Outer Space Institute Report

Handle with Care:
Nuclear Weapons and Nuclear Power Sources in Outer Space

OSI Report 2026(1)

Handle with Care

Nuclear Weapons and Nuclear Power Sources in Outer Space

Around the world, strategic competition is intensifying in every domain. The three main nuclear powers, the United States, Russia, and China, are striving for technological advantage, including in outer space. During the Cold War, the United States and the Soviet Union experimented with both nuclear weapons and nuclear power sources in space, before the negative effects of nuclear weapon testing and the accidental atmospheric re-entry of a nuclear-powered satellite caused them to agree on new restrictions and adopt new practices.

Today, nuclear power sources are receiving renewed interest, including the possible use of small modular reactors on the Moon as well as nuclear-powered spacecraft. There are also growing concerns about the placement or use of nuclear weapons in space. This report provides an overview of safety and security risks at the intersection of the nuclear and space domains, and does so in light of recent developments.

This report is the result of research, analysis, and consultations conducted by the Outer Space Institute and funded by an arms-length grant from the Mobilizing Insights in Defence and Security (MINDS) program at the Canadian Department of National Defence. It builds on a discussion paper, written by Dr. Roohi Dalal and Ms. Vivienne Zhang, that was prepared in advance of a two-day workshop in Vancouver, Canada, in 2024. The text has been expanded, updated and edited by members of the Outer Space Institute for wider distribution.

History of nuclear technologies in space

The development of nuclear technologies for use in space dates to the early years of the Cold War. Some of these technologies, such as nuclear weapons, have distinctly military uses; others have dual military-civilian uses, such as nuclear power sources for long duration missions.

1. *Nuclear testing in space*

Between them, the United States and Soviet Union tested nuclear weapons in the upper atmosphere and space on around 20 occasions between 1958 and 1962.[1] In the United States, Operation Argus was designed to test whether a nuclear explosion could blind Soviet radars and the electronics in warheads launched on intercontinental ballistic missiles (ICBMs).[2] On three occasions in 1958, low-yield 1-2 kiloton warheads were detonated at 200-540 kilometer altitudes, reportedly "at such

[1] Anatoly Matushchenko, Alexander Chernushev, Konstantin Kharitonov, Victor Mikhailov, Georgy Tsyrkov, Sergey Zelentsov, and Gennady Zolotukhin. "Some characteristics of atmospheric nuclear tests at the USSR test sites (1949–1962)," in *Atmospheric Nuclear Tests: Environmental and Human Consequences* (Berlin/Heidelberg: Springer, 1998) 63-68 at 66.
[2] "Operation ARGUS Factsheet," Defense Threat Reduction Agency, September 2021, https://www.dtra.mil/Portals/125/Documents/NTPR/newDocs/16-ARGUS%20-%202021.pdf

distances above the Earth that there was no possibility of exposure of task force personnel to ionizing radiation."[3] In 1962, Operation Fishbowl was designed to test whether a nuclear explosion could disable ICBMs, an anti-ballistic missile system, and Soviet radio communications.[4] The first tests failed; a nuclear warhead was lost at sea, and a destroyed missile contaminated the launch site with plutonium. However, in the Starfish Prime test, a 1.4 megaton warhead successfully detonated at an altitude of 400 kilometers. The largest nuclear test ever conducted in space, Starfish Prime created a powerful electromagnetic pulse (EMP) that disrupted electrical systems in Hawaii and disabled a number of operational satellites.[5]

Figure 1. Starfish Prime. 45 to 90 seconds after detonation.
Credit: Los Alamos National Laboratory, found in Smithsonian Magazine at:
https://www.smithsonianmag.com/history/going-nuclear-over-the-pacific-24428997/

In the Soviet Union, Project K aimed to determine the vulnerability of early anti-ballistic missile systems to nuclear explosions and how such explosions in space might affect electronics and radio communications. Two series of tests took place in 1961 and 1962 over Kazakhstan and the Astrakhan Oblast in the Soviet Union. The 1961 tests used low-yield 1.2 kiloton warheads while the 1962 tests employed much more powerful 300 kiloton warheads at altitudes of up to 300 km.[6] These tests, especially one on October 22, 1962, created powerful EMPs that knocked out

[3] Ibid.
[4] Roger Allen Meade, *Operation Fishbowl*. No. LA-UR-22-31336. Los Alamos National Laboratory (LANL), Los Alamos, New Mexico, 2022.
[5] Ajey Lele. "Remembering Starfish Prime," The Space Review, July 8, 2024, https://www.thespacereview.com/article/4822/1
[6] Anatoly Zak, "The 'K' Project: Soviet Nuclear Tests in Space," (2006) 13(1) Nonproliferation Review 143–50.

telephone lines and underground power cables, started fires, and set a power plant on fire 600 km away from the test site.[7]

Starfish Prime, the Project K tests, and their unexpected effects on satellites and ground-based infrastructure all took place in 1962, the same year as the Cuban Missile Crisis. The combination of events motivated the United States and the Soviet Union to negotiate the 1963 Partial Test Ban Treaty,[8] which prohibited all nuclear weapons tests except those conducted underground.

2. *Nuclear power sources in space*

At the same time that they were testing nuclear weapons in space, the United States and the Soviet Union were developing space-based nuclear power sources. From the beginning of the space age, nuclear power has been regarded as a solution to an age-old problem of space travel: the lack of a sustained energy source. Unlike solar panels, a nuclear power source can provide consistent power during lunar nights or on long duration missions farther away from the Sun.[9] Early studies identified two types of nuclear power for spacecraft: nuclear fission reactors and radioisotope power sources.

Spacecraft need to be kept warm, and nuclear fission reactors produce heat through controlled chain reactions of highly enriched uranium-235 (HEU),[10] with control rods being used to moderate the rate of the chain reaction. For heating purposes, nuclear fission reactors are more cost-effective than radioisotope thermoelectric generators (see below) for systems requiring more than 100 kW of power.

As for propulsion, two types of nuclear fission systems can be used. Nuclear thermal propulsion (NTP) involves transferring heat from the reactor to a liquid propellant to convert it to a gas, which then expands through a nozzle to provide thrust.[11] Nuclear electric propulsion (NEP) uses a reactor to generate electricity that positively charges gas propellants and pushes the ions out of a thruster.[12] Both types of nuclear propulsion are more effective than chemical propulsion. NTP, which provides a much higher thrust than NEP, is best suited for missions that require both speed and a high payload capacity, such as crewed or cargo missions to Mars. NEP is best suited for long-term missions that require a continuous thrust, such as robotic probes for deep space exploration.

Radioisotope power sources use the heat generated by the natural radiative decay of plutonium-238 to produce power.[13] They are used in radioisotope heater units (RHUs) and radioisotope

[7] Jerry Emanuelson, "Soviet Test 184," Future Science, http://www.futurescience.com/emp/test184.html
[8] Todd Harrison. "Existing International Agreements," in *International Perspectives on Space Weapons* (Center for Strategic and International Studies), 2020, 9-11 at 9, https://www.csis.org/analysis/international-perspectives-space-weapons
[9] Gary L. Bennett, Richard J. Hemler, and Alfred Schock. "Space Nuclear Power—An Overview," Journal of Propulsion and Power 12, no. 5 (1996): 901-910.
[10] "Physics of Uranium and Nuclear Energy," World Nuclear Association, updated March 2026, https://world-nuclear.org/information-library/nuclear-fuel-cycle/introduction/physics-of-nuclear-energy
[11] Beth Ridgeway (editor), "Space Nuclear Propulsion," NASA, updated April 2026, https://www.nasa.gov/space-technology-mission-directorate/tdm/space-nuclear-propulsion
[12] Ibid.
[13] Amanda Barnett (editor), "About RPS," NASA, updated April 2025, https://science.nasa.gov/planetary-science/programs/radioisotope-power-systems/about-rps/

thermoelectric generators (RTGs).[14] RHUs are small devices in spacecraft that maintain the operational temperatures of electronic instruments in extreme temperatures.[15] RTGs are nuclear batteries used to power satellites and uncrewed space probes.[16]

In the United States, plutonium-238 was used in both RHUs and RTGs. Chain reactions do not occur in these devices; instead, heat is generated by spontaneous radioactive decay. The energy produced cannot be modified or stored, though the short half-life of plutonium-238 allows it to "degrade naturally in a manageable manner over the length of a typical space mission, producing a small gradual decline in power output that can be accurately predicted and managed."[17] RHUs and RTGs have no moving parts, require no maintenance, and can withstand harsh environments for decades.

