Status of ESA Missions Compliance and Evolution of Requirements

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02/07/2026

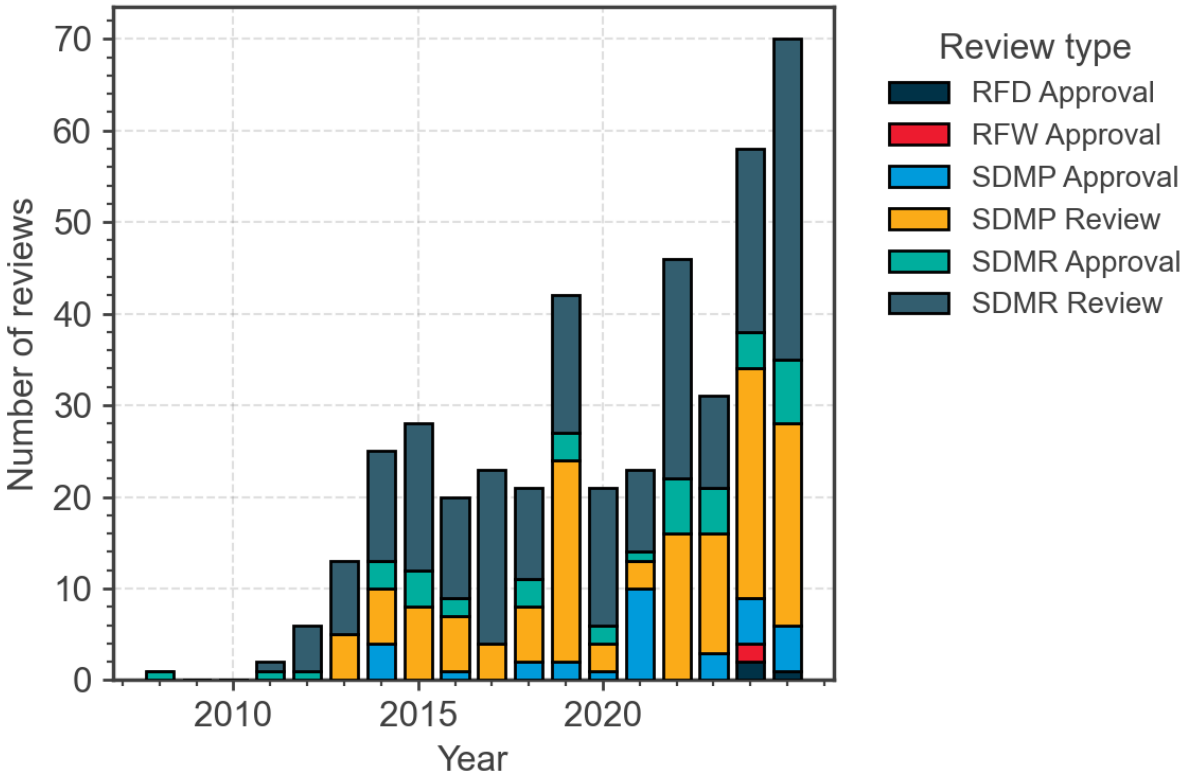
Space Debris Mitigation Assessment at ESA

ESA Space Debris Mitigation Policy defines the process for the assessment of ESA projects

- Applicable to **any project** with ESA contribution, not only to missions for which ESA is the launching state
- **Independent assessment** performed by engineers external to the projects
- Recommended involvement at every review, with **SSR** and **F/QAR** as approval milestones
- Only **ESA's Director General** can **approve deviations** and **waivers** to the requirements

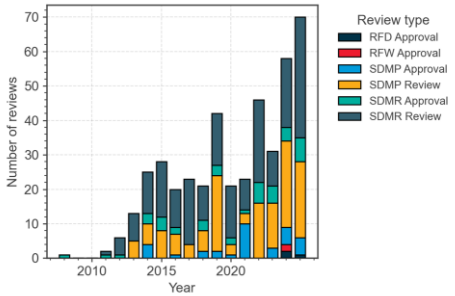
After the Policy update in 2023:

- Significant increase in **awareness** on space debris mitigation needs and internal process
- On-going consolidation of an **ESA-corporate** (harmonised) approach



SRR: System Requirement Review | **F/QAR**: Flight/Qualification Acceptance Review
RFD: Request for Deviation | **RFW**: Request for Waiver
SDMP: Space Debris Mitigation Plan | **SDMR**: Space Debris Mitigation Report

