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Committee on the Peaceful Uses of Outer Space

National research on space debris, safety of nuclear-powered satellites and problems of collisions of nuclear-powered sources with space debris

Note by the Secretariat

Addendum

Contents

I. Introduction

1. The Secretary-General, in a note verbale dated 17 July 1998, invited all Member States to provide information on national research on space debris, safety of nuclear-powered satellites and problems of collisions of nuclear-powered sources with space debris.

2. The present document contains information provided in replies received from Member States between 1 December 1998 and 30 January 1999.

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II. Replies received from Member States*

Italy

[Original: English]

1. Introduction

1. Outer space has become an essential resource for scientific research and for application development in the public and private sectors. Projects for the installation and use of space systems, including large-scale manned missions, are constantly being developed. Nevertheless, these activities are subject to growing risk owing to the uncontrolled production of orbiting debris. During the early 1960s, when manned orbital flights first started, micrometeorites presented the only danger of satellite collision, with a very low rate of collision probability. Today the greatest danger is caused by artificial objects, mainly metallic ones produced during space flights, including:

(a) Spacecraft at the end of their operational life, which are particularly dangerous when they contain radioactive material;

(b) Fragments of satellites that have partially or completely exploded, components from the separation of stages and the separation of stages and satellites;

(c) Fragments of solar panels;

(d) Spent rocket bodies, including the apogee motors;

(e) Fragments of pressurized tanks that have exploded for various reasons.

2. Because of their amount, size and kinetic energy, such debris are an ever increasing and significant danger. Fragments above 1 mm in size are especially worrying. Debris are found mainly in low Earth orbits (below 1,500 km); they have a high relative velocity, are hard to detect with radar technology and optical methods, and have a long orbital life. The research group of the Institute of the National Research Council (CNR) at Pisa (CNUCE) has shown that the new debris created by collisions with orbiting objects may create a chain reaction, which in the long term could even prevent space activity at low Earth orbits.

3. The organizations involved in the planning and regulation of space activities have begun to address the problem and have issued numerous warnings. They have, however, come up against many difficulties in reaching international agreement in a sector with substantial commercial interests. As in other cases of technology assessment, where long-term evaluation of technological progress is required, decisions must be taken despite considerable ignorance regarding medium- and long-term risks. The classical approach of short-term profit, rejecting limitations not based on certain forecasts, can no longer be sustained. Feasible strategies involve long-term delays before achieving results and significant rigidity in the development of new technology, also because of the large capital resources required. On the other hand, they should be flexible and open to constant updating in order to ensure long-term protection for space activities in a framework of continually evolving knowledge.

4. The awareness of the risks already present for space missions is reflected in the setting up of international committees for the coordination of space debris-related activity, in

* The replies are reproduced in the form in which they were received.

particular the Inter-Agency Space Debris Coordination Committee (IADC), and in the introduction of the problem in the agenda of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space in 1994. Technical and legal organizations have formally expressed their position on the matter, focusing above all on the need for concrete measures. The organizations include the American Institute of Aeronautics and Astronautics (AIAA), the Committee on Space Research (COSPAR), the International Academy of Astronautics (IAA), the International Astronautical Federation (IAF), the International Institute of Space Law (IISL) and the International Law Association (ILA).

5. The Italian delegation at the Scientific and Technical Subcommittee has expressed satisfaction with the consideration of the problem. The position of the Italian delegation encourages discussion on the legal and political aspects of the problem. Italy also confirms its support, at the international level and in the appropriate bodies, for all the initiatives aimed at accelerating the acquisition of technology required to draw up programmes for concrete intervention.

2. Italian Space Agency

6. Since the 1980s, the Italian Space Agency (ASI) has devoted attention to the problem of space debris, at the time mainly focused on uncontrolled re-entry into the atmosphere of hazardous space objects. The 1988 re-entry in the atmosphere of the Soviet Cosmos 1900 satellite, carrying nuclear material on board, was an important occasion for ASI activity related to space debris. In parallel, the Italian Department of Civil Defense established a permanent committee to advise on emergencies that were due to re-entries of large space objects; several public administrations are represented on the committee, including the Italian National Agency for Nuclear and Alternative Energy (ENEA) for possible nuclear risks. ASI, with the support of CNUCE, participates in this committee for technical aspects (monitoring, re-entry predictions etc.). CNUCE technical support to ASI is managed under an agreement between ASI and CNR.

