

Analysis of Options for Japan in the Peaceful Uses of Space Nuclear Power

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This paper analyzes institutional, technological, and policy trends in Japan and the United States, focusing on Space Nuclear Propulsion and Power as a key technology for space exploration and sustained deep space activities at the Moon and beyond. The current status of research and development of radioisotope thermoelectric generators (RTG), lunar fission reactors (Fission Surface Power), and nuclear thermal and nuclear electric propulsion (NTP/NEP) are reviewed from a technical perspective. Their international institutional frameworks, relevant export control regulations, and the role of Japan-US cooperation are discussed. Research sources included policy documents and reports from NASA, the U.S. Department of Energy (DOE), and the UN Committee on the Peaceful Uses of Outer Space (UNCOPUOS), as well as company case studies, and interviews with over 30 experts, including government officials in Japan and the United States. The analysis confirmed that Japanese companies need to overcome multiple institutional barriers to participate in U.S. projects in the space nuclear energy field, including the need to establish a U.S. corporation, comply with the U.S. export regulations, and obtain a technical assistance agreement (TAA). It was also suggested that with the increasing security importance of space nuclear power, the current UNCOPUOS regime has limitations and a new framework with like-minded countries such as AUKUS is needed. This study introduces and provides practical suggestions on Japan's policy options and strategic positioning in the field of space and nuclear energy. It is intended to offer information that will contribute to Japanese policy formation in both international cooperation and domestic institutional development in the future.

I. Introduction

Japan's space industry has long been recognized for its advanced technological capabilities, as evidenced by its significant contributions to international space projects such as the International Space Station (ISS) and the Artemis program. However, as global trends shift from state-led space exploration to commercially driven efforts, Japan faces the challenge of adapting its space strategy to remain competitive. In particular, the 2024 research paper, "Japan's Strategy in Space,"¹ identified the following challenges:

- Delayed commercialization: Japan has been slow to transition from a government-led space program to one that encourages private sector participation.
- Insufficient national budget for space development: Japan's technological capabilities are world-class, but government investment in space is relatively limited.
- Limited space technology exports: Japan's space technology exports are heavily regulated, limiting the growth potential of the space industry, especially in the commercial sector, where the United States excels.
- Lack of leadership in space policy: Japan has been criticized for not taking a leading role in global space governance, especially compared to the United States, which has shaped international space norms.

In response to these challenges, Japan has been working to strengthen its space policy by establishing a space strategy fund (contributing 1 trillion yen over 10 years) and formulating a space master plan in 2023. In this study, we further define a space strategy for Japan and conduct a case study on what is needed to promote that strategy.

In defining Japan's space strategy for this case study, we referred to the NASA Strategic Plan 2022² and the Moon to Mars Architecture 2024³. In this context, we decided to focus on space nuclear energy research, which is positioned as an important technological capability to support sustainable exploration and manned activities on the Moon and Mars, and for which full-scale research has just started in Japan in 2024. In Japan, research on a space nuclear battery started in 2024, with funding from the JAXA Space Strategic Fund, and the purpose of this project is to pioneer

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research on space nuclear batteries. In addition, since the use of nuclear energy in space is subject to many regulations, we believe that this is an area that needs to be strategically developed by the government. In addition to the space nuclear battery, we will also include FSP and SNP, for which research has not yet begun. Based on the cooperation between Japan and the United States in the development of next-generation land-based nuclear technology, the possibility of development for use in space and the necessary legal system will be discussed.

Space nuclear power technology is a technological innovation that will enable long-distance and long-range exploration, which was difficult to achieve with conventional chemical propulsion or solar power alone and is attracting attention as a game-changing technology in space exploration since the Apollo era. If Japan can demonstrate its global presence in this field, it means that Japan can play the role of a game changer. In this study, we will examine what is necessary for Japan to advance in space nuclear energy research.

II. Methodology

A. Literature Review (National and International Institutions and Projects)

In this study, official reports, technical plans, and policy documents issued by NASA, the U.S. DOE, the United Nations Office of Outer Space Affairs (UNOOSA), the European Space Agency (ESA), and other governmental and international organizations were surveyed as primary information sources to understand the current status and international trends in space nuclear propulsion technology. In addition, U.S. strategic documents were examined and primary information on U.S. strategic planning documents (e.g., NASA Strategic Plan, Moon to Mars Architecture) and current research projects on lunar reactors and space nuclear propulsion (e.g., Fission Surface Power, DRACO) were reviewed. A qualitative and exhaustive literature review was conducted on the development status, supply chain, and legal and institutional constraints of power sources using radioisotopes (e.g., Pu-238, Am-241, Sr-90).

In addition, press materials from the U.S. private company Zeno Power, and two private Japanese companies, ispace and Astroscale, regarding their efforts were examined, as well as various policy documents and press materials regarding the legal framework of U.S. nuclear export controls (ITAR, EAR, TAA) and the 123 Agreement (also known as a Civil Nuclear Cooperation Agreement).

Finally, materials published by various governments and UNCOPUOS on space security and multilateral frameworks were referenced.

