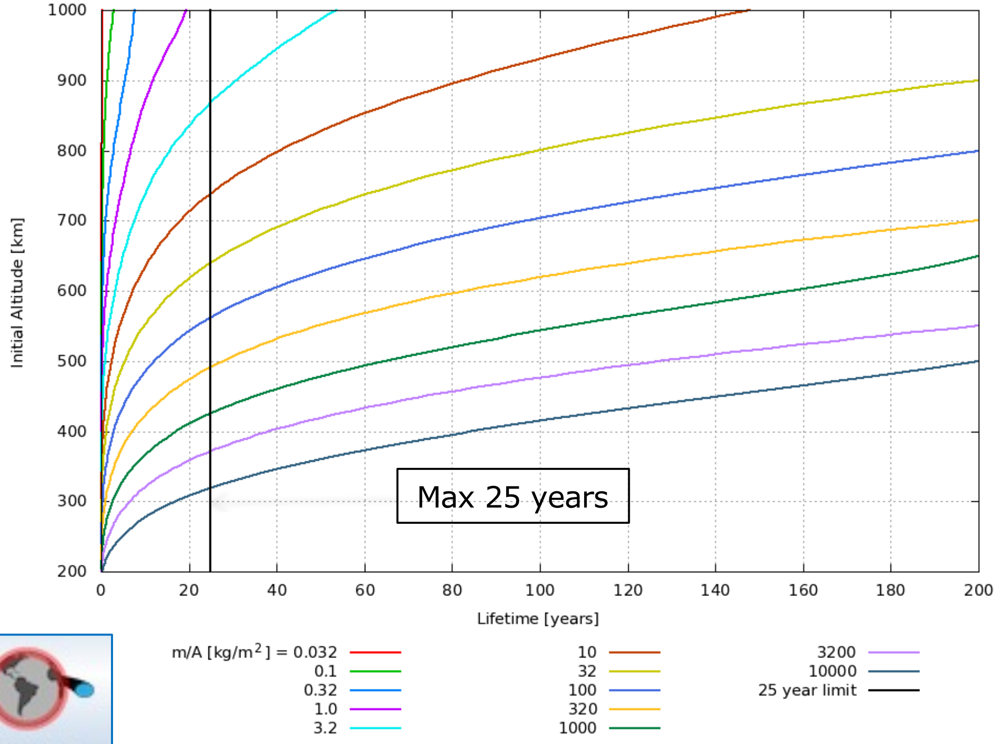
Verification Method(s)	Analysis

Orbit propagation analysis

Orbit Region	LEO
Atmospheric Drag	High relevance
Atmosphere density	NRL-MSISE-00, JB-2006 / JB-2008
Earth Gravitational Attraction	Zonal harmonics J2, J3, J4, J22 (zonal harmonics up to order/degree 15)
Lunar-solar Attraction	Expansion of perturbation up to 2nd order
Solar Activity and geomagnetic index	High sensitivity
Solar Radiation Pressure	Relevant
Propagation time	> 200 years
Frequency of orbital states	>> 1/day

Solar Cycle Methods		
a	Latest prediction	Modified McNish-Lincoln method
b	ECSS Solar Cycle	Sample from ECSS-E-ST-10-04C
c	Monte Carlo Sampling	Random sampling of a daily $F_{10.7}$, A_p and 81-day averaged $F_{10.7}$ from daily data in cycles 18–23
d	Specific Statistical Average for Solar and Geomagnetic Activity	User defined, equivalent constant value for solar flux and geomagnetic activity index $F_{10,7}=201+3.25\ln(A_{avg}C_D/M)-7\ln(H_a)$ $A_p=15$

Cross-sectional Area	a.Average random tumbling b.Worst-case undeployed spacecraft
Solar Radiation Pressure Reflectivity Coefficient	1.2
Drag Coefficient	2.2



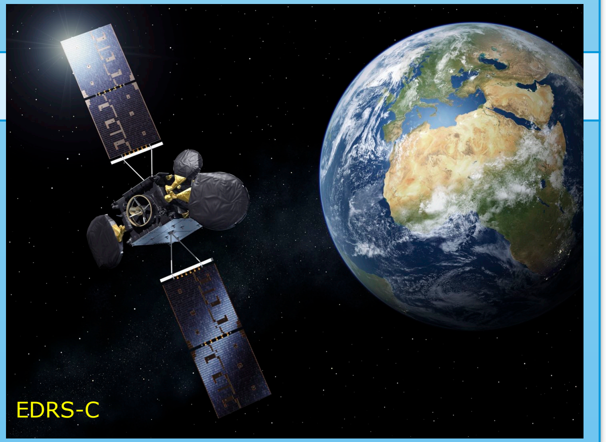
ESA guidelines: ESSB-HB-U-002, Annex A

ESA Reference tool for orbit propagation analysis: DRAMA/OSCAR

ESA DRAMA: https://sdup.esoc.esa.int/drama/downloads

Clearance of the GEO Protected Region

Requirement(s)	ECSS-U-AS-10C, Rev. 1 / ISO 24113:2019 6.3.2.1-6.3.2.3
Objective	**No space system left in GEO after the end of mission**



<u>Guidelines for compliance:</u>

1. Space system disposal such that:

   a. Eccentricity: ***$e < 0.003$***
      Perigee altitude above GEO: ***$\Delta H > 235 + (1000 \cdot C_r \cdot A/m)$ [km]***
      C_r solar radiation pressure coefficient [dimensionless];
      A/m ratio of the cross-section area [m^2] to dry mass [kg];

      or,

   b. Perigee altitude sufficiently above the GEO altitude that **long-term perturbation forces do not cause the space system to enter the GEO Protected Region within 100 years**.

2. In case of orbits with probability of return to or crossing GEO:
   disposal on an orbit where natural perturbations lead to a permanent clearance of the GEO
   (e.g. *Sun-Earth Lagrangian point 2* missions could be disposed into heliocentric orbits with no revisit closer than 1.5×10^6 km from Earth within 100 years).

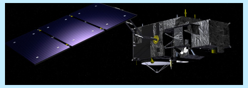
Verification Method(s)	Analysis

Assurance of successful disposal

Requirement(s)	ECSS-U-AS-10C, Rev. 1 / ISO 24113:2019 6.3.1.1-6.3.1.6
Objective	**Probability of successful disposal ≥ *0.9***
<u>Guidelines for compliance:</u> ***1. Probability of successful disposal (at time of disposal) > 0.9*** **2. For mission extensions:** possibly re-authorized pending re-assessment of the status of the spacecraft and confirmation that the capability of the spacecraft disposal still meets the requirement for the proposed extension period.	
Verification Method(s)	Analysis

Space Segment

Propulsion



AOCS

Power

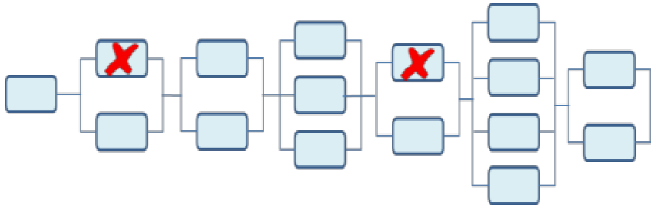
Thermal Control

Structures

Telemetry, Tracking, Command, Data Handling

Communications

Ground Segment



Space System Integrator | Space System Operator

Supply Chain | Space Environment

- **Disposal** is the set of actions performed by a space system to permanently reduce its chance of accidental break-up (passivation) and to achieve long-term clearance of the Protected Regions (e.g. by manoeuvres or natural orbital decay)

Assurance of successful disposal

ISO 24113:2011 – Weak formulation (superseded)

$$R_{Disposal} = \frac{R_{Mission+Disposal}}{R_{Mission}} \geq 0.9$$

$R_{mission}$	mission reliability, i.e. the probability to perform successfully the mission
$R_{Mission+Disposal}$	mission and disposal reliability, i.e. the probability to accomplish successfully both the mission and the disposal
$R_{Disposal}$	disposal reliability, i.e. the conditional probability to have successful disposal assumed the successful mission

ISO 24113:2019 – Strong formulation (actual):

$R_{mission+Disposal} \geq 0.9$

Successful disposal relies on:

a. End of Life strategy, defined in the early phases of the space system development, e.g. using specific functions for de-orbit manoeuvres and passivation.

b. Space system reliability and resources availability to cope with the disposal operations.

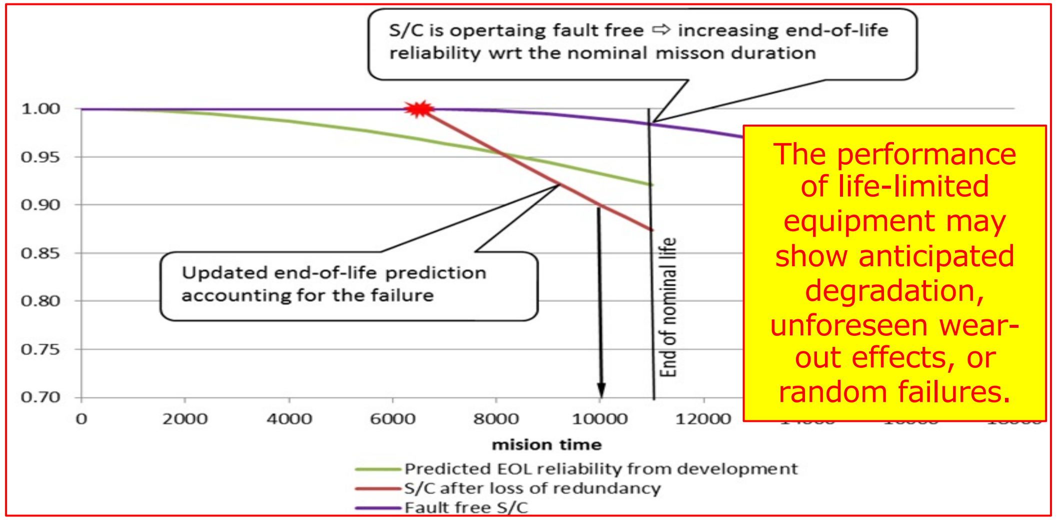
c. No Single Point of Failures (SPFs) resulting in loss of the mission and generation of space debris.

d. Review of the mission plan in case of failures, anomalies or insufficient resource availability.

