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**Committee on the Peaceful
Uses of Outer Space**
Scientific and Technical Subcommittee
Fifty-fourth session
Vienna, 30 January-10 February 2017
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**

The present conference room paper contains submissions received by the Secretariat from:

- (a) Japan on 28 October 2016, and includes additional pictures and figures not included in document A/AC.105/C.1/111;
- (b) Slovak Republic on 7 December 2016;
- (c) Pakistan on 19 December 2016;
- (d) the Space Generation Advisory Council on 17 October 2016, and includes additional pictures and figures not included in document [A/AC.105/C.1/111](#).

The document is issued without formal editing.

* [A/AC.105/C.1/L.355](#).



Replies received from Member States

Japan

Overview

This report outlines the principal research on space debris conducted in the Japan Aerospace Exploration Agency (JAXA).

Major progresses of research introduced in the next section are as follows:

1. Conjunction assessment (CA) results and core technology for space situational awareness (SSA)
2. Technology to observe low earth orbit (LEO) and geosynchronous earth orbit (GEO) objects and their orbits
3. In-situ micro-debris measurement system
4. Protection against impacts of micro-debris
5. Easy-to-demise propellant tank during re-entry
6. Active debris removal

1. Conjunction assessment (CA) results and core technology for space situational awareness (SSA)

Conjunction assessment (CA) results

JAXA receives conjunction notifications from the Joint Space Operations Center (JSpOC). In August 2016, the number of notifications received was 110, which exceeded the specific conjunction threshold value. From 2009 to August 2016, JAXA has executed 19 collision avoidance manoeuvres for low earth orbit (LEO) spacecraft.

Core technology for space situational awareness (SSA)

JAXA determines the orbit of space objects by using observation data acquired from a radar in Kamisaibara Space Guard Center (KSGC) and telescopes in Bisei Space Guard Center (BSGC), predicts close approaches using the latest orbit ephemerides of JAXA satellites, and calculates probability of collision (PoC) using unique methods. JAXA also evaluates the criteria for CA and collision avoidance manoeuvre (CAM) through based on experience. In these evaluations, the trends of each conjunction condition and of prediction errors due to perturbations (e.g. uncertainty in air drag) are analysed.

As a research topic, JAXA studied re-entry analysis by changing the number of observational passes from the ground radar facilities. JAXA found that when the observation arc was longer than around 24 hours, the errors in re-entry prediction were small.

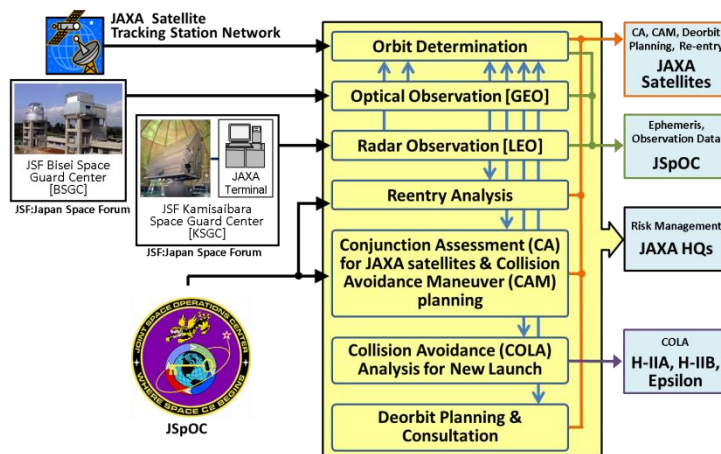


Fig. 1 Activity for the SSA in JAXA

2. Research on technology to observe low earth orbit (LEO) and geosynchronous Earth orbit (GEO) objects and to determine their orbits

