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National research on space debris, safety of space objects with nuclear power sources on board and problems relating to their collision with space debris

Note by the Secretariat*

Addendum

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* The present document contains replies received from Member States between 5 December 2002 and 14 March 2003.

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II. Replies from Member States

Germany

1. All nationally funded activities in the field of space debris research are concentrated in one coherent project entitled "Space debris end-to-end service" (SDETES). The project has now been running for more than one year. It was described in detail in the last report on national research on space debris (see A/AC.105/751/Add.2). In the present report the current status is described.

2. Other activities of German research institutes or companies are executed under contracts with the European Space Agency (ESA) and will be presented in the corresponding report of ESA.

Space Debris End-to-End Service project

Introduction

3. SDETES will support spacecraft manufacturers and suppliers as well as operators in considering all aspects of space debris avoidance and mitigation from the beginning of the design and development through the operational phase of a spacecraft up to the end of the mission, as well as the following phase of initiating disposal measures, such as passivation, and de- or re-orbiting. It is also necessary to provide the user with assistance in how to analyse the risks of space debris, with concepts for debris impact protection measures and with an estimate of the costs. As part of the project, a process will be established to provide engineering guidelines and tools for designers and operators of spacecraft to handle the space debris problem in conformity with existing standards. The SDETES guidelines will describe the process in the form of instructions. Communication between analysts, scientists and others considering the guidelines will be intensified in the future.

4. The project is divided into the following six main work packages (WPs):

(a) End-to-end service concept;

(b) Studies of national needs and the status of knowledge;

(c) Mitigation measures applying to spacecraft design;

(d) Mitigation measures applying to spacecraft operation;

(e) Application of a national pilot project;

(f) Programmatic aspects.

5. The project is sponsored by the German Aerospace Centre (DLR) by means of public funds from the German Ministry of Education and Research (BMBF).

End-to-end service concept (WP 1000)

Review of standards

6. As a first step, a comparative review of existing national and international space debris mitigation standards has been performed. The following standards have been examined:

(a) Standard of the National Aeronautics and Space Administration (NASA) of the United States of America;

(b) Safety Requirements—Space Debris of the centre national d’études spatiales of France;

(c) Draft European Space Debris Mitigation and Safety Standard (EDMS);

(d) Space Debris Mitigation Standard of the National Space Development Agency (NASDA) of Japan;

(e) Branch Standard—Space Technology Items of the Russian Aviation and Space Agency (Rosaviakosmos);

(f) Guidelines of the Inter-Agency Space Debris Coordination Committee (IADC) (IADC/SG(2001)107 Rev.2.2).

7. Further information was acquired from other documents like the United States Government Orbital Debris Mitigation Standard Practices, European standards ECSS-E-10-04, ECSS-E-10A, ECSS-E-Q-40A, the IADC Protection Manual and the ESA Space Debris Mitigation Handbook.

8. The standards were evaluated with regard to how they addressed various aspects of mitigation measures, such as “reduction of mission-related objects”, “intentional break-ups”, “venting of residual propellants”, “passivation of batteries, pressure vessels, wheels and so on”, “collision avoidance”, “de- and re-orbiting”, “life-time reduction as a result of post-mission activities” and “removal from orbit”.

Requirements for the end-to-end service

9. The requirements of SDETES from the user’s point of view are collected in a User Requirements Document (URD), intended as a listing of the requirements to be satisfied by the service. They are divided into five categories, addressing the different types of requirements of SDETES (objectives, application and achievements of SDETES, requirements of tools and of documentation).

End-to-end service guideline

10. Based on the requirements listed in the URD, the service guideline for SDETES was established. The SDETES guideline presents all the requirements of the process resulting from the user requirements, describing the measures to be applied during the process in order to accomplish them. Once updated at the end of the SDETES project, the document will serve as the process guideline used during the concept, design and development phases of a space project in order to successfully fulfil all the requirements concerning space debris.

