USE OF NUCLEAR POWER SOURCES IN OUTER SPACE: KEY TECHNOLOGY LEGAL CHALLENGES

Isabelle Bouvet[*]

I. INTRODUCTION

The Sun and chemical combustion are two sources currently used in space activities to produce thrust. Solar radiation may also be converted into electric energy by using solar cell panels, as long as they are exposed to solar radiation. When the distance from the sun is decreasing, light waves from the Sun become less powerful for space missions as the conversion into energy is progressively reaching its limit. Chemical thrust remains a significant source of energy, especially for launch purposes. However, these sources of energy are considered insufficient to allow deep space exploration; specialists call for the development of new technologies in this area.

The design and test of new vehicles and the need to find a reliable source of energy for long-term duration flights are among the important priorities needed to develop and enhance exploration missions. Potentially, nuclear sources could be used to serve space mission requirements that cannot be covered by current sources of energy.

The risks involved in the use of this source of energy for space missions, from the time of the launch, through the injection into orbit, and during the life of the spacecraft around the Earth, or during its trip into deep space, have generated a challenging legal debate culminating in the 1992 adoption of the Principles Relevant to the Use of Nuclear Power Sources in

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[*] LL.M. in Air and Space Law, McGill University, Montreal, Canada. European Center for Space Law (ECSL) and International Institute of Space Law (IISL) Member. Centre National D'Etudes Spatiales (CNES) Directorate for Strategy and Programmes. The present article reflects exclusively the opinion of the author and not that of the institution she belongs to or is connected with. The authors would like to thank Pascal Pempie and Christophe Bonnal for their support.

Outer Space (NPS Principles) under the form of an UN Resolution, a non-binding legal document.

The Twenty-first Century is starting with some very challenging exploration projects where technological breakthroughs will play a key role. In order to understand the technical issues behind the use of technology, it is helpful to review the types of nuclear power sources (Part 1). Analysis of the legal framework and implications that follow from the use of Nuclear Power Sources (NPS) will then be analyzed (Part 2).

II. NUCLEAR POWER SOURCES, A KEY TECHNOLOGY FOR SPACE ACTIVITIES

A. *Basic Mechanisms*

Two types of nuclear energy are commonly considered for space applications: radioisotopes (a source of heat and electricity consisting of hundreds of Watts) and nuclear generators (source of electricity and propulsion, depending on its use (hundreds of kWs to MWs)). These sources of energy continue to be used for the operation of on-board instruments, but not for propulsion purposes.

These technologies, radioisotope heating units (RHUs) and radioisotope thermoelectric generators (RTGs) have been used to keep the thermal equilibrium of some of the on-board equipment, as well as to provide electricity. In the case of RTG, conversion processes are required to transform the heat into electricity. The RTG's electrical source is used for direct electricity needs or for ionic or plasma propellers. For those operations, the level of electricity is not very high, around only a few hundred Watts. However, radioisotope power sources have a low power density. On-board production of electricity is considered a satisfactory spacecraft technology, and because it is a static unit, is notably more attractive from the reliability point of view.[1]

Through the controlled fission of atomic nuclei, a nuclear generator can develop thermal energy. At the beginning of the

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[1] Nikolai Tolyarenko, *Power*, *in* KEYS TO SPACE: AN INTERDISCIPLINARY APPROACH TO SPACE STUDIES 8-9 (A. Houston & M. Rycroft, eds., 1999).

Space Age in the 1960s, energy reactors began to be used for space propulsion tests on the ground. The initial technologies used were thermal nuclear propulsion and electrical nuclear propulsion. Power is generated in fuel by fission reactions. Fission is a nuclear reaction in which an atomic nucleus splits, or fissions, into fragments, usually two fragments of comparable mass, resulting in release of large amounts of energy in the form of heat and radiation. The process not only produces energy, but also additional neutrons that can be used to split other uranium nuclei, produce more neutrons, and start a chain reaction. The power is transferred to conversion systems to become electricity and then sent to the propulsion subsystem. The resulting electricity is converted into thrust by accelerating propellant-derived plasma.

The power level in case of nuclear generators is much higher than for RTGs (hundreds of kWatts) and is capable of overcoming the limitations of other power sources. Due to the high-performance of electric propulsion, specialists consider that nuclear fission has the potential for the greater capability necessary to explore our solar system. This more efficient technology shall both shorten interplanetary trip transfer times and support robotic and human lunar and Mars missions.

When looking at which different types of propulsion nuclear rockets shows the highest Isp, for example, the Isp is 450 seconds when the source of energy comes from a chemical reaction. It increases to 900 seconds[2] for direct fission. The nuclear generator may be designed with a gas core or a liquid core. Radioactivity requires working on a closed cycle in the first case, consequently decreasing the Isp in a significant way (7000 seconds with an open cycle and 1550 seconds for a closed cycle). Additionally, technical solutions for the reactor core will depend strongly on the fuel type.

[2] GEORGE P. SUTTON & OSCAR BIBLARZ, ROCKET PROPULSION ELEMENTS 11 (John Wiley and Sons, eds., 7th ed. 2001).

B. Programs in Different Countries

The first mission that launched a spacecraft powered by radioactive material into space was in 1961 by the U.S. Navy. Since then, more than fifty missions have taken place.

