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Enhancing Safety and Regulations for Commercial Space Transportation with Space Nuclear Systems in the United States

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Abstract

The rapid growth of the commercial space sector, including increased launches and satellites, requires a comprehensive regulatory approach to ensure safety. Although small in numbers today, new space nuclear systems, operated by the commercial sector, are among these new activities. In October 2023, the U.S. Department of Transportation's Federal Aviation Administration (FAA) issued an Advisory Circular (AC), "Launch and Reentry of Space Nuclear Systems." The AC provides comprehensive guidance to assist applicants through the launch and reentry licensing process when space nuclear systems are present. The AC also applies to applicants seeking an independent payload determination.

In the United States, commercial launches, reentries, and spaceport operations are regulated by the FAA's Office of Commercial Space Transportation. With over 700 commercial launches and over 40 commercial reentries licensed since 1989, the FAA has played a pivotal role in regulating commercial space activities in the U.S. The FAA has regulatory authority for the launch or reentry of any radionuclide, emphasizing the safeguarding of public safety, safety of property, and alignment with national and international interests. Launch or reentry of space nuclear systems necessitates a comprehensive review by the government because of the potential high risk to public safety.

This paper presents FAA's initial efforts to enhance public safety in U.S. commercial space transportation as it relates to space nuclear systems and advances it further to take into account future challenges and opportunities for international collaboration.

The paper is also meant to give mission planners, launch and reentry vehicle operators, spaceport operators, and countries developing new national frameworks insight into the complexities of governing space nuclear systems. Through a focus on future considerations and international cooperation, the paper contributes to a more comprehensive understanding of the evolving landscape of commercial space transportation safety and regulation specifically when radioactive material is present. It examines the necessity to develop adaptive regulatory mechanisms that will be able to keep up with the speed of technological advancements and the increased need for international governance in commercial space activities.

1. Introduction

The commercial space industry is growing quickly, in terms of new capabilities and levels of activity. Of the 221 total orbital launches conducted worldwide in 2023, just over half were commercial. Commercial orbital and suborbital launches in 2023 licensed by the U.S. Federal Aviation Administration (FAA) reached a record 117 — up from 54 in 2021. In total, 2,938 satellites were launched in 2023, 97% of which were under 1,200 kilograms in weight — an increase of over a factor of 6 from the 328 small satellites that were launched in 2018. By the end of 2023, a total of 9,691 active satellites were in orbit, an increase of 361 percent over the past five years.[1]

This trend has been further given a boost by technological innovation and deep private

investment. Companies like SpaceX, Blue Origin, Virgin Galactic, and Rocket Lab have helped open space access for new customers and markets by lowering costs and increasing flight rates for a variety of missions and destinations. Developments in the commercial space industry are contributing significantly to toward global economic growth and technological advances. The global space economy was estimated to be about $400 billion in 2023.[2]

Amid this growth, space nuclear systems emerge as a critical component in the future of exploration and commercial ventures. Examples of space nuclear systems are NTP (nuclear thermal propulsion) and RPSs (radioisotope power systems), which promise greater efficiency and longer mission durations compared to traditional systems. For instance, nuclear thermal propulsion is higher in specific impulse and thrust, making it suitable in enabling long-duration missions outside the orbit of Earth, trips to Mars, or explorations of deep space.

Radioisotope power systems are critical to generating reliable power where solar energy is not practicable; for example, in outer planet exploration and on areas of the Moon that are in shadow for most of the time. A number of these missions have been very high profile, such as the Mars rovers or the Voyager spacecraft still beaming results back after many years from launch.

In the United States, new companies are developing space nuclear power sources. At the same time, government agencies are increasingly turning to the private sector to provide services that can lower costs and reduce development time. As a result, a new industry is emerging to provide commercially operated space nuclear systems for various services.

However, when space nuclear systems are part of commercial missions during launch and reentry, a new set of challenges will be introduced in regulation and safety. To begin to address these challenges, the FAA Office of Commercial Space Transportation published an Advisory Circular (AC) in October 2023 titled "*Launch and Reentry of Space Nuclear Systems*"[3] in order to guide applicants through the launch and reentry licensing process when space nuclear systems are present on a launch or reentry vehicle. This also extends to those seeking an independent payload determination.

Commercial space activities involving space nuclear systems introduce unique public safety challenges. For example, various radionuclides carried on space nuclear systems emit radiation which can be harmful to human health. Some radionuclides are long-lived, emit high-energy radiation, or are difficult to decontaminate if released into the environment. Some radionuclides present all these characteristics simultaneously. The AC provides necessary guidance to properly address these unique hazards.

