ESA Space Debris Mitigation and Re-entry Safety Framework – Status and Novelties

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ESA Space Debris Mitigation and Re-entry Safety Regulatory Framework

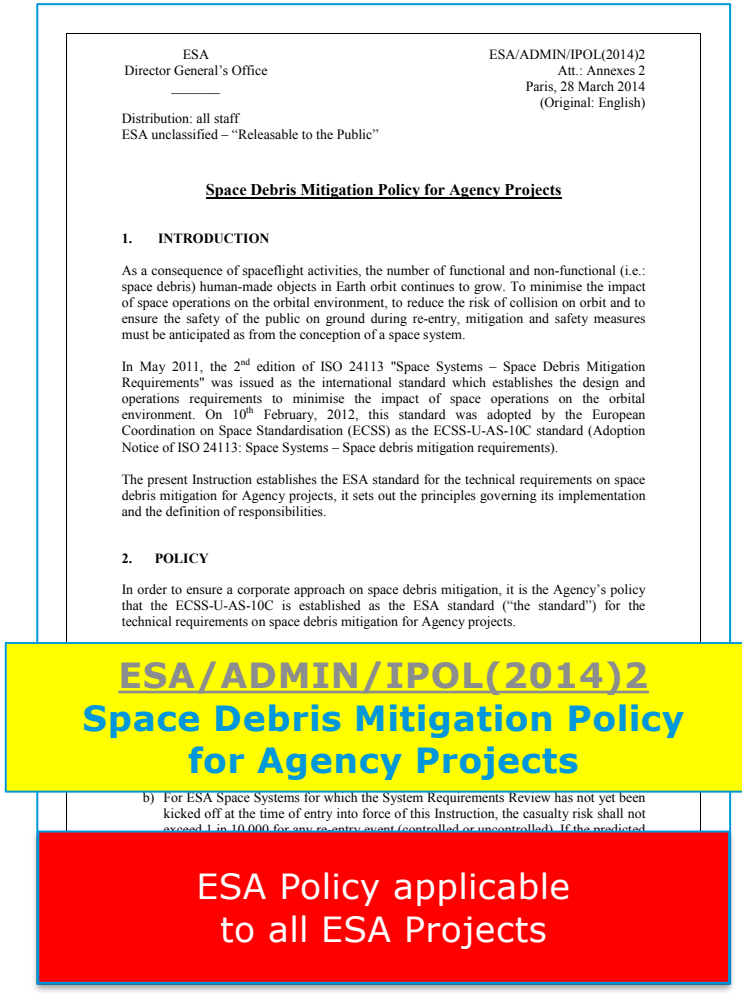
- **ESA Space Debris Mitigation requirements** are defined in the standard **ECSS-U-AS-10C / ISO 24113**, which is made applicable to all ESA Projects by the ESA Space Debris Mitigation Policy **ESA/ADMIN/IPOL(2014)2** (2014), and are explained in **ESSB-HB-U-002**.
- Several requirements were already stated in the **European Code of Conduct for Space Debris Mitigation** (2004) and the first **ESA Space Debris Mitigation Policy ESA/ADMIN/IPOL(2008)2** (2008).
- **ISO 24113:2019** was published in July 2019, replacing ISO 24113:2011 containing updated and new requirements.
- **ECSS-U-AS-10C, Rev. 1**, was approved on 3 December 2019, adopting the requirements in ISO 24113:2019 with some clarifications.
- The **ESA Space Debris Mitigation Policy** will be updated (2021) to endorse the application at Corporate level of ECSS-U-AS-10C, Rev. 1 / ISO 24113:2019, which is already in the List of ESA Applicable Standards (LEAS).

ESA Space Debris Mitigation and Re-entry Safety Regulatory Framework

Reference	Title	Type of document	Date of issue
ESA/ADMIN/IPOL(2014)2	Space Debris Mitigation Policy for Agency Projects	ESA Policy	28/03/2014 (Add. 1: 15/04/2018) (Rev. 1: 2021)
ECSS-U-AS-10C, Rev. 1	Space sustainability - Adoption Notice of ISO 24113: Space Systems – Space debris mitigation requirements	ECSS Standard	03/12/2019
ESSB-ST-U-004, Issue 1.0	ESA Re-entry Safety Requirements	ESA Standard	04/12/2017
ESSB-HB-U-002, Issue 1.0	ESA Space Debris Mitigation Compliance Verification Guidelines	ESA handbook	19/02/2015
ISO 24113:2019 (E)	Space Systems – Space debris mitigation requirements	International Standard adopted by ECSS-U-AS-10C, Rev. 1	07/2019

Major update of ECSS/ISO Space Debris Mitigation standards in 2019

ESA SDM Policy, Standards, and Requirements



ESA
Director General's Office

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 exceed 1 in 10 000 for any re-entry event (controlled or uncontrolled). If the predicted

