

COMMERCIAL USE OF MICROREACTORS IN OUTER SPACE AND THE ROAD TOWARDS A SPACE NUCLEAR LAW

Jakub Handrlíca

Abstract: The entire world has entered the New Space Era. Advanced space technologies have significantly reduced launch costs, and the number of actors launching satellites into orbit has increased continuously. Innovations in technology have opened the door for nanosatellites and microsatellites, which bring the opportunity to enable missions that large satellites cannot accomplish, such as providing constellations for low-data-rate communications and in-orbit inspection of larger satellites. All these technological advances have opened outer space for commercial use by private entities. In the New Space Era, the state has lost its previously established monopoly on exploring and utilising outer space. Having said this, the New Space Era also presents considerable challenges for the prospective deployment of nuclear technologies in outer space. Current projects of companies such as Westinghouse, Rolls-Royce, and Mitsubishi include microreactors for space applications, such as space mining and delivering power to human settlements in outer space. In July 2025, the Czech start-up Stellar Nuclear announced the commencement of work towards a lunar microreactor. Considering the involvement of commercial entities in these projects, one may predict that the private sector will have considerable interest in the use of nuclear energy in space activities in the future. This article argues that nuclear law needs to reflect prospective challenges arising from the future commercialisation of nuclear use in outer space. The current legal framework has reflected an étatist approach to space activities, primarily focusing on government-led space projects. This approach, however, is insufficient to address the challenges arising from the prospective commercialisation and privatisation of nuclear activities in outer space. The future legal framework must address the risks arising from the gradual emergence of private nuclear space corporations, innovators, and start-ups. In this respect, this article argues that future space nuclear law cannot be a pure extension of existing legal frameworks. The realities of outer space differ considerably from those of Earth, and therefore, a holistic approach will be needed to establish a new legal framework.

Resumé: Celý svět vstoupil do nové kosmické éry. Vyspělé kosmické technologie výrazně snížily náklady na vypouštění satelitů a počet subjektů, které je vypouštějí na oběžnou dráhu, se neustále zvyšuje. Inovace v oblasti technologií otevřely dveře nanosatelitům a mikro-satelitům, které přinášejí příležitost umožnit plnění úkolů, které velké satelity nemohou splnit, jako je poskytování konstelací pro komunikaci s nízkou rychlostí přenosu dat a inspekce větších satelitů na oběžné dráze. Všechny tyto technologické pokroky otevřely vesmírný prostor pro komerční využití soukromými subjekty. V nové kosmické éře tak stáť ztratil svůj dříve zavedený monopol na průzkum a využívání vesmíru. Nová kosmická éra současně představuje značnou výzvu pro perspektivní nasazení jaderných technologií ve vesmíru. Současné projekty korporací, jakými jsou např. Westinghouse, Rolls-Royce and Mitsubishi, zahrnují mikroreaktory pro vesmírné aplikace, jako je těžba nerostů a dodávka energie lidským obydlím v kosmu. V červenci 2025 zveřejnil svůj záměr vyvinout lunární mikroreaktor i český start-up Stellar Nuclear. Vzhledem k zapojení komerčních subjektů

do těchto projektů lze předpokládat, že soukromý sektor bude mít v budoucnu o využití jaderné energie ve vesmírných aktivitách značný zájem.

Tento článek předkládá argumenty ve prospěch tvrzení, že jaderné právo musí zohlednit výzvy vyplývající z budoucího nasazení komerčních jaderných technologií v kosmu. Současný právní rámec odráží etatistický přístup ke kosmickým činnostem a zaměřuje se především na projekty, vedené a realizované exekutivami států. Tento přístup však nestačí k řešení výzev vyplývajících z budoucí komercializace a privatizace jaderných činností ve vesmíru. Budoucí právní rámec se musí zabývat riziky vyplývajícími z postupného vzniku soukromých korporací, inovátorů a start-upů, provozujících nové jaderné technologie v kosmickém prostoru. Kosmické jaderné právo budoucnosti ovšem nemůže být pouhou kopií právního rámce, který byl v minulosti vytvořen pro pozemské jaderné aplikace. Podmínky v kosmickém prostoru se do značné míry odlišují od podmínek, které existují na Zemi a pro které by existující právní rámec vytvořen. Vytvoření podmínek budoucího právního rámce proto musí být založeno na holistickém přístupu, který bude reflektovat všechna specifika využívání jaderné energie v kosmickém prostoru.

Key words: nuclear law; space law; space nuclear law; New Space Era; space commercialisation; microreactors

About the author:

Jakub Handrlica is a full professor at the Faculty of Law, Charles University in Prague. His main areas of research interest have been energy law, nuclear law and space law. He is an active member of the International Nuclear Law Association (AIDN/INLA) and the International Institute for Space Law (IISL). In 2020, he was awarded the title of Research Professor by the Czech Academy of Sciences. Since 2023, he has been a member of the OECD/NEA Global Forum Working Group on Re-Establishing Nuclear Law Education Programmes. He is also a member of the editorial board of the *Journal of Energy and Natural Resources Law*. From the academic year 2025/26, he has served as module coordinator in the Master's programme Space Law and Geopolitics at the Law School, LUISS University in Rome, Italy. Email: jakub.handrlica@prf.cuni.cz .

