IAC-03-IISL.5.01

NUCLEAR AND RADIOISOTOPIC POWER IN SPACE: THE CUMULATIVE CONTENT AND EFFECT OF THE UNITED NATIONS SPACE TREATIES AND DECLARATIONS

Ricky J. Lee*
Ricky J. Lee & Associates
University of Western Sydney, Australia

ABSTRACT

The use of nuclear power in space has been a constant source of controversy ever since the early days of space development. The General Assembly declaration, for example, was intended partly to address the concerns of States concerning the use of nuclear power sources in space. Since the 1980s, however, the development of nuclear and radioisotopic means of power generation and propulsion has arguably gone beyond the scope of the General Assembly declaration.

This paper concerns itself with an analysis of the legal effect of the principles contained in the General Assembly declaration and their cumulative effect with the legal principles of the United Nations space treaties. These principles are then applied to the applications of nuclear power generation, radioisotopic power generation, nuclear propulsion and radioisotopic propulsion and the likely impact of any privatisation of such activities in space.

INTRODUCTION

The deployment and testing of nuclear weapons in space has long been the subject of significant legal focus. In 1963, the international community agreed to prohibit the testing of nuclear weapons in outer space.[1] The Outer Space Treaty of 1967 also prohibited the deployment of nuclear weapons in outer space and on celestial bodies.[2]

It was not until more recent times that concerns have been raised with the use of nuclear and radioisotopic power sources in space. In 1992, the General Assembly adopted the Principles Relevant to the Use of Nuclear Power Sources in Outer Space (the "**NPS Principles**"). The NPS Principles set out certain legal and regulatory requirements on the use of nuclear and radioisotopic power sources for non-propulsive purposes.

From the view of a launch operator or satellite operator, regardless of whether the venture is of a public or private nature, it is prudent to consider the cumulative effect of the United Nations treaties and declarations on the conduct of a space activity involving nuclear or radioisotopic power sources.

THE NEED FOR NUCLEAR AND RADIOISOTOPIC POWER SOURCES

Currently, around four hundred watts of electricity are needed for small satellites around Earth orbit. For short times and low power levels, chemical fuel cells and solar power cells may be used but at high power levels, for long durations and also for interplanetary probes, nuclear power is the only means of generating sufficient electricity known today. Further, solar power cells understandably require their exposure to the Sun while the spacecraft is in close proximity to it in order to generate sufficient power. The aggregate of these factors means that spacecrafts utilising solar or chemical cell

Historically, the former Soviet Union and the United States have taken a markedly different approach to the development of power sources in space. The United States has launched one nuclear reactor and forty-two radioisotopic fuel cells into space, while the Soviet Union had launched thirty-seven nuclear reactors and six radioisotopic fuel cells.[3] Nuclear reactors rely on the fission reaction, as in terrestrial nuclear reactors and nuclear weapons, to generate energy. On the other hand, radioisotopic fuel cells rely on the energy generated from the radioactive decay of unstable elements, such as plutonium-238.

In either case, the energy generated from a nuclear reaction is calculated by the following well-known formula:

$$E = \Delta m \times c^2$$

where E is the energy released (measured in electron-volts or eV), Δm is the loss in total mass and c is the speed of light in vacuum. In the case of a fuel cell using plutonium-238, the decay involves the creation of uranium-234 and an α particle (identical to a helium nucleus):

$$^{238}_{94}\mathrm{Pu} \rightarrow ^{234}_{92}\mathrm{U} + ^{4}_{2}\mathrm{He}$$

For each atom of plutonium, the loss of mass between the plutonium nucleus and the sum of the daughter nuclei produces 5.59MeV of energy.

Plutonium-238 is often chosen for space missions because it has a reasonably long half-life of 87.4 years with each gram, which costs around US$300, producing forty-seven kilowatt-hours over a ten-year mission. This nevertheless dwarfs in comparison to the energy generated by nuclear fission reactors, as the same mass of uranium-235 can produce five hundred thousand times the energy produced by the decay of plutonium-238 over ten years. This is particularly crucial in the use of nuclear energy for the propulsion of spacecrafts.