Implementation monitoring

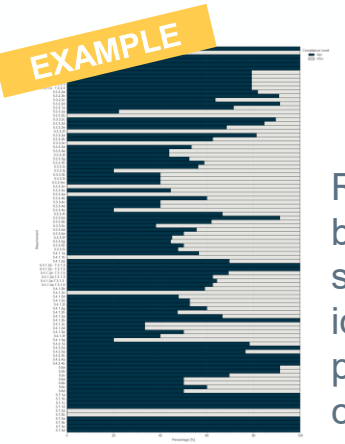


Technical reviews

Detailed compliance assessment and recommendations to the projects

Target to update Policy, Requirements and Handbook by 2030

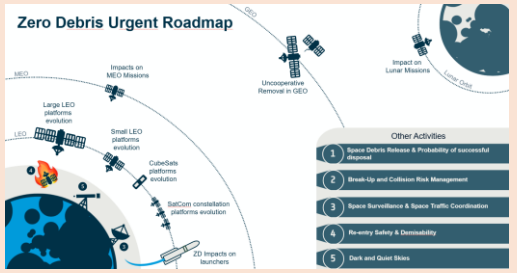
Extended statistics on overall compliance level



Requirement-by-requirement statistics to identify current pain points and challenges

Requirement evolution

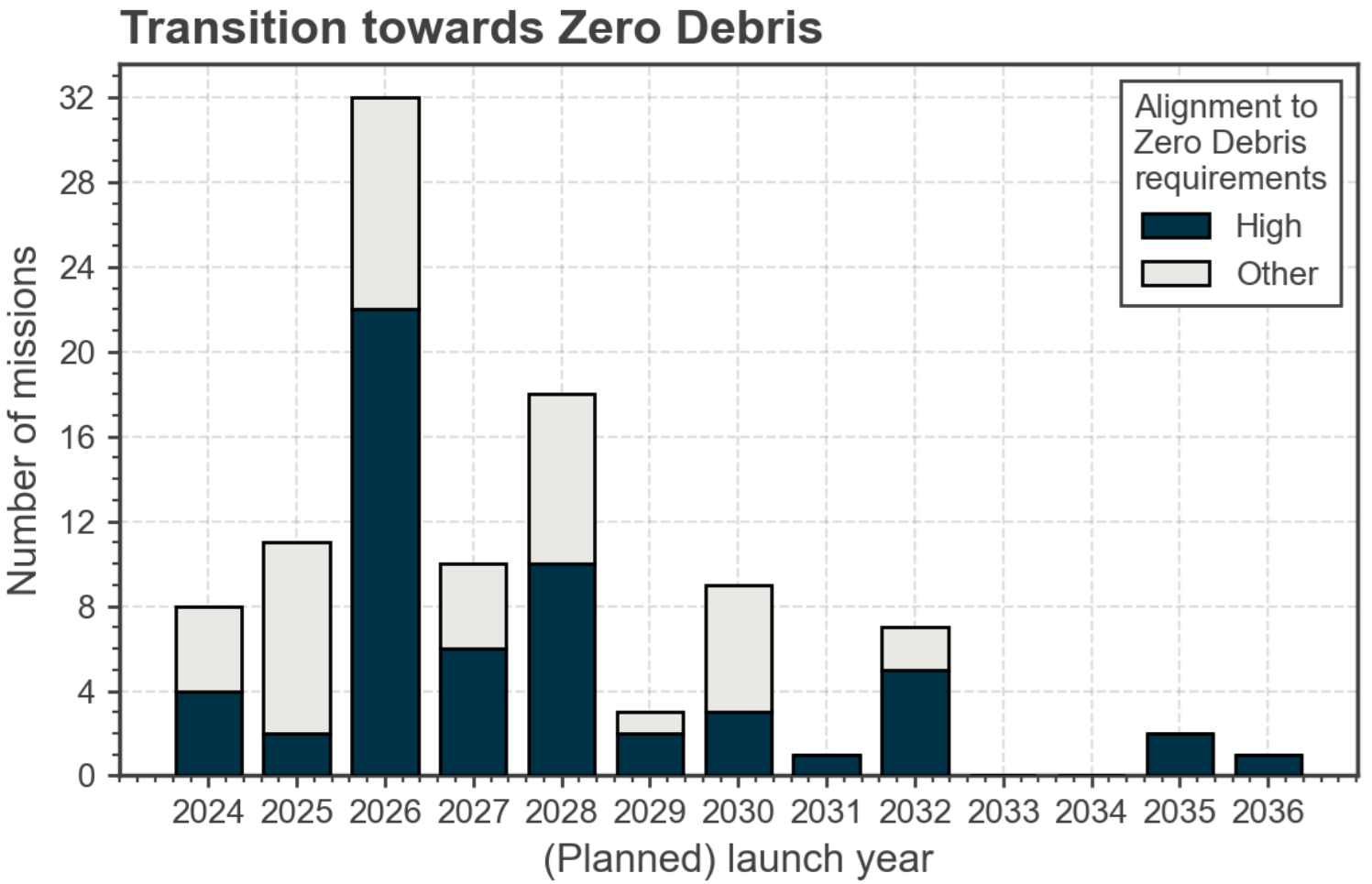
Feedback from R&D activities



Feedback from community engagement

Transition to Zero Debris: how is it going?

