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Updated and risk-informed process for launching space nuclear systems in the United States of America

Working paper prepared by the United States of America

Background

In December 2017, the President of the United States issued the "Presidential Memorandum on Reinvigorating America's Human Space Exploration Program", referred to as Space Policy Directive-1. The Directive charges the National Aeronautics and Space Administration to "lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations".[1] Space nuclear systems, including radioisotope power systems, such as radioisotope thermoelectric generators and radioisotope heater units, and fission reactors used for power and propulsion, will play an important role in realizing this vision. The National Aeronautics and Space Administration's long history of safe launches of nuclear power systems utilized during the Apollo era, as well as from decades of successful robotic exploration missions to Mars and other bodies in the solar system and beyond, most recently with the successful launch of the Mars 2020 Perseverance rover mission on 30 July 2020, paved the way for the next chapter in space exploration.

In furtherance of the nuclear mission safety track record of the United States, the President of the United States issued the "Presidential Memorandum on Launch of Spacecraft Containing Space Nuclear Systems" (National Security Presidential Memorandum-20).[2] That policy establishes an updated and risk-informed process for launching space nuclear systems that are funded or licensed by the United States federal Government, including those developed and implemented by United States commercial interests. The key policy tenet is: "The United States shall develop and

[1] United States, "Presidential Memorandum on Reinvigorating America's Human Space Exploration Program", 11 December 2017, sect. 1.
[2] United States, "Presidential Memorandum on Launch of Spacecraft Containing Space Nuclear Systems", 20 August 2019.

use space nuclear systems when such systems safely enable or enhance space exploration or operational capabilities."[3]

The goals and guidance contained in the Principles Relevant to the Use of Nuclear Power Sources in Outer Space (General Assembly resolution 47/68) and the implementation guidance set forth in the Safety Framework for Nuclear Power Source Applications in Outer Space (A/AC.105/934) were considered in the development of the policy. The key policy tenet is a specific example of how National Security Presidential Memorandum-20 is consistent with the safety intent of the Principles, specifically principle 3, as well as the guidance for Governments in section 3.2 of the Safety Framework. Furthermore, the establishment and improvement of a national policy on space nuclear safety is itself consistent with the guidance in section 3.1 of the Safety Framework.

Consistent with objective 2 of the 2017–2021 workplan 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, the United States has created the present paper to demonstrate how States and international intergovernmental organizations can utilize the Principles and complementary Safety Framework as a foundation for sound nuclear safety policy and apply advances in knowledge, practice and standards regarding radiation protection and nuclear safety in order to further enhance and improve safety policy.

Discussion

The Principles offer a non-binding, broad set of goals and guidelines, including on safety. The intent of the specific safety goals in the Principles is fulfilled by following the implementation guidance set forth in the Safety Framework. By its terms, the Safety Framework is not intended to "supplement, alter, or interpret" relevant documents such as the Principles (ibid., preface); rather, it "provides a foundation for the development of national and international intergovernmental safety frameworks" for implementing guidance such as that contained in the Principles (ibid., sect. 1.2). Thus, the Safety Framework takes the safety intent contained in the goals and guidelines of the Principles and provides practical guidance for implementation. Furthermore, the general guidance provided by the Safety Framework enables new approaches to safety based upon continuing advances in knowledge and practice since the adoption of the Principles. Thus, the utility of the Safety Framework is to allow States and international intergovernmental organizations to innovate new approaches based on the expansion of knowledge and best practices gained from experience and therefore continuously improve safety.

Based on the practical experience of the United States in safely using space nuclear power, and in developing and implementing space nuclear safety policy reform, the United States believes that, together, the Principles and the complementary Safety Framework provide sufficient guidance to States and international intergovernmental organizations seeking to develop policy to ensure the safe development and use of nuclear power in space.

National Security Presidential Memorandum-20 was developed in consultation with United States space nuclear safety experts, who are cognizant of the advances in knowledge and practice gained over the past 58 years of the safe use of nuclear power in space. The document illustrates how the goals and guidance contained in the Principles and the Safety Framework can be implemented in nuclear safety policy.