1. Per nuclear ad astra^{1,2}

The entire world has entered the *New Space Era*.³ Launch costs have decreased significantly, and the number of actors launching satellites into orbit is expected to continue increasing. Lower costs of space travel are opening the door to the establishment of extraterrestrial footholds. Experts have identified 17,000 asteroids which can be exploited for resource extraction, with one estimate putting the size of the space industry at \$2.7 trillion per year by 2050. At the same time, the segments of the space industry involving nanosatellites and microsatellites have been growing. Smaller and lighter satellites require smaller and less expensive launch vehicles and can sometimes be launched in batches. Further, smaller and lighter satellites bring the opportunity to enable missions that large satellites cannot accomplish, such as providing constellations for low data rate communications, in-orbit inspection of larger satellites, testing or qualifying new hardware before using it on a more expensive spacecraft, manufacturing of pharmaceuticals under space conditions (space pharmacy), etc.

These technological advances have created opportunities for commercial use by private entities.⁴ Thus, in the New Space Era, the state has effectively lost its previously established monopoly on the exploration and use of outer space. In this respect, the New Space Era has been characterised both by intensive technological development and by gradual commercialisation and privatisation of space activities. Having said this, the New Space Era also presents considerable challenges for the prospective deployment of nuclear technologies in outer space.⁵ Currently, several advanced nuclear technologies⁶ are being researched and developed by established energy companies, innovators, and nuclear start-ups. Current projects include microreactors⁷ for space applications, such as space mining and delivering

¹ This is a written version of my presentation Nuclear Law in the New Space Era, delivered at the XXVth Nuclear Inter Jura Congress, which was organised by the International Nuclear Law Association (AIDN/INLA) in Warsaw, Poland, from the 3rd to 7th of November 2024.

² This paper was written under the umbrella of the project 'A fleet of small modular reactors on the horizon! Do we need a new nuclear law?' (registration number 24-10062S), supported by the Czech Science Foundation.

³ CLERC, P. 'Towards a new legal ecosystem for the exploitation of space' in SMITH, L., BAUMANN, I., WINTERMUTH, S. (eds), *Routledge Handbook of Commercial Space Law* (Routledge 2023) and FORGANNI, A., 'Legal Considerations on Space Commercialisation', in LIEBERMANN, S., ATHANOSOPOULOS, HK., HOERBER, T. (eds), *The Commercialisation of Space. Politics, Economics and Ethics* (Routledge 2023). Also see SCHNEIDER, S., 'NewSpace and the law', in HOFMANN, M., BLOUNT, PJ. (eds), *Elgar Concise Encyclopedia of Space Law* (Edward Elgar 2025).

⁴ DENIS, G., ALARY, D., PASCO, X., PISOT, N., TEXIER, D., 'From new space to big space: How commercial space dream is becoming a reality' (2020) 166 *Acta Astronaut.* 431.

⁵ BENNETT, GL., 'Dream of the Stars – The Benefits of Nuclear Power and Propulsion', in BENKO, M., SCHROGL, KU. (eds), *Outer Space – Future for Humankind: Issues of Law* (Eleven International Publishing 2021).

⁶ This article aims to address exclusively prospective peaceful uses of nuclear energy in outer space.

⁷ The International Atomic Energy Agency (IAEA) defines them as very small reactors with power levels generally anticipated to range from less than 1 MWe to 30 MWe. See IAEA (ed), *Small Modular Reactors. Advances in SMR Developments 2024* (IAEA 2024) 13. The US Department of Energy (DOE) defines microreactors by using three distinctive features: (i) microreactors are factory-fabricated: All components of a microreactor are fully assembled in a factory and shipped to the location, (ii) microreactors are transportable: Smaller unit designs will make microreactors very transportable by truck, shipping vessel, plane, or railcar, (iii) microreactors are self-adjusting: These advanced nuclear technologies won't require many specialised operators and would utilise passive safety systems that prevent any potential for overheating or reactor meltdown.

power to human settlements in outer space.⁸ In 2023, the UK-based company Rolls-Royce unveiled its concept of a space microreactor at the *UK Space Conference* in Belfast. It is the result of £ 2.9 million in funding from the UK Space Agency, exploring how nuclear power could support a future Moon base for astronauts. According to its statement, Rolls-Royce will be ready to deploy a microreactor on the Moon in the early 2030s. At the same time, similar endeavours are underway in the USA. In January 2025, NASA and the US Department of Energy (DoE) selected Westinghouse to develop a space microreactor design through the *Fission Surface Power (FSP)* project. This project focuses on developing concept designs for small, electricity-generating nuclear fission reactors that could provide astronauts with a reliable power supply for use on the moon and beyond. In Japan, Mitsubishi Heavy Industries (MHI) is developing a space microreactor. The fact is, however, that the development of space microreactors is currently not limited to large and traditional nuclear corporations, such as Rolls-Royce and Westinghouse. On the contrary, space microreactors have very recently become the subject of interest also for nuclear start-ups. The Stellar Nuclear start-up, based in the Czech Republic, may represent a salient example of this tendency. In July 2025, Stellar Nuclear was awarded a research grant by the Technology Agency of the Czech Republic to design a space microreactor for use on the Moon and beyond.