Generally the observation of low earth orbit (LEO) objects is mainly conducted by a radar system, but JAXA attempts to apply an optical system to reduce the cost of system construction and operation of these operations. Fig. 2 shows the system which consists of numerous optical sensors to cover a large area of the sky. 15 cm-sized objects or larger are detectable at 1000 km altitude and 36 per cent of them are un-catalogued using a set of systems consisting of a 18 cm telescope and a CMOS sensor, according to survey observations. Additionally, JAXA succeeded in detecting a polar orbiting passive atmospheric calibration sphere (POPACS) in the orbit, which was an aluminium sphere of 10cm diameter. A large complementary metal-oxide-semiconductor (CMOS) sensor with low noise (Fig. 3) has also been developed. The sensor is able to observe objects five times wider and detect objects 1-magnitude fainter than the previous one. For GEO observation, a new observation method uses the data of two nights for the initial orbital determination. The method reduces observation time to two thirds, which allows the observation of 1.5-times more objects.

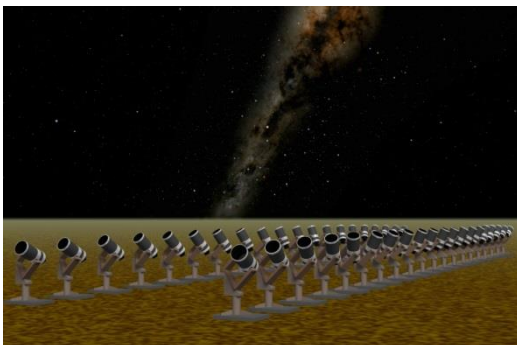


Fig. 2 The array of the optical sensor at one site. In order to detect many LEO objects twice, two narrow rectangular regions are observed by changing observational direction of each optical sensor.

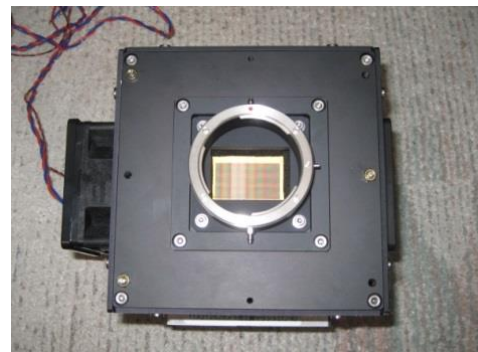


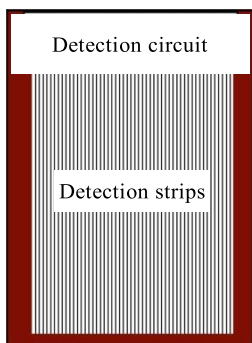
Fig. 3 The CMOS sensor manufactured by Canon. It can observe objects five times wider and detect objects 1-magnitude fainter than the previous one.

3. In-situ micro-debris measurement system

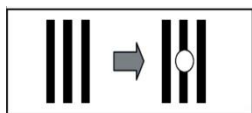
JAXA has developed an on-board detector for the in-situ measurement system of sub-millimetre class micro-debris, which can be detected from the ground. The sensor in this in-situ measurement system, named SDM, is the first which uses conductive (resistive) lines to detect debris. Fig. 4 shows the sensing principle and Fig. 5 shows the SDM product.

If the system were supplied to many spacecraft, the acquired data could help to improve the debris environment model. The first SDM was launched with the Japanese cargo ship H-II Transfer Vehicle (HTV) on August 19, 2015. This was the world first micro-debris measurement demonstration experiment on the ISS using a conductive (resistive) strip lines concept for detection. JAXA is currently analysing the acquired data.

Micro-debris measurement systems are essential for risk assessment of survivability of spacecraft against debris and for cost-effective protection design of spacecraft. However, limited measurement systems are available. JAXA has provided with 2 SDMs to the commercial satellite IDEA OSG 1 developed by a start-up company named ASTROSCALE. It is encouraged that space agencies launch their spacecraft with SDM, share their data, and contribute to the improvement of debris and meteoroid models.



(a) Detector strips on thin film



(b) Strips severed by debris particles

Numerous thin, conductive strips are formed with a fine pitch on a thin polyimide film (of nonconductive material). A dust particle impact is detected when one or more strips are severed by the perforation. [US patent registered]

Fig. 4 Sensor principle



Fig. 5 Engineering Model of SDM



Fig. 6 Flight experiment on HTV-5

4. Protection against impacts of micro-debris

The amount of sub-millimetre class micro-debris is increasing in low earth orbit. The impact of micro-debris can inflict critical damage on a satellite due to its impact velocity of 10 km/s on average.

