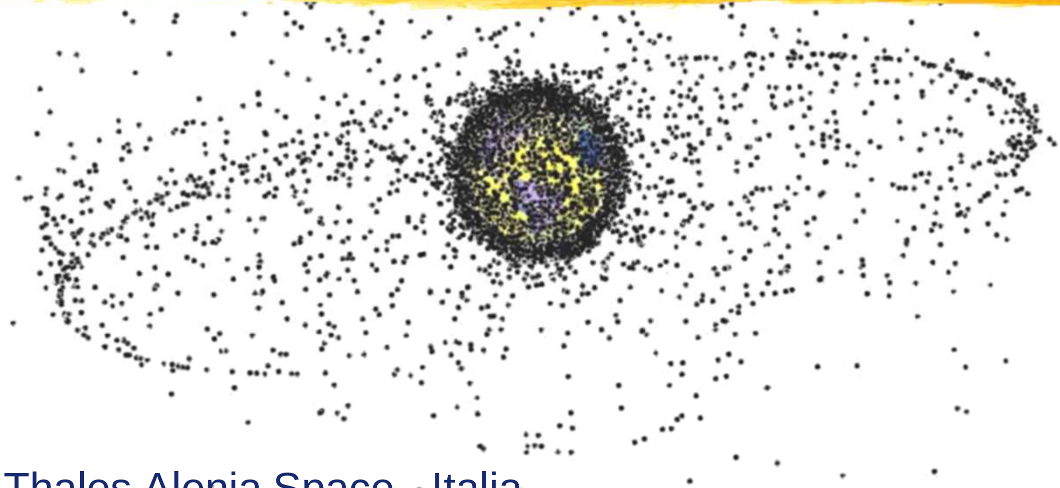
An overview of Space Debris Mitigation documents and requirements



R. Destefanis, Thales Alenia Space - Italia
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CleanSat Workshop & Technologies for Space Debris Mitigation

18 March 2015, ESA/ESTEC, Noordwijk, The Netherlands

Standards development: ECSS

Voting members

Observers

European Cooperation for Space Standarization (ECSS)

European Space Agency

European Industry,

represented by

EUROSPACE

The Association of European Space Industry

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

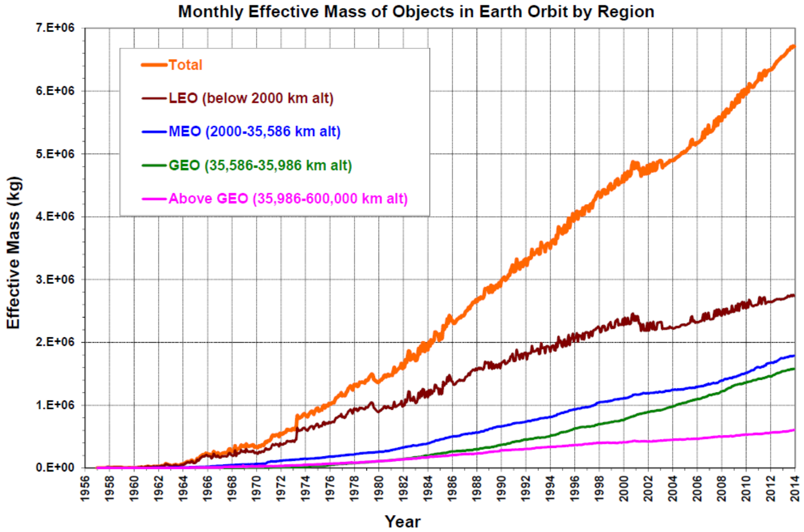
- → **CEN,**
- → **EUMETSAT,**
- → **EDA**

