ESA Requirements on EOL De-orbit

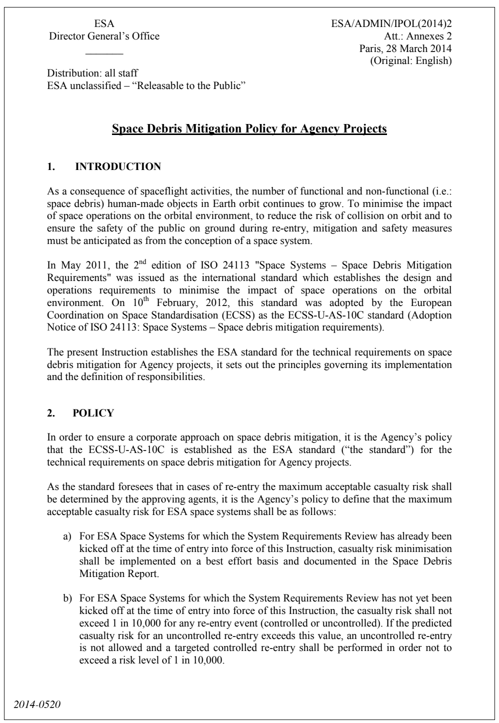
Technical Day on De-orbit Strategies
ESTEC, Noordwijk, 17th March 2015

Prepared by:
Independent Safety Office (TEC-QI)

Ref. TEC-QI/15-228

ESA Space Debris Mitigation Policy and Requirements

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



ESA
Director General's Office

ESA/ADMIN/IPOL(2014)2
Att.: Annexes 2
Paris, 28 March 2014
(Original: English)

Distribution: all staff
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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.

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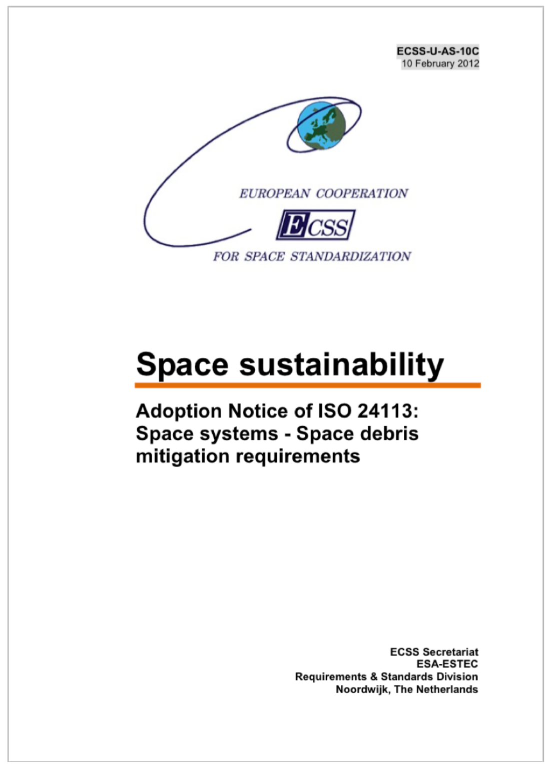

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ESSB-HB-U-002
ESA Space Debris Mitigation Compliance Verification Guidelines

- ESSB-HB-U-002 – ESA Space Debris Mitigation Compliance Verification Guidelines has been issued in Feb-2015.
- ESSB-HB-U-002 is an handbook providing guidelines on the verification of the ESA Space Debris Mitigation requirements.
- ESSB-HB-U-002 was prepared by ESA Space Debris Mitigation Working Group.
- ESSB-HB-U-002 will be regularly updated based on the feedback from ESA and Industry users and the outcome of on-going studies (e.g. in the frame of the Clean Space Initiative).

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estec

European Space Research
and Technology Centre
Keplerlaan 1
2201 AZ Noordwijk
The Netherlands

T +31 (0)71 565 6565
F +31 (0)71 565 6040
www.esa.int

DOCUMENT

ESA Space Debris Mitigation Compliance Verification Guidelines

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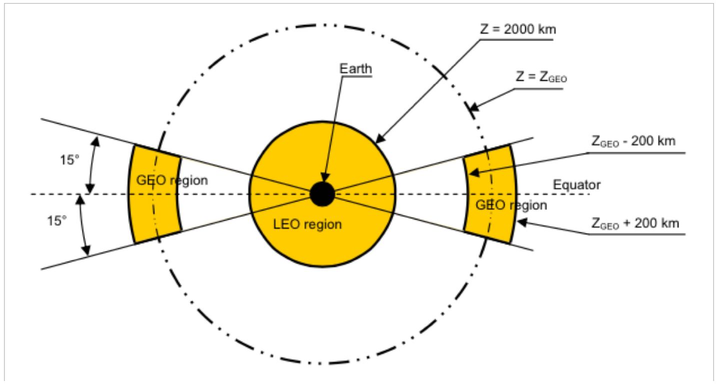
Protected Regions

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 6,378 km up to an altitude (Z) of 2000 km