In Russia, a significant number of spacecraft powered by nuclear power plants (NPP) have been launched into near Earth orbit. Russia has also worked on a prototype nuclear rocket engine that was tested on the ground. In 1987-1988, the former Soviet Union developed *Topaz*. The electricity from the *Topaz* system was used to power an electric propulsion subsystem, based on thermionic energy conversion and providing 5kW of power. It was tested in flight. Between 1985 and 1994, *Topaz-2* was built (6kW thermionic NPP) and experimental studies took place in the United States within the Nuclear Electric Propulsion Space Test Program (NEPSTP).

In France, experiments on nuclear generators for electric and thermal propulsion purposes took place in the 1980s (ERATO and MAPS project). The ERATO[3] project's goal was to obtain a technological and design basis to enable comparisons with classical means of energy production. Studies on electronuclear reactors took place from 1982 to 1989. More recently, studies were conducted on nuclear thermal propulsion in the MAPS project, with CNES co-sponsorship.

In the United States, SNAP reactors were experimented with between the 1960s and the 1970s, and several tests were even conducted on the ground. In 1965, one reactor flew in Earth orbit. Although the nuclear generator operated in space, it was shutdown because of an electrical malfunction. All other U.S. missions with NPS were RTG based. In the 1997 *Cassini* mission, NASA sent an RTG on-board. In the U.S., NPS was used in numerous space missions[4] and each of the flown NPS

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[3] Pascal Pempie, *Association Aéronautique et Astronautique de France International Space University, Short Course on Nuclear Rocket Thermal Propulsion* (Centre National d'Etudes Spatiales, May 2002).

[4] Examples of U.S. space missions using NPS: *Nimbus* in 1968 (the vehicle was destroyed during the launch); *Apollo* in 1969-1972; *Pioneer 10* and *Pioneer 11* in 1972; *Viking 1* and *Viking 2* in 1975; *Voyager 1* and *Voyager 2* in 1977; *Galileo* in 1989; *Ulysses* in 1990; and *Cassini* in 1997.

systems respected a very detailed safety procedure. Depending on the mission, the energy needed may range from a few kWs to thousands of kWs in the distant future. In terms of missions for low Earth orbit and geostationary transfer orbit, chemical propulsion remains the best choice. For crewed planetary missions, high Isp is necessary to shorten the duration of the journey. Specifically, in these cases, nuclear thermal rockets are considered suitable technology, but are not required for automatic missions, where there are no constraints on the travel duration.[5] Nuclear electric power may be used in space to produce electricity on-board as well as for energy on the surface of a planet, e.g., on Mars. The major difficulty faced by engineers in the early stages of the space developments was to fly the newly-created technology. Although many projects were developed in the span of 40 years, none flew successfully, except for the U.S. SNAP-10A program. It is important to underline that alternative technology also has a promising future. The U.S. project, Variable Specific Impulse Magneto Plasmic Rocket (VASIMR), uses plasma to create extremely high impulse thrust through a magnetic process.

The objective of NASA's new initiative in 2003, Nuclear Systems Initiative (NSI), was to enable significantly enhanced science-driven solar system exploration. The proposed NASA NSI contains two elements: Radioisotope Power Systems Development, and Nuclear Fission Electrical Power and Propulsion Research and Development.

On January 14, 2004, U.S. President Bush established a new vision for U.S. exploration.[6] The fundamental goal of this new exploration vision is to advance U.S. scientific, security and economic interests through a robust space exploration program. Among the policy goals are the development of innovative technologies, knowledge, and infrastructures both to explore and to support decisions about destinations for human exploration. A new Exploration Systems Enterprise was created to support the

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[5] *See* Pempie, *supra* note 3.

[6] *See* President George W. Bush, Renewed Spirit of Discovery, The President's Vision for U.S. Space Exploration, White House Press Release (Jan. 14, 2004) *available at* http://www.whitehouse.gov/space/renewed_spirit.html (last visited Sept. 13, 2004).

development of new crew transport capabilities, namely the *Crew Exploration Vehicle*, as well as other exploration systems and technologies. It was planned that this enterprise would work in close liaison with the Space Science Enterprise[7] to use the Moon as a testing ground for solar system exploration vehicles and technologies.[8] To enable the success of this enterprise,[9] constraints of distance, energy and time must be overcome.

Within the definition of new priorities NASA reinforced the NSI that is now relayed by the *Prometheus* project.[10] *Prometheus* belongs to the Exploration Enterprise.[11] NASA's Project *Prometheus* is designed to develop the technologies needed to enable this vision for the future. There are two basic types of technologies under consideration for this program, radioisotope-based systems and nuclear fission-based systems. Radioisotope Power System (RPS) development would focus on two technologies, the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) and the Stirling Radioisotope Generator (SRG). The fission power and propulsion research would focus on developing the nuclear systems needed for revolutionary new capabilities in space exploration. Project *Prometheus* would include research on reactors, advanced heat-to-power conversion, and power management and distribution technologies to provide spacecraft flexibility, long-mission durations, and significantly more power for science instruments. The program has also identified a planetary science mission that will be uniquely enabled by nuclear fission electric power and propulsion: the *Jupiter Icy Moons Orbiter*. It would be an ambitious mission to orbit three planet-sized moons of Jupiter - Callisto, Ganymede and Europa

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[7] The Space Science Enterprise will include six themes: solar system exploration, Mars exploration, Lunar exploration, astronomical search for origins, structure and evolution of the universe and Sun-Earth connection.

