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Item 7 of the provisional agenda*
Space debris

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

I. Introduction

1. In its resolution 69/85, the General Assembly expressed its deep concern about the fragility of the space environment and the challenges to the long-term sustainability of outer space activities, in particular the impact of space debris, which is an issue of concern to all nations. It considered it essential that States pay more attention to the problem of collisions of space objects, especially those with nuclear power sources, with space debris, and other aspects of space debris, and 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. The Assembly also considered that, to the extent possible, information thereon should be provided to the Scientific and Technical Subcommittee 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 fifty-first session, the Scientific and Technical Subcommittee agreed that research on space debris should continue and that Member States should make available to all interested parties the results of that research, including information on practices that had proved effective in minimizing the creation of space

* A/AC.105/C.1/L.341.

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debris (A/AC.105/1065, para. 103). The Subcommittee also agreed that Member States and international organizations with permanent observer status with the Committee should be invited to provide reports on research on space debris, the safety of space objects with nuclear power sources on board, problems relating to the collision of such space objects with space debris and ways in which debris mitigation guidelines were being implemented (A/AC.105/1065, para. 104), and on this basis an invitation was issued in a note verbale dated 31 July 2014 to provide the reports by 20 October 2014, so that the information could be made available to the Subcommittee at its fifty-second session.

3. The present document has been prepared by the Secretariat on the basis of information received from three Member States, namely Austria, Germany and Switzerland, and from three non-governmental organizations with permanent observer status with the Committee, namely the Committee on Space Research (COSPAR), the Secure World Foundation (SWF) and the Space Generation Advisory Council (SGAC). Information provided by SGAC, which includes pictures and figures related to space debris, will be made available as a conference room paper at the fifty-second session of the Scientific and Technical Subcommittee.

II. Replies received from Member States

Austria

[Original: English]
[20 October 2014]

Since 1982, the Institute for Space Research of the Austrian Academy of Sciences has operated a satellite laser ranging (SLR) station at the Lustbühel Observatory in Graz. Day and night, seven days a week, this station measures distances to more than 60 retro-reflector equipped satellites, such as geodetic satellites, global navigation satellite system (GNSS) satellites (GALILEO, GPS, GLONASS, COMPASS, etc.), Earth observation satellites, and various scientific and research satellites. The single-shot accuracy of the Graz measurements is about 2 to 3 mm; distance differences down to 0.2 mm can be distinguished. With these results, the Graz SLR station is considered one of the most accurate in the world.

In 2012 the Graz laser station started to test laser ranging of space debris objects. New specialized single-photon detectors were developed, and the laser ranging software for space debris tracking was adapted. For the first time photons diffusely reflected by space debris objects were measured to determine the distance to those objects. Although the accuracy of the measurements is not in the millimetre range, given that the selected debris objects are one to a few metres in size, this approach does allow for significantly better orbit determination.

Additional improvements to orbit determination are possible if other SLR stations are able to detect the diffusely reflected Graz photons. In 2012 the first such experiment was successful: photons emitted in Graz were diffusely reflected by the bodies of satellites and detected at the Zimmerwald SLR station in Switzerland, which for this purpose had been synchronized with the Graz station. This method can be extended without problems to several other receive-only stations.

Since 2013 the Graz laser station has been involved in the space situational awareness programme of the European Space Agency. In the coming years cooperation will be increased at the European and international levels.

Germany

[Original: English]
[27 October 2014]

In Germany, research activities on issues related to space debris are being carried out in all relevant fields, such as space debris environment modelling, observation of space debris, studies of the effects of hypervelocity impact on spacecraft, and protection of space systems from impact of micro-meteoroids and space debris. German experts actively participate in relevant international forums in the field of space debris research, inter alia in the Inter-Agency Space Debris Coordination Committee (IADC) and in international standardization activities in the field of space debris mitigation.

