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Committee on the Peaceful Uses of Outer Space

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

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I. Introduction

1. In paragraph 33 of its resolution 58/89 of 9 December 2003, the General Assembly considered that it was essential that Member States pay more attention to the problem of collisions of space objects, including those with nuclear power sources, with space debris, and other aspects of space debris, called for the continuation of national research on that question, for the development of improved technology for the monitoring of space debris and for the compilation and dissemination of data on space debris, also considered that, to the extent possible, information thereon should be provided to the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space, and agreed that international cooperation was needed to expand appropriate and affordable strategies to minimize the impact of space debris on future space missions.

2. At its fortieth session, the Scientific and Technical Subcommittee invited Member States and regional space agencies to continue to provide reports on national research on space debris, safety of space objects with nuclear power sources on board and problems relating to their collision with space debris (A/AC.105/804, para. 120). In a note verbale dated 24 July 2003, the Secretary-General invited Governments to submit any information on the matter by 31 October 2003 so that that information could be submitted to the Scientific and Technical Subcommittee at its forty-first session.

3. The present document has been prepared by the Secretariat on the basis of information received from Member States and international organizations.

II. Replies received from Member States

Brazil

[Original: English]

1. Since 1977, the Division of Space Mechanics and Control of the National Institute for Space Research (INPE) has conducted studies on the motion and control of artificial and natural objects around Earth, as well as other celestial bodies. Since 1991, those studies have investigated the orbital perturbation of objects due to the action of force or torque, or both. Since 1998, such studies have been extended to the motion of space debris, including the modelling of debris cloud dispersal from a single originating point-source and how the debris cloud deforms along the object’s line of motion.

2. From 6 February to 15 May 2003, the Brazilian Space Agency (AEB) monitored the re-entry of the Italian satellite BeppoSax into the Earth’s atmosphere. The INPE technical sub-team provided:

(a) Overall technical support to the multidisciplinary team;

(b) Translation of the technical reports published periodically by the Italian team on the Internet;

(c) Timely and precise estimates of the point of impact.

3. In 2003, INPE also created a course entitled "CMC-214-4 artificial satellites: constellations and space debris", for the space engineering and technology postgraduate programme of the Institute.

Finland

[Original: English]

Finland has several ongoing space debris research activities and applications:

(a) Debris In-orbit Evaluator (DEBIE) space debris sensors and data-processing units were launched on board the Project for On-board Autonomy (PROBA) satellite in October 2001;

(b) DEBIE will later fly on the International Space Station (ISS) in a more operational role;

(c) A low-Earth orbit space debris survey was carried out using European incoherent scatter radars (demonstrated capability: 1 centimetre and larger objects) in Lapland;

(d) The University of Turku carried out a geostationary orbit space debris survey using the European Space Agency (ESA) telescope in the Canary Islands.

France

[Original: French]

1. Introduction

1. The aim of the present report is to provide an overview of the activities carried out in France during the period 2002-2003 with respect to space debris. Those activities related to the following three areas:

(a) International cooperation: cooperation with European partners in the framework of the Network of Centres, and with other agencies of the Inter-Agency Space Debris Coordination Committee (IADC) and the Committee on the Peaceful Uses of Outer Space;

(b) Regulatory activities: the drafting of regulations on space activities, in particular those concerned with limiting the proliferation of debris;

(c) Technical activities: activities carried out by the Centre national d'études spatiales (CNES), research bodies and industry.

2. International cooperation

(a) Network of Centres

2. Space debris is the subject of a pilot project taken up by the Network of Centres. The project currently involves four space agencies: the British National Space Centre (BNSC), CNES of France, the German Aerospace Center (DLR) and ESA, following the withdrawal of the Italian Space Agency (ASI). The main aim is to develop cooperation in Europe on activities relating to space debris.

3. The main achievements to date have been the formulation of an integrated programme comprising a plan of work for each agency and the designation of four areas of enhanced cooperation:

(a) On-board optical observation;

(b) In situ detection and analysis of materials;

(c) High-speed impacts and protection;

(d) Preparation of a European standard.

4. At the same time, a special task force on space surveillance has been formed. The contract was awarded to a consortium led by the National Office for Aerospace Study and Research (ONERA) in association with QinetiQ, Alcatel Space and the University of Bern (see subsection 4 (i) below). The aim is to define the specifications, architecture, performance and cost of a future European space surveillance system.

