ACCELERATING SAFE SPACE NUCLEAR APPLICATIONS VIRTUAL WORKSHOP

Informal Proceedings of Workshop held October 16, 2025

SPACE SAFETY INSTITUTE (SSI)
THE AEROSPACE CORPORATION
November 26, 2025

Organizers

Ron Birk, The Aerospace Corporation
Brian Weeden, The Aerospace Corporation
Randy Bell, The Aerospace Corporation

Panelists

Bhavya Lal, Rand School of Public Policy
Alex Gilbert, VP Regulation, Zeno Power
Susan Voss, President, Global Nuclear Analysis
Dan Clayton, Sandia National Lab
Pat McClure, Space Nuclear Power Corporation

Disclaimer: This is an informal summary of the discussions and content shared during the workshop. It is intended to primarily be a vehicle for continued collaboration amongst the participants and not a rigorous treatment of the subject matter. An effort has been made to accurately report and synthesize the major themes, but it has not been through a rigorous peer-review process that would typically accompany publishing. Inconsistencies, errors, and unrefined content may exist, and it is therefore not representative of the official stances of any of the organizing entities.

Contents

Executive Summary

The Aerospace Corporation's Space Safety Institute convened a virtual workshop to discuss safety and policy challenges for Space Nuclear Power and Propulsion (SNPP). The workshop brought together more than 100 participants from industry, academia, and government to discuss ideas for overcoming these challenges to make SNPP a reality.

The importance of SNPP is increasingly recognized for civil, commercial and national security missions in lunar surface, cislunar, and Earth orbit applications where its high power density and solar independence make it desirable. The first session of the workshop focused on policy challenges and potential solutions. At the national policy level, there is a strong need for clear policy goals and drivers to guide national efforts, but they cannot be too prescriptive. The key is to have a minimum viable policy that addresses the most important issues that need to be resolved early in the process and then iterates over time to resolve additional issues further along. Participants identified that the most pressing policy issues as liability and potential indemnification (especially for commercial SNPP systems), export controls, and clarifying safety zones for the lunar surface. Constructive U.S. participation in United Nations efforts, including private sector perspectives, can help inform the international community about U.S. policies and plans, shape other countries' own efforts, and lay the foundation for international norms and standards.

The second session of the workshop focused on technical challenges and potential technical solutions. Safety is crucial and needs to be factored into any space nuclear program from the start and through the life cycle including operations and ultimately disposal. It was recommended to utilize newer regulatory guidance such as NSPM-20 to perform simplified, probabilistic, system-level safety analyses to identify bounding cases rather than high-fidelity, highly specific, high-precision calculations as long as the system fits within the safety envelope. As an alternative to the traditional monolithic approach to safety where the spacecraft must contain all systems required to mitigate failures, today it is conceivable that a system-of-systems approach could achieve this guidance through corresponding systems and spacecraft that provide necessary safety mitigations. There are also limited appropriate test facilities that could test SNPP fission systems end-to-end.

The workshop recommended a series of next steps including developing a common SNPP lexicon, improving digital tool usage, and driving to a near-term simplified in-space demonstration as part of a cohesive tech development roadmap led by a national government champion.

Event Overview

On October 16, 2025, The Aerospace Corporation's Space Safety Institute convened a virtual workshop to discuss safety and policy challenges for Space Nuclear Power and Propulsion (SNPP). The workshop brought together more than 100 participants from industry, academia, and government to discuss ideas for overcoming these challenges to make SNPP a reality.

SNPP has long been recognized as enabling for deep space applications. The importance of SNPP is increasingly recognized for civil, commercial and national security missions in lunar surface, cislunar, and Earth orbit applications. Two distinct features make nuclear power important— independence from solar illumination and high-power density. These features are separate and distinct. Independence from solar illumination makes nuclear the ideal power source for applications where there is an absence of sunlight such as lunar night, Martian dust storms, and rare trajectories that have extended eclipse conditions. High power density could make nuclear attractive over solar in some extremely high-power applications. The US Government has shown renewed interest in space nuclear power. Recent administrations have made bold statements and issued revised policies and plans regarding space nuclear power and propulsion. Industry and academia have highlighted the need for accelerated development and deployment of space nuclear systems to achieve economic and national objectives.

The event was held under the Chatham House Rule in a non-attribution setting. The following report summarizes main points of discussion and key takeaways. The organizers identified the following high-level questions to guide the workshop discussions:

- What are the appropriate safety guidelines for the non-terrestrial operation of nuclear fission systems?
- Where is the distinction between safety and environmental exposure?
- What improvements are needed in safety decision support tools and analysis methods?
- What safety restrictions should be applied to either streaming radiation or surface contamination on celestial surfaces?