To assess debris impact on a satellite, JAXA is conducting hypervelocity impact tests and numerical simulations for materials of spacecraft component and bumper shield. JAXA has also started investigating power harnesses' electrical failure caused by debris impact.

The results of this research are reflected in the “Space Debris Protection Design Manual” (JERG-2-144-HB) which was published in its original version in 2009 and revised in 2014.

Furthermore, JAXA has developed a debris impact risk assessment tool, named TURANDOT. TURANDOT analyses debris impact risks against a three-dimensional model of a spacecraft. This tool is updated to apply NASA’s latest debris environment model (ORDEM3.0).

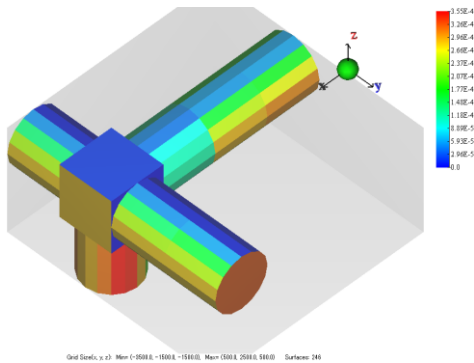


Fig. 7 an example of out from TURANDOT

5. Easy-to-demise propellant tank during re-entry

A propellant tank is usually made of titanium alloy. Although the light weight, and good chemical compatibility with propellant of titanium alloy are suitable characteristics for propellant tank material, its high melting point prevents a propellant tank from demising during re-entry, posing a risk of ground casualties.

JAXA conducted research to develop an aluminium-lined, carbon composite overwrapped tank with a lower melting temperature. As a feasibility study, JAXA conducted fundamental tests including a liner material aluminium compatibility test with hydrazine propellant and an arc heating test. JAXA tried manufacturing the EM#1 tank which was shorter in size compared to a nominal tank as shown in Fig. 9. Using this EM#1 tank, a proof pressure test, external leak test, pressure cycle test, and burst pressure test were conducted and all of them showed positive results. Vibration tests were conducted on the PMD (Propellant Management Device) to confirm its tolerance to the launch environment shown in Fig. 10. Following the test of the EM#1 tank and PMD model, the EM#2 tank is now in the process of being manufactured. The shape of the EM#2 tank is the same as the nominal tank, which includes a PMD. The EM#2 tank will be used for proof pressure tests, external leak tests, pressure cycle tests, vibration tests (with wet and dry condition) and burst pressure tests. After the EM#2 tank, PM manufacturing and testing are planned. It is expected that in the future costs and manufacturing lead time will be less than that of previous titanium tanks.



Fig. 8 EM#1 tank

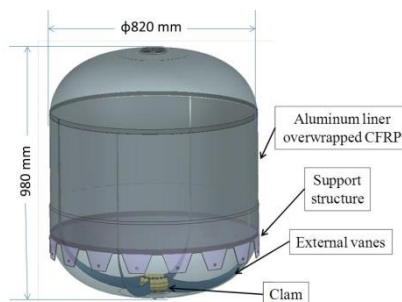


Fig. 9 Concept of CFRP propellant tank

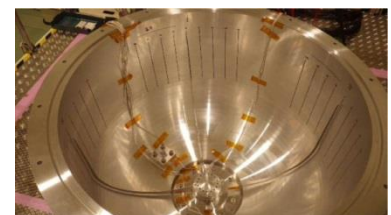


Fig. 10 Vibration test for PMD

6. Active debris removal

JAXA organizes a research program, which aims at realization of a low-cost active debris removal mission. As shown in Fig. 11, the program consists of an active debris removal scenario study, research and development (R&D) of key-technology, and R&D of on-orbit service technology for robotic servicing in the near future.