This paper discusses FAA's preliminary step to assure public safety with respect to the use of space nuclear systems for commercial space transportation in the U.S. The paper will also look into future challenges and possible areas for international cooperation. This paper seeks to provide an overview of the changing landscape on the regulation of safety and complexities in governing commercial space transportation, specifically those involved in the use and/or handling of radioactive materials in space nuclear power systems. A special emphasis will be put on the need to develop adaptive regulatory mechanisms that can go in pace with technological development and the increasing need for international cooperation in commercial space activities.

2. Regulatory Background

2.1 Overview of the FAA's Role in Commercial Space Transportation Regulation

The FAA plays a pivotal role in regulating the burgeoning commercial space transportation industry in the United States. This regulatory oversight is managed by the FAA's Office of Commercial Space Transportation (AST), which was established to protect public health and safety, the safety of property, and the national security and foreign policy interests of the United States during commercial launch and reentry operations. AST is responsible for issuing licenses for commercial launches, reentries, and the operation of launch and reentry sites both within the United States and by U.S. citizens abroad.[4] Title 51 of the U.S. Code contains the statutory authority for the FAA's regulatory role.[5] Notably, 51 USC sections 50904 and 50905 outline the FAA's mandate to issue launch and reentry licenses.

2.2 Statistics on FAA's Regulatory Activities Since 1989

Since the first FAA commercial launch license in 1989, the FAA has licensed more than 700 U.S. commercial launches (orbital and suborbital) and 44 reentries from Earth orbit (see figure 1).[6] The missions include placing communication and Earth observation satellites in Earth orbit, executing scientific experiments, and transporting humans and cargo to and from the International Space Station. The FAA licenses U.S. launches and reentries both inside and outside the United States. Currently there are 14 FAA licensed non-federal launch sites (spaceports).

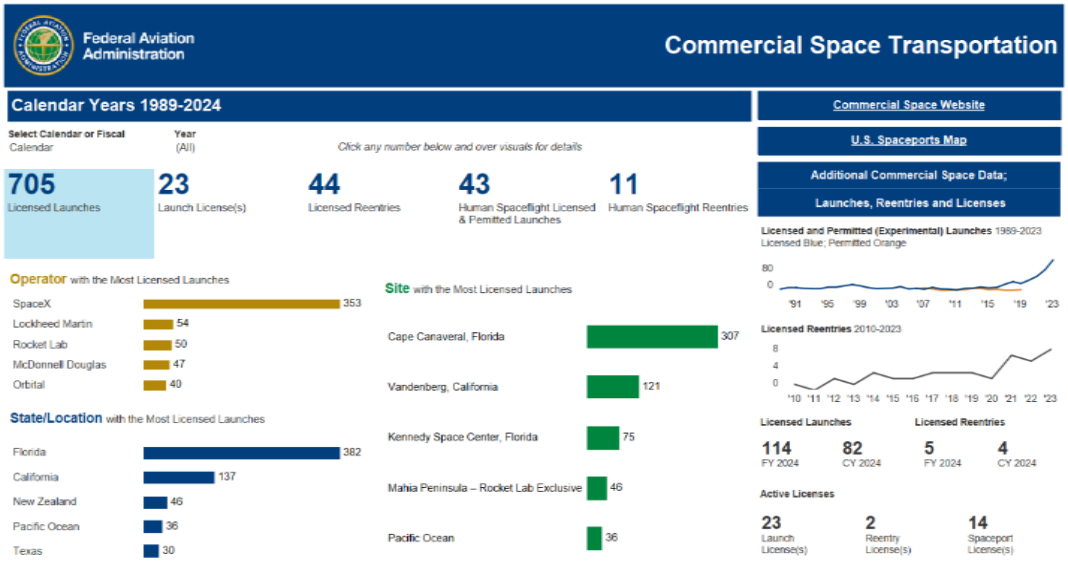

Figure 1. FAA Licensed Launches and Reentries

3. Advisory Circular (AC) Details

3.1 Purpose and Scope of the AC

The FAA set up its new licensing regulations, at 14 CFR part 450, such that the FAA evaluates the launch or reentry of any radionuclide on a case-by-case basis, and issues an approval if the FAA finds that the launch or reentry is consistent with public health and safety, safety of property, and national security and foreign policy interests of the United States. The AC provides a means of compliance and guidance for applicants proposing to launch or reenter space nuclear systems under the requirements of part 450.