Nuclear reactors rely on the fission reaction to generate energy. This involves the absorption of a neutron by a uranium-235 nucleus to form a highly-unstable uranium-236 nucleus, which almost spontaneously divides into two unstable nuclei. For example:

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow ^{236}_{92}\mathrm{U}^{*} \rightarrow ^{144}_{56}\mathrm{Ba} + ^{89}_{36}\mathrm{Kr} + 3 \cdot ^{1}_{0}\mathrm{n}$$

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow ^{236}_{92}\mathrm{U}^{*} \rightarrow ^{140}_{54}\mathrm{Xe} + ^{94}_{38}\mathrm{Sr} + 2 \cdot ^{1}_{0}\mathrm{n}$$

Chain reactions results from the neutrons produced in each fission reaction being absorbed by other uranium-235 nuclei. In a nuclear reactor, the chain reaction is controlled by water or graphite being used to slow down neutrons by collisions between them and the water molecules or carbon atoms in the graphite. While the risk of nuclear explosions is a common concern, what has been the focus of much academic attention is the potential spread of radioactive material in the atmosphere or on the ground. This is because the daughter nuclei of a fission reaction are unstable and are radioactive. In the second example given above, the xenon-140 nucleus undergoes a series of emissions of β^- particles, or electrons produced by the transformation of a neutron into a proton and an electron, as follows:

$$^{140}_{54}\mathrm{Xe} \xrightarrow{\beta^-} {}^{140}_{55}\mathrm{Cs} \xrightarrow{\beta^-} {}^{140}_{56}\mathrm{Ba} \xrightarrow{\beta^-} {}^{140}_{57}\mathrm{La} \xrightarrow{\beta^-} {}^{140}_{58}\mathrm{Ce}$$

The cerium-140 nucleus is stable and will not undergo any further decay. In the process, however, it is apparent that a substantial amount of radioactivity would already have taken place before nuclear stability can be reached. Depending on the level of energy involved, a β^- particle have a stronger effect on biological matter than x-rays with two hundred thousand electron-volts of energy.

PATH TO THE NPS PRINCIPLES

One sad reality in the development of international law is that unfortunate events are often the catalysts and this is no exception in the case of the law concerning nuclear and radioisotopic power sources in outer space.

On 24 January 1978, the re-entry and disintegration of *Cosmos-954* left radioactive debris over six hundred square kilometres of Canadian territory, equivalent in area to the size of Austria. *Cosmos-954* was launched by the Soviet Union on 18 September 1977 carrying a nuclear reactor using enriched uranium, or uranium-235. Its mission, along with its sister satellite *Cosmos-952*, was ocean surveillance for three weeks, after which they were to be boosted into a higher "parking" orbit to allow for the natural radioactive decay to occur over 600 years. However, *Cosmos-954* could not be boosted into its proposed higher orbit as a result of a malfunction that took place near the end of its mission.

During the time between the malfunction and the eventual re-entry of *Cosmos-954*, there were worldwide fears of nuclear explosions and the introduction of deadly hazards into the atmosphere. These fears were further intensified by the re-entry of *Cosmos-1402* in 1983 and that of *Cosmos-1960* in 1988 as well as the Earth flyby of the interplanetary probe *Cassini* in 1999 on its journey to Saturn. These events partly prompted a multidisciplinary effort to study various means to improve the safety of nuclear and radioisotopic power sources in scientific and engineering circles as well as the legal means for the regulation of the use of such power sources in space. Both aspects of these efforts continue today, as can be seen in the attention regularly given to the issue by both the Scientific and Technical Sub-Committee and the Legal Sub-Committee of the Committee on the Peaceful Uses of Outer Space ("**COPUOS**").

It is not surprising that discussions took place in 1978 on this issue in both subcommittees of COPUOS. A Working Group was created in the Scientific and Technical Sub-Committee in the same year to study the technical feasibility of establishing standards for radiation levels, restrictions on nuclear power sources, safeguards, precautions, early notification of re-entry and appropriate emergency assistance for search, recovery and clean-up operations.[4] At about the same time, the Legal Sub-Committee was similarly instructed to analyse safety measures, notifications and other legal aspects of using nuclear and radioisotopic power sources in space.

After years of study and development, it was not until 1992, however, that the NPS Principles were adopted by the General Assembly. As discussed below, this has the effect of filling in some of the gaps in the regulation of nuclear and radioisotopic power sources in space.

THE NPS PRINCIPLES AS CUSTOM

As considered below, the NPS Principles contain eleven provisions of which Principles 1, 6, 7, 8, 9 and 10 merely restate the application of provisions of existing treaties to nuclear power sources.