(b) United Nations

5. Following the presentation given at the fortieth session of the Scientific and Technical Subcommittee in February 2003 on the IADC space debris mitigation guidelines setting out the basic preventive principles for limiting the generation of space debris (A/AC.105/C.1/L.260), the representative of France proposed that the Legal Subcommittee should examine the legal aspects involved in applying such principles, beginning in 2005. The Subcommittee was not able to reach consensus on the proposal.

(c) Inter-agency Space Debris Coordination Committee

6. France participated in the twenty-first meeting of IADC, held in Bangalore, India, from 10 to 13 March 2003, which was attended by all 11 members. The French delegation was led by CNES and included representatives from ONERA, the Délégation générale pour l'armement/Direction des centres d'expertise et d'essais (DGA/DCE) and the Commandement de la défense aérienne et des opérations aériennes.

3. Regulatory activities

(a) Development of space law in France

7. On 13 March 2003, the Technology Directorate of the Ministry for Research and New Technologies held a symposium at the National Assembly on the development of space law in France. The international treaties require States to supervise their citizens' space activities, which raises the question of developing a specific set of laws. The symposium highlighted the following issues:

(a) The importance of establishing a legal framework in France covering launch clearance for space objects and registration;

(b) The need to adapt some branches of national legislation (for example, intellectual property or insurance);

(c) The need to clarify the concept of public service as it applies to space activities; and

(d) The usefulness of defining and consolidating the scope of the tasks attributed to CNES.

8. The participants in the symposium also agreed by consensus on the importance of taking into account comparative law, that is, drawing on the experience gained from the implementation of existing national laws (for example, those of Australia, the United Kingdom of Great Britain and Northern Ireland and the United States of America) so as to retain the tried and tested aspects and not reproduce the weaknesses and also of reflecting the European and international context in the framing of such legislation.

(b) Development of standards

9. The European standard prepared by the inter-agency working group (comprised of representatives of ASI, BNSC, CNES, DLR and ESA) has been completed. Minor adjustments were made following the ASTRA 1K communications satellite operations. The document was submitted to the European Cooperation for Space Standardization (ECSS) for inclusion in the European standards system. At the international level, IADC presented its space debris mitigation guidelines to the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space in February 2003. IADC is currently preparing a background document containing explanations and justifications. At the same time, the International Organization for Standardization (ISO) has set up a working group to study the requirements and devise a strategy, with the aim of formulating a set of international regulations. For the immediate future, seven working topics have been adopted, corresponding to the seven chapter headings in the mitigation guidelines. The working group will coordinate the efforts of the various ISO teams concerned with debris and maintain permanent contacts with IADC.

4. Technical activities

(a) Alcatel Space

10. Alcatel participated in the ESA study on space surveillance (see subsection 4 (i) below). The main aspects addressed by Alcatel Space were system architecture and optical sensors. Alcatel also led an ESA study on the detection and monitoring of near-Earth asteroids.

(b) National Office for Aerospace Study and Research

(i) Space surveillance

11. The development of the Grand réseau adapté à la veille spatiale (GRAVES) space surveillance radar has continued. The radar will be able to detect satellites up to an altitude of 1,000 kilometres (km), with a detection period of less than 24 hours. The transmission site lies just outside Dijon and the reception site on the Albion Plateau (military base). Extension work and reliability testing were being carried out. The air force expected the system to become operational in June 2005.

12. In the civil domain, ONERA led an ESA study on the feasibility of a European space surveillance system, in collaboration with QinetiQ, Alcatel Space and the University of Bern. DGA/DCE acted in an advisory capacity. The aim was to define

the specifications, architecture, performance and cost of a future European space surveillance system. The work done to date has made it possible to assess requirements and tasks. For low-orbit surveillance, the solution adopted was an ultra high frequency (UHF) radar system of the GRAVES type. For the geostationary orbit, the solution adopted was a network of telescopes with diameters of between 0.5 and 1 metre (m).

(ii) Observation of the Hubble Space Telescope solar panels: implications for our understanding of debris

13. Two solar panels of the Hubble Space Telescope were recovered in March 2002 after orbiting the Earth for eight years at an altitude of around 600 km. Examination of their 120 square metre surface will provide information on the environment and how it has changed since the previous mission. A large number of impacts have left their mark. The aim of the early analyses is to map crater distribution according to size. A photographic examination has been made of one panel (front and rear). The largest impacts were examined using a video-microscope. A detailed examination of micro-crater residues will be made in order to identify the nature of the particles (debris or meteorites). The results will make it possible to improve the flux models and could have an influence on solar panel design.

