

Update of FSOA Technical Regulation

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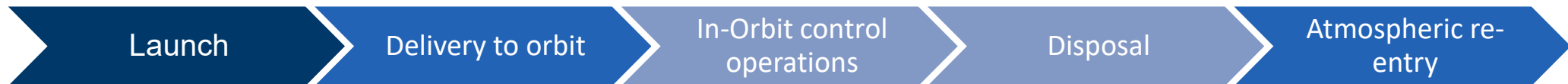
IAA Space Debris
Committee

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The French Space Operations Act and associated Technical Regulation

“The French Space Operations Act (FSOA / LOS) defines the frame used by the French government to authorize and supervise space operations under his responsibility”

- ✓ Ensure the **implementation by France of its international commitments** according to the UN Treaties on space law
- ✓ Create a framework to **oversee space operations carried out from French territory and by French entities**
 - ➔ **Authorization regime** for operations (launchers and orbital systems) in outer space
- **Technical Regulation (TR)** reflects the mandatory **technical requirements to be fulfilled** to obtain such authorizations
 - Deals with all aspects and all phases of space operations



- Objective: Ensuring the **sustainability** and **safety** of spaceflight
 - Long-term impact (footprint) of a mission on the environment (*Sustainability*)
 - Short-term impact (dangerousness) of the environment on a mission (*Safety*)
- Two main parts
 1. Launch of a space objet and return to Earth of elements of a Launcher
 2. **In-orbit control and return to Earth of a space objet**

Evolution of FSOA regulatory framework

• Context:

- Update of the French Space Operation Act (FSOA)
- Need to adapt the contents of the associated Technical Regulation (TR) to the New Space environment
 - ✓ Increased space traffic
 - ✓ Diversification and multiplication of space actors
 - ✓ Development of innovative systems
- Emergence of « **Space Traffic Management** » concept



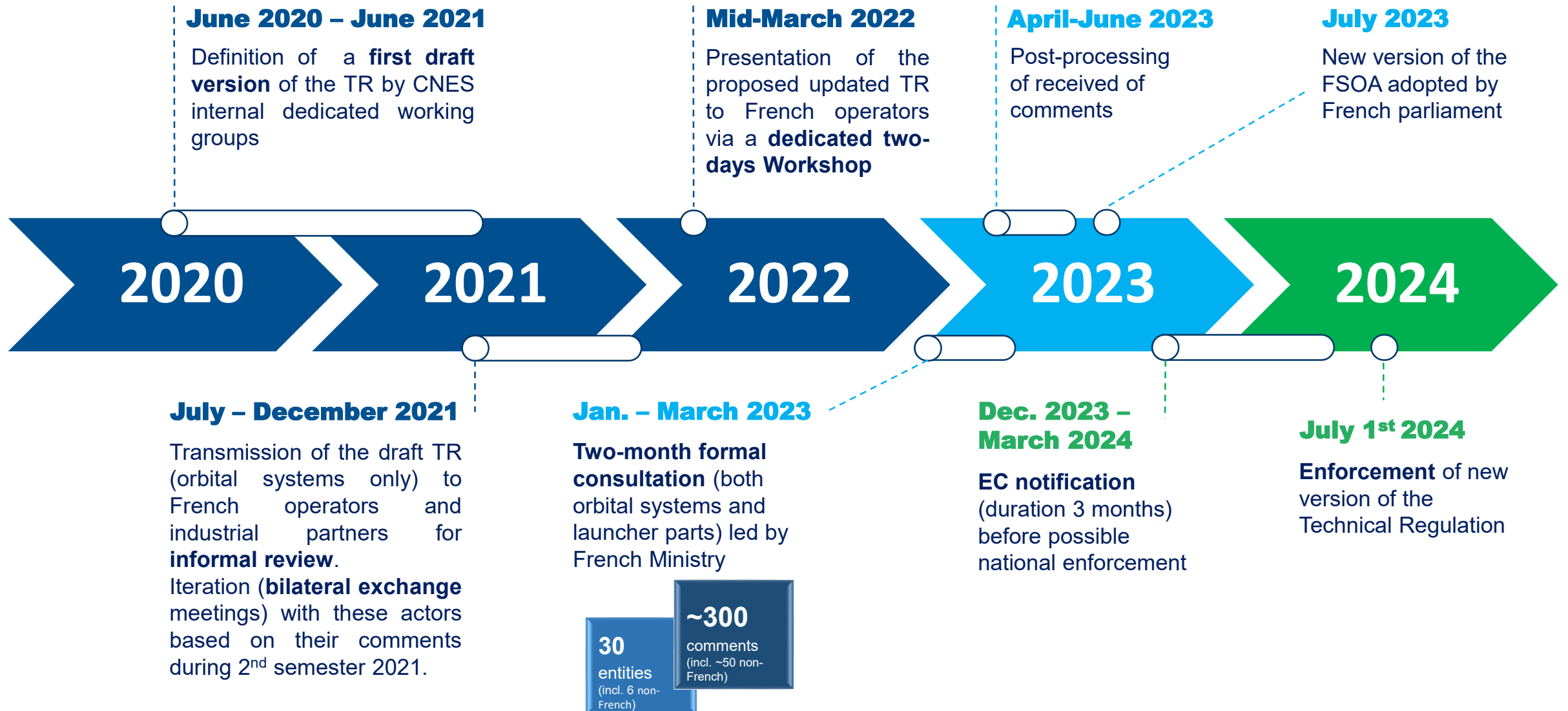
• Aim:

- Overcome the **risk related to debris** in orbit / **Limit debris generation** through preventive measures
- Pushing technological developments : **vector of innovation**
- Provide a **regulatory framework for new innovative activities** (e.g. On Orbit Servicing), cover other new topics (constellations, nanosats, ...) and better consider collision risks

• Methods:

- Work started in June 2020 with a feedback on the application of the current TR
 - **Close coordination with French ecosystem** all along the process
- Ensure **coherence with International standards** and regulations

Consultation and participation of the French space ecosystem



Requirements related to the conduct of space operations

Ability to control the space object – *no transitory measures*

Space systems shall be designed, produced and implemented in such a way as to enable the operator to receive, throughout the operation, **information on the state of the space object** and to **send commands** with the aims **to ensure the prevention of collisions** in orbit and the **ability to perform disposal actions** or any operation necessary to preserve the integrity of the object.

- Sending a non-communicant S/C is not permitted by FSOA
- Dimensioning of TM/TC chain in order to fulfil the main objectives of the TR
 - TM link to obtain regular information on state of the object and its orbital position
 - TC to be able to interact with the object and change its state/position whenever required



Identification of space objects – *transitory measures until 31 December 2028 (file submission)*

Space systems shall be designed, produced and implemented and their mission defined so that any space object is **unambiguously identifiable as soon as possible and no later than 3 days after injection** by space surveillance systems

- Addresses in particular 'small objects' injected simultaneously
- No mandatory carrying of dedicated on-board equipment (radar/optical reflector or transponder), can be ensured by sufficient separation between injected payloads
- For maneuvering objects launched in clusters, one week is acceptable, for non-maneuvering objects, a detectability within 3 days is acceptable

Prevention of fragmentation

Intentional release of debris – *no transitory measures*

Space systems implemented by the operator shall be designed, produced and implemented in such a way as **not to generate debris during the operation when it is conducted nominally**

The above provisions do not apply to:

- pyrotechnic systems. However, these shall not generate products greater than or equal to 1 mm in their largest dimension;
- solid or hybrid rocket motors. These shall not however generate combustion debris greater than or equal to 1 mm in size in the protected regions A and B.

- For S/C, one exception allowed regarding the release of a “service module” which has to respect the other requirements of the TR
- For launchers, 1 element (e.g. stage) may be placed into orbit for single launch, 2 elements for multiple launch



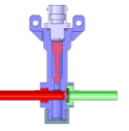
Accidental break-up – *no transitory measures*

The probability of occurrence of accidental disintegration of any space object shall be **less than 10^{-3} until the end of disposal phase**. Its calculation shall include the failed modes of propulsion and power systems, mechanisms and structures, but shall not take into account external impacts.