[8] Since August 1, 2004, NASA has a new organization where the Exploration Systems Mission plays a major role.

[9] The Exploration Systems Enterprise has been allocated $13.4 billion (U.S.D.) over the next five years.

[10] In Greek mythology, Prometheus was the wisest of the Titans who gave the gift of fire to humanity.

[11] In NASA Fiscal Year 2005, $438 million (U.S.D.) are requested for Project Prometheus to develop advanced nuclear technologies for power and propulsion.

- which may harbor vast oceans beneath their icy surfaces. *Prometheus* constitutes a significant extension of the NSI.

C. *Risk and Safety Measures*

Although living organisms are exposed to natural environmental radiation, a significant higher amount of radiation could constitute a serious risk, should this source of energy reach living organisms and humans. Since the discovery of X-Ray technology in 1885, these risks have been increasingly underlined. Established in 1955, the mandate of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) is to assess and report levels and effects of exposure to ionizing radiation.[12] In its 1972 and 1977 reports, two categories of effects to radiation exposure were identified, somatic effects for an irradiated individual and genetic effects for their progeny.[13] In the 2001 report,[14] UNSCEAR reviewed the hereditary risks that follow parental exposure to radiation. Radiation causes damage to the cells as a result of radiation interactions and radiation exposure. Living organisms can tolerate the natural radiation environment, but this is no longer the case when the amount of radiation is too high. The associations between radiation exposure and the development of cancer are predominantly based on populations exposed to relatively high levels of ionizing radiation.

In space, a primary risk on board the satellite comes from the material that composes the different forms of NPS: basically plutonium and uranium.[15] These sources of energy contain a large amount of radioactive material and require the adherence to stringent safety requirements. These requirements will depend on the source of energy used and the purpose for which it is used, such as heating processes, on-board electricity power, or

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[12] Regular reports are published by the U.N. Scientific Committee on the Effects of Atomic Radiation, *available at:* http://www.unscear.org/ (last visited Sept. 13, 2004).

[13] MARIETTA BENKÖ, WILLEM DE GRAAF & GIJSBERTHA C.M. REIJNEN, SPACE LAW IN THE UNITED NATIONS, 64-68 (Martinus Nijhoff Publishers 1985).

[14] *Hereditary Effects*, United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR 2001 Report to the General Assembly (Oct. 2001).

[15] The recent U.S. *Cassini* mission contained over seventy-two (72) pounds of plutonium.

propulsions purposes. Moreover, each sequence of a space mission (launch, placement into orbit, life, end of life, reentry) will require specific safety measures. In 1964 in the U.S., an RTG, SNAP-9A, burned into the atmosphere and the dispersion and dilution of the material in the atmosphere successfully prevented dense radioactivity from falling on the ground. In 1968, a second U.S. RTG, SNAP-19, was recovered in the ocean. In this situation, the NPS had been put in containment to avoid the dispersion of the radioactivity. In 1968, the *Nimbus* B-1 satellite was destroyed, along with the rocket. A different method used for SNAP-10 consists of putting the satellite in a very far-distant orbit, largely reducing any long-term reentry risk.

In Russia, a significant number of satellites using nuclear generators have been utilized. In the famous 1978 case of *Cosmos 954*, a Soviet satellite which re-entered in Canadian territory, the impact did not occur near human presence. In a second accident involving the Soviet craft *Cosmos 1402*, radioactivity was dispersed in the high atmosphere over the ocean.

Each of the above-mentioned cases demonstrated an inherent amount of risk. Scenarios can be imagined where the dilution and dispersion would not be sufficient if the size of the radioactive particles remained too big, or a radioactive cloud could expose humans to the effects of radiation. Additionally, when RTGs are contained in a specific material or cased, considering the long life duration of that radioactive energy, an accident could still happen, such as an explosion or high impact collisions and provoke RTG leakage. These are worst-case scenarios and fortunately have never been experienced. However, the goal is to show that despite successful past experiences, risks should never be underestimated. RTG risk exists at both the launching and re-entry phases. In the case of nuclear generators, as long as the reactor has not been activated at the time of the launch, the re-entry phase may represent the only period of radiation risks.

For obvious reasons, safety requirements are of highest importance in space missions. RTGs are fuelled with radioactive material and emit ionizing radiation. The energy produced progressively decreases until the spacecraft system no longer has power. Safety measures include such necessities as placing the

RTG in a specific containment system to immobilize the radioactive material. Using the necessary technology can prevent accidents on Earth in case of a re-entry failure.

A nuclear generator is not considered dangerous as long as it has not been activated and the fission process has not started. However, radioactive material may have negative effects for an extremely long time. Furthermore, compared to RTGs, the range of radiation is much broader. Consequently, any crash on Earth must be avoided.[16] The first necessary safety measure is to ensure the reactor is not activated until the spacecraft has reached its planned orbit. One of the interesting properties of these nuclear generators is that they are capable of lasting for hundreds of years. If a satellite is put in an orbit below 2000 km, risk is incurred at the end of the satellite lifetime and reentry before a sufficient radioactivity decrease has occurred. One of the techniques the Soviets used to mitigate this problem after the *Cosmos 954* accident was to separate the radioactive part of the spacecraft and put it in a distant orbit. Back-up procedures would also ensure that, should this process fail, the fuel would be dispersed at a very high altitude. As already stressed by authors,[17] this process involves risk since the radioactivity would not be entirely spread out that it can be either placed in an orbit distant from the Earth, or dispersed in the Earth atmosphere at a high altitude. No clear evidence has been given on the radioactive danger represented by the second option and the ground effects of this radioactive energy.