These different nuclear power sources have achieved different levels of adoption. Nuclear thermal and electric rockets were tested by the United States and Soviet Union as early as the 1950s but none has ever flown.[18] This might soon change due to new NTP and NEP research and development (see following section). As for RHUs and RTGs, they have always been part of deep space travel. The first RTGs went into space in 1961 on US satellites Transit 4A and 4B.[19]

The United States also experimented in 1965 with an automated fission reactor using HEU in the SNAP-10A satellite.[20] The reactor ceased operation 43 days after reaching orbit due to an electrical component failure. This was the first and only time that the United States has used a fission reactor in a spacecraft.

From 1968 to 1978, the United States developed SNAP-19 RTGs and deployed them on a series of meteorological satellites, laying the foundation for NASA missions beyond Earth orbit.[21] Every Apollo lunar mission utilized a nuclear power source. For Apollo 11, RTGs powered the package of scientific instruments that Neil Armstrong and Buzz Aldrin left on the Moon.[22]

---

[14] Amanda Barnett (editor), "RPS Technology: Overview," NASA, updated April 2025, https://science.nasa.gov/planetary-science/programs/radioisotope-power-systems/overview/#overview
[15] Amanda Barnett (editor), "Heat: Radioisotope Heater Units (RHUs)," NASA, updated April 2025, https://science.nasa.gov/planetary-science/programs/radioisotope-power-systems/thermal-radioisotope-heater-units/
[16] Phil Davis (editor), "Power Generators: Radioisotope Power," NASA, updated April 2025, https://science.nasa.gov/planetary-science/programs/radioisotope-power-systems/power-radioisotope-thermoelectric-generators/#h-previous-generations-of-rtgs
[17] Phil Davis (editor), "FAQ-Radioisotope Power Systems," NASA, updated April 2025, https://science.nasa.gov/planetary-science/programs/radioisotope-power-systems/faq/
[18] Richard Stone. "One nuclear leap to Mars?" Science, Vol 301, Issue 5635, August 2003, p. 906-909, https://www.science.org/doi/10.1126/science.301.5635.906
[19] George R. Schmidt, Thomas J. Sutliff, and Leonard Duddzinski. 2009. "Radioisotope Power: A Key Technology for Deep Space Explorations." Presented at the 60th International Astronautical Congress, October 2012, p. 5, https://ntrs.nasa.gov/citations/20120016365
[20] Yukari Sekiguchi. "Preventing Nuclear Risks in Outer Space," Center for Strategic and International Studies, July 2020, https://nuclearnetwork.csis.org/preventing-nuclear-risks-in-outer-space/
[21] Robert L. Cataldo and Gary L. Bennett. "U.S. Space Radioisotope Power Systems and Applications: Past, Present and Future," NASA, published January 2011, https://ntrs.nasa.gov/api/citations/20120000731/downloads/20120000731.pdf
[22] John Uri. "50 Years Ago: First Apollo Lunar Surface Experiment Package Accepted," NASA, originally published 2018, updated August 2024, https://www.nasa.gov/history/50-years-ago-first-apollo-lunar-surface-experiment-package-accepted/

RTG technology further accelerated after 1976 when Multi-Hundred Watt RTGs (MHW-RTGs) were developed.[23] These were designed for multi-mission operations and produced higher electrical and heat outputs. RTGs were deployed in interplanetary NASA missions from 1972 onward. Some of the missions used General-Purpose Heat Source RTGs (GPHS-RTGs), which produced almost twice the energy output as MHW-RTGs. Multi-Mission RTGs (MMRTGs), which use less plutonium-238, have been used in more recent missions due to a plutonium shortage in the United States.[24]

In 1965, the Soviet Union launched two RTG-powered communication/navigation satellites, Cosmos 84 and 90. Polonium-210, which has a much shorter half-life than plutonium-238 (138 days versus 87.7 years), was used as the heat source. Polonium RTGs were later used in 1969 in some Soviet lunar missions.[25] While the United States mostly adopted nuclear power sources in civil space missions beyond Earth orbit, the Soviets also used them in military spacecraft in low Earth orbit.[26] Between 1967 to 1988, the Soviet Union launched 35 Radar Ocean Reconnaissance Satellites (RORSAT) powered by fission reactors[27]—because the deployment altitude was too low for solar panels, due to atmospheric drag. In 1987, the Soviet Union launched ocean surveillance satellites Cosmos 1818 and 1867, equipped with experimental thermal reactors dubbed TOPAZ that used HEU with no moving parts.[28]

Recent developments

In the past decade, several kinds of new space actors have emerged: states that previously did not have a space program; and non-state actors, including private companies with their own launch capabilities. Space is increasingly viewed as "contested, congested and competitive".[29] And from 2022 onward, the war in Ukraine has demonstrated the military potential of commercial satellite systems such as SpaceX's Starlink,[30] and therefore the dual-use character of many space systems.

1. *A nuclear weapon in space?*

The 1967 Outer Space Treaty prohibits the deployment of nuclear weapons in space, and this rule has been consistently respected since then. However, from early 2024 through 2025, there was

[23] Robert L. Cataldo and Gary L. Bennett. "U.S. Space Radioisotope Power Systems and Applications: Past, Present and Future," NASA, published January 2011, https://ntrs.nasa.gov/api/citations/20120000731/downloads/20120000731.pdf
[24] Jeff Foust. "Plutonium availability constrains plans for future planetary missions," SpaceNews, 4 May 2023, https://spacenews.com/plutonium-availability-constrains-plans-for-future-planetary-missions/
[25] Asif Siddiqi. "Beyond Earth: a Chronicle of Deep Space Exploration, 1958–2016," National Aeronautics & Space Administration, Vol. 4041, 2018, https://www.nasa.gov/wp-content/uploads/2018/09/beyond-earth-tagged.pdf?emrc=967232
[26] Gary L. Bennett. "A Look at the Soviet Space Nuclear Power Program." In Proceedings of the 24th Intersociety Energy Conversion Engineering Conference, pp. 1187-1194. IEEE, 1989, p. 1187.
[27] Ibid., p. 1890.
[28] Ibid., p.1188.
[29] NATO Space Operations Centre. "NATO's approach to space," NATO, updated July 2025, https://www.nato.int/en/what-we-do/deterrence-and-defence/natos-approach-to-space
[30] Adam Sataraino et. al. "Elon Musk's Unmatched Power in the Stars," New York Times, July 2023, https://www.nytimes.com/interactive/2023/07/28/business/starlink.html?smid=nytcore-ios-share

considerable speculation about the possible placement of a nuclear weapon in orbit by Russia. The actual placement of a weapon seems unlikely, however, and Russia might simply have a technological development project with no plans for actual use. Russia could also be seeking to create uncertainty about its intentions and actions, as a way of destabilizing NATO states.