Assurance of successful disposal

- The principal contributors to the successful disposal are:
  - **On-board systems (components, units) able to perform the required functionality at the required performance**
  - **No break-ups by any internal explosion or burst** (mitigation by failure tolerance / design for minimum risk)
  - **No break-ups by collision** with other space systems, debris and meteoroids
  - **Availability of sufficient consumables/propellants** on board to perform all required disposal operations
  - **Operator** to plan and execute correctly all collision avoidance and disposal manoeuvres
  - **Health monitoring** (anomaly detection ➔ corrective actions)

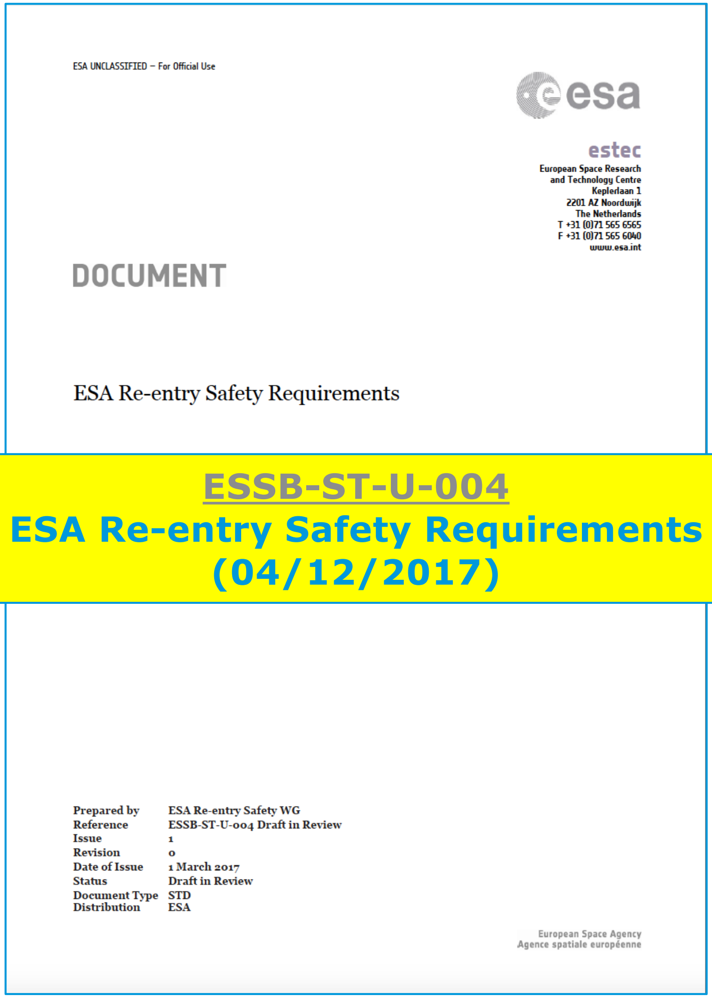
- Margins and uncertainties should be taken into account for the execution of all manoeuvres (e.g. assuming maximum mass, worst-case 3σ propulsion performance) including:
  - The nominal mission operations;
  - Predictable in-orbit collisions avoidance;
  - De-orbit/re-orbit operations for disposal;
  - Potential specified mission extensions;
  - Worst-case propellant residuals.



ESA Re-entry Safety Requirements

- In general re-entry involves risk on-ground for human population and Earth environment, therefore Safety requirements are implemented.
- ESSB-ST-U-004 is the ESA Re-entry Safety Requirements document for ESA space systems, which has the objectives of:
  - ✓ Enforce the applicability and verification of the re-entry casualty risk requirement established by the ESA Space Debris Mitigation Policy;
  - ✓ Introduce requirements from SDM guidelines (ESSB-HB-U-002) and lessons learnt from the 5 ESA Automated Transfer Vehicles (ATVs) controlled re-entries);
  - ✓ Define specific safety requirements to cover the hazards for human life and environment, including:
    - ❑ Impacting fragments,
    - ❑ Floating fragments,
    - ❑ Pressurized or explosive fragments,
    - ❑ Hazardous chemical substances,
    - ❑ Radioactive substances;
  - ✓ Provide additional requirements and guidelines in order to plan and perform:
    - ❑ Safe re-entry operations,
    - ❑ Re-entry notifications,
    - ❑ Retrieval operations.

ATV-1 (re-entry observation campaign, 2008)



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DOCUMENT

ESA Re-entry Safety Requirements

Prepared by	ESA Re-entry Safety WG
Reference	ESSB-ST-U-004 Draft in Review
Issue	1
Revision	0
Date of Issue	1 March 2017
Status	Draft in Review
Document Type	STD
Distribution	ESA

European Space Agency
Agence spatiale européenne

ESSB-ST-U-004
ESA Re-entry Safety Requirements
(04/12/2017)

Re-entry casualty risk mitigation

Requirement(s)	ECSS-U-AS-10C, Rev. 1 / ISO 24113:2019 6.3.4.1-6.3.4.2	
	ESA/ADMIN/IPOL(2014)2 Section 2 – Policy	
	ESSB-ST-U-004 Section 5 Clause 5;	
Objective	**Re-entry casualty risk < 10^{-4}**	
Verification Method(s)	Analysis	

Guidelines for compliance:

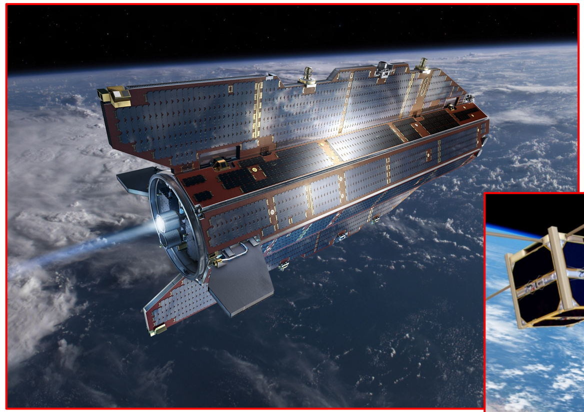
1. Re-entry casualty risk, i.e. the risk of serious injury or death associated to the re-entry of the space system, below 10^{-4} for any re-entry event (controlled or uncontrolled re-entry).
2. Compliace achievable through:
   a. Minimization of re-entry surviving fragments, e.g. by adopting **design for demise** techniques;
      and/or,
   b. Minimization of human population exposed to re-entry effects, e.g. by performing **controlled re-entry**.
3. Demonstration of compliance by analysis performed with the **ESA DRAMA** tool.

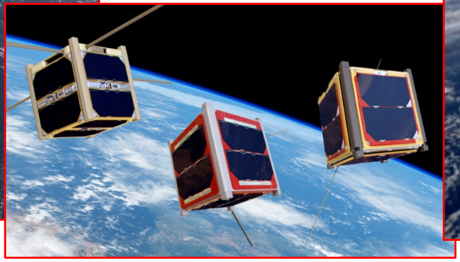
- **Casualty** is any person who is killed or seriously injured by accident.
- **Casualty risk** is the probability of serious injury or death.

Uncontrolled and controlled re-entry

Uncontrolled re-entry

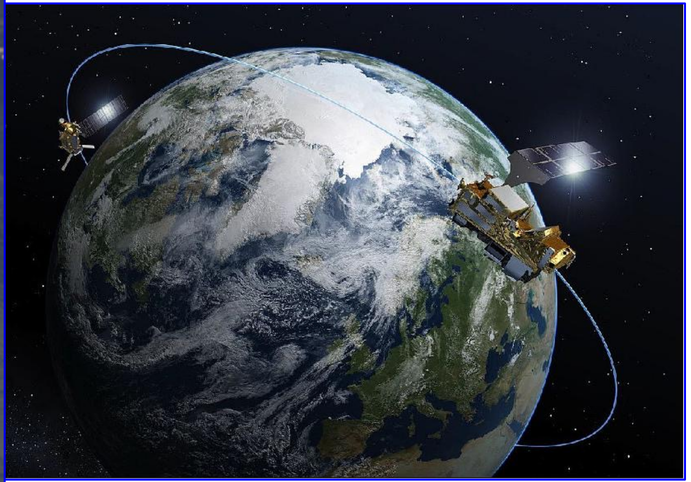
type of re-entry where the time of re-entry or the zone of impact of fragments on the Earth surface are not controlled



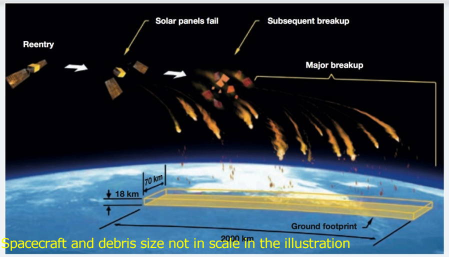


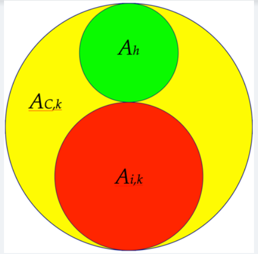
Controlled re-entry

type of re-entry where the time of re-entry is controlled and the impact of fragments on the Earth surface is confined to a designated zone



Re-entry casualty risk formulas





Casualty risk for uncontrolled re-entry

$$\boxed{E_{C,unc}} = \sum_{k=1}^{N} \boxed{A_{C,k}}\,\boxed{\rho_p(i,\Delta\varphi,\omega)}\ \boxed{< 10^{-4}}$$

Impacting fragments can have sufficient kinetic energy to result in **casualties**.