Given the involvement of commercial entities in these projects, one can predict that the private sector will be significantly interested in utilising nuclear energy in space activities in the future.⁹ It is crystal clear that commercial use of nuclear power in outer space will require a transparent and predictable legal framework, which will guarantee a high level of safety and transparency. The fact is, however, that the discourse in nuclear law hasn't paid any considerable attention to the legal framework applicable to future commercial use of nuclear energy in outer space so far. The following examples may demonstrate this more clearly: In 2022, Sweet & Maxwell published the 3rd edition of *The Law of Nuclear Energy*, authored by Helen Cook. While the author addresses¹⁰ advanced nuclear technologies and their legal implications in extensive detail in her book, the issues of prospective nuclear use in outer space remain beyond the author's attention. Neither the *Principles and Practice of International Nuclear Law*, published¹¹ by the Nuclear Energy Agency of the Organisation for Economic Development and Co-operation in the same year, nor did it pay any attention to legal issues prospectively arising from nuclear use in outer space. Lastly, neither the very recently published 3rd edition of the *Burges Salmon Guide to Nuclear Law* addresses the issue of nuclear technologies in outer space in any way.¹² The presentations held at the *XXVth Nuclear Inter Jura Congress*, which took place in Warsaw, Poland from 3–7 November 2024, have demonstrated the same degree of disinterest in the deployment of advanced nuclear technologies in outer space. While the overall theme of the Congress was '*Nuclear New*

⁸ VERTADIER, H., GILBERT, A., 'The importance of nuclear energy governance in establishing sustainable lunar settlements' in *Proceedings of the 74th International Astronautical Congress* (IAC 2023). For a general outline on microreactors see ZHANG, Z. et al., 'Microreactors' in WANG, J., TALABI, S., BILBAO Y LEON, S. (eds), *Nuclear Power Reactor Designs. From History to Advances* (Academic Press 2023).

⁹ LOCKE, J., LAL, B., 'Emergence of a Commercial Space Nuclear Enterprise' (2020) 206 *Nucl. Technol.* 1109. See also GILBERT, A., DESAI, HS, MATTHEWS, J., 'Commercial nuclear innovation "new space" age', *Nuclear Newswire*, 26 April 2024.

¹⁰ COOK, H., *The Law of Nuclear Energy* (3rd edition, Sweet & Maxwell 2022) 423.

¹¹ OECD/NAE (eds.), *Principles and Practice of International Nuclear Law*, Paris, OECD/NEA, 2022.

¹² SALTER, I., TRUMAN, I. (eds), *Burges Salmon Guide to Nuclear Law* (Burges Salmon 2025).

Build Renaissance: In Search of New Approaches to Legal and Regulatory Challenges, almost exclusive attention was paid to the prospects of advanced nuclear technologies on land (small modular reactors) or at sea (transportable nuclear power plants). Thus, one may argue that the existing discourse of nuclear law is almost entirely oriented toward earthly applications and, in principle, ignores (or at least marginalises) the prospective deployment of nuclear technologies in outer space. A notable exception is Alex Gilbert's speech, which was delivered at the First International Conference on Nuclear Law: The Global Debate, organised by the IAEA in Vienna from 25–29 April 2022. In his speech, Gilbert urged the establishment of a *space nuclear law*, a special branch of law, addressing uses of advanced nuclear technologies in outer space.¹³

The discourse on space law has not shown much of a different picture. Here, literature has paid considerable attention to legal issues arising from the privatisation and commercialisation of space activities.¹⁴ Despite this, only a few authors¹⁵ have addressed the phenomenon of space commercialisation with respect to the prospective deployment of advanced nuclear technologies in outer space so far. One may easily argue, however, that this disinterest in legal scholarship regarding the commercial uses of nuclear power in outer space has been caused by the fact that major international agreements do not address this topic explicitly at all.¹⁶ Consequently, while the newly published *Elgar Concise Encyclopedia of Space Law* contains¹⁷ a separate entry on *Space nuclear power sources*, it does not address the issue of commercial use of advanced nuclear technologies at all. Neither the *Future of Outer Space Law*, which Routledge very recently published in its series *Routledge Research in Air and Space Law*, nor does it contain any significant reference to the future use of nuclear energy in outer space.

This article aims to develop further the idea of the need for a *space nuclear law*. The current legal framework has reflected an *étatist* approach to activities in outer space. This approach, in principle, focuses on the obligations of the state *vis-à-vis* other states in the field of space exploration. It reflects the state's monopoly on any space activities, including those involving the peaceful use of nuclear energy. This approach, however, is insufficient to address

¹³ See also his newest article GILBERT, A., 'Governance of nuclear energy in outer space' (2024) 113 *Nuclear Law Bulletin* 7.

