SAFETY OF THE USE OF NUCLEAR POWER SOURCES IN OUTER SPACE:
MEASURES AT THE INTERNATIONAL AND NATIONAL LEVELS
SPACE NUCLEAR POWER SOURCES (NPS)

• Have been developed and used in space applications where unique mission requirements and constraints on electrical power and thermal management precluded the use of non-nuclear power sources.

• According to current knowledge and capabilities, space NPS are the only viable energy option to power some space missions and significantly enhance others.

• Several ongoing and foreseeable missions would not be possible without the use of space NPS. Past, present and foreseeable space NPS applications include radioisotope power systems (for example, radioisotope thermoelectric generators and radioisotope heater units) and nuclear reactor systems for power and propulsion.
SPACE NUCLEAR POWER SOURCES (NPS)

• Have unique safety considerations compared with terrestrial applications. Unlike many terrestrial nuclear applications, space applications tend to be used infrequently and their requirements can vary significantly depending upon the specific mission. Mission launch and outer space operational requirements impose size, mass and other space environment limitations not present for many terrestrial nuclear facilities. For some applications, space NPS must operate autonomously at great distances from Earth in harsh environments. Potential accident conditions resulting from launch failures and inadvertent re-entry could expose NPS to extreme physical conditions.
• Nuclear reactors can provide almost limitless power for almost any duration.

• The choice of nuclear power can make deep space missions possible and much more efficient. For example, in a comparison between a typical chemical propulsion mission to Mars and one using nuclear propulsion, owing to the mass ratio efficiencies and the larger specific impulse, the chemically powered mission took a planned total of 919 d and provided a stay of 454 d on the planet. By comparison, a nuclear powered mission was completed in 870 d while it provided 550 d on the planet.

• Research is underway on propulsion units that will be capable of transferring significantly heavier payloads into Earth orbit than is currently possible using conventional chemical propellants, which today costs about US$10,000/pound to lift a payload into orbit and about US$100,000 to deliver a pound of supplies to the Moon.
• Missions have included interplanetary missions to the outer limits of the Solar System, for which solar panels were not suitable as a source of electrical power because of the long duration of these missions at great distances from the Sun.

• Examples of the use of these power sources on US probes include Apollo, Viking, Pioneer, Voyager, Galileo, Ulysses and Cassini missions. None of these missions illustrate the utility of space NPS better than Pioneer 10, which completed the first mission to the planet Jupiter and became the first spacecraft to achieve escape velocity from the Solar System. The probe was launched in 1972 and equipped with an array of instruments for measuring such phenomena as the solar wind and the magnetic and radiation fields surrounding Jupiter. Regarding Saturn, its instruments detected another ring and discovered two new satellites, as well as measuring the planet’s magnetic field. What was apparently the spacecraft’s last signal was received on 22 January 2003 by the Jet Propulsion Laboratory’s Deep Space Network.
Since 1961, the United States of America has had 30 launches involving space radioisotope power system (RPS) applications and one launch of a space reactor. This number includes Curiosity rover which has been successfully performing its tasks on Mars (launch took place in 2011).

During the period 1970-1988, the Union of the Soviet Socialists Republics (USSR) launched the series of Cosmos spacecraft carrying NPS on board. Nuclear-powered spacecraft were launched into a low operating orbit of 265 kilometres, with later insertion of NPS into a high orbit of 900-1,000 kilometres on completion of the operational life of the spacecraft. A total of 33 satellites were launched, starting with the Cosmos 367 satellite and ending with the Cosmos 1932 satellite, including two satellites with thermonuclear reactors in an operating orbit of 800 kilometres. One of the rovers launched to the Moon under the Soviet “Lunokhod” programme, had a radioisotope heater unit on board.

In 1997, the United States, the European Space Agency (ESA) and the Italian Space Agency (ASI) sent to Saturn system a robotic spacecraft Cassini–Huygens. The mission is ongoing and planned to be concluded by 2017. Cassini orbiter is powered by three radioisotope thermoelectric generators (RTGs).

China has announced that its first lunar rover, to be launched in 2013, will be powered by a nuclear source.