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

ESA Policy applicable to all ESA Projects

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

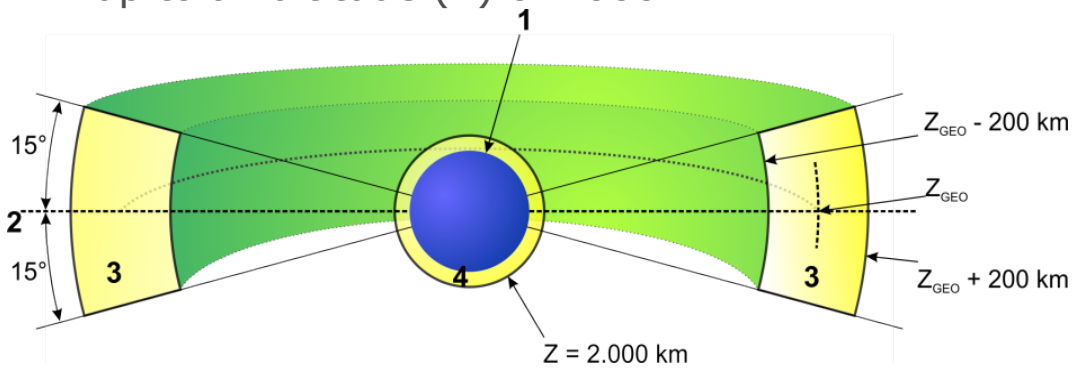
Document Reference	Type of Document	Document Management and Change/Update Process
ESA/ADMIN/IPOL(2014)2	**ESA policy**	• Head of the ESA Department of Product Assurance and Safety (TEC-Q) is in charge of the management. • ESA Independent Safety Office (TEC-QI) in charge of the maintenance. • Effective 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.

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)

ECSS-U-AS-10C, Rev. 1: Clarifications to ISO 24113:2019

- To stress that space debris mitigation requirements apply to space objects in any bounded Earth orbit and also to space objects in unbounded Earth orbits in case there is a risk for interference with the LEO and GEO protected regions.
- To assess the probability of successful disposal based on reliability analyses with verification methods, which are to be agreed with the approving agents, accounting for existing ECSS implementation practices.

ECSS-U-AS-10C, Rev. 1: Clarifications to ISO 24113:2019

3.8 – Earth orbit

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

Note 1: The requirements in ISO 24113:2019 do not apply to space objects in an unbounded Earth orbit if, for at least 100 years after the space objects enter the unbounded Earth orbit:

- the assessed risk of the space objects interference with the LEO and GEO protected regions, or
- the assessed risk of the space objects re-entry

is less or equal to the corresponding threshold set by the approving agent.

ECSS-U-AS-10C, Rev. 1: Clarifications to ISO 24113:2019

3.20 – Probability of successful disposal

probability that a spacecraft or launch vehicle orbital stage is able to complete all of the actions associated with its disposal

Note 1: The calculation of this probability includes consideration of uncertainties in the availability of resources, such as propellant, required for the disposal.

Note 2: The calculation of this probability can include consideration of the inherent reliabilities of subsystems that are necessary to conduct the disposal, monitoring of those subsystems, and operational remediation of any observed subsystem degradation or failure.

Note 3: The calculation of this probability can include an assessment of the risk that a space debris or meteoroid impact will prevent the disposal, but this is not mandatory.

Note 4: In the previous edition of this document, ISO 24113:2011, the probability of successful disposal was defined as a conditional probability, i.e. the probability of successfully performing a disposal given that the nominal mission had been completed. In this document the probability is no longer conditional.

Note 5: The calculation of this probability can be based on reliability analyses performed according to “ECSS-Q-ST-30 - Space product assurance – Dependability”, “ECSS-Q-HB-30-08 - Space product assurance - Components reliability data sources and their use”, or any other methods set by the approving agent.

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 on-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

Disposal reliability

- ***6.3.1.1*** *The probability of successful disposal of a spacecraft or launch vehicle orbital stage shall be at least 0,9 through to the end of life.*
- ***6.3.1.6*** *In case the mission lifetime is to be extended, the capability of a spacecraft to perform successful disposal shall be reassessed considering the status of the spacecraft at the beginning of the mission lifetime extension.*

- ESA interpretation (Safety drivers):
  - The current definition of “probability of successful disposal” in ISO 24113:2019 is only concerned with Space Debris Mitigation, but not directly considering human safety (e.g. human spaceflight safety, Earth population on ground safety).
  - The re-entry casualty risk shall be the key driver for the Space System platform reliability when controlled re-entry is planned and performed (**ESSB-ST-U-004 – ESA Re-entry Safety Requirements**).
  - Safety priority is to avoid that re-entering fragments (debris) are spread outside the identified nominal safe target re-entry area and be potentially harmful for Earth population.
  - 0.9 is the minimum probability of successful disposal acceptable only in order to ensure compliance with the clearance of the LEO and Protected Regions required for Space Debris Mitigation (ISO 24113:2019).