¹⁴ SMITH, L., BAUMANN, I., WINTERMUTH, S. (eds.), *Routledge Handbook of Commercial Space Law* (Routledge 2024). Also see ISHKIBAYEVA, G., NURMUKHAN, D., TELEUYEV, G., 'Legal analysis of the global space agencies and private companies engaged in space service' (2025) 8 *Social and Legal Studies* 263, DEY, A., JAGADANANDAN, J., 'Balancing commercialization and sustainability in outer space: Addressing new challenges' (2025) 229 *Acta Astronautica* 895, HERTZFELD, HR., 'Commercialization as applied to outer space: a definition' in HOFMANN, M., BLOUNT, PJ. (eds), *Elgar Concise Encyclopedia of Space Law* (Edward Elgar 2025).

¹⁵ See IAVICOLI, V., 'Nuclear power sources in outer space for peaceful purposes: an evolving legal framework' in CINELLI, C. (ed), *Regulation of Outer Space: International Space Law and the State* (Routledge/G. Giappichelli Editore 2024) and BOHLMANN, U., RENCELJ, M., 'Nuclear Technologies in Future Space Exploration and Questions of Environmental Law' in BENKO, M., SCHROGHL, KU. (eds), *Outer Space – Future of Humankind: Issues of Law* (Eleven International Publishing 2021). Also see IAVICOLI, V., 'Il ruolo insostituibile delle NPS nello spazio: Criticità e prospettive del quadro giuridico', in *Liber Amicorum Sergio Marchisio, Vol. II – Il Diritto della Comunità Internazionale tra caratteristiche strutturali e tendenze innovative* (Editoriale Scientifica 2022).

¹⁶ In fact, the only instrument of international law referring to the topic is so far the Convention on Early Notification of a Nuclear Accident, which refers to 'the use of radioisotopes for power generation in space objects' (Art. 1.2.f).

¹⁷ LONG, J. 'Space nuclear power sources', in HOFMANN, M., BLOUNT, PJ. (eds), *Elgar Concise Encyclopedia of Space Law* (Edward Elgar 2025).

the challenges arising from the prospective commercialisation and privatisation of activities in outer space. Future laws must address risks arising from the gradual emergence of private nuclear space corporations, innovators, and start-ups.

2. *Étatist* approach to nuclear activities in outer space

The *étatist* approach to nuclear activities in outer space has been enshrined in the *Principles Relevant to the Use of Nuclear Power Sources in Outer Space* (Principles).¹⁸ This statement deserves further clarification. The fact is that the Preamble provides that:

‘in some missions in outer space nuclear power sources are particularly suited or even essential owing to their compactness, long life and other attributes.’

Thus, the Preamble itself does not exclude commercial use of nuclear energy in outer space by private entities.¹⁹ At the same time, the *Principles* provide that:

States shall bear international responsibility for national activities involving the use of nuclear power sources in outer space, whether such activities are carried on by governmental agencies or by non-governmental entities (...). When an international organisation carries on activities in outer space involving the use of nuclear power sources, responsibility for compliance with the aforesaid Treaty and the recommendations contained in these Principles shall be borne both by the international organisation and by the States participating in it.²⁰

This wording has been influenced by the wording of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies²¹ (Outer Space Treaty), which provides²² for the international responsibility of the states for space activities in general.²³ Having cited this provision, it is crystal clear that the Principles basically *admit* commercial use of nuclear energy in outer space, not only within government-led projects but also by private entities (*non-governmental entities*).

When referring to the *étatist* character of the regulation, one refers to the fact that the Principles exclusively govern the mutual relations between the states.²⁴ In this respect, the Principles use the term *launching state*, or *state launching*, to refer to the state that *exercises jurisdiction and control over a space object with nuclear power sources on board at a given point in time that is relevant to the principle concerned*.²⁵

¹⁸ Resolution adopted by the General Assembly of the United Nations. 48/67 *Principles Relevant to the Use of Nuclear Power Sources in Outer Space* (85th plenary meeting, 14 December 1992).

¹⁹ See QUIZHI, H., ‘Towards a New Legal Regime for the Use of Nuclear Power Sources in Outer Space’ (1986) 14 *J. Space L.* 95. Also see: VENTURINI, G., ‘The Legal Regime of the Use of Nuclear Power Sources in Space Missions’, in BLACK-BRANCH, J.L., FLECK, D. (eds.), *Nuclear Non-Proliferation in International Law, Vol. V – Legal Challenges for Nuclear Security and Deterrence* (T.M.C. Asser Press 2020).

²⁰ Principle 8.

²¹ Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (adopted 5 December 1979, entered into force 11 July 1984) 610 UNTS 205.

²² Article VI.

²³ See KYRIAKOPOULOS, GD., ‘Responsibility for national activities’, in HOFMANN, M., BLOUNT, PJ. (eds), *Elgar Concise Encyclopedia of Space Law* (Edward Elgar 2025).

²⁴ See BOHLMANN, U. et al., ‘The Nuclear Power Sources Principles: Principles Relevant to the Use of Nuclear Power Sources in Outer Space’, in HOBE, S., SCHMIDT-TEDD, B., SCHROGL, KU. (eds), *Cologne Commentary on Space Law, Outer Space Treaty, Vol. III.* (Carl Heymanns Verlag 2015).