There are three themes for R&D of active debris removal key-technology: non-cooperative rendezvous, capture technology for non-cooperative targets and de-orbiting technology to remove massive targets. An electrodynamic tether (EDT) system is promising as the active debris removal device, which allows de-orbit debris without any propellant and can easily be attached to the non-cooperative debris object. A demonstration flight of the EDT named KITE is planned for the FY2016. An illustration of the KITE mission is shown in Fig. 12. An experimental EDT module will be installed on the HTV. It will be activated just before re-entry of the HTV to the Earth, and its function as a de-orbit device will be demonstrated.

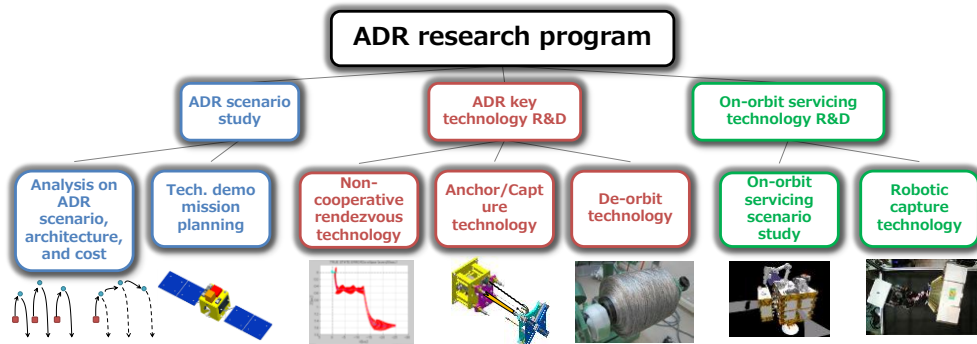


Fig. 11 Structure of JAXA active debris removal research program



Fig. 12 A demonstration flight of EDT using HTV-6

Slovak Republic

National Space Debris Research

In the second half of 2016, a 70-cm telescope became available to the Faculty of Mathematics, Physics and Informatics of the Comenius University (FMPI CU). It will be used to observe space debris objects in order to specify their trajectories and physical attributes, such as their own rotation and their surface properties. Planning, as well as processing the observations of space debris for this system will be developed with the help of the SK PECS project conducted by the European Space Agency, the contractor of which is the Department of Astronomy, Physics of the Earth, and Meteorology (DAPEM) of FMPI CU. This project is conducted in cooperation with Switzerland, namely with the University of Bern.

Currently, the faculty is researching the possibilities of application of its All-sky Meteor Orbit System (AMOS) to monitor space debris objects, namely the specification of their trajectories and their physical attributes. AMOS is currently utilizing five cameras in Slovakia, two cameras on the Canary Islands (Spain) and two more cameras in Chile. In the coming years, more cameras are planned to be installed in other areas around the world in order to increase the sky coverage by the AMOS network.

Security of space objects with nuclear power sources

Objects with nuclear power sources orbiting the Earth are jeopardizing the currently operating infrastructure only when they are uncontrollable. This threat is comparable to a threat by any discontinued satellite without nuclear power source.

Space objects with nuclear power sources can put the Earth's population to danger only when a satellite, its reactor or any of its radioactive parts endure the descent through Earth's atmosphere. In such case, it is necessary to specify the trajectories of these objects as accurately as possible, as well as to specify the model of their behaviour (own rotation and its direction). Consequently, the objects' impact locations and probabilities can be calculated with a high level of accuracy, and the local governments can be warned in time.

These objects will potentially be observable with the optical systems mentioned above.

Problems connected with the collisions between space objects with nuclear power sources and other space objects

In case of a collision of any satellite with or without nuclear power source, such satellite becomes severely damaged, if not completely destroyed. Such collision can create hundreds or thousands fragment larger than 10 cm in the diameter. If a satellite with nuclear power source is destroyed, the chance that the radioactive parts endure the descent through the Earth's atmosphere is very low. Because of this reason, the damage caused by the impact on the planet's surface will be significantly lower than if a whole satellite enters the atmosphere.