In February 2024, a public statement by US House intelligence committee chair Rep. Mike Turner regarding a "serious national security threat"[31] was followed by reports that Russia was developing a nuclear anti-satellite (ASAT) weapon.[32] Later reports specified this would involve placing a nuclear explosive device into orbit (rather than, for example, a nuclear-powered spacecraft or jamming device).[33]

Additional details were revealed by Mallory Stewart, Assistant Secretary of State for Arms Control, Deterrence, and Stability, on May 3, 2024. Stewart stated:

> The United States is extremely concerned that Russia may be considering the incorporation of nuclear weapons into its counterspace programs, based on information we deem credible. The United States has been aware of Russia's pursuit of this sort of capability dating back years, but only recently have we been able to make a more precise assessment of their progress. […] This is not an active capability that has already been deployed […] there is no imminent threat. We aren't talking about a weapon that could be used to attack humans or cause structural damage on Earth. Instead […] our analysts assess that detonation in a particular placement in orbit of a magnitude and location would render lower Earth orbit unusable for a certain amount of time.[34]

At the same time, there was widespread speculation concerning Cosmos 2553,[35] which was launched on February 5, 2022 into a circular orbit around the Earth with an altitude of 2000 km and an inclination of 67.1 degrees. The Russian Ministry of Defense described the satellite as a "[t]echnological spacecraft […] equipped with newly developed onboard instruments and systems for testing them under the influence of radiation and heavy charged particles."[36] Satellite-tracker Bart Hendrickx explained that this was likely a cover story, and that there were compelling reasons

---

[31] Anthony Adragna and Olivia Alafriz. "House Intelligence chair issues warning on 'serious national security threat'," Politico, 14 February 2024, https://www.politico.com/live-updates/2024/02/14/congress/turners-cryptic-warning-house-intelligence- 00141423

[32] Reuters, "US believes Russia developing space-based nuclear weapons, says source," 20 February 2024, https://www.reuters.com/world/us-believes-russia-developing-space-based-nuclear-weapon-says-source-2024-02-20/

[33] Unshin Lee Harpley, "DOD Official Confirms Russia is Developing an 'Indiscriminate' Space Nuke," Air and Space Forces Magazine, 2 May 2024, https://www.airandspaceforces.com/dod-official-russia-indiscriminate-space-nuke/

[34] Aerospace Security Project. "The Nuclear Option: Deciphering Russia's New Space Threat," Center for Strategic and International Studies, May 2024, https://www.csis.org/events/nuclear-option-deciphering-russias-new-space-threat.

[35] Warren P. Strobel, Dustin Volz, Michael R. Gordon and Micah Maidenberg. "Russia Launched Research Spacecraft for Antisatellite Nuclear Weapon Two Years Ago, U.S. Officials Say," Wall Street Journal, 16 May 2024, https://www.wsj.com/politics/national-security/russia-space-nuke-launched-ukraine-invasion-c4aad62e.

[36] "Cosmos-2553 - the first Neitron radar satellite", Russia Strategic Nuclear Forces, 5 February 2022, https://russianforces.org/blog/2022/02/cosmos-2553_-_the_first_neitro.shtml

for it to be a military radar reconnaissance satellite, given that the manufacturer had only built other radar imaging satellites since 2000 and Cosmos 2553 repeated its ground track with an accuracy of about one kilometer every four days—an ideal path for interferometric synthetic aperture radar imaging, i.e. using radar imaging to map surface deformation on Earth.[37] Hendrickx further noted that "it is not impossible that the satellite is performing radiation studies as a secondary mission," but "there are no obvious signs from publicly available source material that the mission of Cosmos-2553 has any direct connection with the suspected nuclear weapon."[38] The story of Cosmos 2553 likely ends there: In April 2025, observations revealed that the light-curve showed variation consistent with tumbling, suggesting that the satellite, whatever its nature, had lost attitude control and become space debris.[39]

Nevertheless, these developments have raised some old questions about the possible advantages of placing a nuclear weapon in space. One can consider the potential "use cases" of a nuclear weapon in orbit from two perspectives: a space-to-ground attack and a space-to-space attack.

A space-to-ground attack could employ a surface or near-surface detonation to create an EMP to disrupt and damage communications and electronics. Such an attack could have substantial consequences for ground-based infrastructure.[40] In a space-to-space attack, the radiation generated from a nuclear explosion could immediately damage nearby objects through high-energy photons and particles. It could also damage objects, including on Earth's surface, by driving strong internal electrical currents.[41] The detonation could also cause protracted changes to Earth's plasma environment, greatly degrading the operational environment for satellites in low Earth orbit for months to years. Even small yields in the tens of kiloton range could cause substantial damage—for adversaries and allies alike.

The indiscriminate nature of the potential damage was recognized by the Commander of 3 Canadian Space Division on February 14, 2026. Brigadier General Christopher Horner told the Canadian Broadcasting Corporation that Canada "should absolutely be" concerned about Russia potential deploying a nuclear weapon in orbit.[42] "That would be cataclysmic," he said.

[37] Bart Hendrickx. "Russia research on space nukes and alternative counterspace weapons (part 1)", The Space Review, 13 May 2024, https://www.thespacereview.com/article/4793/1.
[38] Ibid.
[39] Joey Roulette. "Russian satellite at centre of nuclear weapons allegations is spinning out of control, analysts say," Reuters, April 2025. https://www.reuters.com/business/media-telecom/russian-satellite-linked-nuclear-weapon-program-appears-out-control-us-analysts-2025-04-25/
[40] Don Snyder, et al. *The Effects of High-Altitude Nuclear Explosions on Non-Military Satellites*. RAND, 2025, https://www.deepspace.ucsb.edu/wp-content/uploads/2025/04/The-Effects-of-High-Altitude-Nuclear-Explosions-on-Non-Military-Satellites-RAND_RRA3028-2025.pdf
[41] Ibid.
[42] Benjamin Lopez Steven and Emma Godmere. "Head of military's space division warns Russia is considering putting nuclear weapons in orbit," CBC News, February 14, 2026, https://www.cbc.ca/news/politics/russia-space-nuclear-weapon-canada-military-division-chief-9.7088665

"Everything that we have come to rely on from a communications platform level or from a GPS level — if [Russia] were to deploy a capability like that and then detonate it — would be wiped out."

In this context, we have to ask: What purposes might arguably be served by stationing a nuclear weapon in space? What are the weaknesses in these arguments? Could these purposes be achieved through other means, for instance, cyberattacks or kinetic weapons such as pellet rings[43] that can target entire satellite systems at once?

Advantages: Stationing a nuclear weapon in space diversifies operational domains, such as land, ocean, air, and space. The attack can also occur without an immediate launch, and in this way, there is the possibility of gaining a timing advantage.

Disadvantages: The act of placing a nuclear weapon in space is inherently escalatory. The weapon, moreover, will be unreliable because of its exposure to the space environment, including space weather, debris and meteoroids. The timing advantage is also not guaranteed, as the orbital path may greatly restrict the timing of the weapon's use. Finally, a nuclear weapon in space would be vulnerable to attacks from both ground-based missiles and space-based weapons.

On balance, it is difficult to see any net advantage to placing a nuclear weapon in orbit, compared with using existing and expanding capabilities on land, at sea, and in the air.

Again, it is possible that reports about a Russian space-based nuclear weapon were disinformation intended to confuse and agitate NATO states. A perceived nuclear threat in space could force these states to invest more in their own capabilities, including the survivability of their satellite systems as well as the ability to reconstitute them. It is also possible that Russia intended to send a signal, not about space as such, but about its general willingness to use nuclear weapons—for instance, in Ukraine.

The United States and its NATO allies should avoid being pulled into a classic "security dilemma," where misinformation leads to misunderstandings and potentially misplaced and escalatory actions. An understanding of the multiple disadvantages to placing a nuclear weapon in space leads to only one rational conclusion, namely, that no such step should be taken.

