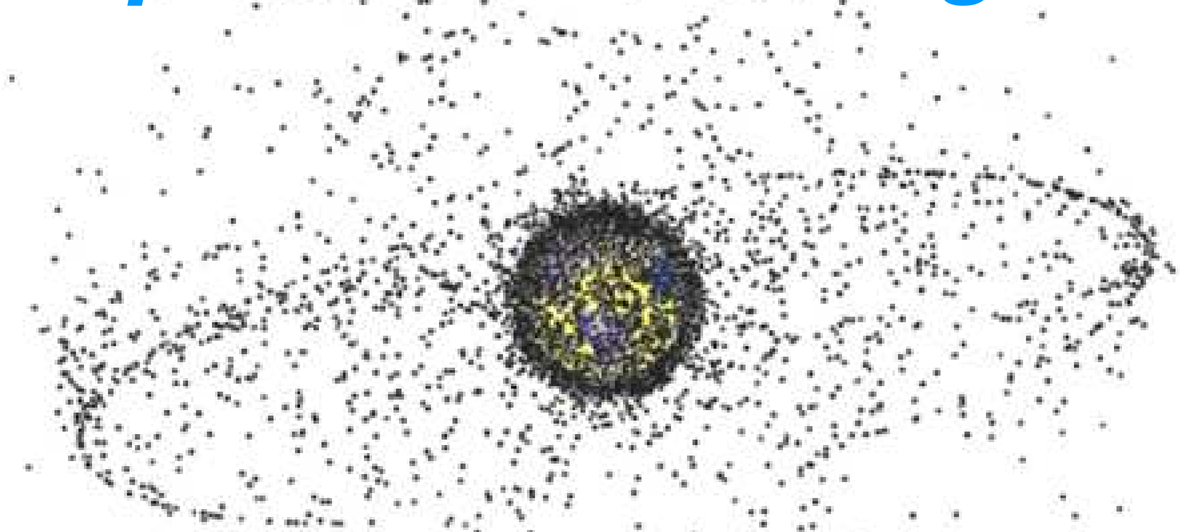
ECSS-U-AS-10C
Space Debris Mitigation



Standardization training program
ESA ESTEC , June 27, 2016
- PART 2 -

Space Debris Mitigation

Space Debris Mitigation
Guidelines and Standards

SDM: Standards and Guidelines I

In the last 20 years, Space Debris Mitigation Standards, Guidelines or Handbooks have been issued by several national, regional and international organizations.

Since the mid-1990s, space agencies in Europe have developed guidelines.

In 1993, the Inter-Agency Debris Coordination Committee (IADC) was formed (now composed of 11 national Space Agencies).

In 2002, IADC published the “Space Debris Mitigation Guidelines" and presented to the UN-COPUOS STSC, which served as a baseline for the "UN Space Debris Mitigation Guidelines".

IADC

SDM: Standards and Guidelines II

EUROPEAN COOPERATION ECSS FOR SPACE STANDARDIZATION

In 2006, the "European Code of Conduct" was signed by ESA, ASI, BNSC, CNES and DLR.

In 2007, UN-COPUOS STSC "UN Space Debris Mitigation Guidelines“ approved by the 63 STSC member nations as voluntary high-level space debris mitigation measures

In 2007, NASA policy was established to control the generation of orbital debris: NASA Procedural Requirements 8715.6A, NASA Technical Standard 8719.14 (2007). All NASA projects are required to provide debris assessments and End of Mission (EoM) planning.

In 2008, ESA “Space Debris Mitigation for Agency Projects” was published. The requirements were <u>made applicable</u> to all space vehicles, including launchers, satellites and inhabited objects. The document was updated in 2014 (ESA/ADMIN/IPOL(2014)2).

SDM: Standards and Guidelines III

In June 2008, Space Debris Mitigation requirements are also part of the French Loi relative aux Opérations Spatiales (LOS, N°2008-518).

ISO International debris standards were developed from 2003 by TC20/SC14 committee "Space systems and operations", with the participation of 12 nations.

The ISO key document is "ISO 24113 - Space Debris Mitigation". This standard (published July 2010, 1st ed., May 2011, 2nd ed.) is based on the IADC and UN guidelines, and aims at translating the existing recommendations into quantitative implementation requirements.

The European Cooperation for Space Standardisation (ECSS) supports ISO TC20/SC14 development through ECSS SDWG.

ECSS-U-AS-10C Adoption Notice of ISO 24113: Space systems - Space debris mitigation requirements published February 10, 2012

National standards are used by several agencies (ROSCOSMOS, JAXA,…)

Space Debris Mitigation

**European Cooperation for
Space Standardisation (ECSS)
&
ISO TC20/SC14 Space Debris Mitigation
Standards**

ECSS Membership

Observers

Voting members

European Space Agency

esa

European Industry,

represented by

EUROSPACE
The Association of European Space Industry

Some organization have an observer role on ECSS, e.g.