In the case of the new provisions, namely Principles 3 to 5, one would suggest that they are merely extensions of existing principles, such as Article IX of the Outer Space Treaty. In any event, the widespread acceptance by States of the underlying provisions and the absence of significant dissensions during the debates suggest that the NPS Principles may be considered to have crystallised into international law either at the time of their declaration or soon after.

DESIGN

The Outer Space Treaty requires States to avoid harmful contamination and adverse changes to the environment of the Earth resulting from the introduction of "extraterrestrial" matter.[5] Even if the re-entry of nuclear or radioactive material is not considered to be "extraterrestrial" in character, the Outer Space Treaty nevertheless requires States to undertake "appropriate international consultations" before proceeding with an activity that has the potential of causing harmful interference with the space activities of other States.[6] Therefore, it is clear that, at the very least, States will be obliged to enter into consultations with potentially affected States concerning the potential effects of the nuclear or radioisotopic power source *before* its launch.

Even if the Outer Space Treaty does not impose an obligation to take necessary measures to avoid potential harm to other States through nuclear and radioisotopic power sources, the NPS Principles impose significant conditions on the design of nuclear and radioisotopic power sources onboard spacecrafts. Generally, Principle 3 requires the probability of accidents with potentially serious radiological consequences must be kept extremely small. Further, foreseeable safety-related failures or malfunctions must be capable of being corrected or counteracted by procedural or automatic means.

Specifically, Principle 3 requires the design of spacecrafts to ensure "with a high degree of confidence that the hazards, in foreseeable operational or accidental circumstances, are kept below acceptable levels as follows:

- observance and compliance of appropriate standards imposed by the International Commission on Radiological Protection; and
- take into account relevant and generally accepted international radiological protection guidelines to limit exposure in accidents.

Further, Principle 3 requires spacecraft design to, "with a high degree of confidence, restrict radiation exposure" geographically and to individuals to the limit of 1 millisievert per year.

In the case of spacecrafts containing nuclear reactors onboard, Principle 3 allows reactors utilising uranium-235 to be used on interplanetary missions or in Earth orbit. Those in Earth orbit are required to be inserted into a "sufficiently high orbit" or will eventually be "parked" in a sufficiently high orbit after its mission. A "sufficiently high orbit" is defined as one where the risk of collisions with existing or future spacecrafts are kept to a minimum and sufficient time is given for the radioactive material to decay. There is no recommended minimum altitude specified, though one may have thought that such a provision may be prudent. The design of the spacecraft must ensure that critical mass is not attained being reaching its operational orbit, including explosions, re-entries, impact or the submersion in or intrusion of water.

In the case of radioisotopic fuel cells, Principle 3 permits their use only in interplanetary missions or in Earth orbit provided that ultimate disposal is made. They must be designed with a system of containment that will withstand the heat and other conditions of re-entry and impact on the surface of the Earth or water to ensure that no radioactive material may be scattered into the atmosphere, the ocean or the soil. It appears from this that the international community considers radioisotopic power sources to be potentially more dangerous than nuclear reactors. This is likely to be the result of concerns over the long radioactive half-life and the potency of plutonium-238 and other radioisotopic materials.

Principle 4 requires the launching State which, for the purposes of the NPS Principles, is defined as the State exercising jurisdiction and control over a space object with a nuclear power source onboard, to conduct a safety assessment to ensure that the requirements of Principle 3 have been met.[7] Both Article XI of the Outer Space Treaty and Principle 4 of the NPS Principles require the results of the safety assessment to be publicised before the launch.

It has been highlighted that the NPS Principles do not provide for the appropriate measures to be taken where a third State disagree with the safety assessment of a nuclear power source to be launched.[8] This is partly because the concurrence of third States is not necessary for a space object containing a nuclear power sources to be launched. Presumably if a third State did indeed disagree with a safety assessment, Article IX of the Outer Space Treaty may be invoked to require relevant consultations to be held between the States concerned.