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**

Outline

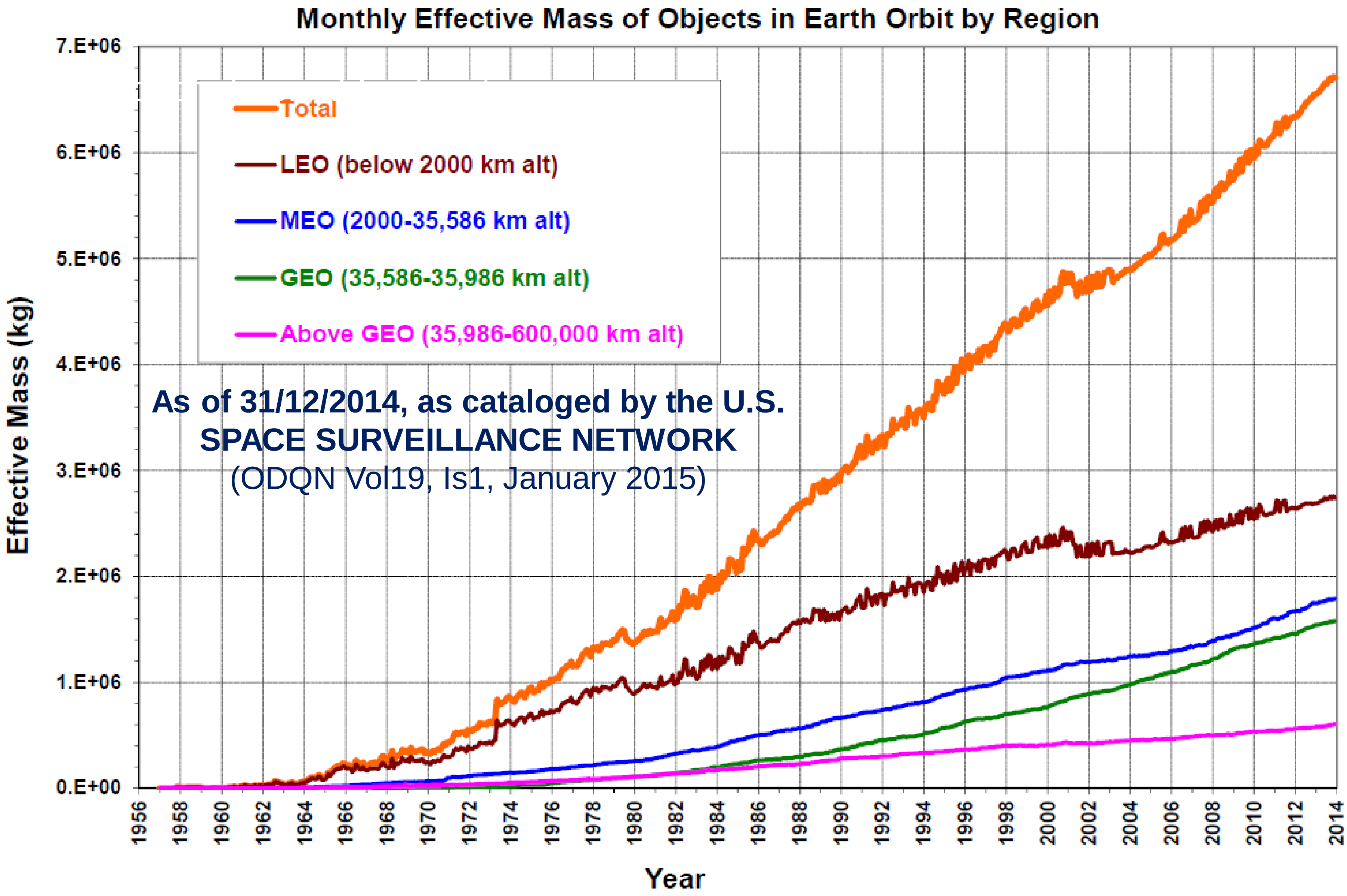
- Introduction
  - What Space Debris Mitigation is about
  - A global issue
  - Remediation and mitigation
- Space Debris Mitigation documents
  - Guidelines, Standards, Regulations
  - International, Regional, National
- ISO development activities and process
- Main Space Debris Mitigation Clauses
- Requirement evolution



Introduction

What Space Debris Mitigation is about
A global issue
Remediation and mitigation

Introduction – A Global Issue



Introduction - what Space Debris Mitigation is about

Defense Meteorological Satellite Program Flight 13 (DMSP-F13)