2. *Direct ascent nuclear weapons*

[43] Michael Byers and Aaron Boley. *Who Owns Outer Space? International law, astrophysics, and the sustainable development of space*. Cambridge University Press, April 2023, pp. 370-371.

In 2022, a Chinese study reportedly examined whether satellite constellations could be disrupted with ground-based nuclear missiles.[44] Many of disadvantages identified above would apply to any such action, including the escalation risk and near-certain loss of safe access to low Earth orbit for everyone.

3. *The dual-use character of nuclear propulsion systems*

The resurgence of interest in nuclear-powered spacecraft is widespread. The European Space Agency (ESA) is funding nuclear electric propulsion (NEP) engine designs and feasibility studies to determine the advantages of NEP over solar and chemical propulsion.[45] ESA has also funded a study of a possible European nuclear thermal propulsion (NTP) capability for Moon and Mars travel.[46] China has tested a compact lithium-cooled nuclear reactor prototype that can supply continuous power for at least 10 years and could potentially be used for NEP engines.[47] The US Air Force Research Lab (ARFL) is also exploring nuclear fission reactors and "high power" technologies including power conversion, radiation shielding/electronic hardening, and hybrid propulsion systems in its Joint Emergent Technology Supplying On-orbit Nuclear Power (JETSON) project.[48] According to Breaking Defense, AFRL and the Defense Advanced Research Projects Agency (DARPA) are both exploring fission reactors "to generate on-board electricity for spacecraft operating systems".[49] Meanwhile, the US military's Defense Innovation Unit is studying how "highly maneuverable, small spacecraft using fusion and radioisotopes" can "maneuver at-will in cislunar space and enable high-power payloads that will support the expansion of DoD space missions."[50] And in April 2026, NASA Administrator Jared Isaacman announced that a spacecraft called Space Reactor 1 Freedom would be launched to Mars in 2028 to demonstrate advanced nuclear electric propulsion in deep space.[51]

---

[44] Stephen Chen, "Chinese physicists simulate nuclear blast against satellites," South China Morning Post, 20 October 2022, https://www.scmp.com/news/china/science/article/3196629/chinese-physicists-simulate-nuclear-blast-against-satellites

[45] Robert Lea, "Europe Wants to Build a Nuclear Rocket for Deep Space Exploration," Space.com, 3 May 2023, https://www.space.com/european-space-agency-nuclear-propulsion

[46] European Space Agency, "Nuclear rocket engine for Moon and Mars," 2 June 2025, https://www.esa.int/Enabling_Support/Space_Transportation/Future_space_transportation/Nuclear_rocket_engine_for_Moon_and_Mars

[47] Christopher McFadden, "China Tests Nuclear-Powered 'shrinkable' Engine for Mars Spaceship," Interesting Engineering, 20 March 2024, https://interestingengineering.com/innovation/china-nuclear-powered-engine-mars

[48] Theresa Hitchens. "AFRL Picks 3 Contractors for Jetson Effort to Develop Fission Powered Spacecraft," Breaking Defense, October 2, 2023. https://breakingdefense.com/2023/10/afrl-picks-3-contractors-for-jetson-effort-to-develop-fission-powered-spacecraft/

[49] Ibid.

[50] Defense Innovation Unit, "Powering the Future of Space Exploration: DIU Launching Next-Generation Nuclear Propulsion and Power," 17 May 2022, https://www.diu.mil/latest/powering-the-future-of-space-exploration-diu-launching-next-generation

[51] Joey Roulette, "NASA plans moon base, nuclear spacecraft in multibillion-dollar moon program expansion," Reuters, 24 March 2026, https://www.reuters.com/science/nasa-cancel-orbiting-lunar-station-build-moon-base-instead-2026-03-24/

Nuclear propulsion in space seems almost inevitable. In 2023, the Aerospace Corporation reported that "advances in electric and chemical propulsion are expected to move at a slower rate than nuclear propulsion".[52] However, caution is required, because these technologies will be inherently dual use. NTP and NEP could greatly improve the maneuverability and survivability of civilian spacecraft, allowing them to conduct deep space scientific research using less propellant while being able to steer clear of space debris. They could also facilitate on-orbit servicing, refueling, and space debris removal.[53] Yet the same technologies could power military counterspace capabilities such as co-orbital anti-satellite attacks, radiofrequency jammers, and blinding lasers. Indeed, many US defense stakeholders advocating for nuclear propulsion portray their dual use character as an advantage.[54]

As for nuclear fission reactors, China and India have both used RTGs in recent lunar missions. China's lunar surface lander Chang'e 3 and the Yutu rover launched in 2013 used plutonium dioxide-238 RTGs for thermal energy generation.[55] In 2018, Chang'e 4 and Yutu-2 were both equipped with RHUs and RTGs co-developed by China and Russia.[56] India's Chandrayaan-3, launched in 2023, was equipped with two RHUs. These RHUs used the radioactive source americium-241, because of the global plutonium-238 shortage.[57]

Similar dual use challenges are present in the nuclear fuels used in space. A prominent example is HALEU, which refers to uranium enriched to 10-20% 235U. This type of fuel is the most likely to be used in large quantities in proposed nuclear reactors in space, because of its high energy-output to mass ratio. Until May 2025, NASA and DARPA were collaborating on the development of the Demonstration Rocket for Agile Cislunar Operations (DRACO) that was intended to demonstrate a NTP system.[58] Although DRACO was terminated as part of the Trump Administration's public service cuts, newer initiatives are pursuing the same goal—with a Senate bill directing NASA to spend a minimum of $110 million on nuclear propulsion and a further $10 million on a "center of excellence" for nuclear propulsion research where "a large population of industry partners who are

[52] Laura Speckman. "Emerging In-Space Propulsion Technologies: Commercial Technologies and New Programs 2023 Q1 Update," Aerospace Corporation, January 2023, p.3, https://aerospace.org/sites/default/files/2023-01/FY23_12003_CTO_Revise_SOP_Emerging_InSpace_wht_ppr_r7.pdf

[53] Shaw, John E., Daniel R. Bourque, and Marcus Shaw, "Dynamic Space Operations: The New Sustained Space Maneuver Imperative," Æther: A Journal of Strategic Airpower & Spacepower 2 (2023): 8-16, https://www.airuniversity.af.edu/Portals/10/AEtherJournal/Journals/Special-Edition_Winter2023/Shaw.pdf

[54] Christopher Stone, "Powering Maneuvers in Space," Air & Space Forces Magazine, 17 February 2022, https://www.airandspaceforces.com/article/powering-maneuvers-in-space/

[55] "Chang'e-3 Moon-landing Mission," eoPortal, updated December 2013, https://www.eoportal.org/satellite-missions/chang-e-3#spacecraft

[56] Anwen Zhu, Yuhua Tang, and Hui Du. "Application of Space Nuclear Power Sources in Moon and Deep Space Exploration Missions in China," IAEA Webinar Atoms for Space, 15-16 February 2022, https://nucleus.iaea.org/sites/fusionportal/Atoms%20for%20Space/03_Beijing%20Institute%20of%20Spacecraft%20System%20Engineering.pdf

[57] Srinivas Laxman, "Nuclear Energy Keeps Chandrayaan-3 Propulsion Module Going," Times of India, 31 October 2023, https://timesofindia.indiatimes.com/science/nuclear-energy-keeps-chandrayaan-3-propulsion-module-going/articlesh ow/104834737.cms; Ajay Singh, Mohit Tyagi, D. Banerjee, G. Sugilal, and C.P. Kaushik. "Nuclear Batteries: Harnessing Energy of Radioactive Materials for Long Lasting Low Power Applications," Bhabha Atomic Research Centre, n.d., https://barc.gov.in/ebooks/9788195473328/paper16.pdf