Safety measures need to be clearly defined at the national level. In the United States, safety measure reviews include close collaboration between the U.S. Department of Defense, the Department of Energy (DoE) and NASA. A preliminary Safety Analysis Report (SAR) is prepared after an initial design is selected for the mission. The SAR is regularly published during the developmental phase of the mission design. In addition to internal agency reviews, a safety review panel, called the Interagency Nuclear Safety Review Panel, is set up and supported by experts from government, industry and academia. Chaired by

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16 *See* Benkö, SPACE LAW IN THE UNITED NATIONS, *supra* note 13.
17 *Id.*

the three coordinators appointed by the Secretary of the Department of Defense, the administrator of NASA and the Secretary of the Department of Energy, the review panel provides an independent risk evaluation assessment. It is important to underline the level of depth with which this work is assessed; all potential risks are carefully reviewed for each phase of the mission.[18] Based upon agency and DoE recommendations, NASA may request nuclear safety launch approval to the White House Office of Science and Technology Policy (OSTP). The decision to approve the launch belongs to the OSTP Director. Clearly, this process has proven to be very efficient. Failures were handled in such a way that no accident occurred that was detrimental to human life.

Although mechanisms are extremely well defined to ensure the highest level of safety, there may be some cases where the RTG shield is broken, producing leaks. For 40 years, NPS technology has constituted a major achievement for space activities, notably for exploration purposes. Despite few accidents, nuclear power sources have been used with the strict and full respect of safety requirements in existence. However, as with any human action, risk exists. When studying high-risk technology, analysis is often made of the benefits this technology brings, and statistics are used to evaluate whether foreseeable risks are acceptable in light of the ultimate result reached. Localized risks are circumscribed to a specific territory. In the case of outer space activities, one should keep in mind that the radioactive material are above the oceans, territories and airspace of numerous countries, which, as a consequence, are incurring risks without having been informed.

The study of nuclear technology and space activities at the beginning of the Twenty-first Century is of particular importance. Despite already strong experience in the field, until now NPS was used mainly for on-board equipment in space exploration projects. Now, with only a few years before the realization

[18] *See* Don Williamson, Jr., *Process to Launch Nuclear Power Sources into Space, An Overview of the Process Necessary to Choose and Launch Nuclear Power Sources into Space,* 10 (May 2000), *available at* http://fti.neep.wisc.edu/neep602/SPRING00/TERMPAPERS/williamson.pdf (last visited Sept. 13, 2004).

of the International Space Station core completion, major space faring nations, starting with the United States, are looking at the next step: space activities beyond near Earth orbit. In the preparation for these new challenges as detailed above, nuclear power sources have been identified as a key technology and significant budget allocations are planned to be made towards their development. However, legal requirements at both the international and national levels will not be neglected and will have an increasing role to play. At the same time, although this energy was identified, it is still necessary to further explore alternative power sources.

III. Legal Principles Governing Nuclear Power Sources

A. *International Law*

Immediately after the *Cosmos 954* accident in 1978, a working group was established within the Scientific and Technical Subcommittee of UNCOPUOS (STSC). The group issued its report in 1981.[19] In the 1980s, the issue was discussed in different fora in order to identify the legal measures needed. Two conventions were adopted on September 26, 1986: the Convention on Early Notification of a Nuclear Accident (Notification Convention)[20] and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (Assistance Convention).[21]

Under the Notification Convention, in the event of a nuclear accident, States' Parties shall notify, directly or through

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[19] In 1979, in accordance with G.A. Res. 33/16 (Nov.10, 1978), the Scientific and Technical Subcommittee established a Working Group of experts to consider the technical aspects and safety measures relating to the use of NPS in outer space. *See* Vladimir Kopal, *The Use of Nuclear Power Sources in Outer Space: A New Set of United Nations Principles?*, 19 J. SPACE L. 103, 104 (1991).

[20] Convention on Early Notification of a Nuclear Accident, Sept. 26, 1986, art. 2, IAEA Doc. INFCIRC/335, *available at* http://www.iaea.org/Publications/Documents/Infcircs/Others/inf335.shtml (last visited Sept. 13, 2004) [hereinafter Notification Convention].

[21] Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, Sept. 26, 1986, IAEA Doc. INFCIRC/336, *available at* http://www.iaea.org/Publications/Documents/Infcircs/Others/inf336.shtml (last visited Sept. 13, 2004) [hereinafter Assistance Convention].

the International Atomic Energy Agency (IAEA) those States which are, or may be, physically affected.[22] They must provide information about the nuclear accident, its nature, the time of its occurrence and its location.[23] The objective is to provide relevant information about nuclear accidents as early as possible in order that transboundary radiological consequences may be minimized. The use of radioisotopes for power generation in space objects is expressly mentioned in the scope of the Convention.[24] The objective of the Assistance Convention is to facilitate prompt assistance in the event of a nuclear accident or radiological emergency; to minimize its consequences; and to protect life, property and the environment from the effects of radioactive releases.[25] The goal of this Convention is to minimize the consequences of the accident, protect life, property and the environment from the effects of radioactive releases. Furthermore, this Convention provides that a State Party needing assistance in the event of a nuclear accident or radiological emergency may call for such assistance from any other State Party, directly or though the IAEA.[26] The Convention provides of set of rules on assistance that will be applicable to accidents caused by NPS use in outer space.[27]

B. *International Space Law*

Space law treaties provide a set of rules to ensure the peaceful use of outer space. Broadly defined, many articles are applicable to the use of NPS in outer space and a few are presented here.