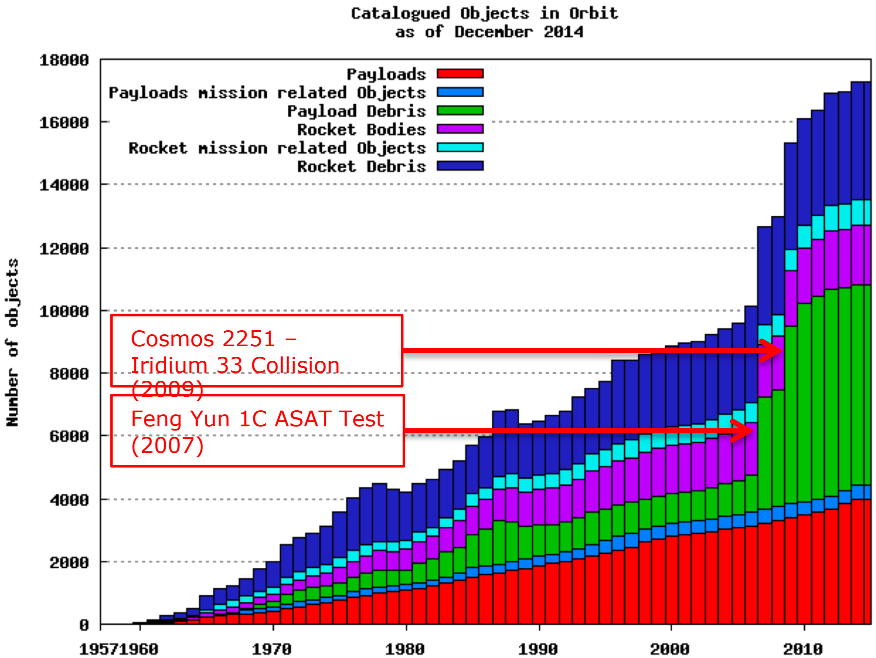


2. GEO Protected Region

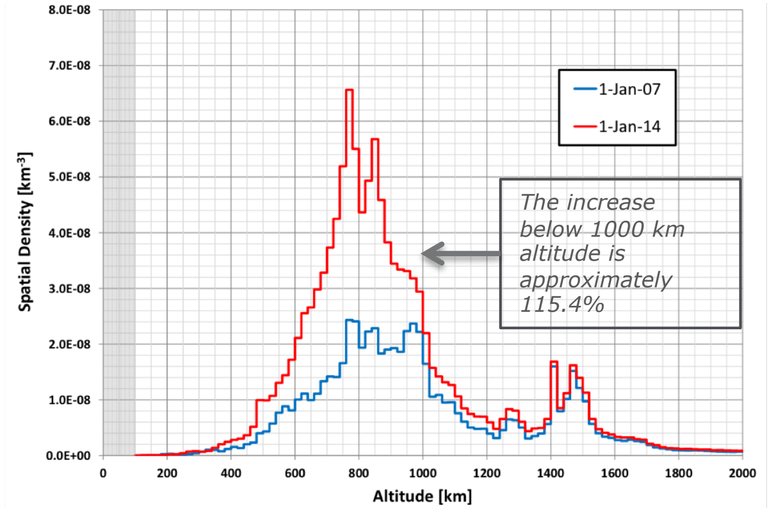
Geosynchronous Protected Region is a segment of a spherical shell defined by:

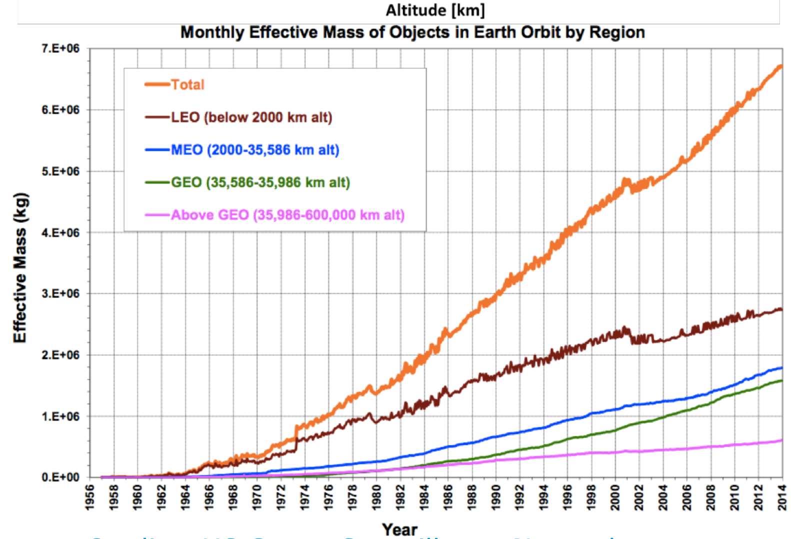
- lower altitude boundary = geostationary altitude minus 200 km
- upper altitude boundary = geostationary altitude plus 200 km
- latitude sector: 15 deg South ≤ latitude ≤ 15 deg North
- geostationary altitude (ZGEO) = 35,786 km (with respect to the spherical Earth with an equatorial radius of 6,378 km)

Space Debris Population



Credits: ESA DISCOS





Credits: US Space Surveillance Network (SSN)

