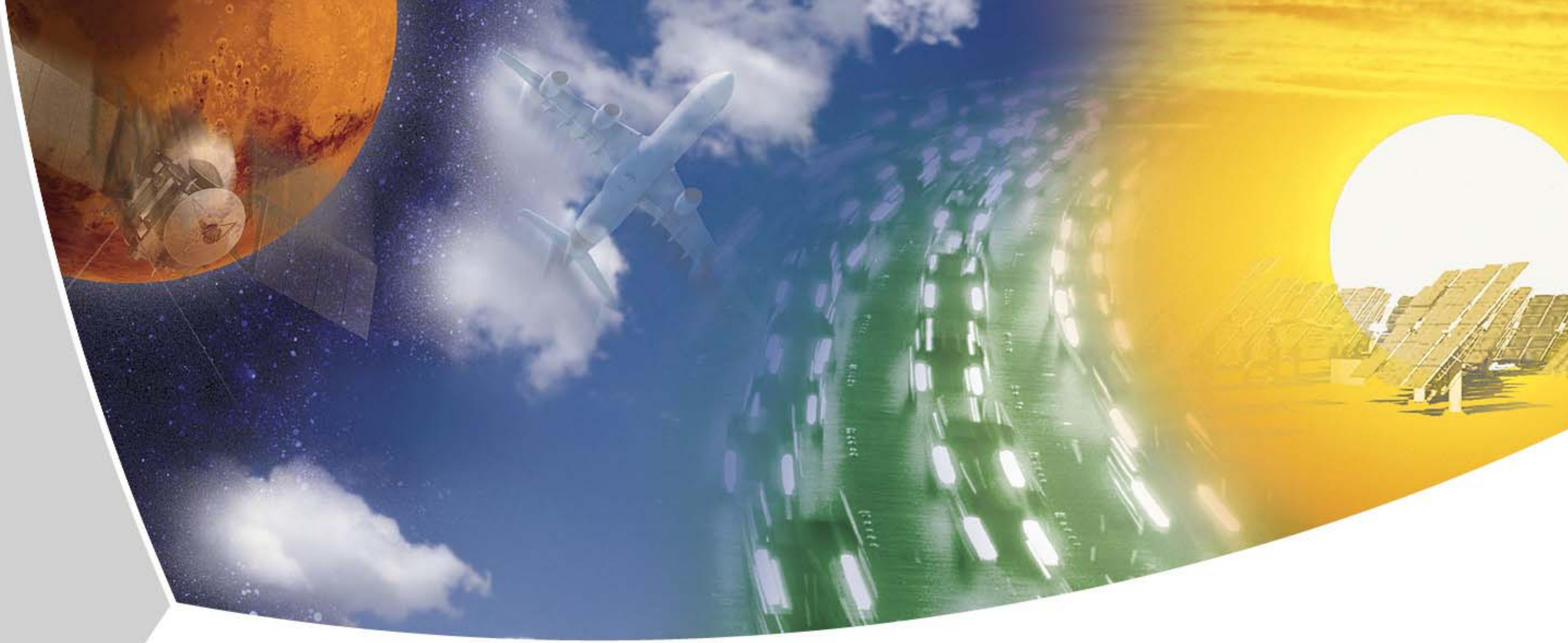


45th Session of the Scientific and Technical Sub-Committee of the UN COPUOS

UN Space Debris Mitigation Measures – German National Implementation Mechanism

Uwe WIRT, DLR e.V., German Space Agency

19 February 2008, Vienna

Deutsches Zentrum für Luft- und Raumfahrt e.V.

Scope

In Resolution 62/217 "International cooperation in the peaceful uses of outer space", the General Assembly in para 26 endorses the Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space and in para 27 agrees that the voluntary guidelines for the mitigation of space debris reflect the existing practices as developed by a number of national and international organizations, and invites Member States to implement those guidelines through relevant national mechanisms.

This presentation outlines relevant process/procedures being under development at the German Space Agency DLR for the implementation of these guidelines.

Contents

From Guidelines to Implementation (1/4)

UN COPUOS STSC
Space Debris Mitigation Guidelines

Fundamental principles

IADC*)
Space Debris Mitigation Guidelines

Technical Guidelines

European Code of Conduct (ECoC) on Space Debris Mitigation

Nat. Guidelines derived from ECoC

Applicable Rules

International Standards, e.g. ISO)**

Support documents, tools

How shall things be done?

By which means can things be done?

*): Inter-Agency Space Debris Coordination Committee
**): International Organisation for Standardization