For space projects sponsored by the Space Administration of the German Aerospace Centre (DLR), space debris mitigation requirements are a mandatory part of the product assurance and safety requirements for DLR space projects. These requirements ensure the implementation of internationally recognized mitigation measures, including those identified in the Space Debris Mitigation Guidelines of IADC and those of the Committee on the Peaceful Uses of Outer Space. The general objectives are to limit the creation of new space debris and thus to limit the risk to current and future space missions and the risk to human life. The measures to be adopted in order to achieve these objectives include the conduct of a formal space debris mitigation assessment and specific design measures, inter alia to prevent the release of mission-related objects, fragmentations, malfunctioning and on-orbit collisions, together with measures pertaining to passivation, end-of-life disposal and re-entry safety.

Development work has been carried out at the German Space Operations Centre to enhance the collision avoidance system used for German civil satellite missions, with various tools supporting the evaluation and analysis of critical conjunctions. At the end of 2013, the thresholds for the satellite constellation TerraSAR-X/Tandem-X were increased, which resulted in up to 10 warnings per day. Since August 2013, 189 critical events have been analysed for those two satellites and four collision avoidance manoeuvres have been executed.

An optical space debris observation station has been installed for scientific purposes by the DLR Institute of Technical Physics. The station is equipped with a 17 inch Dall-Kirkham telescope and various high-end camera systems. Since 2013, various objects in low-Earth orbit down to 0.1 m in size can be passively monitored using optical means. Image analysis of optically detected tracks, especially of uncatalogued objects, makes it possible to deduce initial orbits for precise tracking. In continuous tracking mode, a closed loop accuracy of 2 inches is reached. A laser system for time-of-flight laser ranging is currently being installed. In combination with passive optical tracking this system will allow for three-dimensional tracking of orbital objects during station passage to an accuracy of a few metres.

Efforts are under way to develop a network of optical stations set up by the German Space Operations Centre in close cooperation with the Astronomical Institute of the University of Bern, Switzerland. It is intended for continuous monitoring of the geostationary ring, and its telescopes are operated telerobotically. The data captured will make it possible to track and predict the orbit of geostationary objects larger than approximately 50 cm. The Sutherland Observatory in South Africa has been chosen as the location for the first telescope, to be set up in 2015. A first test campaign has been successful, and the results were even better than expected.

The objective of another planned project is to establish a European node of the Falcon Telescope Network. It should provide academia with opportunities to participate in meaningful, hands-on and authentic science experiments. This should encourage students to engage in science through a variety of projects and initiatives utilizing the unique resources available within the Network and conduct space situational awareness (SSA) research and improve SSA catalogues. The Falcon Telescope Network, a global network of small aperture telescopes, has been developed by the Center for Space Situational Awareness Research in the Department of Physics at the United States Air Force Academy in collaboration with educational partners. It is shared with university partners within the United States of America and internationally for the purpose of undergraduate space situational awareness and astronomy research education and community science, technology, engineering, and mathematics outreach.

In order to develop an autonomous space surveillance capability, a country must have the basic capability of utilizing sensor data, for instance to establish a space object catalogue. As a first step a project is being prepared to develop and implement key technologies for cataloguing space debris. A sensor simulator will be used that simulates measurement data. These data will allow further development of key functionalities such as object correlation, orbit determination and implementation of an object database. Complementary methods for orbit determination and propagation are being investigated so as to have fast and accurate methods available within the process chain of a simulated space surveillance system.

Research is continuing at the Fraunhofer Institute for High-Speed Dynamics to improve the experimental characterization of a new light gas gun facility. The facility is capable of accelerating particles in the size range of 100 µm to 2 mm to hypervelocity. The purpose of this facility is to reach higher-impact velocities as compared to standard light gas gun facilities, and at the same time reduce facility wear. This will result in improved performance with regard to laboratory-scale experimental impact testing of the survivability of spacecraft components in a space debris environment.

As space objects enter denser regions of the atmosphere, friction with the Earth’s atmosphere generates heat owing to the high velocity of the orbiting space object. The thermal energy can melt or vaporize the entire space object or parts of it. In many cases the space object burns up completely during the atmospheric re-entry, but parts of it can also survive the re-entry process and hit the ground.

In order to better understand the process during the fragmentation of a space object and to enable analysts to pre-estimate the risk for people and property on the ground, a new project is under preparation to develop validation methods. The project will make it possible to analyse the atmospheric re-entry and the fragmentation process associated with it, and to evaluate the risk for inhabited areas with regard to surviving parts.