Thanks to its worldwide coverage, the AMOS system will be able to observe destructions of such objects in the atmosphere. The obtained data can help to calculate the destruction models and the impact locations much more accurately.

Pakistan

1. Pakistan believes that outer space is a common heritage of humankind which is being extensively used for well-being of mankind. Pakistan is party to all the five major international treaties on outer space and fully supports all initiatives which contribute to the safety, security of space operations and long-term sustainability of outer space activities. Pakistan also supports any instrument and process aimed at mitigating orbital space debris, and believes that all satellite operators should take appropriate measures to offset the possibility of creation of such debris. Pakistan is against all sorts of militarization and weaponisation of outer space including particularly the placement and/or use of all kinds of conventional and nuclear weapons in that domain.
2. Pakistan believes that space debris has been created by the past operations of the space-faring nations, and hence they have a moral responsibility and obligation to assist the new entrants towards the implementation of space debris mitigation measures through provision of Conjunction Assessment Risk Analysis (CARA) systems, Situational Awareness Systems for live monitoring of space objects and arranging finances for this purpose.
3. Pakistan would be taking all possible steps to implement the space debris mitigation guidelines to the greatest extent possible and direct her research towards implementation while remaining within her technological and budgetary resources limitations.
4. Pakistan is participating in joint observations and debris research activities under the Asia-Pacific ground-based Optical Space object Observation System (APOSOS), network of APSCO. A 15 cm optical tracker has been installed at Sonmiani for detecting, monitoring and tracking of space objects both in LEO and MEO orbits. Presently acquired information is being shared with APSCO.

Replies received from international organizations

Space Generation Advisory Council

Space Debris and Nuclear Power in Space: A Deadly Combination

Introduction

The space debris issue is now at the forefront of discussions on the sustainability of space. With the increased number of small satellites, it is unclear if current policies are enough to mitigate the risk of space debris. With increased interest in long duration mission, the number of spacecraft launched with a nuclear power source on board is also increasing. The collision between a nuclear powered spacecraft and space debris can lead to nuclear contamination of earth or the space environment with dire consequences. This calls for implementation of new policies to maintain the safety of these spacecraft, and to raise awareness about the threats to the sustainable use of outer space.

The Space Debris Problem

Ever since the first satellite was launched in 1957, Earth's orbits have continuously become more crowded. Many nations and commercial enterprises have launched their own spacecraft into orbit around Earth, and many of these are still present. Among all floating objects in space, an estimated 6 per cent are still operational [2], while almost 60 per cent of space objects are fragments produced by explosions and collisions. More than 20,000 pieces of space debris with a size of a tennis ball or larger orbit the earth with a velocity of nearly 17,500 mph [1]. These uncontrolled fragments and other debris (such as discarded rocket bodies, and retired satellites) can collide with each other and generates more debris, in a cycle popularly known as the "Kessler syndrome" [2]. The Kessler syndrome in turn results in an exponential growth of orbital debris as time progresses, with an ever-increasing risk for operational bodies in orbit. In addition to their number, these pieces of debris have enough energy to break the rigid wall of satellites, and destroy satellites [3]. The rise in the number of space debris objects can clearly be seen in Fig. 1. Moreover, by following the number of collisions recorded by the International Space Station (ISS), and the number of times the ISS has had to manoeuvre to avoid debris, one can see the true impact of these objects on space operations.

Currently, the debris field in Low Earth Orbit (LEO) is unstable. Simulations have shown that even without any future launches, the debris field will slowly grow [3]. With regular launch rates and no mitigation measures, the quantity of debris in orbit is likely set to grow exponentially [4-6]. Fragments generated from the anti-satellite test conducted by China in 2007, and the collision between Iridium 33 and Cosmos 2251 in 2009 were major factors in the jump in the number of space debris [6]. Research has concluded that 60 per cent of tracked fragments have been generated by explosions and collisions in space, mostly due to US and Soviet Union activities in lower earth orbit [3]. Every year on an average 120 to 150 satellites are launched that result in an additional 300 to 500 fragments per year (11 per cent) in outer space [3]. The rise in the number of small satellites being launched into orbit, and plans for constellations of small satellites by several commercial entities clearly shows that these numbers will be growing even further.