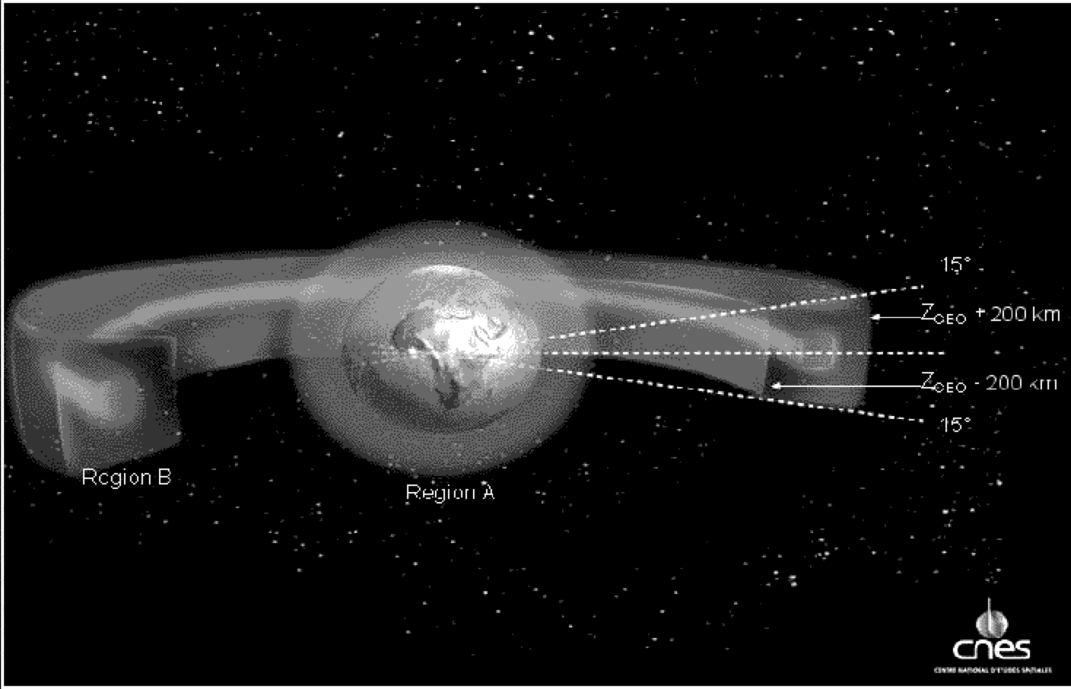
From Guidelines to Implementation (2/4)

European Code of Conduct Requirements, Protected Regions

Section No.	Section	Req. - ID	Keyword
CoC - 3	**MANAGEMENT MEASURES**		
CoC - 3.1	APPLICABILITY	*SD-MM-01*	*Applicability*
CoC - 3.2	SPACE DEBRIS MANAGER	*SD-MM-02*	*Space Debris Manager*
CoC - 3.3	SPACE DEBRIS MITIGATION PLAN	*SD-MM-03*	*Space Debris Mitigation Plan*
		SD-MM-04	*Space Debris Tasks of any Space Project*
		SD-MM-05	*Space Debris Mitigation Plan Description*
		SD-MM-06	*Space Debris Mitigation Compliance*
CoC - 3.4	PROJECT REVIEWS	*SD-MM-07*	*Project Reviews*
		SD-MM-08	*Project Reviews Reporting*
CoC - 4	**DESIGN MEASURES**		
CoC - 4.1	PREVENTION MEASURES		
CoC - 4.1.1	Mission related objects	*SD-DE-01*	*Simple/Multiple Payload(s) Launch*
		SD-DE-02	*Retail Released Parts*
		SD-DE-03	*Suborbital Space Object*
CoC - 4.1.2	Fragmentation	*SD-DE-04*	*Intentional Destruction*
		SD-DE-05	*Accidental Destruction*
CoC - 4.1.3	Solid propellants and py-rotechnics	*SD-DE-06*	*Solid Propellant and Pyrotechnic Use*
CoC - 4.1.4	Materials and technolo-gies	*SD-DE-07*	*Materials and Technologies Selection*
CoC - 4.1.5	Malfunction		
CoC - 4.2	END-OF-LIFE MEASURES		
CoC - 4.2.1	Passivation	*SD-DE-08*	*Passivation*
CoC - 4.2.2	De-orbiting	*SD-DE-09*	*De-Orbiting*
CoC - 4.2.3	Re-orbiting	*SD-DE-10*	*Re-Orbiting*
CoC - 4.3	IMPACT PROTECTION MEASURES		
CoC - 4.4	RE-ENTRY SAFETY MEASURES		
CoC - 4.4.1	Safety policy	*SD-DE-11*	*Safety Policy*
CoC - 4.4.2	Re-entry	*SD-DE-12*	*Safe Re-entry on Ground*
CoC - 5	**OPERATIONAL MEASURES**		
CoC - 5.1	PREVENTION MEASURES	*SD-OP-01*	*Operational Procedures*
CoC - 5.2	END-OF-LIFE MEASURES		
CoC - 5.2.1	Passivation	*SD-OP-02*	*Passivation*
CoC - 5.2.2	Protected regions		
CoC - 5.2.3	Disposal	*SD-OP-03*	*Disposal (general)*
		SD-OP-04	*Disposal of Geostationary Spacecraft*
		SD-OP-05	*Disposal Probability Success*
CoC - 5.3	IMPACT PROTECTION MEASURES		
CoC - 5.4	RE-ENTRY SAFETY MEASURES		
CoC - 5.4.1	Safety policy	*SD-OP-07*	*Nuclear Reactor and Power Sources*
CoC - 5.4.2	Re-entry	*SD-OP-08*	*Re-entry and Traffic Regulations*

List of European Code of Conduct Requirements

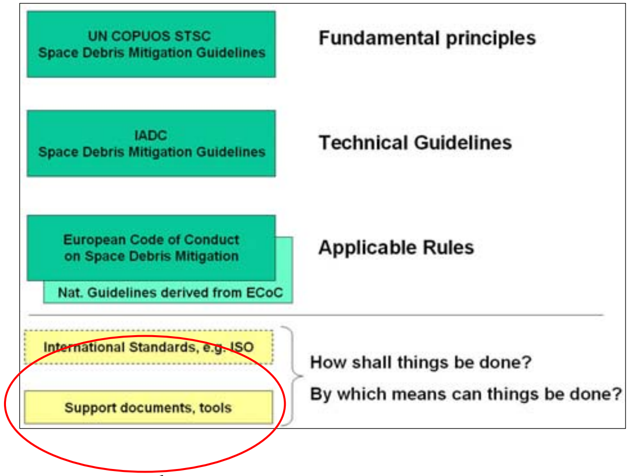
Protected Regions
(Credits: Centre National d´Etudes Spatiale, CNES)



From Guidelines to Implementation (3/4)