Furthermore, an ongoing project at Technische Universität Braunschweig is investigating the effects of active deorbiting of spacecraft at their end of life in accordance with the Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space, and the effects of active debris on the long-term evolution of future space debris. In this context the criticality of high-risk objects with respect to their effects on the environment in the case of a collision is analysed. This approach tries to capture the effects of the collision-cascading process more accurately. In another activity, different disposal strategies for medium-Earth orbit constellation objects are being analysed. Of special interest is the long-term risk of collision between disposed-of constellation spacecraft and other constellation and non-constellation objects.

Switzerland

[Original: English]
[20 October 2014]

The Astronomical Institute of the University of Bern (AIUB) continues its research efforts to better understand the near-Earth space debris environment. AIUB uses its 1-metre ZIMLAT telescope, a small robotic telescope named ZimSMART and the new ZimSpace telescope, all located at the Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald near Bern to discover and physically characterize small-size debris. A major result of this research has been the creation of a unique catalogue of high area-to-mass ratio debris in geostationary and highly elliptical orbits. The catalogue has been built up and is maintained in collaboration with the European Space Agency and the Keldysh Institute of Applied Mathematics in Moscow. The latter is operating the International Scientific Optical Network (ISON) with which AIUB has, for many years, shared observation data in the context of a scientific collaboration endeavour. ISON is cooperating with the Basic Space Science Initiative of the Office for Outer Space Affairs. Recent studies by AIUB have focused on deep surveys for small-size debris in highly elliptical orbits, including geostationary transfer, and Molniya-type orbits. The observations indicate a substantial population of "unknown" objects in these orbital regions, i.e. objects that are not contained in any of the publicly available orbit catalogues. Characterizing these objects will be of great importance in order to identify the sources of the debris and eventually design efficient and economically viable mitigation measures. In 2010 a study was initiated to find small-size debris in the region of the navigation satellite constellations. That study is the first of its kind in this orbit region. The results to date indicate a breakup of a larger object in the current navigation satellite constellations. In support of the discussion on the active removal of large objects from low-Earth orbits, AIUB is conducting an observation programme to assess tumbling rates of large debris objects in orbits at altitudes of 700 to 1,000 km by means of optical light curves.

The Swiss Space Center at the Swiss Federal Institute of Technology in Lausanne (EPFL) and its partners have continued research and development in the area of active debris removal under its “Clean-mE” programme. During 2014 their efforts were focused on system studies to address the challenges of non-cooperative rendezvous. EPFL worked under a European Space Agency contract to evaluate possible in-orbit demonstrations using CubeSat technologies and reduce the risk to future large missions for the removal of large debris. CubeSats are nano-satellites whose mass lies between 1 and 10 kg. Proposed CubeSat in-orbit demonstrations include testing of rendezvous sensor technologies and testing of net capture technology. Low-level activities continued on the CleanSpace One project.

III. Replies received from international organizations

Committee on Space Research

[Original: English]
[4 November 2014]

More than 55 years of space flight activities since the launch of Sputnik 1, in 1957, have generated a significant number of man-made objects in Earth orbits. The vast majority of those objects are non-functional and referred to as “space debris”. The sizeable population of that space debris constitutes an increasing threat to robotic and manned spacecraft. Over the last two decades, collision and breakup events have amplified concerns that this environmental hazard will become a central issue in the decades to come.

Although many space actors currently apply a variety of measures to reduce the creation of space debris, this will not be sufficient to control the future growth of the population of space debris because there is already a sufficient amount of derelict debris in Earth orbit to cause collisional breakups in the future, even without any new objects being placed into orbit. The prevention of catastrophic collisions, each creating thousands of new fragments, is thus of primary concern for the long-term evolution of the environment. Means to prevent collisions include debris mitigation, collision avoidance and removal of debris from the environment, also termed active debris removal. Collision avoidance measures require precise knowledge of the trajectories of all objects that could produce a catastrophic collision. Today such knowledge is available for a very limited number of objects only. For active debris removal, and for collision avoidance involving non-functional objects, new technologies need to be developed to change the trajectories of debris objects or to deorbit them. Substantial scientific research is essential to devise efficient and economically viable measures to stabilize the space debris population.