LAUNCH

In essence, the legal principles relating to the launch of a space object containing a nuclear power source is no different to those relevant to the launch of a solar or chemical powered spacecraft. For example, Article VI of the Outer Space Treaty applies to require States to bear international responsibility for "national" space activities and to authorise and continually supervise the space activities of non-governmental entities. Indeed, the application of Article VI has been affirmed by the NPS Principles.[9]

Similarly, the Registration Convention and General Assembly Resolution 1721B of 1961 require one of the States responsible for launching the space object to make an entry for it in its national register of space objects as well as that of the United Nations.[10] States are required to provide information relating to the orbital parameters and the launching State(s) of the space object.[11] The Registration Convention does not require the State of registry to submit details of the power source onboard.

OPERATION

Article IX of the Outer Space Treaty requires States to conduct all their activities in outer space with "due regard to the *corresponding* interests of all other State Parties to the Treaty". It may be argued, as often does by students in the Manfred Lachs Space Law Moot Court Competition of the International Institute of Space Law, that this provision imposes a general duty on the part of States to take all reasonable steps to avoid causing damage to the property of other States. However, the better proposition appears to be that the word "*corresponding*" is used in a limiting context with the effect of confining the duty to the rights of other States to conduct space activities.

Even within such contextual limits, however, it appears that States operating space objects containing nuclear or radioisotopic power sources is required to have due regard to the space activities conducted by other States. Although unclear, this may have the effect of requiring States to avoid collisions and radiation damage to other space objects.

Further, Article VIII requires the State of registry to retain jurisdiction and control over the space object.[12] As only one State can effectively exercise control and jurisdiction over a space object or a component thereof at any one time, where there are multiple launching States the Registration Convention requires them to agree among themselves which one was to be the State of registry.[13] This is particularly relevant in the context of the NPS Principles, which defines a "launching State" not as the States involved in the launch of the space object but rather the State exercising control and jurisdiction over the space object. Although the Registration Convention allows the State of registry to submit additional information to the United Nations concerning a space object, it is often suggested that an amendment requiring States to provide details of any nuclear and radioisotopic power source onboard may be appropriate.

ACCIDENT AND DISTRESS

Neither the Registration Convention nor the Rescue Agreement requires States to publicise information concerning space objects that have malfunctioned and have a risk of re-entry into the atmosphere. In recognition of this, the NPS Principles require a launching State (defined as the State with jurisdiction and control) to inform States concerned and the United Nations of a malfunctioning space object with a nuclear power source onboard that has a risk of re-entry to the Earth as soon as the malfunction is known.[14] The information must be updated "as frequently as practicable", especially when the anticipated time of re-entry approaches to enable States to have sufficient time to prepare responses.[15]

In addition to the information submitted pursuant to the Registration Convention, the NPS Principles require information about the type of nuclear power source and the "probable physical form, amount and general radiological characteristics of the nuclear material and the components that are likely to reach the surface of the Earth.[16] The launching States are further required to, as far as reasonable practicable, "respond promptly to requests for further information or consultations sought by other States".[17]

The NPS Principles require *all* States with space monitoring and tracking facilities to communicate any relevant information on the malfunctioning space object to the United States and the States concerned to enable assessments and the planning of precautionary measures.[18] Upon re-entry, States with returned components are required under the Rescue Agreement to take effective steps immediately to eliminate potential danger or harm.[19] To this end, there is an obligation to provide all necessary assistance to eliminate actual and potential harmful effects and to carry out recovery and clean-up operations.[20] This obligation is imposed under the Rescue Agreement on the States responsible for the launch and under the NPS Principles on the State having jurisdiction and control over the space object.

LIABILITY FOR DAMAGES

The Outer Space Treaty provides that the States responsible for the launch are liable for damage to another State.[21] This is supplemented by the provisions of the Liability Convention which provides for absolute liability for damage caused on the surface of the Earth and to aircraft in flight and fault liability for damage caused in outer space and on celestial bodies.[22] Where there is more than one State responsible for the launch, their liability under the Liability Convention is joint and several.[23] These requirements are repeated in the NPS Principles in the context of space objects with nuclear and radioisotopic power sources onboard.[24]

The Liability Convention provides that the compensation payable by the States responsible for the launch is to be determined in accordance with the principles of justice and equity to the extent necessary to restore the victims to their positions before the damage occurred, or *restitutio in integrum*.[25] This is the same formulation as prescribed by the Permanent Court of International Justice in the *Chórzow Factory Case*.[26] The same formulation can be found the NPS Principles.[27]

In relation to the costs of the recovery and the clean-up, the Rescue Agreement and the NPS Principles contain two substantially identical but procedurally different provisions. Under the Rescue Agreement, the expenses incurred for the recovery and return of the components of the space are to be reimbursed by the States responsible for the launch.[28] The costs of the clean-up and other steps taken to eliminate the hazardous nature of the returned components are excluded from this reimbursement provision. Presumably this is because the costs of the recovery and return are technically not "damage", while the clean-up costs of eliminating hazardous materials are necessarily "damage". Consequently, it is appropriate to establish a head of liability for recovery costs that is separate to that for damage.