11. The guideline can be tailored to work with every space project, independently of which exact debris mitigation standards are being applied to the individual space project. In addition to all technical requirements resulting from the user requirements, existing space debris standards and other space debris considerations, the guideline also includes so-called “work instructions” for each requirement. The work instructions describe all steps to be performed in applying a particular debris mitigation requirement and verifying its compliance. It is an important output from the project, since it provides links to all results of the project and is intended to be the main reference document for the user of the service.

Study of national needs and the status of knowledge (WP 2000)

12. In order to obtain a better understanding of the national needs and status of knowledge about space debris, a study of the space-flight community in Germany has been prepared and carried out through audits, interviews and questionnaires. A target group was identified from among entities such as industry, satellite operators, research institutes, the national space agency, ministries, governmental authorities and insurance companies. The evaluation and analysis of inputs from the target group provided feedback for the SDETES concept.

Design measures for mitigation and reduction of the space debris risk (WP 3000)

Meteoroid and debris analysis

13. A meteoroid and debris analysis is being performed, providing information on critical orbits and risk levels for certain specific orbits such as the International Space Station, Sun-synchronous orbits and the geostationary orbit. A web-based database containing pre-calculated results from the ESA Meteoroid and Space Debris Terrestrial Environment Reference Model (MASTER) and the NASA ORDEM debris models has been developed. This will provide users of the service with easy access to impact fluxes and the possibility to analyse easily the impact risk for different orbits.

Spacecraft system design

14. All design measures resulting from the application of space debris mitigation measures will be identified, analysed and described. A very important issue during the project is the design synthesis, in which the effects of measures relating to space debris are assessed as a whole, taking into account the interaction of all spacecraft subsystems. The SDETES will describe which technical options are available to achieve a certain space debris requirement, their advantages and disadvantages, and how they can affect other spacecraft subsystems. Thus, if the user has to apply certain space debris standards in its satellite project, SDETES will provide technical solutions to requirements resulting from those standards.

Protection system design

15. The protection of the spacecraft is an important aspect of the project. The end-to-end service will provide information on available protection systems and corresponding verification methods. Advanced damage equations for impact protection systems are under development to consider more realistic particle geometries. This will allow the user to select the appropriate protection system and perform more accurate damage analyses, achieving effective design measures. The main tasks to be performed in this work package are:

(a) Description of meteoroid and space debris protection systems and their corresponding damage equations;

(b) Description of the criticality of spacecraft subsystems;

(c) Description of damage and failure processes;

(d) Development of methods to increase the protection and survivability of critical subsystems;

(e) Performance of impact tests for the development and verification of advanced damage equations;

(f) Upgrading the Meteoroid/Orbital Debris Protection Analysis Tool (MDPANTO) risk analysis tool and development of a mass optimization algorithm for meteoroid and space debris protection systems.

Operational measures for mitigation and reduction of the space debris risk (WP 4000)

Operational measures

16. Actual space debris standards include requirements to avoid creating space debris during spacecraft operation and for the spacecraft's disposal at the end of the operational phase. In this work package, the operational measures resulting from space debris considerations are analysed and the resulting mission and design requirements are described. The main tasks to be accomplished are:

(a) Analysis of satellite requirements resulting from operational measures for debris mitigation;

(b) Operational measures for debris mitigation and for spacecraft protection;

(c) Planning and execution of manoeuvres for achieving re-entry, re-orbiting or de-orbiting to orbits with a limited lifetime;

(d) Planning and execution of manoeuvres for collision avoidance;

(e) Description of the effects of different mission requirements on the spacecraft design;

(f) Assessment of the cost and effort required to apply the identified operational measures.

Radar analyses

17. The possibilities of radar observation of satellites and debris objects will be analysed, describing its possible applications in satellite projects. All expected results and tasks to be performed to prepare such analysis will be described, allowing a project team to assess the costs and benefits of such a study. Radar analysis can be used for the support of measures for end-of-life disposal in low-Earth orbit, medium-Earth orbit and geostationary orbit. The possibility of assessing spacecraft malfunctions using radar data will also be examined.