(c) In situ measurements

14. An experiment using metal oxide silicon detectors is to be conducted on board the International Space Station (ISS), in the framework of the material exposure and degradation (MEDET) project. The flight models have been delivered and stored in anticipation of project rescheduling. Following the halting of the Franco-Brazilian Microsatellite project, a new flight opportunity would have to be found for the detectors currently being developed, the intention being to carry out experiments on the Russian section of ISS or in cooperation with Argentina or on Ariane 5. Detectors based on silica aerogel enable particles to be recovered. An experiment is planned in the framework of the MEDET project. The importance of coupling polyvinylidene fluoride detectors to other types of detector has become apparent. CNES has joined forces with ONERA to evaluate the Hubble's solar panels. The main focus of their work has been damage assessment (laws of performance) and chemical analysis (debris source). Through the Network of Centres, a cooperative exercise to analyse the former solar generators of the Mir space station is planned.

(d) Space mathematics

15. The optical observations of debris in the geostationary orbit have continued. The Télescope à Action Rapide pour les Objets Transitoires (TAROT) [rapid action telescope for transient objects] and its electronic systems have been out of action for several months because of lightning damage. Nevertheless, some observation work has been done on the Telecom 2 satellites.

16. Work to develop a software package capable of evaluating in-orbit and launch-phase collision risk has almost been completed (ARC software). The study was entrusted to SchlumbergerSema. Their main task was to establish effective filter algorithms for the extent of the launch window, as the combinatorial aspects of the problem were substantial. That software will be used by the Centre for Operational

Orbitography and by the Automated Transfer Vehicle control centre. Other methods were being evaluated internally.

17. Work on the modelling and prediction of meteorite showers was being done together with the Institute for Celestial Mechanics and Computation of Ephemerides in order to devise a means of predicting the date and intensity of meteorite showers.

18. University laboratories have been contacted with a view to assessing the feasibility of cooperation on debris-related matters. Various topics of study have been proposed. Lastly, ONERA has continued development of a platform of tools grouped together into a common interface for the purpose of facilitating the application of computer software to debris-related problems.

(e) Operations

(i) Monitoring collision risk

19. The risk-monitoring procedure set up in 2000 continues to be in use. A large number of near misses (<1,500 m) were observed between the catalogued debris and the Satellite pour l'observation de la Terre (SPOT) and HELIOS satellites (on average one miss at less than 1,500 m distance per satellite per week). Three warnings with a probability of $<10^{-3}$ were detected. The main problem is the inaccuracy of the two-line data and the related extrapolation models, which precluded correct evaluation of the actual risk. The Centre for Operational Orbitography will assimilate the ARC software into space mathematics as it is developed. No atmospheric re-entry took place in 2002, but the Centre helped monitor the ASTRA 1K satellite re-entry and has been processing information received from other bodies such as DGA/DCE, the National Aeronautics and Space Administration (NASA) of the United States and the Russian Aviation and Space Agency (Rosaviakosmos).

(ii) Telecom 2 end of lifetime

20. In the case of the Telecom 2 family of satellites, the value specified for re-orbiting at lifetime end is 6 metres per second (m/s) or an increase of 164 km on the semi-major axis. This value is lower than the IADC recommendation, whose formula for Telecom 2 resulted in 285 km (10.4 m/s). The IADC recommendation does not apply to Telecom 2, which was launched before the recommendation was published, but various studies have been carried out to see what altitude might be reached. Taking account of the natural change in excentricity would make it possible to meet the IADC recommendation at a ΔV of 9.5 m/s. Another factor to be included is the east-west dissymmetry in the propulsion system arising from jet effects. At lifetime end, the estimate for ergol mass is highly inaccurate: a change from a success probability of 90 per cent to one of 99 per cent means that larger margins must be factored in, with a commensurate reduction in lifetime. The impact on length of operational lifetime is not inconsiderable.

21. Once the manoeuvre has been completed, electrical passivation will be performed.

(iii) SPOT-1 end of lifetime

22. De-orbiting operations for SPOT-1, which was launched in 1986, are being studied. Operations will consist of transferring the satellite to a circular orbit below the operational orbit so as to avoid the risk of collision with other satellites in the same family; then, a series of apogee manoeuvres (from 11 to 14) will reduce the perigee altitude. Thereafter, atmospheric friction will cause the satellite to come back to Earth in less than 25 years, thus ensuring compliance with the CNES standard, the European standard and the IADC recommendations.