Considering all the reviews performed up to January 2026, regardless of the system type and mission phase, 57% of the missions to which ESA contributes have a high level of alignment with the Zero Debris principles



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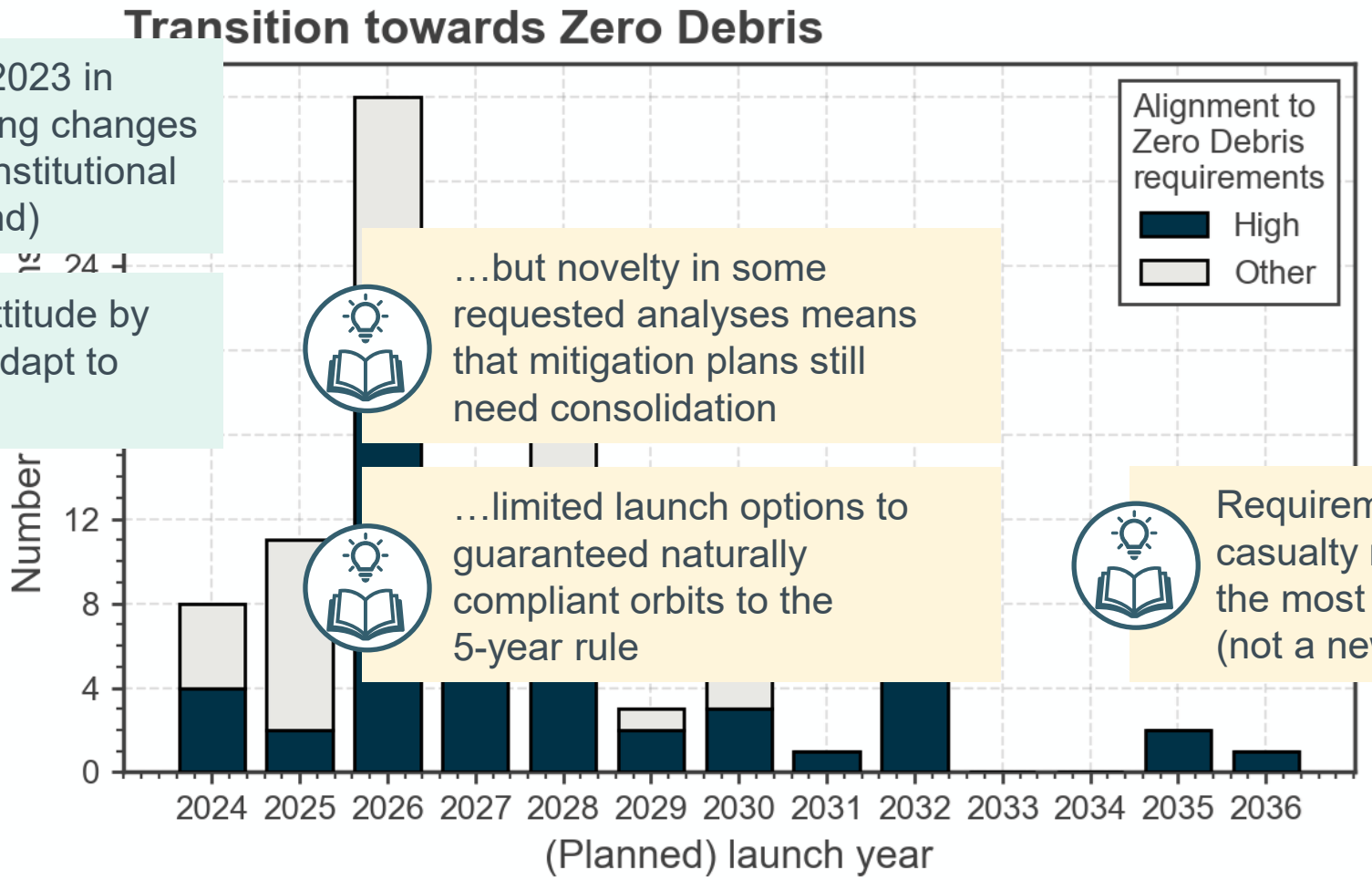
Effective work pre-2023 in anticipating upcoming changes and prepare large institutional projects (and beyond)

Often, pro-active attitude by small missions to adapt to the 5-year rule



…but novelty in some requested analyses means that mitigation plans still need consolidation

…limited launch options to guaranteed naturally compliant orbits to the 5-year rule

Requirement on the casualty risk still one of the most challenging ones (not a new one!)