²⁵ Principle 2.

Thus, the Principles provide for a general rule, under which ‘in order to minimise the quantity of radioactive material in space and the risks involved, the use of nuclear power sources in outer space shall be restricted to those space missions, for which non-nuclear energy sources cannot operate in a reasonable way.’²⁶ This general principle is subsequently elaborated in further obligations of the *launching states*:

1. States launching space objects with nuclear power sources on board shall endeavour to protect individuals, populations, and the biosphere against radiological hazards.²⁷
2. Further, a launching state shall ensure that a thorough and comprehensive safety assessment is conducted at the time of launch. This assessment shall cover all relevant phases of the mission and all systems involved, including the means of launch, the space platform, the nuclear power source and its equipment, and the means of control and communication between ground and space.²⁸
3. Any state launching a space object with nuclear power sources on board shall, in a timely fashion, inform states concerned in the event this space object malfunctions with a risk of re-entry of radioactive materials to the Earth.²⁹ In this respect, the *Principles* also provide for obligations of states to mutual assistance in the case of an expected re-entry into the Earth’s atmosphere of a space object containing a nuclear power source on board and its components.³⁰
4. Lastly, the *Principles* also provide that each state which launches or procures the launching of a space object and each state from whose territory or facility a space object is launched shall be internationally liable for damage caused by such space objects or their parts. This fully applies to the case of such a space object carrying a nuclear power source on board.³¹

Consequently, while a comprehensive set of rules has been established regarding mutual relations between states, a similar set of regulations governing relations between the launching state and private entities aiming at nuclear use in outer space have been absent.³² This situation clearly reflects the overall trend of the past few decades, where states have possessed a monopoly on nuclear use in outer space. However, with the gradual commercialisation and privatisation of outer space, one must expect the deployment of advanced nuclear technologies there also by private entities. In the future, such entities may be represented either by commercial nuclear corporations or by nuclear innovators and start-ups. One must bear in mind that the current legal framework contains only very few provisions that may apply *vis-à-vis* the prospective deployment of microreactors in outer space. In this respect, the Outer Space Treaty provides that:

A State Party to the Treaty on whose registry an object launched into outer space is carried shall retain jurisdiction and control over such object, and any personnel thereof, while in outer space or on a celestial body. Ownership of objects launched into outer space, including objects landed or constructed on a celestial body, and of their parts, is not affected by their

²⁶ Principle 3.

²⁷ Ibid.

²⁸ Principle 4.

²⁹ Principle 5.

³⁰ Principle 7.

³¹ Principle 9.

³² MIRMINA, SA., DEN HERDER, DJ., ‘Nuclear Power Sources and Future Space Exploration’ (2005) 6 *Chic. J. Int. Law* 149.

presence in outer space or on a celestial body or by their return to the Earth. Such objects or parts found beyond the limits of the State Party to the Treaty on whose registry they are carried shall be returned to that State Party, which shall, upon request, furnish identifying data prior to their return.³³

It is crystal clear that this provision has not been drafted with respect to any operation of nuclear installations in outer space.³⁴ However, its application *vis-à-vis microreactors will mean that the installation will, in principle, be governed by the legal and regulatory framework of the launching state*. This concept has been further developed by soft law, namely by the *Safety Framework for Nuclear Power Source Applications in Outer Space* (Safety Framework), which has been adopted jointly by the United Nations Committee on the Peaceful Uses of Outer Space Scientific and the IAEA.³⁵ In this respect, the Safety Framework provides that:

[T]he government that oversees and authorises the launch operations for space NPS (=nuclear power sources) missions should establish a mission launch authorisation process focused on nuclear safety aspects. The process should include an evaluation of all four relevant information and considerations from other participating organisations. The mission launch authorisation process should supplement the authorisation processes covering non-nuclear and terrestrial aspects of launch safety. An independent safety evaluation (i.e., a review, independent of the management organisation conducting the mission, of the adequacy and validity of the safety case) should be an integral part of the authorisation process. The independent safety evaluation should consider the entire space NPS application – including the space NPS, spacecraft, launch system, mission design and flight rules – in assessing the risk to people and the environment from relevant launch, operation and end-of-service phases of the space mission.

In this respect, the Safety Framework also argues that, unlike many terrestrial nuclear applications, space applications tend to be used *infrequently*, and their requirements can vary significantly depending upon the specific mission.³⁶ While this statement can be considered correct for the time being, the future will most probably imply a more *frequent* use of advanced nuclear technologies in outer space. The projects, currently under development by corporations such as Westinghouse, Rolls-Royce, and Mitsubishi, envisage *long-term* operation of microreactors on the Moon and other celestial bodies for powering human settlements and space mining.³⁷ Consequently, the existing framework remains silent on a myriad of issues that will arise with respect to the prospective commercial and long-term deployment of microreactors in outer space. To illustrate the gaps in the existing legal framework, the following issues must be highlighted:

1. The concept of international responsibility of the *launching state*, as provided by both the Outer Space Treaty and the Principles, implies that the state must identify the regulatory authority that will be in charge of authorising and controlling the microreactors, which are envisaged to be operated on celestial bodies for several decades. Details on the overall arrangements of such authorities are currently

³³ Article VIII.

