

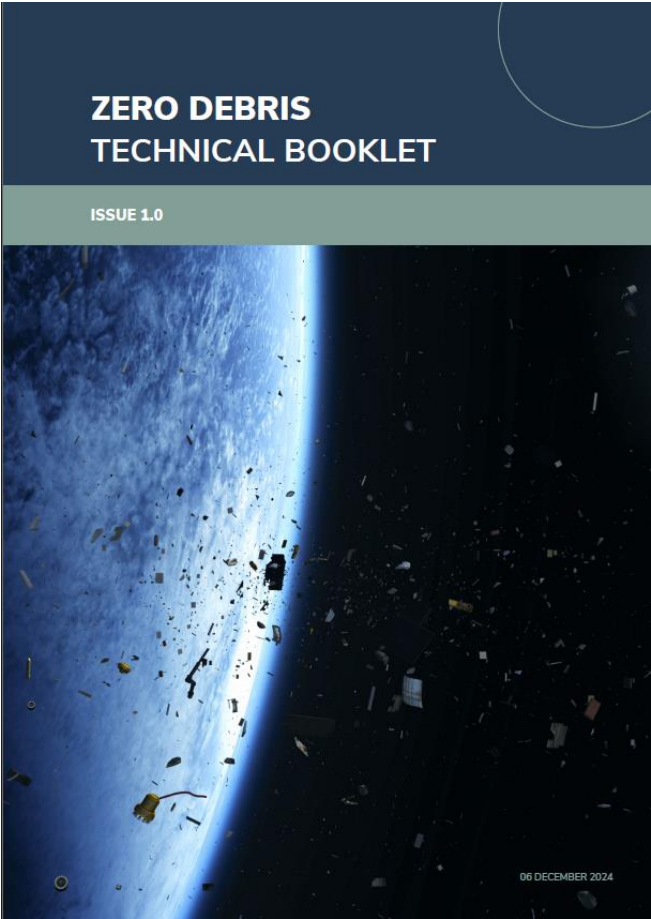
Analysis of Coverage of ZD Technical Booklet by the ESA Clean Space Roadmap

Clean Space team

11/06/2025

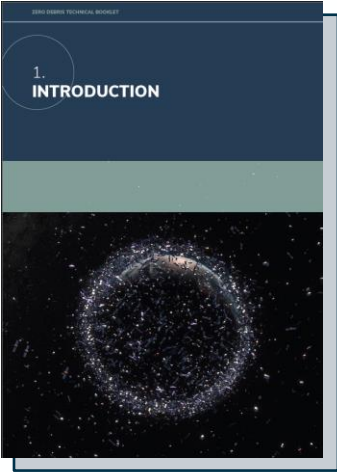
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- The aim of the Booklet is to serve as a resource for the **ZD Community** to direct its resources towards **research** and **future technology developments**.
- **Mapping of Key Enablers with ZD roadmap**

Introduction



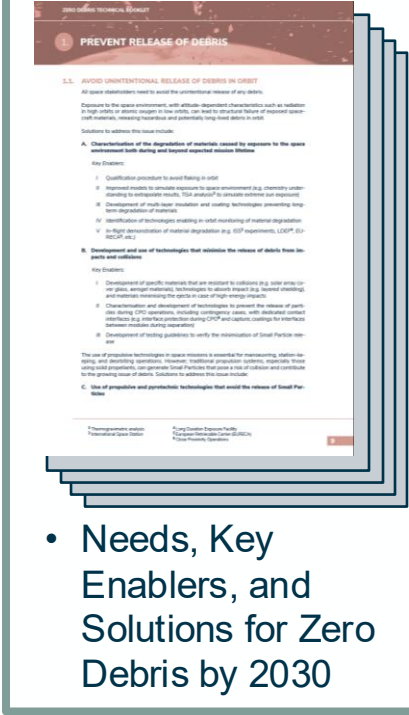
- Background
- Scope

Glossary



- Description of terms used

Technical Chapters



- Needs, Key Enablers, and Solutions for Zero Debris by 2030

Vision for a Circular Economy in Space



- Long-term Vision

Example of NEED

Example of SOLUTION

Examples of
KEY ENABLERS
considered essential to achieve the
2030 targets of the ZD Charter

- I Affordable Disposal solutions for Small Spacecraft (e.g. propulsion systems, drag-sails, aerobrakes, tethers, plug and play Disposal subsystem for CubeSats, based on COTS⁷ technology)
- II Evaluation and use of alternative strategies for orbital clearance and backup options for objects in Earth orbit (e.g. technical implications of Disposal strategies for MEO, GEO, GTO, HEO, etc.)
- III Spacecraft architectures which increase the probability of successful Disposal by accounting for possible mission extensions, failures and external factors (e.g. redundancy for Disposal capabilities, back-up deorbiting systems, incorporating margins)
- IV Technologies enabling safe autonomous and/or independent de-orbiting that can be integrated before launch or in-orbit (e.g. autonomous activation of de-orbiting devices, etc.)
- V Improved understanding of operational practices for de-orbiting (e.g. sharing of best practices, operational procedures, de-orbiting in degraded/safe mode, high-drag attitude control)