[58] Theresa Hitchens, "DARPA's DRACO nuclear propulsion project ROARs no more," Breaking Defense, 27 June 2025, https://breakingdefense.com/2025/06/darpas-draco-nuclear-propulsion-project-roars-no-more/

also invested in nuclear propulsion research" are located.[59] The interest in HALEU for NTP is also manifest in ESA's study, mentioned above.[60] Separately, the United States,[61] Russia and China[62] have all announced plans to build nuclear reactors on the Moon, and many proposed designs include large quantities of HALEU as a fuel. In fact, NASA, in commissioning studies for fission surface power systems, requires the use of HALEU to address non-proliferation concerns.[63]

However, recent research has highlighted the weapons potential of HALEU, especially in the large quantities needed for new reactor designs.[64] In the past, HALEU was used in commercial reactors in such small quantities that it would have been impractical to use that material to make a nuclear weapon. For this reason, strict security measures were only applied to uranium enriched above a 20% level (highly enriched uranium, or HEU), and the US Atomic Energy Commission allowed exports of up to 20% uranium-235, as part of its Atoms for Peace program, provided that the quantities were below the threshold of weapons significance.[65] However, modern designs for small modular reactors and microreactors use hundreds to thousands of kilograms of 19.75% uranium-235 HALEU. The fuel for just one of these reactors could produce an explosive yield similar to or greater than the nuclear bomb dropped on Hiroshima. In 2024, Kemp et al. called for a re-evaluation of HALEU proliferation and security risks, with the goal of setting a new technically justified lower enrichment limit for weapons-usable uranium.[66] They suggested that HALEU enriched above a 10-12% level should be subject to the same security requirements as HEU.

Despite nuclear applications in space often being seen as technical solutions for sustained space exploration and development, the fuels being used could have significant impacts on the nuclear non-proliferation regime. Meanwhile, nuclear powered space applications, while not seen as nuclear weapons in the traditional sense, could enable offensive military activities such as power jamming, co-orbital maneuvering, or directed energy attacks.

4. *Safety risks of nuclear-powered satellites*

[59] Jeff Foust, "Making a new case for space nuclear power," The Space Review, July 2025, https://thespacereview.com/article/5028/1
[60] ArianeGroup, CEA, and Framatome Space, "ALUMNI Project: Executive Summary," Institut des Sciences Appliquées et de la Simulation pour les Energies bas carbone (ISAS), August 2024, https://esamultimedia.esa.int/docs/STS/Executive_Summary/ALUMNI_Executive_summary_v05_pub.pdf
[61] Ellen Bausback, "NASA's Fission Surface Power Project Energizes Lunar Exploration," NASA, 31 January 2024, https://www.nasa.gov/centers-and-facilities/glenn/nasas-fission-surface-power-project-energizes-lunar-exploration/; Sam Skove. "Duffy to announce nuclear reactor on the moon," Politico, August 2025, https://www.politico.com/news/2025/08/04/nasa-china-space-station-duffy-directives-00492172
[62] Reuters, "Russia says it is considering putting a nuclear power plant on the moon with China," 5 March 2024, https://www.reuters.com/technology/space/russia-china-are-considering-putting-nuclear-power-unit-moon-ria-2024-03-05/
[63] Jeff Foust, "NASA plans for lunar fission power systems face fiscal challenges," SpaceNews, 20 July 2023, https://spacenews.com/nasa-plans-for-lunar-fission-power-systems-face-fiscal-challenges/
[64] R. Scott Kemp et al., "The weapons potential of high-assay low-enriched uranium," Science 384, No. 6700, June 2024, pp. 1071-107, https://www.science.org/doi/10.1126/science.ado8693
[65] US AEC, "Research Reactors for Foreign Application: Report to the General Manager by the Director of Reactor Development," (1954), https://fissilematerials.org/library/haf54.pdf
[66] R. Scott Kemp et al., "The weapons potential of high-assay low-enriched uranium," Science 384, No. 6700, June 2024, pp. 1071-107, https://www.science.org/doi/10.1126/science.ado8693

Nuclear-powered satellites can pose a safety risk on Earth, as demonstrated by the atmospheric re-entry of Cosmos 954, a reconnaissance satellite launched by the Soviet Union in September 1977 that was heated by a uranium-235 fast fission nuclear reactor containing around 50 kg of highly enriched uranium.[67] Launched into low Earth orbit at an altitude of approximately 270 km, the satellite soon began making erratic maneuvers that culminated in an uncontrolled re-entry on January 24, 1978.[68] The re-entry followed a northeastward track over the Canada's Northwest Territories, spreading debris along a 600 km path.[69] A joint Canada-US clean-up effort resulted in the recovery of twelve large debris fragments, ten of which were radioactive, including several at lethal levels.[70] Canada submitted a claim to the Soviet Union under the 1972 Liability Convention, whereupon the Soviet Union made a CAD $3 million contribution to the clean-up costs.[71]

Cosmos 954 is not the only nuclear-powered satellite to have malfunctioned. In 1973, a failed launch of a similar Soviet satellite resulted in nuclear fuel entering the Pacific Ocean north of Japan.[72] Later, after Cosmos 954, the Soviet Union included an ejection mechanism in their fission reactor satellites, whereby the reactor would be propelled into a high-altitude disposal orbit (around 1000 km) in the event of a malfunction or at the end of the satellite's operational life.[73] Given the long timescale for orbital decay at such high altitudes, the fuel would undergo sufficient radioactive decay before re-entry. However, in 1983 the ejection mechanism on Cosmos 1402 failed. This caused both the satellite and its reactor to undergo uncontrolled re-entries in January[74] and February 1983, respectively. The reactor re-entry occurred over the South Atlantic Ocean, 1600 km east of Brazil.[75] At least a portion of the reactor must have ablated, as radioactive strontium was detected in rain samples in Arkansas shortly after the event,[76] and 44 kg of excess 235U was detected in the stratosphere more than one year after the incident.[77]

Following the Cosmos 1402 re-entry, Soviet satellites were equipped with a backup core ejection mechanism. However, even this mechanism failed on Cosmos 1900, which was launched in 1987

[67] David M. Harland, Ralph D. Lorenz, *Space Systems Failures – Disasters and rescues of satellites, rockets, and space probes*, 2005, Berlin, Heidelberg, New York: Praxis Publishing (Springer).
[68] Leo Heaps, *Operation Morning Light: Terror in our Skies: The True Story of Cosmos 954*, 1978, New York: Paddington Press Ltd.
[69] Ibid.
[70] Settlement of Claim between Canada and the Union of Soviet Socialist Republics for Damage Caused by "Cosmos 954" (Released on April 2, 1981), https://www.jaxa.jp/library/space_law/chapter_3/3-2-2-1_e.html
[71] Ibid.
[72] William J. Broad, "Satellite Fuel Core Falls 'Harmlessly'," New York Times, 8 February 1983, https://www.nytimes.com/1983/02/08/science/satellite-s-fuel-core-falls-harmlessly.html
[73] Gary L. Bennett, "A Look at the Soviet Space Nuclear Power Program," The 24th lntersociety Energy Conversion Engineering Conference "International Forum on Energy Engineering," 6-11 August 1989, https://nuke.fas.org/space/sovspace.pdf
[74] Anthony Tucker and Nick Davies, "Russian spy satellite tumbles to Earth," The Guardian, 24 January 2013, https://www.theguardian.com/theguardian/2013/jan/24/satellite-cosmos-1402-russia-space
[75] William J. Broad, "Satellite Fuel Core Falls 'Harmlessly'," New York Times, 8 February 1983, https://www.nytimes.com/1983/02/08/science/satellite-s-fuel-core-falls-harmlessly.html
[76] R. K. Guimon et al. "Radioactive strontium fallout from the nuclear-powered satellite Cosmos-1402," Geochemical Journal, Vol. 19, No. 4, 1985, p. 229-235, https://geochemical-journal.jp/papers/view/533
[77] Robert Leifer et al. "Detection of Uranium from Cosmos-1402 in the Stratosphere," Science, 238(4826), 1987, p. 512-514, https://doi.org/10.1126/science.238.4826.512

to an altitude of about 275 km.[78] The failed ejection mechanism left the reactor at an altitude of about 716 km, lower than the planned 1000 km, making a re-entry within the next century likely.[79]