National Security Presidential Memorandum-20 provides safety guidelines consistent with international standards and United States regulatory practice for nuclear facilities and activities. "Nuclear safety analysis and review is a critical step before any launch of a space nuclear system"[4] and provides assurance that the safety guidelines are satisfied. The safety guidelines established in National Security

[3] Ibid, sect. 2.
[4] Ibid., sect. 5.

Presidential Memorandum-20 apply consistently across space nuclear system types and:

- Assist mission planners and launch authorization authorities in ensuring launch safety
- Ensure that an accident resulting in even low-consequence radiation exposure to any member of the public is unlikely, and that potential accidents that could result in higher-consequence exposures are progressively less likely
- Are informed by comparison with guidelines developed for other previous and current nuclear activities, and are comparable to relevant United States standards
- Direct relevant United States agencies and departments to determine any additional guidelines that are appropriate for the safe operation of nuclear reactors in space or on other planets[5]

The organization sponsoring a mission utilizing a space nuclear system is responsible for preparing a safety analysis. The mission safety analysis will be in the form of a Safety Analysis Report and will incorporate technical peer review and include a concise, high-level summary of key risk information. According to the policy:

> "This summary should include: the likelihood of an accident resulting in an exposure in excess of 5 [roentgen equivalent man] rem [total effective dose] TED[6] [as defined in the *Code of Federal Regulations*] to any member of the public; the number of individuals who might receive such exposure in an accident scenario; and comparisons of potential exposure levels to other meaningful measures such as nuclear space launch safety guidelines, background radiation, average public exposure from natural and manmade sources, and other relevant public safety standards."[7]

When appropriate, the policy allows for the use of system-specific Safety Analysis Reports as reference reports to meet mission assurance requirements. These system-specific Safety Analysis Reports will address bounding accident analysis results coincident with the safety guidelines in the policy. The system-specific Safety Analysis Report strategy is based on a generic nuclear power system type (radioisotope heater unit, radioisotope thermoelectric generator, fission power, etc.) and uses bounding estimates for accident probabilities and hazard and accident risks, and it could rely on past developed accident analysis reports if available.[8] The Safety Analysis Report provides data that inform the level of authority for making launch authorization decisions following a three-tiered process based upon the characteristics of the system, the level of potential hazard and national security considerations.

Tier I applies when all of the following apply:

- The quantity of radioactive material does not exceed 100,000 times the A2 value established in the current standards of the International Atomic Energy Agency (IAEA)[9] for the safe transport of radioactive material.[10]
- Safety analysis finds that there is no credible accident scenario (less than a one in a million chance) that might result in radiation exposure of 5 roentgen

[5] Ibid.

[6] United States, *Code of Federal Regulations*, Title 10, Chapter III, Part 835, para. 835.2. Available at https://ecfr.federalregister.gov/.

[7] United States, "Presidential Memorandum on Launch of Spacecraft Containing Space Nuclear Systems", sect. 5 (b).

[8] Ibid.

[9] International Atomic Energy Agency, *Regulations for the Safe Transport of Radioactive Material: Specific Safety Requirements*, IAEA Safety Standards Series No. SSR-6 (Rev. 1) (Vienna, 2018).

[10] United States, "Presidential Memorandum on Launch of Spacecraft Containing Space Nuclear Systems", sect. 4 (a).

equivalent man (rem) or greater total effective dose to any member of the public.[11]

- The space nuclear system is not a nuclear reactor.[12]

Tier II applies when any of the following applies:

- The quantity of radioactive material exceeds 100,000 times the A2 value established in the current IAEA standards for the safe transport of radioactive material.
- Safety analysis finds that the there is a credible accident scenario (greater than or equal to a one in a million chance) that might result in radiation exposure of 5 rem to 25 rem total effective dose to any member of the public.
- The system is a nuclear reactor that uses low-enriched uranium fuel.[13]

Tier III applies when either of the following applies:

- Safety analysis finds that there is a credible accident scenario (greater than or equal to a one in a million chance) that might result in radiation exposure greater than 25 rem total effective dose to any member of the public.
- The system is a nuclear reactor using any nuclear fuel other than low-enriched uranium.[14]

The 1992 Principles are specific that space "nuclear reactors shall use only highly enriched uranium 235 as fuel." This is contrary to the more general guidance for implementation contained in the Safety Framework, which allows States and intergovernmental organizations to enhance safety based upon advances in knowledge and practice. The United States has learned through study and analysis that the safety of space nuclear applications can be enhanced by allowing for the best fuel for a given application.[15] Thus, the National Security Presidential Memorandum-20 policy provides for the use of other enrichments and other fuels as a means to ensure safety.

For United States federal government missions in tiers I and II, the head of the sponsoring department or agency is the launch authorization authority;[16] however, the President's authorization is required for tier III launches.[17]

For tiers II and III, described above, National Security Presidential Memorandum-20 calls for an independent review of the Safety Analysis Report to be conducted by the Interagency Nuclear Safety Review Board, administered by the National Aeronautics and Space Administration.[18] The Interagency Nuclear Safety Review Board is a permanent group with membership from United States government agencies that are stakeholders in nuclear-enabled missions. The Interagency Nuclear Safety Review Board will review nuclear safety analyses during the mission development life cycle, "ultimately including the mission [Safety Analysis Report], and report its findings, in the form of a Safety Evaluation Report, to the head of the sponsoring agency in order to inform the decision to proceed with launch and, for Tier III missions, inform any decision to request Presidential launch authorization".[19]

For United States commercial launches in all three tiers, the United States Secretary of Transportation, as the launch authority for commercial launches,[20] is directed to

[11] Ibid., sect. 3 (a) (ii).
[12] Ibid., sect. 4 (b) (iii) and (c).
[13] Ibid., sect. 4 (b).
[14] Ibid., sect. 4 (c).
[15] Johns Hopkins Applied Physics Laboratory, *Nuclear Power Assessment Study: Final Report – Radioisotope Power Systems Program* (Laurel, Maryland, 2015), chap. 6.
[16] United States, "Presidential Memorandum on Launch of Spacecraft Containing Space Nuclear Systems", sect. 4 (a) and (b) (iii).
[17] Ibid., sect. 4 (c).
[18] Ibid., sect. 5 (c).
[19] Ibid.
[20] Ibid., sect. 4.

issue public guidance describing the process that will be used to evaluate any application for a licence involving a space nuclear system.[21] At the request of the Secretary of Transportation, the Interagency Nuclear Safety Review Board shall review any nuclear safety analysis associated with a potential commercial launch of a space nuclear system under review by the Secretary of Transportation.[22]

Conclusion

The issuance of National Security Presidential Memorandum-20 signals a greater degree of transparency in establishing safety policies, requirements and processes. Consistent with the spirit of the Principles and the Safety Framework, National Security Presidential Memorandum-20 provides the United States with an architecture for ensuring compliance with safety policies, for establishing processes to satisfy fundamental safety requirements and objectives, and ultimately for the fulfilment of safety in the use of nuclear power in space. The National Aeronautics and Space Administration's history of successful launches of space nuclear systems validates many of the commonly held principles guiding governmental policy actions, mission management and nuclear safety risk management expressed in the Safety Framework.

Based on our experience with space nuclear safety practice, and in developing the National Security Presidential Memorandum-20 policy reform, the United States believes that the safety goals and guidelines contained in the Principles are wholly reflected in the implementation guidance contained in the complementary Safety Framework, and that together they provide sufficient guidance to States and international intergovernmental organizations to provide a sound foundation for the safe development and use of nuclear power in space. Furthermore, the more general implementation guidance in the Safety Framework allows advances in knowledge and practice to further enhance nuclear policy and thus advances the safety intent of the Principles.

[21] Ibid., sect. 5 (d).
[22] Ibid., sect. 5 (c).