It depends on the space system design and fragmentation process ← Casualty area

Average population density → It depends on the orbit inclination, latitude step size (circular orbits), argument of perigee (elliptic orbit)

Fragments are pieces produced by fragmentation of a space system during re-entry due to ablation, mechanical stresses, explosions or induced separation, or the space system itself if not fragmented into pieces.

Casualty area ($A_{C,k}$) is the equivalent impact area specified by the formula $(A_i^{1/2}+A_h^{1/2})^2$, where $A_{i,k}$ is the average projected area of the fragment k-th, and A_h is the cross-section of a human being conventionally equal to 0,36 m^2.

Casualty risk for controlled re-entry

$$\boxed{E_{C,con}} = 1 - \prod_{k=1}^{N}\left(1 - \sum_{n}\sum_{m} \boxed{\left(P_{i,k}\right)_{n,m}}\,\boxed{\left(\rho_{p,k}\right)_{n,m}}\,\boxed{\left(A_{C,k}\right)_{n,m}}\right)\ \boxed{< 10^{-4}}$$

Local impact probability

Local population density

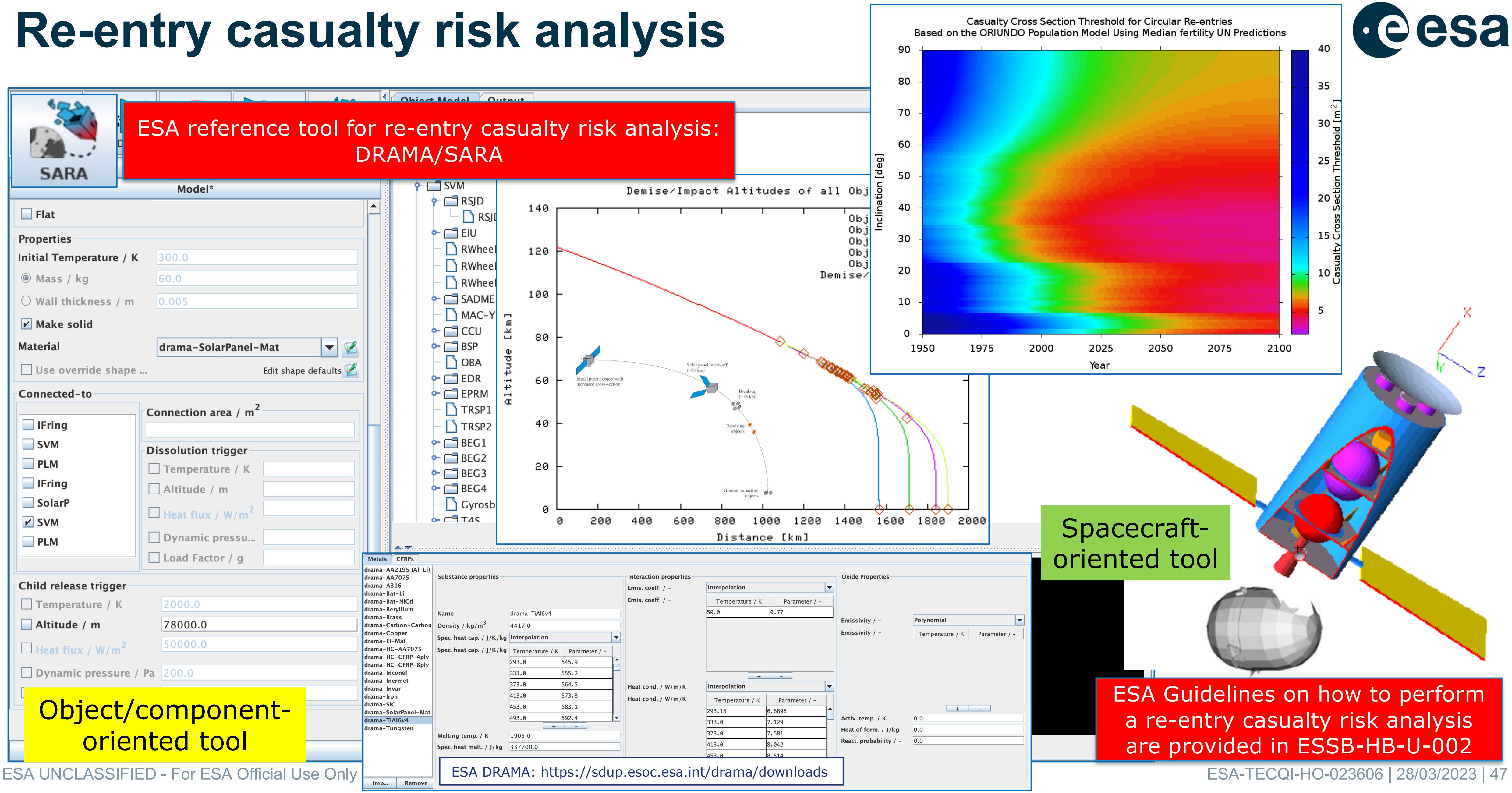
Local casualty area

Casualty risk for a failed controlled re-entry

$$\boxed{E_{C,con,fail}} = E_{C,unc}\boxed{P_f}\ \boxed{< 10^{-4}}$$

Failure probability

Re-entry casualty risk analysis



Controlled re-entry notification

- **Declared Re-entry Area (DRA):**

  area on-ground where the re-entry debris are enclosed with a probability of 99% given the delivery accuracy

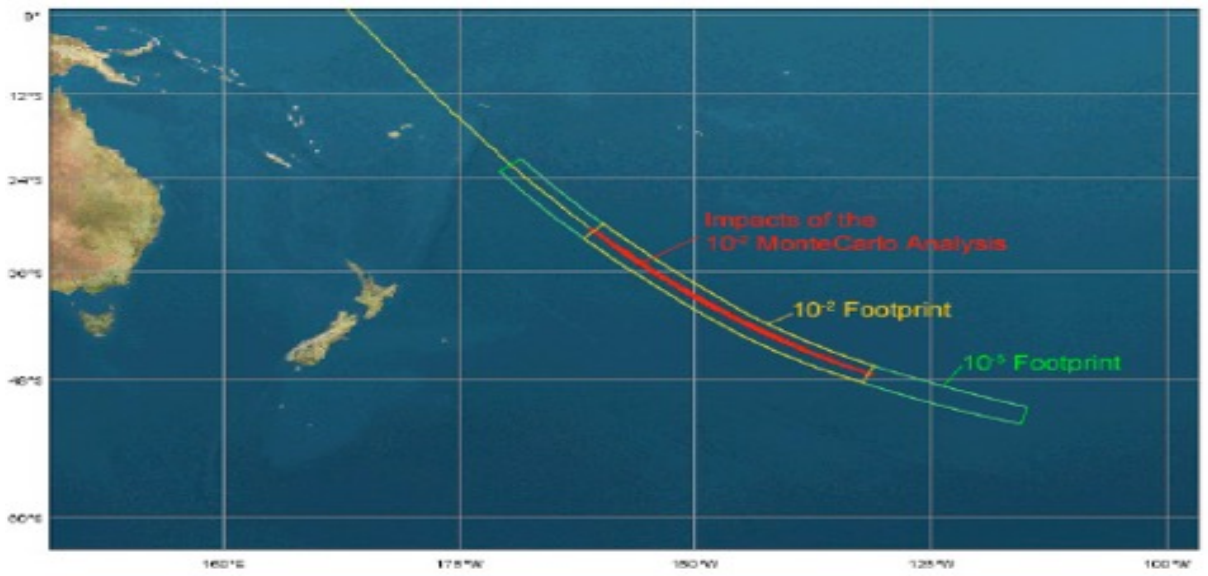
  → **10^{-2} footprint**

- **Safety Re-entry Area (SRA):**

  area on-ground where the re-entry debris are enclosed with a probability of 99.999% given the delivery accuracy

  → **10^{-5} footprint**

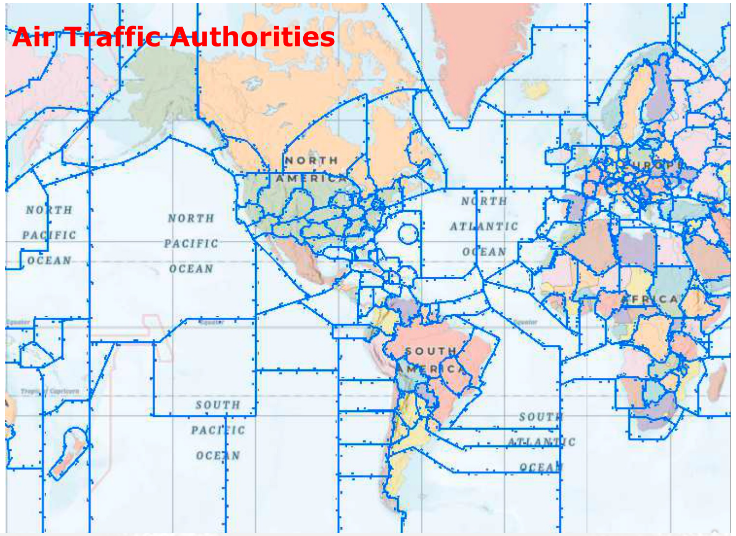
Requirements for the computation of the DRA and SRA and re-entry notification procedures are in **ESSB-ST-U-004**