UN-Guideline 1: Limit debris released during normal operations	IADC-Guideline 5.1 Limit Debris Released during Normal Operations	European Code of Conduct Guideline/s on Design Measures
Space systems should be designed not to release debris during normal operations. If this is not feasible, the effect of any release of debris on the outer space environment should be minimized.	In all operational orbit regimes, space systems should be designed not to release debris during normal operations. Where this is not feasible any release of debris should be minimised in number, area and orbital lifetime. Any program, project or experiment that will release objects in orbit should not be planned unless an adequate assessment can verify that the effect on the orbital environment, and the hazard to other operating space systems, is acceptably low in the long-term. The potential hazard of tethered systems should be analysed by considering both an intact and severed system.	SD-DE-01
		a) For the launch of a single payload, there should be only one element (for example, stage) of the launch vehicle injected into orbit, excluding the payload.
		b) For the launch of multiple payloads, there should be at most two elements (for example, stage, adaptation structure for multiple payloads) of the launch vehicle injected into orbit, excluding payloads.
		SD-DE-02
		a) For payloads, mission related components (for example, attachments of electrical wiring, devices retaining antennas, apogee boost motor heat shields, solid propellant thruster nozzle blanks, observation instruments protections, explosive bolts, springs, belts) should be designed so that released parts are retained.
		b) Devices, which by design release objects other than payloads into orbit, should be avoided (for example, "yo-yo" device).
		When a) or b) cannot be fulfilled, potential space debris should be identified (number, size, orbit parameters, orbit evolution, orbital lifetime, etc.) and included in the space debris mitigation plan.
		SD-DE-03
		Any suborbital space object (for example, launch vehicle stage, adaptation structure for a launch of multiple payloads) should not generate long-lived space debris.
		SD-DE-06
		Solid propellants likely to generate space debris in the form of particles greater than 10 microns should be avoided.
		The use of pyrotechnics (for example, pyrotechnic cutters) in orbit should not generate any particle of size greater than 10 microns.
		SD-DE-07
		The materials, their application, and the design (structures, tanks, propellant, equipment, surface materials, etc.) should not generate space debris during the orbital phase of any space system.
		Where the generation of space debris due to the materials and basic technologies cannot be avoided, the number, size, and lifetime of debris generated should be minimized.
		The materials and basic technologies selected for space systems should be qualified accordingly (for example, qualification plans should include tests - radiation, shock, etc. - demonstrating minimal space debris production).

From Guidelines to Implementation (4/4)



-		1.7.3 Supporting Documents	
	a	The supporting documents aim to direct those involved in the management, design, operation, and mission control to appropriate sources of information and tools to assist in implementing the requirements for space debris mitigation (para 5.3.2.2).	
		Doc-ID	Title
	b	CoC_v1.0 [040628]	European Code of Conduct for Space Debris Mitigation, Issue 1.0, 28 June 2004
		support to implem of the CoC_v1.0 [040628]	Support to Implementation of the European Code of Conduct for Space Debris Mitigation, Issue 1.0, 28 June 2004
		ESA/IRC(2000)14	European space debris policy
		871914	NASA-STD-8719.14, Process for Limiting Orbital Debris
		IADC Mitigation Guidelines rev 1 September 2007	IADC Space Debris Mitigation Guidelines, Revision 1, September 2007
		IADC.SD.AI20.3.10.2004	Support to the IADC Space Debris Mitigation Guidelines, Issue 1, 5 October 2004
		IADC.PM.v3.3.04.04.2004	Inter-Agency Space Debris Coordination Committee, PROTECTION MANUAL, Version 3.3, Revision April 04, 2004
		AC105_890E-1	Report of the Scientific and Technical Subcommittee on its forty-fourth session, held in Vienna from 12 to 23 February 2007, 6 March 2007, Annex IV Space debris mitigation guidelines of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space

Reference	Document Title
Technical documents	
R031r001_ETA	Review of Space Debris Standards
R031r002_ETA	Requirements considered by the Space Debris End-to-End Servic
R031r003_ETA	End-to-End Service Guide (this document)
R031r004_ETA	Investigation of National Needs & Status of Knowledge (Technica WP 2000)
R031r005_ETA	Identification of possibilities for Radar facilities to support debris pr measures
R031r008_ETA	Synthesis of the DLR Project Space Debris End-to-E
R031r002_EMI_3310	Damage Process and Identification of Protection syst
R031r002_EMI_3320	Experimental and Numerical Protection System Desi
R031r002_RWTH	Analytical Optimization of Protection Systems (Techn WP 3330)
R031r001_OHB	Protective Measures for Satellites against Meteoroids
R031r002_OHB	Spacecraft Design Measures for the Avoidance of Sp
R031r003_OHB	System Requirements
R031r004_OHB	Design Synthesis Report
R031r005_OHB	Operational Measures for the Avoidance of Space De
R031r001_HTG	Review of Re-entry Phenomena and Related Analysi
R031r002_HTG	Criteria for SC-Design and Re-entry with Minimized C
R031r001_ILR	Long Term Analysis
R031r002_ILR	Cost/Benefit Analysis of Debris Mitigation Measures
Exemplary pilot project documentation	
R031r006_ETA	Debris and Meteoroid Risk Analysis for the pilot proje
R031r007_ETA	Debris preventive measures and recommendations f
R031r003_EMI	Shielding Concept for the pilot project
R031r006_OHB	Documentation of exemplary Mission and Satellite Design
R031r007_OHB	System Design and effort assessment
R031r008_OHB	Operational Measures for the pilot project
R031r009_OHB	Inputs to Measures and Recommendations for the pilot project

