46th International Astronautical Congress

A TECHNICAL REVIEW OF THE U.N. PRINCIPLES ON THE USE OF NUCLEAR POWER SOURCES IN OUTER SPACE

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October 1995
Oslo, Norway

- **Background on U.N. Principles**
- **Overview of the U.N. Principles**
- **Assessment of the U.N. Safety Criteria and Guidelines**
- **Concluding Remarks**

Background

- The United Nations began discussing the use of nuclear power sources (NPS) in outer space following the 1978 reentry of the Soviet reactor-powered satellite Cosmos 954 over Canada. The principal U.N. forums for discussions on the use of NPS in outer space have been the Committee on the Peaceful Uses of Outer Space (COPUOS), its two standing committees of the whole--the Legal Subcommittee (LSC) and the Scientific and Technical Subcommittee (STSC)--and special working groups established within the subcommittees to deal with this topic.

- The first technical consensus on the technical and scientific aspects relating to the use of NPS in space was achieved in 1981 by the STSC Working Group on the Use of Nuclear Power Sources in Outer Space. For various reasons this consensus was broken in the Legal Subcommittee leading to nine more years of discussions until a new "consensus" was reached in 1990. Within the U.S., technical experts found many flaws and inconsistencies with the 1990 principles. Some corrections were made before the U.N. General Assembly adopted the principles in 1992. This presentation outlines the U.S. technical concerns.

Principles Relevant to the Use of Nuclear Power Sources in Outer Space

Preamble
Principle 1. Applicability of International Law
Principle 2. Use of Terms
Principle 3. Guidelines and Criteria for Safe Use
Principle 4. Safety Assessment
Principle 5. Notification of Reentry
Principle 6. Consultations
Principle 7. Assistance to States
Principle 8. Responsibility
Principle 9. Liability and Compensation
Principle 10. Settlement of Disputes
Principle 11. Review and Revision

After Considering Some Definitions That The U.S. Delegation Worked For In The Preamble and Principle 2, The Rest Of This Presentation Will Focus On The Assessment Of Principle 3, "Guidelines and Criteria for Safe Use".

Principles Relevant to the Use of Nuclear Power Sources in Outer Space
Overall Preamble and Principle 2 ("Use of Terms")

After the U.S. delegation repeatedly pointed out the technical inaccuracies and inconsistencies in the principles (especially Principle 3, "Guidelines and Criteria for Safe Use"), the other delegations would only agree to some clarifying definitions in the overall Preamble to the Principles and to the terms in Principle 2. The key definitions that modify Principle 3 are listed below:

- The Preamble states the principles only apply to current systems that are not used for propulsion.
- The Preamble acknowledges the need for future revisions and Principle 11 calls for review and revision in two years so there is hope that a more technically accurate and realistic document can be prepared.
- Principle 2 states that ". . . the terms 'foreseeable' and 'all possible' describe a class of events or circumstances whose overall probability of occurrence is such that it is considered to encompass only credible possibilities for purposes of safety analysis".
- Principle 2 states that "The term 'general concept of defence-in-depth' when applied to nuclear power sources in outer space considers the use of design features and mission operations in place of or in addition to active systems, to prevent or mitigate the consequences of system malfunctions. Redundant safety systems are not necessarily required for each individual component to achieve this purpose. Given the special requirements of space use and of varied missions, no particular set of systems or features can be specified as essential to achieve this objective".
- Principle 2 modifies the term "made critical" in Principle 3 to allow zero-power testing.

Principle 3: Guidelines and Criteria for Safe Use

Preamble

In order to minimize 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 which cannot be operated by non-nuclear energy sources in a reasonable way.

Assessment

U.S. delegation stated that ". . . we believe that is appropriate for all the principles to stress that the use of nuclear power sources should be based on technical needs with full consideration of safety and environmental concerns. It is, however, incongruous for one principle to have its own preamble. We propose deleting this paragraph and having an appropriate statement on this idea in an overall preamble". The U.S. also recommended that "shall" and "must" should be replaced with "should" and that "foreseeable" be replaced with "credible". These changes would be consistent with the non-binding, recommendatory nature of the principles and with a realistic approach to safety analyses. Even though these changes were not adopted, given the non-binding nature of the principles, the U.S. has been proceeding at the operational level with these changes.