- Robustness of the design shall be confirmed from the design stage to guarantee very low probability of rupture
- Operator is requested to list sources of on-board energy and their failure modes
- Use of LBB systems, venting devices, electrical protections, shielding, long-term resistant materials... are to be considered to lower the risk



Prevention of fragmentation



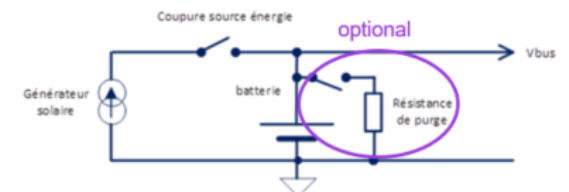
Passivation – no transitory measures

Any space object shall be designed, produced and implemented in such a way that, following the decommissioning phase:

- **all energy reserves on board are permanently depleted** or in such a state that they do not present a risk of generating debris
- **all means of generating energy on board shall be permanently deactivated**, or all equipment directly powered by such means of energy production is placed in such a state that it does not present a risk of generating debris;
- **all platform or payload radio electric transmission capacities shall be permanently disabled.**

The provisions of this Article do not apply to controlled re-entries

- Energy production means do not need to be deactivated if there is no risk of debris generation after end of life
- Acceptable solutions are described in Good Practice Guide
 - ✓ For electrical passivation
 - ✓ Energy production means isolation: opening circuits with SA sections recommended, short-circuiting of SA sections possible
 - ✓ Battery discharge through S/C loads (target SoC below 1% after 3 months)
 - ✓ In case no (or incomplete) electric passivation is implemented, present a justification file covering risks related to short circuit, over-voltage, over-temperature, collision at high kinetic energy, ...
 - ✓ For fluidic passivation, decrease residual pressure (objectives provided, or demonstrate final pressure at 200°C is below the burst pressure of the system) and the quantity of propellant in the tanks



Intentional destruction – no transitory measures

1. The operator shall **avoid the intentional destruction** of any space object in orbit.
2. When the operator intends to carry out an intentional destruction, it shall notify the Minister for Space of its necessity. This destruction may only take place at altitudes that are low enough to limit the lifetime in orbit of the fragments produced.

Prevention of collisions



Prevention of collisions at separation from a launcher or a dispenser – *no transitory measures*

- Each **injected object** shall be on a trajectory leading to **no collision with the launcher/dispenser**, or with the **other injected objects**, for a minimum duration of **5 days** following injection, or **until the space object is able to perform collision avoidance maneuvers**;
- Each **injected object** shall follow a trajectory that does not lead to a **collision with manned objects** for a minimum duration of **3 days** following injection, or **until the space object is able to perform collision avoidance maneuvers**

- Control the separation strategy which guarantees distancing between the various objects, and from manned objects
- For orbital systems, this has to be included in the launcher/dispenser interface document
- As soon as the object becomes maneuverable the risk is controlled, this can alleviate the constraint on the launch operator

Availability of collision avoidance maneuvers – *transitory measures until 31 December 2026 (file submission)*

Systems of maneuvering space objects shall be designed and implemented such that they are **available to perform a CAM** within maximum **5 days after injection**, or, in the case of a multiple launch of several satellites, as soon as possible after injection, by presenting a strategy minimizing the period of unavailability of the collision avoidance capacity.

- 5 days is considered to be sufficient time to initiate the operational loop with the collision avoidance services
- For multiple injections (e.g. for constellations), a typical delay of one week is acceptable
 - An operator can provide guarantees by the injection strategy adopted and via statistical estimate of the risks of collision with objects > 10 cm, while the collision avoidance system of the injected satellites is not active
- **Request to present a strategy that minimizes the period of unavailability of the collision avoidance capacity**

Prevention of collisions

Threshold for collision avoidance maneuvers – *no transitory measures*

In the event of a collision alert with a catalogued space object, **collision avoidance measures shall take priority** over the mission. The **collision probability threshold** requiring collision avoidance measures **shall be defined**, and its relevance justified, **in the operational concept**

- Methods used for evaluating collision probabilities vary according to the operators/entities
 - Not possible, at this stage, to have an internationally recognized method
 - European Best Practices recommended in the Good practices guide
- So as to avoid any kind of collision probability threshold, relevance of the chosen threshold needs to be justified (e.g. using recommended practices, through dedicated analysis of the residual collision risk with catalogued objects depending on the selected threshold, ...)