Requirement-by-requirement assessment

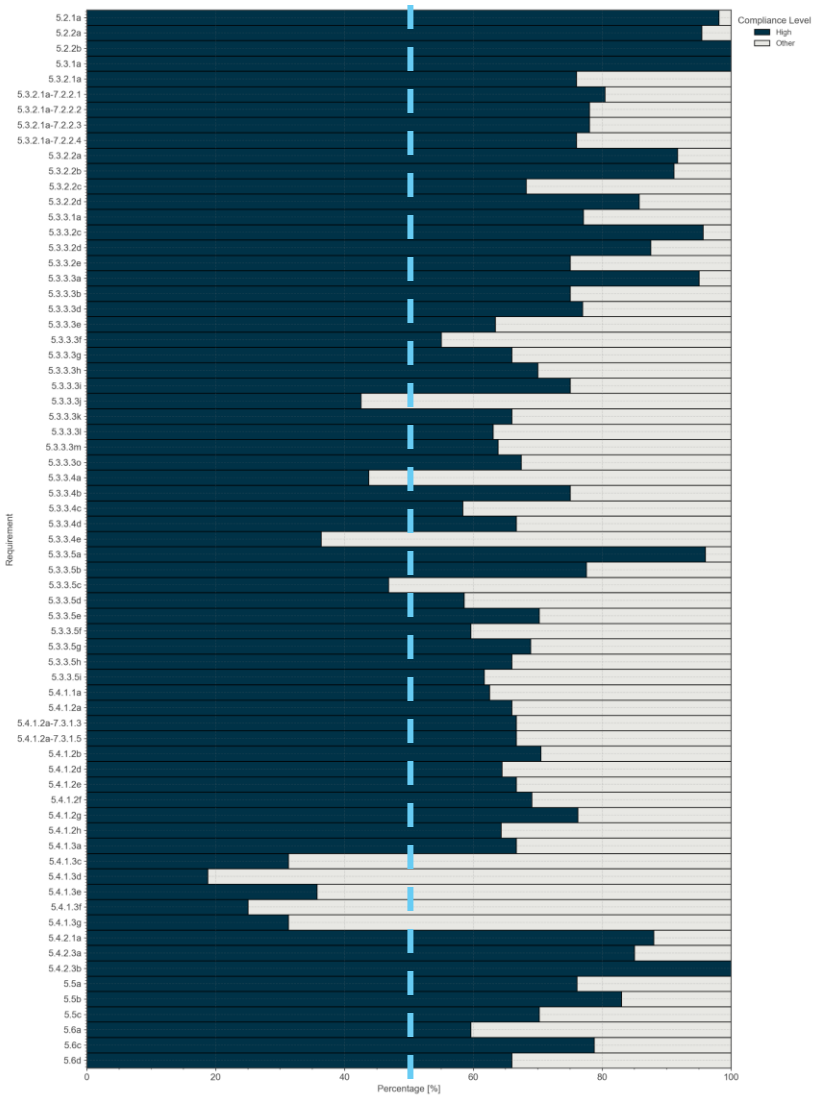
Evaluation of the compliance level to each requirement considering

- **Satellite** missions (no launch vehicles nor elements)
- Projects **pre-PDR** (ESSB-ST-U-007 as formal applicable doc)

Statistics compiled looking at **reviews** at **any stage** and result shown including requirements applicable in at least **10 instances**

Compliance level < 50% observed for

- **design-for-removal** requirements (5.4.1.3),
- the requirements on the **probability of unintentional contact** in close proximity operations (5.3.3.4a/e)
- timeliness in the **reaction of collision avoidance** alerts (5.3.3.3j),
- the **quantification of the position and velocity accuracy** of the combined ground, space, and space surveillance segment (5.3.3.5c)



Example: Design-for-removal

FORMULATION

VERIFICATION

5.4.1.3 Preparation for removal

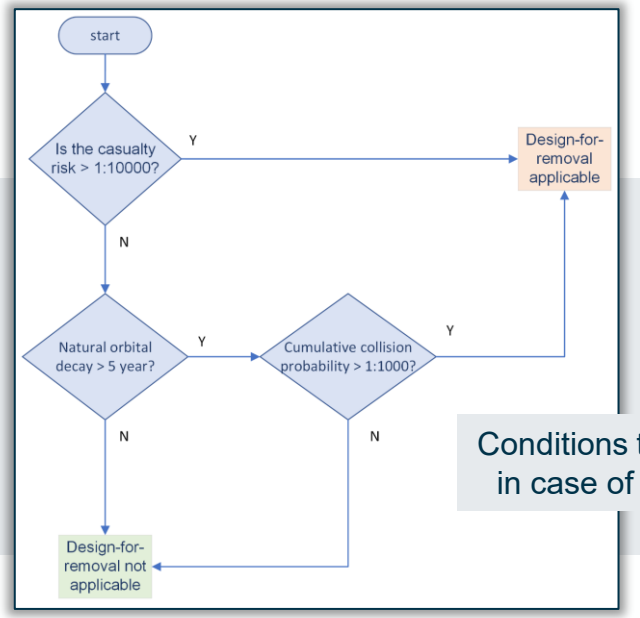
a. A spacecraft operating in the LEO protected region shall be prepared for removal by implementing measures that enable removal by external removal services, both in cooperative and un-cooperative condition, unless it always fulfils both of the following conditions:

1) The spacecraft in free drift from its operational orbit fulfils one of the following conditions:
   (a) Natural orbital decay duration below 5 years
   (b) Cumulative collision probability with space debris larger than 1 cm lower than 10^{-3} during the orbit lifetime

2) The spacecraft on-ground re-entry casualty risk is lower than 10^{-4} in case of uncontrolled re-entry.

NOTE 1 A method for verification of this requirement is specified in clause 6.

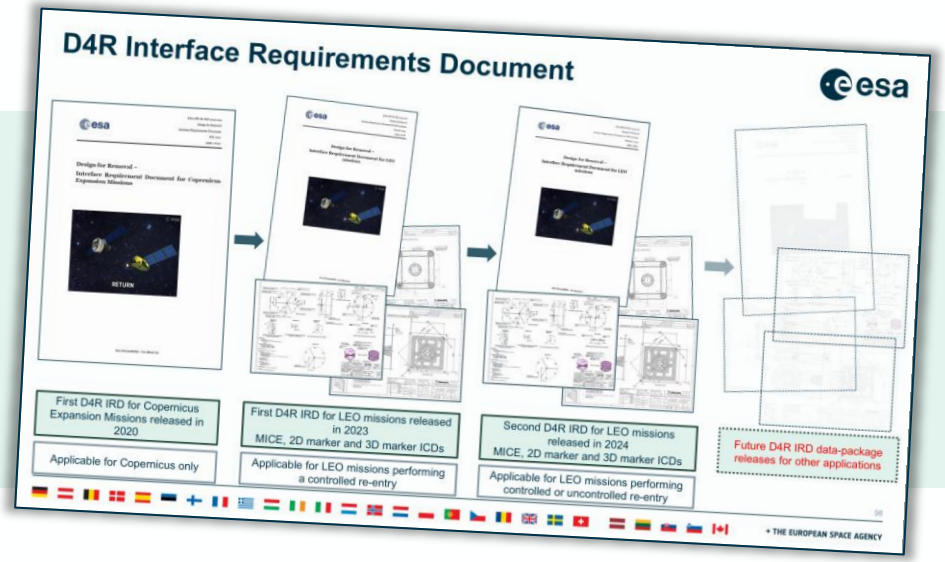
NOTE 2 Preparation for removal for spacecraft with an on-ground re-entry casualty risk higher than 10^{-4} is a remediation measure in case of failure to perform the controlled re-entry.



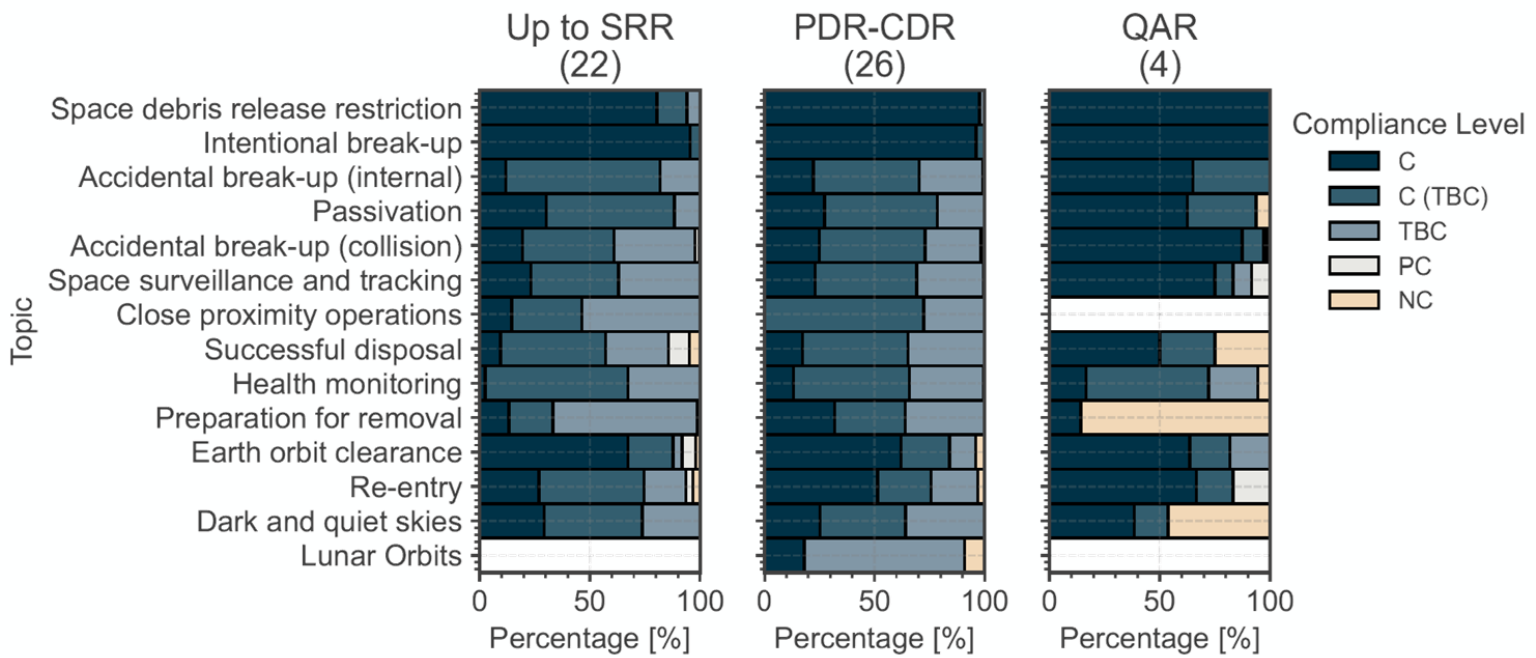
Conditions to be evaluated in case of in-orbit failure

