30 YEARS OF SPACE DEBRIS MITIGATION GUIDELINES IN EUROPE

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ABSTRACT

The space debris issue was not immediately identified in the beginnings of the space conquest: the main risks seemed to come from meteorites. The early returns of spacecraft on Earth revealed small size impacts by non-natural particles. The link was quickly established with several in-orbit explosions of launcher upper stages that generated these objects. Under NASA leadership the first passivation measures have successfully been applied to deal with this situation. This led to the NASA standard containing the first preventive measures.

For its part, Europe began to implement mitigation measures as early as 1983 when performing the end of life operations of the Symphonie A and B satellites, and was later faced with the in-orbit explosion of an Ariane upper stage in 1986. This situation pushed the CNES to develop its own standard on space debris derived from the NASA standard. The work in this context was then extended to the main European partners: 5 space agencies, ASI, BNSC, CNES, DLR and ESA formed a working group to develop the technical content of preventive measures. After extensive discussions this work finally resulted in the publication of the EDMS (European Debris Mitigation Standard) and later of the CoC (Code of Conduct on space debris mitigation) in 2004.

In 1993 the debris subject became truly international with the establishment of the IADC (Inter Agency Space Debris Coordination Committee) and with the start of activities in the frame of the United Nations Scientific and Technical Subcommittee of the COPUOS (Committee on Peaceful Uses of Outer Space). Two major documents have materialized this work: in 2002 the IADC Mitigation Guidelines were published and the high level principles of COPUOS in 2007. These documents are still the technical and political bases of all regulations. In parallel, the ISO has developed, with strong involvement of European partners, a set of detailed standards on space debris to facilitate their application by manufacturers and operators.

These measures have initially been applied on a voluntary basis by space agencies and by some operators. However, according to the Treaties of the United Nations, States are responsible for activities conducted in space by their operators. This led to the establishment of national regulatory regimes in some countries as the licensing systems in the U.S and in UK or the Space Operations Act in France.

1. DISCOVERY OF THE PROBLEM

In the early days of the space age the main fear came from meteorites: available models were very rough and the review of the first vehicles back to Earth showed that they greatly overestimated the risk. Alongside the risk debris appeared gradually. The first fragmentation in space occurred in 1961: on June 29 an upper stage Able Star exploded two hours after injecting the US satellite Transit 4A. The event produced at least 294 trackable fragments.

Other fragmentations followed this event:

- in 1965 another US Titan 3C upper stage exploded at an altitude of 739 km adding 475 trackable debris to the terrestrial environment [1].
- in 1968 the USSR realized 2 anti-satellite tests (ASAT): Cosmos 249 and Cosmos

252, producing 110 and 140 trackable fragments in orbits with long life (2135 km x 538 km).

Some experts are beginning to evoke the very long orbital lifetime of some orbital debris, sometimes more than a century.

As part of the Apollo program the first calculations of collisions with artificial objects are made and the risk is considered negligible. The general consensus is that space is large, that the objects remain intact, and that the atmosphere provides a natural cleaning.

In 1974 surface examination of the Apollo capsules in the frame of the Skylab missions highlighted hypervelocity impacts, initially attributed to meteorites. Subsequent analyzes showed that this was also space debris (B. Cour-Palais). In 1977 D.Kessler and B.Cour Palais predicted that the risk from space debris will soon exceed the risk from meteorites [2].

The risk from space debris appeared more clearly when the first projects were planned for long-duration missions with larger vehicles: manned stations such as Skylab and the SPS projects (solar power stations) in geostationary orbit. The calculations of risk of collision with small objects have been reworked and the results appeared more significant. Similarly the ground risks in the event of a falling space object began to be identified with the reentries of Skylab, Salyut 7 and Cosmos 954 (24 January 1978).

The awareness of this new risk led in 1979 to the establishment of the orbital debris program at NASA JSC (decision C.Kraft especially with the participation of D.Kessler and J.Loftus), but the subject is barely recognized at NASA and much less at national and international level.