- What is the licensing pathway for commercial SNPP missions (both in-orbit and on the lunar surface) and how should the USG cover its "continuing oversight" obligation?
- What are the appropriate export controls on space SNPP technologies?
- What is the framework for conducting multinational commercial space SNPP missions (both in-orbit and on the lunar surface)

Policy Challenges and Potential Solutions

Moderator*: Brian Weeden, The Aerospace Corporation*
Panelists*¿Bhavya Lal, Rand School of Public Policy, Alex Gilbert, VP Regulation, Zeno Power*

The first session of the workshop focused on policy challenges and potential solutions. The U.S. has had many space nuclear power and propulsion (SNPP) programs through the years, albeit without deploying operational systems. Reasons include lack of a clearly defined market demand to enable commercial engagement, fragmented roles and responsibilities, range of interests among U.S. government agencies, insufficient funding, and a lack of test facilities and infrastructure to do end-to-end testing. Specifically on safety, one challenge past SNPP programs have discovered is that more levels of review can potentially lead to worse safety arising from additional system complexity to account for extremely-low probability failures.

Currently, there are stronger policy drivers and other demand for SNPP, including ties to the Artemis Program and a broader Moon to Mars architecture, as well as increased interest in robotic exploration of the Solar System. Participants specifically highlighted the challenge in surviving the 14-day long lunar night as a significant driver for nuclear power on the lunar surface. There is competition from other international players, who are already operating nuclear power sources on the Moon in the form of Chinese lunar landers with radioisotope power systems with plans for future expansion. A key driver is value of U.S. playing a leadership role setting international norms and standards for safe SNPP operations.

One of the main safety challenges for SNPP is avoiding threats to the Earth, either during launch or re-entry. The latter is a challenge even for cislunar space activities, as seen with a recent non-nuclear mission that failed to reach lunar orbit and ended up re-entering the Earth’s atmosphere.

There are good opportunities to learn from how safety and regulation of nuclear power sources is done in other domains. The maritime domain has a long history of safe use of nuclear power sources in a similar analog to space, noting maritime applications of nuclear power has had decades to develop a safety regime. The terrestrial nuclear reactor industry is switching to a risk-informed safety framework to help lower regulatory barriers while maintaining high safety standards.

Safety standards are distinct from security issues, such as proliferation, but are often considered in conjunction. Recent U.S. national policies like Space Policy Directive 6 (SPD-6) and NSPM-20 have helped provide more focus on streamlining approvals and moving towards providing the same rulebook for government and commercial players. Using highly-enriched uranium in fission systems and plutonium-238 in radioisotope systems can be particularly challenging due to the proliferation concerns, but it can be done. Notably, the medical community has developed safe and efficient standards for commercial use and transportation of a wide range of radioisotopes. There may be opportunities for the SNPP community to learn from satellite servicing community experience and efforts such as CONFERS who similarly had to work across the international community to establish a lexicon and set standards for in-space servicing, assembly, and manufacturing (ISAM).

At the national policy level, there is a strong need for clear policy goals and drivers to guide national efforts, but they cannot be too prescriptive. The key is to have a minimum viable policy that addresses the most important issues that need to be resolved early in the process and then iterates over time to resolve additional issues further along. Fix the big challenges early to enable work to progress and avoid trying to develop a comprehensive framework at the start.

Participants identified the most pressing policy issue that needs resolving now is liability and potential indemnification, especially for commercial SNPP systems. The second most pressing issue is export controls and refining where they are necessary for radioisotopes and related technologies. A third pressing issue is to clarify how safety zones or a similar concept will function on the lunar surface, as those are likely critical to safe lunar testing and deployment. Clarifying the overall regulatory framework for commercial SNPP, perhaps through implementation of mission authorization and defining reactor licensing/regulation agencies for space operations, is also important.

On the international side, participants highlighted the recently created Action Team on Lunar Activities Coordination (ATLAC) within the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS) as a potentially important venue for further discussions. Participants also mentioned the long-running effort of the Working Group on Nuclear Power Sources (NPS), also within UN COPUOS, to develop principles for safe space operations. Constructive U.S. participation in ATLAC and NPS, including private sector perspectives, can help inform the international community about U.S. policies and plans, shape other countries' own efforts, and lay the foundation for international norms and standards. Such norms are not automatically set by those who go first, but rather by countries behaving a certain way and convincing others to follow.

Group Discussion: Technical Challenges and Potential Solutions

Moderator*: Randy Bell, The Aerospace Corporation*
Panelists*: Susan Voss, President, Global Nuclear Analysis; Dan Clayton, Sandia National Lab; Pat McClure, Space Nuclear Power Corporation*

The second session of the workshop focused on technical challenges and potential technical solutions.