Clean Space roadmap 25-28: Main Blocks

Main blocks

System level Integration and Validation aspects

Reliability and resilience

Passivation Systems

De-orbiting Systems and technologies

Design for Demise (D4D)

Launcher evolution/adaptation

SDM requirements consolidation and development of verification models

Dark and Quiet Skies

Design for Removal (D4R)

Removal Services (CAT, multi-debris removal studies, debris removal in protected regions)

Space Surveillance and Tracking (SST) & Space Traffic Coordination (STC)

Impacts of spacecraft re-entry on the Earth's environment

Atmospheric and Ocean - Ground Testing and Tech Development

Atmospheric - Field Data

Atmospheric and Ocean - Modelling

93
activities
considered

Clean Space CMIN25
roadmaps:

- Ecodesign (*)
- Zero Debris
- In-Orbit Servicing (*)

(*) Only extracts from the
Ecodesign and IOS roadmaps
are considered in this mapping



Satellites platforms evolution

- System level integration & validation aspects
 - Following phases of LEO ZD P/Fs (Large, Small, Cubesats) (OPS, EOP, TEC)
 - Implementation of the ZD RM for Satcoms constellations sustainability (CSC)
 - Adaptation of constellations for Navigations in MEO & Disposal Strategies in MEO (NAV)
 - Adaptation of Lunar Missions (HRE)
- Technology building blocks
 - Reliability and resilience of disposal systems
 - De-orbiting Systems
 - Passivation Systems
 - Design for Demise (D4D)
 - Dark and Quiet Skies



Launchers evolution/adaptation



SDM requirements consolidation and development of verification models

- System studies
- Reliability and resilience
- Passivation
- Design for Demise (D4D)
- Dark and Quiet Skies



Design for Removal (D4R)



SST & STC



Chapter distribution

Chapter	Axis Title
chapter_1	8
chapter_2	61
chapter_3	32
chapter_4	32
chapter_5	65
chapter_6	59

Coverage of NEEDS by this roadmap (1/3)

Chapter	Needs	Enablers mapped count
1. Prevent Debris Release	1.1. Avoid unintentional release of debris in orbit	2
	1.2 Do not intentionally release debris	6
2. Guarantee Timely and Successful Clearance	2.1 Improve orbital clearance with high probability of successful de-orbiting	28
	2.2 Prepare space objects for removal	14
	2.3 Demonstrate removal services	19
3. Prevent Break-up/ Collision Debris Generation	3.1 Improve collision risk assessment	14
	3.2 Standardised evaluation of implied and encountered risks	1
	3.3 Improve collision avoidance capabilities during design stage	1
	3.4 Minimise risks linked to untrackable objects by design	4
	3.5 Minimise risks of internal break-ups	12
4. Improve Space Traffic Surveillance and Coordination	4.1 Improve space traffic coordination and information sharing	6
	4.2 Improve space surveillance performance	22
	4.3 Enhance correlation and uncertainty quantification methodologies	3
	4.4 Robust tasking of tracking for larger catalogues	1
5. Prevent Casualties on Ground	5.1 Reduce risks linked to uncontrolled re-entry	57
	5.2 Reduce technical impacts of controlled re-entry	6
	5.3 Minimising debris impacts on human population and infrastructure	2
6. Understand & Mitigate Adverse Consequences of Space Objects and Debris	6.1 Understand environmental impacts of re-entry	44
	6.2 Protect Dark and Quiet skies	15

Most mapped needs

Needs	Enablers mapped
5.1 Reduce risks linked to uncontrolled re-entry	57
6.1 Understand environmental impacts of re-entry	44
2.1 Improve orbital clearance with high probability of successful de-orbiting	28
4.2 Improve space surveillance performance	22
2.3 Demonstrate removal services	19
6.2 Protect Dark and Quiet skies	15

The risk and environmental impacts of re-entry are the **highest-priority** areas in this roadmap in terms of number of enablers mapped. However, this can, for example, be due to **many aspects needing to be investigated to fully cover a solution** (D4D for different equipment)

Less mapped needs

Needs	Enablers mapped
1.1. Avoid unintentional release of debris in orbit	2
3.2 Standardised evaluation of implied and encountered risks	1
3.3 Improve collision avoidance capabilities during design stage	1
4.4 Robust tasking of tracking for larger catalogues	1
5.3 Minimising debris impacts on human population and infrastructure	2

Despite the limited representation of these needs and enablers in the current CS roadmap, we recognize their significance. These areas highlight **opportunities** where contributions from the **ZD community** would be highly valuable and appreciated.

Some needs (e.g. 1.1. or 3.3.) are also partially covered with on-going activities (thus not part of the future CS roadmap and not mapped here).

Topic	Activity
System level integration & validation aspects	Adaptation of Lunar missions for Zero Debris

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- Next steps for this mapping:



- Include **past and on-going** activities – not only future roadmap.
- Weight this mapping according to the allocated **budget** for each activity



- Main **gaps** of the CS roadmap – and **opportunities for the community** – are highlighted
 - Open to discuss more in depth these gaps in dedicated meetings
 - Conversely, in the future ESA would like to use the mapping of the community to prioritize ESA's activities (next steps of the Booklet TBD).