→ CEN,

→ EUMETSAT,

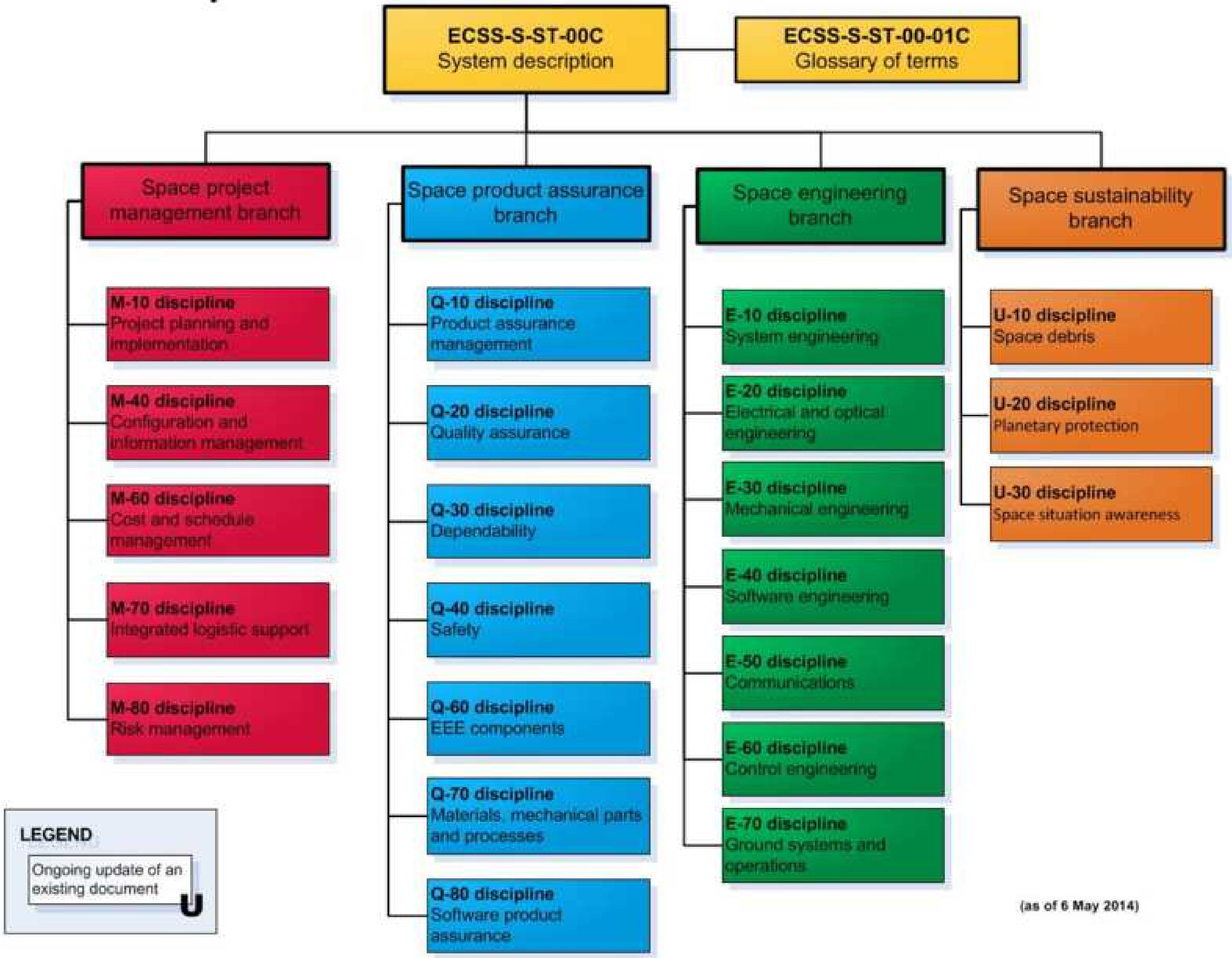
→ EDA

National Space Agencies

agenzia spaziale italiana	Italy
cnes CENTRE NATIONAL D'ETUDES SPATIALES	France
DLR	Germany
Netherlands Space Office	The Netherlands
Norsk Romsenter NORWEGIAN SPACE CENTRE	Norway
UK SPACE AGENCY	United Kingdom
CSA ASC	Canada

ECSS Branch Structure

ECSS Disciplines



ISO (International Organization for Standardization)

ISO is a network of the national standards institutes of 163 countries, on the basis of one member per country, with a Central Secretariat in Geneva, Switzerland, that coordinates the system.

- Established in 1947 to promote standards in international trade, communications, and manufacturing
- Over 200 Technical Committees, each administered by a designated Secretariat

ISO/TC20 Aircraft and Space Vehicles

Secretariat: USA (ANSI), Secretary: Christopher Carnahan

Chair: James Rusty Rentsch (USA), Creation date: 1947

Scope: Standardization of materials, components and equipment for construction and operation of aircraft and space vehicles as well as equipment used in the servicing and maintenance of these vehicles.

Structure:

- ISO TC 20/SC 1 Aerospace electrical requirements
- ISO TC 20/SC 4 Aerospace fastener systems
- ISO TC 20/SC 6 Standard atmosphere
- ISO TC 20/SC 8 Aerospace terminology
- ISO TC 20/SC 9 Air cargo and ground equipment
- ISO TC 20/SC 10 Aerospace fluid systems and components
- ISO TC 20/SC 13 Space data and information transfer systems
- **ISO TC 20/SC 14 Space systems and operations**
- ISO TC 20/SC 15 Airframe bearings

SC 14 Membership (12)

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Secretariat: ANSI (US)/AIAA

- Chair: Paul Gill (US)
- Secretary: Nick Tongson (US)

Participating Members

- Brazil
- China
- Finland
- France
- Germany
- India
- Italy
- Japan
- Russia
- Ukraine
- United Kingdom
- United States

ISO TC20/SC14 - ECSS A-liaison Organization that make an effective contribution to the work of the technical committee or subcommittee for questions dealt with by this TC or SC.

ISO / ECSS Approach to Space Debris Mitigation

The development of space debris mitigation standards within ISO TC20/SC14 started in 2003:

- in response to industry calls for an internationally-agreed set of space engineering implementation standards
- to transform UN and IADC debris mitigation guidelines into a set of measurable and verifiable requirements

ISO set up the 'ad hoc" Orbital Debris Coordination Working Group (ODCWG) to lead this activity, which in 2012 became a full working group (WG7)

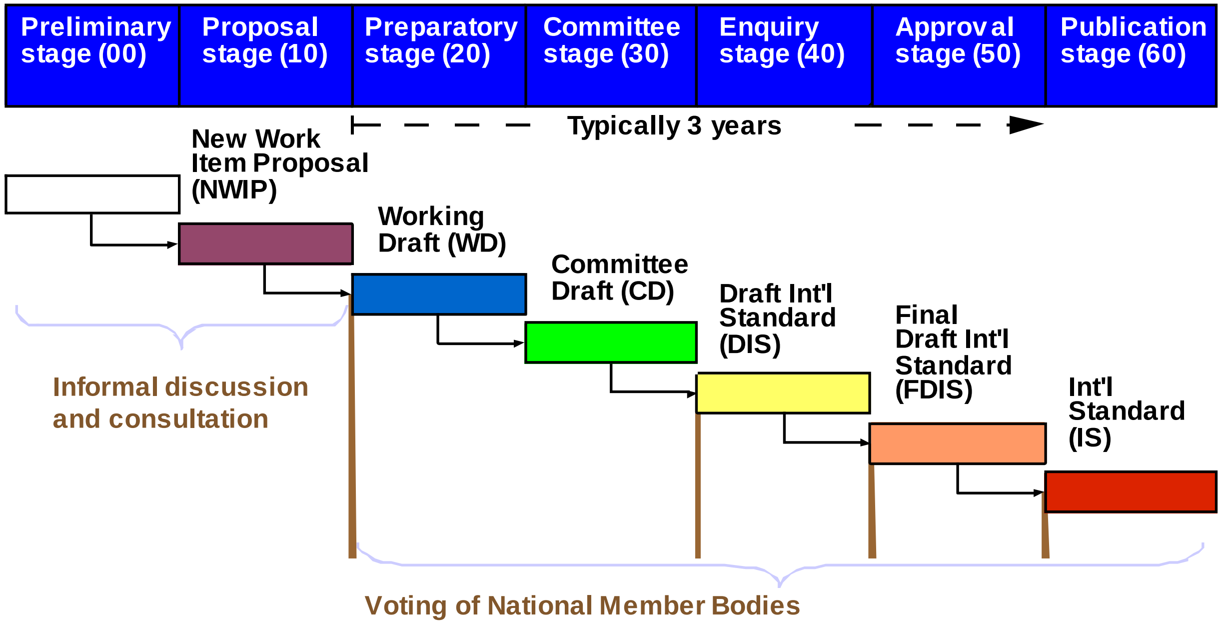
The ODCWG comprises technical experts from all nation members of TC20/SC14: Brazil, Canada, China, France, Germany, Israel, Italy, Japan, Russia, Ukraine, UK, and USA

The WG7 task is to:

- Oversee and coordinate the development of debris mitigation standards within the ISO TC20/SC14 Working Groups
- Develop and maintain multidisciplinary standards dedicated to space debris mitigation

ISO TC20 SC14

- Level playing field: development of key standards in the international arena
- Long development process (typically 3 years or more)
- Unstructured set of standards, many items related to space debris issue, content variable both in terms of quality and usefulness:
- WG7 (ODWG) attempt to develop and coordinate a framework of SDM standards, consolidating the debris standards into a smaller more coherent set of documents



ISO documents – ECSS Classification HP/LP

ECSS High Priority (HP) SDM items (6):

- **ISO 24113 - Space Debris Mitigation (ECSS adoption)**

- ISO 16164 - Disposal of satellites operating in or crossing LEO
- ISO 16127 - Break up prevention of un-manned S/C
- ISO 16699 - Disposal of Orbital Launch Stages

- ISO 26872 - Disposal of satellites operating at geosynchronous altitude (for the time being used as reference information when needed, w/o ECSS adoption process)
- ISO 27852 - Estimation of orbit lifetime (for the time being used as reference information when needed, w/o ECSS adoption process)