According to the terms of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty), States bear international responsibility for national activities in outer space, the Moon and other celestial

[22] Notification Convention, *supra* note 20, at art. 2.
[23] *Id.* at art. 2 (a).
[24] *Id.* at art. 1.
[25] Assistance Convention, *supra* note 21, at art. 1.1.
[26] *Id.* at art. 2.1.
[27] *Id.* at arts. 2-19.

bodies.[28] Article IX provides that States shall be guided by the principle of cooperation and mutual assistance and shall conduct all their activities with due regard to the corresponding interests of all other States. States shall conduct exploration so as to avoid harmful contamination or adverse changes in the Earth's environment. In Article XI, State Parties conducting space activities shall inform the Secretary-General of the UN of the nature, conduct, locations and results of such activities. This issue is linked to the question of advanced notification of the use of NPS in outer space. Such a specific provision addressing this issue was not included in the NPS Principles, nor is it mentioned in the Convention on the Registration of Objects Launched into Outer Space.[29] Apart from the specific information the State needs to furnish,[30] the "general function of the space object" is mentioned but the nuclear power source is not specified. This gap is regrettable because the Convention has a stronger legal value than the NPS Principles. Finally, the Outer Space Treaty prohibits the use of nuclear weapons.[31]

The Convention on International Liability for Damage Caused by Space Objects (Liability Convention),[32] provides that a launching State shall be absolutely liable to pay compensation for damage caused by its space object on the surface of the Earth or to aircraft in flight.[33] The term "damage" means loss of life, personal injury or other impairment of health; or loss of or damage to property of States or of persons, natural or juridical, or property of international intergovernmental organisations.[34] Clearly, if an accident occurs because of the use of NPS in outer space, this provision will apply. The Liability Convention recog-

[28] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, Jan. 27, 1967, art. VI, 610 U.N.T.S. 205 [hereinafter Outer Space Treaty].

[29] Convention on Registration of Objects Launched into Outer Space, adopted on Nov. 12, 1974, GAOR, 1023 U.N.T.S. 15.

[30] Such as the name of the launching State, date and location of launch, and the basic orbital parameter.

[31] Outer Space Treaty, *supra* note 28, at art. IV.

[32] Convention on International Liability for Damage Caused by Space Objects, Mar. 29, 1972, 24 U.S.T 2389, T.I.A.S No. 7762 [hereinafter Liability Convention].

[33] *Id.* at art. II.

[34] *Id.* at art. I (a).

nizes the need to ensure the prompt payment of a full and equitable measure of compensation to victims of such damage.[35]

Harmful contamination through the introduction of extra-environmental matter on the Moon and other celestial bodies could introduce adverse environmental changes. The Agreement Governing the Activities of the States on the Moon and other Celestial Bodies (Moon Agreement) states that States' Parties shall take measures to prevent the disruption of the existing environmental balance.[36]

C. *The United Nations Committee on the Peaceful Uses of Outer Space and the 1992 Principles Relevant to the Use of Nuclear Power Sources in Outer Space*

1. The NPS Principles

Discussed since 1978 by delegates at the Legal Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space (LSC) the use of nuclear power sources in outer space became a specific item of the agenda in 1980.[37] In 1990, the Committee on the Peaceful Uses of Outer Space (COPUOS) started to define some provisions for an NPS legal regime, notably Principle 3, guidelines and criteria for safe use.[38] On December 14, 1992 the UN General Assembly unanimously adopted the Principles Relevant to the Use of Nuclear Power Sources in Outer Space.[39] It is interesting to note that these Principles and the Outer Space Treaty were adopted before the activities themselves occurred. Although NPS was used by the main space-faring nations and, at times even governed by provisions at national levels, no specific legal document at the international

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[35] *Id.* at Preamble.

[36] Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, Dec. 5, 1979, Art 7.1, U.N. GAOR, Doc. A/RES/34/68 [hereinafter Moon Treaty].

[37] *See* Eilene Galloway, *United Nations Consideration of Nuclear Power for Satellites,* in PROCEEDINGS OF THE TWENTY-SECOND COLLOQUIUM ON THE LAW OF OUTER SPACE 131 (1979).

[38] *See* Nandasiri Jasentuliyana, *The Legal Sub-Committee of COPUOS Achieves Progress in the Legal Dimension in Outer Space Activities,* 18 J. SPACE L. 35 (1990).

[39] Principles Relevant to the Use of Nuclear Power Sources in Outer Space, Dec. 14, 1992, U.N. Doc. A/Res/47/68 [hereinafter NPS Principles].

level existed. Resolutions do not have a binding force; however, the recognition at the international level of the utility of NPS is a major milestone in the development of international space law.

As previously discussed, nuclear power sources involve different types of energy, and when dealing with outer space, the main types of energy are RTG and nuclear generators. One of the major drawbacks of the NPS Principles is the lack of textual mention of all the NPS used in outer space. The text limits its application to generation of electric power on board space objects, without referring to nuclear propulsion. Consequently, the Principles only partly cover NPS use in outer space.