³⁴ YANG, C., 'Towards a New Legal Framework Governing the Use of Nuclear Power Sources in Outer Space' (2014) 39 Ann. D. Aerien & Spatial 486.

³⁵ UN/IAEA (eds.), *Safety Framework for Nuclear Power Source Applications in Outer Space* (IAEA 2009).

³⁶ *Ibid.*, at p. 1.

³⁷ See HANDRLICA, J., 'Euratom and the use of nuclear energy to power lunar basis' (2024) 15 *CYIL* 229.

unavailable. The fact is that while the agenda of existing nuclear regulatory authorities has been specialised exclusively to terrestrial installations, the agenda of existing space regulatory authorities has been focused, in principle, on non-nuclear applications.

2. Further, any rules on the authorisation of microreactors for commercial use in outer space are missing so far. In the same vein, any consensus on the basic requirements that a future license holder must fulfil remains absent.
3. Neither are the rules for continuous control over microreactors operated by commercial corporations in outer space present. One must bear in mind that in the event of noncompliance with the obligations arising from the license, the regulatory authority will be required to enforce fulfilment of these obligations, or – in extreme cases – suspend the operation of the installation.
4. Lastly, any operation of microreactors in outer space will imply the production of nuclear waste. Clear rules for managing this waste will be necessary for any future deployment of microreactors in outer space.

3. Modern approach to nuclear activities in outer space

A robust legal framework must accompany any prospective deployment of microreactors for space applications. Such a legal framework must address the mutual relations between the *launching state*, on the one hand, and the *private entity (non-governmental entities)*, as referred to in the Principles) aiming to use nuclear power in outer space in a commercial context. The fact is that the *launching state* will still bear international responsibility for any launched space object bearing advanced nuclear technologies. This will most probably become the trigger for establishing new rules that will specify provisions for the safe operation of their technologies in outer space.

Having said this, one must bear in mind that the existing international framework for peaceful uses of nuclear energy is, in principle, Earth-oriented. It was designed to be applicable to Earthly circumstances, including technical, environmental, and political aspects. As such, the legal framework presumes that nuclear installations will be operated in circumstances where gravity and earthly conditions of radiation release do exist.³⁸ Also, the existing legal frameworks reflect the experiences with nuclear incidents that occurred on Earth, rather than in outer space.³⁹ A nuclear incident in a space microreactor may not only cause damage to the Moon settlement and its industrial installations, but also harm the space environment and, very likely, the systems of satellite communication. Thus, terrestrial navigation systems for naval and air transport will be compromised, similar to satellite systems for weather, environmental, and security monitoring. At the same time, a nuclear incident occurring in outer space may harm satellite constellations, providing connectivity services for both the

³⁸ See NASCIMENTO, JA., GUIMARÃES, LN., ONO, S., LOBO, PD., 'Advanced micro-reactor for space and deep sea exploration' in *2011 International Nuclear Atlantic Conference – INAC 2011 Belo Horizonte, MG, Brazil, October 24-28, 2011* (Associação Brasileira de Energia Nuclear 2011).

³⁹ See ABEYRATNE, RIR., 'The Use of Nuclear Power Sources in Outer Space and Its Effect on Environmental Protection' (1997) 25 J. Space L. 17. Also see GOREN, D., 'Nuclear Accidents in Space and on Earth: An Analysis of International Law Governing the Cosmos-954 and Chernobyl Accidents' (1992–1993) 5 *Geo. Int'l Envtl. L. Rev.* 855.

public and private sectors on Earth. To summarise, such an incident may cause major outages in naval and air transport, connectivity services, and the functioning of security monitoring.⁴⁰

Lastly, although part of the same solar system, Earth and the other planets in this system are subject to two separate and distinct legal orders. The Earth's land is divided into different territories of sovereign states; the Earth's sea and the Antarctic are subject to the legal system developed progressively by international conventions and following jurisprudence. In strict contrast, outer space is, in principle, free of any state sovereignty. The Outer Space Treaty declared⁴¹ that outer space, including the Moon and other celestial bodies, shall be the province of all humankind. Celestial bodies shall be free for exploration and use by all states without discrimination of any kind. At the same time, celestial bodies are not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.⁴² Consequently, while the earthly land is being divided by land borders and oceanic zones, outer space has no such division.⁴³ Consequently, concepts used in the existing legal framework regarding the peaceful use of nuclear energy are hardly applicable to the realities of outer space, as they strictly follow the territorial jurisdiction of the concerned states. Any future legal framework for the commercial use of nuclear installations in outer space must be based not solely on a legal approach but on a holistic approach that incorporates technical, astronomical, and strategic considerations.⁴⁴

Having said this, the following paragraphs will briefly analyse challenges for a future legal framework in three particular fields of nuclear law.