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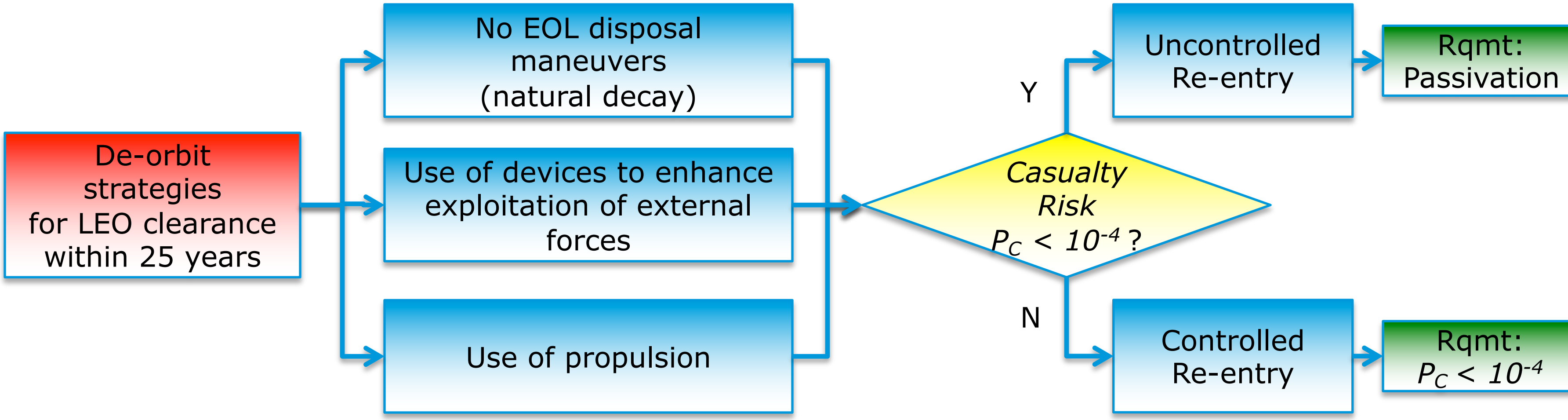
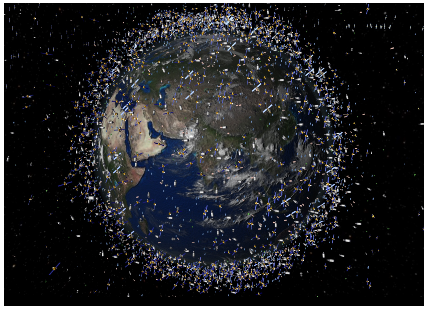
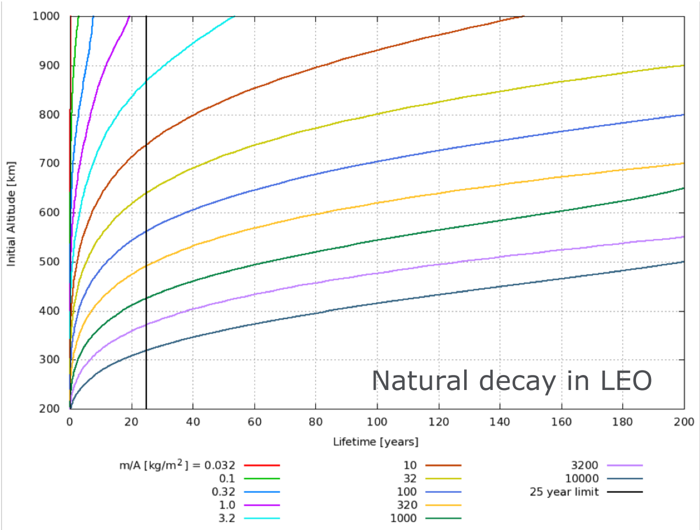
EOL De-orbit Strategies







LEO Clearance and Disposal Maneuvers

Requirement 6.3.3.1: LEO clearance

- **Presence in the LEO Protected Region limited to maximum of 25 years from the end of mission**

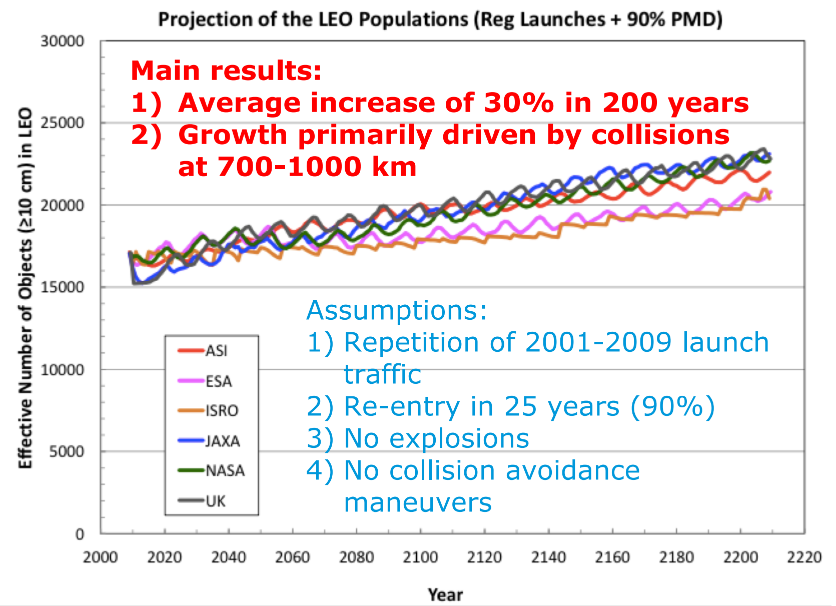
Requirement 6.3.3.2: LEO disposal maneuvers (possible options)