To minimize the quantity of radioactive material in space and the risks involved, the use of nuclear power sources is restricted to space missions that cannot be reasonably operated by non-nuclear energy sources.[40] The provisions call for very careful utilization of the radioactive material without providing specific technical constraints. Recognizing the need to protect the biosphere against radiological hazards, the provisions accept the existence of hazards in "foreseeable operational or accidental circumstances" as long as those hazards are "kept below acceptable levels". Radioactive material shall not cause a "significant contamination of outer space".[41] "[G]enerally accepted" relevant international radiological protection guidelines "shall" be taken into account. The valuable recommendations made by the International Commission on Radiological Protection will serve as the baseline scenario.[42]

The design for the nuclear power source systems restricts radiation exposure to a "limited geographical region" and to individuals to the principal limit of "1 mSv in a year".[43] This level, used for terrestrial application of NPS, is very low for safety reasons, and is considered to be the maximum permissible radiation dose tolerable by humans. Another important mechanism is the in-depth defense. According to Principle 3.1 (d),

[40] *Id.* at Principle 3.
[41] *Id.* at Principle 3.1 (a).
[42] *Id.* at Principle 3.1 (b).
[43] *Id.* at Principle 3.1 (c).

foreseeable safety-related failures or malfunctions "must be capable of being corrected or counteracted by an action or a procedure, possibly automatic".

Principle 3.2 recognizes the usefulness of nuclear generator operations in interplanetary missions, in low-Earth orbits if they are stored in sufficiently high orbits after the operational part of their mission, and in "sufficiently high orbit in which the orbital lifetime is long enough to allow for a sufficient decay of the fission products[...]".[44] Also, it must be of "minimum" danger to "existing and future outer space missions" and pose a "minimum" risk of collision with other space objects.[45] When measuring this orbit, decay time needed before re-entering in the atmosphere is taken into account.[46] Nuclear generators "shall use only highly enriched uranium 235 as fuel."[47] Clearly, the intention is the prevention of the use of other nuclear fuels in outer space for safety reasons. Furthermore, nuclear power sources "shall not be made critical before they have reached their operating orbit or interplanetary trajectory."[48] These two requirements are significant steps in the elaboration of NPS Principles.

The design and construction of the nuclear generators meet important safety criteria by ensuring that nuclear generators are not critical before reaching the operating orbit "during all possible events, including rocket explosion, re-entry, impact on ground or water, submersion in water or intrusion of water into the core".[49]

Limits are defined as 1 mSv in a year of enriched 235 uranium, but there are no detailed specifications. The provisions are such that the designer and operator have the responsibility to build the reactor according to these limitations. Those provisions highlight the enormous burden of responsibility placed on States intending to launch.[50]

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[44] NPS Principles, *supra* note 39, at Principle 3.2 (b).

[45] *Id.*

[46] *Id.*

[47] *Id.* at Principle 3.2 (c).

[48] *Id.* at Principle 3.2 (d).

[49] *Id.* at Principle 2 (e).

[50] Marietta Benkö, Gerhard Gruber & Kai-Uwe Schrogl, *The UN COPUOS: Adoption of Principles Relevant to the Use of Nuclear Power Sources in Outer Space,*

Utilization of radioisotope generators is permitted for interplanetary missions and in Earth orbit, provided that they are stored in a high orbit at the conclusion of the operational part of their mission. As a response to an existing practice, radioisotope generators "shall be protected" by a containment system capable of withstanding the "heat and aerodynamic forces of re-entry in the upper atmosphere under foreseeable orbital conditions".[51] "[T]he containment system and the physical form of the isotope shall ensure that no radioactive material is scattered into the environment so that the impact area can be completely cleared of radioactivity by a recovery operation."[52] Although these provisions are of significant importance, a zero risk scenario cannot exist.

As far as safety assessment is concerned, the "launching State", defined by the NPS Principles as a, "State which exercises jurisdiction and control over a space object with nuclear power sources on board at a given point in time relevant to the principle concerned."[53] Launching States shall ensure prior to the launch through cooperative arrangements, that a "thorough and comprehensive safety assessment is conducted".[54] These arrangements will be signed between the State, as well as any parties who have "designed, constructed or manufactured the nuclear power sources, or who will operate the space object, or from whose territory or facility such an object will be launched."[55] The Principles reflect the high degree of complexity of those operations, yet, leave open the issue of what constitutes a "procuring state".

In line with Article XI of the Outer Space Treaty, "the results of this safety assessment, together with, to the extent feasible, an indication of the approximate intended time-frame of the launch, shall be made publicly available prior to each

PROCEEDINGS OF THE THIRTY-SIXTH COLLOQUIUM ON THE LAW OF OUTER SPACE 235 (1993) [hereinafter *Adoption of Principles*].

[51] NPS Principles, *supra* note 39, at Principle 3.3 (b).

[52] *Id.*

[53] *Id.* at Principle 2.1.

[54] *Id.* at Principle 4.1

[55] *Id.*

launch."[56] Additionally, the Secretary-General of the UN shall be informed how States may obtain safety assessment results "as soon as possible prior to each launch".[57]

Should a re-entry of radioactive material occur as a result of a malfunctioning of the space object, the launching State[58] "shall in a timely fashion", inform the States concerned.[59] With the same frequency, the launching State "shall" provide and update the international community and the Secretary-General of the United Nations on the anticipated time of re-entry.[60] In this case, "as far as reasonably practicable," this State "shall...respond promptly to requests for further information or consultations sought by other States."[61]

A specific provision on the notification of re-entry is a major step. However, progress would be assured by an amendment to this provision providing a systematic information notification prior to the launch of any planned use of NPS in outer space.