Table 3 SDETES reference documentation

CODE LEVELS FOR DESTRUCTIVE RE-ENTRY ANALYSIS					
Code Level	Complex-ity	Code	Applicability	Execution effort	Code availability
1	Very simple	DAS	Simple objects	Day	Free download
		OSRP			*Self implemen-tation*
		Nuts & Bolts			
2	Simple	ORSAT	Single objects and complete S/C (decomposed into single objects), ground dispersion with one break-up event, debris casualty area	Day up to weeks	By contract with NASA (?)
		MORSAT			
		J-ORSAT			?
				... up to ...eral ...nths	By contract with HTG

...lysis

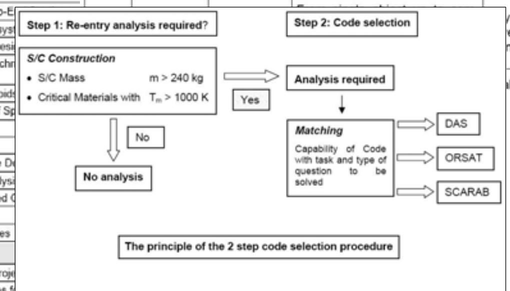
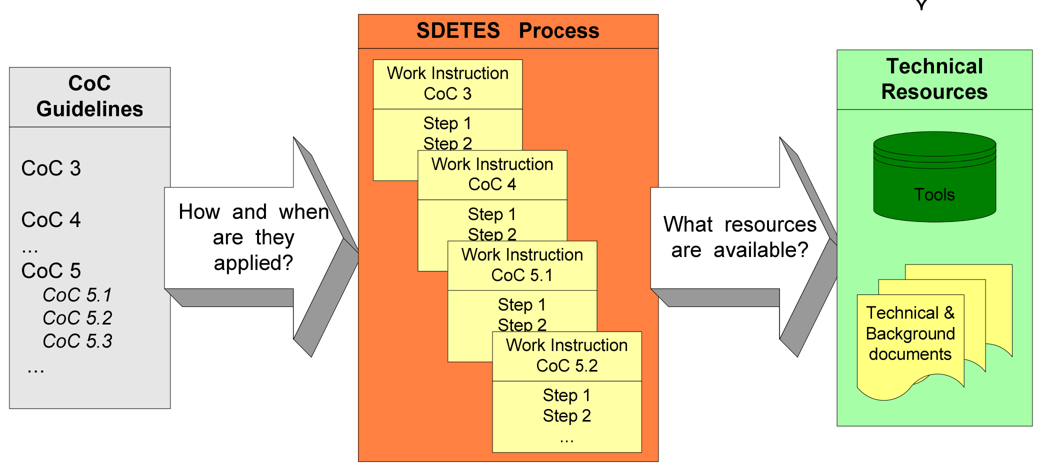


Figure 3-1: Principle of the analysis code selection procedure

Today



SDETES: Space Debris End-to-End Service

Contents

Product Assurance Requirements Tailoring Process (1/5)

European Cooperation for Space Standardization

European Space Components Cooperation

Space Station & Shuttle Safety

Military Standards

European CoC Space Debris

NASA STD 8718.14

Product Assurance Requirements Tailoring Process (2/5)

Deutsches Zentrum für Luft- und Raumfahrt e.V. German Aerospace Center

STATEMENT OF COOPERATION

Product Assurance and Safety Requirements for DLR Space-Projects
Issue 5.0; November 2004

Based on the previously applicable issue of the Product Assurance and Safety Requirements for DLR Space-Projects, the new issue has been prepared by a working group composed of competent representatives from important prime aerospace contractors and DLR Product Assurance experts.
The purpose to revise the previous issue was to achieve a harmonisation with the current valid ECSS standards under consideration of DLR specific space activities, and to get a common approach with industrial policy.
The new issue is the result of keeping to these principles.
In order to determine the extend to which the requirements are made applicable to a specific project in the most cost-effective manner, the content of this document has been designed to enable tailoring by DLR based on identified specific project objectives and constraints.

Bonn, 18 November, 2004

Quality Expert Working Group

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W. Jobi Head of Product Assurance Support Projects DLR	M. Scheuer-Leeser Head of Quality & Product Assurance DLR