5. Miscellaneous information

(a) National Air and Space Academy symposium

23. The National Air and Space Academy held a symposium entitled "Europe and space debris" in Toulouse, on 27 and 28 November 2002. The main recommendations were:

(a) International cooperation: the existing structures (IADC, the Network of Centres, the Committee on the Peaceful Uses of Outer Space, ECSS, ISO, and so forth) and their expertise should be used;

(b) Technical, financial and legal aspects:

(i) A "zero debris" culture should be promoted;

(ii) The proposed rules should not be so strict as to be inapplicable;

(iii) Consideration should be given to enabling manufacturers and operators to participate in IADC;

(iv) The registration agreement should apply to all space objects (including non-operational ones);

(v) A national legal system is needed to control the activities of a launching State;

(c) Space surveillance: an autonomous means of space surveillance in Europe should be promoted. This calls for a federal alliance between the existing surveillance systems and for the development of dedicated detection equipment.

(b) Break-ups in orbit

24. Only two break-ups in orbit were reported in 2002, which was the best result in 13 years. Unfortunately, the vehicles concerned were the upper stages of Ariane, which were launched before passivation measures could be applied.

(c) Situation in the geostationary orbit

25. A total of 27 objects were placed into the geostationary orbit in 2002 (26 satellites and 1 launch stage). Thirteen satellites reached lifetime end: 5 were correctly re-orbited in compliance with IADC recommendations; 5 were partially re-orbited and will travel in the protected region up to 200 km above the geostationary orbit; and 3 were simply abandoned in orbit.

(d) Conclusion

26. The amount of debris in orbit must be reduced by applying prevention measures that can restrict space activity. Those measures must be applied by all the actors involved. It is important that international authorities participate in formulating regulations; that calls for a comprehensive programme of technical activities enabling full participation at the Network of Centres, IADC and the Committee on the Peaceful Uses of Outer Space.

Indonesia

[Original: English]

The Government of Indonesia reported that it did not conduct any national research on space debris, safety of space objects with nuclear power sources on board and problems of their collision with space debris.

Latvia

[Original: English]

Latvia reported that it did not have national programmes associated with the use of outer space, space objects or space debris.

Mauritius

[Original: English]

Mauritius reported that it did not carry out any space activities.

Peru

[Original: Spanish]

Peru reported that it was not conducting national research into space debris, safety of space objects with nuclear power sources on board and problems of their collision with space debris. However, the National Aerospace Research and Development Commission (CONIDA) was the national and international focal point for monitoring space debris (deactivated satellites) in connection with its re-entry into the Earth’s atmosphere and its probable areas of impact, for purposes of prevention and warning of international security and civil defence systems.

Turkey

[Original: English]

1. The main space activities of the Information Technologies and Electronics Research Institute (BILTEN) of the Scientific and Technical Research Council of Turkey focus on a small satellite project and on the remote sensing geographic information system. In that framework, a programme is being conducted by BILTEN for monitoring space debris that will enable time predictions on possible collisions and re-entry of space debris into the atmosphere. In the near future, the efficiency of the programme will be enhanced with data from the BILSAT small satellite.

2. BILTEN is also conducting a feasibility study to establish a cost-effective system for monitoring space objects from the ground. Financial shortcomings are the main handicap for the accomplishment of this project.

United Kingdom of Great Britain and Northern Ireland

[Original: English]

1. Introduction

1. During the past year, the British National Space Centre (BNSC) has maintained its active commitment to addressing the space debris problem. In particular, BNSC continued to encourage coordination at national, European and international levels to achieve consensus on the most effective mitigation solution.

2. Through its membership in IADC, BNSC actively pursued international agreement on a variety of issues. The primary purpose of IADC was 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 and to identify debris mitigation options. The United Kingdom participated in the twenty-first meeting of IADC, which was hosted by the Indian Space Research Organization and held in Bangalore, India, from 10 to 13 March 2003. Of particular note was the presentation on the IADC space debris mitigation guidelines given at the fortieth session of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space, in February 2003 (A/AC.105/C.1/L.260).

3. Within Europe, ESA coordinated research capabilities through the European Network of Centres Space Debris Coordination Group, the ESA Council approved the pilot project on space debris in June 2000 and the qualification phase of the project in December 2001. BNSC is a member of the group, together with ESA and the three national agencies ASI, CNES and DLR. The Network of Centres is working towards the production of an updated integrated European work plan.