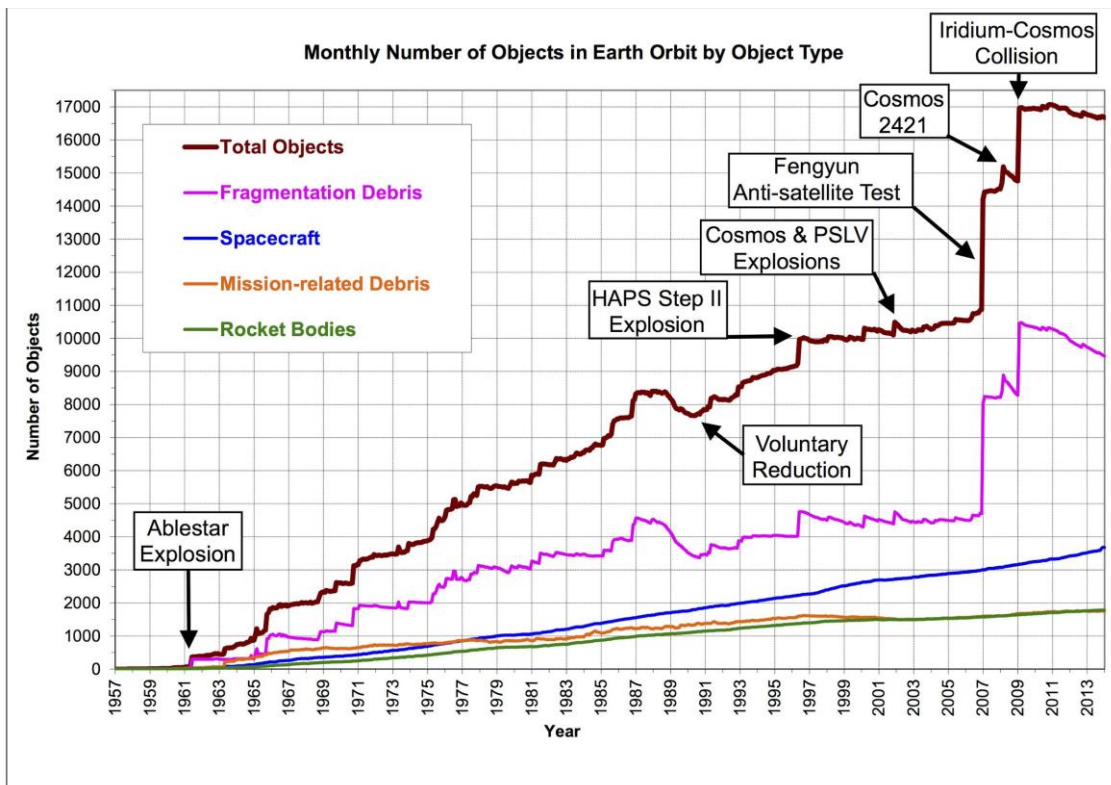


Fig. 1. The timeline of the growth in the number of objects being tracked in orbit. Due to limited tracking capabilities (limited to larger than 10 cm), the actual number of objects in orbit is estimated to be 2 to 3 times the numbers in the figure [7]

The probability of collision with respect altitude is shown in Fig. 2. The major risk of collision is in the orbital altitude of 500 km-1200 km, and 1400-1600 km. These range of orbits are mostly used for scientific experiments or earth observation.

The Inter-Agency Space Debris Coordination Committee (IADC) developed a set of guidelines such as the 25 year rule which are now being followed by many stakeholders [8]. In addition, some States have developed their own space debris mitigation standards based on those guidelines. Recent studies are inconclusive whether the 25 year rule might be a suitable solution, highlighting the need for the revision of these guidelines based on recent developments in the sector.

Concrete actions taken by States who have adopted the IADC guidelines include:

- The improvement of the design of launch vehicles and spacecraft;
- The deorbiting of satellites;
- The development of specific software and models for space debris mitigation.