B. Interview Survey (Japanese and U.S. experts)

In addition to the literature review, semi-structured interviews were conducted with 30 Japanese and U.S. experts involved in the space nuclear energy field. The interviews were conducted between March 2025 and June 2025, and findings were obtained from 15 experts from each country. The subjects were as follows, ensuring diversity in terms of affiliation and areas of expertise.

U.S. Interviewees

From the United States, interviews were conducted with individuals in the following positions.

- Government officials involved in space nuclear policy
- Project personnel in U.S. government agencies related to space reactors
- Employees of private companies involved in the development of nuclear reactors
- Experts with legal and negotiation experience in space policy and export control

Japanese Interviewees

From Japan, the following individuals with deep policy and technical involvement in the space and nuclear sectors were interviewed.

- Government officials in charge of space and nuclear policy
- Employees of independent administrative agencies related to space and nuclear energy
- Japanese company officials in the nuclear industry
- Japanese company officials in the space industry
- Legal and export control practitioners familiar with regulations governing exports between the U.S. and Japan in the commercial space sector

These interviews provided a valuable opportunity to gain qualitative insight into policy decisions, practical issues, and barriers and possibilities for international cooperation that cannot be captured in literature or official presentations.

III. Trends in Space and Nuclear Technology Development

There are three main areas of space nuclear technology: Radioisotope Thermoelectric Generator (RTG), Fission Surface Power (FSP), and Space Nuclear Propulsion (SNP). In this section, we describe the technical characteristics of each of these three technology areas and the results of a survey of related research projects.

A. RTG

RTGs are devices that generate electric power by utilizing the heat emitted by the decay of radioactive isotopes. Instead of chemical reactions or sunlight, the decay energy of radioactive materials (mainly plutonium-238) is extracted as heat, which is then converted into electric power using thermoelectric conversion elements. Typical power generation ranges from tens of watts to several hundred watts. The following is a comparison of the characteristics of the radioisotopes used in RTGs and examples of their use.

1. Comparison of RTG Isotopes

RTGs using plutonium-238 (Pu-238) as a fuel source have been developed and operated mainly in the United States, but research on RTGs using other isotopes such as americium-241 (Am-241) and strontium-90 (Sr-90) has been progressing recently.

Due to its high energy density and relatively safe radiation properties, Pu-238 has been employed by many of NASA's Mars rover missions over the years as a long-lived and reliable means of providing power.

Table 1. Comparison of RTG features by Isotope

Isotope	Half-life (in Physical Chemistry)	Heating Value (W/g)	Major Radiation	Advantage	Disadvantage
Pu-238	87.7 years	0.57	Alpha rays	High output, proven	Limited supply, high manufacturing costs
Am-241	432 years	0.11	Alpha + gamma rays	Long life, some countries have technology to recover from spent fuel	Low output, shielding required
Sr-90	28.8 years	0.93	Beta rays	Waste-derived, low cost	Difficulty in radiation shielding, safety issues

Americium-241 (Am-241) has a lower power output than Pu-238 but has advantages in that it has a longer half-life and can provide a sustainable power supply. RTGs using Pu-238 require special permission from the U.S. DOE due to security concerns, but those using Am-241 do not, therefore universities and companies can conduct research under Nuclear Regulatory Commission (NRC) licenses. Am-241 can be separated from spent nuclear fuel, and research on the extraction and utilization of Am-241 is being conducted in Europe (especially in the United Kingdom) since 2019. In addition, ORANO of France has succeeded in extracting Am-241 from spent fuel. Since 2024, Japan has also been conducting research and has succeeded in separating Am-241 from spent nuclear fuel. Research is also being conducted in the United States, but interviews revealed that the United States does not have its own supply chain for americium and instead procures it from European countries.

Sr-90 has a relatively short half-life and high-power output and is cost-effective but shielding and radiation control to ensure safety are problems. Research is underway in the U.S. for future commercial use and long-life power supply in extreme environments.

2. Status of RTG Utilization

NASA has used RTGs with Pu-238 to power many of its Mars rovers, and NASA and the U.S. DOE have a memorandum of understanding under which U.S. DOE will supply Pu-238 for NASA's science exploration programs.⁴ However, the supply has been noted to be inadequate for NASA's future demand.⁵ In such circumstances, interviews revealed that there is also demand in the United States for RTGs that use radioactive isotopes other than Pu-238 that are cheaper, easier to obtain, less toxic, and more stable.

Although different from RTG, the Rosalind Franklin rover, scheduled for launch in 2028, will be equipped with a radioisotope heater unit (RHU) using Am-241 provided by ESA to protect the rover's electronics and batteries from the extreme cold of Mars. This will be the first use of Am-241 in a space mission. However, an Am-241 RTG will not

be used; the RTG is a device designed to provide power, but on the Rosalind Franklin rover, power will be provided by solar cells and batteries, and the RHU will primarily provide only heat.⁶ The Rosalind Franklin rover was scheduled to launch in 2022 on a Russian Proton rocket, but ESA ceased cooperation with Russia due to Russia's invasion of Ukraine. ESA has since signed a new agreement with NASA and plans to launch in 2028 on a U.S. commercial rocket and land in 2030.