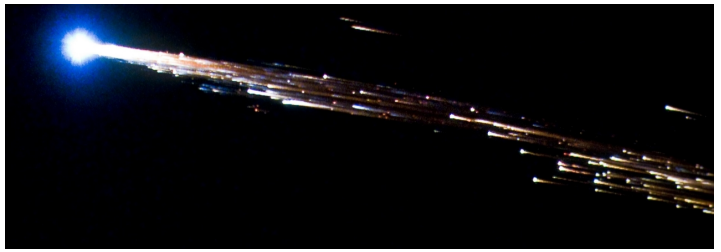
In-orbit break-up risk and passivation

- **Nominal mission:**
  - **6.2.2.1:** The **probability of accidental break-up** of a spacecraft or launch vehicle orbital stage in Earth orbit shall be less than 10^{-3} until its end of life.
  - **6.2.2.2:** The determination of accidental break-up probability shall quantitatively consider all known **failure modes for the release of stored energy, capable of causing an accidental break-up**, excluding those from external sources such as impacts with space debris and meteoroids.
  - **6.2.2.5:** The condition of a spacecraft shall be **monitored periodically** during its operation to detect any **anomalies** that could lead to an accidental break-up.
  - **6.2.2.6:** During the operation of a spacecraft, if an anomaly is detected which could lead to an accidental break-up then a **contingency plan** shall be implemented to mitigate this risk.
- **End of mission / disposal:**
  - **6.2.2.3:** A spacecraft or launch vehicle orbital stage, for which a controlled re-entry has not been planned, shall be **passivated in a safe and controlled manner before the end of life**.
  - **6.2.2.4:** If for any reason a launch vehicle orbital stage cannot perform a controlled re-entry as planned then it shall be passivated in a safe and controlled manner.

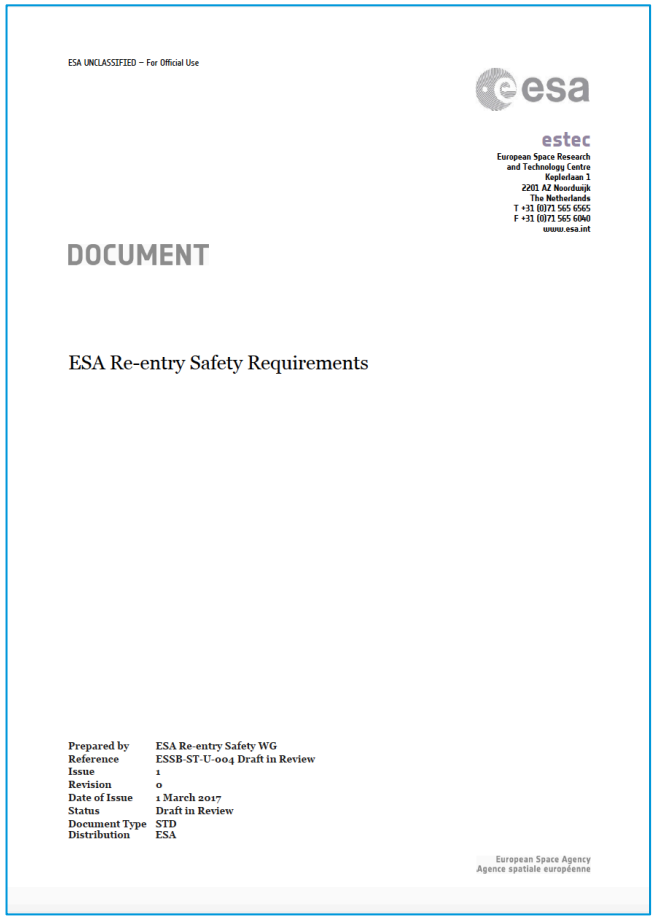
- ESA interpretation:
  - No debris are generated after the end of mission due to break-up of the space system as a result of release of energy from on-board sources (e.g. battery explosion)
    - ➔ **Energy depletion and permanent disconnection of energy storages from energy sources**
  - Once the passivation measures are implemented, the residual risk is assessed.
    - ➔ **Residual risk of debris generation negligible**

ESA Re-entry Safety standard

- 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 **10^{-4} 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 to plan and perform:
    - ❑ Safe re-entry operations,
    - ❑ Re-entry notifications,
    - ❑ Retrieval operations.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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-HB-U-002 – Issue 2