If notified of an expected re-entry of a space object containing a nuclear power source on board, all States "possessing space monitoring and tracking facilities, in the spirit of international cooperation, shall communicate the relevant information

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[56] *Id.* at Principle 4.3.

[57] *Id.*

[58] *Id.* at Principle 2. For State launching, the same definition as for launching State is used.

[59] *Id.* at Principle 5. The information shall be in accordance with the following format:

(a) *System parameters*:
- (i) Name of launching State or States, including the address of the authority which may be contacted for additional information or assistance in case of accident;
- (ii) International designation;
- (iii) Date and territory or location of launch;
- (iv) Information required for best prediction of orbit lifetime, trajectory and impact region;
- (v) General function of spacecraft;

(b) *Information on the radiological risk of nuclear power source(s)*:
- (i) Type of nuclear power source: radioisotopic/reactor;
- (ii) The probable physical form, amount and general radiological characteristics of the fuel and contaminated and/or activated components likely to reach the ground. The term "fuel" refers to the nuclear material used as the source of heat or power.

[60] *Id.*

[61] *Id.* at Principle 6.

that they may have available" to the Secretary-General of the United Nations and the State concerned "as promptly as possible."[62] Such rapid communication would allow States that might be affected to assess the situation and take any precautionary measures deemed necessary.[63] Traditional space law principles of international responsibility for national activities involving the use of nuclear space power are covered by Principle 8, and are in accordance with Article VI of the Outer Space Treaty.

The liability principle follows the space law definition of a launching State.[64] The launching State shall bear international liability for "damage caused by such space objects or their component parts".[65] This Principle fully applies to the case of such a space object carrying a nuclear power source on board[66] and constitutes an important complement to the existing mechanisms established by the Outer Space Treaty and the Liability Convention. It is important to note the existence of such provisions, as they usually belong to international conventions and are not part of UN resolutions.[67] Their adoption by the States show the importance accorded to these Principles.

If a dispute occurs, it "shall be resolved through negotiations or other established procedures for the peaceful settlement of disputes", in accordance with the Charter of the United Nations and the Liability Convention for signatories.[68]

Lastly, and of great importance, is the final provision, which stated that the NPS Principles shall be reopened for revision by the Committee on the Peaceful Uses of Outer Space "no later than two years after their adoption".[69] This important provision stresses the need to take into account new applications of NPS, and the possible need to review the work of the LSC. Al-

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[62] *Id.* at Principle 7.

[63] *Id.* at Principle 7.

[64] Liability Convention, *supra* note 32. According to Article 1 (c), a launching state is a State which launches or procures the launching of a space object and a State from whose territory or facility a space object is launched.

[65] NPS Principles, *supra* note 39, at Principle 9.

[66] *Id.*

[67] *Adoption of Principles*, *supra* note 50, at 238.

[68] NPS Principles, *supra* note 39, at Principle 10.

[69] *Id.* at Principle 11.

though this issue has been on the agendas of both Subcommittees since 1992, their revision has still not occurred.

2. Latest Developments in the COPUOS

In 1998, the LSC recommended that the Working Group on the Use of NPS in Outer Space suspend its consideration of this agenda item pending receiving the results of the work of the STSC. In 2000, the LSC agreed without prejudice to the possibility of reconvening the Working Group. The group would be reconvened if, in the opinion of the LSC, sufficient progress had been made in the STSC to warrant such an action.

The STSC adopted a multi-year work plan in 1998. During its first year, terrestrial processes and technical standards that might be relevant to NPS were identified. It included factors such as distinguishing nuclear power sources in outer space from those used in terrestrial nuclear applications. The work of the IAEA in this area, its conventions and documents were also relevant to the STSC work plan.[70] In the second year, the work plan reviewed national and international processes, proposals, standards and national working papers relevant to the launch and peaceful use of NPS in outer space. At the STSC session in 2002, the Subcommittee's Working Group on the Use of NPS in Outer Space finalized its report titled, "A Review of International Documents and National Processes Potentially Relevant to the Peaceful Use of NPS in Outer Space."[71]

Following the 2002 STSC, the LSC agreed that opening a discussion on the revision of the NPS Principles was not warranted.[72] In 2003, the STSC agreed to follow another multi-year work plan for the period 2003-2006 to establish the objectives, scope and attributes for an internationally based framework of goals and recommendations for the safety of planned and currently foreseeable application of NPS. It is foreseeable that the STSC could work in coordination with the International Atomic

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[70] *Report of the Legal Subcommittee on its Thirty-Ninth Session*, U.N.G.A. COPUOS, 39th Sess., U.N. Doc. A/AC.105/738 (2000).

[71] *Report of the Legal Subcommittee on its Forty-First Session*, U.N.G.A. COPUOS, 41st Sess., at 11, U.N. Doc. A/AC.105/787 (2002).

[72] *Id.*

Energy Agency because of the significant experience of the IAEA in this field.

3. Evaluation of the NPS Principles

The NPS Principles are important because they contain a set of rules applying to NPS electricity for on-board use. They also provide for a detailed safety assessment, a re-entry notification process, responsibility and liability mechanisms and assistance to States. Even before the adoption of the NPS Principles, countries conducting this type of space activity were already ensuring the safest utilization of this source of energy for their space activities. Parts of the NPS Principles are even based on this previous experience.