Section 1.1

States launching space objects with nuclear power sources on board shall endeavour to protect individuals, populations and the biosphere against radiological hazards. The design and use of space objects with nuclear power sources on board shall ensure, with a high degree of confidence, that the hazards, in foreseeable operational or accidental circumstances, are kept below acceptable levels as defined in paragraphs 1 (a) and (c).
Such design and use shall also ensure with high reliability that radioactive material does not cause a significant contamination of outer space

Assessment

Wherever it appears, the word "hazards" should be replaced with the word "risks" because the term "risks" has a quantitative definition (essentially probability multipled by consequences) that is accepted internationally. The term "foreseeable" connotes everything one can envision beforehand. In safety analysis reports a wide range of postulated accidents are considered, some of which border on the incredible but they are still "foreseeable" in the sense of prescience or foreknowledge. A better and more useful word than "foreseeable" would be "credible". NOTE: Eventually the U.N. recognized this concern in the definitions given in Principle 2. Finally, since most governments do not have official dose limits for accidents (just as they do not have injury or fatality limits for airplane or automobile crashes) the reference to dose limits should be replaced with the international concept of "as low as reasonably achievable" (ALARA). It should be noted that outer space is already highly radioactive with cosmic rays, the solar wind, Van Allen Belt, etc.

Section 1.2

During the normal operation of space objects with nuclear power sources on board, including re-entry from the sufficiently high orbit as defined in paragraph 2 (b), the appropriate radiation protection objective for the public recommended by the International Commission on Radiological Protection shall be observed. During such normal operation there shall be no significant radiation exposure.

Assessment

Section 1.2 is misleading because there is no "appropriate radiation protection objective for the public" for reentry accidents just as there are no limits for other kinds of accidents (e.g., airplane crashes, ship sinkings, etc.). Like most nations, the U.S. only uses numerical radiation dose guidance when the accident is fully defined and not for all "foreseeable" accidents. To some extent, the problem of what is meant by "foreseeable" was solved with the definition that was finally incorporated in Principle 2.

Section 1.3

To limit exposure in accidents, the design and construction of the nuclear power source systems shall take into account relevant and generally accepted international radiological protection guidelines.
Except in cases of low probability accidents with potentially serious radiological consequences, the design for the nuclear power source systems shall, with a high degree of confidence, restrict radiation exposure to a limited geographical region and to individuals to the principal limit of 1 mSv in a year. It is permissible to use a subsidiary dose limit of 5 mSv in a year for some years, provided that the average annual effective dose equivalent over a lifetime does not exceed the principal limit of 1 mSv in a year.
The probability of accidents with potentially serious radiological consequences referred to above shall be kept extremely small by virtue of the design of the system.

Assessment

The use of dose limits for accidents or potential exposure situations is not consistent with current ICRP guidance (i.e., ICRP Publication 60 which was published in November 1990 and supersedes the approach taken in Principle 3). Since it is not possible to control accidents (accidents are by defintion events which are out of control), the application of rigid dose limits is not physically realizable. Applying dose limits to radiological accidents is similar to apply injury and/or fatality limits to airplane or automobile crashes. (The IAEA supported the U.S. position.)
The establishment of dose limits is contrary to the philosphy of probabilistic risk assessments which is the generally accepted international basis for assessing risk.
Finally, since the design of the NPS is not usually a factor in the probability of accidents the last requirement is technically meaningless.

Section 1.4

Systems important for safety shall be designed, constructed and operated in accordance with the general concept of defence-in-depth. Pursuant to this concept, foreseeable safety-related failures or malfunctions must be capable of being corrected or counteracted by an action or a procedure, possibly automatic.

The reliability of systems important for safety shall be ensured, inter alia, by redundancy, physical separation, functional isolation and adequate independence of their components.

Other measures shall also be taken to raise the level of safety.

Assessment

Since "defense in depth" has specific meanings in designing terrestrial nuclear power plans and these are not necessarily applicable to space systems the U.S. codified the U.N. interpretation in the definition given in Principle 2. The U.S. also achieved clarification with the definition of "foreseeable" given in Principle 2. The U.S. has officially noted that Section 1.4 makes no provision for passive safety systems, such as radioisotope thermoelectric generators (RTGs), or for the preferred solution, in the case of either passive or active systems, of countering risks by system or mission design. The U.S. also stated that "inter alia" should be replaced with "for example" since there need not necessarily be other means of ensuring reliability beyond those listed in the remainder of the sentence, or that any or all of those listed must be employed in a given NPS.