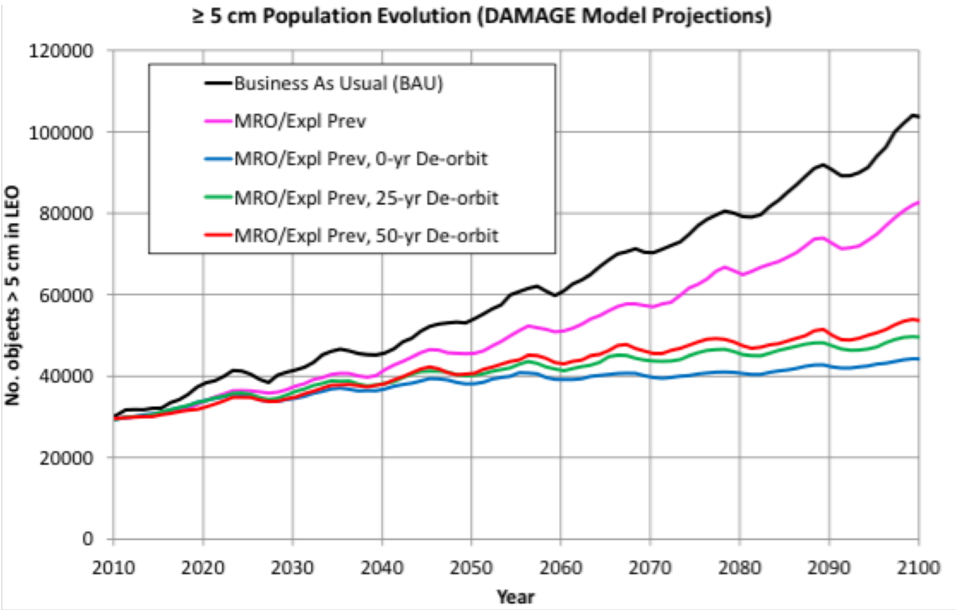
- **Retrieving** and performing a controlled re-entry to recover it safely on the Earth
- **Manoeuvring** in a controlled manner into a **targeted re-entry** with a well-defined impact footprint
- **Manoeuvring** in a controlled manner to an orbit with a **shorter orbital lifetime**
- Augmenting orbital decay by **deploying a device**
- Allowing its orbit to **decay naturally**
- Manoeuvring in a controlled manner to an orbit with a perigee altitude sufficiently above the LEO Protected Region for at least 100 years

Ref. TEC-QI/15-228

LEO Clearance Rationale

- Presence in LEO limited to max 25 years to mitigate debris population growth over next 100 years as compromise between:
  - Reduction of debris generation risk due to in-orbit collisions and break-ups
  - Cost burden for implementation of de-orbit capability (e.g. propellant mass allocation)





Credits: IADC, 2014

EOL Disposal Reliability

Requirement 6.3.1.1: disposal reliability threshold

- **Probability of successful disposal > 0.9 at the time disposal is executed**

Requirement 6.3.1.2: disposal reliability assessment

- Probability of successful disposal as conditional probability weighted on the mission success, i.e. $P(D|M)$

Requirement 6.3.1.3: disposal reliability constraints

- Start and end of the disposal phase chosen so that all disposal actions are completed within a period of time that ensures $P(D|M) > 0.9$

- The assessment of the EOL disposal reliability should include:
  - **EOL disposal reliability assessment during the development phase**
  - **EOL disposal reliability in-orbit assessment**

Ref. TEC-QI/15-228

EOL Disposal Reliability Assessment during the Development Phase

$$P(D|M) = \frac{R_{Mission+Disposal}}{R_{Mission}} \geq 0.9$$

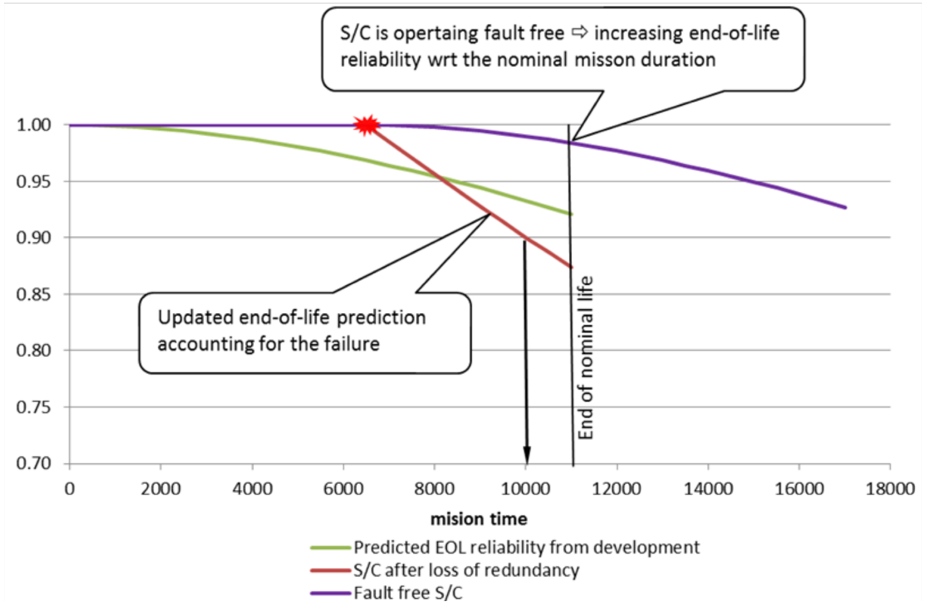
$P(D\|M)$	conditional probability to have successful disposal assumed the successful mission
$R_{Mission}$	mission reliability, i.e. the probability to perform successfully the mission
$R_{Mission+Disposal}$	mission and disposal reliability, i.e. the probability to accomplish successfully both the mission and the disposal

- $R_{Mission}$ and $R_{Mission+Disposal}$ need to take into account:
  - System reliability for disposal operations
  - Resources availability for disposal operations
  - Probability of internal explosion leading to structural break-up and preventing disposal operations
  - Probability of collision with other objects likely to cause break-up and preventing disposal operations
- $R_{Mission}$ = 1 in case mission reliability is not defined or available

Ref. TEC-QI/15-228

EOL Disposal Reliability In-orbit Assessment

- Reliability predictions cannot cover systematic or random hazardous faults prior to launch
- Monitoring equipment performance is needed for decision-making on advanced or extended termination of nominal mission
- The health of a space system can be monitored to identify unanticipated degradation
- Care should be taken on anomalies potentially affecting multiple equipment parts and lowering the effectiveness of redundancies