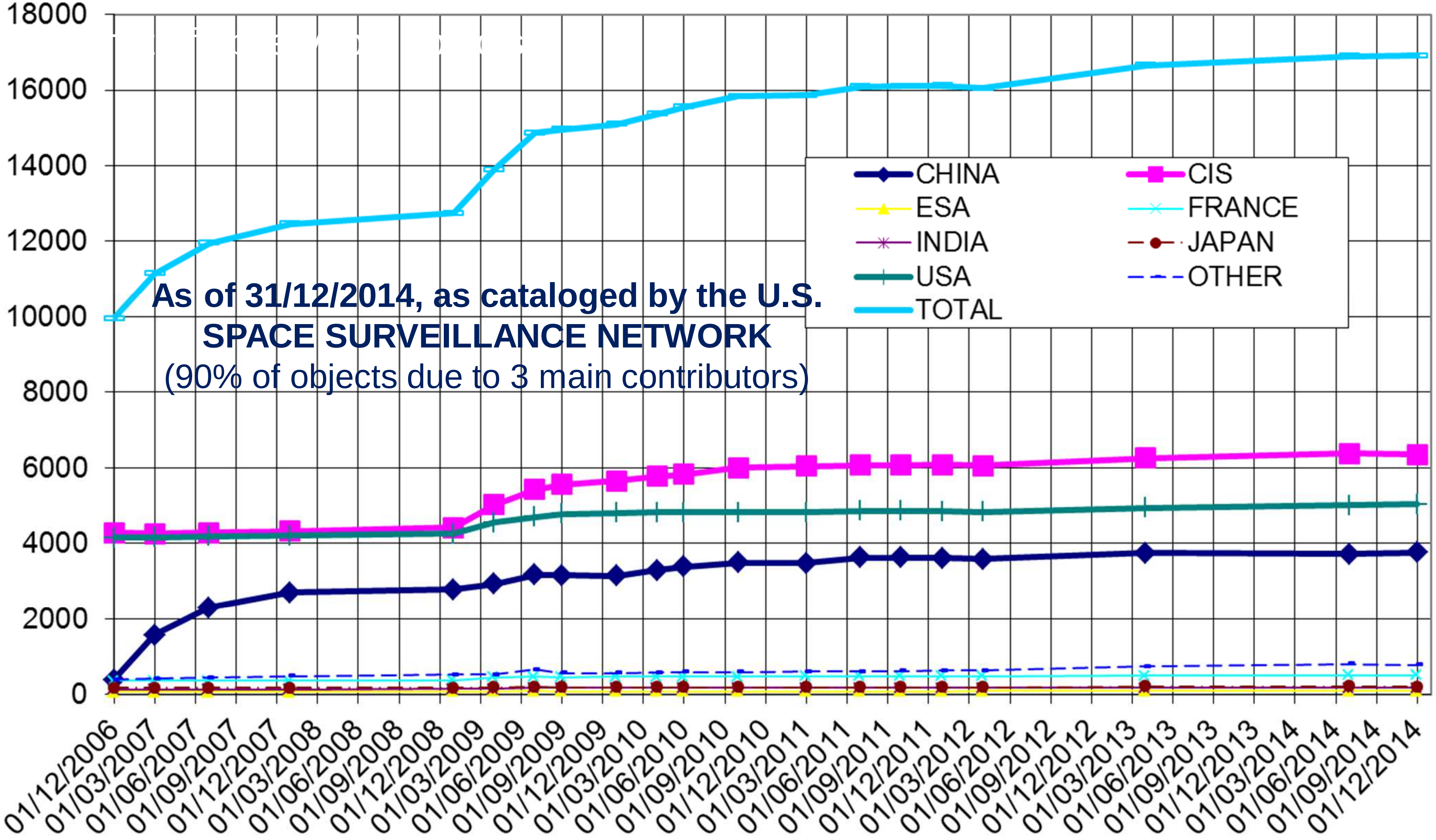
- Launched in 1995, sun-synchronous polar orbit, 800 km altitude
- Operational (with a backup role since 2006)
- "Catastrophic event" produced 43 pieces of space debris, on February 3rd, 2015 (noted on February 25th).
- Power subsystem experienced "a sudden spike in temperature" followed by "an unrecoverable loss of attitude control"
- As DMSP operators were deciding to "render the vehicle safe" the Joint Space Operations Center identified a debris field near the satellite

Introduction - what Space Debris Mitigation is about

Defense Meteorological Satellite Program Flight 13 (DMSP-F13)

- In April 2004, DMSP-F11, launched in 1991experienced a catastrophic breakup that produced 56 cataloged debris.
- DSMP-F11 was non-operational and passivated:
  - electrical power generation system: batteries discharged and disconnected from the charging circuit.
  - No nitrogen remained on board (due to a leak detected early in the mission)
  - The only energy source assessed to be on the S/C was approximately 6 kg of hydrazine.