Coordination in the event of a collision alert between two operators of maneuvering space objects– *no transitory measures*

In the event of a known collision alert between two maneuvering space objects, **the operator shall coordinate with the other operator to decide on a maneuvering strategy** leading to the maneuver of at least one of the two objects

- Initially a priority rule has been proposed (based on S/C presence in orbit, then eccentricity)
- No consensus could be found and requirement would only make sense if it was applied at the international level
- Scope is therefore limited to a coordination between operators

Prevention of collisions



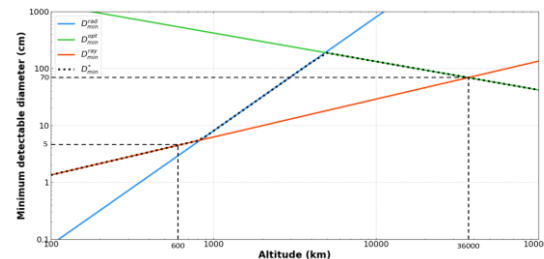
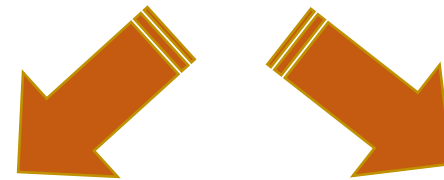
Probability of collision with a space object – *no transitory measures*

The probability of occurrence, calculated before launch, **for the entire life of the space operation**, of an accidental collision with a space object larger than 1 cm shall be **assessed and minimized**. Additionally, this estimation shall include the reentry phase for objects operating in protected region A.

- Introduction of the necessity to minimize the probability of collision with any object larger than 1cm
- Clarification that this is the integrated probability over the entire orbital life of a space object in protected region A (including natural re-entry once the system is passivated), and not just during its operational lifetime
- Confirmation of threshold via internal studies not yet available, so a simple assessment is requested for now
- Recommended method described in a Good practice guide

Non-trackable objects

- Objects that are currently difficult to detect
- Purely statistical study
- Dedicated methodology taking into account orbit propagation and estimation of flow of objects impacting on average the target orbit



Trackable objects

- Objects taken into account in spacecraft collision avoidance process
- Take into account the methods for managing collision avoidance (in particular adjustment of the PoC threshold and target residual risk)

Prevention of collisions

Data sharing – *transitory measures until 31 December 2026 (file submission)*

The operator shall **share, as soon as possible and no later than 3 days after injection**, with any pertinent actor or entity, **the necessary up-to-date information** to monitor the risks of collision with catalogued space objects it may encounter. This information shall include **at least ephemeris** (from own orbit restitution means, or space surveillance systems), **maneuver plan and covariance**

- Includes at the same time the « *Knowledge of space objects orbits* » and the « *Data sharing needs* »
- Quality of the data provided should be checked (in particular covariance matrices)
 - Data may be certified by an external body
- The frequency of data delivery is ideally once a day, although in GEO orbit once every three days is generally sufficient
- Good practices provided together with the requirement
 - Have redundant orbit determination methods (e.g. angular and Doppler measurements)
 - Configure several stations for first acquisition, on different sites, and considering margins on the expected visibility
 - Favor continuous functioning of the onboard transmitter as soon as the onboard energy constraints allow it
 - Being able to receive orbit information from external entities
- For non-maneuvering objects best possible strategy taking into account the definition of the space object(s)



Prevention of orbital saturation

Obligation of disposal – *no transitory measures*

- a) The space systems shall be designed, produced and implemented such that, following their operational phase, they perform disposal actions by either: 1. release from Earth's gravitational pull; **or** 2. atmospheric re-entry, whether controlled or not; **or** 3. entering a graveyard orbit between protected region A and protected region B; **or** 4. entering a graveyard orbit above protected region B.
- b) For objects operating **in an orbit included in or passing through protected region A, only a release from the operational orbit by an atmospheric re-entry is permitted.**
- c) For objects operating in an orbit included in or passing through protected region B, if the targeted graveyard orbit has an eccentricity below 0.1, it shall be located above protected region B