The NPS Principles provide a specific consensual language, using very general and sometimes vague terms, such as, "reasonably practicable," "possible harmful effects," "in a reasonable way," "does not cause a significant contamination,"[73] "with a high degree of confidence,"[74] "the hazards kept below acceptable levels," "as far as reasonably practicable"[75]. The wording chosen is also used in many other international space law texts,[76] and it is one of the conditions that made it possible for COPUOS to reach consensus on topics which would not have been adopted otherwise. However, considering the risky activity involved, it is unfortunate that some of the provisions are not more specific. One observer considers using so many qualifying terms weakens the impact of highly important safety criteria.[77] In contrast, the terminology used for technical regulations governing any terrestrial activity requiring strong safety provisions is precise. Failure to respect these rules will result in enforcement of the regulation. In the case of international space law, not only are the terms vague, but the enforcement provisions are also unclear.

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[73] NPS Principles, *supra* note 39, at Principle 3.

[74] *Id.* at Principle 3.1.

[75] *Id.* at Principle 6.

[76] "States parties to the Treaty shall... render... all possible assistance..." to astronauts in the event of an accident. Outer Space Treaty, *supra* note 28, at art. V.

[77] Carl Q. Christol, *Nuclear Power Sources for space Objects: A New Challenge for International Law*, PROCEEDINGS OF THE THIRTY-SIXTH COLLOQUIUM ON THE LAW OF OUTER SPACE (1993).

As mentioned above, the NPS Principles do not address nuclear propulsion. Experiments on nuclear propulsion have been conducted for many years, and the risks involved are known. Keeping the NPS Principles without extending their application to nuclear generators may weaken the scope of the Principles.

It is also necessary to clarify the applicability of the Outer Space Treaty. From the text of the Outer Space Treaty, its applicability seems to be limited to outer space. Considering the legal issues inherent to the Moon Agreement,[78] the addition of a special provision on the applicability of the NPS to the Moon and other celestial bodies would be an important clarification.

During exploration missions, astronauts face several types of radiation, such as solar and cosmic. During a flight with NPS on board, the proximity between astronauts and nuclear power sources will be considered in the development of spacecraft security and safety measures. For many years, NASA studies on this issue have been conducted through biological and physical research programs.[79] Specific provisions on the protection of astronauts during space missions utilizing NPS on board will need to be developed in the appropriate fora.

The lack of binding force of the NPS Principles is a subject of great attention because the commitment is not same as that of an international convention. Transforming them into an international convention may not necessarily be the best solution for several reasons because such a transformation would freeze the text, avoiding the possibility for further adaptations and create the risk that some countries would refuse ratification. When adopting principles, the decisions that may be reached by consensus are different from what countries will accept as drafts for future international conventions. The ultimate result

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[78] The main space faring nations, namely the former U.S.S.R. and the U.S., did not ratify this agreement, object of a great controversy. Several issues were at stake, mainly the exploitation of the Moon's resources and the level of information to provide by States about their activities.

[79] NASA and DoE decided to build a NASA Space Radiation Laboratory to study sun and space radiation in order to ensure the safety of the spacecraft crew. The Laboratory became operational in 2003. *See* Brookhaven National Laboratory, Laboratory News, *NASA and DOE Dedicate New NASA Facility at Brookhaven Lab* (Oct. 14, 2003), *available at* http://www.bnl.gov/bnlweb/pubaf/pr/2003/bnlpr101403.htm (last visited Sept. 17, 2004).

may be fewer provisions in the binding text than are currently covered in the NPS Principles. Obviously, none of these are really satisfactory solutions.

IV. CONCLUSION

Work on technical standards will probably begin at the conclusion of the STSC 2002-2006 multi-year work plan. Consequently, it seems difficult to foresee any deep revision of the NPS Principles before the end of the STSC. Should such a review take place, its success will be possible mainly if at least one delegation or a group of delegations strongly supports the changes. If the Principles are reopened in the near future for review, their revision could take years before reaching a new consensus. However, some provisions could be adopted to strengthen the framework and extend its scope. On very specific issues, circumscribed applicable mechanisms could be put into place to avoid gaps between the Principles and technology developments.

COPUOS, its STSC, LSC, and other fora such as the International Commission on Radiological Protection, have an important role to play in the development of relevant standards. In addition, appropriate provisions need to be implemented at the national level by all countries using NPS for their space activities.

Finding a balance between the development of high technology with respect to technical standards and the need for protective legal mechanisms concerning the use of NPS in outer space is not easy to find. Considering the inherent risks involved in the use of these types of technologies, it will be important to keep in mind that the use of nuclear power sources should be restricted to space missions that cannot be reasonably operated by non-nuclear energy sources. For this reason, alternative technology development is to be encouraged.

In view of the fact that Russia has been working on NPS technology for years and the U.S. has recently decided to focus on this technology to accomplish the objectives defined in its new space exploration vision, the pertinent question is how will other countries react? Some countries may be interested in purchasing this technology for scientific or military purposes. Whether these countries build their own systems or purchase them, this development will open the door to technology transfer issues.

The use of nuclear power sources in outer space is a challenging issue of great importance, and future developments in this area, both technical and legal, should be examined with the greatest care and responsibility to avoid all possible risks.