Ref. TEC-QI/15-228

Other SDM Requirements to Preserve LEO

Requirement 6.1.1.2: mission-related objects on-orbit presence

- MROs outside the GEO Protected Region
- **MROs presence in the LEO Protected Region limited to a maximum of 25 years after release**

Requirement 6.1.2.1: pyrotechnic particle release

- **To avoid the release of products > 1 mm from pyrotechnic devices**

Requirement 6.1.2.3: solid rocket motors particle release in LEO

- **To avoid release of solid combustion products in the LEO Protected Region**

Requirement 6.2.2.1: break-up probability threshold

- Probability of accidental break-up < $\mathbf{10^{-3}}$ **until its end of life**

Requirement 6.2.2.3: passivation

- During the disposal phase, permanently **depletion or making safe all remaining on-board sources of stored energy** in a controlled sequence

Ref. TEC-QI/15-228

Re-entry Casualty Risk

Requirement 6.3.4.1: re-entry casualty risk acceptance

- ***Maximum acceptable casualty risk set in accordance with norms issued by approving agents***

→ **ESA/ADMIN/IPOL(2014)2**

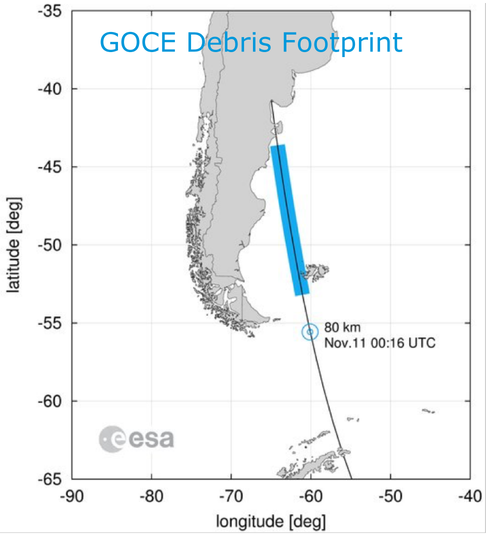
a) *For ESA Space Systems for which the System Requirements Review has already been kicked off at the time of entry into force of this Instruction (28/03/2014), casualty risk minimisation shall be implemented on a best effort basis and documented in the Space Debris Mitigation Report.*

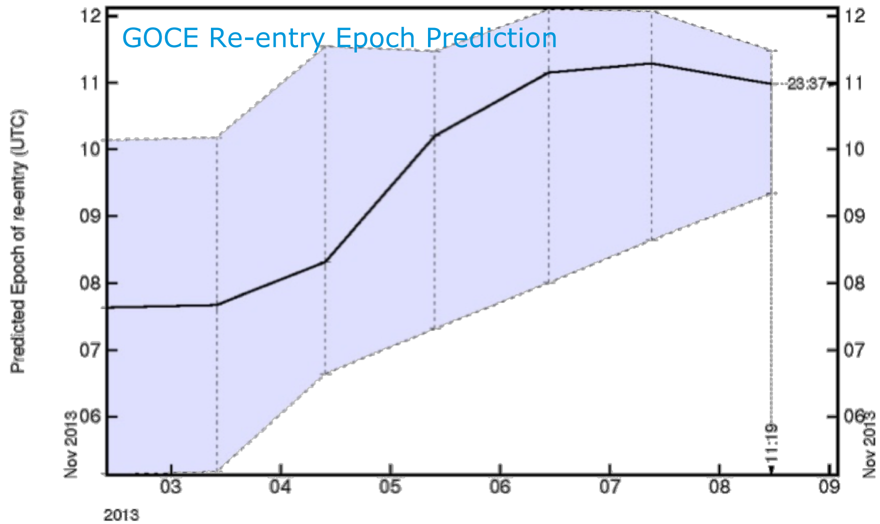
b) *For ESA Space Systems for which the System Requirements Review has not yet been kicked off at the time of entry into force of this Instruction (28/03/2014),* ***the casualty risk shall not exceed 1 in 10000 for any re-entry event (controlled or uncontrolled)****. If the predicted casualty risk for 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 10000.*

Uncontrolled Re-entry

- The time of re-entry is not controlled
  - The re-entry epoch can be usually predicted with an uncertainty of about 20% of the time between the prediction and the expected re-entry event
- The ground zone of impact is not controlled
- Physical characteristics (mass, size, material) of on-ground surviving fragments are predictable
- The casualty risk for human population is estimable

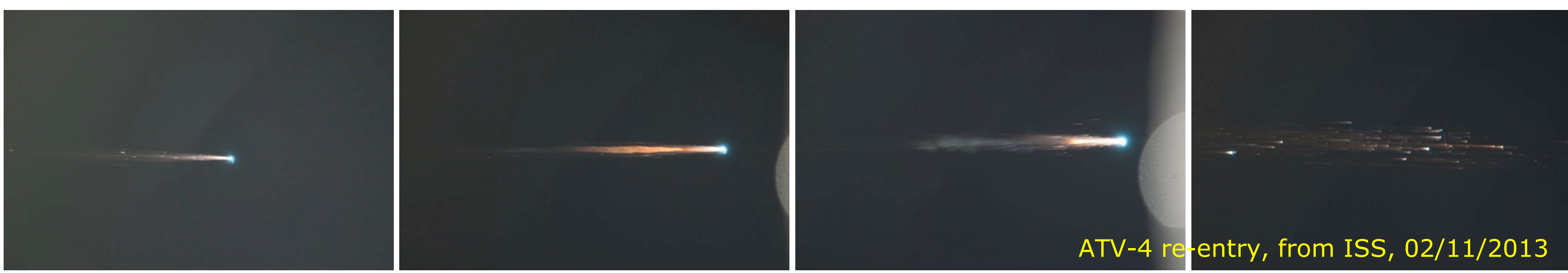
GOCE
Uncontrolled Re-entry
(11/11/2013)