Introduction – A Global Issue



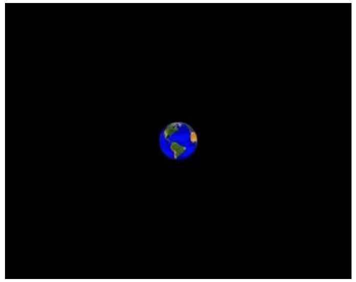
Introduction – Remediation & Mitigation

Remediation:

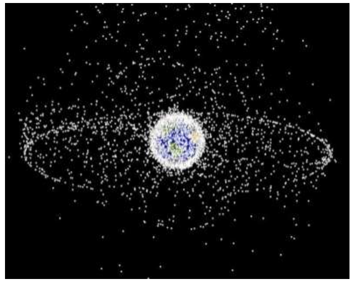
- Removing existing, non-cooperative objects is difficult and expensive. Investigated techniques need development and testing, are constrained by policy and legal issues, economic viability:
  - Ground based laser cleansing
  - Active Debris Removal

Fundamental need: Mitigation

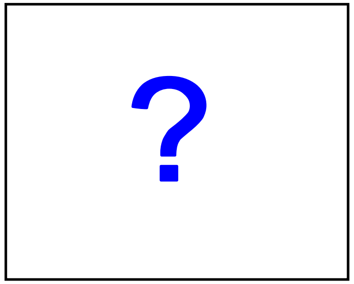
- Avoid / limit Mission Related Objects (MRO) release
- Avoid break-up (reliability, passivation at End of Mission)
- Remove S/C & R/B from protected region after End of Mission
- Re-entry casulaty risk limitation
- Avoid on-orbit collision



Pre 1957



2008



2015+

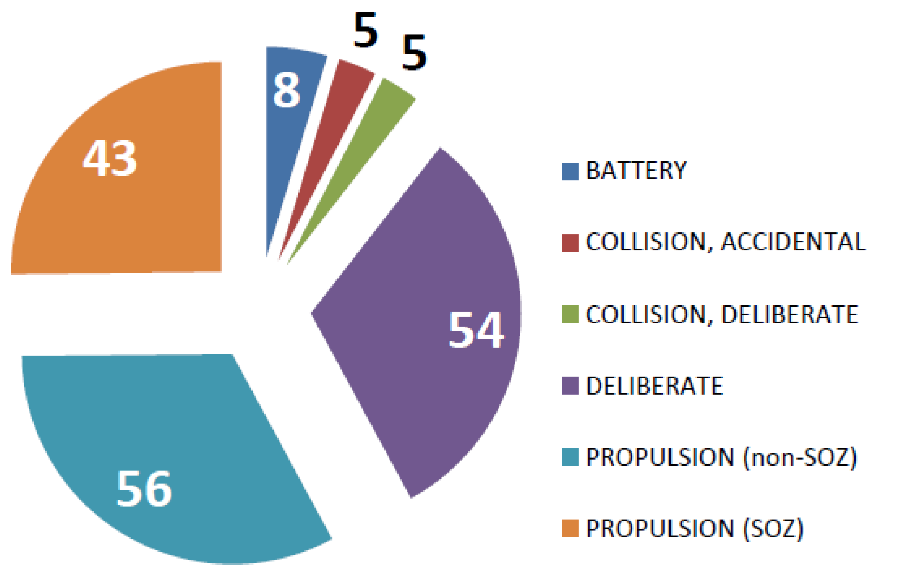
Introduction - what Space Debris Mitigation is about

Catalogued objects:

- Listed in the U.S. SPACE SURVEILLANCE NETWORK “TLE” catalogue, with assigned origin, regular tracking 16,906 as of 31 December 2014, but extrapolations lead to more than 25,000 objects > 10 cm and 750,000 between 1 and 10 cm.

Objects origin:

- About ~60% of objects, ~240 break-up events (according to ESA DISCOS database as of May 2014):
  - 31% due to propulsion system
  - 3% due to battery
  - 5% due to collision
  - 24% due to deliberate break-up
  - 36% unidentified causes



Space Debris Mitigation documents

Guidelines, Standards, Regulations
International, Regional, National

Space Debris Mitigation Standards and Guidelines

EUROPEAN COOPERATION ECSS FOR SPACE STANDARDIZATION

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

IADC

International:

- In 1993, the Inter-Agency Debris Coordination Committee (IADC) was formed (now composed of 13 national Space Agencies). In 2002, IADC published the “Space Debris Mitigation Guidelines" and presented to the UN-COPUOS STSC

- In 2007, the UN-COPUOS STSC 63 STSC member nations approved the "UN Space Debris Mitigation Guidelines“ as voluntary high-level space debris mitigation measures
- Many other international documents: ITU, FCC…