Many methods have been proposed for cleaning space debris, and the space sector is taking initiatives to tackle this problem. On orbit servicing [9], active debris removal [10-11], and passive de-orbiting capabilities are all being studied to maintain a more stable space debris environment.

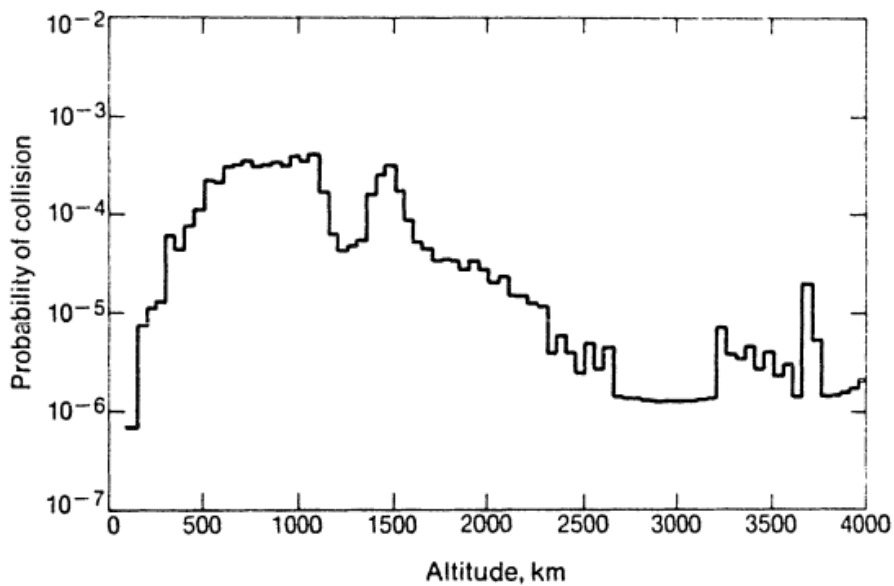


Fig. 2. Probability of collision vs altitude [3]

Nuclear power source in Space

Initial advancements in Nuclear Power technology led to engineers trying to integrate this new technology in different sectors from planes to marine vehicles; space was no exception. Both the United States and the Soviet Union attempted to launch nuclear reactors to space: The US launched SNAP-10A while the Soviet Union ran the RORSAT program. Several disasters resulted, including:

- Launch failure, 25 April 1973. Launch failed and the reactor fell into the Pacific Ocean north of Japan
- Kosmos 954 re-entry over Canada due to a boost failure, irradiating 124000 square km of the North Western Territories.

The RORSAT program was designed to eject its nuclear cores into orbit, some of which are still in orbit and decaying as we speak. The mishaps of these programs led to a halt of nuclear activities in earth orbit.

Nowadays, traditional fission reactors are no longer used for space missions. Instead, radioisotope thermoelectric generators (RTGs) are now used for exploration class missions such as the Curiosity rover. These systems rely on the heat generated by the decay of a radioactive sample for energy generation and much simpler in design and safer than traditional reactors. Still, they do pose a risk of contamination if the fuel container leaks.

The main concern in the use of RTGs in spacecraft is contamination due to a launch failure or failure during operations in earth orbit. Risk assessment for previous missions has shown the risk for such mishaps is different for different phases of the mission, with the risk being as high as 1 in 10 for the Cassini-Huygens [12]. Previous mission failures leading to contamination (such as the 1964 U.S. Transit-5BN-3 launch failure, and the 1969 Russian Lunakhod launch failure) have led to intact re-entry requirements for RTGs, which reduces the likelihood of contamination. This has reduced the impact of failures that came after these missions (such as the Russian Mars96, and the Apollo 13 lunar lander re-entry), with no contamination being recorded despite the failures. Despite these efforts, all spacecraft including those with

RTGs are prone to collisions. If an RTG fuel container is damaged due to a collision, then contamination is unavoidable.