The Committee on Space Research (COSPAR) has been addressing the topic of space debris for more than a third of a century. For many years the COSPAR Panel on Potentially Environmentally Detrimental Activities in Space (PEDAS) has held multiple sessions about space debris at every COSPAR biannual Scientific Assembly. Those sessions have addressed: (a) the characterization of the current and future space debris environment through measurements and modelling; (b) risks posed to spacecraft by collisions with space debris; (c) means to protect spacecraft;

(d) strategies and policies to mitigate the creation of new space debris; and (e) the scientific foundation and technical framework for remediating the space debris environment and thereby limiting the proliferation of space debris.

At the 2014 PEDAS sessions, 38 papers were presented on the theme "Space debris: responding to a dynamic environment". At the 41st Scientific Assembly of COSPAR, in 2016, the PEDAS sessions will be "Space debris: providing the scientific foundation for action", which is a step forward. Four half-day sessions will focus on advances in collision risk assessment for space missions, on-orbit collision assessment, re-entry risk assessments, debris mitigation and debris environment remediation techniques and their effectiveness with regard to long-term environment stability, as well as traditional topics such as ground and space-based observations and methods for using them, in situ measurement techniques, debris and meteoroid environment models, national and international debris mitigation standards and guidelines, hypervelocity accelerator technologies, and on-orbit shielding concepts. Interdisciplinary and multidisciplinary papers on space weather and near-Earth objects are particularly encouraged.

The challenges of stabilizing the space debris population are substantial, but spacefaring nations and international scientific organizations such as COSPAR are devoting considerable efforts to promoting the long-term sustainability of operations in near-Earth space for the benefit of all.

COSPAR continues to be a leader in promoting a better understanding of the nature and risks of the space debris environment and in encouraging spacefaring nations and organizations to act responsibly in space through each mission phase, including deployment, operations and disposal.

Secure World Foundation

[Original: English]
[20 October 2014]

In 2014, the Secure World Foundation (SWF) continued to work on space debris and on-orbit safety issues as part of its focus on the long-term sustainability of space activities. As part of its information awareness activities, SWF was able to provide testimony before the Space Subcommittee of the House Committee on Science, Space, and Technology of the United States of America as part of a hearing on dealing with the threat of space debris. The written testimony included a comprehensive overview explaining the importance of space debris mitigation, space traffic management, space debris removal and remediation, and space situational awareness to minimizing the threat space debris poses to space activities. The testimony also provided the Subcommittee with recommendations on how to improve the implementation by the United States Government of the space debris mitigation guidelines in national regulations and how to improve space situational awareness services to help all satellite operators avoid collisions in space.

Similarly, SWF staff members regularly raised the issue of space debris in discussions at meetings and conferences about the uses of outer space that might not otherwise have addressed the question. Examples of such initiatives included speeches and presentations at a workshop entitled "Emerging space economies: next steps toward prosperity" held by the Wilton Park international discussion forum, a round table on promoting space security and sustainability hosted by the Council on Foreign Relations and a spotlight talk at the International Symposium on Personal and Commercial Spaceflight that addressed the responsibility of the growing commercial space sector to participate actively in practices that mitigate space debris.

SWF staff participated in the 3rd European Workshop on Space Debris Modelling and Remediation, held in Paris from 16 to 18 June 2014. SWF participation included co-chairing the first ever session on the legal, policy and other non-technical challenges related to space debris remediation, and a presentation on a draft protocol for determining how to ask permission to interact with a space object for remediation. The protocol uses the principles established in the existing outer space treaties to create a list of steps a State can take for determining which State has jurisdiction and control over a space object. In cases where the determination cannot be made, the protocol suggests steps that can be taken to notify the world community of its intent to remediate a space object in a safe and responsible manner.