7. ASI also takes part in European Space Agency (ESA) activities and in the Italian delegation to the two subcommittees of the Committee on the Peaceful Uses of Outer Space. The most important international responsibility of ASI, however, is its membership in IADC. ASI was admitted as the tenth member in July 1998 and has already made relevant contributions to the activities of IADC at its general assembly in Toulouse, held from 2 to 6 November 1998.

8. The interest of ASI in the problem of space debris led to the establishment, in February 1995, of a Space Debris Working Group, which carried out a survey of the space debris activities in Italy and proposed some guidelines for future work. In its final report (June 1996), the Group reviewed the major aspects of this problem and the results obtained and proposed a three-year plan of research to be conducted in Italy. The international juridical framework has also been surveyed.

9. ASI has supported several research projects in the field of space debris, in particular, a recent study for a space system to take a spacecraft out of orbit at the end of its life by means of long conducting wires.

3. Institute of the National Research Council at Pisa

Activities

10. The traditional role of CNUCE in the field of celestial mechanics and space flight dynamics has naturally resulted in the commitment of CNUCE in the related field of space debris. Since 1979 when the Skylab re-entered the atmosphere, the Institute has dealt with the determination of the orbital evolution and prediction of re-entries of potentially dangerous and uncontrolled space objects. The Institute has direct contacts with national authorities, which have gradually taken on responsibilities for emergencies in this field, as well as foreign organizations in Europe, Japan, Russia and the United States involved in related tasks.

11. During recent years, besides taking part in a dozen re-entry campaigns, CNUCE has actively collaborated with the Civil Defense Department and the Data Evaluation Center for the management of nuclear emergencies, including those arising from spacecraft re-entry, especially with regard to the production of manuals and procedures. This technical and organizational work has led to the consolidation of duties, responsibilities and procedures on the national level, with a great improvement both in the interface with all the other organizations concerned and in their operational readiness.

12. After the establishment of ASI in 1988, the traditional activity of CNUCE in the field of re-entries and space debris expanded in the broader context of national space activities and the collaboration between government organizations and civil defence institutions. The Space Objects Monitoring Service (SMOS) was set up at Pisa, partially implementing the proposals made by the specialized working group set up by the former Ministry for Civil Defense in which ASI and CNUCE representatives also took part.

13. When problems related to the overcrowding of circum-terrestrial space owing to man-made space debris came to the fore, CNUCE/SMOS, in collaboration with the Space Mechanics Group of the Department of Mathematics of the University of Pisa, began studying increasingly sophisticated mathematical models for the long-term evolution of the debris population. The two final models were produced under an ESA contract, which extended from 1992 to 1996, and are briefly described in a subsequent section.

14. The activities of SMOS, besides forecasting the uncontrolled re-entry of potentially dangerous space objects, also involve regular monitoring of international space activities and location in Earth orbit, development, improvement and implementation of application software, issuing of reports, technical support for ASI in the space debris field, study of the long-term evolution of the orbiting debris population and evaluation of the effectiveness of mitigation measures.

Software development

15. The future evolution of the debris population in Earth orbit depends on many variables, some of which are under human control (the number and type of launches, measures for preventing explosion/collision events etc.), while others are more specifically physical (mass distribution and velocity of fragments deriving from explosions or collisions, resistance to impact of other objects, collision probability and impact velocity for different orbits, effect of atmospheric drag on the re-entry of objects of different shapes, sizes and altitudes). A quantitative study of the problem requires the development of rather complex models and algorithms in order to provide realistic simulations and sufficient flexibility to allow for the investigation of many alternative scenarios, with suitable options or numerical parameters to be chosen as inputs for the simulations.