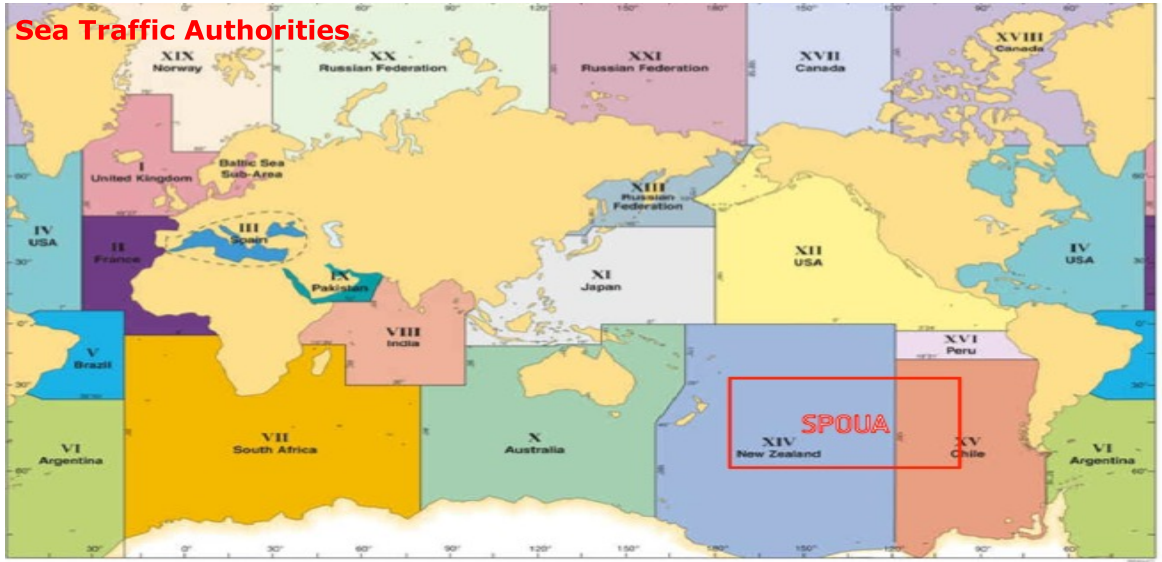


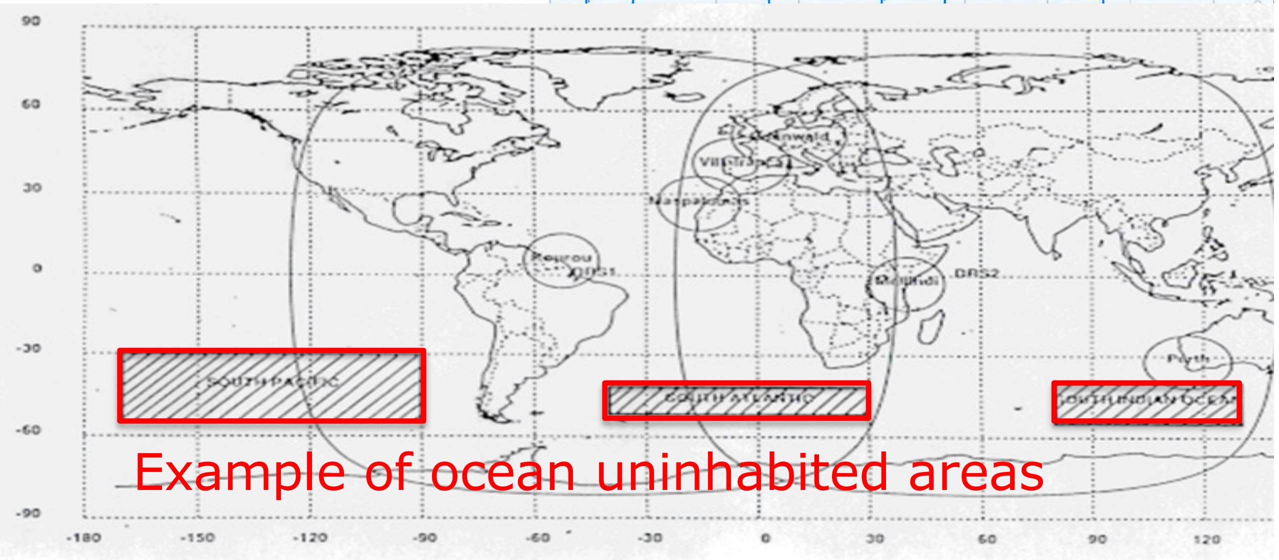
The operator of the space system performing controlled re-entry shall contact the relevant authorities overseeing the affected air and maritime traffic space to supply them, in line with the authorities' procedures, with a re-entry notification including all the technical information the authorities need in order to issue NOTice to AirMen (NOTAM) and NOTice to MARiners (NOTMAR) messages.

Controlled re-entry impact zone selection

- Impact footprint ensured over an ocean uninhabited area with sufficient clearance of landmasses, air and maritime traffic routes, and any kind of asset
- SRA does not enter into Territorial waters of any State (22.2 km from the State coastline)
- A State is informed if the SRA interferes with its Economic Exclusive Zone (370.4 km from the State coastline)
- South Pacific Ocean Uninhabited Area (SPOUA) is the largest unpopulated area (e.g. used for ATVs re-entries)
- Zones classified as Marine Protected Areas for environment safeguard may be a constraint







Example of Re-entry Safety Review Process: ATV

- The ESA Re-entry Safety Review Panel (RSRP) was established to review and assess all public safety aspects related to re-entering ESA spacecraft and vehicle, e.g. re-entry of the ESA Automated Transfer Vehicles (ATV).
- The ATV RSRP duties and responsibilities were:
  - Perform the safety reviews of the ATV configurations and of planned and contingency operations products relevant to re-entry, including flight dynamics, model assumptions, risk assessments, tracking and monitoring support;
  - Perform the safety review of ATV re-entry observation campaign(s) and recovery operations (when foreseen);
  - Review and approve the ATV Safety Dossier provided by the Project and related hazard reports, flight rules, supporting data and plan of notification to national and international bodies;
  - Assess and provide recommendations to the ESA ATV Re-entry Safety Review Board on the approval or disapproval of non-compliances submitted by the ATV Project against ESA level requirements.

ESA Director General

↑

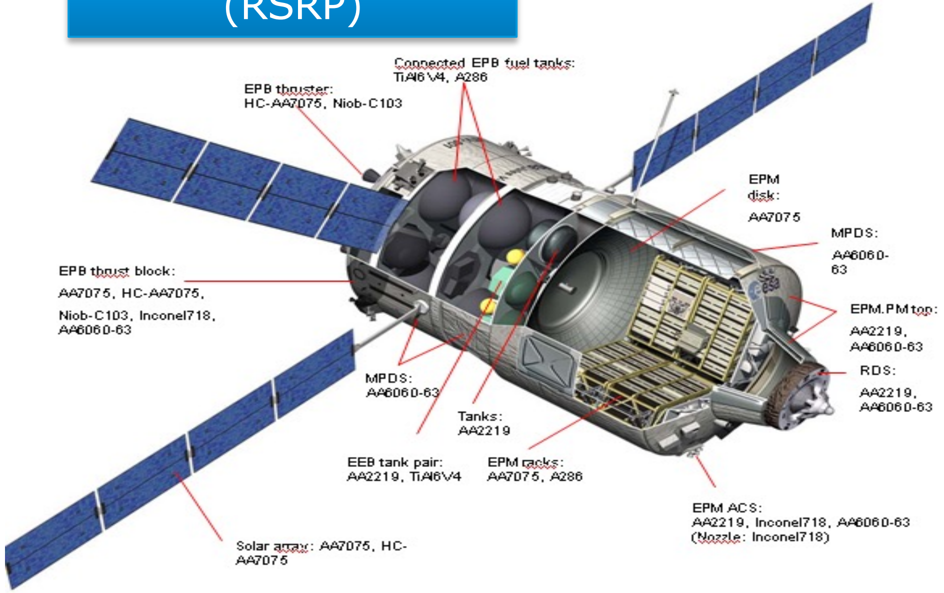
Review Safety Board (RSB)

↑

Review Safety Panel (RSRP)

5 ATV controlled re-entries performed between 2008-2015

ATV-5 re-entry (from ISS, 2015)



Topics

Definition of Space Debris Mitigation (SDM)

Organizations involved in the solution of the Space Debris problem

Definition of the Protected Regions

Rules and guidelines to preserve the Protected Regions

European Space Agency process for ensuring Space Debris Mitigation

National regulations and cooperation agreements on Space Debris Mitigation

ESA Projects SDM compliance planning and reporting

- The ESA Space Debris Mitigation (SDM) Policy requires that the compliance with the Space Debris Mitigation requirements is to be documented at different phases of all ESA Projects.