The NPS Principles, on the other hand, provide that the compensation payable by the launching States in accordance with the Liability Convention and the Outer Space Treaty includes the reimbursement for "duly substantiated expenses for *search, recovery* and clean-up operations, including expenses for assistance received from third parties".[29] This means that, subject to the added requirement of "duly substantiating" the expenses, these costs are to be considered part of the "damage" to be compensated by the launching States. If the above analysis relating to the Rescue Agreement is correct, then the two provisions are clearly inconsistent. While this produces a procedural discrepancy, in practice it is doubtful that the relevant States concerned would make two separate claims relating to recovery costs and the damage arising from the return of a space object.

NUCLEAR PROPULSION

One issue of particular concern to space lawyers in this field is the utilisation of nuclear power sources for propulsion. The preamble to the NPS Principles specifies that:

> ... this set of Principles applies to nuclear power sources in outer space devoted to the generation of electric power on board space objects for non-propulsive purposes ... this set of Principles will require future revision in view of emerging nuclear-power applications and evolving international recommendations on radiological protection.

While it may be suggested that this has the effect of prohibiting nuclear or radioisotopic propulsion in space, this interpretation is not supported by the wording of the above paragraphs as well as the reference to the need for revision to cover "emerging" applications. In practice, this means that only the existing general principles in the treaties would apply to such a space object and the safety requirements of the NPS Principles would have no application.

CONCLUSIONS

It is clear from the above analysis that the space treaties, as supplemented by the NPS Principles, have created a body of law substantially adequate in addressing the safety concerns with the use of nuclear and radioisotopic power sources in space. At the same time, it should be recognised that this must be a continuing endeavour, especially in the context of the Registration Convention and nuclear propulsion, to ensure that the legal protection afforded the international community does not diminish over time as a result of technological developments.

Notes

This paper is written in the personal capacity of the author and does not necessarily represent the views of any organisations with which he is associated.

* Principal, Ricky J. Lee & Associates and Lecturer, School of Law, University of Western Sydney, Australia. Member IISL, IBA and ILA. Email: rjlee@rickylee.id.au.

[1] Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Over Water (1963) 480 UNTS 45.
[2] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (1967) 610 UNTS 205.
[3] Bennett, "Space Applications" in Rowe (ed.), *CRC Handbook of Thermoelectrics* (1995) at p. 515.
[4] COPUOS, *Report on the Fifteenth Session of the Scientific and Technical Subcommittee* (1978) U.N.Doc. A/AC.105/216, at 28-32.
[5] Outer Space Treaty, Article IX.
[6] *Ibid.*
[7] NPS Principles, Principle 2.
[8] COPUOS, *Report of the Chairman of the Working Group on Agenda Item 3* (1993) U.N.Doc. A/AC.105/544.
[9] *Ibid.*, Principle 8.
[10] Registration Convention, Articles II and IV.
[11] *Ibid.*, Article IV.
[12] Outer Space Treaty, Article VIII.
[13] Registration Convention, Article II.
[14] NPS Principles, Principle 5(1).
[15] *Ibid.*, Principle 5(2).
[16] *Ibid.*, Principle 5(1).
[17] *Ibid.*, Principle 6.
[18] *Ibid.*, Principle 7(1).
[19] Rescue Agreement, Article 5(4).
[20] Rescue Agreement, Article 5(4) and the NPS Principles., Principle 7(2).
[21] Outer Space Treaty, Article VII.
[22] Liability Convention, Articles I and II.
[23] *Ibid.*, Article V.
[24] NPS Principles, Principle 9(1).
[25] Liability Convention, Article XII.
[26] *Case Concerning the Factory at Chórzow (Claim for Indemnity) (Merits)* (1928) PCIJ Ser. A, No. 17.
[27] NPS Principles, Principle 9(2).
[28] Rescue Agreement, Article 5(5).
[29] NPS Principles, Principle 9(3).