2. FIRST MITIGATION MEASURES BY NASA

In 1981, following an explosion of a new launcher stage Delta after three years in orbit, it was decided to drain the residual propellants at end of mission: this is the first set of preventive measures. The information is also sent to Japan, which had a similar launcher.

In the early 1980s observations show that an uncatalogued population exists and is more important for satellites operations than the catalogued population:

- discovery of aluminum residues in impacts observed on Apollo capsules in the frame of the Skylab missions (1981)
- observation of solid rocket burns in geosynchronous orbit by the reflection of sunlight and highlighting alumina dust produced.
- in June 1983 a window of the shuttle STS 7 had to be changed because of an impact diameter 4mm containing titanium residue (debris): it was shown for the first time that an uncatalogued debris could damage a spacecraft. (particle of 0.2 mm to 5 m/s)

In 1988 the presidential directive on national space policy, signed by President Reagan, actually marks the beginning of mitigation activities.

This Directive established the policy that all space sectors will seek to minimize the creation of space debris [2]. The Directive also established a process to implement that policy. The directive further states that design and operations of space tests, experiments and systems will strive to minimize or reduce accumulation of space debris consistent with mission requirements and cost effectiveness.

Finally after several years of effort NASA released in August 1995 the first document containing the orbital debris mitigation guidelines: NASA Safety Standard (NSS) 1740.14 Guidelines and Assessment Procedures for Limiting Orbital Debris. This document established the basic principles that will be taken later in all other documents [3]:

- the limitation of the release of mission-related debris.
- the limitation of risk of collision with both large and small debris.
- a 25-year rule to limit the post-mission lifetime of all NASA payloads, rocket bodies, and mission-related debris to 25 years or less.
- the protection of the GEO belt for active spacecraft, ensuring that any object moved to a super-GEO orbit does not reenter the GEO regime for over 100 years (which usually means it will never reenter the GEO regime).

- a reliability metrics in excess of 90% for systems needed to attain post mission disposal.
- The depletion of onboard energy sources after completion of mission.
- the limitation of the risk of human casualty to be less than 1:10,000 for any reentering object.
- the limitation of the lifetime and sever risk of tethers.

3. EXPLOSION OF ARIANE STAGE V16

On 13 November 1986 the upper stage of Ariane flight V16 which launched the satellite Spot1 exploded in orbit. The near-circular 800 km altitude and highly inclined (98 degrees) orbit facilitated the detection of debris produced during this event. To date this fragmentation was the worst event in space with the production of over 500 cataloged debris with lifetimes in orbit of several decades, and even more than a century for some of them. This event had two important consequences: the start of work on space debris in Europe and the confirmation of the international nature of the issue.

3.1. Beginning of the activities in Europe

The first prevention measures were implemented in 1983 and 1984 by DLR and CNES to manage the end of life of Franco-German Symphonie satellites A and B. These satellites were launched into geostationary orbit in 1974 and 1975. The purpose of the end of life operations was only to release the geostationary operational corridor: the altitude of the two satellites was increased by about 50 km. Today this value is deemed insufficient but it already shows a willingness to protect the geostationary orbit.

But it is really the explosion of the Ariane V16 stage in 1986 which resulted in the start of debris activities in Europe. Building on its experience following the fragmentation of Delta stages, NASA quickly informed ESA and CNES on the severity of the problem and the passivation solutions to consider.

Thus a "breakup upperstage conference" was held at the Johnson Space Center in May 1987 to share information available. Following this event ESA has set up a "space debris working group" whose participation was open to European partners.

In 1988 the working group issued their report, which led to an ESA Council "Resolution on the Agency's Policy vis-à-vis the Space Debris Issue" (approved as ESA/C(89)24 in 1989) where the main objectives of future activities were defined:

- minimize the creation of space debris to ensure safe access to space, and to reduce the risk for manned and unmanned space flight;
- reduce the risk on ground due to re-entries of space objects;
- reduce the risk for geostationary satellites;
- acquire through own facilities, or in cooperation with other space agencies the data on space debris which are necessary to assess the extent of the problem and its consequences;
- analyze the legal aspects of space debris.