As part of its efforts to facilitate cooperative discussions, SWF has cooperated with the Maui Economic Development Board and the Japan Space Forum (JSF) to hold two Advanced Maui Optical Space Surveillance (AMOS) dialogues. The purpose of the dialogues was to foster discussion on policy issues related to space situational awareness cooperation and data-sharing. The first dialogue was held in Tokyo on 26 February 2014 just prior to the third JSF International Symposium on Sustainable Space Development and Utilization for Humankind. The second dialogue was held on the island of Maui, United States, on 11 September 2014 during the 2014 AMOS conference. Both dialogues brought together Government and private sector representatives from multiple countries to discuss ways to improve space situational awareness data-sharing and cooperation.

Finally, as part of its general outreach efforts on the issue, SWF once again featured space debris prominently in its publication entitled "Space sustainability: a practical guide", which had been updated and republished this year. That document can be downloaded free of charge from the SWF website at www.swfound.org/media/121399/swf_space_sustainability-a_practical_guide_2014__1_.pdf.

Space Generation Advisory Council

[Original: English]
[7 November 2014]

The space debris situation

Ever since the first satellite was launched in 1957, Earth's orbit has become more crowded. Many nations and commercial enterprises have launched their own spacecraft into orbit around Earth, and many of those craft are still in orbit. Of the objects in space only 6 per cent are still operational, while almost 60 per cent are fragments produced by explosions and collisions. These uncontrolled fragments, along with other pieces of space debris such as discarded rocket bodies and retired satellites, can collide with each other and generate yet more debris. This cycle, popularly known as the Kessler syndrome, results in an exponential growth of orbital debris as time progresses, and hence in an ever-increasing risk to operational bodies in orbit.

The distribution of space debris according to altitude shows that the amount of space debris at an altitude of 1,000 km more than doubled between the beginning of 2007 and April 2012. Fragments generated by the anti-satellite test conducted by China in 2007 and the collision between the Iridium 33 and Cosmos 2251 satellites in 2009 were major factors in the jump in the amount of space debris. Incidents such as the Iridium-Cosmos collision show the important role that debris-debris collision can have in changing the space debris environment.

Currently the debris field in low-Earth orbit is not stable. Simulations have shown that, even without any future launches, the debris field will slowly grow. However, this is an optimistic and unrealistic scenario, since space launches are not expected to stop any time soon. With regular launch rates and no mitigation measures, the quantity of debris in orbit is likely to grow exponentially.

The distribution of the 500 largest space debris objects makes it possible to identify a high collision risk by looking at the relationship between the apogee and perigee altitudes versus inclination distributions of the existing low-Earth orbit rocket bodies and spacecraft that have the highest mass and collision probability products. These objects are the most likely to cause catastrophic collisions that can increase the amount of space debris in low-Earth orbit, as previously seen in the Iridium-Cosmos collision.

Spacecraft carrying nuclear power technology

There are three general scenarios to consider with respect to nuclear-powered spacecraft:

Scenario 1: The spacecraft is equipped with a radioisotope thermal generator (RTG) for on-board power and instrument heating (e.g. deep space probes);

Scenario 2: The spacecraft is nuclear-powered and uses the energy generated to power the spacecraft, including at the launch phase (e.g. Project Rover and the Nuclear Engine for Rocket Vehicle Applications programme (NERVA));

Scenario 3: The spacecraft is designed to use nuclear technology for propulsion, but not for its launch. Nuclear propulsion will only be used once the spacecraft is in orbit.

Scenarios 2 and 3 basically differ in the launch phase and are considered in the following section.

Scenario 1 is the most common and has been used mostly for deep-space missions. The energy that solar arrays can derive from sunlight decreases in accordance with the inverse square law: as the distance from the Sun increases, the power available to a spacecraft using solar power diminishes. Nuclear technology provides a reliable source of heat and energy for spacecraft systems once they are beyond the point where solar arrays, for all practical purposes, become ineffective. An RTG basically converts the heat released by the natural decay of radioactive material (usually Pu-238) into electrical power, using the Seebeck effect. It should be noted that this is not a fission reaction.

Missions such as the Mars Science Laboratory (which landed the Curiosity rover on Mars) and solar system probes, such as Voyager 1 and 2, and Pioneer 10 and 11, have utilized RTGs for reliable power and thermal management.