The means of compliance that the FAA sets forth in the AC generally follows the guidelines outlined in Presidential Memorandum on Launch of Spacecraft Containing Space Nuclear Systems (NSPM-20). NSPM-20 addresses the authorization process for government and commercial launches of spacecraft containing space nuclear systems, and categorizes launches of spacecraft containing space nuclear systems in three Tiers based upon the characteristics of the system, the level of potential hazards, and national security considerations.

The AC encompasses every part of the licensing procedure for launches and reentries that use space nuclear systems. The AC is a comprehensive document that touches on several areas, such as safety evaluations and operational procedures, and aligns with national and international standards. The FAA wants to ensure that all commercially licensed launches and reentries with space nuclear systems are conducted in a manner that protects public health and safety, property, and the environment. And by providing detailed guidance across a number of technical spaces and competencies, the AC greatly aids commercial nuclear ventures.

3.2 Guidance Provided by the AC for Launch and Reentry Licensing

The AC describes the process for obtaining a launch and reentry license that involves space nuclear systems step-by-step. Critical aspects of this process consist of the submission associated with an application as well track record expectations, safety, and environmental consequence assessment.[7] The FAA also performs an initial review using a set of preliminary safety and environmental assessments that confirms completeness and identifies any immediate areas for concern. From this, a thorough analysis of safety is conducted to identify possible hazards which may arise such as radiation exposure, accident scenarios, and measures for mitigation. The FAA must also assess the environmental impacts associated with issuing a launch or reentry license. The FAA collaboratively works with the Department of Energy, Nuclear Regulatory Commission, and other relevant agencies. The FAA then conducts a final review that includes input from other federal agencies before making the license decision. If a license is approved, the company may be given detailed conditions and restrictions they must meet during their mission. The FAA regulations lifecycle management process is detailed in figure 2.[8]

Figure 2. Lifecycle Management, FAA License

3.3 Application of the AC to Independent Payload Determination

In addition to conducting a safety review as part of a license evaluation process, the FAA also reviews payloads being launched or reentered. Specifically, the FAA may prevent the launch or reentry of a payload if it determines that its launch or reentry would jeopardize the public health and safety, safety of property, or national security or foreign policy interests of the United States.[9] In addition to a launch or reentry operator, a payload owner or payload operator may request a payload review and determination.

Applicants desiring a stand-alone payload determination for space nuclear systems (separate from a launch or reentry license) can look to the AC for step-by-step guidance. They must submit a payload review application with technical details, safety analyses, and regulatory compliance documentation that is both particular to the payload and particular to the regulatory regime. In its application and applicant must identify, among other things, hazardous materials, radioactive materials and the amounts of each, and the intended operations during the lifetime of the payload, including anticipated life span and any planned disposal.[10]

Once an application is submitted, the FAA conducts an evaluation of the payload. The FAA works closely with other federal agencies as part of an interagency review. Agencies consulted include the Departments of State, Defense, Commerce, and Homeland Security (U.S. Coast Guard), the Federal Communications Commission, the National Aeronautics and Space Administration, the Office of the Director of National Intelligence, and other agencies such as the Nuclear Regulatory Commission and the Department of Energy. During a payload review, the FAA can request additional information, if necessary, to make a review determination. This ensures that the applicant addresses all the considerations that the FAA may have.

The FAA continuously works with its U.S. Government partners to coordinate activities for the launch or reentry of commercial nuclear systems. For example, the Common Standards Working Group, which the FAA, Air Force, and NASA formed in 2004 for the purpose of, among other things, developing and maintaining a stable framework of common safety standards and recommended practices for the space launch industry, formed a Nuclear Sup-group in September 2022 to foster clear communications and coordination among agencies

and to assess current nuclear safety standards and recommended practices to meet both the needs of commercial and government space launch. The Department of Transportation is also a member of the Interagency Nuclear Safety Review Board, along with NASA, the Department of Defense, the Department of Energy, the Environmental Protection Agency, the Nuclear Regulatory Commission, and the Department of State.

After completing its interagency review and own independent assessment, the FAA may issue a favorable payload determination. The independent determination is not a license from the FAA but may enable valuable feedback on FAA and interagency issues for payload owners before the time when a launch or reentry operator applies for a future license with the same space nuclear system onboard. A launch or reentry license may also contain specific conditions or requirements necessary to ensure the safe and compliant operation of the launch or reentry.