The year 1987 marked the beginning of systematic space debris research in Europe. This work was initially coordinated by a Space Debris Advisory Group (SDAG). Subsequently, in 1999, the SDAG was replaced by a Network of Centres (NoC) Space Debris Working Group (SDWG), consisting of ESA, ASI, BNSC, CNES, and DLR [5].

Following the explosion of the Ariane V16 passivation measures on upper stages were quickly decided by CNES, which was responsible for the design of Ariane launchers at that time.

In continuation of these initial measures CNES has decided to develop its own standard, largely based on the NASA standard (MPM-CNES-51-00-12 Safety requirements - Space debris). This document was approved by the Director General of CNES (G.Brachet). It contained three sets of requirements:

- Management Requirements (Space Debris Manager for each program, Mitigation Plan): tailoring waiver, organization (space debris authority, space debris manager), reviews, mitigation plan.
- Design Requirements (Limitation by design of debris generation, casualty risk):
    - Prevention measures: Separation of components, Explosion, Powder and pyrotechnics,

Materials and technologies, Malfunction
    - Protection measures, Safety requirements, return phases requirement•
- Operational Requirements (Passivation, Protected Zones, 25-year rule, GEO rule): Passivation, Safety requirements, Avoidance maneuver, Disposal (Basic principles, Requirements for the orbital phase vehicles, Requirements for the suborbital phase vehicles

The first version of this document was published in March 1999. It was followed by several revisions to reflect the feedback. The standard was intended for internal projects CNES: its application was recommended, but the final decision remained in the hands of project managers. His main interest was to take stock of the essential measures to be implemented and used as a reference to inform and persuade various managers.

Most projects of launchers or satellites being developed in a European context, CNES proposed the document to other European agencies (ASI, BNSC, DLR and ESA) participating in the European space debris working group. A new working group was established to develop a European standard from the CNES standard. This led to the publication in September 2000 of the EDMS (European Standard Mitigation debris), then of the European Code of Conduct on space debris in June 2004 [5].

The primary objectives of the European Code of Conduct for Space Debris Mitigation are [6]:

- prevention of on-orbit break-ups and collisions,
- removal and subsequent disposal of spacecraft and orbital stages that have reached the end of mission operations from the useful densely populated orbit regions,
- limitation of objects released during normal operations.

The Code of Conduct defines 2 protected zones in space: the low Earth orbits (altitudes below 2000 km) and the geostationary region at large (+ or – 200 km around the geostationary altitude, + or – 15 degrees in inclination).

Management requirements in the Code of Conduct ask every project to prepare a space debris mitigation report containing among others the list of requirements, the compliance matrix and justifications for non-compliance. The content of the report must be submitted for each major project review.

Then the design requirements contain:

- preventive measures: limiting mission related objects, minimizing the risk of fragmentation, reduction of debris produced by solid propulsion and pyrotechnic devices, materials selection
- measures for end of life: tanks passivation, taking into account the de-orbiting or re-orbiting maneuvers.
- ground safety: non-contamination by hazardous materials, risks to ground <10-4 (except for France, which has specific requirements in the « Doctrine de Sauvegarde »)

Finally the third part gives requirements concerning operations:

- prevention measures: operating procedures
- measures for end of life: passivation, limitation to 25 years maximum duration of stay in protected areas, use of the IADC formula for defining the geostationary graveyard orbit, requirements for vehicles in Medium Earth orbit, probability of success of the end of life operations> 0.9

A major difficulty concerned the degree of implementation to the projects of these agencies. Finally, the code of conduct remained in the form of recommendations, exceptions being possible in some cases. However, the projects were asked to draft a complete compliance matrix clearly identifying unmet recommendations. In addition, to strengthen its application, the code of conduct was signed by the presidents or CEOs in order to clearly demonstrate the highest level of commitment of these five agencies in the fight against the proliferation of debris.