- Only allowed strategy for LEO is an atmospheric re-entry (only change with respect to previous version)
- No order of preference defined, specific requirements for each case are detailed via dedicated articles

Limitation of the orbit of non-maneuvering space objects – *no transitory measures*

Systems **not equipped with propulsion capable of modifying the orbit** shall be designed, produced and implemented for **orbits with an apogee of less than 600 km**

- Objective to prohibit satellites not equipped with propulsion systems above 600 km because they cannot perform collision avoidance maneuvers (as currently most debris are located around 700-900km altitude)
- Drag enhancing devices are not considered to be propulsion devices
 - This requirement is not redundant with the requirements on reentry duration after end of life
- Performance of the on-board propulsion system shall be justified to be considered maneuvering object



Prevention of orbital saturation

Maximum orbital lifetime before atmospheric re-entry – *transitory measures until 31 December 2026 (file submission)*

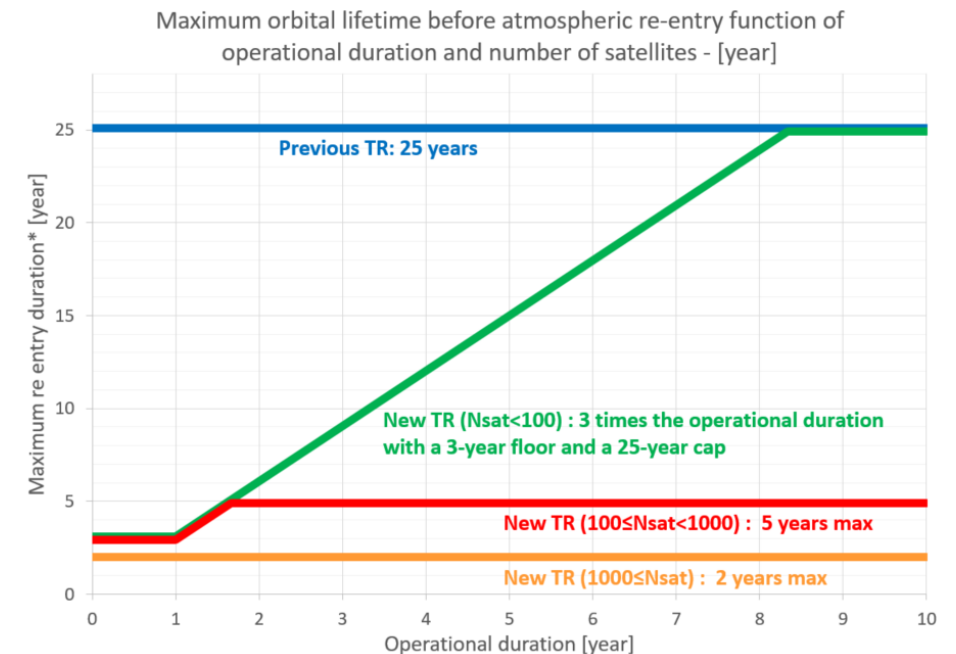
Residual orbital lifetime in LEO may not exceed **3 years** for systems with an operational phase of less than 1 year, **or 3 times the operational phase**, and in any case **may not exceed 25 years**. Residual duration in orbit is **considered as soon as the absence of a maneuvering capacity**.

- Decision to link re-entry duration to mission lifetime rather than specifying a specific threshold
- Maximum allowed re-entry duration of 25 years, and minimum of 3 years to allow for demonstration missions
- **Best possible strategy to achieve the objective of the article, within the limit of 25 years**

Maximum presence in orbit following disposal of large constellation satellites – *no transitory measures*

For **large constellation** satellites in LEO, residual orbital lifetime shall be limited to: **5 years** for large constellations whose total number of satellites is less than 1000 **or 2 years** for large constellations whose total number of satellites is greater than or equal to 1000.