While most nuclear reactors in LEO have been relocated to orbits above 900 km,[80] even this approach does not eliminate every risk. As the amount of space debris increases, so too does the probability of a collision in a "nuclear safe" orbit. And the radioactive debris produced by a collision could pose a threat to the Earth, if the impact was sufficiently energetic to put some fragments on highly elliptical orbits with low perigees. The atmospheric drag experienced at these low perigees could then cause the radioactive debris to re-enter the atmosphere on a shorter timescale than that for a circular orbit at the "nuclear safe" altitude.

In addition to potential collisions with debris, nuclear-powered spacecraft have historically contributed to the debris population through the release of sodium-potassium (NaK) droplets, which, after spacecraft fragmentation debris, are the second largest contribution to the space debris population at altitudes of approximately 900 km.[81] These NaK droplets are electrically conducting spheres, from a few millimeters to a few centimeters in size, located mostly between the altitudes of 850 km to 1000 km.[82] Many of these droplets appear to have been released from coolant loops during the ejection of the reactor core of RORSAT satellites to high-altitude orbits.[83] Two leakages from TOPAZ reactors have also made minor contributions to the debris population.[84] Recent research has shown that there is an ongoing release of NaK droplets between 900 km and 1000 km, as NaK particles have been detected at altitudes that now should have been cleared of NaK droplets from 1980s and 1990s ejection mechanism releases.[85] NaK droplets pose a severe risk to other spacecraft, as they are highly corrosive and ignitable, and can result in an explosion upon any reaction with air or water, which might be emitted by other spacecraft.[86] Collisions with NaK can make up a large fraction (13-16%) of collisions between small debris particles and large satellites.[87] Such collisions could lead to fragmentation of the satellite, adding to the debris population.

---

[78] NASA Space Science Data Coordinated Archive: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/displayTrajectory.action?id=1987-101A

[79] "Spacecraft information: COSMOS 1900," In-The-Sky.org, updated May 2026, https://in-the-sky.org/spacecraft.php?id=18665

[80] Robert Frisbee, Stephanie Leifer and Shishir Shah, "Nuclear safe orbit basing considerations," Conference on Advanced SEI Technologies, 4-6 September 1991, https://doi.org/10.2514/6.1991-3411

[81] Carsten Wiedemann et al., "The Contribution of NaK Droplets to the Space Debris Environment," Proc. 7th European Conference on Space Debris, Darmstadt, Germany, 18–21 April 2017, published by the ESA Space Debris Office, https://conference.sdo.esoc.esa.int/proceedings/sdc7/paper/367/SDC7-paper367.pdf

[82] Mark Matney et al. "The NaK Population: A 2019 Status," Proceedings of the International Orbital Debris Conference, Sugar Land, TX, 9-12 December 2019, https://ntrs.nasa.gov/citations/20190033494

[83] Carsten Wiedemann et al., "The Contribution of NaK Droplets to the Space Debris Environment," Proc. 7th European Conference on Space Debris, Darmstadt, Germany, 18–21 April 2017, published by the ESA Space Debris Office, https://conference.sdo.esoc.esa.int/proceedings/sdc7/paper/367/SDC7-paper367.pdf

[84] Ibid.

[85] Mark Matney et al. "The NaK Population: A 2019 Status," Proceedings of the International Orbital Debris Conference, Sugar Land, TX, 9-12 December 2019, https://ntrs.nasa.gov/citations/20190033494

[86] Zarook Shareefdeen and Hadeel Al-Najjar, "Pollution Effects and Management of Orbital Space Debris," *ACS Omega*, 9(5): 5127–5141, 2024, https://doi.org/10.1021%2Facsomega.3c06887

[87] Paula H. Krisko, "The predicted growth of the low Earth orbit space debris environment - an assessment of future risk for spacecraft," NASA, January 2007, https://ntrs.nasa.gov/citations/20070024897

Due to these kinds of risks, countries have in recent decades refrained from launching nuclear-powered satellites to low Earth orbit. As for the nuclear propulsion systems being designed today, they will not be activated during launch, meaning that the propulsion system will only be turned on after the vehicle has left Earth's atmosphere.[88] This is intended to minimize the risk of releasing radioactive materials in the event of a launch failure.

5. *Uncertainties of lunar nuclear systems*

The United States, China, and Russia are leading efforts to establish a sustained human presence on the Moon, which is seen as a potential source of resources as well as a test site and perhaps even a gateway for future crewed missions to Mars and beyond. Lunar resources of interest include water-ice and Helium-3—a helium isotope found in lunar regolith that is believed to be able to fuel fusion reactors without producing radioactive waste.[89] Commercial actors are now seeking to capitalize on the new "lunar economy", which at the moment is composed mostly of government grants and contracts to develop technologies such as reusable lunar landers.[90]

Military actors and analysts in both the United States and China increasingly emphasize the importance of cislunar space for protecting national security and commercial interests. Nuclear applications are seen as crucial for effective cislunar operations. A widely-read report by Charles Galbreath from the Mitchell Institute for Aerospace Studies highlights nuclear propulsion as a likely "critical enabler to empower future USSF [US Space Force] cislunar operations".[91] The US Government agrees. In 2022, the NASA-DOE Fission Surface Power Project was created to build and launch a 40-kilowatt lunar surface nuclear power plant by 2032.[92] In 2025, the second Trump Administration expanded and accelerated the plan, aiming for at least 100 kilowatts and a launch date of 2030.[93]

Separately, China and Russia are collaborating on an International Lunar Research Station (ILRS) for "multi-discipline and multi-purpose scientific research activities, including exploration and use of the Moon, moon-based observation, fundamental research experiments and technology verification, with the capability of long-term unmanned operations with the prospect of subsequent

---

[88] Susan D'Agostino. "Is using nuclear materials for space travel dangerous, genius, or a little of both?" Bulletin of Atomic Scientists, 28 July 2021, https://thebulletin.org/2021/07/is-using-nuclear-materials-for-space-travel-dangerous-genius-or-a-little-of-both/

[89] European Space Agency, "Helium-3 Mining on the Lunar Surface," n.d., https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Space_for_Earth/Energy/Helium-3_mining_on_the_lunar_surface

[90] Luigi Scatteia and Yann Perrot. "Lunar Market Assessment: Market Trends and Challenges in the Development of a Lunar Economy," PWC, September 2021, https://www.pwc.com.au/industry/space-industry/lunar-market-assessment-2021.pdf, p.33; Berger, Eric. "A Startup Will Try to Mine Helium-3 on the Moon," Wired, March 2024, https://www.wired.com/story/interlune-helium-3-moon-mining/

[91] Charles S. Galbreath, "Securing Cislunar Space and the First Island Off the Coast of Earth," Mitchell Institute for Aerospace Studies, 17 January 2024, https://mitchellaerospacepower.org/securing-cislunar-space-and-the-first-island-off-the-coast-of-earth/

[92] Andrew Jones. "Nuclear Power on the Moon: NASA Wraps up 1st Phase of Ambitious Reactor Project," Space.com, February 2, 2024, https://www.space.com/nasa-moon-nuclear-reactor-project-first-phase-complete.