16. Such research has grown significantly in Italy over the past 10 years. An initial, simple mathematical model, based on a system of just two differential equations, proved suitable to illustrate the mechanism that can ultimately lead to a chain reaction of orbiting debris. A realistic numerical model was later developed on the basis of an accurate estimate of collision probability as a function of altitude and quantitative description of the "sink" and "source" mechanisms (air drag, launches, explosions, collisions), which increase or decrease the debris population. These processes have been modelled mathematically with a system of 150 differential equations for the Earth orbiting objects, divided into 15 altitude shells and 10 mass bins (each differing in mass by factor 10 from the previous one, from one milligram to 10 tons). This model has confirmed both the danger of a chain reaction and the fact that the related time of occurrence depends on the parameters, especially the resistance of larger bodies to collisional destruction.

17. A further research phase was carried out between 1993 and 1995 at the Pisa-based CNUCE in the context of an ESA/ESOC contract with the Consorzio Pisa Ricerche (Pisa Research Consortium). Its purpose was to develop physical models, mathematical algorithms and numerical codes for the analysis of long-term evolution of the space debris population in Earth orbit. The project focused on development, implementation on UNIX workstations, validation and use of three numerical codes and the corresponding pre- and post-processing programs.

18. The contract also required a variety of highly specialized support activities, including the following: detailed study of past and future traffic models (launches, satellite constellations, space stations, military and commercial requirements); identification of the physical characteristics and the type of utilization of all carrier rockets now in use or to be used; development of atmospheric density models, also taking into account the solar flux variations; development of a sufficiently accurate and fast orbital propagator designed to survey thousands of objects at the same time; study and assessment of different models to describe fragmentation events (high and low energy explosions and collisions); and simulation of the current space debris population (produced by launches, decays and past fragmentations) for masses exceeding one milligram.

4. Protecting space vehicles

19. Space engineers must carefully take into account the risk to operational space structures of collisions with potentially damaging space trash. At an impact velocity of about 10 km/s, the impact pressure reaches values up to some Mbar; the interaction is dominated by the shock pressure; the material is subject to solid-liquid-vapour phase transitions. Orbital debris pose a particularly severe threat to the International Space Station, because of its large dimensions (more than 11,000 m^2 of surface area), its long operational life (greater than 10 years) and the permanent presence of human beings on board. The evaluation of the potential hazards of debris impact shows the need for the space station modules to be protected with special shields.

20. Italy has carried out relevant activities in this area. At the Center of Studies and Activities for Space of the University of Padova, a gas gun has been designed and built to accelerate small metal projectiles to high velocities. It works with pressurized helium in two stages, with a maximum pressure and peak temperature in the second stage of 6,000 bar and 5,000 degrees, respectively. Accurate diagnostics allow monitoring of all stages of acceleration and a duty cycle up to one shot per minute. Masses of 0.5 and 2.5 are accelerated, respectively, to 6 and 2.1 km/s. Although they are lower than the typical debris velocities, the impacts they produce have the same physical structure and effects and are quite useful in

understanding the complex and fast phenomena in hypervelocity collisions, which include shock waves, melting and vaporization, fragmentation, ejection of fragments in different directions, and fast heating and fast cooling both for the target and the projectile. The gun is also useful as a prototype for a larger machine, capable of attaining larger velocities.

21. Although the microscopic phenomena involved are essentially known, the physics of hypervelocity collisions is far too complex to be amenable to analytical treatment: complex computer codes are needed to describe their effects on a metal layer and on a multilayer shield. Advanced codes of this kind, based on the smoothed particle hydrodynamics (SPH) technique, have been implemented and are being currently used at the University of Rome “La Sapienza”. SPH codes, originally developed for astrophysics, describe the evolution of the medium by means of extended “particles” whose motion and properties are measured over a period of time.

22. Alenia Aerospazio in Turin is responsible for the structural design and manufacturing of several modules of the International Space Station. Protecting shields are carefully designed and evaluated for each one of them. The shielding strongly affects the overall design, with a mass increase that can be as high as 1.5 ton per module. A methodology has been developed for the risk assessment of damaging debris impacts and for the design and testing of appropriate shielding. An innovative shielding concept has been developed at Alenia. The three-wall system is composed of a thin external layer made of aluminium spaced with an intermediate bumper made of a combination of ceramic fibres and high-strength fabric mixed with Epoxy resin; the internal wall made of aluminium alloy is the module structure to be protected. Hypervelocity experiments are performed using a light gas gun at the Ernst Mach Institute in Freiburg (Germany); aluminium spheres with a diameter from 0.9 to 1.75 cm are fired at velocities between 3 and 7 km/s. The experiments and the effectiveness of shielding are compared and evaluated with numerical simulations in collaboration with the University of Rome “La Sapienza”. With these shields, the probability of perforation of the pressure shell of the European module has been reduced to less than 1.5 per cent over 10 years.