Regarding the use of RTGs on the moon, NASA has selected Zeno Power to lead a team to develop RTGs using Americium for lunar missions in a project called Tipping Point.⁷ In April 2025, Zeno Power announced a strategic alliance with ispace to jointly develop technologies to successfully survive the lunar night on a lunar exploration mission⁸. Zeno Power has also won funding to build RTG-powered satellites for the U.S. military and is developing strontium-based RTGs.⁹

B. Lunar Surface Reactor (Fission Surface Power)

The lunar surface reactor has been touted as a core technology in sustainable space exploration as a permanent power source for future lunar bases. In 2024, NASA positioned FSP as the primary power supply technology for early manned exploration missions to Mars. Prior to FSP usage on Mars, NASA plans to demonstrate the technology on the lunar surface. NASA and the U.S. DOE are working under the FSP program to design and demonstrate a small fission reactor with a power output of 40 kW, and in 2022, three companies (Lockheed Martin, Westinghouse, and IX) had been awarded conceptual design contracts.¹⁰ The program requires the ability to provide stable power during the lunar night (approximately 14 days) on the lunar surface, making it suitable for long-duration high-load applications that solar power and batteries cannot handle. During interviews, it was revealed that minerals (silicon oxide and magnesium oxide) are believed to exist on the moon's surface, and that these minerals may be useful for manufacturing spacecraft and semiconductors on the moon. The fuel is expected to be highly enriched uranium (HEU) or high assay low enriched uranium (HALEU). Through interviews, it became clear that while HEU would be smaller and more compact, it is not practical from the perspective of security and safeguards, whereas HALEU would be larger but would be subject to fewer regulations for use, making it more suitable for commercialization. As a result, research is mainly focused on HALEU.

Other countries besides the United States have begun to consider the development of lunar reactors. Russia and China have announced that they will cooperate to build a lunar reactor by 2035.¹¹ Roscosmos Director Yuri Borisov stated that solar power alone is not sufficient to power future settlements on the Moon and that nuclear energy is needed. The Russian plan envisions unmanned, automated installations and will draw on Russian expertise in space nuclear energy.¹²

In Japan, Japan Aerospace Exploration Agency (JAXA) has launched a public call for "Lunar Infrastructure Construction Technology" in 2025, including infrastructure elements such as power supply, communications, and thermal control.¹³

C. Space Nuclear Propulsion

SNP is being actively researched and developed by NASA and the U.S. DoD as a next-generation propulsion technology that will enable deep space exploration. The first is the Nuclear Thermal Propulsion (NTP) method, which obtains thrust by jetting hydrogen heated in a fission reactor out of a nozzle. Second, Nuclear Electric Propulsion (NEP) converts the thermal energy obtained from the fission reactor into electric power and supplies it to electric propulsion systems such as Hall thrusters.

NTP technology in the United States originated with the Nuclear Engine for Rocket Vehicle Application (NERVA) program, which was in development by the U.S. between 1955 and 1973. This was a system that propelled the vehicle by expelling hydrogen heated by a nuclear reactor. The concept eventually underwent more than 20 successful ground combustion tests but was cancelled due to budget cuts and political reasons in the 1970s.¹⁴ Current NTP technology development is based on the data and design concepts from NERVA, especially in the areas of heat-resistant materials and reactor control.

In the United States, NASA and the U.S. DOE were jointly promoting the "Demonstration Rocket for Agile Cislunar Operations (DRACO)" program, and DARPA had selected Lockheed Martin as the lead contractor for a NTP technology demonstration in 2027. Development of a thermonuclear propulsion reactor utilizing a small fast neutron reactor (HALEU fuel) was also underway in the United States, with BWXT and General Atomics as the lead companies involved.¹⁵ In interviews, the lack of opportunities for demonstration was cited as a challenge in advancing NTP research. In NTP, heat spewing experiments as high as 2000K are required, and there are no experimental facilities on land that can accommodate such experiments.¹⁶ It is also difficult to conduct a demonstration in space for something that has not been tested on land, and it is considered a challenge to conduct the experiments on land first. The DRACO program was cancelled due to budget reasons in 2025.

On the other hand, with regard to NEP, NASA is conducting a design study for a Moon-Mars cargo transport using a combination of tens of kW-class power supply and electric propulsion based on Kilopower technology; there is a natural synergy between the NEP system and the FSP system, as both have the same basic system, and both have the same capability to deliver cargo to the Moon and Mars. As the U.S. alternates between iterations of these systems, they are expected to converge and show significant commonality.¹⁶

IV. International Projects and Institutional Frameworks for Space Nuclear Energy (International Frameworks)

A. U.S. Institutions and Policy Documents

In the United States, the development and utilization of space nuclear energy systems are being institutionalized through several presidential memorandums and policy documents. The three main policy documents are listed below.

The NSPM-20 (issued in 2019) is a key document that establishes safety, liability, and regulatory procedures with respect to the launch of space nuclear systems.¹⁷ In particular, it provides guidance on launch risk assessment and quantitative evaluation of radiological effects, typified by the application of probabilistic risk assessment methods by Sandia National Laboratories.¹⁸

For NASA project launches, "NPR 8715.26" defines the safety confirmation process for space nuclear missions¹⁹, and radiation effects are assessed in cooperation with the U.S. DOE and other organizations in accordance with this process. In 2023, the FAA issued Advisory Circular 450.198-1A, which provides guidelines for nuclear material management during launch and reentry and encourages private companies to take actions from the design phase.²⁰

SPD-6 (2020) lays out a national strategy for space nuclear energy systems and establishes a roadmap from research and development to mission implementation for RTG, lunar reactor (FSP), and space nuclear propulsion (NTP/NEP) technologies.²¹ It also explicitly states that cooperation with commercial and international partners will be pursued.