Nuclear safety

While the Convention on Nuclear Safety⁴⁵ has provided the rules for authorisation, this Convention will not be applicable to any advanced nuclear technologies deployed in outer space – neither to those serving as means of propulsion nor to those which will serve as a source of power for space mining, or for human settlements. The Convention was designed exclusively to reflect the peculiarities of Earth-based nuclear installations. Consequently, its framework is not suitable for covering the specific nature of nuclear use in outer space. The use of nuclear power in outer space has unique safety considerations compared with terrestrial applications. Mission launch and outer space operational requirements impose size, mass, and other space environment limitations that are not present for many terrestrial nuclear facilities. Space nuclear technologies are envisaged to operate *autonomously* at great distances from Earth in harsh environments. Potential accident conditions resulting from launch failures and inadvertent re-entry could expose these technologies to extreme physical conditions. These and other unique safety considerations for the use of space nuclear technologies are significantly

⁴⁰ For a more robust projection of potential consequences of a nuclear incident in Outer Space, see CHENGZHI, Y. et al, 'Scheme research of nuclear reactor power system for lunar base' (2016) 50 *At. Energy Sci. Technol.* 464.

⁴¹ Art. I.

⁴² Art. II.

⁴³ ZHANG, WL., 'Extraterritorial Jurisdiction on Celestial Bodies' (2019) 47 *Space Policy* 148.

⁴⁴ See TURNER, KM., 'Recognizing and addressing the challenge of interdisciplinary collaboration, design and governance in sociotechnical systems' in CINELLI, C. (ed), *Regulation of Outer Space: International Space Law and the State* (Routledge/G. Giappichelli Editore 2024). Also see DENOYELLE, L., 'The Legal Moonscape: Navigating the Legal and Sustainability Challenges of Lunar Mining and Settlement' (2025) 1 *SMD* 29.

⁴⁵ Convention on Nuclear Safety (adopted 17 June 1994, entered into force 24 October 1996) INFCIRC/449.

different from those for terrestrial nuclear systems.⁴⁶ This is the reason why the Convention limits its technological scope to *land-based civil nuclear power plants under its jurisdiction, including such storage, handling and treatment facilities for radioactive materials as are on the same site and are directly related to the operation of the nuclear power plant.*⁴⁷

Having said this, it is crystal clear that a future nuclear safety framework addressing the operation of microreactors in outer space cannot be based solely on the existing Convention on Nuclear Safety. The main obstacle to the non-applicability of this Convention to space-based microreactors is not represented by the wording of the Convention, which explicitly refers to *land-based civil nuclear power plants*. The regime of the Convention is, per se, not applicable, as the concept of the Convention does not reflect the peculiar circumstances under which space microreactors will be operated.⁴⁸ Thus, new solutions will need to be found, particularly with respect to controlling nuclear installations at great distances, enforcing safety standards on distant celestial bodies, and facilitating the exchange of information. Most likely, the deployment of artificial intelligence in the nuclear industry will also bring novel solutions to nuclear safety governance. Most probably, these issues will be governed first by soft law mechanisms, rather than a binding international treaty.

Management of nuclear waste

Any prospective use of advanced nuclear technologies in outer space will imply the need to address the problem of nuclear waste. Microreactors deployed to power mining colonies or human settlements on space objects will produce nuclear waste, which needs to be stored and subsequently disposed of safely. The fact is that neither the Principles nor the Safety Framework had explicitly addressed the issue of nuclear waste arising from the use of nuclear technologies in outer space. Neither the provisions of the Joint Convention on the Safety of Spent Fuel Management nor the Safety of Radioactive Waste Management⁴⁹ seem to be applicable. The reason is that the Convention has been designed for earthly circumstances, where each state possesses sovereignty over specific territory. Consequently, the nuclear waste is to be disposed of in this particular territory. However, as outer space is free from any state sovereignty, this concept will be barely applicable to nuclear waste produced by Lunar or Martian microreactors. At the same time, the safest approach to nuclear waste management in outer space will most probably be the temporary storage of this waste on one of the celestial bodies, rather than on Earth.⁵⁰ A very recently published study, authored by a research team based at Shenzhen University, argues *that short-term solutions include burying*

⁴⁶ See UN/IAEA (eds.), *Safety Framework for Nuclear Power Source Applications in Outer Space*, Vienna (IAEA 2009) 1.

⁴⁷ Convention on Nuclear Safety, Article 2(i).

⁴⁸ LEI, S., GUOQING, Z., YAOHUI, W., CHANG, W. & BO, L., 'A review of the construction of the supporting energy system for the lunar base' (2025) 12 *Front. Astron. Space Sci.* <https://doi.org/10.3389/fspas.2025.1609140>.

⁴⁹ Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management (adopted 5 September 1997, entered into force 18 June 2001) INFCIRC/546.

⁵⁰ See COOPERSMITH, J. 'Creating an infrastructure for space exploitation: Space disposal of high-level nuclear waste' in *Space 2000 – Proceedings* (American Society of Civil Engineers 2000) and KIM, H., PARK, C., KWON, O.J., 'Conceptual design of the space disposal system for the highly radioactive component of the nuclear waste' (2016) 115 *Energy* 155. Also see COOPERSMITH, J. 'Nuclear waste disposal in space: BEP's best hope?' in *Beamed Energy Propulsion – 4th International Symposium on Beamed Energy Propulsion* (American Institute of Physics 2005).