Standards development: ISO

International:

- The development of space debris mitigation standards within the ISO committee TC20/SC14 "Space systems and operations", started in 2003, with the participation of 13 nations (Brazil, China, Finland, France, Germany, India, Italy, Japan, Kazakhstan, Russian Federation, Ukraine, United Kingdom, and United States):
  - 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 an 'ad hoc" Orbital Debris Working Group (WG7) to lead this activity
  - The ISO key document is "**ISO 24113 - Space Debris Mitigation**", 2nd ed., May 2011) is based on the IADC and UN guidelines
  - Several other lower level standards have been developed by ISO TC20/SC14

Standards development: ECSS

European Cooperation for Space Standarization (ECSS)

Voting members

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National Space Agencies

Italy

France

Germany

The Netherlands

Norway

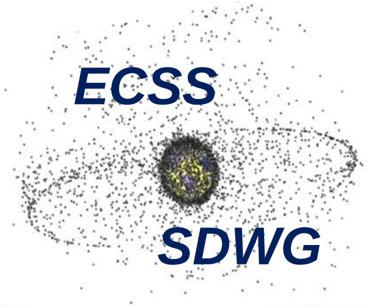
United Kingdom

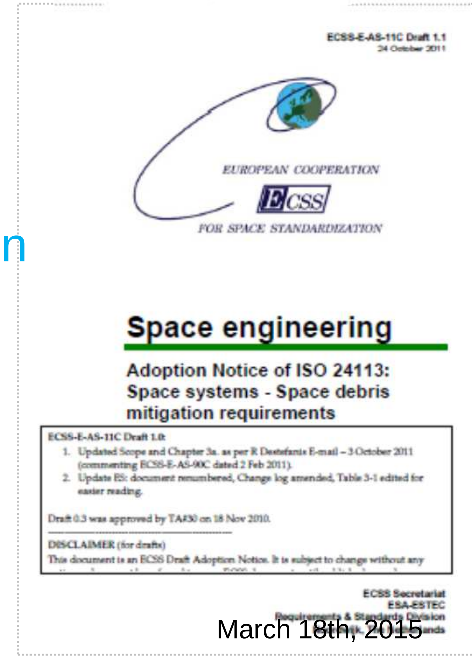
Canada

Standards development: ECSS

International / regional:

- The European Cooperation for Space Standardisation (ECSS) decided in 2003 to set up a ECSS Space Debris Working Group (SDWG) to:
  - Contribute to the development of world wide space debris implementation standards in the framework of the ISO TC20/SC14
  - Use the European Code of Conduct for Space Debris Mitigation (developed on cooperative basis among interested space agencies in Europe) as a reference for the implementation standards requirements
- ECSS relies on ISO to produce norms related to SD:
  - Key standards adopted by ECSS: ECSS-U-AS-10C Adoption Notice of ISO 24113: Space systems - Space debris mitigation requirements published February 10, 2012
  - Decision on a case-by-case basis
  - Modifications, delta requirements, interpretations, as necessary




ECSS-E-AS-11C Draft 1.1
24 October 2011

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space engineering

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

ECSS-E-AS-11C Draft 1.0:
1. Updated Scope and Chapter 3a. as per R Destefanis E-mail – 3 October 2011 (commenting ECSS-E-AS-90C dated 2 Feb 2011).
2. Update ES: document renumbered, Change log amended, Table 3-1 edited for easier reading.

Draft 0.3 was approved by TA#30 on 18 Nov 2010.

DISCLAIMER (for drafts)
This document is an ECSS Draft Adoption Notice. It is subject to change without any

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division

Standards development: ESA

International / regional:

- 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

Standards development: France

National:

- 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

4 juin 2008 — JOURNAL OFFICIEL DE LA RÉPUBLIQUE FRANÇAISE — Texte 1 sur 129

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

Article 1[er]

Pour l'application de la présente loi, on entend par :

1° « Dommage » : toute atteinte aux personnes, aux biens, et notamment à la santé publique ou à l'environnement directement causée par un objet spatial dans le cadre d'une opération spatiale, à l'exclusion des conséquences de l'utilisation du signal émis par cet objet pour les utilisateurs ;

Standards development: other nations

In 2007, NASA policy was established to control the generation of orbital debris:

- NASA Procedural Requirements 8715.6A,
- NASA Technical Standard 8719.14 (2007)