4.0 Nuclear Safety Analysis

4.1 Tiers and Safety Analysis Report

To ensure the safe operation of space nuclear systems, the FAA established a detailed nuclear safety analysis process outlined in the Advisory Circular and the 2019 Presidential Memorandum on Launch of Spacecraft Containing Space Nuclear Systems (NSPM-20).[11]

The scope and content of the nuclear safety analyses demonstrating compliance with the public health and safety criteria should be commensurate with the level of mission radiological risk incurred. Figure 3 provides applicants a way to determine which nuclear safety analyses could be used to demonstrate acceptable level of public health and safety for various space nuclear systems.[12]

The process begins with an applicant preparing a detailed SNS device and mission description and submitting a Radioactive Materials Onboard Report (RMR). The FAA evaluates the radiological hazard to determine if a Radiological Emergency Response Plan is needed. A criticality hazard analysis follows, assessing the presence of fissile, fertile, or fissionable isotopes and the device's potential for criticality.

Missions are categorized into Tier I, II, or III, dictating the level of further analysis required. Tier I may need no additional analysis if exposure potentials are low, while Tiers II and III require more comprehensive radiological safety analyses. The tiers were established in NSPM-20 and are also based on risk and radioactive material type.

Finally, an applicant prepares a Safety Analysis Report (SAR) based on the tier level, ensuring all potential hazards are addressed. This tiered approach allows scalable regulatory oversight, applying stringent safety measures to high-risk missions and streamlining lower-risk ones, demonstrating the FAA's commitment to high safety standards in commercial space transportation involving nuclear systems.

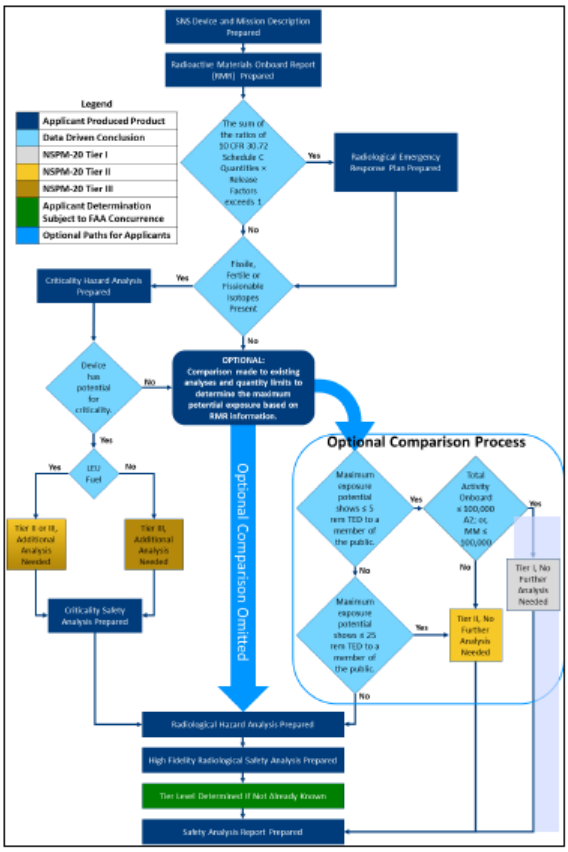

Figure 3. Nuclear Safety Analysis Flow Chart

4.2 Emphasis on Public Safety, Property Safety, and Alignment with National/International Interests

The FAA framework emphasizes public safety and the protection of property, especially space nuclear systems that carry certain inherent risks. It guides the 'what, how, and why' for applicants.

Besides public and property safety, the FAA ensures national security and foreign policy interests of the United States are addressed. The United States has signed a variety of treaties and other agreements that address the use of space and nuclear technology. The FAA upholds this regulatory framework, which amounts to a series of laws by which public and private U.S. space activities must abide.

5. Importance of Comprehensive Reviews for Space Nuclear Systems Due to High Risks

The potential dangers of space nuclear systems demand a thorough vetting of every phase of those risks, from launch to inevitable reentry and disposal. Comprehensive safety and environmental reviews are conducted to ensure public safety. The review process of the FAA includes evaluation and coordination with other Federal agencies and provides a robust level of safety and risk abatement. The potential accident scenarios are scrutinized under the light of risks that are associated with ionizing radiation. From those potential scenarios, subject matter experts assess the level of exposure (primarily to humans) that might result if an inadvertent event were to occur. And they assess the level of effectiveness that is associated with the amount and type of safety measures put in place. Altogether, this makes for three substantive areas to review when flagging pathway documents: the potential accident pathways themselves, the potential level of exposure to all relevant stakeholders (again, primarily humans), and the level of effectiveness at dealing with exposure conditions under the duress of what might be a not-so-successful event.