- The ESA Projects shall provide:

1. **Space Debris Mitigation Plan (SDMP)**

2. **Space Debris Mitigation Report (SDMR)**

ESA Projects SDM compliance planning and reporting

	Space Debris Mitigation Plan (SDMP)	Space Debris Mitigation Report (SDMR)
Delivery	PRR, SRR	PDR, CDR, QAR, FAR, (EOM/ELR)
Approval	**SRR**	**QAR/FAR, (EOM/ELR)**
Document Content	1. Statement of planned compliance of the proposed design with all SDM requirements, including justification for all non-compliances 2. Description of design and operational measures planned for achieving compliance with the SDM requirements 3. Identification of the verification and validation methods and plans to demonstrate compliance with the applicable SDM requirements 4. For space systems that will re-enter: ▪ Preliminary re-entry casualty risk analysis with rationale for the planned re-entry approach and identification of the tools and methodologies used for the assessment ▪ Identification of the space system functions that contribute to the planned controlled re-entry, if applicable ▪ Identification of the re-entry scenario, including nominal and degraded de-orbit cases; ▪ Verification and validation plan to demonstrate compliance with the re-entry casualty risk requirement	1. Description of the design and operational measures implementation for achieving compliance with the SDM requirements 2. Analysis and Test reports in support of the implementation of the SDM requirements 3. List of objects (mission-related objects or space debris) planned to be released as part of the nominal mission, including characteristics, orbital characteristics and predicted orbital lifetime 4. List of events which can cause violation of the requirements and relevant consequences (e.g. description and characteristics of debris generated, etc.) 5. Verification Control Document covering all SDM requirements with related justification 6. Assessment of the compliance of the selected launch services with SDM technical requirements in the standard 7. For space systems that will re-enter: ▪ Re-entry casualty risk analysis, including methodology, assumptions, model uncertainties, identification of simulation tools, and results of the assessment for both nominal and degraded cases ▪ Description of the space system functions that contribute to the controlled re-entry, if applicable ▪ Description of the re-entry scenario, including nominal and degraded cases ▪ Definition of the flight rules ▪ Definition of the notification plan to the Authorities, if applicable

ESA Projects SDM compliance assessment

1. **Development phase:**

   The Space System compliance with the Space Debris Mitigation requirements shall be assessed in the frame of the **Technical Project Reviews**.

2. **In case of major deviations during the orbital lifetime:**

   The Space System compliance with the Space Debris Mitigation requirements shall be assessed, prior of the disposal phase, by the **Space Debris Mitigation Review Panel**, chaired by the Head of the Independent Safety Office (TEC-QI) and composed of experts in the relevant technical disciplines.

3. **In case of non-compliance (development or operation phase):**

   The Projects shall apply for a **Request for Waiver**.

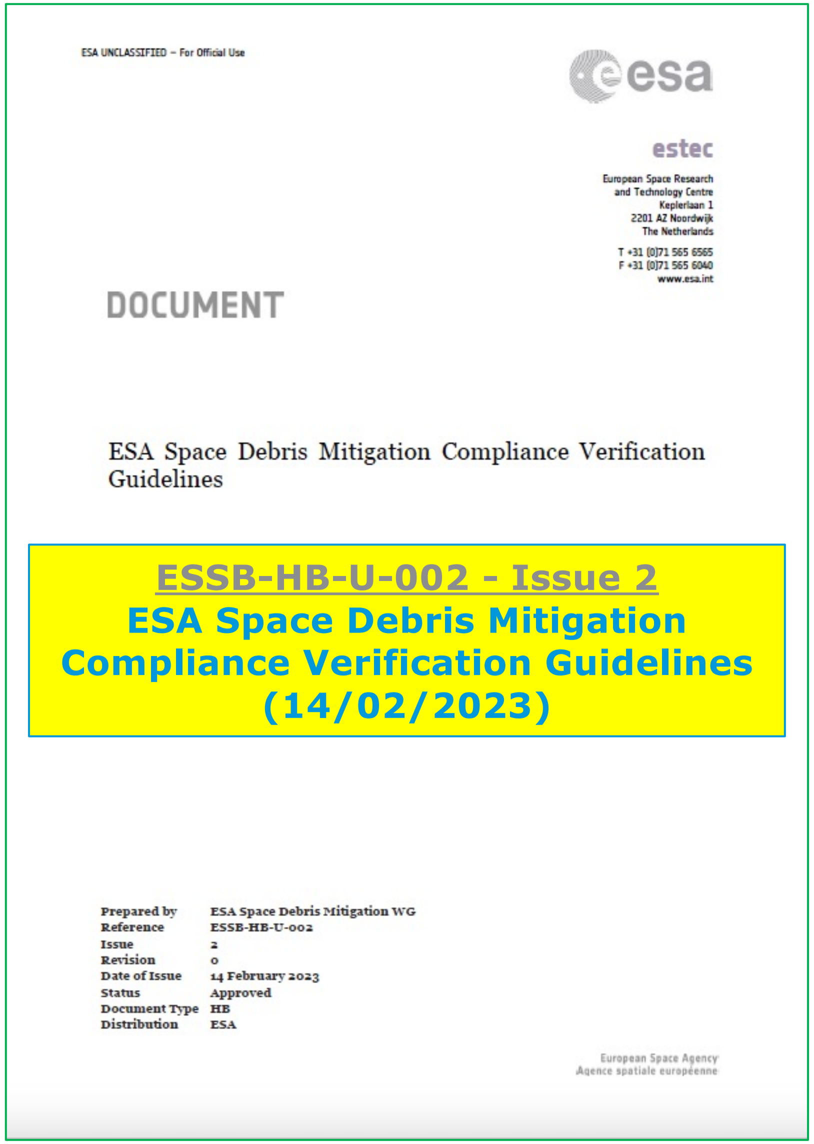
   The Space Debris Mitigation Technical Authority shall make recommendations for the approval of the associated Request for Waiver.

ESA SDM responsibilities

Role in ESA	Responsibility
Directors (D/All)	Implementation of the policy within their respective areas
Study / Project / Mission Managers	Preparation and maintenance of the Space Debris Mitigation Plan (SDMP) and Space Debris Mitigation Report (SDMR) in accordance with the Implementation Requirements
Director of Technology, Engineering and Quality (D/TEC)	Approval of waivers to the Space Debris Mitigation requirements, delegated by the Director General
Programme Director (D/Programme)	Approval of waivers to the Space Debris Mitigation requirements, delegated by the Director General
Head of the Department of Product Assurance and Safety (TEC-Q)	Management of the implementation of the policy, and the approval of the SDMP at the time of the System Requirements Review (SRR) and the SDMR at the time of the Acceptance Review (AR)
Inspector General (DG-I)	Coordination of Technical Project Reviews, including assurance of SDMP and SDMR being reviewed
Head of the Independent Safety Office (TEC-QI)	Technical Authority for the: • Custodianship/maintenance of the Space Debris Mitigation Policy with the related requirement; • Independent supervision of SDM requirements verification of compliance; • Processing of waivers with the technical support from the Directorate of Technology, Engineering and Quality Directorate (TEC) and the Space Debris Office (OPS-SD); • Reporting on the status of implementation of the ESA Space Debris Mitigation Policy.

ESA SDM compliance verification guidelines

- ESSB-HB-U-002 is the ESA reference handbook providing guidelines for the verification of the ESA Space Debris Mitigation requirements.
- The handbook was prepared by an ESA Working Group covering several disciplines, i.e. space environment and modeling, system engineering, astrodynamics, aerothermodynamics, power systems, propulsion systems, structural engineering, thermal engineering, materials science, Reliability, Availability and Maintainability (RAM), Safety, etc.
- Since Space Debris Mitigation is a continuous evolving subject, the guidelines needs to be regularly updated to reflect the:
  - feedback from the ESA Industrial partners;
  - outcome of research and technological development activities;
  - international agreements to cope with space sustainability.



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DOCUMENT

ESA Space Debris Mitigation Compliance Verification Guidelines

ESSB-HB-U-002 - Issue 2
ESA Space Debris Mitigation Compliance Verification Guidelines (14/02/2023)

Prepared by	ESA Space Debris Mitigation WG
Reference	ESSB-HB-U-002
Issue	2
Revision	0
Date of Issue	14 February 2023
Status	Approved
Document Type	HB
Distribution	ESA

European Space Agency
Agence spatiale européenne

SDM requirements compliance verification

- The Space Debris Mitigation requirements:
  - are defined in specific normative documents;
  - consist in technical requirements relevant for the design and operations of a space system;
- In general, the compliance with each requirement shall be demonstrated through the verification process.
- Verification methods are set in agreement with the owner of the requirement, flown-down through verification requirements or specified compliance verification guidelines.

Verification is a **process** which demonstrates through the provision of objective evidence that the **product** is designed and produced according to its **specifications** and the agreed **deviations** and **waivers**, and is free of **defects**.