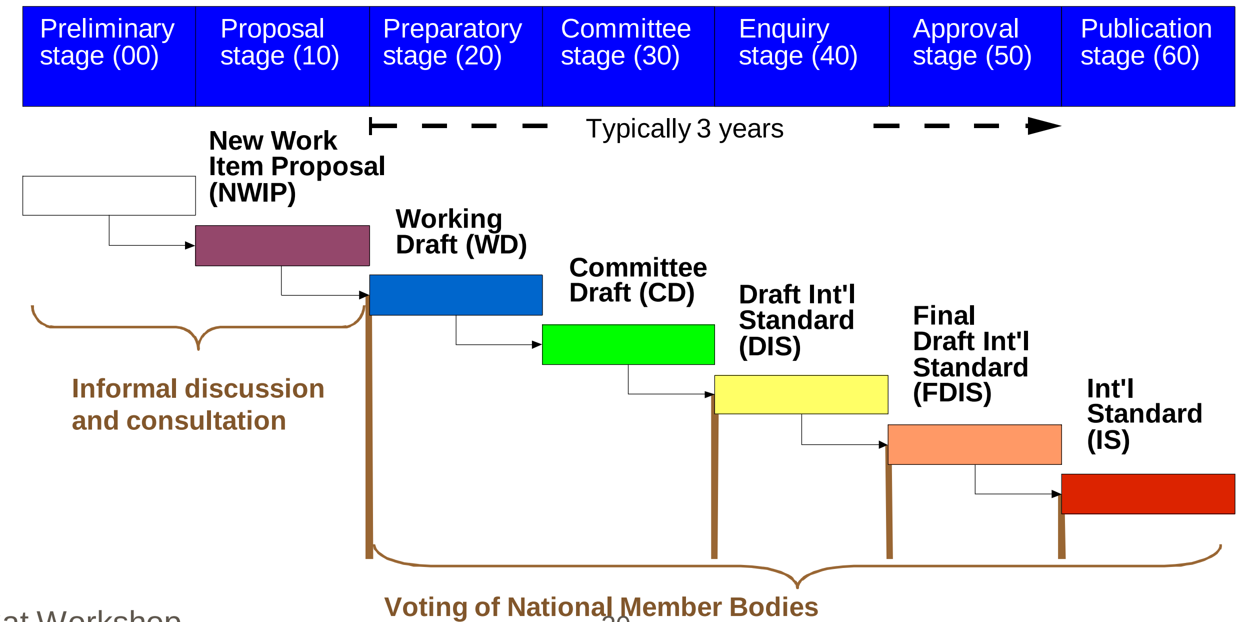
National standards / regulations are also used by several agencies (ROSCOSMOS, JAXA, UKSA, DLR…)

Space Debris Mitigation

ISO development activity and process

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 TC20/SC14 ORBITAL DEBRIS MITIGATION STANDARDS

WG1 DESIGN
- Tests of small-scale satellites (19683)

WG2 INTG & TEST

WG3 OPERATIONS
- <u>Disposal at GEO</u> (26872)
- <u>Disposal in LEO</u> (16164)
- Estimating mass remaining usable propellant (23339)
- Re-entry Risk Magment for unmanned S/C (27875)
- <u>Estimation of orbit lifetime</u> (27852)
- Orbit determination and estimation (11233)
- Avoiding collisions with orbiting objects (16158 TR)
- Disposal of Orbital Launch Stages (16699)

WG4 ENVIRON.
- Process-Based implementation of M/D Env. Models (14200)
- Earth atmosphere density (14222)

WG5 MANAGEMENT

WG6 MATERIALS

WG7 (ODWG)
- <u>Space Debris Mitigation</u> (24113)
- <u>SDM Design and Operation Manual for S/C</u> (18146)
- Test procedures for S/C material ejecta upon HVI (11227)
- Survivability of unmanned S/C against SD and MM impacts (16126)
- <u>Prevention of Break-up of of un-manned S/C</u> (16127)

Notes
As of February 2015
1) Abbreviated titles used
2) Text colour code:
Green: IS published
Brown: FDIS stage
Red: DIS stage
Blue: CD stage
Black: WD stage
4) <u>Items of ECCS high priority underlined</u>
5) Controversial items not shown.
6) To be added: TR – SDM Design and Opes Manual for LV

Main Space Debris Mitigation Clauses

Main Space Debris Mitigation Clauses

EUROPEAN COOPERATION ECSS FOR SPACE STANDARDIZATION

Many documents, but similar main clause / guidelines

Clauses developed initially with a top down approach:

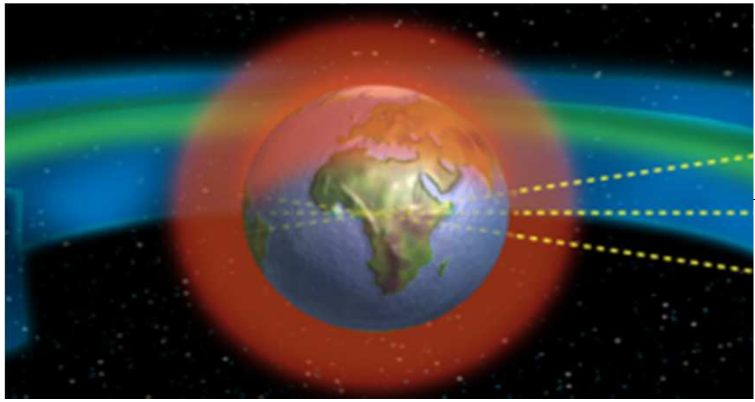
- Protected regions
- Avoiding the intentional release of space debris (MRO) into Earth orbit as part of the nominal mission
- Avoiding break-ups in Earth orbit until EoL
- Remove spacecraft and launch vehicle orbital stages after EoM:
  - from GEO protected region to a higher orbit (> GEO + 200 km)
  - from LEO protected region within 25 years after End of Mission
    - Associated reliability rqmts
  - Passivation after the EoM
    - Associated reliability rqmts
- Evaluate and control of Re-entry Risk
- Avoid on-orbit collision
  - Trackable objects
  - Untrackable «small» objects

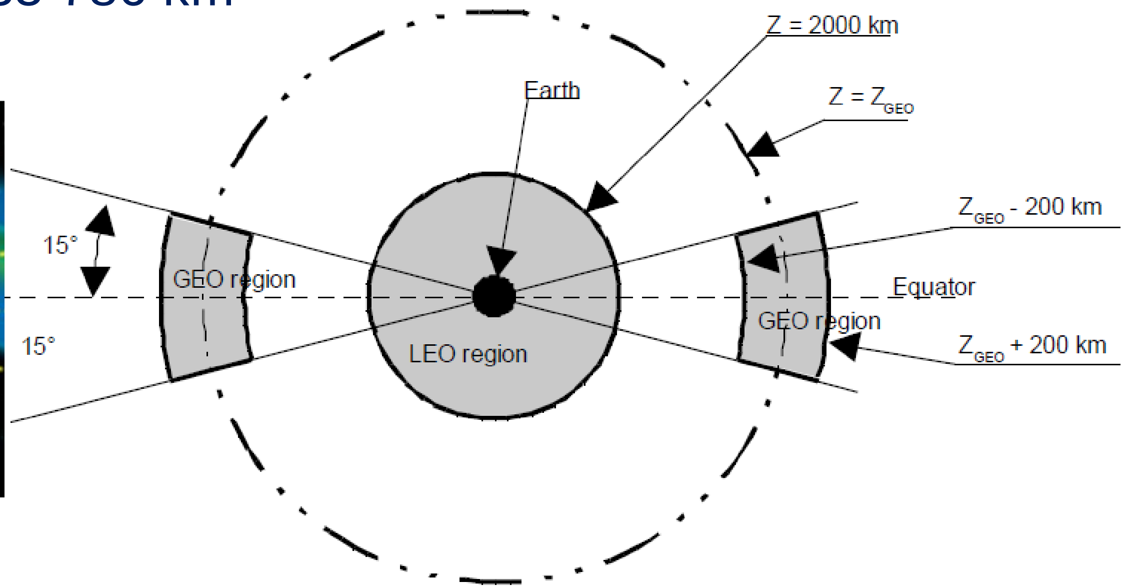
ISO/ECSS/ESA: Protected regions

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





ISO/ECSS/ESA: Avoid MRO

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

- Non-combustion debris: no objects are released
  - Debris identification: objects released as part of the nominal mission (if any) identified and listed
  - Lifetime data / calculation for each MRO identified:
    - If in LEO protected region → presence limited to < 25 years after release
    - If close to GEO protected region → show that remains outside the GEO
  - Debris released during launch operations (ECSS adoption) shall not exceed:
    - a. One, for the launch of a single spacecraft
    - b. Two, for the launch of multiple spacecraft
- Pyrotechnic devices: demonstrate that they do not release into orbit any particles > 1 mm.
- SRM products in GEO: no solid combustion products (ECSS adoption: larger than 1 mm) are released into the GEO protected region
- In LEO "..methods to avoid the release of solid combustion products that might contaminate the LEO protected region shall be considered".