ISO documents – ECSS LP Classification

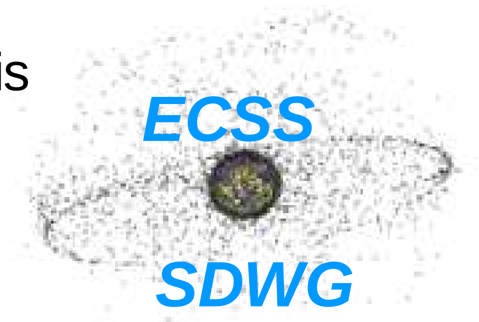
ECSS Low Priority (LP)" SDM items (8):

- ISO 27875 - Re-entry risk management for unmanned S/C and launch vehicle orbital stages
- ISO 23339 - Unmanned S/C - Estimating the mass of remaining usable propellant
- ISO 11227 - Test procedures to evaluate S/C material ejecta upon hypervelocity impact
- ISO 14200 - Guide to process-based implementation of meteoroid and debris environmental models
- ISO 16126 - Assessment of survivability of unmanned S/C against space debris and meteoroid impacts to ensure successful postmission disposal
- ISO 16158 - Avoiding collisions with orbiting objects (TR)
- ISO 11233 - Orbit determination and estimation - Process for describing techniques (TS)
- ISO 14222 - Earth Atmosphere density above 120 km

ECSS Approach to Space Debris Mitigation

ECSS decided in 2003 to set up a ECSS Space Debris Working Group (SDWG) to:

- Contribute to the development of worldwide space debris implementation standards in the framework of the ISO TC20/SC14 ODCWG



ECSS relies on ISO to produce norms related to SD:

- SDWG members participate to ISO WGs / ODCWG meetings and activities
- Inputs and comments to ISO SDM documents provided through SDWG

Key standards adopted by ECSS:

- ECSS-U-AS-10C Adoption Notice of ISO 24113: Space debris mitigation requirements, February 10, 2012
- Decision on a case-by-case basis
- Modifications, delta requirements, interpretations, as necessary

ISO / ECSS - Space Debris Mitigation

ISO 24113 defines the primary space debris mitigation requirements applicable to all […] space systems […] near-Earth space, including launch vehicle orbital stages, operating spacecraft, and any objects released […]

The requirements aim [..at…] ensuring that spacecraft and launch vehicle orbital stages are designed, operated, and disposed of in a manner that prevents them from generating debris throughout their orbital lifetime

Second Edition published May, 2011

ECSS-U-AS-10C Adoption Notice of ISO 24113: Space systems - Space debris mitigation requirements

- Published February 10, 2012


Space engineering

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

Space Debris Mitigation

ESA Requirements on Space Debris Mitigation

space for europe

European Space Agency

ESA Policy on Space Debris Mitigation

Since 2008 , ESA has adopted a Space Debris Mitigation Policy based on the "European Code of Conduct for Space Debris Mitigation"

A new ESA Space Debris Mitigation Policy has entered into force on 28 March 2014: ESA/ADMIN/IPOL (2014)2 " Space Debris Mitigation Policy for Agency Projects "

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.

As the standard foresees that in cases of re-entry the maximum acceptable casualty risk shall be determined by the approving agents, it is the Agency's policy to define that the maximum acceptable casualty risk for ESA space systems shall be as follows:

a) For ESA Space Systems for which the System Requirements Review has already been kicked off at the time of entry into force of this Instruction, casualty risk minimisation shall be implemented on a best effort basis and documented in the Space Debris Mitigation Report.

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 casualty risk for an uncontrolled re-entry exceeds this value, an uncontrolled re-entry is not allowed and a targeted controlled re-entry shall be performed in order not to exceed a risk level of 1 in 10,000.

2014-0520

ESA/ADMIN/IPOL(2014)2 and ECSS / ISO

ESA/ADMIN/IPOL(2014)2	ECSS-U-AS-10C	ISO 24113
Space Debris Mitigation Policy for Agency Projects	Adoption Notice of ISO 24113: Space Debris Mitigation Requirements	Space Debris Mitigation Requirements
28/03/2014	10/02/2012	15/05/2011

Space Debris Mitigation Policy for Agency Projects

1. INTRODUCTION

2. POLICY

EUROPEAN COOPERATION

ECSS

FOR SPACE STANDARDIZATION

Space sustainability

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

INTERNATIONAL STANDARD

ISO 24113

Space systems — Space debris mitigation requirements

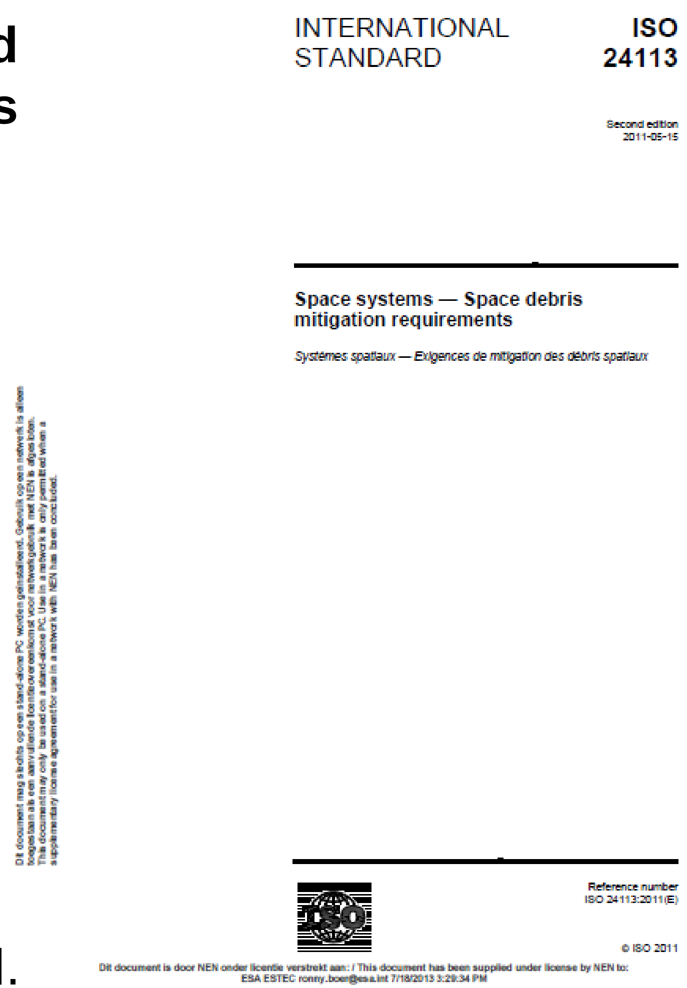
ESA/ADMIN/IPOL(2014)2 and ECSS / ISO

The ESA/ADMIN/IPOL(2014)2 established the ECSS-U-AS-10C (Adoption Notice of ISO 24113: Space Systems – Space debris mitigation requirements) as "the ESA standard for the technical requirements on space debris mitigation for Agency projects"

De facto, the ESA/ADMIN/IPOL(2014)2 includes the requirements addressed in ISO 24113 "Space Systems - Space Debris Mitigation Requirements" together with the modifications described in ECSS-U-AS-10-C.

In addition, ESA/ADMIN/IPOL(2014)2 contains several ESA specific provisions, e.g.,:

- the casualty risk for any re-entry shall not exceed 1 in 10,000 for any re-entry event. In case the predicted casualty risk for uncontrolled re-entry exceeds this value, a targeted controlled re-entry shall be performed.