5.1 Insights for Stakeholders

FAA regulations and the Advisory Circular are

particularly relevant for mission planners, vehicle operators, and spaceport operators. Mission planners must understand the FAA's regulatory requirements to design and execute missions involving space nuclear systems safely. The FAA's detailed safety guidelines help anticipate and mitigate potential risks. Spaceport operators will likely play a critical role in supporting launches and reentries involving space nuclear systems. They must ensure their facilities meet necessary safety and environmental standards and are prepared to handle the unique challenges posed by these systems, including implementing robust safety protocols and emergency response plans.[13]

6. International Collaboration

Opportunities exist in the realm of international collaboration. As space activities become more global and cooperation increases with commercial providers, there is a growing need for international regulatory interoperability.

The FAA promotes its commercial space transportation regulations as a model for other countries to consider as they develop their own regulations. Increased compatibility can increase international partnerships and enable industry growth. At the same time, governments can maintain public health and safety during space activities with common alignment in regulations. Avoiding regulatory confliction between countries is a key challenge for commercial activity that spans multiple nations.

Nations have international obligations and commitments that guide the use of space nuclear power sources. Among those are the Outer Space Treaty, Liability Convention, and Registration Convention,[14] the United Nations (UN) Principles Relevant to the Use of Nuclear Power Sources in Outer Space,[15] and safeguards established by the UN International Atomic Energy Agency (IAEA).[16]

The UN principles establish that nuclear power sources should not be the go-to power source for space operations. The objective of the UN principles is to restrain operators from choosing nuclear power when safer alternatives exist. Specifically, the principles state that "[i]n order to minimize the quantity of radioactive material in space and the risks involved, the use of nuclear power sources in outer space shall be restricted to those space missions which cannot be operated by non-nuclear energy sources in a reasonable way."[17]

For commercial activity, new policies, voluntary standards, and new rulemaking may be needed. Addressing the long term sustainability of space is an increasingly important consideration for nations updating their existing space governance and for new actors in space.[18]

As renewed international interest in exploration of the Moon and other destinations accelerates,[19] the Artemis Accords reinforce the commitment by the United States and signatory nations to the Registration Convention, the Rescue and Return Agreement, as well as best practices and norms of responsible behavior.[20] Section 5 of the Accords note that "[t]he Signatories recognize that the development of interoperable and common exploration infrastructure and standards, including but not limited to fuel storage and delivery systems, landing structures, communications systems, and power systems, will enhance space-based exploration, scientific discovery, and commercial utilization."[21] As of June 2024, 43 countries have signed the Artemis Accords.[22]

Collaborative efforts will not only address the current challenges but also pave the way for innovative solutions and advancements in space nuclear technologies.

7. Consideration of Future Challenges and Opportunities

As the commercial space sector continues to evolve, there are several future challenges and opportunities in regulating space nuclear systems. One of the primary challenges is the rapid pace of technological advancement. New, portable, and innovative space nuclear technologies are being developed, which may present unforeseen safety and regulatory challenges. Regulators such as the FAA must continuously update its regulatory frameworks to keep pace with these advancements and ensure that all new technologies are safely integrated into commercial space operations.

Another challenge is adapting to a variety of missions and destinations from low and high Earth orbits, orbits around the Moon or to the Moon's surface and other planetary and deep space exploration operations. Furthermore, different agencies with oversight of nuclear materials, communications, safety, security, or contingency response have different authorities in different locations. For example, agencies may lack certain authorities for activities that occur off the Earth's surface. Although traditional government space missions may have more clarity than regulating commercial missions, the combination of joint government and commercial partnerships can add complexity.

Adapting to commercial space activity from ground development and terrestrial transportation to pre-launch activity at the launch site, in addition to during launch, orbital operations, continual supervision, and disposal can involve multiple agencies and regulators with different authorities that need to work together. Regulatory agencies may need to scale their regulatory scopes and obtain new legislation.

Enhancing contingency planning for potential mishaps and accidents for both domestic and international locations is also a challenge because of the unique risks from space nuclear systems.

8. Conclusion

The development and regulation of commercial space transportation involving space nuclear systems mark a significant milestone in the evolution of space exploration and commercial activities. This paper has provided an in-depth analysis of the FAA's role in ensuring the safety and regulatory compliance of these technologies. By examining the FAA's regulatory authority, initial efforts, and future challenges, we gain a comprehensive understanding of the intricate landscape of space nuclear system regulation. The FAA's detailed Advisory Circulars, such as AC 450.45-1, and robust licensing processes establish clear guidelines to address the unique risks associated with space nuclear systems. These efforts underscore the FAA's commitment to public safety, property protection, and compliance with national and international standards. Rigorous safety evaluations and interagency coordination ensure that space nuclear systems are operated safely, mitigating potential hazards, and promoting a safe commercial space environment.