Argentina has confirmed that it plans to supply its national satellites with NPS.
• The presence of radioactive materials or nuclear fuels in space NPS and their consequent potential for harm to people and the environment in Earth's biosphere due to an accident require that safety should always be an inherent part of the design and application of space NPS.

• United States has confirmed that over nearly 50-year history, three accidents involving United States RPS have occurred, none of which were caused by a failure of the RPS, all of whose safety features performed as designed: the mission abort of the TRANSIT 5BN-3 navigational satellite in 1964; the launch abort of the NIMBUS-B-1 meteorological satellite in 1968 that resulted in the RPS falling in the Pacific, where its heat source was recovered; and the Apollo 13 lunar mission, which was successfully targeted to the Tonga Trench in the Pacific Ocean after the mission was aborted.

• The Russian Federation reported that as a result of failures in the systems for insertion into high orbit, Cosmos 954 and Cosmos 1402 entered the dense layer of the Earth's atmosphere and were destroyed. The NPS of Cosmos 1900 were inserted in an orbit of 720 kilometres. Consequently, in high orbits of 700-1,000 kilometres, there are currently 15 nuclear power plants with nuclear fuel and semiconductor heat conductors, 16 fuel element assemblies with nuclear fuel and 16 NPS without nuclear fuel and with secondary-circuit semiconductor heat conductors.

• About July 4, 2008, Comos 1818 was either hit by an object or a coolant tube cracked due to thermal stresses by repeated solar heating. The US Space Surveillance Network reported that about thirty objects were formed. The satellite was powered by TOPAZ 1 nuclear reactor.
• There was a major accident on January 24, 1978 when Cosmos-954 could not be boosted to a higher orbit and re-entered the Earth’s atmosphere over Canada.

• Debris was found along a 400-mile tract north of Great Bear Lake. No large fuel particles were found but about 4,000 small particles were collected. Four large steel fragments that appeared to have been part of the periphery of the reactor core were discovered with high radioactivity levels. There were also 47 beryllium rods and cylinders and miscellaneous pieces recovered, all with some contamination.

• Fortunately, this incident resulted in no danger to humans because of the remoteness of where in Canada the remnants of the reactor came to rest.
United Nations Committee on the Peaceful Uses of Outer Space (COPUOS)

- Established by General Assembly resolution 1472 (XIV) in 1959.

- Has two standing subsidiary bodies: Scientific and Technical Subcommittee (STSC) and Legal Subcommittee (LSC).

- Reports annually to the General Assembly Fourth Committee.

- 74 Member States and 32 international intergovernmental and non-governmental organizations with permanent observer status. In June 2013, two more States (Belarus and Ghana) were recommended for the membership and one IGO for the permanent observer status.

- Mandated to:
  - Review international cooperation in the peaceful uses of outer space;
  - Devise programmes in this field to be undertaken under the auspices of the United Nations;
  - Encourage continued research and dissemination of information on outer space matters;
  - Study legal problems arising from the exploration of outer space.
Agenda and main recent results of COPUOS and its two Subcommittees

Recent achievements:


• Space Debris Mitigation Guidelines (2007)

• Safety Framework for the Use of Nuclear Power Sources in Outer Space (2009)

Current issues:

• Space applications for developing nations;
• Space debris;
• Long-term sustainability of space activities;
• Near-Earth objects;
• Space and climate change;
• National space legislation and mechanisms of international space cooperation;
• Definition and delimitation of outer space;
• Use of Geospatial Data for Sustainable Development.
• Outer Space Treaty, 1967 (102 States parties / 26 additional signatures);
• Rescue Agreement, 1968 (92/24);
• Liability Convention, 1972 (89/24);
• Registration Convention, 1975 (60/4);
• Moon Agreement, 1979 (15/4).

• Declaration of Legal Principles Governing the Activities of States in the Exploration and Uses of Outer Space (1963);
• Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting (1982);
• Principles Relating to Remote Sensing of the Earth from Outer Space (1986);
• **Principles Relevant to the Use of Nuclear Power Sources in Outer Space (1992);**
• Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interests of All States, Taking into Particular Account the Needs of Developing Countries (1996).
Principles Relevant to the Use of Nuclear Power Sources in Outer Space

• Result of the work conducted by STSC and LSC from 1978.