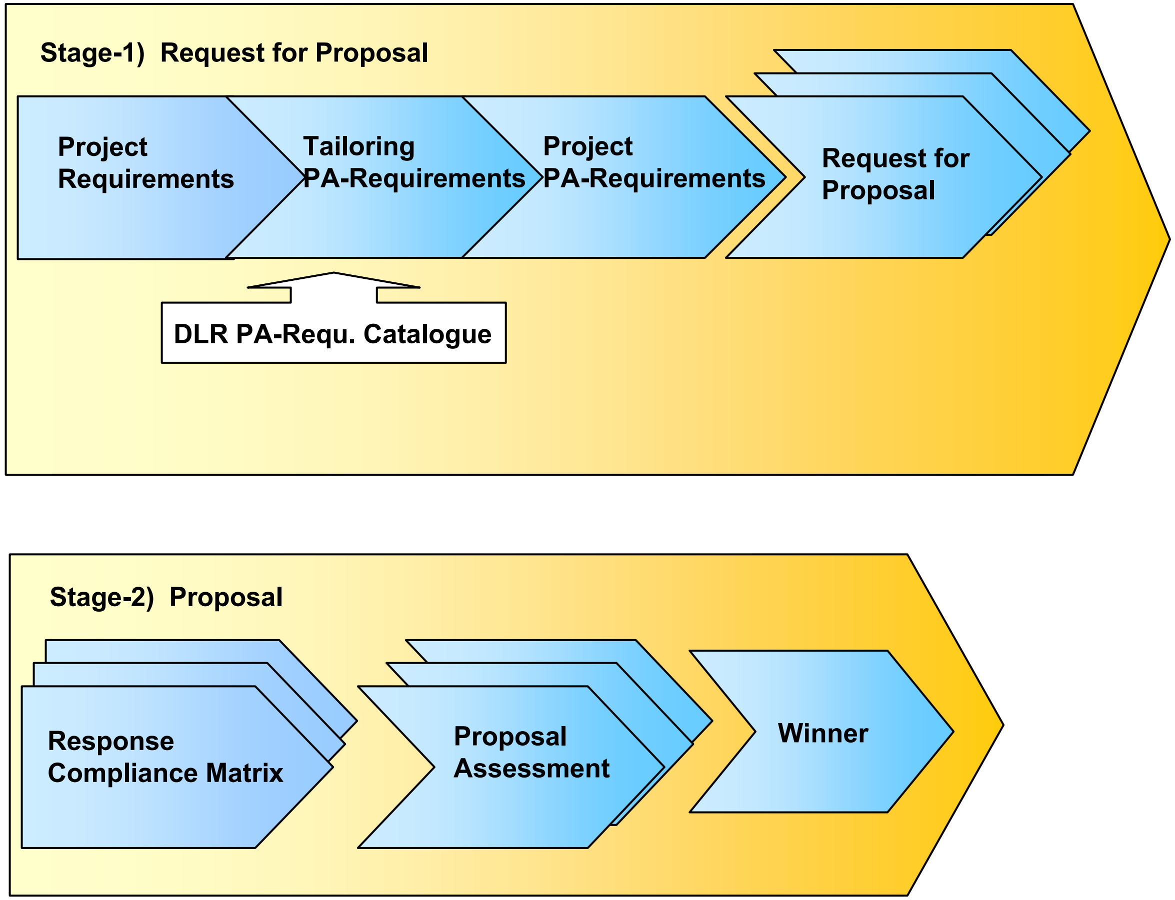
AeroSpace Quality Expert Group 2004

Product Assurance Requirements Tailoring Process (3/5)

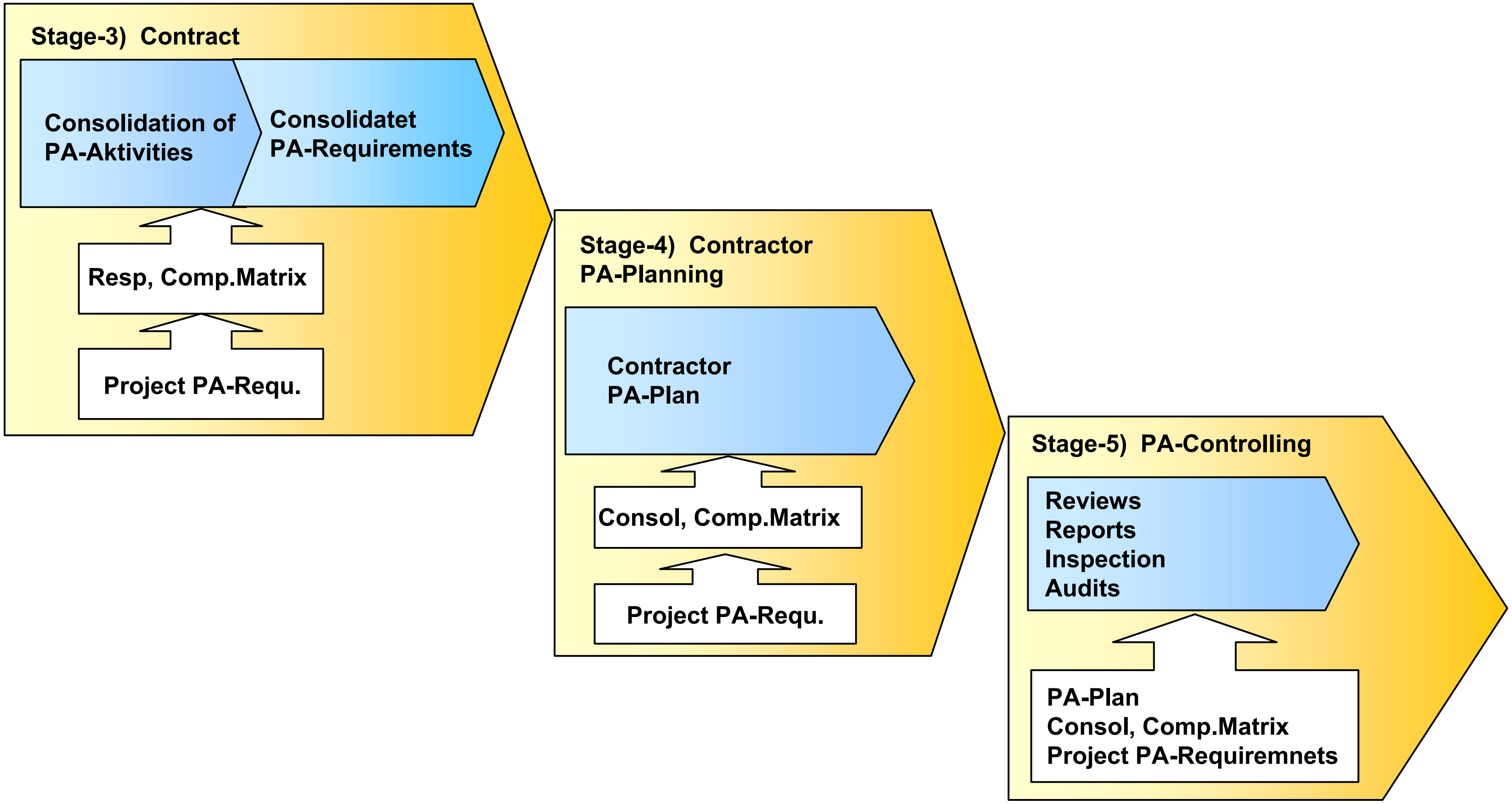
Content of the DLR Standard Product Assurance Requirements Catalogue