INTERNATIONAL STANDARD

ISO 24113

Second edition 2011-05-15

Space systems — Space debris mitigation requirements

Systèmes spatiaux — Exigences de mitigation des débris spatiaux

Reference number ISO 24113:2011(E)

Space Debris Mitigation

Technical Regulation in the Frame of the French Space Law (FSL - LOS)

French Space Law (FSL - LOS)

LOIS

LOI n° 2008-518 du 3 juin 2008 relative aux opérations spatiales (1)

NOR : *ESRX0700048L*

L'Assemblée nationale et le Sénat ont adopté,

Le Président de la République promulgue la loi dont la teneur suit :

TITRE I[er]

DÉFINITIONS

French Space Law (FSL - LOS)

The French Space Law (FSL - LOS) entered into force on December 10th, 2010. The associated Technical Regulation ministerial order published on March 31st, 2011

It is based on a principle of prior authorisation for:

- Operators, irrespective of nationality, intending to launch or bring back to Earth a space object on French territory.
- French operators intending to launch or bring back to Earth a space object
- Persons of French nationality intending to launch a space object
- French operators intending to control such an object in space

French Space Law : Other Safety Objectives

Protection of public health and the environment

Mitigating risk of dangerous contamination during launch or re-entry

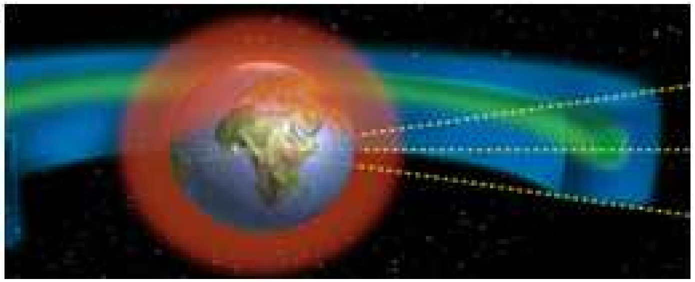
Mitigating space debris:

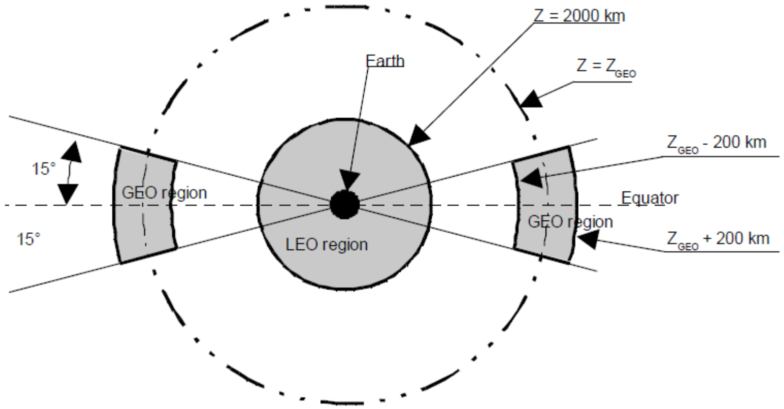
- Do not generate debris during nominal operations
- Minimise the probability of accidental break down
- Remove space vehicles and orbital stages from protected regions after the end of the mission
- Prevent collisions with GEO satellites whose orbital parameters are known.

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space Debris Mitigation

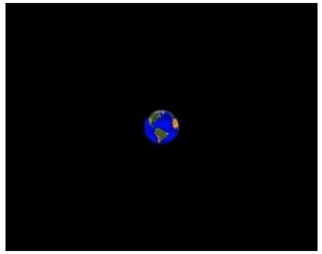
Space Debris Mitigation Requirements Discussion





Space Debris Mitigation – Main Measures

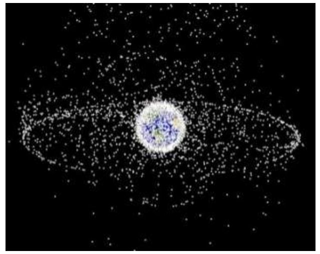
For Spacecraft and Launch Vehicle orbital stages:



Pre 1957

Avoid the intentional release of space debris (Mission Related Objects MRO) into Earth orbit during normal operations

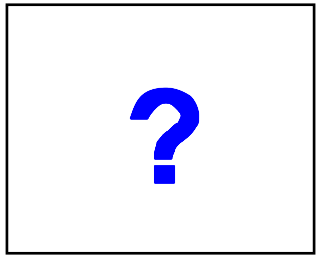
Avoid break-ups in Earth orbit (including passivation at the End of Mission)



2008

Remove spacecraft and launch vehicle orbital stages from the protected regions:

- GEO to a graveyard orbit (GEO + 200 km)
- LEO within 25 years after End of Mission (re-entry controlled or uncontrolled, higher orbit)



2016+

[Perform the necessary actions to minimize the risk of collision with other space objects]

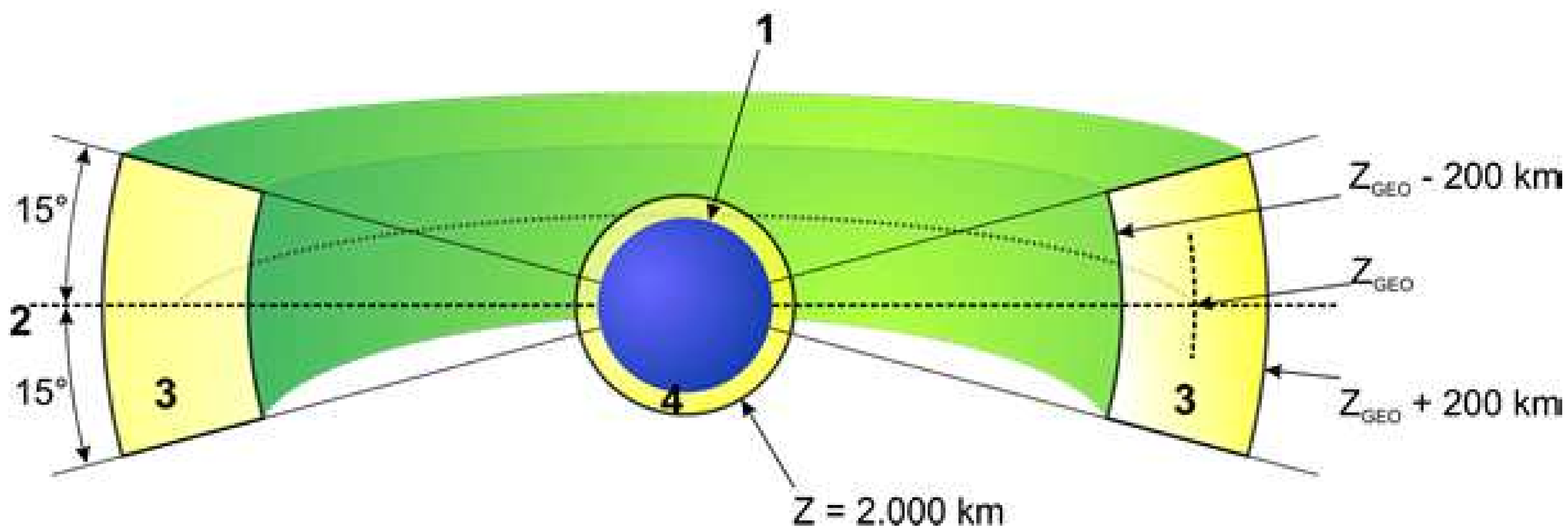
[Evaluate and control of Re-entry Risk]

Rqmt's: protected regions - ch.5

LEO protected region: a shell that extends from the surface of a spherical Earth with an equatorial radius of 6 378 km up to an altitude, Z, of 2 000 km.