• Received certain criticism from some delegations at the late stages of the development (technical inaccuracy and inconsistencies in the text).

• Adopted by General Assembly resolution 47/68 of 14 December 1992. General Assembly also agreed that both STSC and LSC should continue their work on NPS for future revisions.
Principle 1. Applicability of international law

Activities involving the use of nuclear power sources in outer space shall be carried out in accordance with international law, including in particular the Charter of the United Nations and the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies.

Principle 2. Use of terms

1. For the purpose of these Principles, the terms "launching State" and "State launching" mean the State which exercises jurisdiction and control over a space object with nuclear power sources on board at a given point in time relevant to the principle concerned.

Principle 3. Guidelines and criteria for safe use

Principle 4. Safety assessment

Principle 5. Notification of re-entry

Principle 6. Consultations
Principle 7. Assistance to States

Principle 8. Responsibility

In accordance with article VI of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, States shall bear international responsibility for national activities involving the use of nuclear power sources in outer space, whether such activities are carried on by governmental agencies or by non-governmental entities, and for assuring that such national activities are carried out in conformity with that Treaty and the recommendations contained in these Principles.

Principle 9. Liability and compensation

Principle 10. Settlement of disputes

Principle 11. Review and revision

These Principles shall be reopened for revision by the Committee on the Peaceful Uses of Outer Space no later than two years after their adoption.
Safety Framework for Nuclear Power Source Applications in Outer Space
Late 1990-ies: collection of concerns expressed by Member States of COPUOS

- NPS Principles contained a number of unsatisfactory features.
- NPS Principles did not address accident prevention.
- NPS Principles did not contain a satisfactory safety level.
- NPS Principles became inconsistent with best safety practices at the international and national levels.
- NPS Principles were not formed in terms which are generally applicable to all uses of NPS in space.
- NPS Principles might soon became inconsistent with the requirements of emerging NPS space programmes.
Safety Framework for Nuclear Power Source Applications in Outer Space

• Work initiated by the Working Group on NPS of STSC.

• Between 2003 and 2006, the Working Group reviewed information from national and regional space agencies on the content of relevant national space NPS programmes and all planned or currently foreseeable applications. It also carried out a detailed review of existing international safety principles and standards of potential relevance to space NPS applications.

• In 2006, it held a joint technical workshop with the IAEA, at which the unique safety aspects of using NPS applications in space were discussed, as well as the scope, attributes and objectives of a possible space NPS safety framework.

• STSC agreed to the formation of a joint partnership between the NPS Working Group and the IAEA, to develop a safety framework for nuclear power source applications in outer space. This partnership was realised through a Joint Expert Group (JEG) which worked throughout the period 2007 – 2009.

• The Safety Framework was adopted by the STSC at its 46th session in February 2009. In accordance with the agreed working arrangements the Safety Framework was considered and agreed to by the IAEA Commission on Safety Standards at its meeting in April 2009. The Safety Framework is available in A/AC.105/934 and by the IAEA secretariat as a joint publication of the STSC and IAEA.
Safety Framework for Nuclear Power Source Applications in Outer Space: Purpose

- The purpose of the Safety Framework is to provide high-level guidance in the form of a model safety framework. It provides a foundation for the development of national and international intergovernmental safety frameworks while allowing for flexibility in adapting such frameworks to specific space NPS applications and organizational structures. Such national and international intergovernmental frameworks should include both technical and programmatic elements to mitigate risks arising from the use of space NPS. Implementation of such frameworks not only would provide assurance to the global public that space NPS applications would be launched and used in a safe manner, but could also facilitate bilateral and multilateral cooperation on space missions using NPS. The guidance provided reflects an international consensus on measures needed to achieve safety and applies to all space NPS applications without prejudice.
Reservation by Venezuela (Bolivarian Republic of)

... although the document makes no explicit reference to the uses of nuclear power sources in low-Earth orbits, it contains a number of ambiguous statements that leave open the possibility that this inadmissible practice will be retained in future space development programmes. The scope for discretion in decision-making in what is a matter of great delicacy should be addressed by the Subcommittee. The second point that should be made is that responsibility before the peoples of the world lies *solely and entirely* with United Nations Member States; and that responsibility is not transferable.