- Objective to limit the deorbit duration given the scale factor
- 1000 chosen arbitrarily as an order of magnitude above 100 (defining the limit for a large constellation)
- *Note: first requirement still needs to be fulfilled for large constellations*



Prevention of orbital saturation

Characteristics of a graveyard orbit above protected region B – *no transitory measures*

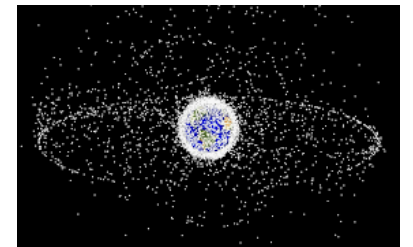
A graveyard orbit above protected region B shall be such that, under the effect of natural disturbances, **within one hundred years of the end of the operation, the space object does not return to protected region B.**

- No change with respect to previous requirement
- First approximation is reminded in Good Practice Guide, but the use of an orbit propagator tool is recommended (e.g. STELA)

Characteristics of a graveyard orbit between protected region A and protected region B – *no transitory measures*

A graveyard orbit between protected region A and protected region B shall be such that, under the effect of natural disturbances and associated uncertainties, **within one hundred years of the end of the decommissioning phase, the space object does not return to either protected region A, nor protected region B**, nor interferes with the **operational orbits of the constellations** already present between these two regions

- Newly introduced requirement, not present in the 2017 version, to tackle MEO orbits disposal
 - Inspired by ODMSP requirement with the aim to protect regions A and B as well as GNSS constellations
- It is recommended to use low eccentricity disposal orbits to limit the affected orbital zones
- Concerning the mention to “operation orbits of constellations”, the operator shall explicit the logic behind the selection of the disposal orbit based on the constellations present at time the FSOA filing is provided



Prevention of orbital saturation

Reliability of decommissioning operations – *transitory measures until 31 December 2026 (file submission)*

The probability of being able to successfully carry out the disposal operations (including passivation operations as well as disposal maneuvers) **shall be equal to or greater than 0.9**

- Space debris / meteoroid impact probability assessment not included
- Reliability computation method described in the Good Practice Guide
 - ✓ First step is to identify the equipment needed for disposal activities (taking into account nominal and potential alternative scenario)
 - ✓ Then evaluation of failure rates is necessary (no method made mandatory, although the operator shall justify its relevance)
 - ✓ e.g. Incorporation of feedback from previous missions, reliabilities provided by manufacturers, equivalent to other equipment, ...
 - ✓ Reliability is computed on the cumulated duration in orbit, taking into account realistic operational temperatures
 - ✓ It is recommended to consider the probability to have propellant availability within the probability of successful disposal
- A probability of 0,85 is requested until end 2026 (transitory disposition)

Reliability of decommissioning operations for constellations – *transitory measures until 31 December 2026 (file submission)*

Each satellite in a constellation shall have a probability of being able to successfully carry out the disposal operations (including passivation operations as well as disposal maneuvers) complying with the following rule:

- A constellation whose number (N) of satellites is **less than 50: $P > 0.9 + N \times 0.001$**
- A constellation whose number (N) of satellites is **equal to or greater than 50: $P > 0.95$**

- Adaptation of the previous rule to take into account the number of S/C within a constellation
- A minimum probability of 0,85 progressive up to 0,9 is requested until end 2026 (transitory disposition)

Specific requirements for the return of objects



Quantitative objectives for human safety for return to Earth of a space object – *no transitory measures*

With regard to the return of a space object, the quantitative safeguard objectives, expressed as the **maximum probability of causing at least one casualty (collective risk) is 10-4.**

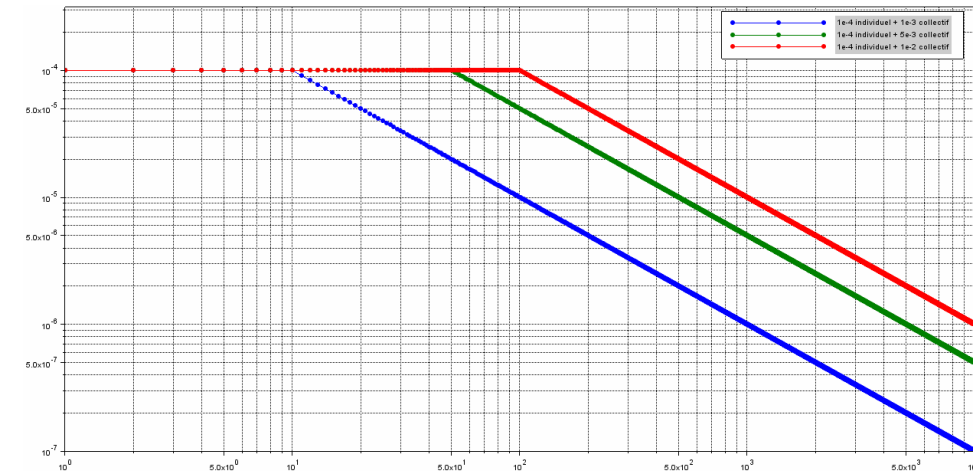
- Computation method described in details in the Good Practice Guide
- Recommended use of DEBRISK and ELECTRA software