Some accidents involving nuclear-powered spacecraft have been reported in the past. The first occurred in 1964, when the TRANSIT 5BN-3 navigational satellite performed an uncontrolled re-entry into the Earth’s atmosphere after a hardware malfunction. The satellite completely burned up in the upper atmosphere as it was designed to, but the long-term effects on the human population are hard to determine. Re-entries of this kind result in an increased loading of radionuclides in the upper atmosphere, which can in time spiral down to sea level. As the half-life of the RTG material is typically long (thousands of years), it is possible that harm was caused to the public and the environment.

Two other well-known incidents involving nuclear-powered spacecraft were related to the Apollo 13 mission, which re-entered the atmosphere with a fully functional RTG on board, and the Cosmos-954 radar ocean reconnaissance satellite (RORSAT), which made an uncontrolled re-entry and crashed into an unpopulated area of the Northwest Territories of Canada. RORSAT was designed to burn up upon re-entry but failed to do so, and a significant amount of nuclear material reached Earth. The RTG from the Apollo 13 mission plunged into the South Pacific, where it remains to date. It survived the re-entry and impact, and no release of radiation has been detected.

These incidents have led to changes in the design of nuclear power systems for use in space systems. Those nuclear power systems are now being designed to withstand re-entry and impact so that they reach the ground intact and, most importantly, without releasing any radioactive material. The RTG from Apollo 13 had already been designed in such a way, which demonstrates the validity of this approach.

Launch

Launch is considered the most critical phase of a mission involving a nuclear-powered spacecraft, and also the mission phase with the highest potential threat to the general population.

At this point it is also important to introduce the concept of “criticality”. Essentially criticality refers to the point where fission is initiated in a nuclear core and by-products will start to accumulate. Prior to criticality there are no by-products present in the nuclear fuel. The fuel is relatively benign in comparison to the by-products, as it is typically an alpha-radiation emitter and poses a significant risk to human health only if ingested. However, once criticality is achieved, fission by-products start to accumulate in the system. That poses a much greater hazard to human health, as a significant part of those by-products are beta and gamma emitters, which may cause damage to humans from external exposure alone.

Scenario 2 requires criticality to be achieved before launch and uses the heat derived from a nuclear reaction to power the ascent of the spacecraft. This was investigated and tested in the mid-twentieth century in the Rover-NERVA programme. However, under this scenario any failure of the rocket could potentially result in the release of fission by-products. In comparison, scenario 3 assumes that the spacecraft is launched into orbit using conventional propulsion methods. It is obvious that the release of any nuclear material, either before or after criticality is achieved, is undesirable. However, in order to limit the severity of any potential consequences, ideally a nuclear reactor should not achieve criticality until it is safely in orbit.

Earth orbit missions and the debris impact hazard

An impact involving space debris must be considered catastrophic as a worst-case scenario, given the significant energies involved. Furthermore, the worst-case example would be a breach of core containment, resulting in fission products being released into space. In the case of an RTG, it is assumed the collision results in the RTG being destroyed and scattered as particulate matter. This is not necessarily a concern for the public or Earth's environment, depending on where in orbit the collision occurs, because as long as atmospheric drag is not a factor and the orbit can be considered stable, it can generally be assumed that the nuclear material will stay aloft. However, it is also possible that such a collision will impart sufficient energy to some debris to move it into an orbit where atmospheric drag does become a factor, either from the initial impact or from the resultant secondary impacts occurring at a later time.

Given what is known about how orbital debris spreads into a shell around the orbital focus at the orbit's altitude, this model would effectively result in a band of radiation at a certain orbital altitude.

This would not pose a significant direct threat to astronauts or spacecraft, although anyone carrying out an extravehicular activity at the altitude in question may face direct health hazards. Therefore it is likely that a collision resulting in nuclear material being released into orbit would lead to restrictions on where extravehicular activities can be carried out. However, reputational issues also need to be considered, as the general public tends to distrust nuclear technology. An incident of this nature could effectively lead to the premature termination of current and future nuclear spacecraft programmes. Thus, the consequences of such an incident would be severe, even if they did not pose any immediate health hazard.