4. CONVERGENCE AT INTERNATIONAL LEVEL

A new version of the national space policy was signed by President G.H.W. Bush in November 1989 (National Space Policy Directives and Executive Charter, NSPD-1, November 2, 1989): this document confirmed the objectives of the activities on space debris and added a new goal for the USA: encourage other countries to implement measures to limit debris: « The United States government will encourage other spacefaring nations to adopt policies and practices aimed at debris minimization ».

International cooperation was then developed primarily at three levels: at the level of Countries under UNCOPUOS, at the IADC with Space Agencies and to the industrial level with ISO.

4.1. The IADC:

The Inter-Agency Space Debris Coordination Committee is a technically oriented intergovernmental organization created in 1993. Members are countries or national or international space organizations which are carrying out space activities, through either manufacturing, launching and operating spacecraft or manufacturing and launching rockets.

The members share a number of common interests in space debris research which may be developed into a variety of cooperative research activities.

The members of the IADC are the following space agencies : ASI (Italy), CNES (France), CNSA (China), CSA (Canada), DLR (Germany), ESA (European Space Agency), ISRO (India), JAXA (Japan), NASA (USA), NSAU (Ukraine), ROSCOSMOS (Russia), UK Space Agency (UK).

The main objectives of the IADC are:

- to exchange information on space debris research activities between member space agencies
- to facilitate opportunities for cooperation in space debris research
- to review the progress of ongoing cooperative activities
- to identify debris mitigation options.

Technical meetings are held annually to facilitate these cooperative research activities.

Among the many activities of the IADC can be noted: the conduct of coordinated campaigns to predict he re-entry of a space object, observation campaigns of small debris with optical or radar facilities, comparison of environmental models and its evolution, and the drafting of a protection manual for risk analysis in case of hypervelocity impact. But the main achievement of the IADC is the publication in October 2002 (revised 2007) of the document « IADC Space Debris Mitigation Guidelines » which is still the basis for all technical regulations around the world.

The 5 European space agencies, members of the IADC have played a major role in the preparation of this document.

4.2. The UN-COPUOS

The Committee on the Peaceful Uses of Outer Space (COPUOS) was set up by the General Assembly of the United Nations in 1959 to review the scope of international cooperation in peaceful uses of outer space, to devise programs in this field to be undertaken under United Nations auspices, to encourage continued research and the dissemination of information on outer space matters, and to study legal problems arising from the exploration of outer space.

The Committee has two standing Subcommittees: the Scientific and Technical Subcommittee (STSC) and the Legal Subcommittee (LSC).

In 2003 the Inter Agency Space Debris Coordination Committee (IADC) presented to the UN-COPUOS its proposal on space debris mitigation, which was then reviewed by the 67 Member States of the UN-COPUOS.

In February 2004 the STSC established a Space Debris Working Group (SDWG) with the objective to prepare a high level document defining “principles” that should take into account both the initial IADC proposal and the Member States comments. Fourteen Countries participated on a voluntary basis in the Working Group, with one observer, the European Space Agency (ESA).

The SDWG was able to submit to the UN-COPUOS a first proposal in June 2005. One year later the proposal was accepted by the STSC, with minor comments, and in June 2007 the COPUOS

endorsed the “Space Debris Mitigation Guidelines” and put it as an annex in its report to the UN General Assembly [4].

The Seven guidelines establish the high level principles for space debris mitigation:

1. Limit debris released during normal operations
2. Minimize potential for break-ups during operational phases
3. Limit the probability of accidental collision in orbit
4. Avoid intentional destruction and other harmful activities
5. Minimize potential for post-mission break-ups resulting from stored energy
6. Limit the long-term presence of spacecraft and launch vehicle orbital stages in LEO after the end of their mission
7. Limit the long-term interference of spacecraft and launch vehicle orbital stages with GEO region after the end of their mission

In its Resolution A/RES/62/217 “International cooperation in the peaceful uses of outer space”, published in January 2008, the General Assembly endorsed the Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space and agreed that the voluntary guidelines for the mitigation of space debris reflect the existing practices as developed by a number of national and international organizations, and invites Member States to implement those guidelines through relevant national mechanisms [4].