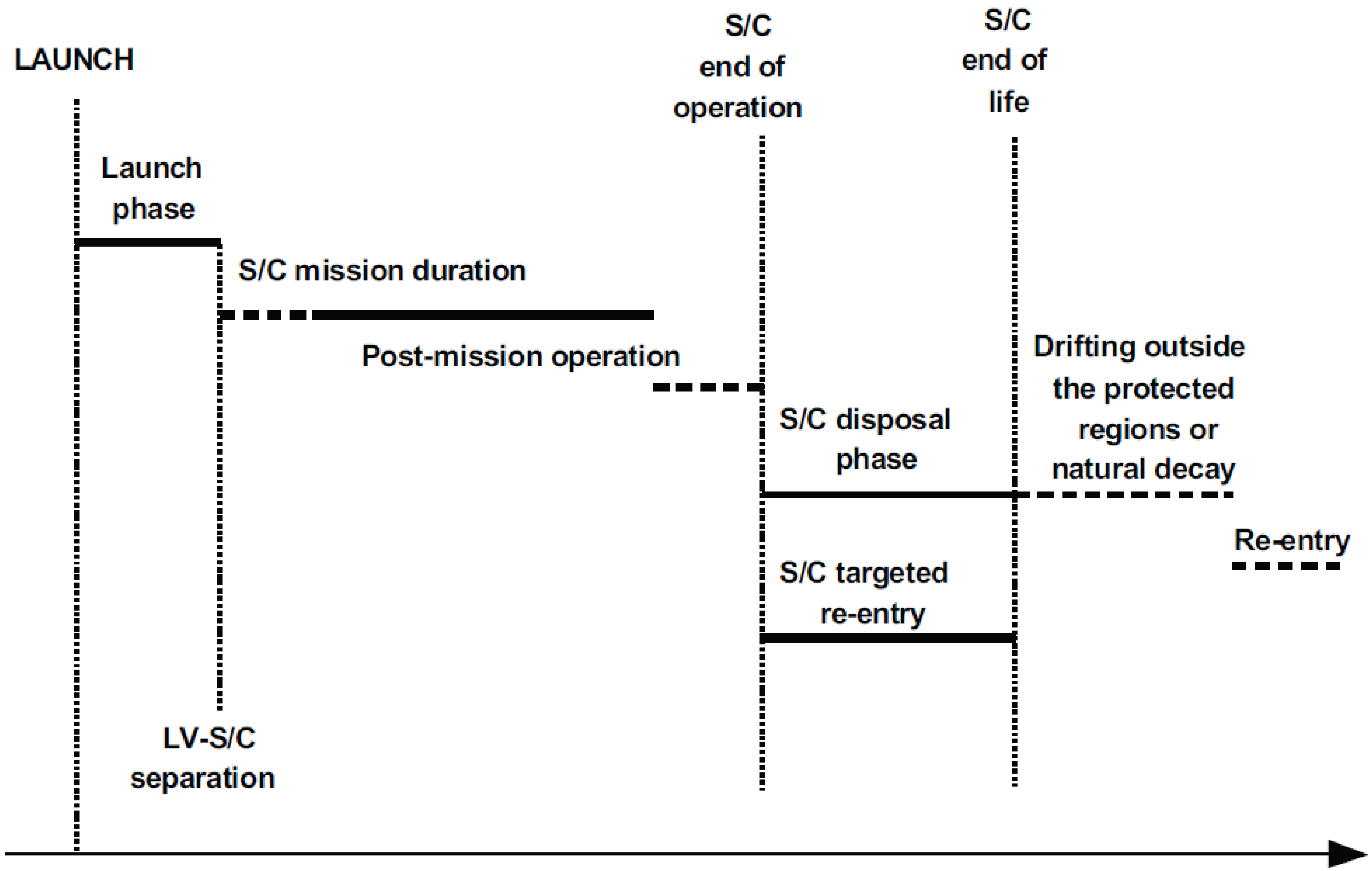
GEO protected region: a segment of a spherical shell with :

- lower altitude: geostationary altitude minus 200 km;
- upper altitude: geostationary altitude plus 200 km;
- latitude sector: 15° South ≤ latitude ≤ 15° North,
- ZGEO ~ is approximately 35 786 km



Post-launch life cycle phase

Post-launch life cycle phases of an Earth-orbiting spacecraft (S/C)



Rqmt's : Avoid MRO into Earth orbit - ch.6.1

Release of space debris during normal operations into Earth orbit to be avoided

Non-combustion debris: no objects are released as part of the nominal mission (review of design)

- Debris released during launch operations shall not exceed:
  - a. One, for the launch of a single spacecraft
  - b. Two, for the launch of multiple spacecraft

  (ECSS-U-AS-10C (and FSOA) only. *This is to limits the possibility during launch operations to release adapters or dispensers in case of single or multiple launches*.)
- Debris identification: objects released as part of the nominal mission (if any) identified and listed (*e.g., with dimensions, mass, material, phase of the mission, time and orbit of the expected release*)
- Lifetime data / calculation for each MRO identified:
  - If in LEO protected region: presence limited to < 25 years after release (*demonstration using a rapid semi-analytic propagators*).
  - If MRO close to GEO protected region: show that it remains outside the GEO region (*with a rapid semi-analytic propagators*).

Rqmt's : Avoid MRO into Earth orbit - ch.6.1

Pyrotechnic devices: Review of design to screen pyros and to show that they do not release into orbit any particles > 1 mm.

Solid rocket motors

- SRM products in GEO:
  - ECSS requires no solid combustion products larger than 1 mm are released into the GEO protected region.
  - (ISO requires that no solid combustion products are released and methods to avoid the release are considered in LEO protected region).

Slag

Rqmt's: Avoiding break-ups in Earth orbit - ch.6.2

Intentional break-ups

- Declaration that no intentional break-up of a spacecraft is planned (in Erath Orbit).

Accidental break-ups

- The probability of S/C accidental on-orbit break-up $< 10^{-3}$ until EoL. (*Develop a break-up prevention plan, to be reviewed / updated as part of the normal spacecraft design review process and during the operation phase*).
- After the S/C end of operations (and before its end of life), proper actions are to be taken in order to deplete or make safe all remaining on-board sources of stored energy in a controlled sequence in order to avoid break-ups after the end of life (passivation). Note: link with EoM disposal.

S/S / items identification & failure analysis

- System level risk assessment, considering each source of stored energy, potential failure modes resulting in a break-up (and risk mitigation measures, in the design, operational and disposal phases).

Rqmt's: Avoiding break-ups in Earth orbit- ch.6.2

S/S / items to be screened for potential S/C break-up:

- Electrical systems, especially batteries
- Propulsion systems and associated components
- Pressurized systems
- Rotating mechanisms

Industry best practice. Consider environmental extremes & potential mechanical degradation or chemical decomposition (during mission and following passivation)

After the end of operations, passivation to be performed to avoid break-ups after the end of life:

- Energy sources on board to be depleted
- Onboard energy generation systems to be permanently deactivated.
- List of components to be passivated at the end of disposal phase (example)

Rqmt's: Avoiding break-ups in Earth orbit- ch.6.2

List of components to be passivated at the end of disposal phase

Passivation strongly design dependent. It may be impossible to completely deplete some energy sources (residual ergols or pressurizers, battery disconnect, etc.).