Re-entry analyses

18. In the course of this work package, numerical analyses of the destruction or the burn-up of a spacecraft during re-entry will be performed. All existing re-entry analysis tools are being reviewed and compared, establishing a method for selecting the appropriate tool for a given spacecraft analysis. Parametric re-entry simulations are being performed with the SpaceCraft Atmospheric Re-Entry Aerothermal Break-Up (SCARAB) re-entry analysis tool, assessing the effects of different materials and shapes on the destruction process during atmospheric re-entry. For the pilot project, the selected satellite will be accurately modelled and its atmospheric re-entry

analysed in order to evaluate the constructive and operational measures applied to the spacecraft design.

Long-term analyses

19. Long-term simulations of the development of the future debris population under the consideration of various mitigation measures are being performed using the LUCA long-timescale analysis tool. Those simulations, together with a newly developed cost estimation method, will provide an overview of the costs and benefits of debris protection and mitigation methods. A total of 12 different scenarios provide an assessment of the number of debris objects in space over the next 50 years and show how specific mitigation measures, such as end-of-life disposal manoeuvres, affect those numbers. The results are then coupled with the cost model, allowing an assessment of the cost-effectiveness of each measure.

Application of a national pilot project (WP 5000)

20. The usefulness of the SDETES concept will be demonstrated by applying it to a national satellite project. The system and the mission of the selected pilot spacecraft will be reviewed according to the SDETES concept. Further specific requirements will be compiled in the course of the project. The tasks to be performed in the course of the pilot project are:

(a) Identification of the meteoroid and space debris environment to be applied in the pilot project;

(b) Identification of sensitive components to be protected against the impact of space debris;

(c) Analysis of the potential risk of damage to the pilot satellite as well as potential damage caused by the satellite itself, including space debris generated by losing components or survival of atmospheric re-entry;

(d) Assessment of the design and operational measures required to fulfil the selected space debris standards such as EDMS and to ensure the survivability of the spacecraft in the space debris environment;

(e) Selection of construction measures and assessment of the effort required to implement such measures;

(f) Study of the interaction and problems of selected design measures, selecting the optimal solutions and gaining experience on the practical application of SDETES;

(g) Performance of a cost-benefit analysis of the applied measures.

Programmatic aspects (WP 6000)

Cost-benefit analysis

21. The benefit of the space debris mitigation measures will be identified and compared to the cost of applying them to a satellite project. An appropriate cost model accepted by industry has been chosen and modified for the exercise. The use of a real satellite as the basis for the pilot project will allow a good comparison with real costs. The cost aspect of the project is very important for the user, as it will

allow the SDETES customer to obtain an overview of the cost effects of applying debris mitigation measures in a space project. The cost model will be applied to the results of the long-timescale population analysis, providing an assessment of the relation between cost and future benefit.

Legal aspects

22. Laws and directives related to the legal liability for damage produced by spacecraft collisions or by spacecraft parts impacting on the ground after re-entry will be compiled. The legal risk to satellite manufacturers and operators as well as specific laws and legal loopholes will be described. Specific recommendations for the legal aspects of debris-related issues will be made.

Synthesis

23. In the synthesis, the results and experiences gained during the pilot project will be incorporated into the SDETES guideline and the work instructions, ensuring their applicability and maximizing their technical usefulness for satellite design teams.

International cooperation

24. This project started as a national project, but it is the intention of DLR to implement it through international cooperation. A first opportunity is the ESA Network of Centres Space Debris, into which the SDETES project is integrated. At the same time, the project can be considered a contribution to the activities of IADC and to the initiative of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space at its thirty-seventh session to investigate the effectiveness and economic aspects of space debris mitigation measures.

Conclusion

25. The SDETES project for the first time forms an integral concept for spacecraft designers, manufacturers, suppliers and operators to consider space debris mitigation from the beginning of a space project or programme up to the end of the mission. They will receive a guideline to be followed during the design, development and operational phases of a spacecraft, including from the consideration of requirement specifications for the spacecraft, through recommendations for construction measures, up to operational measures. All aspects related to space debris are considered from the point of view of the satellite design team and not just from a scientific point of view, ensuring the technical viability of the recommendations. The service is designed to support the application of any current space debris standards, helping the user to understand, apply and verify any requirements of the project related to space debris mitigation. Thus, SDETES will provide a technical background and increase the competitiveness of industry customers in view of the introduction of binding space debris standards.