4.3. The ISO

In Europe the natural framework for the development of standards in the space domain is the ECSS (European Cooperation for Space Standardization). On the topic of space debris ECSS chose not to duplicate the work already underway as part of the ISO (International Organization for Standardization) but to be heavily involved in these activities. A specific working group, the ECSS working group on space debris was set up with the participation of space agencies, industry and European operators. Its aim is to strengthen and coordinate the European contribution to the development of ISO standards on the debris.

Within ISO, the standards on debris are prepared as part of the Subcommittee (SC) 14 of the Technical Committee (TC) 20. Work started in 2003 and resulted in the publication of the standard 24113 (Space Systems-Space Debris Mitigation Requirements) in 2006. This document is largely based on the European Code of Conduct and consistent with the mitigation guidelines of COPUOS and IADC. Its objective is to formulate the requirements for space debris in a measurable and verifiable form to facilitate their application in the context of industrial contracts. The 24113 standard contains all the requirements: this high level document is supplemented by several lower level standards (implementation standards) whose purpose is to specify the requirements, give justifications and suggest solutions and methods. The ECSS considers that 6 ISO implementation standards have high priority and imply a strong European participation

- ISO 26872 - Disposal of satellites operating at geosynchronous altitude
- ISO 27852 - Estimation of orbit lifetime
- ISO 16127 - Break up prevention of un-manned S/C
- ISO 16164 - Disposal of satellites operating in or crossing LEO
- ISO 16699 - Disposal of Orbital Launch Stages
- ISO 18146 - Design and Ops of S/C in the Orbital Debris Environment

5. THE PROBLEM OF THE APPLICATION

The various documents described above, NASA and CNES standards, European Code of Conduct, IADC Mitigation Guidelines, ISO 24113, UNCOPUOS guidelines are only recommendations. There is no text internationally legally binding on space debris. However, the texts of the United Nations (Outer Space Treaty of 1967 and 1972 Convention) define the responsibility of the launching States and indicate that these States should set up a legal mechanism to monitor the activities in space of their nationals: in case of damage on ground or in orbit, the States that meet the launching State criteria could be found liable and should compensate the victims.

5.1. ESA :

The European Space Agency (ESA), although an international intergovernmental organization, can be considered as a Launching State.

As International Organization ESA cannot become a Party to the Outer Space Treaty and the Registration Convention. However during its very first meeting on 24/25 June 1975, the ESA Council approved the text of ESA's Declarations of Acceptance concerning the Rescue Agreement and the Liability Convention. In December 1978 the ESA Council also approved the Declaration of Acceptance concerning the Registration Convention.

ESA fulfills several criteria of the registration Convention, therefore ESA is a Launching State.

The Code of Conduct contains the technical requirements: ESA however held that the document was impractical in its present form especially in binding business agreements. They considered that many of its provisions need to be clarified and implementation standards, associated with requirements, need to be established. This has led the Director General of ESA to sign the directive ESA/ADMIN/IPOL(2008) « Space Debris Mitigation for Agency Projects ». This instruction contains requirements for Agency projects. The requirements are applicable to all space vehicles, including launchers, satellites and inhabited objects. This directive is based on the technical requirements of the Code of Conduct.

The new version of the instruction, published in 2014, refers to the ISO 24113 standard, the technical content of which is very similar to the Code of Conduct.

5.2. United Kingdom

The Outer Space Act 1986 (OSA) is the legal basis for the regulation of activities in outer space (including the launch and operation of space objects) carried out by persons connected with the United Kingdom. The Act confers licensing and other powers on the Secretary of State acting through the UKSA. The Act ensures compliance with UK obligations under the international conventions covering the use of outer space to which the UK is a signatory [4].

Under the legislation of the OSA, the Secretary of State for the Department of Trade and Industry (DTI) shall not grant a license unless he is satisfied that the activities authorized by the license will not jeopardize public health or the safety of persons or property, will be consistent with the international obligations of the United Kingdom, and will not impair the national security of the United Kingdom. Further the Secretary of State requires the licensee to conduct his operations in such a way as to prevent the contamination of outer space or adverse changes in the environment of the Earth, and to avoid interference with activities of others in the peaceful exploration and use of outer space.