Item	Passivation actions
Batteries (BTA)	-Interrupt power supply (switch off PCDU) -Limit batteries re-charging (*)
-Electro-explosive devices -Pyrotechnic devices -Actuators (e.g., NEAs, TKFs)	Deactivate if not already used during mission / remove electrical power (switch off PCDU)
-Reaction Wheels (RW) -GYRO -C-GYRO	Remove electrical energy inputs (switch off PCDU)
-Propellant tank (propellant and pressurant) -Propulsion PRP S/S lines	-Depressurizing tank (as far as possible) -Empty tank (as far as possible) (**) -Empty propellant lines (as far as possible)
Heat Pipe	Demonstrate low probability of rupture

Rqmt's: GEO disposal – ch.6.3

At End of Mission S/C or LV to be removed from GEO protected region. Disposal actions to be completed before S/C EoL.

- GEO S/C shall perform disposal manoeuvres. During the design phase, provisions and resources (e.g., propellant) for GEO disposal manœuvres to be allocated.
- GEO disposal - IADC formula. A "simple" method to comply with the requirement using the so called IADC formula:

$$\Delta H = 235 + (1\,000 \times CR \times A/m)\ [km];\ \ eccentricity < 0.003$$

- GEO disposal - 100 years rule. More complex method, using a long-term semi-analytic orbit propagator to show the S/C not to re-enter GEO region within 100 years
- The operator may require / need to implement specific GEO disposal strategies, with impacts on the design (e.g., use of pressurizer)
- The passivation activities (e.g., tanks and piping venting) may influence the final orbital parameters in the disposal orbit.

Rqmt's: LEO disposal – ch.6.3

For LEO missions, if re-entry safety requirement is satisfied, LEO S/C shall demonstrate compliance with the 25 year rule.

At EoM, a LEO S/C shall perform disposal manoeuvres to limit its presence in LEO protected region < 25 years (from EoM) by (ISO / ECSS) in order of preference:

- retrieving it and performing a controlled re-entry to Earth
- manoeuvring it in a controlled manner into a targeted re-entry
- manoeuvring it to an orbit with a lifetime < 25 years
- augmenting its orbital decay by deploying a device so that the lifetime is < 25 years
- allowing its orbit to decay naturally so that the remaining orbital lifetime is < 25 years
- manoeuvring it to an orbit with a perigee altitude sufficiently above the LEO protected region that long-term perturbation forces do not cause it to re-enter the LEO protected region within 100 years
  - Note, French Space Law rqmt is for "rentrée atmosphérique, de manière contrôlée" except "en cas d'impossibilité, dûment justifiée"

Rqmt's: LEO disposal – ch.6.3

For most of LEO missions (orbit < 1300-1400 km), a perigee lowering option can be selected:

- Compute the orbital lifetime (rapid semi-analytic propagator). If lifetime > 25 years, define an orbit with lifetime < 25 years to be reached at the EoM
- Determine the delta-v and/or propellant necessary
- Allocate propellant in the resource budget.

LEO S/C with perigee > 1300-1400 km may consider manoeuvres to an orbit with a perigee >> LEO protected region.

- Show that long-term perturbation forces do not cause the S/C to re-enter LEO protected region within 100 years.

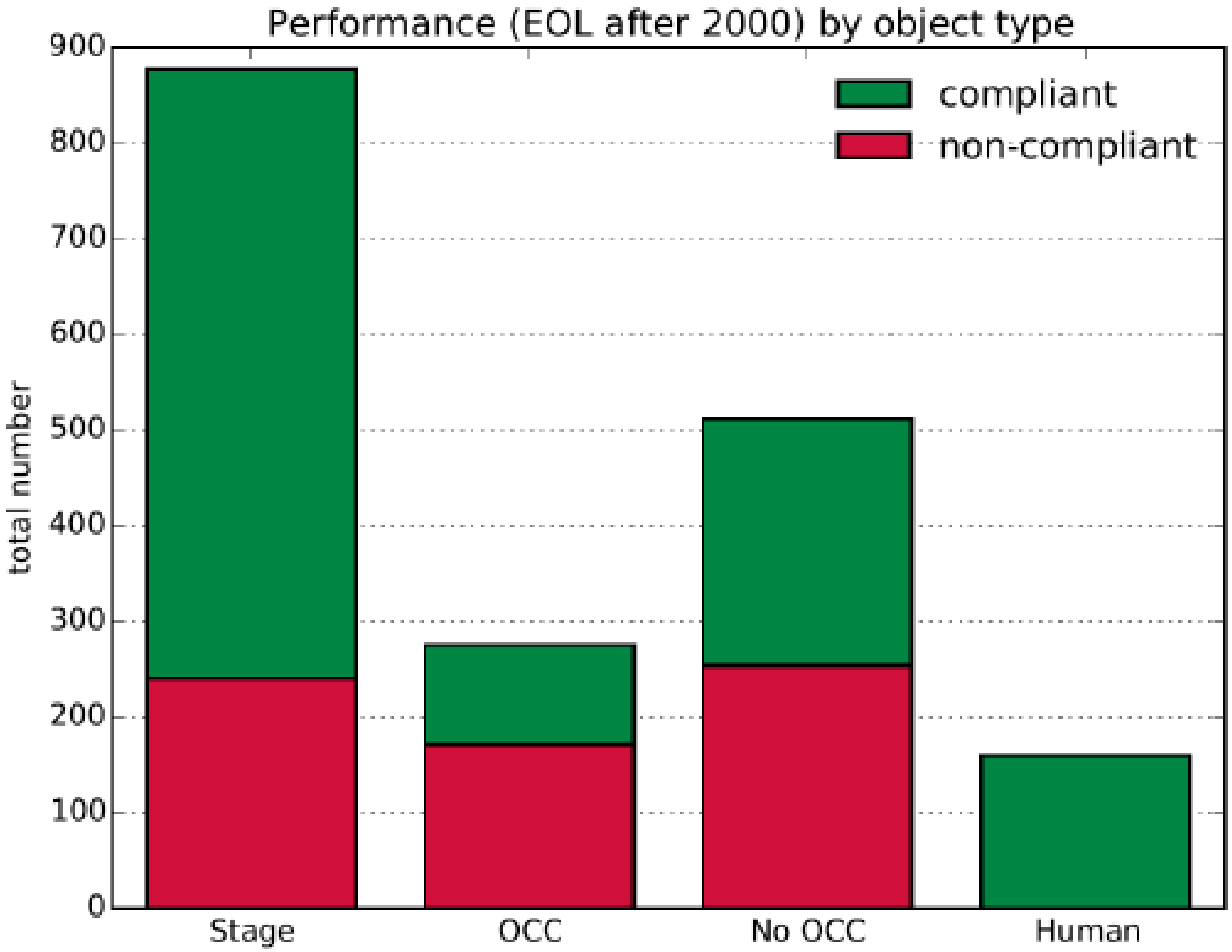
Proper assumptions for the evaluation of lifetime &/or propagation to be justified, e.g.:

- Initial orbit parameters and epoch, S/C cross-sectional area, drag coefficient, Atmosphere model, Earth gravity models, Solar radiation pressure, Third body perturbations, Solar proxies, etc.)