Requirements should not prescribe a solution

Projects willing to set clear interfaces for Industry



Requirement-by-requirement assessment



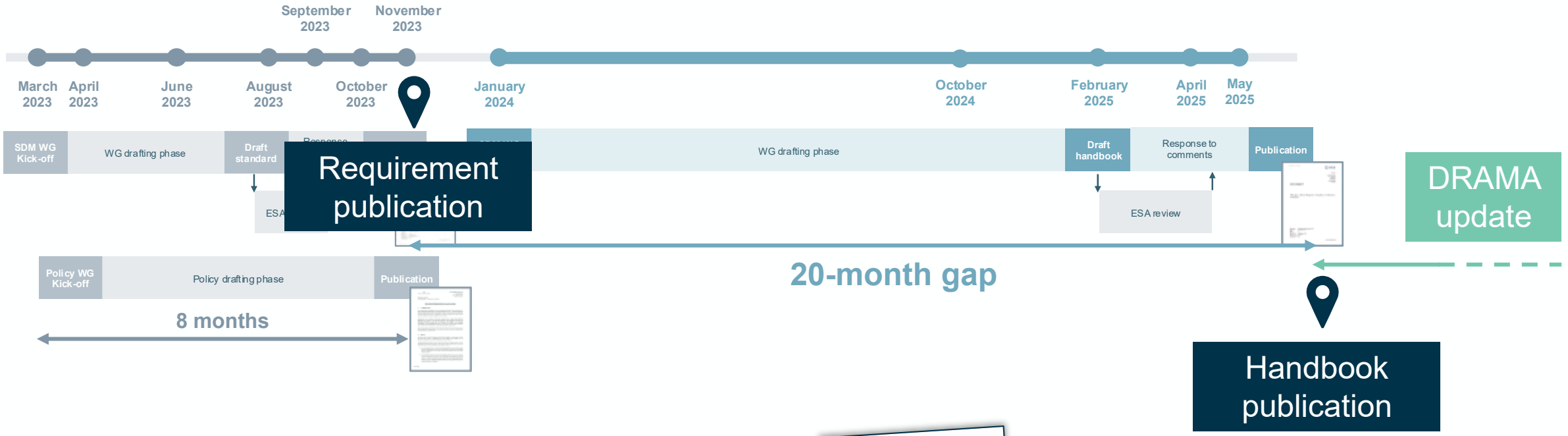
Check on the maturation level of the requirements along the reviews*

Negative trend observed for requirements under

- accidental break-up due to internal causes,
- passivation,
- dark & quiet skies

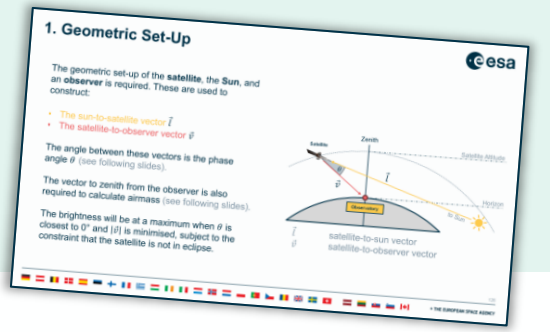
*Note: too few reviews in QAR phase to make it statistically relevant