Finally, the U.S. federal government issued a regulation in 2021 on "Promoting Small Modular Reactors for National Security and Space Exploration," noting the applicability of SMRs to the military and space sectors.²²

In interviews, we learned that FSP and SNP are safer than RTG in the event of an accident during launch. This is because FSP and SNP do not initiate a nuclear reaction unless a switch is turned on, so safety can be ensured by turning on the switch after launch. In another interview, it became clear that when considering launch safety, it is necessary to develop an alloy that can withstand a fall into water. We will also keep a close eye on the agreement reached by the U.S. DOE in the field of metallurgy.

B. European Initiatives and NLSAP

The European Space Agency (ESA) is developing a safety assessment framework for space nuclear missions based on the International Safety Guidelines for the Use of Nuclear Sources in Outer Space (UN-SF) developed by UNCOPUOS. The Preliminary Nuclear Launch Safety Authorization Process (NLSAP) institutionalizes the evaluation of radioactive properties, accident consequence analysis, and flight safety assessment at launch.²³ It also describes the methodology for safety with respect to the launch of a new Radioisotope Power System (RPS) using Am-241 for the development and mission of the first RPS in Europe.

C. Japanese Institutions and Problems

In Japan, the main system that exists is for safety assurance, based on the Space Activities Act. Without a clear review system for the use of space nuclear technology, a Japanese version of the NSPM-20 needs to be developed. In response, the Japan Atomic Energy Agency (JAEA), which is developing RTGs using Am-241, will conduct a probabilistic risk assessment in cooperation with Manned Space Systems Corporation, referencing U.S. safety standards. In addition, environmental effects of radioisotopes, etc. are being modeled by JAEA's WSPEEDI, which is expected to be used for future institutional design.²⁴ The handling of Am-241 in Japan will be subject to regulation under the Law Concerning the Regulation of Radioisotopes, etc., but will be easier than the regulation under the Nuclear Reactor Regulation Law when Pu-238 is used.

Furthermore, in interviews, it was suggested that when establishing a regulatory framework in Japan, it would be beneficial to consolidate regulatory authority under a single ministry, based on lessons learned from NASA's efforts to date. In the United States, nuclear energy regulation falls under the jurisdiction of the U.S DOE, which has inventory government authority, but there are many cases where research cannot be conducted. Although the DRACO program was being conducted by NASA and DARPA, it was discovered that launch permission must be obtained from the U.S. Department of Defense (DoD), requiring a complicated process.

Table 2 summarizes the situation in each country.

Table 2. Comparison of National Systems for Space Nuclear Energy

Region	Institution Name/Policy	Safety Review Method	Target Technology	Reference System
United States of America	NSPM-20 / SPD-6 / FAA Circular	Pre-review by DOE/NASA/FAA	RTG, FSP, NTP/NEP	Radiation Risk Assessment
Europe	NLSAP (ESA)	Design evaluation from initial stages	RTG Center	UN-SF Guidelines
Japan	Space Activities Act (Provisional)	No specific system (by JAEA on a trial basis)	RTG (Am)	Refer to U.S. system

V. U.S.-Japan Space Cooperation and Export Controls

Japan is a major player in space exploration, producing its own rockets and satellites and participating in international projects. Despite its technological prowess, Japan's space market, valued at about 4 trillion yen (about 3 billion dollars) in 2020, is only a fraction of the global space market,²⁵ which is expected to grow threefold, from 630 billion dollars in 2023 to 1.8 trillion dollars by the early 2030s.²⁶

Japan also plans to launch a space strategy fund at JAXA in 2024, with the aim of funding Japanese space-related companies and other entities with 1 trillion yen over 10 years. However, in interviews, it was pointed out that these funds will be limited to research and development (R&D) and that it is unclear who will utilize the resulting technologies. In the United States, rather than R&D, there are programs in which the government promotes development while utilizing the services of companies. NASA's Commercial Orbital Transportation Services (COTS) and Commercial Lunar Payload Service (CLPS) programs, as well as the U.S. Space Command's Commercial Augmentation for Space Resilience (CASR) program, seek to promote the use of private-sector services. In this context, some of the first Japanese companies have cooperated with U.S. companies and received contracts for U.S. government projects. This section discusses actual examples of Japanese companies cooperating with U.S. companies in the space industry and examines export regulations in both countries that pose barriers to accelerated cooperation between Japanese and U.S. companies in the field of space nuclear energy.

A. Institutions and Regulations Concerning Contracts for U.S. Operations

The following systems are in place with respect to export controls from U.S. companies to Japanese companies.