4. At a national level, BNSC maintained its support of the United Kingdom Space Debris Coordination Group, which meets annually to provide a forum for the coordination of all debris research and policy activities in the United Kingdom. In September 2002, the annual meeting was held at the University of Southampton and

was attended by representatives from many of the leading research groups in industry and academia in the United Kingdom, including the European Aeronautic Defence and Space Company (EADS) Astrium, Century Dynamics, the Natural History Museum, the National Environment Research Council Space Geodesy Facility, Observatory Sciences, QinetiQ, Rutherford Appleton Laboratory, Surrey Satellite Technology Ltd. and the University of Southampton. The meeting discussed recent international developments, in particular with respect to debris mitigation guidelines and standards and provided an opportunity to report on the latest research in the United Kingdom.

5. The United Kingdom has particularly strong debris research capabilities, which BNSC has regularly called upon for impartial technical support and advice. During the past year, organizations in the United Kingdom conducted a wide range of activities, some of which are summarized below.

2. Observation and measurement of the debris population

(a) Debris observation campaign

6. The Ministry of Defence of the United Kingdom, supported by Observatory Sciences Ltd., participated in the 2002-2003 IADC geostationary Earth orbit debris search campaign. The Ministry’s network of passive imaging metric sensor telescopes was used.

7. The orbits of objects detected by the network during the campaign were determined and the data was submitted to the IADC campaign coordinator. The observations and their analysis were positive contributions towards creating a more detailed catalogue of debris in geostationary Earth orbit (GEO).

(b) In situ detectors and measurement of retrieved surfaces

8. Research at the Department of Mineralogy at the Natural History Museum in London continued to focus on the characterization of impacts on spacecraft surfaces, specifically the Mir Trek experiment and the Japanese Space Flyer Unit. The museum is currently working with Unispace Kent on a survey of residue in impact craters on Hubble Space Telescope solar cells retrieved by the shuttle orbiter Columbia during the third service mission, which was funded by ESA.

9. Together with researchers at the Lawrence Livermore National Laboratory of the United States and Imperial College in London, the Natural History Museum has continued its assessment of techniques for in situ analysis and preparation of particles captured in silica aerogel. During the year, preliminary testing of a multi-layer polymer foil device for the sampling of space debris and micrometeoroids took place and a model suitable for deployment in low-Earth orbit was designed.

10. Debris and micrometeoroid impact data from the DEBIE detectors, which were launched aboard the polar-orbiting PROBA satellite in late 2001, were analysed by the Open University and Unispace Kent. Those results will eventually be used to update particulate models of the space environment.

3. Debris environment modelling

11. Modelling of the debris environment, its long-term evolution and the potential risks it poses to possible future space systems is a major activity among debris researchers in the United Kingdom.

(a) Support to the IADC Environment and Database Working Group

12. United Kingdom researchers at QinetiQ and the University of Southampton continued to support BNSC membership of the IADC Environment and Database Working Group by participating in several of the Group's debris environment modelling studies. The United Kingdom debris models Integrated Debris Evaluation Suite (IDES) and Debris Analysis and Monitoring Architecture for the Geosynchronous Environment (DAMAGE) were regularly called upon to support those activities.

(b) Modelling debris in high Earth orbit

13. The University of Southampton's research programme to develop the DAMAGE software tool concluded during the reporting period. It was funded by the Engineering and Physical Sciences Research Council of the United Kingdom. DAMAGE is a dedicated model to analyse space debris in high Earth orbits, and GEO in particular. The modelling and analysis of the debris environment in GEO and the associated risk to orbiting systems pose unique challenges for the modeller, which are distinct from the treatment of debris in low-Earth orbits.

(c) Fast debris cloud propagator

14. A postgraduate (PhD) research programme to develop a fast debris cloud propagator was recently completed at the University of Southampton. The work addressed the issue of the computational expense associated with the propagation of a debris cloud composed of many fragments over a long period of time (10 to 100 years). Such cloud evolution is required in all standard debris environment and risk analysis tools and there is generally a trade-off to be made between the accuracy of the propagation and the computational effort. The work undertaken looked at the propagation of debris clouds emanating from a break-up event, with the cloud fragments treated as a statistical distribution. It was shown that the propagation of the parameters that define the statistical characteristics of a cloud significantly reduced the computational effort, particularly for clouds with large numbers of individual fragments. The results were shown to be sufficiently accurate to be used for long-term debris risk assessments.

(d) Modelling the interaction of space tethers with the debris environment

15. As part of another PhD research programme at the University of Southampton a software tool was developed to study the debris impact risk to tether space systems. The software employed the probabilistic continuum dynamics method and enabled both single- and double-stranded flexible tethers to be modelled. The technique provides, within the constraints of computational expense, an accurate means of assessing the sever risk for a particular tether mission.

4. Spacecraft debris protection risk assessment and collision avoidance

16. The assessment of risk to and protection of spacecraft from hypervelocity debris impacts is another research area in which the United Kingdom continues to be very active.