Quantitative objectives for human safety for return to Earth for large constellations – *no transitory measures*

The quantitative safeguard objective including all returns to Earth of large constellation satellites, **expressed as the maximum permissible probability of at least one victim (collective risk), is 10-2.**

- Satellite of constellations have to respect the 10-4 individually
- Addition of a cumulative risk for large constellations
- Options considered:
 - 10-3 cumulative risk (blue curve) for any constellation
 - 5.10-3 cumulative risk (green curve) for constellations of 50 or more S/C
 - 10-2 cumulative risk (red curve) for large constellations
- Continuity until 100 S/C, then digressive threshold for large constellations



Specific requirements for In-Orbit Servicing

Introduction of 21 specific requirements broken down by mission phases

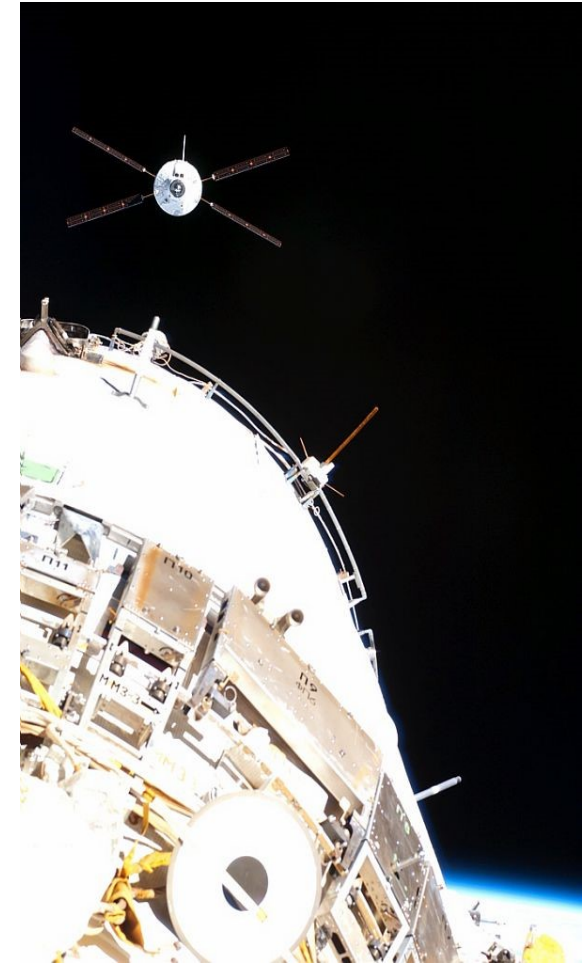
- ✓ For all phases (4)
- ✓ In the proximity area (9)
- ✓ During the approach and contact phases (4)
- ✓ In the attached phase (1)
- ✓ For separation and distancing phases (3)

Mainly coming from **CNES ATV experience and international guidelines** (ESA CPO, CONFERS, ...)

Focused on limitation of debris generation, e.g.