Example: Dark & Quiet Skies



VERIFICATION

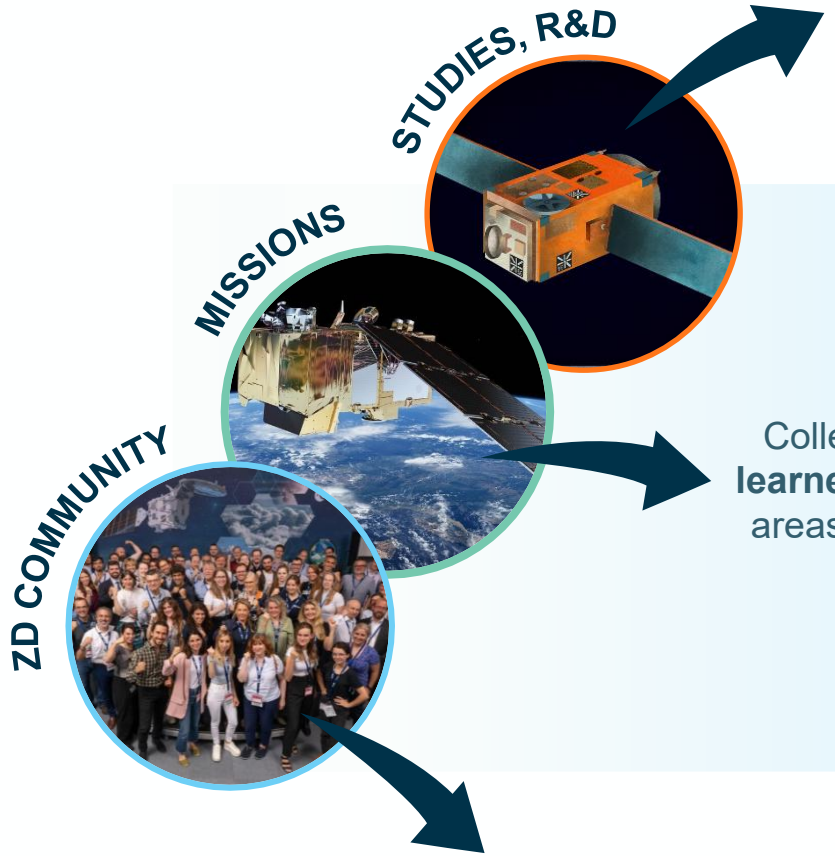
Even if several (informal) resources were made available, most projects have postponed the verification of the requirement until a dedicated tool was available in DRAMA



What's next?

Ongoing **activities** to define future requirements:

- Zero Debris platform studies
  (Large, Small, CubeSat, constellations, Lunar, etc)
- Technology developments
- Impacts of threshold evolution



Collection of **lessons learned,** identified **gaps**, areas of **improvement**

Active **collaboration** and exchanges with Industry, Operators, Regulators, Universities
Zero Debris Charter and Booklet, bi-laterals, workshops, webinars

Requirements evolution

Approach

- Convene ESA Working Group around Q3 2027
- Cover both Space Debris Mitigation and Re-entry Safety Requirements
- Directly address the update of the Handbook
- Identify gap/needs for DRAMA developments
- Target publication in 2030

Requirements evolution: Disposal and Passivation

Supporting studies

Ongoing studies are analysing the feasibility of more stringent requirements on the probability of successful disposal and probability of successful passivation

Satellite Communications Constellation

Study ongoing, values are undefined yet.

Zero-Debris Small and Cubesat LEO Platforms

Future requirements aim at increasing the probability of successful passivation up to **0.91** (TBC)
Successful deorbiting could go up to **0.95** (TBC) using deorbit systems independent from spacecraft platform

Zero-Debris Large LEO Platforms

Future requirements aim at increasing the probability of successful disposal up to **0.93 – 0.95** (TBC) and the probability of successful passivation up to **0.95** (TBC)

Mission and Projects lessons learned and collected compliance will also support refining thresholds for requirements evolution.

5.3.2.2.c

The overall probability of successful disposal of a spacecraft or launch vehicle orbital stage in Earth orbit shall be kept above 0,9 through to end of life, including the contributions from system reliability and from collisions with space debris or meteoroids preventing the successful disposal.

5.4.1.2.a

A spacecraft or launch vehicle orbital stage operating in Earth orbit shall be designed to guarantee a probability of successful passivation through to the end of life of:
1) At least 0,90
2) At least 0,95, when operating in the LEO protected region in an orbit with a natural orbital decay duration longer than 25 years
3) At least 0,95, when operating in the GEO protected region

Requirements evolution: Close Proximity Operations

Supporting studies

- **Lessons learned from past and ongoing missions**
- **Close Proximity Operations working group**

Identified Gaps

- The time horizon over which the probability of unintentional contact should be computed is not clearly defined
- The mathematical definition and calculation method for the probability of unintentional contact are not clearly defined:
  - Integration of reliability aspects
  - Consideration of nominal and off-nominal trajectories