References

[1] Satellite Industry Association, June 13, 2024, "SIA Releases 27th Annual State of the Satellite Industry Report," https://sia.org/commercial-satellite-industry-continues-historic-growth-dominating-global-space-business-27th-annual-state-of-the-satellite-industry-report/

[2] Satellite Industry Association, "2024 State of the Satellite Industry Report," June 13, 2024 https://sia.org/news-resources/state-of-the-satellite-industry-report/. The $400 billion global estimate includes revenue from satellite services, ground equipment, satellite manufacturing, launch industry, space sustainability activities, and about $114 billion in government space budgets.

[3] Advisory Circular AC 450.45-1 "Launch and Reentry of Space Nuclear Systems" Federal Aviation Administration, October 20, 2023 is available at: https://www.faa.gov/space/legislationregulationguidance/commercial-space-advisory-circulars-acs/commercial-space

[4] See more at https://www.faa.gov/about/office_org/headquarters_offices/ast

[5] 51 USC 509 is available from the FAA Office of Commercial Space Transportation at https://www.faa.gov/space/legislation_regulation_guidance

[6] FAA Office of Commercial Space Transportation, 2024. https://www.faa.gov/data_research/commercial_space_data

[7] Ibid.

[8] FAA Commercial Space Transportation regulations, Title 14, Code of Federal Regulations, Chapter III, are available at: https://www.ecfr.gov/current/title-14/chapter-III/subchapter-C

[9] 51 USC 50904.

[10] 14 CFR § 450.43 Payload review and determination. https://www.ecfr.gov/current/title-14/chapter-III/subchapter-C/part-450/subpart-B/section-450.43

[11] "Presidential Memorandum on Launch of Spacecraft Containing Space Nuclear Systems Infrastructure & Technology, August 20, 2019. https://trumpwhitehouse.archives.gov/presidential-actions/presidential-memorandum-launch-spacecraft-containing-space-nuclear-systems/

[12] Advisory Circular AC 450.45-1 "Launch and Reentry of Space Nuclear Systems" Federal Aviation Administration, October 20, 2023, page 32. https://www.faa.gov/space/legislationregulationguidance/commercial-space-advisory-circulars-acs/commercial-space

[13] Launch site operator regulations can be found in 14 CFR Part 420: https://www.ecfr.gov/current/title-14/chapter-III/subchapter-C/part-420?toc=1

[14] See United Nations, Space Law Treaties and Principles at https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties.html

[15] Principles Relevant to the Use of Nuclear Power Sources in Outer Space, United Nations 1992, https://www.unoosa.org/oosa/en/ourwork/spacelaw/principles/nps-principles.html

[16] See IAEA at https://www.iaea.org/

[17] Principles Relevant to the Use of Nuclear Power Sources in Outer Space, United Nations 1992, https://www.unoosa.org/oosa/en/ourwork/spacelaw/principles/nps-principles.html

[18] UN Long Term Sustainability of Space guidelines are available at https://www.unoosa.org/documents/pdf/PromotingSpaceSustainability/Publication_Final_English_June2021.pdf

[19] A 2022 CSIS report surveyed 106 cislunar and Lunar activities from 19 nations and found that 24 were led by commercial industry. Kaitlyn Johnson, "Fly Me to the Moon, Worldwide Cislunar and Lunar Missions," Center for Strategic & International Studies, February 2022, pages 24- 25. https://aerospace.csis.org/fly-me-to-the-moon-worldwide-cislunar-and-lunar-missions/

[20] Artemis Accords, 2020, https://www.nasa.gov/artemis-accords/. Section 1 of the Accords note that: "The principles the Accords are intended to apply to civil space activities conducted by the civil space agencies of each Signatory. These activities may take place on the Moon, Mars, comets, and asteroids, including their surfaces and subsurfaces, as well as in orbit of the Moon or Mars, in the Lagrangian points for the Earth-Moon system, and in transit between these celestial bodies and locations."

[21] Ibid.

[22] US Department of State, June 2024, https://www.state.gov/artemis-accords/#:~:text=As%20of%20June%202024%2C%20there,and%20transparent%20cooperation%20in%20space.