- International Traffic in Arms Regulations (ITAR): Regulates exports of defense-related goods and technology; may apply to dual-use (civilian-military) technology; may also cover commercial space equipment and propulsion equipment.²⁷
- Export Administration Regulations (EAR): Regulations governing the export control of commercial technology, applicable to a wide range of areas including satellite components and communications technology.²⁸
- Technical Assistance Agreement (TAA): An agreement required for U.S. companies to provide technical assistance and technology transfer to overseas partners. When a Japanese company participates in a NASA technology development project, a TAA governs discussions to avoid unauthorized technology transfers.

ITAR regulates the international transfer of defense-related technologies and products, and the technologies covered by the ITAR are listed in the US Munitions List (USML). Since the USML includes space equipment and related technologies, Japanese companies that wish to receive technology transfers from the United States must obtain a TAA in advance and can only share technological information within the scope permitted by export licenses identified through discussions under the TAAs.

EAR applies to a broader range of dual-use items (products that can be used for both civilian and military purposes), and eligible items are defined in the Commerce Control List (CCL).

The main concerns for Japanese companies identified through interviews were that obtaining a TAA and export licenses is time-consuming and costly, that there is a risk of significant sanctions if information is leaked outside of the authorized scope, and that personnel with access to ITAR-eligible technology in collaboration with U.S. companies may be limited. In addition, there are restrictions on the number of personnel who can access ITAR-eligible technologies when collaborating with U.S. companies. Under the current circumstances, Japanese companies are

required to develop legal and compliance systems that comply with U.S. regulations, handle technology restriction clauses in contracts, and ensure physical and digital security to control technology access.

In addition, when Japanese companies receive U.S. government defense and national security contracts, restrictions may be imposed on them regarding Foreign Ownership, Control, or Influence (FOCI) in accordance with the National Industrial Security Program Operating Manual (NISPO), which are the guidelines for industrial security established by the U.S. Department of Defense.²⁸ FOCI refers to a situation in which a foreign interest has the power to influence, directly or indirectly, the management or operations of a U.S. company. When such influence exists, a company's access to classified information may be restricted. If a company seeking a facility security clearance (FCL) to handle classified information in the United States is determined to be affected by FOCI, it will not be allowed to obtain an FCL until appropriate mitigation measures are taken. The following measures are available to mitigate the effects of FOCI, and participating Japanese companies must act in accordance with these mitigation measures.

- **Board Resolution:** Applies when a foreign interested party does not have the right to appoint a director.
- **Security Control Agreement (SCA):** Applicable when a foreign interested party has the right to appoint a director but has no substantial influence on the operation of the company.
- **Special Security Agreement (SSA):** Applicable when a foreign interest beneficially owns or controls a company.
- **Proxy Agreement and Voting Trust Agreement:** Applicable when a foreign interest wholly owns the company but excludes its involvement in management.

These measures are selected according to the company's situation and approved by the Defense Counterintelligence and Security Agency (DCSA). FOCI is a U.S. government regulation that applies to classified contracts and may not apply to NASA's unclassified contracts.

B. Specific Case Study: ispace and Astroscale

The Japanese company ispace announced in March 2025, that its U.S subsidiary, ispace Technologies U.S. (ispace-U.S) received contract funding from its U.S. partner Draper under the NASA CLPS Task Order CP-12 contract.²⁹ The mission, planned for 2026, will use ispace-U.S.'s APEX 1.0 lander to transport and operate multiple U.S. government and commercial lunar science payloads to the Schrödinger Basin, located on the far side of the Moon near the South Pole.

Since the CLPS program requires that the primary contractor be a U.S. company, ispace entered a partnership agreement with Draper, a U.S. company and the primary contractor, in order to participate in the mission. Furthermore, under the CLSP, when a foreign company participates in a mission, it must also do so through a U.S. corporation, and the majority of its shares must be held by a U.S. person or U.S. company, among other conditions. In addition, as indicated in Section III, ispace had announced a cooperative relationship with Zeno Power Systems in 2023 and is considering the use of strontium RTGs developed by Zeno as a means of supplying power on lunar missions.³⁰

The Japanese company, Astroscale, which provides orbital services, has also established a U.S. corporation and has been awarded a contract with the U.S. Space Force and for the first time in history, will perform refueling operations on geostationary orbit satellites for the U.S. Space Force.³¹ In order to operate under U.S. technical regulations, Astroscale U.S. has been certified with FOCI mitigation measures, with only U.S. directors and without information sharing with Astroscale-Japan other than accounting and other financial information.

Through this study, we learned that FOCI mitigation does not directly apply to NASA procurement contracts that are non-confidential, and which may require the U.S. company to hold a majority share of the foreign company. In this case, there are concerns that the foreign headquarters will not be able to treat the U.S. corporation as a consolidated subsidiary, and thus will not be able to recognize the U.S. corporation's proceeds towards sales by the parent company, which will reduce the company's corporate value. Being able to count such sales to the home company would be more beneficial from the perspective of corporate management. During the interviews, there were comments that FOCI regulations are relatively easy to comply with for companies listed on the stock exchange if they are subject to SSA. In DoD projects, there are participating foreign companies that comply with FOCI regulations through SSA measures. It is expected that NASA's regulations on foreign companies in the procurement process will be the same as the FOCI regulations.

