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Use of nuclear power sources in outer space

Preliminary analysis of how the Principles Relevant to the Use of Nuclear Power Sources in Outer Space contribute to the safety of space nuclear power source applications

Prepared by the Chair of the Working Group on the Use of Nuclear Power Sources in Outer Space in collaboration with representatives of the delegation of France and of the European Space Agency

Introduction and background

1. The present document was prepared by the Chair of the Working Group on the Use of Nuclear Power Sources in Outer Space of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space, in collaboration with representatives of the delegation of France and of the European Space Agency.

2. The Principles Relevant to the Use of Nuclear Power Sources in Outer Space were negotiated in the wake of radiological damage caused by the re-entry of the Soviet spacecraft Cosmos 954 over the Northwest Territories of Canada on 24 January 1978, during which debris were scattered over parts of the Northwest Territories, Alberta and Saskatchewan. The problems encountered and questions raised during the discussions on the settlement between Canada and the Union of Soviet Socialist Republics served as a blueprint for what would become the structure of most of the Principles.

3. The negotiations and discussions on the Principles between 1982 and 1990 increasingly focused on finding a compromise for principle 3, on the safe use of nuclear power sources (NPS) in outer space, which had become the core aim of the requests made by Canada during the negotiations. The Committee on the Peaceful Uses of Outer Space eventually adopted the Principles by consensus on 26 June 1992. Subsequently, on 14 December 1992, the General Assembly adopted, without a vote, resolution 47/68, entitled "Principles Relevant to the Use of Nuclear Power Sources in Outer Space".

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4. The Principles contain a “review and revision” clause (principle 11), reflecting an acknowledgement of the need to adapt to sometimes rapidly changing technical capabilities. The review and revision principle was initially introduced only in relation to principle 3, the one most specifically linked to changing technical capabilities and knowledge, but was later extended to cover the others. In an effort to achieve consensus on the Principles, the Committee agreed to reduce the timespan included in the review and revision clause, within which the Principles were to be reopened for revision, from 10 years to only 2.

5. In 2003, the Scientific and Technical Subcommittee of the Committee decided to work on an international technically based framework of goals and recommendations for the safety of nuclear power source applications in outer space. That initiative culminated in the adoption in May 2009 of the Safety Framework for Nuclear Power Source Applications in Outer Space. The Safety Framework is not a revision of the Principles and does not supplement, alter or interpret them.

6. In contrast to the Principles, the Safety Framework is entirely devoted to the safety of space NPS applications. Benefiting from effective international cooperation, the drafting of the Safety Framework resulted in a document that focuses on general safety requirements for space NPS applications, rather than on specific solutions linked to changing technical capabilities.

Scope

7. Against this background, the present document contains an analysis of how the Principles contribute to the safety of space NPS applications and, where pertinent, provides comparisons with the provisions contained in the Safety Framework.

8. The analysis addresses exclusively the contributions of the Principles to the safety of space NPS applications and does not consider any other potential benefits of the Principles.

Contributions to safety during the design and development of space nuclear power source applications

9. The sixth preambular paragraph of the Principles establishes that the Principles apply to nuclear power sources in outer space devoted to the generation of electric power on board space objects for non-propulsive purposes, which have characteristics generally comparable to those of systems used and missions performed at the time of the adoption of the Principles. Hence, the Principles do not apply to the design of space NPS applications exclusively for propulsive purposes or with characteristics not comparable to those of systems used and missions performed in 1992, and therefore can be considered as not contributing to the safety of systems or missions with such characteristics.

10. Principle 1 of the Principles addresses the safety of space NPS applications indirectly by affirming that, as part of the collective body of space law, the Principles are to be considered as *lex specialis*, supplementing general international law to appropriately regulate the peaceful uses of outer space. Therefore, in carrying out activities involving NPS applications in outer space, it is necessary to respect the relevant international conventions, such as those drafted under the auspices of the International Atomic Energy Agency, including the Vienna Convention on Civil Liability for Nuclear Damage, the Convention on Early Notification of a Nuclear Accident, the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, the Convention on the Physical Protection of Nuclear Material and Nuclear Facilities, the Convention on Nuclear Safety, the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, and the Convention on Supplementary Compensation for Nuclear Damage. Principle 1 can therefore be considered as indirectly providing for

relevant safety provisions during the terrestrial design and development phases of space NPS applications through the provisions of the aforementioned international conventions. It should be noted that the applicability of those international conventions is also included in the Safety Framework.