Rqmt's: LEO disposal – ch.6.3

LEO disposal compliace 2000-2012 by type (courtesy of ESA)

– OCC = Orbit Control Capacity



Rqmt's: successful disposal – ch.6.3

Probability of successful disposal of the S/C in LEO or GEO to be computed and a probability > 0.9 has to be reached

- Note "disposal" definition: actions performed by a S/C or LV orbital stage to permanently reduce its chance of accidental break-up and to achieve its required long-term clearance of the protected regions

The probability has to be evaluated as a conditional probability weighted on the mission success at the time disposal is executed

$$P(D|M) = \frac{R'_{\text{system}}(T_{\text{mission}} + T_{\text{disposal}})}{R_{\text{system}}(T_{\text{mission}})} \times P_{\text{propellant}}$$

- Identification of scenario and resources for disposal: start from nominal mission reliability evaluations; include estimation and availability of amount of propellant
- Identification of S/S for disposal and disposal reliability calculations
  - S/C bus, excluding P/L
  - Remove unnecessary S/S / equipment
  - Reliability figures composed at functional level

Rqmt's: successful disposal – ch.6.3

- Evaluation of "passivation" reliability calculations
  - Note that passivation may be very S/C dependent
  - Note that level of passivation has to be evaluated wrt consequences
- Obtained reliability is composed with the availability of the resources (e.g., propellant) at the time disposal is executed
- Start and end of the disposal phase to be chosen ensuring compliance with the probability of successful disposal requirement
- Passivation is not applicable in case of controlled re-entry
- Note that start and end of the disposal phase to be chosen ensuring compliance with the probability of successful disposal requirement

- In other standards (e.g. French Law): the requirement is related to the necessary resources, which must be available with a probability > 0.9.

Rqmt's: Re-entry risk ch.6.3.4

For the re-entry of a spacecraft or launch vehicle orbital stage (or any part thereof), ISO 24113 / ECSS-U-AS-10C do not specify S/C reentry maximum acceptable casualty risk, but ask for this value to be set in accordance with norms issued by approving agents and the re-entry to comply with it.

Re-entry risk assessments (analyses, reports, etc.) are to be performed to show compliance with proper processes, methods, tools, models and data.

In case the total casualty risk is larger than 10^{-4}, uncontrolled re-entry is not allowed. Instead, a controlled re-entry must be performed.

- A number of existing guidelines use 10-4 as the upper limit for the casualty risk threshold per re-entry (e.g., ESA, NASA); ESA/ADMIN/IPOL(2014)2: the casualty risk shall not exceed 1 in 10,000 for any re-entry event (controlled or uncontrolled).

Saudi Arabia, 2001

Rqmt's: Re-entry risk ch.6.3.4

French Space Law:

- Maximum acceptable total casualty risk (probabilité maximale admissible de faire au moins une victime (risque collectif)):
  - 2*10-5 pour un retour intègre
  - 2*10-5 pour une rentrée atmosphérique contrôlée avec destruction de l'objet spatial
- If a controlled reentry is impossible "en cas d'impossibilité, dûment justifiée"):
  - 10-4 pour une rentrée non contrôlée avec destruction de l'objet spatial

Lottie Williams struck by a metal fragment possibly from the re-entry of a Delta II rocket body (Tulsa, Oklahoma, January 1997)

Rqmt's: Space debris mitigation plan ch.7

A space debris mitigation plan (SDMP) shall be prepared with the following minimum content:

- the applicable space debris mitigation requirements;
- the verification and validation means to assess compliance with the applicable space debris mitigation requirements;
- a compliance matrix;
- justifications for non-compliance.

The SDMP shall be approved by approving agents.

ECSS-U-AS-10C

Summary of ECSS –U-AS-10C modifications of ISO 24113 :

- deleted limitation of applicability to unmanned systems
- added requirement on max number of space debris that can be release during launch operations
- modified requirement to include maximum size of solid combustion products that can be released in GEO protected region (1mm)

Ref: www.ecss.nl


ECSS-U-AS-10C
10 February 2012

EUROPEAN COOPERATION
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FOR SPACE STANDARDIZATION

Space sustainability

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

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

Space Debris Mitigation

Application of SDM Requirements to Sentinel-1A Case Study

Sentinel 1A - SDM Assessment

Discusses / verifies compliance with applicable “Requirements on Space Debris Mitigation” (ESA/ADMIN/IPOL(2008)2, April 1, 2008 and ESA/ADMIN/IPOL(2014)2, 28 March 2014)

- Compliance matrix established; discussion and justification provided for all of the requirements:
- Design and operational requirements (dealt together)

Detailed discussion and analyses provided in appendices for key requirements:

- Orbital lifetime and post-mission disposal
- Casualty re-entry risk

Dedicated chapter collecting proposed S/C and lower tiers requirements

Study case: Sentinel-1
Mass: 2 tons satellite
Orbit: SSO, polar orbit
Altitude: about 693 km
Main feature: large SAR antenna

The first of the dual Sentinel-1 satellites, **Sentinel-1A**, was launched on 3 April 2014. The second– **Sentinel-1B** – was launched on 25 April 2016

Sentinel 1A - SDM Assessment

S/C physical characteristics		
Mass	2194.51	kg
Dimensions	1.34 x 1.34 x 3.40	m
X-sec area (rand. tumb)	23.32	m^2

Orbital characteristics		
Semi-major axis	7080.15	km
Eccentricity	0.001266693	
Inclination	98.1124	deg
RAAN	308.545	deg
Argument of Perigee	68.9302	deg
Mean Anomaly	291.228	deg
Average altitude	693 (almost circular)	km
Orbits	Sun-synC, dawn-dusk Polar	
Epoch	2012/30/10-00:00:00.000	

SDM Requirements

Detailed analyses for key requirements (orbital lifetime, post-mission disposal, re-entry casualty risk) performed with several tools:

- DAS (Debris Assessment Software, NASA)
- DRAMA (Debris Risk Assessment and Mitigation Analysis, ESA).
- STELA (CNES)
- SCARAB (HTG)

Mission Related Objects (MRO)

- Launchers: requirement on procurement of launch service
- Spacecraft: no objects released as part of the nominal mission

Fragmentation

- No intentional destruction envisaged

Solid propellant and pyrotechnics

- Solid rocket motors: no solid propellant used
- Pyrotechnics: no particles > 1 mm released
  - Self contained cable capture Thermal Knife for SAW
  - Non Explosive Actuators (NEA) for SAR antenna

SDM requirements

Space System EoL Measures

- Propellant accuracy: 2 σ factor / + 5 kg accuracy determined
- Passivation: recommendations on items / approach provided
- Reliability of successful EoL disposal evaluation based on S/S needed for disposal

LEO 25-year Orbit Lifetime:

- Need for disposal maneuvers
- Parameters for perigee lowering maneuvers and amount of propellant for 25-year disposal at EoM dteremined:
- > 23 kg (for disposal in 2020)
- > 30 kg (for disposal in 2024)

SDM requirements

Re-entry casualty risk assessment (re-entry risk $< 10^{-4}$):

- Preliminary assessment performed with DAS & DRAMA tools, but Casualty Re-entry Risk always significantly above the 10-4 requirement:
- 9 E-04 (1:1100) according to DAS
- 7.19 E-04 (1:1391) according to DRAMA
- Additional high fidelity analysi performed with SCARAB 6-DoF and sensitivity tools, performed at a later stage, showed limited non-compliance