C. Japanese Government Technology Funds and U.S. Transfers

Currently, policies and systems are under development regarding whether technology developed through Japanese government-supported funds (e.g., Space Strategic Fund) can be transferred to the United States through collaboration with U.S. companies, and there are discussions regarding the need to develop rules on the foreign usage of technology developed with Japanese government funding. In particular, if there are defense applications or nuclear-related

technologies, Japanese export control law, the Foreign Exchange and Foreign Trade Control Law,³² and the RI Regulation Law (governing radioisotopes) regarding the export of Am-241RTG would apply.

Under the current Japanese system, Japanese corporations are sometimes restricted from sharing intellectual property (IP) and other technologies developed using Japanese government funding, even with their U.S. subsidiary corporations, and this was pointed out to be inefficient in interviews. To encourage Japanese companies to be active in overseas markets in the future, it is necessary to revise the system by allowing the exchange of all but sensitive technologies.

Although there are various regulations, we learned that there are examples of Japanese companies that are active in the U.S. market. In the interviews, we learned that to increase the number of Japanese companies active in the United States, it is important for Japanese companies to first demonstrate their technological capabilities. Among the various companies in the United States, Japanese companies need to hone and demonstrate their unique technological capabilities to stand out. It was suggested that the Japanese government needs to provide companies with opportunities for R&D and demonstrations.

Furthermore, during interviews, it was suggested that a private space industry association similar to the Commercial Space Federation (CSF)³³ in the United States should be established in Japan. The establishment of such industry associations would make it easier for the government to incorporate opinions on needs of the space industry.

VI. Legal and Bilateral Cooperation and Export Controls

A. Japan-U.S. Next-Generation Reactor Development Under the Framework of the 123 Agreement

The United States and Japan have conducted nuclear technology cooperation for peaceful purposes under the U.S.-Japan Nuclear Cooperation Agreement ("123 Agreement"), which was signed in 1988. This is an agreement under Section 123 of the U.S. Atomic Energy Act, which provides the legal framework for the transfer of nuclear materials and technology.³⁴

Under this framework, for example, ARC Clean Technology (U.S. headquarters), which is leading the SMR commercialization project in Canada, is developing a small sodium-cooled reactor in cooperation with IHI and other Japanese companies. Japanese companies are participating in the development of a small modular reactor (SMR) ground reactor, and plans are underway to manufacture and provide a pressure vessel for a sodium-cooled fast reactor (SFR) in Japan.³⁵ Cooperation between NuScale Power and IHI is also underway, with Japanese companies looking to be part of the supply chain for the international development of SMR technology.³⁶

B. Potential for Expansion into the Space Sector

Based on the cooperative relationship for land-based nuclear technology, Japanese companies may become more involved in nuclear technology in the space sector, such as lunar reactors. For example, NASA's Fission Surface Power (FSP) program, in cooperation with U.S. companies (e.g., Lockheed Martin and BWXT), emphasizes participation from the conceptual design stage.³⁷ For U.S.-Japan cooperation in developing space reactors, there may be a need for discussions and revisions based on the 123 Agreement. In addition, it will be necessary to develop a supply chain for space applications while complying with U.S. regulations (ITAR and EAR).

C. Limitations of Application of the 123 Agreement and Consistency with the Foreign Exchange Law, ITAR, and EAR

The 123 Agreement is only a legal framework based on terrestrial use, and its direct application to space applications is limited. On the other hand, when Japan provides nuclear technology to foreign countries, "technology provision" regulations under the Foreign Exchange and Foreign Trade Law (Foreign Exchange and Foreign Trade Law) apply.³⁸

In the United States, advanced technologies, including those for space applications, are governed by ITAR and EAR, and Japanese companies are required to establish a U.S. corporation or obtain a TAA when they cooperate with U.S. companies to receive NASA or U.S. DOE projects.³⁹

D. Impact of Recent U.S. Executive Orders

Four nuclear-related U.S. Executive Orders were issued in May 2025. They are focused on strengthening the U.S. nuclear fuel supply system and strengthening of export controls for nuclear reactor technology. These orders may lead to an even stricter export control framework for joint development with allies, including Japan.⁴⁰ At the same time, it is also intended to promote cooperation with strategic partner countries, and whether Japan will be selected as a trusted partner will be a key policy issue going forward.

VII. Security and Multilateralism

With the development of space nuclear energy, security concerns and the need for international institutional design have increased. In particular, the risk of military diversion of nuclear materials and reactors used in space and the development of international controls on dual-use technology are urgent problems. The Outer Space Treaty, the Nuclear Nonproliferation Treaty (NPT), and the Missile Technology Control Regime (MTCR) have served as relevant laws and regulations, but a new multilateral agreement or framework needs to be considered to address the unique challenges of space nuclear energy.

A. AUKUS Framework and Implications for Space Nuclear Energy

AUKUS (Australia-United Kingdom-United States), signed in 2021 between the United States, the United Kingdom, and Australia, is a framework for sharing military technology, including the joint development and deployment of nuclear submarines. It provides for practical cooperation on nuclear technology security. This is a rare example of an exceptional transfer of nuclear technology to a non-nuclear weapons state under NPT and IAEA safeguards.⁴¹ In September 2024, the AUKUS Joint Statement announced initial cooperation with Japan in the area of maritime UAV systems under Pillar II (technical cooperation on advanced capabilities).