(a) Support to the IADC Protection Working Group

17. QinetiQ continued to provide active United Kingdom participation in the IADC Protection Working Group, on behalf of BNSC. The United Kingdom currently chairs the Working Group, a two-year position that is due to end at the twenty-second meeting of IADC to be held in April 2004. A major ongoing task of the Working Group has been the development of a protection manual containing technical information relating to spacecraft debris risk assessment and protection. That activity, which is overseen by the Working Group chairman, is nearing completion and the resulting document will be published on the IADC web site.

(b) Satellite survivability modelling

18. QinetiQ continued to use the SHIELD software model to evaluate the survivability of unmanned spacecraft designs in the debris environment and to recommend appropriate cost-effective protection strategies. Further simulations were performed to quantify the debris impact, penetration and failure risks on a representative three-dimensional model of the meteorological operational spacecraft, which is due to be launched in 2005. That assessment has enabled the identification of the most vulnerable elements of the spacecraft design, thus indicating where additional protection may be most beneficial.

19. QinetiQ was also involved in an ESA contract, which is being led by the Ernst Mach Institute in Germany, to characterize the response of typical spacecraft equipment to debris and meteoroid impacts. An extensive impact test programme will be performed and the resulting damage equations incorporated into SHIELD. With those new equations, SHIELD will be able to provide a more accurate assessment of the survivability of typical unmanned spacecraft.

(c) Numerical simulation of hypervelocity impacts

20. Century Dynamics continued to develop, sell and support the AUTODYN software to the worldwide space community, including agencies, industry and academia.

21. A two-year research project being conducted for ESA is nearing completion and will result in a significant step forward in the capability to model composite materials under hypervelocity impact. During the last year three other projects, for and with ESA and BNSC/Astrium, were completed: they related to the protection of honeycomb satellite structures, damage to carbon fibre reinforced plastic-based structures and very oblique impacts on the X-Ray Multi-Mirror science mission.

(d) Hypervelocity impact testing

22. The University of Kent continued to make extensive use of its two-stage light gas gun for hypervelocity impact research. The maximum speed of the gun was increased and now exceeds 8 km s^{-1}. Space debris-related work during the past year

included an investigation of impact damage to space tethers. In the coming year, one of the postgraduate research programmes at Kent will focus on analysing the impact damage to typical spacecraft materials.

23. The two-stage light gas gun at the Open University's new Hypervelocity Impact Laboratory is approaching operational status. The facility accelerates millimetre-sized projectiles to velocities typical of space debris and is used for detector response and debris damage assessment. The gun complements the Van de Graaf microparticle facilities in the same laboratory.

5. Debris mitigation

(a) Support to the IADC Mitigation Working Group

24. In the IADC Mitigation Working Group, the BNSC representative, QinetiQ, undertook a study of the IADC recommendation for re-orbiting GEO satellites that have reached the end of their useful life. This is aimed at improving knowledge of the elements involved in ensuring that re-orbited satellites will not interact with the GEO region at a later date. The work was done in collaboration with the University of Southampton and the Aerospace Corporation of the United States.

(b) Debris mitigation standards

25. EADS Astrium continued its coordinated activities on the theme of debris, with a particular focus on industrial issues associated with debris mitigation. Work carried out in EADS Astrium, led by the United Kingdom, resulted in the conclusion that the current European and international draft standards and guidelines were not suitable for industrial implementation, due in part to the way in which the requirements were formulated. An EADS Astrium "roles and responsibilities" analysis, together with the scientific community research on space debris, identified key roles for standardization bodies and spacecraft designers and manufacturers.

26. EADS Astrium fully supported the policy of ECSS and BNSC in pursuing an ISO approach to the development of space debris standards and to that end actively participated in discussions on debris mitigation:

(a) At the national level (British Standards Institution (BSI);

(b) At the European standardization level (ECSS), particularly in the space debris working group mandated to represent ECSS within the framework of ISO;

(c) At the European trade association level (Eurospace);

(d) By providing technical support to the delegation of the United Kingdom to IADC.

27. EADS Astrium also took a leading role in the ISO Orbital Debris Coordination Group and provided the necessary technical expertise to support the United Kingdom delegation. The group leads the definition of a standards framework for end-of-life manoeuvres.

28. In the United Kingdom, EADS Astrium continued to build on strong technical capabilities in debris, including collision modelling and collision avoidance.