5. Effects of meteoroid streams on space platforms investigated by ground-based radars

23. Natural meteoroids are an important component of near Earth space environment and represent a potential risk for all Earth-orbiting space platforms; they significantly increase during enhanced (outburst or storm) activity of meteoroid streams, e.g. those related to the Leonids event, which occurs once a year. Their size is generally small (millimetre), but their velocities (up to 70 km/s) are very high; they can damage or erode satellite surfaces and external structures or cause electromagnetic shocks. Meteoroid flux predictions and investigations on their effect on penetration, charge production and plasma generation are relevant aspects for developing strategies for the safe deployment of the near Earth-orbiting space platforms.

24. Ground-based radars are a powerful tool for the observation of space objects, in particular those with all-weather and day-and-night performance. The CNR FISBAT Institute at Bologna has used a radar facility since 1992 to observe and measure the ionization cloud in the wake of a meteoroid. Impact probabilities of storm meteoroids on space platforms in low-Earth orbit were calculated using the available data; it has been shown that the impact probability deduced by radar measurements is generally larger by a factor 2 than the one obtained by visual observations. Furthermore, radar data show that impact probability values of storm meteoroids can increase by factors of 10^2-10^4 and more over the sporadic background.

6. Juridical work

25. At the University of Rome "La Sapienza" there is an active interest in studying governmental responsibility for activities in space; among them, at present, those arising from the production of debris is dominant. These responsibilities are void if the ownership of a spacecraft is not officially recognized, for example, through registration under the Convention on Registration of Objects launched into Outer Space. Italy has neither signed nor ratified it yet, but the Ministry for Foreign Affairs has begun steps to adhere to this important tool of international legislation of great importance for space debris.

Japan

[Original: English]

1. Introduction

1. Japan has conducted a series of activities related to space debris in accordance with the Fundamental Policy of Japan's Space Activities issued by the Space Activities Commission of Japan in January 1996.1

2. Systematic and organized activities have been conducted since the Japan Society for Aeronautical and Space Sciences (JSASS) established the Space Debris Study Group in 1990. The National Aerospace Laboratory (NAL), the Institute of Space and Astronautical Science (ISAS), the National Space Development Agency (NASDA) of Japan and other space-related organizations (participating collectively as Japan) have been a consistent member of the Inter-Agency Space Debris Coordination Committee since 1992 and have also contributed to the Committee on Space Research, the Committee on the Peaceful Uses of Outer Space, the International Astronomical Federation and other international organizations.

3. The present report is a brief overview of the recent space debris activities in Japan regarding their measurement, database, protection and mitigation.

2. Measurement

4. ISAS and the Communication Research Laboratory have been conducting optical observation of space debris in low-altitude and geostationary orbits. ISAS and Kyoto University have been conducting radar observation in low Earth orbit. ISAS uses bistatic radar observation technology and Kyoto University uses very high frequency (VHF) middle and upper atmosphere radar (MU radar).[2,3,4]

5. In 1998, NAL, NASDA and the Japan Space Forum announced a new construction plan for a space debris radar and optical observation system.[5] This system will make it possible to observe space debris down to one metre in diameter (at an altitude of 600 km) and its construction is to be completed in 2003.