In general, verification methods can be:

- **Analysis** (incl. similarity)
- **Test**
- **Inspection**
- **Review of design**

References:
(1) ECSS-E-ST-10-02C – Space Engineering - Verification
(2) ECSS-E-HB-10-20A – Space Engineering – Verification guidelines

ESA Request for Deviation / Waiver (RFD / RFW)

- Request for Deviations / Waivers (RFDs / RFWs) are requested, in general, in for cases of a non-compliance with a requirement.
- In case of a non-compliance with a SDM requirement, a rationale should demonstrate on <u>valid technical basis</u> why the non-compliance was not solved and if or why <u>additional risk</u> would be necessary to be taken by ESA.
- The responsibility is shared between two ESA relevant Directors:
  - ➢ Directorate of the Programme, and
  - ➢ Directorate of Technology, Engineering and Quality (D/TEC)
- <u>It is strongly recommended for Projects to minimize the use of RFDs/RFWs by solving the non-compliances.</u>

	ESA PROJECT NAME SPACE DEBRIS MITIGATION REQUEST FOR DEVIATION (RFD) / WAIVER (RFW)		Page 1 of X
1. RFD/RFW Number: XXX - Issue Y			2. Date: dd/mm/yyyy
3. Requested Type: ☐ Deviation (RFD)		☐ Waiver (RFW)	
4. Title of RFD/RFW:			
5. ESA Project Submittal:		Directorate:	
6. Applicable Requirement: ECSS-U-AS-10C - Requirement XXXX			
7. Description of the Non-compliance:			
8. Rationale for Acceptance:			
9. ESA Technical Project Review Board Recommendation:			
10. ESA Project Manager (XXX-XX) Signature:		Date: xx/xx/xxxx	
11. Technical Authority Recommendations:			
12. Recommendation for	☐ Approval	☐ Not Approval	
ESA Technical Authority - Head of Independent Safety Office (TEC-QI) Signature:		Date: xx/xx/xxxx	
13. Approval			
ESA Programme Director (D/XXX) Signature: Date: xx/xx/xxxx		ESA TEC Director (D/TEC)) Signature: Date: xx/xx/xxxx	

Template in ESSB-HB-U-002

Example of ESA SDM Policy implementation: MetOp-SG

Before System Requirements Review (SRR) - 2013

Spacecraft Wet Mass: 3754 kg
Total Propellant Mass: 254 kg

→ Disposal by de-orbit and uncontrolled re-entry:
Delta-v: 88 m/s
Propellant Mass: 145 kg

→ Re-entry casualty risk > 10^{-4} ($7x10^{-4}$)

→ **Not Compliant for re-entry**

→ Design trade-off for system re-design required

Orbit: 817 km x 817 km, inc. 98.7˚

Main impacts at system design and operation level:

- Higher thrust engine
- Bigger propulsion tank (mono-propellant with re-pressurization tanks)
- Propellant mass increase (by 3)
- Higher system reliability
- Increase of the number and resources for disposal manouvers
- Ground operation control required until re-entry

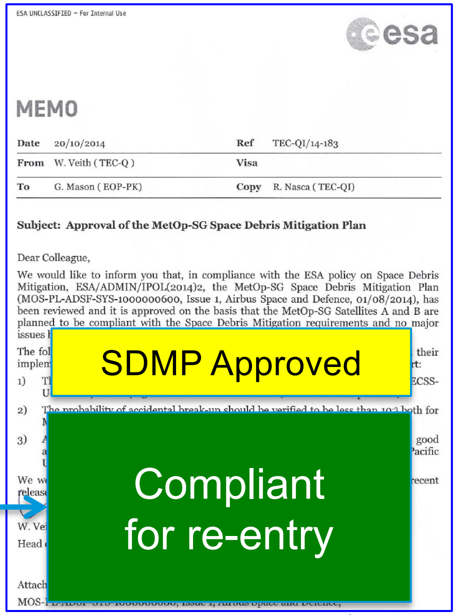
After System Requirements Review (SRR) - 2014

Spacecraft Wet Mass: 4400 kg
Total Propellant Mass: 760 kg

→ Disposal by controlled re-entry:
Delta-v: 237 m/s
Propellant Mass: 438.5 kg

→ Re-entry casualty risk << 10^{-4} (controlled re-entry targeting SPOUA)

→ **Compliant for re-entry**



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MEMO

Date	20/10/2014	Ref	TEC-QI/14-183
From	W. Veith (TEC-Q)	Visa	
To	G. Mason (EOP-PK)	Copy	R. Nasca (TEC-QI)

Subject: Approval of the MetOp-SG Space Debris Mitigation Plan

Dear Colleague,

We would like to inform you that, in compliance with the ESA policy on Space Debris Mitigation, ESA/ADMIN/IPOL(2014)2, the MetOp-SG Space Debris Mitigation Plan (MOS-PL-ADSF-SYS-1000000600, Issue 1, Airbus Space and Defence, 01/08/2014), has been reviewed and it is approved on the basis that the MetOp-SG Satellites A and B are planned to be compliant with the Space Debris Mitigation requirements and no major issues [illegible]

SDMP Approved

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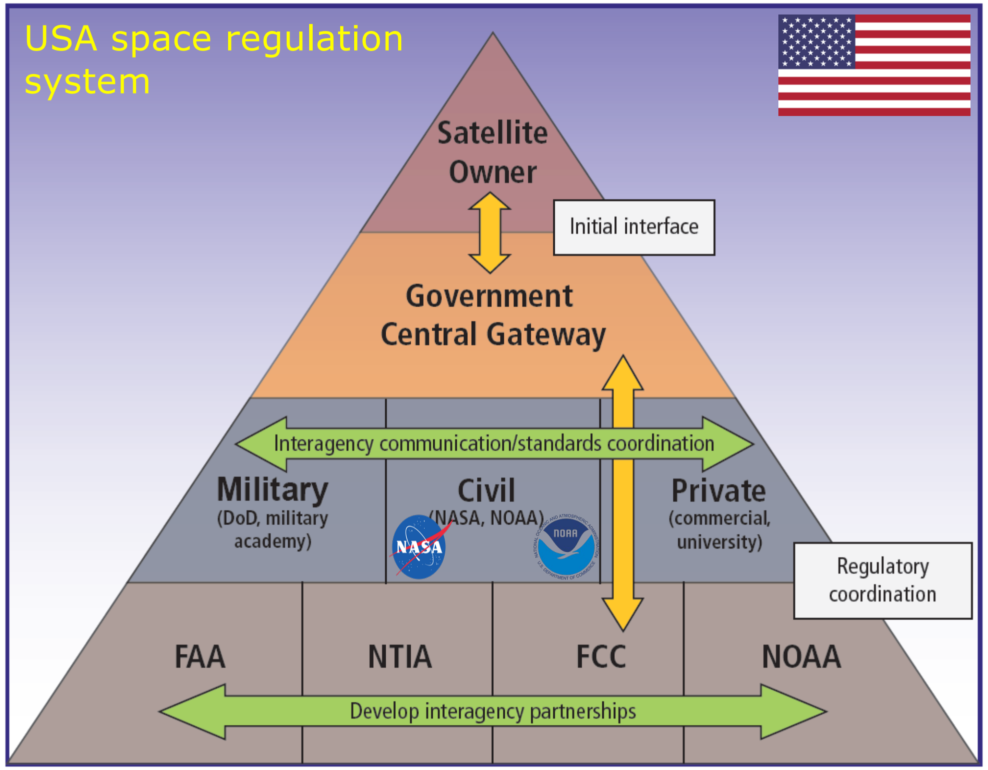
National regulations and cooperation agreements on Space Debris Mitigation

National SDM Regulations

- The Space Debris Mitigation requirements applicable for space activities lead by individual States are defined by their respective Governments with their own respective mechanisms.
- In general, States are gradually adopting space laws, including Space Debris Mitigation requirements, usually inspired by the IADC guidelines.
- However, the implementation of national laws to regulate Space Debris Mitigation is not an homogenous process among all the States since arrangements, effectiveness, and timing depend on the States' historical background and management.
- An informative summary about the current policy and requirements applied by other States can be found in "Compendium - Space Debris Mitigation Standards Adopted by States and International Organizations - UN COPUOS, 19/01/2021".

National SDM Regulation example: USA

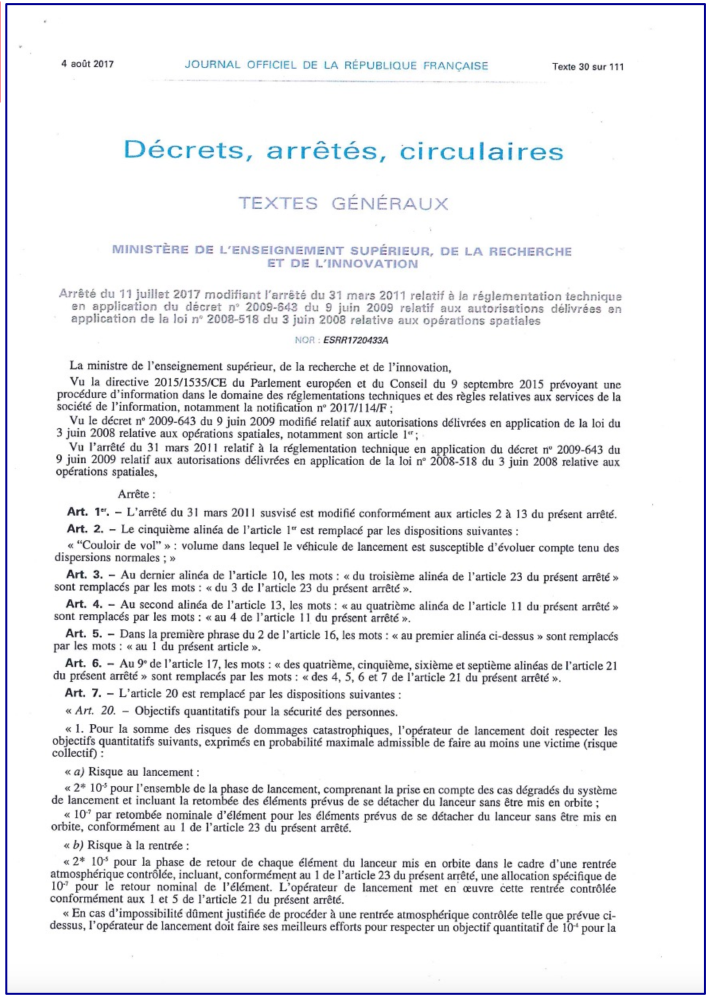
USA has different organizations regulating the space activities depending on the category and purpose of the space system, i.e. the owners vet internal policy and strategy and coordinate with a centralized government gateway, which confirms whether military, civil, or private policy should be applied, determines what regulatory approvals are required, and assists in coordinating approvals (possibly ensuring similar standards are applied (e.g. the NASA standard is "NASA-STD-8719.14C – Process for Limiting Orbital Debris - 05/11/2021").