Subject	Source
Product Assurance Management	ECSS-Q-00, ECSS-Q-20, ECSS-Q-20-09, ECSS-M-00, ECSS-M-20, ECSS-M-30, ECSS-M-30-01, ECSS-M-40, ECSS-M-50
Quality Assurance & Verfification	ECSS-Q-20, ECSS-Q-20-04, ECSS-M-40, ECSS-E-10, ECSS-E-10-02, ECSS-E-20
Dependability	ECSS-Q-30, ECSS-Q-30-02, ECSS-Q-30-01, ECSS-Q-40-12, ECSS-Q-60-11, ECSS-E-10-05, NSTS/ISS, MIL
Safety	ECSS-Q-40, ECSS-Q-40-02, ECSS-Q-70-29, ECSS-M-20, ECSS-Q-40-12, ECSS-Q-70-36, ECSS-E-30-01, CoC-SD, STD-8719, NSTS/ISS
EEE-Parts Procurement	ECSS-Q-60, ECSS-Q-60-01, ECSS-Q-60-05, ESCC, NSTS/ISS, MIL
Mechanical Parts, Materials & Processes	ECSS-Q-70, ECSS-Q-70-04, ECSS-Q-70-10, ECSS-Q-70-21, ECSS-Q-70-28, ECSS-Q-70-36, ECSS-Q-70-01, ECSS-Q-70-06, ECSS-Q-70-11, ECSS-Q-70-22, ECSS-Q-70-29, ECSS-Q-70-37, ECSS-Q-70-02, ECSS-Q-70-07, ECSS-Q-70-18, ECSS-Q-70-26, ECSS-Q-70-30, ECSS-E-30-01, ECSS-Q-70-71, ECSS-Q-70-08, NSTS/ISS
Software Product Assurance	ECSS-Q-00, ECSS-Q-80, ECSS-E-40
Mission Operation	ECSS-Q-20, ECSS-E-70

Product Assurance Requirements Tailoring Process (4/5)



Product Assurance Requirements Tailoring Process (5/5)

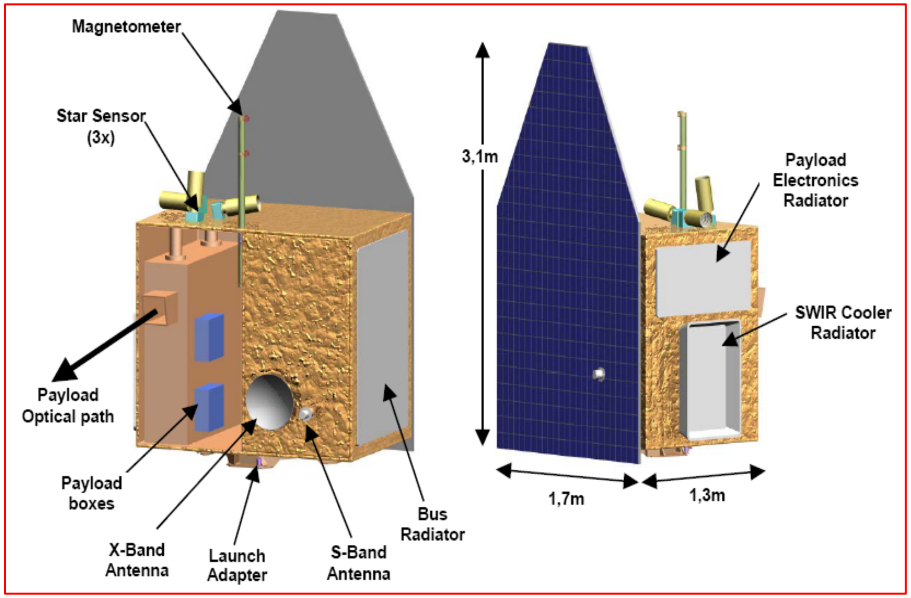


Contents

Space Debris Mitigation Measures – Examples upon Subjects of Analysis and Implementation (1/7)

- EnMAP (Environmental Mapping and Analysis Program)

Bus	Modified OHB Bus
Instrument	New Design
S/C Weight	740 kg
S/C Dimension	1,3m x 1,7m x 3,1m
Orbit altitude	643 km
Orbital period	ca. 98 min
Orbit inclination	97.96°, SSO
Mission lifetime	5 years

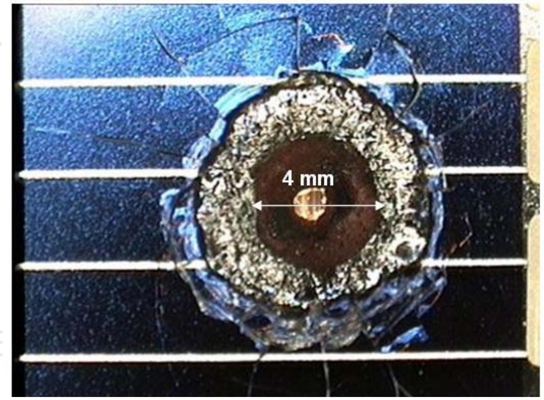


Space Debris Mitigation Measures – Examples upon Subjects of Analysis and Implementation (2/7)