- ESSB-HB-U-002 – ESA Space Debris Mitigation Compliance Verification Guidelines is the ESA reference handbook providing guidelines for the verification of the ESA Space Debris Mitigation requirements.
- The handbook is 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.
- ESSB-HB-U-002 Issue 1 was published in 2015 and is currently under review.
- Comments for changes to ESSB-HB-U-002 are welcome in view of upcoming preparation of the Issue 2 (including reference ECSS-U-AS-10C, Rev. 1 / ISO 24113:2019 and further details on requirements implementation and verification).
- **ESSB-HB-U-002 Issue 2 publication is expected by end-2021**


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DOCUMENT

ESA Space Debris Mitigation Compliance Verification Guidelines

Prepared by	ESA Space Debris Mitigation WG
Reference	ESSB-HB-U-002
Issue	1
Revision	0
Date of Issue	19 February 2015
Status	Approved
Document Type	HB
Distribution	ESA

Under review

European Space Agency
Agence spatiale européenne

Passivation – Measures for battery

Passivation measures for energy storages, e.g. batteries, to ensure by design that the lowest probability of failure is achieved (amid the State of the Art technology) with adequate failure tolerance with respect to radiation, thermal, and ageing conditions by allowing non-accidental permanent depletion of energy may include:

- disconnection of the battery from the solar array through two fully independent commands (e.g. arm and fire commands) with at least one of the commands set as high priority command activated from the Ground Segment.
- disconnection of the battery from the main bus and connection of the battery to a permanent load (bleeder resistor in parallel to the battery) by means of 1 failure tolerant latching relay based circuit to ensure discharge and no further recharge of the battery to maintain a State of Charge (SoC) permanently below the threshold for thermal runaway onset (depending on the cell chemistry and technology) while ensuring by design that the involved electronics stay within operative temperatures limits and remain in stable conditions with respect to the radiation environment.
- permanent isolation of solar array and/or battery maintained even in case of a main power bus powered down to 0 V (battery permanently depleted), e.g. through short-circuiting sections or open-circuiting of all solar array sections such as to interrupt further energy transfer to energy storage units (e.g. battery).
- *[CONTINUE TO NEXT SLIDE]*

Content under review in ESSB-HB-U-002 Issue 2 ESA Working Group

Passivation – Measures for battery

- *[CONTINUE FROM PREVIOUS SLIDE]*
- reversibility of the passivation function when only one of the two independent commands is accidentally activated as a safety provision to avoid accidental execution of passivation.
- probability of accidental execution of passivation lower than 10^{-4} (TBC) until end of mission.
- a minimum reliability to execute the disconnection of the battery from the solar array at end of the operation phase (actual technology can demonstrate a reliability higher than 0,99 - TBD).
- a minimum reliability to maintain the disconnection of the battery from the solar array with very low residual break-up risk during the disposal phase until re-entry, or for at least 100 years. Solutions free of Single Point of Failure are preferable, but not essential, to ensure these conditions (e.g. actual technology can demonstrate a reliability higher than 0,95, and residual risk below 10^{-4} - TBD).
- passive thermal protection of the battery to protect the battery from high temperature, e.g. with a safe State of Charge (SOC) and temperature conditions defined according to the selected cell chemistry and technology.

Content under review in ESSB-HB-U-002 Issue 2 ESA Working Group

Passivation – Risk assessment for Battery

The Spacecraft Developer should perform an assessment of the probability and impact (risk) of debris generation due to battery cell explosion. The residual risk assessment for the battery takes into account:

a. Reliability of the safety features implemented in the battery cells and modules to prevent thermal runaway and explosion.
b. Level of qualification and flight acceptance tests of the battery cells implemented in the Spacecraft.
c. Maximum State of Charge (SoC) of the battery cells after the end of mission and its evolution (minimum SoC implies less risk).
d. Maximum exposure temperature of the battery cells to check that the battery cells can withstand the worst-case thermal in-orbit conditions (no attitude control) without exhibiting thermal runaways or explosions.
e. Estimated Delta-v (kinetic energy) gained by space debris generated in case of battery structural break-up and the likelihood of the debris to interfere in long-term with the Protected Region, if the spacecraft is outside the Protected Regions (e.g. for spacecraft in graveyard orbit above the GEO Protected Regions, or in MEO).

Content under review in ESSB-HB-U-002 Issue 2 ESA Working Group

ESSB-HB-U-002, Issue 2 – Other Highlighs not in ECSS-U-AS-10C, Rev.1 / ISO 24113:2019

Guidelines in ESSB-HB-U-002 Issue 2, which are not yet explictly treated in ECSS-U-AS-10C, Rev.1 / ISO 24113:2019:

- Disposal from bounded Earth orbits outside the Protected Region (e.g. MEO, HEO) and from lunar orbits
- Disposal from unbounded Earth orbits and from Sun-Earth Lagrange points orbits
- Orbits intereference assessment
- Spacecraft ”Design for Removal”
- Space transportation platforms

Content under review in ESSB-HB-U-002 Issue 2 ESA Working Group

Thank You

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