Credits: Aerospace Corporation

National SDM Regulation example: France

France has a law (French Space Operation Act, FSOA, applicable to French space operators and manufacturers and all space operations performed from French territory, both for launch vehicles and spacecraft, and delegates CNES as authority for the authorization of launch and space operations, i.e. "Arrêté du 11 juillet 2017 modifiant l'arrêté du 31 mars 2011 relatif à la réglementation technique en application du décret no 2009-643 du 9 juin 2009 relatif aux autorisations délivrées en application de la loi no 2008-518 du 3 juin 2008 relative aux opérations spatiales" (LOS).



4 août 2017 — JOURNAL OFFICIEL DE LA RÉPUBLIQUE FRANÇAISE — Texte 30 sur 111

Décrets, arrêtés, circulaires

TEXTES GÉNÉRAUX

MINISTÈRE DE L'ENSEIGNEMENT SUPÉRIEUR, DE LA RECHERCHE ET DE L'INNOVATION

Arrêté du 11 juillet 2017 modifiant l'arrêté du 31 mars 2011 relatif à la réglementation technique en application du décret n° 2009-643 du 9 juin 2009 relatif aux autorisations délivrées en application de la loi n° 2008-518 du 3 juin 2008 relative aux opérations spatiales

NOR : ESRR1720433A

La ministre de l'enseignement supérieur, de la recherche et de l'innovation,

Vu la directive 2015/1535/CE du Parlement européen et du Conseil du 9 septembre 2015 prévoyant une procédure d'information dans le domaine des réglementations techniques et des règles relatives aux services de la société de l'information, notamment la notification n° 2017/114/F ;

Vu le décret n° 2009-643 du 9 juin 2009 modifié relatif aux autorisations délivrées en application de la loi du 3 juin 2008 relative aux opérations spatiales, notamment son article 1er ;

Vu l'arrêté du 31 mars 2011 relatif à la réglementation technique en application du décret n° 2009-643 du 9 juin 2009 relatif aux autorisations délivrées en application de la loi n° 2008-518 du 3 juin 2008 relative aux opérations spatiales,

Arrête :

Art. 1er. – L'arrêté du 31 mars 2011 susvisé est modifié conformément aux articles 2 à 13 du présent arrêté.

Art. 2. – Le cinquième alinéa de l'article 1er est remplacé par les dispositions suivantes :

« "Couloir de vol" » : volume dans lequel le véhicule de lancement est susceptible d'évoluer compte tenu des dispersions normales ; »

Art. 3. – Au dernier alinéa de l'article 10, les mots : « du troisième alinéa de l'article 23 du présent arrêté » sont remplacés par les mots : « du 3 de l'article 23 du présent arrêté ».

Art. 4. – Au second alinéa de l'article 13, les mots : « au quatrième alinéa de l'article 11 du présent arrêté » sont remplacés par les mots : « au 4 de l'article 11 du présent arrêté ».

Art. 5. – Dans la première phrase du 2 de l'article 16, les mots : « au premier alinéa ci-dessus » sont remplacés par les mots : « au 1 du présent article ».

Art. 6. – Au 9° de l'article 17, les mots : « des quatrième, cinquième, sixième et septième alinéas de l'article 21 du présent arrêté » sont remplacés par les mots : « des 4, 5, 6 et 7 de l'article 21 du présent arrêté ».

Art. 7. – L'article 20 est remplacé par les dispositions suivantes :

« *Art. 20.* – Objectifs quantitatifs pour la sécurité des personnes.

« 1. Pour la somme des risques de dommages catastrophiques, l'opérateur de lancement doit respecter les objectifs quantitatifs suivants, exprimés en probabilité maximale admissible de faire au moins une victime (risque collectif) :

« *a)* Risque au lancement :

« $2^* 10^{-5}$ pour l'ensemble de la phase de lancement, comprenant la prise en compte des cas dégradés du système de lancement et incluant la retombée des éléments prévus de se détacher du lanceur sans être mis en orbite ;

« 10^{-7} par retombée nominale d'élément pour les éléments prévus de se détacher du lanceur sans être mis en orbite, conformément au 1 de l'article 23 du présent arrêté.

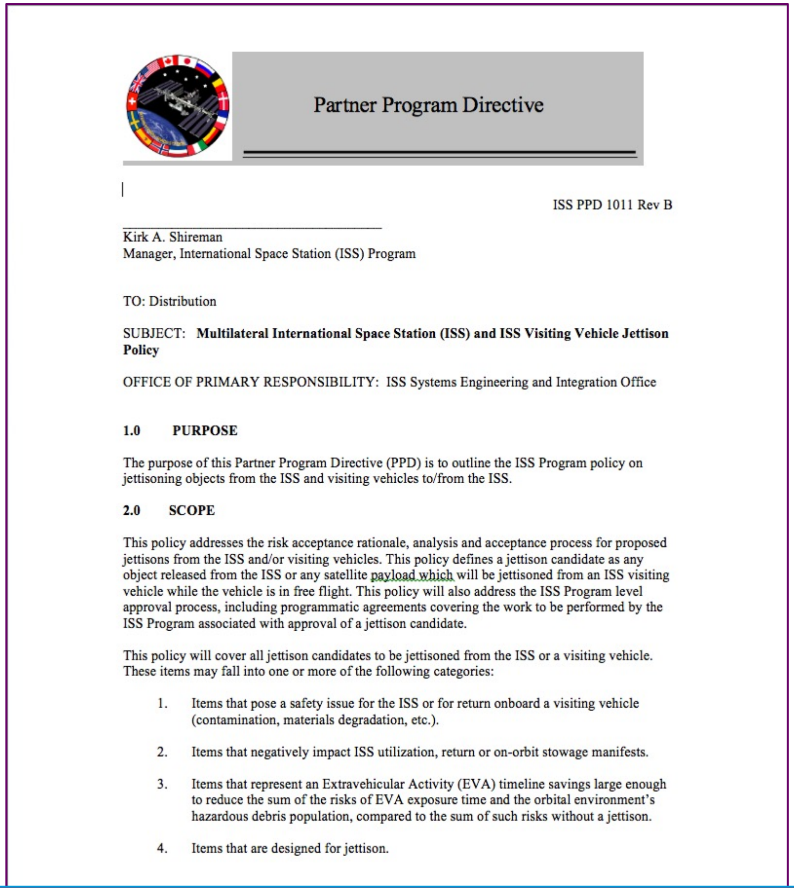
« *b)* Risque à la rentrée :

« $2^* 10^{-5}$ pour la phase de retour de chaque élément du lanceur mis en orbite dans le cadre d'une rentrée atmosphérique contrôlée, incluant, conformément au 1 de l'article 23 du présent arrêté, une allocation spécifique de 10^{-7} pour le retour nominal de l'élément. L'opérateur de lancement met en œuvre cette rentrée contrôlée conformément aux 1 et 5 de l'article 21 du présent arrêté.

« En cas d'impossibilité dûment justifiée de procéder à une rentrée atmosphérique contrôlée telle que prévue ci-dessus, l'opérateur de lancement doit faire ses meilleurs efforts pour respecter un objectif quantitatif de 10^{-4} pour la

International Space Station (ISS) Jettison Policy

- **Multilateral International Space Station (ISS) and ISS Visiting Vehicle Jettison Policy** addressing the risk and acceptance process for hardware jettisons from the ISS by any partner:
  - Trackability;
  - No break-up risk (i.e. passivation) or in-orbit break-up risk less than 10^{-4};
  - No re-contact risk with ISS or collision hazard to Visiting Vehicles (i.e. requirements on clearance);
  - The Space Station Control Board (SSCB) is responsible for authorization of the implementation of the jettison operation.



Partner Program Directive

ISS PPD 1011 Rev B

Kirk A. Shireman
Manager, International Space Station (ISS) Program

TO: Distribution

SUBJECT: **Multilateral International Space Station (ISS) and ISS Visiting Vehicle Jettison Policy**

OFFICE OF PRIMARY RESPONSIBILITY: ISS Systems Engineering and Integration Office

1.0 PURPOSE

The purpose of this Partner Program Directive (PPD) is to outline the ISS Program policy on jettisoning objects from the ISS and visiting vehicles to/from the ISS.

2.0 SCOPE

This policy addresses the risk acceptance rationale, analysis and acceptance process for proposed jettisons from the ISS and/or visiting vehicles. This policy defines a jettison candidate as any object released from the ISS or any satellite payload which will be jettisoned from an ISS visiting vehicle while the vehicle is in free flight. This policy will also address the ISS Program level approval process, including programmatic agreements covering the work to be performed by the ISS Program associated with approval of a jettison candidate.