(c) United Kingdom satellite-licensing process

29. BNSC was responsible for issuing licences to confirm that United Kingdom satellites were launched and operated in accordance with the obligations of the United Kingdom under the United Kingdom Outer Space Act 1986. To assist BNSC in the licensing assessment process, two years ago QinetiQ developed a software tool for performing collision risk and liability assessments of United Kingdom satellites operating in the GEO region. During the past year, this tool has been extended to cover satellites operating in the low-Earth orbit region. Operationally, the tool, which has been given the name Satellite Collision Assessment for the United Kingdom Licensing Process (SCALP), was recently used to assess three United Kingdom satellite systems: Skynet, the United Kingdom Disaster Monitoring Constellation and Bilsat, and AMC-2. All three systems were subsequently granted licences.

(d) Debris Risk Assessment and Mitigation Analysis tool

30. For ESA, QinetiQ is currently developing a Debris Risk Assessment and Mitigation Analysis software tool. The aim of the tool is to enable satellite programmes in Europe to assess their compliance with the draft European space debris safety and mitigation standard. Additionally, the recently upgraded long-term environment model DELTA (also developed by QinetiQ for ESA) is being exploited to update the results in the ESA *Space Debris Mitigation Handbook*, which includes an extensive analysis of the long-term evolution of the debris environment and the effectiveness of mitigation measures.

(e) Active removal of debris from the geostationary orbit

31. An international team comprising QinetiQ, ESYS, OHB-System (D) and Dutch Space recently completed an ESA-funded contract to study the feasibility of robotic spacecraft removing hazardous objects from the geosynchronous orbit. That project, entitled Robotic Geostationary Orbit Restorer, addressed the collision risk in GEO, identified workable economic and technical mission scenarios and proposed an appropriate solution. The analysis included a breakdown of the current utilization of the GEO ring and an assessment of the satellite failures that have afflicted GEO satellites. Also considered were the general trends in the GEO market and the tendencies of satellite operators to remove their assets from the operational GEO region at the end of their useful life. The overall GEO simulation was designed to determine the collision risk in GEO and to take account of the effects of satellite failures, future launch traffic and re-orbiting trends.

32. It was shown that the reduction of the GEO collision risk by the use of an intervention mission was governed principally by the cost-effectiveness of that solution and the willingness of interested parties to implement the solution. The study evaluated economic and technical factors for a number of mission scenarios to arrive at a plausible intervention concept. As a consequence, the favoured technical solution was both innovative and required minimal use of complex robotic elements. The solution employs a satellite using a high-impulse electric propulsion system to visit a large number of target objects. For each visit, the target is captured using a simple bulk capturing device and then transported into a graveyard orbit at a higher altitude than the GEO. The principal development challenges are expected to be that of the grappling equipment, its attitude and orbit control subsystems and the

guidance, navigation and control elements, which are necessary for the safe approach of the uncontrolled and non-cooperative target objects. Costs and schedules for the development phase and operational phases were also produced.

III. Replies received from international organizations

Committee on Space Research

[Original: English]

1. The Committee on Space Research (COSPAR) actively promoted progress in understanding the space debris problem and supported efforts to reach a global solution on debris mitigation. Scientific meetings on space debris were held at the thirty-third COSPAR Scientific Assembly, held in Warsaw from 16 to 23 July 2000 and at the thirty-fourth COSPAR Scientific Assembly, organized jointly with the International Astronautical Federation (IAF) as the World Space Congress, held in Houston, Texas, United States from 10 to 19 October 2002. Furthermore, COSPAR acted as sponsor for the Third European Conference on Space Debris, held at the European Space Operations Centre in Darmstadt, Germany, from 19 to 21 March 2001.

2. Those events, where the complete spectrum of technical issues of space debris were addressed, provided participants from around the globe with a forum for presenting the results of research and for discussing the way forward. Among the important topics discussed were the search for cost-efficient methods to minimize the creation of new debris objects and approaches to reduce the population of on-orbit debris.

3. The scientific meeting on space debris held during the 2002 World Space Congress and jointly organized by COSPAR and the International Academy of Astronautics, comprised 57 solicited and contributed papers and 26 posters. In six sessions, the following main areas were covered: (a) measurements and modelling of space debris and meteoroids; (b) risk analysis; (c) hypervelocity impacts and protection; and (d) debris mitigation measures and standards. The importance of the geostationary ring was underlined by the fact that one session was fully devoted to it. It should be noted that currently more than 300 controlled spacecraft are in the geostationary orbit (GEO).