Through interviews, it was suggested that it would be useful to apply such a framework in the field of space nuclear energy. The establishment of a "space nuclear energy cooperation framework (tentative name: Space Nuclear Partnership)" centered on reliable technology partner countries would enable sustainable research and development and space utilization while limiting security concerns. In other interviews, it was suggested that to advance flight experiments, which currently pose an obstacle to NTP research and development, it is necessary to cooperate with other countries and ensure transparency in order to gain the trust of the international community more quickly.

Through another interview, it was suggested that when considering international cooperation frameworks such as AUKUS in the field of space nuclear power, it is necessary to establish cooperation frameworks that are more oriented toward commercialization. While AUKUS is a military-focused cooperation framework, space nuclear power research is conducted with the intention of private sector involvement in space activities, including on the moon. Therefore, it is important to ensure that regulations are not overly stringent, as this could hinder private companies from actively participating in this field in the future.

B. Why a Multilateral Framework is Needed

Because of the proximity of space nuclear technology to missile and weaponizable technology, international regulation is essential to prevent proliferation. If Japan were to rely solely on bilateral agreements between Japan and the United States, technological collaboration with third countries would become challenging. Therefore, it is important to develop a multilateral framework, such as AUKUS, that clearly states comprehensive rules on security, for the following reasons:

- International guidelines need to be developed to allow the usage of space nuclear technology consistent with the national laws of each country.
- As joint development and launches by multiple countries increases, common safety standards and licensing systems are needed.
- The division of responsibility in the event of an accident or dispute in space should be defined in advance.

In addition, discussions in UNCOPUOS are limited to guidelines and thus have limited legal binding power, making it an inadequate institutional basis for international cooperation. In contrast, agreements such as AUKUS are more effective in space nuclear cooperation because they provide an explicit framework for sharing classified information, technology transfer, personnel exchange, and joint operational planning.

As a framework for multilateral cooperation, the Artemis Program is a U.S.-led international space exploration initiative with an eye toward lunar exploration and beyond to Mars, for which the Artemis Accords have been formulated. Japan and other allied countries are participating in this program, and international cooperation is being promoted through the construction of the Artemis Base Camp and Lunar Gateway. The Artemis Accords, however, are based on the premise of civilian and peaceful use, and do not include elements such as control of sensitive technologies such as nuclear power, security cooperation, or export controls. Therefore, the current framework of the Artemis Accords alone is insufficient to resolve the issues of technical cooperation and export control in the promotion of space nuclear energy.

VIII. Discussion

A. Opportunities for Technical Cooperation

Currently, the United States has the most advanced research and success in space nuclear technology, with a national-level support system in place for U.S. DOE and NASA-led RTG production and FSP and NTP development. On the other hand, Japan, despite its technological potential, has only just begun to develop RTGs using Am-241 domestically. Japan is considering the development of RTGs using Am-241 for scientific exploration. Although the amount of electricity generated by RTGs using Am-241 is one-fifth of that using Pu-238, they can be used as RHUs, and ESA, in cooperation with NASA, is planning to install RHUs on the next Mars rover. Japan needs to consider what kind of scientific exploration purposes it can use RHUs for in the future, using ESA's example as a reference and cooperating with NASA.

NASA is providing financial support for lunar surface services in the Tipping Point Public-Private Partnership to make it a self-sustaining commercial technology. The U.S. company Zeno Power has been selected for this program and is developing Am-241 RTG. Zeno Power is developing RTGs using Sr-90, but interviews revealed that RTGs using Am-241 are rarer and can be sold at higher prices. Considering the low sales volume, it has become clear that developing RTGs for use in space using Am-241 is highly valuable for companies. Zeno Power has also announced a partnership with ispace for lunar transit, and Japan is interested in partnering with these companies for use in NASA's programs.

In addition, Japan-U.S. cooperation in the development of next-generation nuclear reactors on Earth could be increased in the areas of FSP and SNP, where full-scale research has not yet been started in Japan. It would be realistic for Japan and the United States to join forces in the future, with the United States taking the lead in nuclear fuel supply and design, and Japan in charge of supplying highly reliable manufacturing technology and precision structural components. For example, Japanese companies could aim to take part in the supply chain for U.S. nuclear companies (e.g., Lockheed Martin and Westinghouse) that are contracted with NASA's FSP program for lunar reactors. Japan could develop pressure vessels and other components with support from the JAXA Space Strategic Fund and the MEXT Nuclear Energy Initiative (NEXIP). It is important to investigate the direction of the FSP project from current progress. Future uses of NEP can benefit from the technology of lunar reactors.

B. Institutional Problems

The institutional problems identified were restrictions on participation in U.S. space projects by Japanese companies, restrictions on the export of space and nuclear technology in both Japan and the United States, and restrictions on the launch of rockets carrying nuclear materials.

Although ispace and Astroscale are examples of Japanese companies participating in U.S. space projects, there are challenges in dealing with the capital structure requirements due to FOCI and NASA regulations. In addition, when Japanese companies pursue contracts on U.S. government projects in the United States, they need to collaborate with U.S. companies, but Japanese regulations are also an obstacle to collaboration between US and Japanese companies. For example, if a Japanese company developed technology using funding from JAXA Space Strategic Fund and collaborates with a U.S. company using that technology, there would be regulations on the transfer of the technology to the U.S. company.