Under Investigation: Impact/Penetration Risk Analysis

Time span (in year) between collisions with a space debris/meteoroids

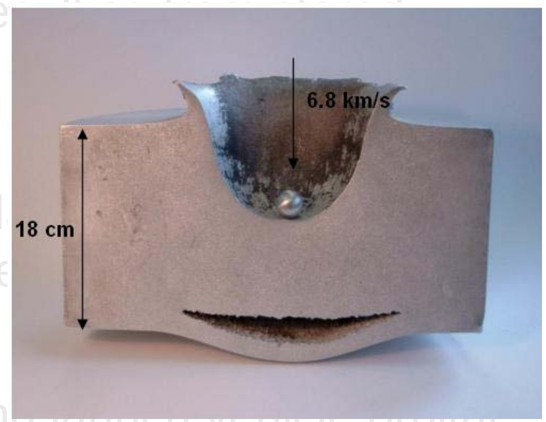
Particle class	Particle size			
	1 mm – 1 cm	**1 cm – 10 cm**	**10 cm – 1 m**	**1 m – 10 m**
Space Debris	14.85	737	17,230	55,503
Natural meteoroids	8.05	2,632	N/A	N/A



Impact on HST solar array
(Credits: European Space Agency, ESA)

Probability (%) of collisions with a space debris/meteoroids over 5 years

Particle class	Particle size	
	1 mm – 1 cm	**1 cm – 10 m**
Space Debris	29%	0.7%
Natural meteoroids	46%	0.2%
Requirement	**1%**	**0.1%**



Impact effect on aluminium plate
(Credits: European Space Agency, ESA)

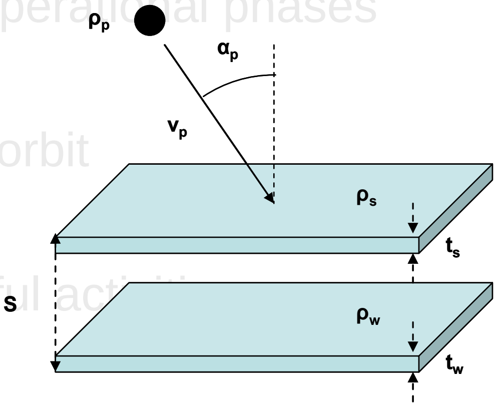
5,268 impacts per year for debris in the range of [1 µm, 1 mm], contribute mainly to surface degradation

Space Debris Mitigation Measures – Examples upon Subjects of Analysis and Implementation (3/7)

Under Investigation: Impact/Penetration Risk Analysis

Penetration to # impact ratio of the spacecraft external walls

	Particle size		
	< 1 mm	[1mm, 1cm]	> 1 cm
Penetration / Impact	0	~1	1



Modelisation of the Honeycomb structure

Penetration probability (%) with respect to incoming particles flux

Penetration Probability	Particle size			
	[1mm, 1 cm]	[1cm, 10cm]	[1mm, 1 cm]	[1cm, 10cm]
	External Walls		External Walls + Housing	
Space debris	41.2%	0.09%	1.29%	0.07%
Natural Meteoroids	15.7%	0.00%	0.17%	0.00%
Requirement	**1%**	**0.10%**	**1%**	**0.10%**

Note: Equipment housing between 2 to 4 mm (aluminium)

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

Space Debris Mitigation Measures – Examples upon Subjects of Analysis and Implementation (4/7)

Under Investigation: Re-entry Safety

Study frame

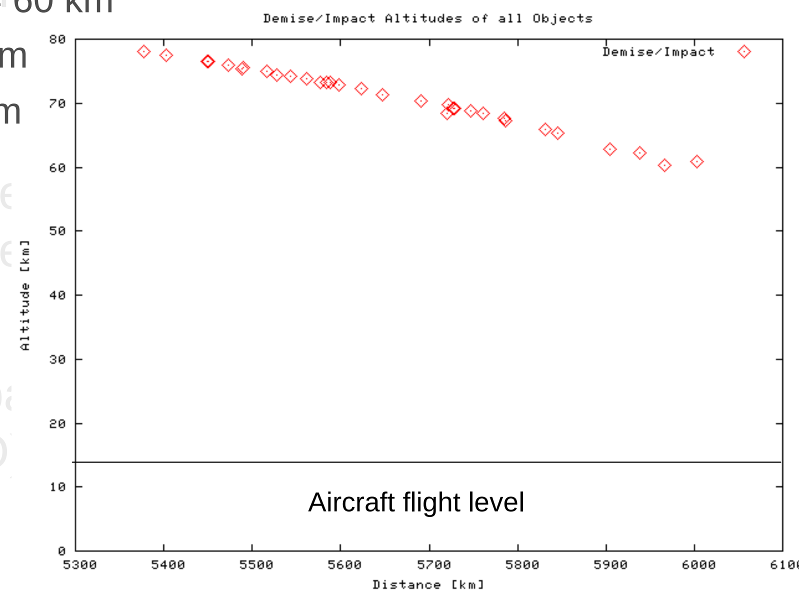
- Altitude at re-entry — 120 km altitude
- Re-entry date — 1st January 2031 – Maximum 25 years de-orbiting
- Re-entry type — Natural orbit decay – Uncontrolled
- Scenario — Break-up altitude 78 km – “Shadowing” effect neglected
- Software — DRAMA*) for Re-entry analysis – Survivability and Risk analysis

Survivability

- No component reaches the surface — Δh = 60 km
- Minimum altitude reaches by a S/C component — 60 km
- Last component to demise in the atmosphere — Prism

Casualty risk on ground

- No component reaches the surface



*): Debris Risk Assessment and Mitigation Analysis, European Space Agency, ESA

Guideline 1: Limit debris released during normal operations

Guideline 2: Minimize the potential for break-ups during operational phases

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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 space stages in the low-Earth orbit (LEO) region after the

Guideline 7: Limit the long-term interference of spa stages with the geosynchronous Earth orbit (GEO mission