Controlled Re-entry

- The time of re-entry is controlled
- The ground zone of impact is controlled
- De-orbit maneuvers are executed to control the re-entry
- The Declared Re-entry Area (DRA) is determinable
- The Safety Re-entry Area (SRA) is determinable
- The main break-up event may be driven by targeting a specific perigee altitude for the last de-orbit maneuver
- The casualty risk for human population is estimable and can be widely minimized by targeting the debris impact over unpopulated areas


ATV-4 re-entry, from ISS, 02/11/2013

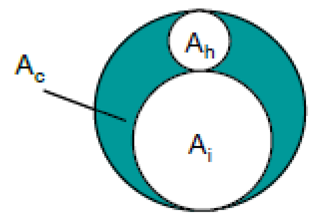
Ref. TEC-QI/15-228

Re-entry Casualty Area

- Fragment casualty area

  equivalent impact area leading a casualty if a person is struck by a piece of fragment (conventionally kinetic energy ≥ 15 J)

$$A_{C,k} = \left[\sqrt{A_{i,k}} + \sqrt{A_h}\right]^2$$



A_i average projected area of the fragment surviving the re-entry

A_h human cross-section, conventionally equal to 0.36 m² (NASA NSS 1740.14)

- Total casualty area

  sum of N surviving fragments

$$A_C = \sum_{i=1}^{N} A_{C,k}$$

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Re-entry Casualty Risk

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- Casualty risk for uncontrolled re-entry ($P_{C,unc}$):

$$P_{C,unc} = A_C \rho_p(i, \Delta\varphi, \omega) < 10^{-4}$$

- A_C: Total casualty area – Depending on space system design and fragmentation process
- $\rho_p(i, \Delta\varphi, \omega)$: Average population density – Depending on orbit inclination, latitude step size (circular orbits), argument of perigee (elliptic orbit)

- Casualty risk for controlled re-entry ($P_{C,con}$):

$$P_{C,con} = 1 - \prod_{k=1}^{N}\left(1 - \sum_{n}\sum_{m} (P_{i,k})_{n,m} (\rho_p)_{n,m} (A_{C,k})_{n,m}\right) < 10^{-4}$$

- $(P_{i,k})_{n,m}$: Local impact probability
- $(\rho_p)_{n,m}$: Local population density
- $(A_{C,k})_{n,m}$: Local casualty area

- Casualty risk for a failed controlled re-entry ($E_{C,con,fail}$):

$$P_{C,unc,fail} = E_{C,unc} P_f = A_C \rho_p(i, \varphi, \Delta\varphi) P_f < 10^{-4}$$

- P_f: Failure probability

Declared Re-entry Area (DRA) and Safety Re-entry Area (SRA)

Declared Re-entry Area (DRA):

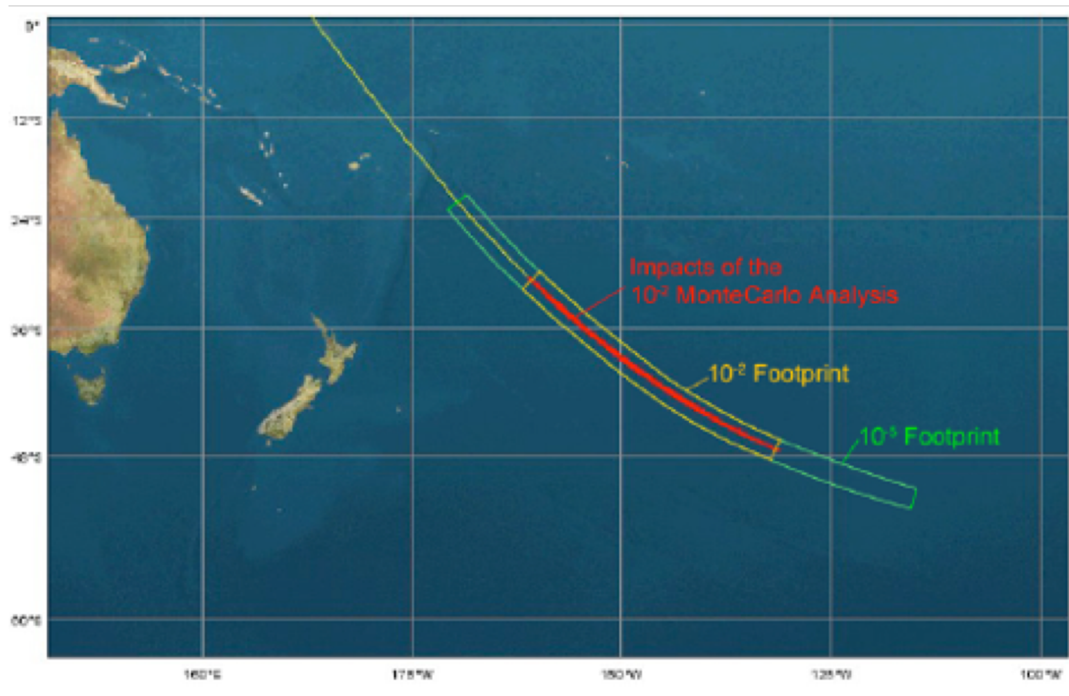
area on-ground where the re-entry debris are enclosed with a probability of 99% given the delivery accuracy

→ 10^{-2} footprint

Safety Re-entry Area (SRA):

area on-ground where the re-entry debris are enclosed with a probability of 99.999% given the delivery accuracy