Our delegation also views with concern the voluntary and non-binding nature assigned to the Safety Framework. The procedure for amending and establishing international standards to regulate the use of nuclear power sources in outer space will need to be promoted. To this end, the role of the Committee on the Peaceful Uses of Outer Space in promoting space law will need to be strengthened.
Document of potential relevance to space NPS (conclusions by the Working Group on NPS)

• Nearly 60 international documents in addition to the existing Principles Relevant to the Use of Nuclear Power Sources in Outer Space were identified as having portions potentially relevant to space NPS launch and operational nuclear safety. Most of those publications are generic in nature and were not written for a specific type of nuclear power application. All but one of the remaining documents were developed for specific terrestrial applications.

A. International conventions of potential relevance.
B. International Atomic Energy Agency and related documents of potential relevance.
C. International Commission on Radiological Protection publications of potential relevance.

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Joint Radiation Emergency Management Plan of the International Organizations

• The Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency are prime legal instruments that establish an international framework to facilitate the exchange of information and the prompt provision of assistance in the specific event of a radiation emergency, with the aim of minimizing the consequences.

• The IAEA is the main co-ordinating body for the development and maintenance of the Joint Plan. The Joint Plan does not prescribe arrangements between the participating organizations, but describes a common understanding of how each organization acts during a response and in making preparedness arrangements.

• Office for Outer Space Affairs serves as the United Nations focal point on re-entry of nuclear-powered space objects for the Joint Plan. In this capacity, the Office maintains close contact with the Incident and Emergency Response Centre of the International Atomic Energy Agency, and provides notifications of nuclear-powered space objects as well as supplementary information on other space objects reentering the Earth’s atmosphere.

• **Event Type: Space object re-entry:** A satellite or other space object with nuclear power source(s) or dangerous radioactive sources on board has given rise to a risk of re-entry of radioactive material to the Earth in the near future, or such re-entry is occurring or has occurred. Who should be notified: IAEA, OOSA, EC, WHO.
United Nations Register on Objects Launched into Outer Space

- Two separate, yet complementary, registers on objects launched into outer space maintained by the United Nations Office for Outer Space Affairs (UNOOSA). First register established in 1961 in accordance with GA resolution 1721 B (XVI) of 20 December 1961. Still used to disseminate information received from Member States who are not party to the Registration Convention. Containing registration data on nearly 6,000 space objects. Second register established in 1976 under the Registration Convention. Containing registration data on nearly 7,500 space objects.

- Space debris and non-functional objects are not included.

- No distinction between civil and military space objects.

- Since 1957, over 40,000 space objects have been tracked in Earth orbit or beyond.

- Over 6,600 are “functional”, (satellites, probes, manned spacecraft and space station components). Remaining are spend rocket boosters, shrouds and detached components or other residual non-functional components resulting from the launch, operation or termination of the space object. These types of objects are collectively known as “non-functional”.
Space NPS: regulation at national levels

• Regulations are existed in the Russian Federation and the United States of America. Argentina and China, as well as the European Space Agency (and EC) have confirmed that their regulations are in the development phase.

• Regulations are in strict compliance with international instruments, even with those of a non-binding nature.

• Governments ensure continuous supervision (licensing, certification).

• Thorough supervision and control at all phases (planning, design, development and manufacturing, delivery to a launch site, launch, mission control and, if necessary, decommissioning.

• Involvement of numerous governmental authorities and agencies.

• Laws and regulations, administrative and managerial standards, technical standards. Nuclear safety guides.
Final remarks

General satisfaction among existing and potential operators of space NPS. They call for strengthening of the relevant international framework through implementation of the Safety Framework.

Proposal to develop detailed and technical guidelines that might help to alleviate the concerns of many developing countries about the effectiveness of the Safety Framework.

Proposal to promote a process that would create international norms and modify those already in existence to regulate the use of NPS in outer space.