[93] Georgina Rannard. "NASA to put Nuclear Reactor on the Moon by 2030 - US Media," BBC, August 2025, https://www.bbc.com/news/articles/cev2dylxv74o

human presence."[94] Some Western experts criticize the opacity of China's lunar objectives and question whether the ILRS will actually be devoted to scientific purposes.[95]

While they would not be on Earth, the possibility of nuclear explosions on the Moon should not be taken lightly. The release of radioactive materials on the Moon could be far-reaching, given the lack of an atmosphere and the potential for long-range ballistic transport. In 1958, both the United States and the Soviet Union had plans to detonate nuclear weapons on the Moon as a show of force. The US plan was canceled, at least in part because of the risk that nuclear fallout might pose to future research projects and crewed missions. A top-secret US study described the risk from nuclear fallout as "an unparalleled scientific disaster, eliminating several possibly very fruitful approaches to such problems as the early history of the solar system, the chemical composition of matter in the remote past, the origin of life on earth, and the possibility of extraterrestrial life. Because of the Moon's unique situation as a large, unweathered body in the middle of the solar system, scientific opportunities lost on the moon may not be recouped elsewhere."[96] As for the Soviet plan, it was canceled due to concerns regarding the safety and reliability of the launch vehicle.[97]

The potential for nuclear accidents on the Moon should also not be dismissed. The extreme temperature variations on the lunar surface (from approximately minus 130°C at night to plus 120°C during the day) complicate the usual challenge of keeping the reactor core consistently cool to prevent a meltdown. Moonquakes and meteoroids might also compromise the safety of any system. While these risks are known, they can be expected to remain a concern.

Existing governance mechanisms

There are a number of treaties and other international instruments relevant to the use of nuclear technologies in space. These rules are currently being tested by geopolitical developments, not just in space but more generally.

1. *Military use*

As mentioned above, the 1963 Partial Test Ban Treaty bans nuclear weapon testing in space while the 1967 Outer Space Treaty (OST) outlaws the deployment of all weapons of mass destruction there.

In 2024, the reports about a Russian nuclear weapon in orbit made the issue a subject of debate in the United Nations Security Council. In April 2024, the United States and Japan introduced a draft

---

[94] "International Lunar Research Station (ILRS) Guide for Partnership." China National Space Administration, June 16, 2021, p.2. https://www.cnsa.gov.cn/english/n6465652/n6465653/c6812150/content.html
[95] Jessy Kate Schingler, Victoria Samson, and Nivedita Raju, "Don't Delay Getting Serious about Cislunar Security," War on the Rocks, July 6, 2022, https://warontherocks.com/2022/07/dont-delay-getting-serious-about-cislunar-security/
[96] Leonard Reiffel. "A Study of Lunar Research Flights Vol I," The National Security Archive of George Washington University, June 19, 1959, p.263, https://nsarchive2.gwu.edu/NSAEBB/NSAEBB479/docs/EBB-Moon02.pdf
[97] Aleksandr Zheleznyakov, "The E-4 project – exploding a nuclear bomb on the Moon," http://www.svengrahn.pp.se/histind/E3/E3orig.htm

resolution affirming the "obligation of all States Parties to fully comply with the OST, including not to place in orbit around the Earth any objects carrying nuclear weapons, or any other kinds of weapons of mass destruction, install such weapons on celestial bodies, or station such weapons in outer space in any other manner."[98] The draft resolution went one step beyond the OST, calling on UN Member States "not to develop nuclear weapons or any other kinds of WMDs specifically designed to be placed in orbit around the Earth."[99]

Russia and China responded by proposing an amendment to the draft resolution, calling upon all states, "and above all those with major space capabilities: (a) to take urgent measures to prevent for all time the placement of weapons in outer space and the threat or use of force in outer space, from space against Earth and from Earth against objects in outer space; (b) to seek through negotiations the early elaboration of appropriated reliably verifiable legally binding multilateral agreements". The proposed amendment took its text from a UN General Assembly resolution on "Further practical measures for the prevention of an arms race in outer space", proposed by Russia and adopted in December 2023.[100] That resolution had been criticized by the United States (speaking also on behalf of France and the United Kingdom) as attempting to "lock [the General Assembly] into the same stagnant debate that has not made progress since 1978", referring to discussions regarding the Prevention of an Arms Race in Outer Space (PAROS[101]).[102] The proposed (April 2024) amendment failed to be adopted following seven votes in favor and seven against.[103]

Russia then vetoed the US and Japanese draft resolution. Thirteen other members of the UN Security Council voted in favour,[104] while China abstained. Russia later asserted that the resolution would have set a dangerous precedent, as it would have been legally binding for all UN member states, including those not parties to the OST.

After exercising its veto, Russia introduced its own draft UN Security Council resolution, co-sponsored by Belarus, China, Nicaragua, North Korea, and Syria. The Russia draft resolution kept the text of the US and Japanese draft resolution but added a paragraph, specifically, the earlier Russian and Chinese draft amendment.[105] On May 20, 2024, the Russian draft resolution also failed

[98] United Nations Security Council Draft Resolution S/2024/302, https://documents.un.org/doc/undoc/gen/n24/113/28/pdf/n2411328.pdf
[99] Ibid.
[100] United Nations General Assembly Resolution A/RES/78/238, "Further practical measures for the prevention of an arms race in outer space," 22 December 2023, https://digitallibrary.un.org/record/4032842?v=pdf&ln=en.
[101] For more information about PAROS, see Paul Meyer, "The CD and PAROS: A Short History," April 2011, https://unidir.org/files/publication/pdfs/the-conference-on-disarmament-and-the-prevention-of-an-arms-race-in-outer-space-370.pdf . For recent developments on PAROS, see the Nuclear Threat Initiative webpage, https://www.nti.org/education-center/treaties-and-regimes/proposed-prevention-arms-race-space-paros-treaty/
[102] 7th session of the United Nations General Assembly First Committee, Explanation of vote, Submitted by the United States on behalf of France, the United Kingdom and the United States, 30 October 2023 https://estatements.unmeetings.org/estatements/11.0010/20231031100000000/M5uNwK8PCzHz/puECMABrADwr_en.pdf
[103] "Security Council Fails to Adopt First-Ever Resolution on Arms Race in Outer Space, Due to Negative Vote by Russian Federation," United Nations Meetings Coverage and Press Releases, 24 April 2024, https://press.un.org/en/2024/sc15678.doc.htm
[104] Ibid.
[105] United Nations Security Council Draft Resolution S/2024/383, 20 May 2024, https://documents.un.org/doc/undoc/gen/n24/140/99/pdf/n2414099.pdf

to pass, with exactly the same votes as the draft amendment (7 in favor, 7 against, 1 abstention),[106] and with the votes of France, the United Kingdom and the United States all serving as vetoes.

Another forum for negotiations on the military use of space is the Open-Ended Working Group (OEWG) on the Prevention of An Arms Race in Outer Space in all its Aspects. The OEWG combines previous efforts in two different UN negotiations spearheaded by two separate groups of states: Western states championing soft law approaches involving norms of responsible behaviour; and Russia and China seeking a treaty that bans space weapons.[107]

2. *Civilian Use*

The regulation of nuclear power sources in space has been widely accepted as a legitimate safety issue and *de facto* assigned to the UN Committee on the Peaceful Uses of Outer Space (COPUOS). Created by the UN General Assembly in 1958, COPUOS is where states collectively pursue the peaceful exploration and use of space.[108] It operates through two subsidiary bodies: the Legal Subcommittee and the Scientific and Technical Subcommittee, with the latter having a Working Group on the Use of Nuclear Power Sources in Outer Space.