Low compliance observed

↓

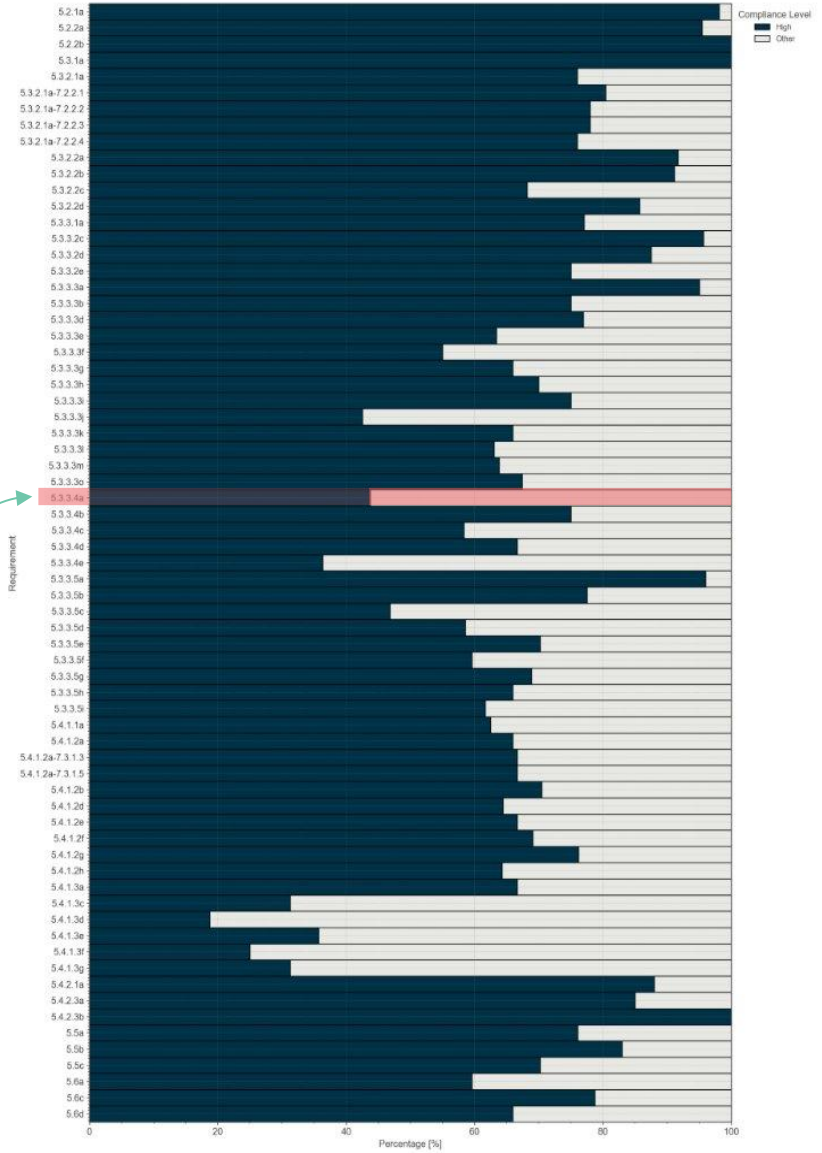
Gaps identified

↓

Actions ongoing

5.3.3.4.a

The probability of unintentional contact between space objects as a result of close proximity operations, or formation flying, in Earth orbit, shall be below 10^{-4}.



Development of a dedicated verification methodology

Requirements Refinement:

- Introduction of confidence interval associated with the P_{UC} threshold
- Development of a dedicated tool to support CPO assessment and requirements verification

Requirements evolution: Lunar Environment

Supporting studies

- **Outcomes from the Lunar Workshop**
- **Dedicated ESA internal studies**

Identified Gaps

- Limited tracking capabilities for satellites in lunar orbit, Lack of a consolidated catalogue of debris in lunar orbit
- Probability-of-collision metrics based on Earth-orbit assumptions are difficult to apply in the lunar environment
- Need to ensure compatibility of disposal strategies with the protection of areas of scientific interest on the lunar surface (uncontrolled vs controlled lunar impact)
- Consequences of lunar surface impacts both in terms of ejecta velocity and dispersion, and with respect to future human activities on the Moon
- Lunar gravitational field modelling uncertainties

Proposed Directions

- Include in-orbit satellite passivation requirements
- The choice of disposal strategy should be mission-dependent, taking into account the payload, the satellite size and the initial orbit, but with a clear order of preference
- Lunar graveyard orbit option should either be further studied (to better characterize bounded variation) or removed
- Requirements should extend to also address effects on the lunar surface.
  - For example, when impact on the lunar surface is selected as a disposal strategy, a requirement on the maximum ejecta velocity could be defined

Protection of areas of scientific interest is a key driver in requirements definition

Policy

Requirements

Handbook

Tools

space.debris.mitigation@esa.int