*spent fuel in permanently shadowed craters to minimise space ray interaction. Long-term proposals involve encapsulating waste in radiation-resistant ceramics and ejecting it into heliocentric orbit via lunar mass drivers.*⁵¹

While a scientific consensus on reliable nuclear waste management in outer space is still missing, one may argue that the issue of nuclear waste mitigation and the obligation to use nuclear sources sustainably actually arise from the concept of the *launching state's* international responsibility, which has been enshrined in the Principles.⁵² In this respect, one may argue that the sustainable development principle must be applicable to nuclear waste produced in outer space, just as it is currently appropriate to nuclear waste produced on Earth. While the *launching state* will bear ultimate responsibility for waste produced under its jurisdiction, the authorisation holder will be primarily responsible. Consequently, the future law of nuclear energy must provide for obligations of the authorisation holders to bear responsibility for their waste in accordance with the *polluter pays principle*. Financial and other arrangements for the safe disposal of waste produced in outer space will be the obligation of the authorisation holder.

Liability for nuclear damages

The fact is that any commercial use of nuclear energy in outer space will represent a source of risk. Consequently, compensation arrangements must be provided by law. In this respect, a significant difference has emerged between space law and nuclear law. Space law has traditionally followed the concept of international liability of the *launching state*. This has been enshrined in the Outer Space Treaty⁵³ and the Convention on International Liability for Damage Caused by Space Objects.⁵⁴ Subsequently, this regime has also been reflected in the Principles, which provide that:

Each State which launches or procures the launching of a space object and each State from whose territory or facility a space object is launched shall be internationally liable for damage caused by such space objects or their parts. This fully applies to the case of such a space object carrying a nuclear power source on board. Whenever two or more States jointly launch such a space object, they shall be jointly and severally liable for any damage caused, in accordance with Article V of the above-mentioned Convention (= Convention on International Liability for Damage Caused by Space Objects).⁵⁵

Under the scheme of international liability, the *launching state* bears liability for damages caused by launched space objects *vis-à-vis* other states. The liability scheme, as applicable in nuclear law, differs somewhat.⁵⁶ The existing nuclear liability conventions provide for the exclusive liability of the authorisation holder. The fact is, however, that this regime has so far been limited to terrestrial nuclear installations.

⁵¹ See LEI, S., GUOQING, Z., YAOHUI, W., CHANG, W. & BO, L., 'A review of the construction of the supporting energy system'.

⁵² Principle 8.

⁵³ Article VII.

⁵⁴ Convention on International Liability for Damage Caused by Space Objects (adopted 29 March 1972, entered into force 1 September 1972) 961 UNTS 187.

⁵⁵ Principle 9.

⁵⁶ KOVUDHIKULRUNGSRI, L., NAKSEEHARAC, D., 'Liability Regime of International Space Law: Some Lessons from International Nuclear Law' (2011) 4 *J. E. Asia & Int'l L.* 291.

A future deployment of advanced nuclear technologies in outer space by commercial entities will imply a significant challenge for the *launching states*. Without any further legal measures, the *launching states* will be held liable for any damages caused by advanced nuclear technologies launched from their territory or launched by an entity under their jurisdiction. Such a situation will undeniably trigger the lawmakers' interest in channelling the liability directly to the authorisation holders and obliging them to provide appropriate insurance. This can be realised in the form of a new instrument of international law. It is a matter of fact that such an instrument must reflect the risk assessment for damages that may occur as a consequence of a nuclear incident in a space nuclear installation, rather than be based upon risk assessments already existing from earthly conditions.

4. A way forward

The gradual commercialisation and privatisation of space activities also pose a myriad of challenges for nuclear law. While the attention of the community of atomic law is being paid today, in particular, to legal issues arising from nuclear new builds on Earth, the New Space Era opens a totally new perspective for the deployment of advanced space technologies at the final frontier of our universe. A future commercial use of advanced nuclear technologies in outer space is highly probable. The law governing nuclear energy must adapt to this future scenario and provide a robust and comprehensive legal framework. The fact is, however, that the future framework cannot represent a pure duplication of existing rules to the realities of outer space. One must bear in mind that the existing legal framework was tailor-made for the earthly realities and circumstances, which do not exist beyond the Earth. Consequently, the legal framework, as applicable to the prospective commercial use of space microreactors, must address the risks and realities of other planets. In other words, the approach to the prospective body of *space nuclear law* cannot be purely legal but must be interdisciplinary and holistic. For example, the future framework for nuclear liability must address the magnitude of damages that will most likely occur in outer space, rather than relying on experiences from nuclear incidents on Earth. This represents a serious task, in particular for the Legal Subcommittee of the Committee on the Peaceful Uses of Outer Space (COPUOS), which has been working under the umbrella of the United Nations' Office for Outer Space Affairs.

Additionally, the international community of nuclear lawyers must initiate a serious discussion on the establishment of a new body of law – *space nuclear law*, which may seem distant but is, in all likelihood, unavoidable.