In 1992, COPUOS adopted Principles on the Use of Nuclear Power Sources in Outer Space. The negotiations on this topic were prompted by the use of RTGs and nuclear reactors in space by the United States starting in the early 1960s as well as the Cosmos 954 re-entry in 1978.[109] The Principles recommend pre-launch safety assessments and re-entry notifications, and that nuclear power sources be designed, constructed, and operated in ways which limit accidents in space and on Earth. They also recommend that nuclear reactors be operated in low-Earth orbit only if they are then raised to a higher "graveyard" orbit after their operational mission, that only highly enriched uranium-235 be used, and that reactors only be made critical after they reach their operating orbit or interplanetary trajectory. Today, the Principles are valuable but somewhat outdated; for example, they do not address the involvement of companies and other non-state actors in missions with nuclear power sources.[110]

The involvement of non-state actors was addressed in 2009, when COPUOS and the International Atomic Energy Agency jointly published the Safety Framework for Nuclear Power Source

---

[106] "For Second Time Since Late April Security Council Fails to Adopt First-Even Resolution on Preventing Arms Race in Outer Space," United Nations Meetings Coverage and Press Releases, 20 May 2024, https://press.un.org/en/2024/sc15700.doc.htm

[107] United Nations, Open-Ended Working Group (OEWG) on the Prevention of An Arms Race in Outer Space in all its Aspects, https://meetings.unoda.org/open-ended-working-group-on-prevention-of-an-arms-race-in-outer-space-2025

[108] "Committee on the Peaceful Uses of Outer Space," United Nations Office for Outer Space Affairs, https://www.unoosa.org/oosa/en/ourwork/copuos/index.html

[109] Carl Q. Christol. "United Nations: General Assembly Resolution and Principles Relevant to the Use of Nuclear Power Sources in Outer Space," International Legal Materials, vol. 32, n° 3, May 1993, https://csps.aerospace.org/sites/default/files/2021-08/Principles%20on%20Nuclear%20Power%20Sources%20in%20Space.pdf, p.917.

[110] Laetitia Cesari. "Buzzword or Real Threat? How Concerns over Nuclear Capabilities in Outer Space Can Trigger the Extension of Space Security Discussions." Fondation pour la recherche stratégique, March 20, 2024. https://www.frstrategie.org/en/publications/notes/buzzword-or-real-threat-how-concerns-over-nuclear-capabilities-outer-space-can-trigger-extension-space-security-discussions-2024.

Applications in Outer Space, which concerns design, application, launch, operation, and end-of-service planning. The Safety Framework recommends, among other measures, that all space actors assess radiation risks, establish and maintain nuclear safety design, and establish a safety culture. It also recommends that governments ensure the rationale for using nuclear power sources in space is well justified, and that they prepare for emergencies.[111]

Both the 1992 Principles and 2009 Safety Framework are non-binding and neither document addresses all of the issues arising from the development and deployment of nuclear power sources in space. Part of the challenge concerns the fact that neither COPUOS, the International Atomic Energy Agency, nor any other existing forum has a mandate to consider the full range of safety, security and non-proliferation risks.

Pathways for verifying nuclear activities in space

One of the greatest challenges in space is verification. There are no verification mechanisms to prevent a nuclear weapon from being deployed in space or to ensure that nuclear technologies are used for peaceful purposes only.

The possibility of pre-launch inspections of satellites was discussed during the negotiations leading to the 1963 UN General Assembly's Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space, which later formed the basis for the 1967 Outer Space Treaty. At the time, the United States said it would only agree to such inspections in the case of specifically defined disarmament agreements.[112]

In 1988, the Soviet Union offered to open its space program to inspection if other states did the same and agreed to prohibit the deployment of all weapons in space.[113] It called for on-site inspections immediately before every launch and the permanent stationing of international inspector groups at all launch sites. "The principal goal of establishing an international space inspectorate is to take measures to verify that any objects being launched into and orbited in space by states party to the agreement are not weapons and are not provided with any type of weapons," the Soviets said, while specifically excluding ballistic missiles from their proposal.[114] Given its timing, the proposal was likely directed at the Strategic Defense Initiative and for that reason was rejected by the United States.

The idea of pre-launch verifications might usefully be revisited today. One can find some support for the idea in international space law, based on the duty to consult set out in Article IX of the OST, which reads, in part:

---

[111] United Nations General Assembly. "Principles Relevant to the Use of Nuclear Power Sources In Outer Space." United Nations Office for Outer Space Affairs. Accessed August 28, 2024. https://www.unoosa.org/oosa/en/ourwork/spacelaw/principles/nps-principles.html.

[112] Central Intelligence Agency, "Report on Satellite Reconnaissance Programs," Approved for Release 2001/08/27, https://www.cia.gov/readingroom/docs/CIA-RDP66R00638R000100140024-2.pdf; Department of State, Office of the Historian, "Telegram from the Department of State to the Embassy in Japan," 13 Nov 1963, https://history.state.gov/historicaldocuments/frus1961-63v25/d431

[113] Reuters, "Soviet Asks Inspection of All Space Programs", 1 April 1988, New York Times, https://www.nytimes.com/1988/04/01/world/soviet-asks-inspection-of-all-space-programs.html

[114] Ibid.

> If a State Party to the Treaty has reason to believe that an activity or experiment planned by it or its nationals in outer space, including the moon and other celestial bodies, would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space, including the moon and other celestial bodies, it shall undertake appropriate international consultations before proceeding with any such activity or experiment. A State Party to the Treaty which has reason to believe that an activity or experiment planned by another State Party in outer space, including the moon and other celestial bodies, would cause potentially harmful interference with activities in the peaceful exploration and use of outer space, including the moon and other celestial bodies, may request consultation concerning the activity or experiment.

The duty to consult, however, is not backed up by any kind of formal review process.[115]

The 1975 Registration Convention provides that states are obliged to provide information on their space objects to a Register of Space Objects maintained by the UN Office of Outer Space Affairs. However, the register is not fully effective due to a lack of monitoring and state compliance, especially with regard to military satellites.[116]

With the right kind of implementation mechanisms, these treaty provisions could provide a firm basis for monitoring and verifying the use of nuclear technologies in space. Payloads could be checked not just for the presence of nuclear material but also the amount, as this might indicate that the payload is a weapon. In other instances, determining the intended use of nuclear material could require access to the spacecraft's instrumentation to verify the nature of the mission. For example, nuclear-powered maneuvering could be used for on-orbit refueling or active debris removal but also for approaching satellites to carry out electromagnetic warfare, e.g. jamming.

The good news is, there are many precedents for effective inspection regimes in both conventional and nuclear arms control. There is also a well-respected global organization, the International Atomic Energy Agency, that has considerable experience conducting nuclear inspections, including in militarized contexts. Some kind of general verification regime will be possible for nuclear materials in space—if the political will is present.

The widespread alarm caused by the 2024 reports of a possible Russian nuclear weapon in low Earth orbit demonstrated that governments and publics are concerned about these issues. Clearly, all states agree on the importance of keeping nuclear weapons out of space; where they disagree, is on how best to do so. And that creates an opportunity to negotiate.

[115] Sandeepa Bhat and Kiran Mohan V., "Anti Satellite Missile Testing: A Challenge to Article IV of the Outer Space Treaty," NUJS Law Review *2*, 2009, https://docs.manupatra.in/newsline/articles/Upload/3CC9A6F0-677A-4385-BF1F-E290A03B22C1.pdf

[116] Tanja Masson-Zwaan, P. Martinez, F. Letizia, C. Melograna, M. Reynders, R. Rovetto, M.A. Skinner, M. Stanciu-Manolescu, M. Strah, O. Volynskaya, and G. Wang, 2024, "The need to improve registration practices in the context of space traffic management," Acta Astronautica 223 (2024): 242-248.