United States of America

United States orbital debris mitigation policy

1. Since the first formal orbital debris policy was issued by a United States government agency in 1987, significant progress has been made in establishing a firm foundation and achieving an inter-agency consensus for orbital debris mitigation standards. The issue of orbital debris was further addressed in President Ronald Reagan's National Space Policy of 5 January 1988. The Presidential decree affirmed that:

> "All space sectors will seek to minimize the creation of space debris. 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."

2. Less than two years later, on 16 November 1989, the Bush Administration expanded this section of the National Space Policy with the added statement:

> "The United States Government will encourage other spacefaring nations to adopt policies and practices aimed at debris minimization."

3. On 14 September 1996, the Clinton Administration issued a new National Space Policy containing an even stronger statement on orbital debris:

> "The United States will seek to minimize the creation of space debris. NASA, the Intelligence Community, and the Department of Defense, in cooperation with the private sector, will develop design guidelines for future government procurements of spacecraft, launch vehicles, and services. The design and operation of space tests, experiments and systems, will minimize or reduce accumulation of space debris consistent with mission requirements and cost effectiveness.
>
> "It is in the interest of the U.S. Government to ensure that space debris minimization practices are applied by other spacefaring nations and international organizations. The U.S. Government will take a leadership role in international fora to adopt policies and practices aimed at debris minimization and will cooperate internationally in the exchange of information on debris research and the identification of debris mitigation options."

4. This Presidential Decision Directive remains the overarching policy statement on orbital debris for the United States.

United States Government Orbital Debris Mitigation Standard Practices

5. Following a meeting of the Inter-Agency Working Group on Orbital Debris in December 1996, NASA and the Department of Defense began in earnest to develop a set of orbital debris mitigation guidelines for United States government agencies. Using existing NASA guidelines for limiting orbital debris, the two agencies, in conjunction with the rest of the working group, completed a set of draft United States Government Orbital Debris Mitigation Standard Practices in December 1997. A United States Government Orbital Debris Workshop for Industry was held in Houston, Texas, from 27 to 29 January 1998 to present those standard practices to the aerospace community. After further review by United States government

agencies and industry, the Government adopted the standard practices in December 2000.

6. The standard practices are organized into four major mission categories:

(a) Control of debris released during normal operations;

(b) Minimizing debris generated by accidental explosions;

(c) Selection of safe flight profile and operation configuration;

(d) Post-mission disposal of space structures.

7. The United States Government Orbital Debris Mitigation Standard Practices are implemented by each government agency according to its own set of policies and procedures. NASA and the Department of Defense, which are responsible for the majority of government satellites, have issued very specific policies, directives, instructions and guidelines to curtail the creation of orbital debris. The Federal Aviation Administration (FAA) and the National Oceanic and Atmospheric Administration (NOAA) have issued regulations for the segments of the commercial aerospace community for which they are responsible and the Federal Communications Commission (FCC), an independent federal agency, issued a Notice of Proposed Rule Making in March 2002 to consider possible rules addressing orbital debris. The Notice remains pending. FCC also considers debris mitigation issues on a case-by-case basis in individual licensing decisions.

National Aeronautics and Space Administration

8. Questions regarding the risks posed by orbital debris have been evaluated by NASA since the days of the Gemini programme in 1966, leading to the establishment of an orbital debris research programme at the Lyndon B. Johnson Space Center in the 1970s. By 1981, NASA had instituted its first de facto orbital debris mitigation policy with a requirement for Delta second stages to be depleted of residual propellants at the end of mission. The first formal guidance on orbital debris appeared as NASA Management Instruction (NMI) 1700.8, "Policy for Limiting Orbital Debris Generation", of 5 April 1993.

9. NMI 1700.8 was superseded on 29 May 1997 by Nasa Policy Directive (NPD) 8710.3. The three principal tenets of this policy are:

(a) To employ design and operation practices that limit the generation of orbital debris, consistent with mission requirements and cost-effectiveness;

(b) To conduct a formal assessment in accordance with NASA Safety Standard (NSS) 1740.14 on each NASA programme or project, of debris generation potential and debris mitigation options, including design options;

(c) To establish and implement additional debris mitigation measures when the assessed debris contributions are not considered acceptable.