As appropriate the assessment should address:

- launch range risks
- risk to downrange areas due to the impact of discarded mission hardware
- over-flight risks
- orbital risks, including the risk of collision and/or debris generation, due to intermediate and final orbits of vehicle upper stages and payloads
- re-entry risks of vehicle upper stages and payloads.

This risk assessment is then used as a basis for the review conducted by assessors to determine if the applicant's proposed activities are compliant with the requirements of the Outer Space Act. The qualitative and quantitative criteria used for this evaluation are based on standards and practices employed by a variety of formal bodies. In each case, the assessor seeks to understand the approach proposed by the license applicant, to judge the quality of this process, to check the degree of consistency within the project, to consider the effectiveness of the proposed technology or process, and to establish its conformance with industry or Agency norms, and the requirements of the OSA.

Although the problem of space debris was not recognized when the OSA was enacted in 1986, the Act is flexible enough to allow interpretation to cover this aspect in the technical evaluation. Thus "physical interference" is used to address probability of collision with other objects in orbit and "contamination" to address safe disposal at end of life.

The IADC Mitigation Guidelines, the European Code of Conduct, and the UN Mitigation Guidelines provide qualitative and quantitative

measures that are used to assess compliance of license applicants' proposed activities and measures with recognized "best practice" within the community.
The most common license is a payload license. In that case, the safety assessors check the satellite platform's specification (e.g. attitude control system, orbit, power storage mechanism, launcher interface and separation mechanism) and the safety processes (plans and procedures) to assess their effectiveness at space debris mitigation.

5.3. France

France has chosen to implement a law on space operations: the aim is to establish a national licensing and control system of space activities conducted under French jurisdiction or where France bears international responsibility in accordance with United Nations Treaties.

Shall obtain an authorization:

- Any operator, regardless of its nationality, who intends to launch a space object from the French national territory or resources or facilities under French jurisdiction,
- Any French operator who intends to launch a space object from the territory of a foreign state or from a territory not subject to the sovereignty of a State.
- Any individual possessing the French nationality or any French corporation headquartered in France who intends to proceed with the launch of a space object or any French operator that controls such an object during its stay in space.

The authorizations are granted by the Minister in charge of Space after implementing the following procedure:

- Administrative review by the Minister of legal, financial and professional guarantees of the operator
- Technical Instruction by CNES: systems and procedures must comply with the Technical Regulations issued by the Minister in charge of space. This control of technical compliance is delegated to CNES

The objectives of the law are the protection of persons, public health, property and environment (on Earth, in the atmosphere and in orbit). For this, the law is based on Technical Regulations which specify the requirements: in the case of space debris, requirements are directly taken from the ISO 24113 standard which has the advantage of representing a comprehensive international technical consensus. The technical regulations were prepared by CNES after consultation with industry and operators

The Act was promulgated by the President of the Republic on June 3, 2008 and published in the Official Journal on June 4, 2008. The authorization process is applicable from December 10, 2010.

6. CONCLUSIONS

The definition of preventive measures may appear to have been done haphazardly with the participation of many actors in several working groups on several levels. The result, however, is perfectly consistent because of the central role played by the IADC whose experts participated in various working groups. This is particularly true in Europe where groups of coordination between the space agencies and with the involvement of industry have been particularly effective. In retrospect we can bring up the logic of the system: at the level of States the work of the UN-COPUOS define the main principles. Then at the level of space agencies, IADC defines the technical content of the rules to be applied (25-year rule for example). Finally, at the level of industry and operators, ISO standards provide a detailed description of the measures to facilitate their implementation.

These documents are only recommendations that have no legal value. Their application is done on a voluntary basis, so we must add in each country an additional level that allows imposing their application. Regulatory systems have been implemented in some countries, licensing systems in the USA and the UK, Space Operations Act in France. If these regulations are different in their form and in their mode of application, the technical content is identical in particular through the work of the IADC remaining the technical international reference on the subject of space debris.

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