Space Debris Mitigation Measures – Examples upon Subjects of Analysis and Implementation (5/7)

Under Investigation: Re-entry Safety, Contamination Aspects

Guideline 1: Limit debris released during normal operations

Guideline 2: Minimize the potential for break-ups during operational phases

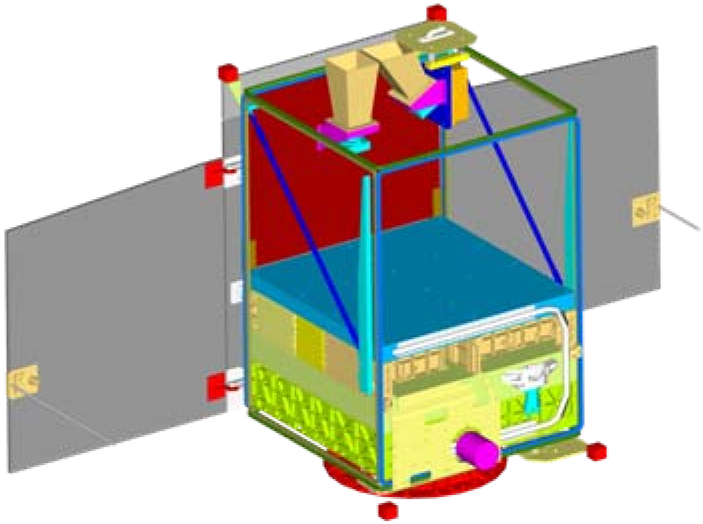
Substance	Hydrazine (N_2H_4)	
Risk	Highly toxic	
Measure	ACS Hydrazine propellant burnout [1.5 kg residual] - $N_2H_4 \xrightarrow{O_3 + OH} N_2 + NH_3$	
	→ - Disposal Maneuver	Lower perigee altitude - Orbital lifetime < 25 years
	- Passivation	Release of onboard stored energy
	- Re-entry	Prevention of potential contamination

Substance	Lithium ion battery (Li-ion)	
Risk	Explosion	
Measure	End of life passivation - Demise at minimum 60 km altitude	
	→ - Passivation	Release of onboard stored energy
		Disconnection of power lines

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

Space Debris Mitigation Measures – Examples upon Subjects of Analysis and Implementation (6/7)

- TET-1 (Technology Test Carrier)



satellite mass	110 kg
satellite envelope	550 x 650 x 880 mm
communications /S –band	uplink: 4 kbits/s downlink: 2200 kbits/s
Orbit	LEO
average height	450 – 850 km
inclination	53° - sun-synchronous
stabilisation	3-axis stabilisation

System

payload segment	460 x 460 x 400 mm
payload mass capacity	40 kg
power consumption	0 – 20 W
peak power consumption	160 W / 20 min (5 times per day)
nominal oper. voltage	20 , DC V
max. current	8 A

Payload segment

Space Debris Mitigation Measures – Examples upon Subjects of Analysis and Implementation (7/7)

- End-of-life Measures / Disposal (European CoC-Requirement SD-OP-03): the current baseline for TET operational orbit is 820km. In order to to limit the permanent or periodic presence of TET in the protected regions to a maximum of 25 years, TET should be de-orbited to a 550 km orbit. Measures under investigation comprise following options:
    - Rising of drag coefficient by enlarging cross section
    - Application of a tether, both conductive (electro-magnetic drag) and non-conductive (momentum exchange) under consideration
    - Application of a propulsion system
    - Application of a mechanical interface for cooperative docking witin the frame of a recovery mission.

- Prevention Measures / Mission Related Objects (European CoC-Requirement SD-DE-02): on both satellite bus and payload level verification is ongoing to ensure that no mission related components (e.g. attachments of electrical wiring, devices retaining antennas, apogee boost motor heat shields, solid propellant thruster nozzle blanks, observation instruments protections, explosive bolts, springs, belts) will be released.

- Prevention Measures / Fragmentation (European CoC-Requirement SD-DE-05): the accidental destruction probability due to an internal origin of any stored energy element (AOCS, propulsion, pressurised parts, energy storage elements - batteries, fuel cells, etc.) which should be lower than or equal to 10^{-4} for the operational phase is under investigation within the frame of the System-FMECA.

- Prevention Measures / Materials and technologies (European CoC-Requirement SD-DE-07): analysis of materials, their application, and the design (structures, tanks, propellant, equipment, surface materials, etc.) not to generate space debris during the orbital phase is ongoing.

- End-of-life Measures / Passivation (European CoC-Requirement SD-DE-08): processes/ technical solutions to eliminate all stored energy to reduce the chance of break-up (e.g. venting or burning excess propellant, discharging batteries, relieving pressure vessels) are under investigation.

Conclusions

- The General Assembly endorsed the Space Debris Mitigation Guidelines of the COPUOS and invited Member States to implement those guidelines through relevant national mechanisms
- This presentation outlined the process for the implementation of these guidelines being under development at the German Space Agency DLR

- The conversion of Guidelines to implementation mechanism/s is not a trivial task
- Substantial resources on different levels upon supporting documents and tools for assistance in the implementation of technical measures for space debris mitigation exist

- Implementation of Guidelines at DLR is carried out by a dedicated sub-process within the frame of the Product Assurance Requirements Tailoring Process.

Acknowledgements

- Mr. Christian CHLEBEK
  Head of Project „EnMAP“

- Mr. Wolfgang JOBI
  Head of Quality and Product Assurance

- Mr. Michael TURK
  Head On-Orbit Verification Programme (OOV)

- Dr. Philip WILLEMSEN
  Deputy Head On-Orbit Verification Programme (OOV)