Today, states are considering the implementation of the Safety Framework for Nuclear Power Source Applications in Outer Space [13]. The Safety Framework would facilitate the conduct of missions involving Nuclear Power Sources (NPS) on a bilateral or multilateral basis by States. While the creation of the guidelines seems to be a good first step, execution measures need to be implemented in order to fully benefit from these guidelines, for example a mission launch authorization procedure needs to be put in place.

The Need for a Global Vision

The peaceful use of outer space, in particular space orbits, is extremely important in providing communications for the global population in the 21st century. It is also integral in contributing to governance mechanisms in addressing a wide array of global problems, for example, monitoring climate change and providing early warnings for natural disasters through the use of satellite images, supporting local development through connecting communities to the internet, and providing the infrastructure necessary for development in information technology industry. As such, space debris mitigation is paramount in ensuring social progress and global development. Nevertheless, existing governance landscape regarding outer space remains comparatively under-developed.

While major international actors (including international organizations, States and NGOs) are devising concrete steps in contributing to realizing the Sustainable Development Goals (SDGs) [14], the lack of an explicit reference to space sustainability leaves space sustainability initiatives outside of the SDGs framework. Relevant stakeholders may consider the following steps to assert the importance of space sustainability, and subsequently, the relevance and potential of space debris mitigation:

- Discuss orbits as finite resources and a global resource
- Assert the relevance and importance of debris mitigation, especially concerning those with nuclear power source, in contributing to longer-term sustainable development through improved operations of space assets.

Conclusion

Today, the most challenging part for space operations is collision avoidance. The space debris problem definitely requires common action by all stakeholders if it is to be rectified. In this regard the IADC guidelines are a starting point. Further action to actively react to the increasing space debris population seems to be the only solution in the long run to tackle this issue. Due to the high risk of collisions in low earth orbit, the use of Nuclear Power Sources should be limited to exploration class interplanetary missions. Safety guidelines put forth by the United Nations COPOUS and IAEA should be taken into account in these cases, along with planetary protection guidelines to make sure missions are undertaken safely and ethically.

The Space Generation Advisory Council's Space Safety and Sustainability Project Group recommends the following:

- Moving towards the implementation of the Safety Framework for Nuclear Power Source Applications in Outer Space by the designation of an international body for the launch authorization for Nuclear Powered Spacecraft.
- Implementation of the Space Debris Mitigation Guidelines

- The United Nations Committee on the Peaceful Uses of Outer Space should monitor and regularly report on the implementation of the guidelines above.
- Considering the fast pace of technology advancements, the guidelines should be revised every five years.
- Recognize the orbits and outer space as a global common, and integrate space sustainability as part of the global development agenda, particularly in relation to achieving the Sustainable Development Goals (SDGs) [13].

Acknowledgements

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About The Space Generation Advisory Council in Support of the United Nations Programme on Space Applications

The Space Generation Advisory Council (SGAC) works at the international, national and local level to link together university students and young professionals in the space sector to think creatively about international space policy issues and inject the new generation’s point of view into international space policy. Having been created as a result of UNISPACE III, our work with the UN, particularly the United Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS), is of central importance to our mission. The SGAC works to give regular input to the work of the committee and its delegates, and acts as a conduit for the opinions of our members and the outcomes of our projects. We take part to work with variety of United Nations action teams and working groups (on space issues), as well as we participate the United Nations programme on space applications. No other space organisation for young adults has a permanent observer status with the United Nations COPUOS and is as active or as engaged in the work of the United Nations as SGAC — a fact of which we feel very proud. In addition to have permanent observer status within COPUOS since 2001, SGAC has held consultative status within the United Nations economic and social council since 2003.

About SGAC Space Safety and Sustainability Project Group

The SGAC Space Safety and Sustainability project group was created with the aim to encourage active participation among students and young professionals in space safety and sustainability related debates and activities. Through this project group, we have created an international space forum to showcase the perspectives of the next generation of space leaders on the safety and long-term sustainability of outer space activities. The project group runs several projects during the year, focusing on the topics of Space Situational Awareness, Space Weather, and Space Debris.