→ 10^{-5} footprint



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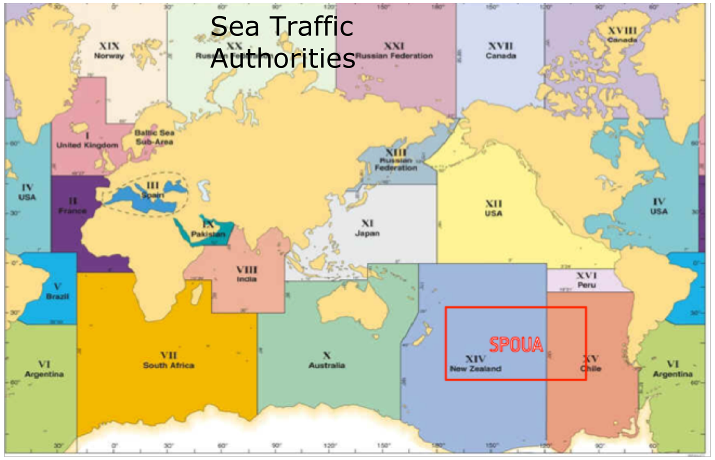
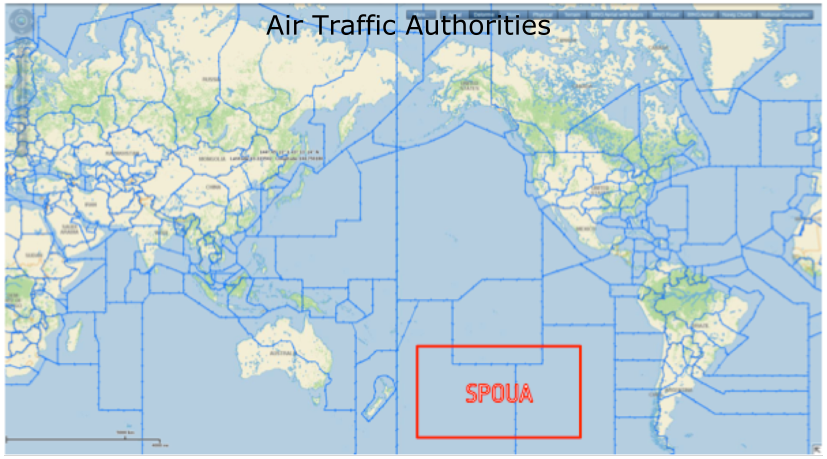
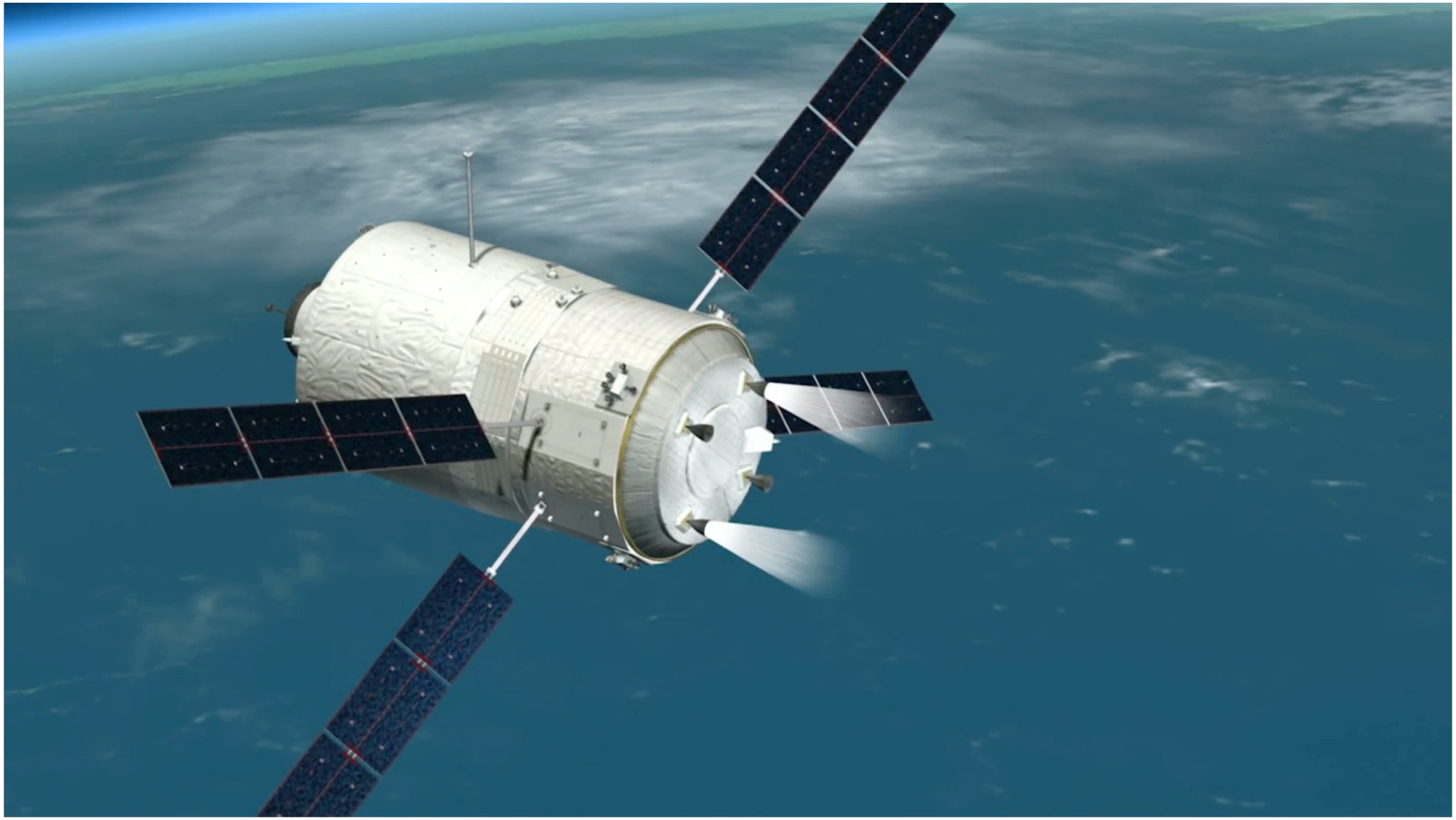
Criteria for Target Impact Area Selection for Controlled Re-entries