Sentinel-1A Case Study

Re-entry

Trajectory and Fragmentation

Object-oriented Tools

Parent Object

↓

Parent object split into child objects at fixed Break-up Altitude

↓

Object ablation
If the melting condition occurs

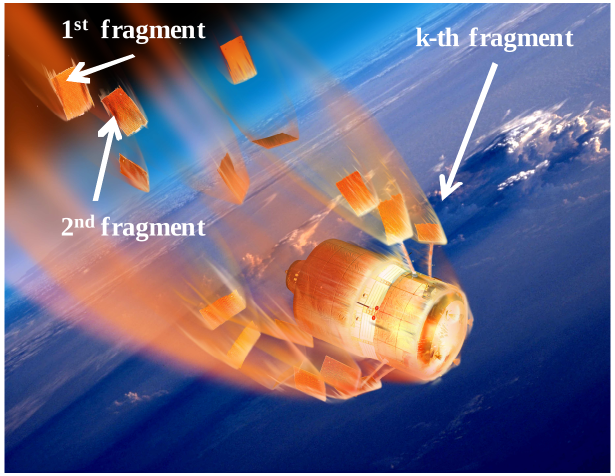
↓

Independent child objects trajectory and thermal status

↓

Possible partially or completely non-demised objects

3DOF Trajectory and
1D Thermal Equations



Spacecraft-oriented Tools

Spacecraft

↓

Fragments generation if the melting condition occurs for finite-elements

↓

Independent fragments trajectory and thermal status

↓

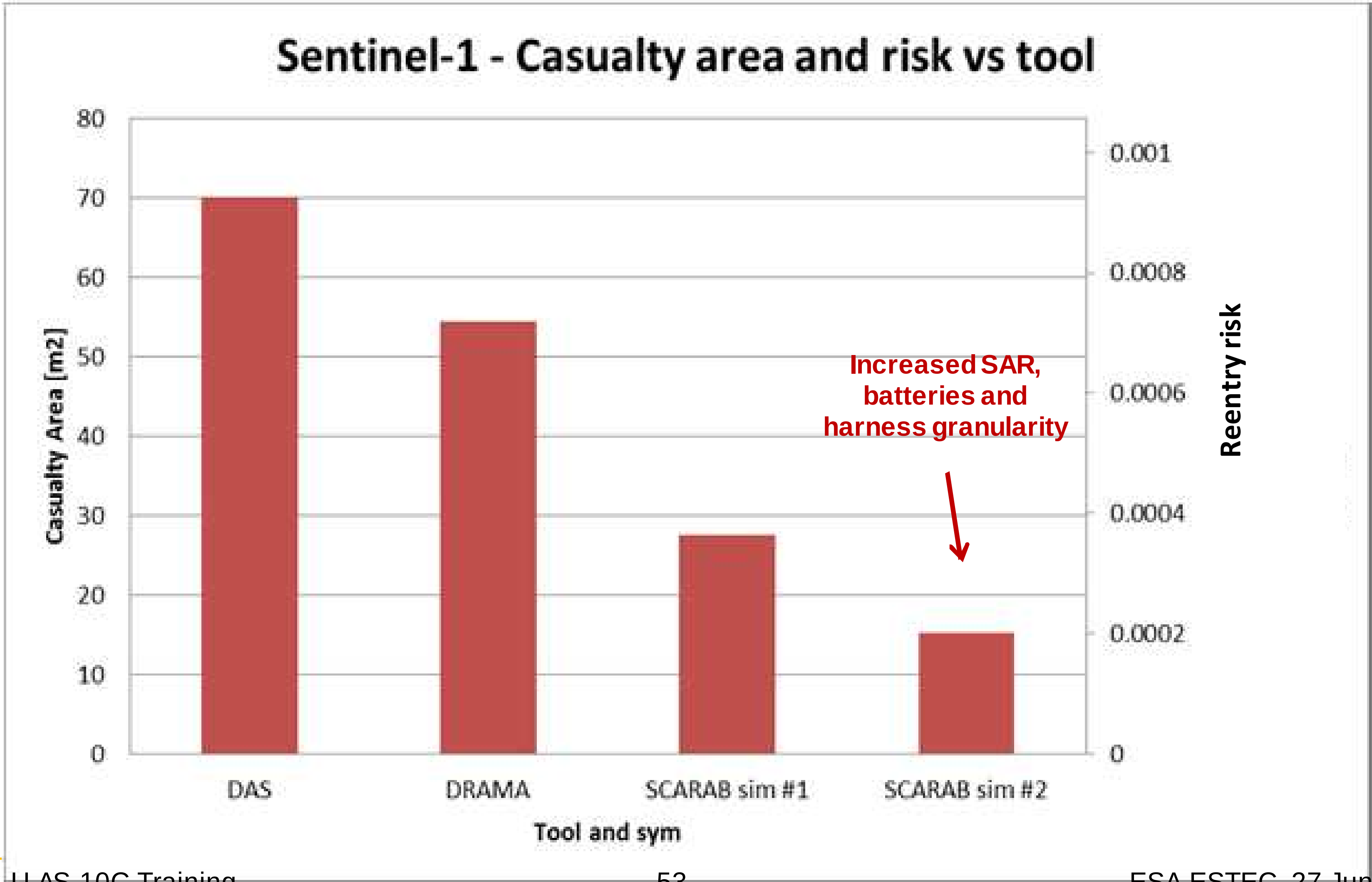
Possible non-demised fragments

6DOF/3DOF Trajectory and
3D/1D Thermal Equations

S-1 Re-entry Analysis – related uncertainty

Impact of tools and impact of granularity

- Reduced Casualty Area (may increase it too?)



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Space Debris Mitigation

SDM Handbooks and Supporting Studies

clean space

Inter–Agency Space Debris Coordination Committee

esa

SDM HBs

- Useful reference documents:
  – ESA, ESA ESSB-HB-U-002 , “ESA Space Debris Mitigation Compliance Verification Guidelines “
  – CNES Guide de Bonne Pratique – Maitrise d’un Objet Spatial
  – ISO 18146: TR - Space Debris Mitigation Design and Operation Manual for Spacecraft
  – IADC-04-06, Rev 5.5, May 2014, Support to the IADC Space Debris Mitigation Guidelines
- ESA, CNES and ISO Handbook on SD Mitigation with different purpose and approaches:
  – ESA HB focused on verification methods and techniques to show compliance with SDM requirements within ECSS/ISO24113
  – CNES HB necessary for the implementation of the French law with indications, documentation required, compliance matrix, to provide verification of the requirements. (However, text of rqmts in French LOS / RT rather different from ECSS/ISO)
  – ISO HB more general and procedural, considers SC life-cycle and S/Ss, provides linking to the various SDM lower level ISO Standards

Conclusions

Conclusions / Feedback / Questions and Answer

Material Covered

Space Debris Overview

- Space Debris: An Increasing Issue
- Space Debris Environment and Critical Events
- Effects of Space Debris on Space Systems
- Re-entry Risk
- Global Perspective for Space Sustainability

Space Debris Mitigation

- Space Debris Mitigation Guidelines and Standards
- ECSS & ISO TC20/SC14 Space Debris Mitigation Standards
- ESA Space Debris Requirements (ESA/ADMIN/IPOL 2014)
- French Space Act Requirements
- ECSS Space Debris Requirements Discussion
- Application of SDM Requirements: Sentinel-1A Case Study
- SDM Handbooks and Supporting Studies
- Evolution of Space Debris Requirements

Conclusions & Outlook

Space Debris Mitigation standards necessary to cope with a global issue at international level

Several SDM documents exist with similar requirements / guidelines

- ECSS relies on ISO to produce norms related to SDM, participate to development of standards, provides inputs and comments to ISO SDM documents

Evolution and improvements of SDM documents and of the compliance worldwide:

- Feedback from users (e.g., manufacturers, operators, regulatory bodies, etc.)
- Experience gained by institutions making the requirements applicable to projects (e.g. ESA, France, IADC, etc.)
- Evolution of the environment and of the space sector (e.g. lean satellites, constellations, etc.)