ISO/ECSS/ESA: Avoiding break-ups in Earth orbit

Intentional break-ups

- Intentional break-up of a spacecraft or launch vehicle orbital stage to be avoided

Accidental break-ups

- The probability of S/C or LV 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.

- At the end of operations (and before its end of life), proper actions are to be taken in order to permanently 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.

ISO/ECSS/ESA: GEO EoM disposal

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

ISO/ECSS/ESA: LEO disposal

A S/C or LV operating in the LEO protected region, with either a permanent or periodic presence, shall limit its post-mission presence in the LEO protected region to a maximum of 25 years from the end of mission by:

- retrieving it and performing a controlled re-entry to recover it safely on the 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

Main issues: 25-yrs figure and prediction of residual lifetime

- Note, French Space Law rqmt is for "rentrée atmosphérique, de manière contrôlée" except "en cas d’impossibilité, dûment justifiée"

ISO/ECSS/ESA: Successful disposal (2)

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 and identify of S/S for disposal and disposal reliability calculations:
  - S/C bus, excluding P/L and unnecessary S/S / equipment
  - Reliability figures composed at functional level
- Obtained reliability is composed with the availability of the resources (e.g., propellant) at the time disposal is executed

ISO/ECSS/ESA: Successful disposal (3)

- Identification of capabilities / equipment for “passivation”, i.e., permanently deplete or make safe all remaining on-board sources of stored energy in a controlled sequence:
  - propellant, pressurizer, batteries, RF emission
- 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 probability to be composed with the probability figures obtained for the EoM manouver

- 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.

ISO/ECSS/ESA: re-entry risk (1)

No detailed requirements are given in ISO / ECSS on S/C or LV reentry maximum acceptable casualty risk. Requirements may be imposed contractually, voluntarily, or by Agencies or by national or international authorities.

- The re-entry of the S/C or LV shall comply with the applicable maximum acceptable casualty risk (note: 10^{-4} typically used as reference figure)
- Re-entry risk assessments (analyses, reports, etc.) are to be performed to show compliance with proper processes, methods, tools, models and data.

Requirements given in the ESA/ADMIN/IPOL(2014)2:

- [...] 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 …

ISO/ECSS/ESA: Reentry risk (2)

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)

Requirement evolution

Requirement evolution

Probability of succesfull disposal:

- Discussion on-going on the possibility to:
  - Split the requiremnt on availability of resources (eg propellant) and functional reliability
  - Set a probability requirement for the for the EoM removal, to be assessed accounting for all S/S and equipment needed at the time the manouver is executed
- Fixed value difficult to be agreed
- Different impacts on different types of S/C

Note, French Space Law:

- Probability of successful disposal of the S/C (LEO or GEO): necessary resources must be available with a probability > 0.9.

Requirement evolution

«Small satellites» or «lean satellites»

- Discussion on-going on Space Debris Mitigation issues related to «lean satellites»
- Applicability of SDM requirements is a mandatory request for all S/C, without relaxation for any specific class of S/C
- ISSO 19683, “Design qualification and acceptance tests of small-scale satellite and units seeking low-cost and fast-delivery”
  - “ Debris mitigation: Every satellite, regardless its size, value, capability or any other nature, shall comply with the debris mitigation requirement (ISO-24113)”.
- “Small” satellite issue to be careful monitored and discussed, to preserve the environment without limiting access to space and innovation

Requirement evolution

Avoid on-orbit collision for trackable objects

- The need to insert in ISO 24113 a requirement dealing with Collision Avoidance (COLA), perhaps making it required for only specific orbital regimes, emerged.
- Need for setting a risk threshold.
- A lower level ISO document exist: TR 16158 - Avoiding Collisions with Orbiting Objects

Avoid on-orbit collision for untrackable «small» objects

- The possibility to insert requirements on prevention of damage caused by impacts of micro-meteoroids and debris emerged.
- Several lower level standards exist:
  - ISO 16126 - Survivability of Unmanned Spacecraft against Space Debris and Meteoroid Impacts - Risk Assessment"
  - ISO 14200 - Process-based Implementation of Meteoroid and Debris Environment Models

Conclusions & Outlook

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.)