1. The impact area should be ensured over an ocean area, with sufficient clearance of landmasses and traffic routes
2. Territorial waters, i.e. 12 nm (22.2 km) from coastline, are considered to be part of of national territories
3. The sovereign state should be informed in case of interference with its Economic Exclusive Zone (EZZ), i.e. 200 nm (370.4 km) from coastline
4. The South Pacific Ocean Uninhabited Area (SPOUA) has been identified as the largest unpopulated area to target the ATVs controlled re-entries (longitude range from 185 deg East to 275 deg East, latitude range from 29 deg South to 60 deg South)
5. Preserving zones classified as Marine Protected Areas for environment safeguard can be a constraint to take into account





ATV Controlled Re-entry



ATV controlled re-entry mission (Credits: ATV-CC / CNES)

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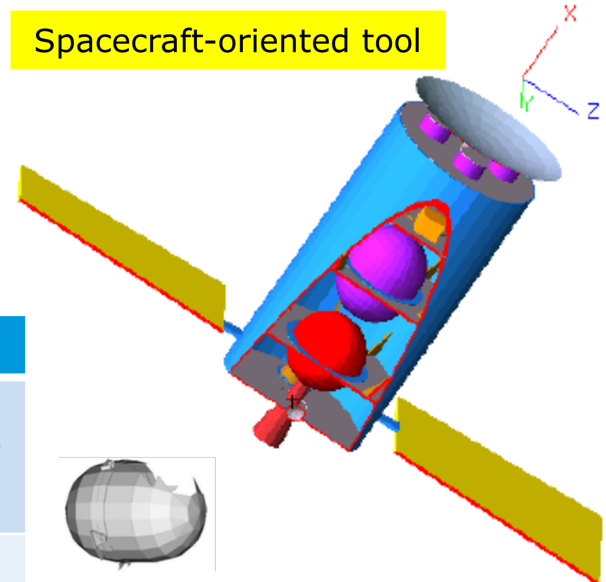
Re-entry Casualty Risk Tools

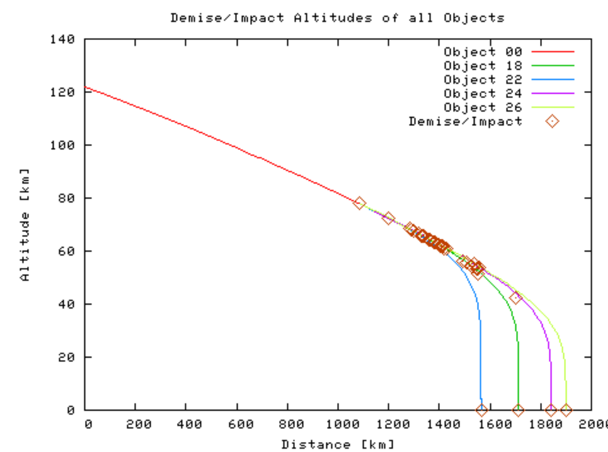
Name	Shape	No.of Obj.	Width/Diam. ...	Length [m]	Height [m]	Mass [kg]	Material
'Parent'	'Cylinder'	1	1.7	4.8	0.0	1200.0	'n/a'
'SolarP'	'Plate'	2	2.0	2.0	0.0	20.0	'n/a'
TCU	Box	1	0.52	0.38	0.27	33.0	'AA7075'
PCU	Box	1	0.23	0.18	0.16	5.0	'AA7075'
BCDR	Box	1	0.57	0.31	0.18	19.0	'AA7075'
BCU	Box	1	0.3	0.2	0.14	4.0	'AA7075'
PPDU	Box	1	0.41	0.32	0.17	13.0	'AA7075'
Batt	Box	1	0.54	0.4	0.21	50.0	'AA7075'
Decoder	Box	1	0.26	0.2	0.[illegible]	[illegible]	[illegible]
CTU	Box	1	0.4	0.25	0.[illegible]	[illegible]	[illegible]
RTU	Box	1	0.32	0.27	0.25	13.5	'AA7075'

Object-oriented tool

Spacecraft-oriented tool



Inputs	DRAMA/SARA	ASTOS/DARS	DAS	SCARAB
Spacecraft Geometry	User-defined list of a parent and multiple child simple shapes (spheres, boxes, cylinders, plates)	User-defined list of multiple parents and child simple shapes (spheres, boxes, cylinders, plates)	User-defined list of multiple parents and child simple shapes (spheres, boxes, cylinders, plates)	Geometrical assembly of panels with user-defined shapes
Material Properties	Constant basic thermal properties	Constant basic thermal properties	Constant basic thermal properties	Temperature-dependent thermal and mechanical properties
Initial Conditions	Orbital state vector (3DOF)	Orbital state vector (3DOF)	Orbital state vector (3DOF)	Orbital state vector + Attitude (6DOF)
Fragmentation Approach	Object-oriented	Object-oriented	Object-oriented	Spacecraft-oriented
Fragmentation event(s)	Single solar array break-off and single break-up	Multiple break-up events	Multiple break-up events	Predictable events



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Questions?

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