The likelihood of a collision with debris also needs to be assessed. Studies have been carried out to assess the size and quantity of debris in orbit, and it is relatively easy to model the probability of a debris impact on this basis. The overall probability is generally low (in the order of 10^{-5} per year). However, when paired with the severe consequences mentioned above, the overall risk ranking can be considered high and should drive any engineering programme towards including significant safeguards to prevent a release of radionuclides, should a collision occur.

Disposal

The disposal of a spacecraft after mission completion also needs to be taken into account. What happens to the critical core?

The simplest answer is to move the spacecraft into a safe graveyard orbit and leave it there. This would lead to a further increase in the number of space debris objects in orbit and, consequently, increase the risk of space debris impact to future missions. Moreover, collisions with an end-of-life nuclear-powered space system can have other consequences, such as a leak of radioactive material into space.

A longer-term sustainable solution is controlled re-entry of the space system. This would require the spacecraft, and particularly its nuclear components, to be designed to withstand the high temperatures, stresses and impact loads of the re-entry process. This has been done previously with RTG systems used in planetary exploration, but it might drive up the costs of the spacecraft.

The case of active nuclear reactors (and their fission by-products) presents a much more challenging task, as it is still not clear whether a reactor capable of withstanding re-entry can actually be manufactured. The risk associated with moving used cores into a graveyard orbit selected specifically for the disposal of nuclear-powered spacecraft taking into account the low probability of future collisions would be lower than that associated with their re-entry. Such a graveyard orbit needs to be selected with the aim of minimizing space debris collisions and reducing future hazards.

Deep-space exploration missions

The use of nuclear-powered spacecraft for deep-space exploration is somewhat more acceptable than for Earth-orbit missions. The increased efficiency of RTGs over solar arrays as the distance from the Sun increases supports the use of nuclear power. While deep-space missions pose the same hazard on launch, they spend less time in Earth's vicinity. Consequently the space debris impact hazard associated with deep-space missions is lower.

However, whether this is indeed the case depends upon the mission profile. If the spacecraft were to depart from Earth on a direct transfer orbit to its destination (which is rarely the case) and an accident were to occur, the resultant radioactive debris would remain on an orbit that could eventually intersect the Earth's orbit, ultimately resulting in radioactive debris entering Earth's vicinity.

Conclusion

The use of nuclear power for spacecraft has made several important missions possible in the past (particularly deep-space exploration missions) and can continue to do so as long as the necessary safety measures are undertaken. In this connection the Space Generation Advisory Council recommends that:

(a) If a spacecraft uses a nuclear core, it should carry that core into orbit and start the fission reaction only in orbit, as opposed to using nuclear propulsion as a means to reach orbit;

(b) For all spacecraft using nuclear power, special emphasis should be placed on the robustness and sturdiness of the nuclear power system. It should be protected against debris impacts, re-entry stresses and extreme temperatures;

(c) Deep-space missions carrying nuclear power systems should use non-direct transfer orbits if possible;

(d) Upon reaching their end of life, all spacecraft in low-Earth orbit using an RTG system should be re-entered in a controlled manner that ensures the intact survival of the nuclear power system;

(e) Upon reaching their end of life, all spacecraft using nuclear reactors or using an RTG in geosynchronous orbit should be transferred to a graveyard orbit. That graveyard orbit should be selected in such a way as to assure stability, i.e. it should not decay or present a collision hazard, for the duration of the nuclear fuel's half-life or until the radiation emitted no longer poses a hazard to human populations;

(f) For every mission for which the use of nuclear power is considered there should be an independent nuclear safety panel (similar to the Interagency Nuclear Safety Review Panel in the United States of America) to assure that all safety procedures are followed;

(g) Safety efforts should focus on planning and prevention rather than investigation of accidents.

About the Space Generation Advisory Council

The Space Generation Advisory Council is an international non-profit organization dedicated to students and young professionals in the space sector. It represents the views of the next generation of space leaders before relevant United Nations bodies and other space organizations.

Having been created in the United Nations environment (namely the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space), the Council's work with the United Nations, particularly the Committee on the Peaceful Uses of Outer Space, is of central importance to its mission. The Council gives regular input to the Committee and acts as a conduit for the opinions of its members.