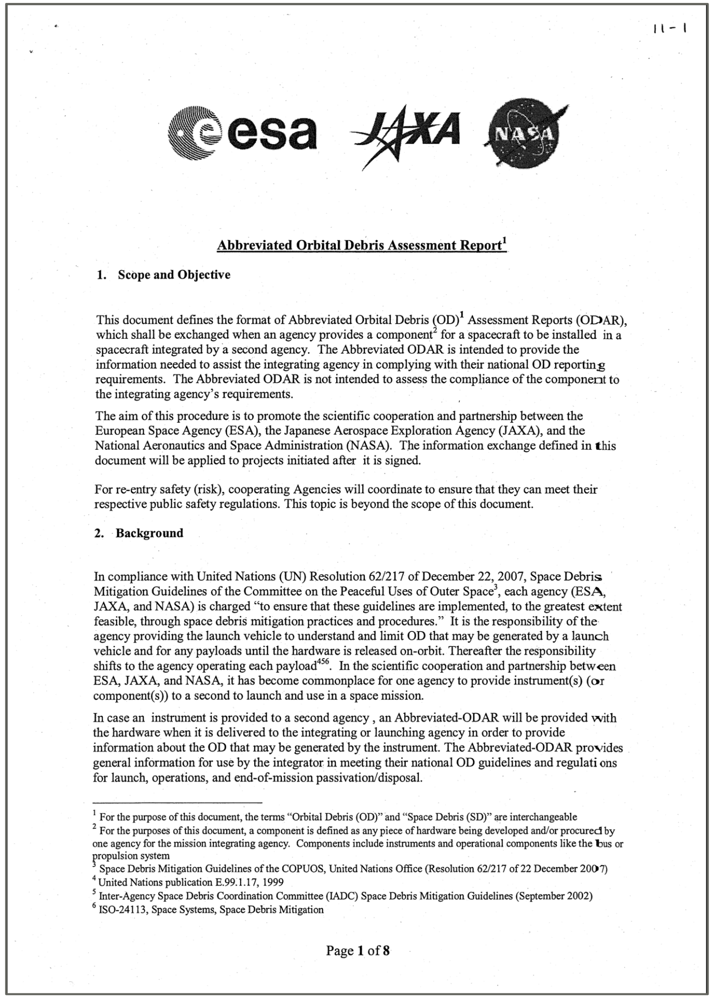
This policy will cover all jettison candidates to be jettisoned from the ISS or a visiting vehicle. These items may fall into one or more of the following categories:

1. Items that pose a safety issue for the ISS or for return onboard a visiting vehicle (contamination, materials degradation, etc.).
2. Items that negatively impact ISS utilization, return or on-orbit stowage manifests.
3. Items that represent an Extravehicular Activity (EVA) timeline savings large enough to reduce the sum of the risks of EVA exposure time and the orbital environment's hazardous debris population, compared to the sum of such risks without a jettison.
4. Items that are designed for jettison.

ISS PPD 1011 Rev B (2017)

International Cooperation and Agreements

- A **Trilateral Agreement between ESA, NASA and JAXA**, signed on 28/09/2012, regulates projects involving agencies' cooperation (with different level of responsibility) and the format and contents of an **Abbreviated Orbital Debris Assessment Report (ODAR)**, establishing that:
  - The Agency acting as space system integrator (i.e. bus-system provider) applies its own policy and requirements and is responsible for final compliance;
  - The Agency providing a component (e.g. a payload) for installation on a space system provided by another Agency, should indicate the compliance for the provided component with the requirements of the Agency acting as space system integrator (i.e. to provide technical information in the Abbreviated ODAR);
  - The Agency providing the launch capability has the responsibility to review the compliance of both the launch vehicle and spacecraft with the SDM and system safety requirements.



Abbreviated Orbital Debris Assessment Report[1]

1. Scope and Objective

This document defines the format of Abbreviated Orbital Debris (OD)[1] Assessment Reports (ODAR), which shall be exchanged when an agency provides a component[2] for a spacecraft to be installed in a spacecraft integrated by a second agency. The Abbreviated ODAR is intended to provide the information needed to assist the integrating agency in complying with their national OD reporting requirements. The Abbreviated ODAR is not intended to assess the compliance of the component to the integrating agency's requirements.

The aim of this procedure is to promote the scientific cooperation and partnership between the European Space Agency (ESA), the Japanese Aerospace Exploration Agency (JAXA), and the National Aeronautics and Space Administration (NASA). The information exchange defined in this document will be applied to projects initiated after it is signed.

For re-entry safety (risk), cooperating Agencies will coordinate to ensure that they can meet their respective public safety regulations. This topic is beyond the scope of this document.

2. Background

In compliance with United Nations (UN) Resolution 62/217 of December 22, 2007, Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space[3], each agency (ESA, JAXA, and NASA) is charged "to ensure that these guidelines are implemented, to the greatest extent feasible, through space debris mitigation practices and procedures." It is the responsibility of the agency providing the launch vehicle to understand and limit OD that may be generated by a launch vehicle and for any payloads until the hardware is released on-orbit. Thereafter the responsibility shifts to the agency operating each payload[456]. In the scientific cooperation and partnership between ESA, JAXA, and NASA, it has become commonplace for one agency to provide instrument(s) (or component(s)) to a second to launch and use in a space mission.

In case an instrument is provided to a second agency , an Abbreviated-ODAR will be provided with the hardware when it is delivered to the integrating or launching agency in order to provide information about the OD that may be generated by the instrument. The Abbreviated-ODAR provides general information for use by the integrator in meeting their national OD guidelines and regulations for launch, operations, and end-of-mission passivation/disposal.

[1] For the purpose of this document, the terms "Orbital Debris (OD)" and "Space Debris (SD)" are interchangeable
[2] For the purposes of this document, a component is defined as any piece of hardware being developed and/or procured by one agency for the mission integrating agency. Components include instruments and operational components like the bus or propulsion system
[3] Space Debris Mitigation Guidelines of the COPUOS, United Nations Office (Resolution 62/217 of 22 December 2007)
[4] United Nations publication E.99.1.17, 1999
[5] Inter-Agency Space Debris Coordination Committee (IADC) Space Debris Mitigation Guidelines (September 2002)
[6] ISO-24113, Space Systems, Space Debris Mitigation

Page 1 of 8

ESA-CNES Agreements on SDM

1. **Arrangement between the European Space Agency and Centre National d'Etudes Spatiales concerning coordination on Safety of ESA launch systems operated at the Guiana Space Centre and their qualification status monitoring – 15/12/2011**
   - The Arrangement applies to launch systems developed by ESA and carried out from CGS
   - ESA shall submit to CNES the technical information required to verify compliance with the French LOS
   - CNES shall grant ESA a certificate of technical conformity to the French LOS applicable requirements
2. **Arrangement between the European Space Agency and Centre National d'Etudes Spatiales concerning coordination on safety of ESA orbital systems controlled from French territory – 13/03/2013**
   - The Arrangement applies to orbital systems for which ESA controls the platform from French territory
   - No obligation for ESA to observe French LOS, but attempt to avoid duplication of work
   - ESA will transmit to CNES the technical information required to verify compliance with the French LOS applicable requirements
   - CNES will perform necessary safety assessments, will agree with ESA on possible corrective measures, and will issue a technical conformance status

Future

Space Debris Mitigation requirements are constantly evolving
in order to cope with the current and upcoming challenges
and to absorb knowhow maturation and lessons learnt
→ Stay tuned

Acronyms

AR	Acceptance Review
ASI	Agenzia Spaziale Italiana
ESB	Engineering Standardisation Board
ESSB	ESA Standardization Steering Board
ATV	Automated Transfer Vehicle
BNSC	British National Space Agency
CDR	Critical Design Review
CID	Current Interrupt Device
CNES	Centre National d'Etudes Spatiales
CNSA	China National Space Administration
COPUOS	Committee on the Peaceful Use of Outer Space
CR	Change Request
CSA	Canadian Space Agency
CSG	Centre Spartial Guyanais
DLR	German Aerospace Center
DRA	Declared Re-entry Area
DRAMA	Debris Risk Assessment and Mitigation Analysis
ECSS	European Cooperation for Space Standardization
ELR	End of Life Review
EOM	End of Mission
ESA	European Space Agency
FAA	Federal Aviation Administration
FAR	Flight Acceptance Review
FCC	Federal Communication Commission
FMECA	Failure Mode, Effects and Criticality Analysis
FSOA	French Space Operation Act
IADC	Inter-Agency Space Debris Coordination Committee
ISO	International Organization for Standardization
ISRO	Indian Space Research Organization
LBB	Leak-before-burst
LEO	Low Earth Orbit
LOS	Loi relative aux Opérations Spatiales
KARI	Korea Aerospace Research Institute
JAXA	Japan Aerospace Exploration Agency
GEO	Geostationary Earth Orbit
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to Airmen
NOTMAR	Notice to Mariners
NTIA	National Telecommunication and Information Administration
PDR	Preliminary Design Review
PRR	Preliminary Requirements Review
PTC	Positive Temperature Coefficient
QAR	Qualification Acceptance Review
QSB	Quality Standardisation Board
RAM	Reliability, Availability, Maintainability
RFD	Request for Deviation
RFW	Request for Waiver
SDM	Space Debris Mitigation
SDMP	Space Debris Mitigation Plan
SDMR	Space Debris Mitigation Report
SoC	State of Charge
SPF	Single Point of Failure
SPOUA	South Pacific Ocean Uninhabited Area
SRA	Safety Re-entry Area
SRM	Solid Rocket Motor
SRR	System Requirements Review
SSAU	State Space Agency of Ukraine
TC	Technical Committee
UKSA	United Kingdom Space Agency
UN	United Nations
UNOOSA	UN Office for Outer Space Affairs

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Thank You