10. Effective 1 August 1995, NSS 1740.14 implemented the requirement of NMI 1700.8 to provide programme and project managers with the necessary documentation and guidelines for assessment of orbital debris generation potential. The comprehensive document covers debris released during normal operations, debris generated by explosions and intentional break-ups, debris generated by on-orbit collisions, vehicle post-mission disposal and survival of re-entering

components. Specially designed debris assessment software (DAS) is available to facilitate the guideline compliance evaluation. Two orbital debris assessment reports are required for each space mission, one at the preliminary design review and the other 45 days prior to the critical design review.

Department of Defense

11. The Department of Defense was the first United States government agency to adopt a formal policy on orbital debris. A memorandum issued by the Secretary of Defense on 4 February 1987, entitled “Department of Defense Space Policy”, called on the Department of Defense to “seek to minimize the impact of space debris on its military operations. Design and operations of Department of Defense space tests, experiments and systems will strive to minimize or reduce accumulation of space debris consistent with mission requirements”. That policy remained in effect for more than 12 years, until it was superseded on 9 July 1999 by the Department of Defense Directive 3100.10, “Space Policy”. The new directive broadened the Department’s orbital debris policy, addressing the creation of orbital debris, the disposal of spacecraft and general spaceflight safety.

12. Specific implementation instructions have been issued by those Department of Defense organizations operating space systems, including United States Space Command, Air Force Space Command and the National Reconnaissance Office. The instructions are consistent with the recommendations of the United States Government Orbital Debris Mitigation Standard Practices.

Other United States government agencies

13. Regulation and licensing of United States commercial space launch activity is under the auspices of the FAA of the Department of Transportation. The FAA has issued regulations to address selected orbital debris practices pertinent to launch operations. Following a two-year review process, new regulations were adopted in 1999 to avoid collisions between launch vehicle components and their released spacecraft and to prevent explosions by passivating upper stages.

14. NOAA of the Department of Commerce exerts licensing and regulatory authority over remote-sensing spacecraft. NOAA also reviewed and finally adopted during 1997-1999 a regulation that requires the applicant to propose a plan for the disposal of the spacecraft at the end-of-mission operations.

15. All commercial United States communications spacecraft are regulated by FCC. For several years, FCC has been evaluating orbital debris mitigation issues as they arise in applications for new satellite systems and services. In May 2002, FCC released an NPRM that covers a wide variety of orbital debris mitigation issues and that specifically refers to the United States Government Orbital Debris Mitigation Standard Practices. Following public comment, it is anticipated that FCC will issue a report and order establishing rules on orbital debris.

United States industry

16. One of the pre-eminent United States public aerospace organizations, the American Institute of Aeronautics and Astronautics, issued the first comprehensive position paper on orbital debris and means for its mitigation in 1981. Many of the elements of today’s orbital debris mitigation policies and guidelines can be found in

that position paper. In 1999, the Institute released a special report on United States laws, policies and regulations pertaining to orbital debris mitigation, with an emphasis on their applications to satellite constellations in low- and medium-Earth orbits. The Aerospace Industries Association has also been active in promoting a dialogue between industry and the Government to achieve a common understanding of the threat of orbital debris and responsible actions that can limit the growth of the orbital debris population.

Summary

17. The United States has taken an active interest not only in orbital debris research but also in the implementation of policies and practices designed to curtail the creation of orbital debris. To date, those policies, which include a mixture of government guidelines and standard practices, commercial regulations and voluntary compliance based upon enlightenment and self-interest, have been highly effective.

18. The generation of mission-related debris has sharply decreased on United States missions. More importantly, only two objects launched by the United States since 1990 have experienced an on-orbit fragmentation. In both cases (a Titan II second stage and a Pegasus XL upper stage), aggressive investigations were undertaken to identify the probable cause and preventative measures were adopted before orbital missions resumed. In low-Earth and geosynchronous orbits, increased attention is being paid to the proper disposal of spacecraft and upper stages at the end of their respective missions.