4. Several papers addressed improved observation capabilities from the ground and in space using radar and optical sensors. Those papers dealt with such topics as:

(a) The beam-park experiments carried out with the radar of the Research Establishment for Applied Science (FGAN) (sensitivity about 2 centimete (cm) at 1,000 km distance);

(b) The positive outcome of the feasibility study on using the European ionospheric radar system European Incoherent Scatter Facility in the Auroral Zone for the detection of small-sized (less than 10 cm) space debris in low-Earth orbit (LEO);

(c) The detection of small-size debris with very long baseline interferometry radar techniques using the Evpatoria facilities in Ukraine;

(d) The optical orbital debris measurement programme at NASA and the United States Air Force Maui Optical Station;

(e) The first results of observations in low-inclination geostationary transfer orbits with the ESA 1-metre telescope in Tenerife (Canary Islands).

5. In several papers the characterization of micro-debris and meteoroids in near-Earth space was discussed. In those papers the following topics were considered:

(a) The contribution of secondary ejecta to the space debris population;

(b) The dust detector of the Geostationary Orbit Impact Detector as flown on the Ulysses and Galileo missions, which was launched in the geostationary orbit in September 1996 on the Russian Express-2 satellite and ended its operations in 2002;

(c) The results of the observing efforts of the Leonid returns in the past years with a preview for November 2002.

6. Several presentations were devoted to improved space debris population models, such as EVOLVE 5.0 and LEGEND, a three-dimensional LEO to GEO evolution model, of NASA and the Meteoroid and Space Debris Terrestrial Reference Model (MASTER)-2001 of ESA. There was a report on the validation of the NASA explosion fragmentation model for particle sizes as small as 1 millimetre. Fragmentation models are of fundamental importance for space debris models as they describe debris clouds and their future evolution.

7. Some presentations considered such important topics as the progress in hypervelocity impact modelling and protection, the results of the post-flight analysis of meteoroid and debris impacts on the Space Shuttle and the outline of cost-effective methods for the protection of unmanned spacecraft against impacts.

8. Several papers addressed optical observations in the geostationary orbit, the population growth of man-made objects in that region and the resulting collision risk. At least two break-ups (an Ekran spacecraft and a Titan Transtage) occurred in GEO. However, the fragments were not catalogued, which means that their orbits are not known. The fragments will not leave the GEO region. Efforts focused on the detection of fragments and the lowering of the detection threshold to 10-20 cm, where significant progress was made. There was a presentation addressing operational issues of collision avoidance in GEO.

9. A considerable effort was devoted by several space agencies to the analysis of debris-preventative measures and their effect on the long-term evolution of the space debris population. Explosion suppression alone has a minor effect on the long-term evolution. Post-mission disposal of spacecraft and rocket upper stages is required, such as immediate de-orbiting at the end of mission or transfer to an orbit with a limited lifetime (for example, less than 25 years). One presentation demonstrated that the stability of disposal orbits for the navigation satellite systems Global Positioning System (GPS), Global Navigation Satellite System (GLONASS) and Galileo was strongly orbit-dependent. Further work was needed to define cost-efficient and stable disposal orbits.

10. During the Scientific Meeting the ESA *Space Debris Mitigation Handbook 2002* was introduced. Participants considered such important issues as investigation of the costs of space debris mitigation methods and discussion of the space debris aspects to be considered and implemented during the design and operation of a spacecraft.

11. An area with increasing importance was the on-ground risk related to the survivability of spacecraft during atmospheric re-entry. Analyses of BeppoSAX and the Upper Atmosphere Research Satellite (UARS) were presented, followed by an update on the ESA SpaceCraft Atmospheric Re-entry and Aerothermal Break-up (SCARAB) analysis tool for destructive re-entry.

12. There was an outline of the draft European space debris safety and mitigation standard being developed by a working group with members of ESA and national space agencies (ASI, BNSC, CNES and DLR). The standard focuses on debris-preventative measures and the concept of the protected zones of LEO and GEO, where pollution has reached maximum values. The standard was based on the IADC space debris mitigation guidelines.

13. A report was presented describing recent space-debris-related activities in Japan (promotion activities, observation, protection, mitigation, and the debris research to be undertaken by the new consolidated space organization of Japan, due to start operating in January 2004).

14. The scientific meeting on space debris provided an up-to-date overview of current worldwide research activities and technical knowledge in the field of space debris. While progress was noted in various research activities, further substantial efforts will be required to ensure that debris-preventative measures are applied uniformly and consistently to the design and operation of space systems by all users of space. In that process, the deliberations on space debris at the Committee on the Peaceful Uses of Outer Space play a key role in the search for a global solution to the application of debris mitigation measures.