As for export controls, as shown in Sections V and VI of this paper, there is an institutional vacuum in nuclear power-related export controls for space utilization in both the United States and Japan. In the case of the United States, these are ITAR, EAR and the 123 Agreement regulations, and on the Japanese side, the Foreign Exchange and Foreign Trade Act. For example, RTG and FSP technologies for space needs to be legally structured differently from those for terrestrial use, and it is necessary to establish an explicit consultation mechanism for space applications as the "second stage" of nuclear collaboration between the United States and Japan in the future.

Finally, as Japan develops and launches the Am-241RTG into space, since accidents are only specified in the "Measures to Ensure Safety and Compensation for Damages to Third Parties" of the Space Activities Law in Japan, similar to the United States, it is necessary to draft a Japanese version of the NSPM-20 that defines compensation for accidents. The NLSAP published by ESA also describes the risks associated with the launch of RTGs using Americium, which can be used as a reference. As with ESA, it is also likely that an application to the FAA will be required for the initial launch collaboration on a U.S. vehicle. This will be influenced by the negotiations conducted by ESA for the launch of the Rosalind Rover.

C. Toward the Formation of an International Framework

In order for Japan and the United States to promote collaboration in the field of space nuclear energy, it is necessary to adapt the various regulations of the two countries in this field. As pointed out in Section VII, in the international development of space nuclear propulsion, there is a limit to the consensus decision-making at the UNCOPUOS alone, and a multilateral agreement needs to be considered to ensure transparency. As non-Western countries such as China

and Russia seek to build nuclear reactors on the Moon, it is necessary to consider building an AUKUS-type technical alliance, which accounts for safety guarantees between the allied countries, and to develop governance in anticipation of future commercial collaboration between Japan and the United States. Japan already has a high level of credibility and established regulatory framework on the peaceful use of nuclear energy, and it would be possible for Japan to participate in the development of the framework technically and institutionally when advancing space nuclear energy research in the future. However, the following issues need to be addressed:

- The Japanese version of the Nuclear Safety Process (NSP) system has not been established, and it is necessary to draft a nuclear safety review system for launches of nuclear energy sources from Japan.
- Clear operating rules need to be established to align with U.S. nuclear export regulations (123 Agreement, ITAR, EAR).

The United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) is considering guidelines for the use of nuclear power sources in space (NPS), with Japan as one of the participants.⁴² This could be used to develop the required legislation while reflecting international consensus in the development of domestic laws. An option for the formation of an international framework is to make it one of the discussions at the next Japan-U.S. Comprehensive Space Dialogue.

IX. Summary and Conclusion

In this paper, we have examined "space nuclear propulsion technology," as an essential element for sustainable exploration and long-duration stays in space from multiple perspectives, focusing on Japan-U.S. collaboration, institutional frameworks, and security issues.

In Section III, we introduced the technical trends of RTG technology, which is important as a low-power power source in space, and of Fission Surface Power (FSP) for lunar activities. In Europe, a new type of RTG using Am-241 is under development. Although still in its early research phase, similar development has started with an outlook on possible international collaboration in the future. Space nuclear power is clearly defined as "game-changing technology" and the United States is leading in the institutional and strategic development of space nuclear power.

Section IV summarizes the role of space nuclear technology within international frameworks such as the IAEA and UNCOPUOS. The United States and ESA are developing legal frameworks for the launch of space nuclear systems, referring to international frameworks, and Japan should consider similar initiatives.

Sections V and VI provides a detailed analysis of U.S.-Japan export control regulations surrounding space nuclear power, the scope of the Department of Energy 123 Agreement, and the requirements for participation in NASA and DOE projects (FOCI, ITAR, EAR compliance, etc.). Specific institutional frictions between the United States and Japan and methods to overcome them were discussed through case studies of ispace and AstroScale.

Section VII focuses on the international security implications of space nuclear technology and makes recommendations regarding the limitations of the current UN-centric framework and the need for new alliance-led security partnerships such as AUKUS.

The discussion in Section VIII integrates technical, institutional, and political considerations into a comprehensive discussion of the future structure of Japan-U.S. collaboration in the technical aspects of space nuclear propulsion, addresses institutional challenges, and the opportunities for forming an international framework.

At the beginning of this paper, we asked: "What is needed for Japan to advance space nuclear energy research in the field of space nuclear energy, which is considered a game-changing technology in space?" In answering this question, this paper concludes that it is necessary for Japan to develop Japan-U.S. cooperation in space, mirroring land-based cooperation. Japan should establish the necessary legislation for the launch of space nuclear systems and consider a multilateral framework for cooperation in space nuclear power. It is important for Japan to establish itself as a "strategic partner" in the future development of space nuclear technology, by not taking a role as a subcontractor, but by actively participating in institutional design and international collaboration. To accomplish this, it is necessary to clearly state the space nuclear energy policy as a national strategy, coordinate regulations between Japan and the United States, and strengthen support for the private sector. The establishment of a next-generation energy infrastructure in space is an area where the true value of Japan's science and technology diplomacy will be tested.

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