Safety is crucial and needs to be factored into any space nuclear program from the start and through the life cycle including operations and ultimately disposal. Safety for a space nuclear program is not the same as terrestrial nuclear safety. All nuclear systems need to consider safety to the public. That said, not all aspects of a space nuclear mission are in proximity to the public. The public is not present during the in-space operations phase of autonomous space nuclear systems. There are safety concerns regarding exposure to the public during launch and re-entry, and during crewed in-space operations.

Furthermore, it was cautioned that rare events (at the extreme tail of probability distributions) shouldn't dominate system safety design and implementation to the detriment of safety during operations by introducing additional system complexity.

Additionally, it is sufficient for safety analysis to address bounding cases rather than be high-fidelity, highly specific, high-precision calculations. If it can be shown that a system fits within a safe envelope, then it is not necessary to perform difficult analysis to

accurately and precisely specify exactly where the system resides – only that it is within the envelope.

A common theme from the panel of experts was that safety analysis does not have to be a daunting and complex computation. In nearly all cases, a simplified model or 'circular cow' approximation can be shown to bound the conditions, then a straightforward calculation can show the consequence is within tolerable limits. This approach was discussed for the source terms associated with novel isotopes, inadvertent criticality and accidental reentry of post-operation space reactors.

Deliberations on space nuclear safety and technical approaches to calculate and implement safety date back to the earliest days of nuclear space development. Some reactors have greater safety challenges than others. For example, NERVA never resolved its inadvertent criticality issues and DRACO had to work beyond prior precedent to address this issue in the modern context.

In the past, the guidance that reentry of a spacecraft with a large inventory of activity had to be prevented with "high reliability" was typically interpreted to imply a monolithic approach where the spacecraft containing the nuclear system needed highly reliable, redundant systems to ensure safe disposal in a graveyard orbit even after an unanticipated failure of the spacecraft. However, today it is conceivable that a system-of-systems approach could achieve this guidance using space-tugs that could rendezvous, dock and reposition a damaged nuclear spacecraft.

Conclusion and Next Steps

Key gaps to address

- Significant uncertainty in the national and global governance framework for enabling future SNPP missions
- Limited appropriate test facilities – absence of facilities to test end-to-end
- Lack of insight on how a deployed reactor relates to other lunar activities
- Cohesive plan specifying the role of nuclear power in lunar infrastructure

Key Policy topics

1. Highest priority is clarifying Third Party Liability, leveraging solutions from existing frameworks in other domains

2. Export controls for nuclear reactors for international solutions – ITAR and Part 810
3. Understanding the implementation of lunar safety zones as outlined in the Artemis Accords

Key Technology topics

- Utilizing NSPM-20 to perform simplified, probabilistic, system-level safety analysis reports
- Expanded use of multiple methodologies and modeling capabilities
- Explore use and safety considerations of alternate radioisotopes
- Needed tests and test facilities to validate the models used for safety

Next Steps

In the compilation of these proceedings with the community, additional next steps were discussed beyond what was covered during the workshop. In the spirit of this workshop being a call to action, it felt appropriate to include them here (steps 4 and 5) for community consideration.

1. Compile key points with respect to gaps in policy and technology in a white paper
2. Establish commonly understood and supported lexicon for SNPP (reference CONFERS Lexicon [4]
3. Leverage community tools (i.e., digital engineering environments [5]) for collaboration on evolving policies, practices, procedures, testing, & operations
4. Drive a community-led commitment to a near-term, small-scale SNPP demonstration to garner genuine senior-level attention on rapid, incremental, space nuclear advancement through a "red team" report, national leadership workshop, or other means.
5. Identify a senior champion within the government to own the SNPP evolution with the mandate, drive, and authority to plan and carry it out.

References

[1] The First Lunar Reactor: What Went Wrong? A Premortem, Bhavya Lal, Ph.D., https://docs.google.com/document/d/13EEFQTc-xziBnZmU2SVpl_A_CI_jAYYzDU_tmzhFGsc/edit?tab=t.0#heading=h.k5ocm6obvaxo

[2] United Nations Action Team on Lunar Activities Consultation (ATLAC), https://www.unoosa.org/oosa/en/ourwork/copuos/atlac/index.html

[3] Solving the Puzzle of Evolving Space Ecosystems, Ron Birk, Cris Guidi, The Aerospace Corporation, https://aerospace.org/paper/solving-puzzle-evolving-space-ecosystems

[4] CONFERS Lexicon, https://satelliteconfers.org/page/confers-Lexicon

[5] Into the LUNAverse: Evolving a Digital Commons for Space Innovation, The Aerospace Corporation, https://aerospace.org/article/lunaverse-evolving-digital-commons-space-innovation

Appendix – Workshop Agenda

1300 Welcome and Introductions

1315 Brief Overview of Nuclear Power and Propulsion Issues

1330 **Group Discussion: Policy Challenges and Potential Solutions**

1430 Break

1445 **Group Discussion: Technical Challenges and Potential Solutions**

1545 Next Steps and Wrap-up

1600 Close