- Collection of intentionally created debris larger than 1mm in their largest dimension
- Ensure that entry into safe mode of the Servicer does not induce a collision risk with the Client
- Mandatory definition of Go/No-Go criteria to continue operations
- Necessity of inspection before docking to verify potential interferences
- Qualification of the concepts of approach and docking before in-orbit servicing
- Control of the composite and entity in charge for collision avoidance purpose
- Separation trajectory not creating short term collision risks between both objects

Preparation of platforms to ADR recommended via a dedicated requirement (with transitory measures and no specific interface required)



Specific requirements for Constellations



Introduction of 10 specific requirements, some specific to large constellations (>100 S/C)

- Requirements valid for any constellation:
 - ✓ Need to guarantee an **intra-constellation collision risk less than 10^{-3}** natural re-entry, or for 100 years
 - *Transitory measure until 31 December 2028 (file submission): present an analysis detailing the disposal strategy implemented in order to limit the risk of intra-constellation collision after end of life*
 - ✓ Define the geometry of the constellation to **ensure sufficient separation** between the satellites of that constellation in order **to ensure robustness against the risk of collision**
- Requirements specific to large constellations:
 - ✓ Large constellation spacecraft shall have an **on-board propulsion system** in order to be able to **implement collision avoidance maneuvers efficiently**
 - ✓ Perform **system testing from an intermediate orbit** (with **natural re-entry within 5 years and below the operational orbit**), on the subsystems of its platform needed for decommissioning
 - ✓ **Ensure sufficient radial separation** with other large constellations or **demonstrate robustness with respect to the risk of collision** between both constellations' spacecraft
 - ✓ Limit the optical disturbance of large constellation satellites by targeting an apparent magnitude greater than or equal to 7
 - *Transitory measure until 31 December 2028 (file submission): minimize optical disturbances*

FSOA TR implementation



✓ Guide of Good Practices

Assistance to operators who submit a *compliance file for FSOA authorization*.

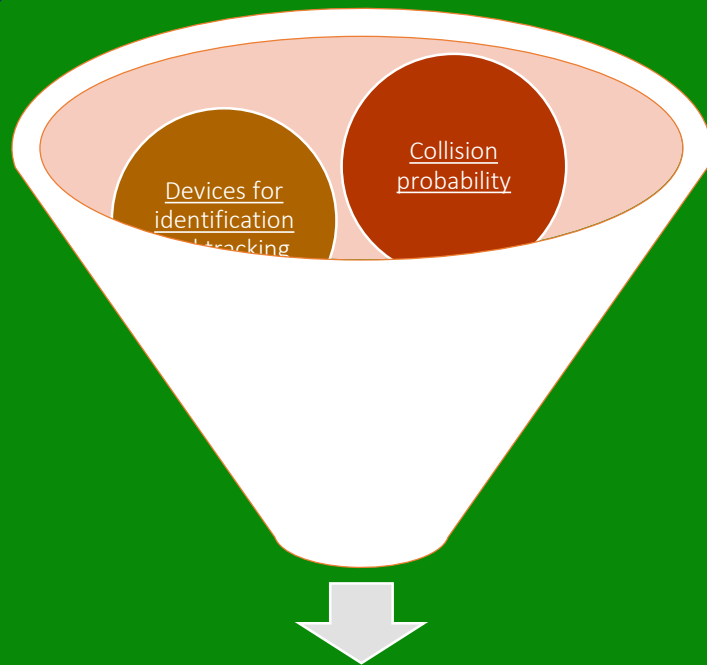
Proposals are made with the objective to reach compliance on various requirements of the Technical Regulation (TR)

- ❖ Covers the technical requirements of the TR. Other subjects (such as documentation / quality requirements) are covered by a FSOA manual made available to operators on a dedicated platform
 - ❖ **Recommended solutions** enabling to reach compliance, but **no compulsory measures**
 - Compliance is assumed to be acquired the relevant recommendations are implemented
 - ❖ No guarantee of completeness, regular updates provided following operator feedback or new technologies developments
-
- ✓ **Software tools** to meet certain criteria required by the FSOA Technical Regulation are provided free of charge to operators and strongly recommended.
 - ❖ **STELA** : Orbit propagator
 - ❖ **DEBRISK** : Fragmentation analysis upon atmospheric re-entry
 - ❖ **ELECTRA** : Casualty risk for different types of re-entries



Technologies development: T4SC

The aim of **Technologies For Space Care (T4SC)** program is to develop technological solutions allowing the platforms to comply with the technical regulations of the FSOA and their evolutions without harming the competitiveness of national industry



Set of coordinated actions using all the tools and skills available at CNES

- Push the industry to evolve and develop on these specifications
- Mature these technologies
- Flight demonstration
- Low cost high reliability
- Available in same time as enforcement of the TR