6. NAL and NASDA conducted post-flight surface analysis and evaluation of the Space Flyer Unit retrieved from space in 1995, which provides additional data on distribution of space debris dust. An on-board dust collection experiment on the manipulator development facility aboard Space Shuttle flight STS-85 was performed in August 1997 in cooperation with the National Aeronautics and Space Administration of the United States of America. NASDA has analysed particles captured by the aero-gel installed in dust collection equipment.[6] As the flight time was not long enough, only a few particles were captured. A

similar device is currently under development for the Japanese Experimental Module (JEM) to be attached to the International Space Station.[7]

7. From 1994 to 1997, NASDA and JSASS conducted a joint study on a new possible on-board debris observation system in order to monitor space objects down to 1 cm in size and presented a baseline specification of such a system as an international cooperative mission.[8]

3. Modelling and database

8. NASDA developed a space debris database known as the Space Debris Orbit Analysis Test System in 1997 and started its operation in April 1998. The objective of the database is to provide a tool for orbital data management and orbital data analysis of the resident objects. Several sub-functions, such as re-entry prediction, collision analysis and debris dispersion analysis are also provided for.

4. Protection

9. NAL and NASDA have conducted a series of studies and tests of a development system for the pressurized module of JEM. By 1998, NAL and NASDA had conducted a numerical analysis of high-velocity impact phenomena, simulated high-speed impact damage tests using a one-stage power gun, a two-stage light gas gun, a rail gun and a shaped charge system,[9,10,11,12] and reflected the data acquired by the analysis and tests into the design of the JEM flight model.

5. Mitigation

10. In order to minimize damage by space debris, NASDA established a Space Debris Mitigation Standard, NASDA-STD-18, in March 1996. NASDA is continuously making efforts to reduce the creation of new space debris by the study of safe controlled re-entry of expendable rocket bodies and spacecraft and of the related engineering criteria for ground hazard alleviation. In accordance with STD-18, NASDA has conducted the passivation and minimization of orbital life of upper rocket stages in order to mitigate the generation of space debris as a regular routine.[12,13]

6. Conclusion

11. As a responsible international partner, Japan has made every possible effort to cope with space debris issues and the management of the outer space environment. Japan will continue to pay utmost attention to those problems and believes that international cooperation is essential to ensure safe and long-lasting space activities by protecting the space environment from space debris.

Notes

[1] Fundamental Policy of Japan's Space Activities, Space Activities Commission of Japan, revised on 24 January 1996.

[2] T. Sato and I. Kimura, “Debris observation with a VHF radar”, *Earth Science Review*, vol. 4, No. 3 (1995).

[3] T. Nakajima and others, “Current and planned space debris activities in Japan”, *Advanced Space Research*, vol. 19, No. 2 (1997), pp. 391-397.

[4] A. Takano, T. Takano and S. Toda, “Technical problems of space debris and international cooperation” (in Japanese), Technical Report of the Institute of Electronics, Information and Communication Engineers, October 1997 (SANE97-64).

[5] T. Tsujino, “Arrangement plan of the first Japanese space debris observation facilities” (in Japanese), 42nd Space Sciences and Technology Conference, October 1998.

[6] Y. Kitazawa and others “Development of a dust collector for a material exposure experiment on the manipulator development facility (in Japanese), *Proceedings of the 17th Shock Wave Symposium,* 1997, pp. 253-256.

[7] Y. Kitazawa and others, “Development of the micro-particle capturer of the JEM exposed facility” (in Japanese), 14th Space Station Conference, JSASS, April 1998.

[8] A. Takano, Y. Arimoto and S. Isobe, “A baseline specification of the GEO debris observation satellite”, 49th International Astronautical Congress, September 1998 (IAA-98-IAA.6.5.04).

[9] A. Takano, “Space debris related activities in NASDA”, *Proceedings of the Second European Conference on Space Debris*, March 1997 (ESA SP-393), pp. 31-34.

[10] K. Shiraki and others, “Hydrocode simulation for the JEM pressurized module structure performance for space debris impact”, 7th ISCOPS (C-8-6).

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[12] M. Katayama and others, “Analysis of JET formation and penetration by conical-shaped charges with the inhibitor”, 1998 Hypervelocity Impact Symposium, Huntsville, AL, United States of America, 16-19 November 1998.

[13] A. Takano, T. Tajima and Y. Kanoh, “Recent efforts toward the minimization of GTO objects and its practices in NASDA”, *Acta Astronautica*, vol. 40, No. 11 (1997), pp. 807-813.