11. Principle 2 of the Principles addresses the use of terms such as “launching State”, “foreseeable” and “defence-in-depth”. These terms need to be considered in relation to the evolution and progress in thinking and understanding since 1992. The terms “foreseeable” and “all possible” are restricted to events or circumstances whose probability of occurrence is credible for the purpose of safety analysis, and the terms are not absolute. Redundant safety systems to ensure that each component achieves “defence-in-depth” are not necessarily required, although “defence-in-depth” against a malfunction does require that equipment be designed and operated in such a way to prevent or mitigate the effects of the malfunction. Unlike the Safety Framework, the Principles do not include any definition of the term “space nuclear power source”. Given the changes and developments in the use of terms that have taken place since 1992, as reflected in the Safety Framework, it is considered that principle 2 of the Principles does not contribute to the safety of space NPS applications during their design and development phases.

12. Principle 3 of the Principles introduces the objective “to minimize the quantity of radioactive material in space” and specifies that the use of nuclear power sources in outer space are to be restricted to those space missions which cannot be operated by non-nuclear energy sources in a reasonable way. This can be regarded as similar to the justification requirement that has become a cornerstone of the recommendations of the International Commission on Radiological Protection. It is set out in the Safety Framework more thoroughly and in stronger terms than in the introductory paragraph of principle 3. The remainder of principle 3 is then divided into three substantive sections, dealing with, respectively, general goals for radiation protection and nuclear safety, nuclear reactors, and radioisotope generators.

13. Section 1 of principle 3 lists four general objectives relating to nuclear safety: paragraph (a) indicates that States are to protect individuals, populations and the biosphere against radiological hazards, and provides for the general need to take safety issues into consideration in the design and use of space NPS. Paragraphs (b) and (c) define acceptable levels of safety in the use of space NPS. Paragraph (d) relates to the design and reliability of safety systems for space NPS. All four objectives are directly relevant during the design and development phases of space NPS applications. As the general goals for radiation protection and nuclear safety have evolved considerably since 1992, the formulations and numerical limits in principle 3 have become outdated. The text of the Principles reflects this in the statement “Future modifications of the guidelines referred to in this paragraph shall be applied as soon as practicable”. Referring to these outdated provisions and requirements, instead of following the modern approach taken in the Safety Framework, could negatively impact safety during the design and development of space NPS applications.

14. The provisions of principle 3 are aimed at protecting individuals, populations and the biosphere, as well as at avoiding a significant contamination of outer space. The scope of the Safety Framework is limited to the protection of people and the environment in Earth’s biosphere and specifically excludes both the protection of environments of other celestial bodies and the protection of humans in the unique conditions in space and beyond the Earth’s biosphere, arguing that there is not enough scientific data to provide a technically sound basis for including such protections. It can, therefore, be argued that the wider scope of the Principles contributes to the safety of space NPS applications with respect to the safety of humans beyond Earth’s biosphere and the potential radioactive contamination of outer space.

15. Section 2 of principle 3 deals with nuclear reactors and contains specific provisions relevant to the design phase of space NPS applications involving nuclear reactors. The provisions include the requirement to use only highly enriched uranium

235 as fuel and various requirements related to the design of the orbits. These provisions no longer reflect the state of the art. Over the past two decades, the terrestrial nuclear technology sector has moved completely away from the use of highly enriched uranium 235 as a fuel in civil nuclear applications and recognition of the range of potential alternative fuels has increased since 1992. Moreover, it is unlikely that the Scientific and Technical Subcommittee would still support the provision that nuclear reactors may be operated in low Earth orbits if they are stored in sufficiently high orbits after the operational part of their mission.

16. Section 3 of principle 3 deals with radioisotope generators and also contains provisions relevant to the design and development phases of space NPS applications. It requires that such generators include a containment system designed and constructed to withstand the heat and aerodynamic forces of re-entry, and that, upon impact, the containment system and the physical form of the isotope must ensure that no radioactive material is scattered into the environment. By focusing on re-entry, the principle reflects the state of the art in 1992, however, scientific and technical insights since 1992 have shown that re-entry does not necessarily pose the most stringent conditions to be taken into account in the design of containment systems. This section therefore contributes to safety, although its focus on re-entry might mislead engineers during the design of space NPS applications.

17. Principle 4 of the Principles is relevant to safety during the design and development phases of space NPS applications because the required safety assessment must be done during those phases, prior to the launch. The specification in principle 4 that the safety assessment is the obligation of the State having jurisdiction and control over the space object provides clarity to mission designers and therefore contributes to the safety of space NPS applications. The requirement for a safety assessment prior to the launch of space NPS applications is also included in a more detailed and thorough way in the Safety Framework. However, in contrast to the Principles, the Safety Framework does not require the results of the safety assessment to be made publicly available prior to the launch. This requirement of the Principles and the additional scrutiny it invites can be considered as contributing to safety during the design and development of space NPS applications.

18. The provisions of principles 8 and 9, which define the international responsibility of States for activities involving the use of nuclear power sources in outer space, including for those carried out by non-governmental entities, and the liability to compensate for damages related to accidents, contribute to the safety of space NPS missions during their design and development phases only insofar as they restate the provisions 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 and the Convention on International Liability for Damage Caused by Space Objects, thereby incentivizing all involved States and intergovernmental organizations to ensure compliance with the Principles.

Contributions to safety during the implementation and operation of space nuclear power source applications

19. In analogy to the analysis made in the section above, principle 1 of the Principles can be considered as indirectly providing for relevant safety provisions during the implementation and operational phases of space NPS applications. The requirement to apply the provisions of relevant international conventions is also included in the Safety Framework.

20. Principle 2 of the Principles does not contribute to the safety of space NPS applications during their implementation and operation.

21. Principle 3 of the Principles contains provisions directly relevant to safety during the implementation and operation of space NPS applications. It specifically prescribes that a nuclear reactor may be made critical only after reaching its operational orbit and requires that there be a highly reliable operational system to

ensure an effective and controlled disposal of the reactor for spacecraft below a sufficiently high orbit.

22. Principle 4 of the Principles requires that a thorough and comprehensive safety assessment be conducted prior to the launch. The safety assessment must cover all relevant phases of the mission and must deal with all systems involved, including the means of launching, the space platform, the nuclear power source and its equipment and the means of control and communication between ground and space. The requirements and rules for operating the space NPS application should take full account of the safety assessment. Principle 4 therefore contributes to the safety of space NPS applications during their implementation and operation.

23. Principle 5 (Notification of re-entry) of the Principles is relevant to safety during the implementation and operation of space NPS applications. The obligations to inform the States concerned in a timely fashion in the event that a space object malfunctions and poses a risk of re-entry of radioactive material to the Earth, and to update the information on that risk as frequently as practicable, with a view to giving the international community sufficient time to plan for any national responses deemed necessary, can be seen as contributing to the safety of space NPS applications by supporting actions to mitigate the consequences of potential accidents. The related provision in the Safety Framework is contained in section 5.4, subparagraph (f) (Accident consequence mitigation), which requires the preparation of relevant information regarding the accident for dissemination to the appropriate governments, international organizations and non-governmental entities and to the general public as part of the timely support of activities to mitigate the consequences of accidents.

24. Closely linked to principle 5, principles 6 and 7 of the Principles deal with information-sharing and assistance in relation to re-entry accidents involving spacecraft containing NPS. Principles 6 and 7 therefore contribute to the safety of space NPS applications; the safety-related aspects of their provisions are also included in the Safety Framework.

Contributions to safety after the end of service of space nuclear power source applications

25. Safety after the end of service of space NPS applications is only addressed by provisions contained in principle 3 of the Principles, which quantitatively link the half-life of on-board radioisotopes with the orbital lifetime of NPS applications after their end of service, neglecting the issue of space debris and their density distribution in orbit. Principle 3 refers repeatedly to the terms “sufficiently high orbit” and “high orbit” without indicating clearly how they should be interpreted. The definition of “sufficiently high orbit” is associated with radioactive decay by way of the requirement that the orbital lifetime be long enough to allow for a sufficient decay of the fission products to approximately the activity of the actinides. With regard to radioisotope power sources in particular, principle 3 states that “in any case ultimate disposal is necessary”, without, however, further explaining what is meant by that statement.

26. These provisions seem to be somewhat ad hoc and lacking in consistency. It is considered that the more generic approach to safety after the end of service of space NPS applications adopted in the Safety Framework is more up-to-date and helpful to practitioners in the field of space NPS.