Section 2.1

Nuclear reactors may be operated:

(i) On interplanetary missions;

(ii) In sufficiently high orbits as defined in paragraph 2.2;

(iii) In low-Earth orbits if they are stored in sufficiently high orbits after the operational part of their mission.

Assessment

Replacing the restrictive phrase "In low-Earth orbits" with "in any orbit or flight trajectory" allows the use of other than low-Earth orbit and also allows for nuclear propulsion missions which may need to use a "flight trajectory" rather than an "orbit". This section does not allow for storage in other orbits such as orbits around the Sun.

NOTE: When the Committee on the Peaceful Uses of Outer Space (COPUOS) adopted an overall preamble that excluded nuclear propulsion this helped correct some of the problems with Section 2.1

Section 2.2

The sufficiently high orbit is one in which the orbital lifetime is long enough to allow for a sufficient decay of the fission products to approximately the activity of the actinides. The sufficiently high orbit must be such that the risks to existing and future outer space missions and of collision with other space objects are kept to a minimum. The necessity for the parts of a destroyed reactor also to attain the required decay time before re-entering the Earth's atmosphere shall be considered in determining the sufficiently high orbit altitude.

Assessment

To provide appropriate mission flexibility, the second sentence should be replaced with "The selection of the sufficiently high orbit should take into consideration the risks to existing and future outer space missions and collision with other space objects". Adoption of Section 2.2 means that many existing nuclear power sources in orbit about the Earth (e.g., RORSAT reactors of the former Soviet Union) could probably be found to be in violation of Principle 3.
Is the U.N. prepared to retrieve them or boost them to higher orbits?

Section 2.4

Nuclear reactors shall not be made critical before they have reached their operating orbit or interplanetary trajectory.

Assessment

As written, Section 2.4 would prohibit zero-power testing before launch. Zero power testing is a means of checking to ensure that the reactor systems work while operating at such a low power that there is very little fission product buildup. This paragraph, if left by itself, would have forced the NPS user to launch multi-million dollar reactors on multi-billion dollar spacecraft with no assurance that they would work. For example, the reactor itself may be needed to power a propulsive system to move the reactor to a higher orbit; thus, eliminating zero-power testing to check the operability of the reactor system could actually reduce overall mission safety. The U.S. delegation formally stated that "The United States believes the Subcommittee's intent in paragraph 2.4 was that NPS would not be operated at power for sustained periods of time so as to generate a meaningful radionuclide inventory. Zero power critical testing is an important part of launch safety that does not produce significant radionuclides. Without such testing, a NPS would be less safe". The U.S. proposed some alternative language which eventually became part of Principle 2.

Section 2.5

The design and construction of the nuclear reactor shall ensure that it can not become critical before reaching the operating orbit during all possible events, including rocket explosion, re-entry, impact on ground or water, submersion in water or water intruding into the core.

Assessment

The phrase "or flight trajectory considering credible launch accidents . . ." should be inserted after "operating orbit" to allow for nuclear propulsion applications and to eliminate the unrealistic phrase "all possible events". To some extent the changes in the overall preamble to exclude nuclear propulsion and the improved definitions of Principle 2 help meet the intent of this assessment.

Section 2.6

In order to reduce significantly the possibility of failures in satellites with nuclear reactors on board during operations in an orbit with a lifetime less than in the sufficiently high orbit (including operations for transfer into the sufficiently high orbit), there shall be a highly reliable operational system to ensure an effective and controlled disposal of the reactor.

Assessment

In a 1991 meeting of the principal U.S. technical experts from NASA, the U.S. Department of Defense (DoD) and the U.S. Department of Energy (DOE), the experts essentially agreed with this Section if storage includes the option of sending the reactor away from the Earth or placing it in other types of safe orbits (e.g., a solar orbit).

Section 3.1

Radioisotope generators may be used for interplanetary missions and other missions leaving the gravity field of the Earth. They may also be used in Earth orbit if, after conclusion of the operational part of their mission, they are stored in a high orbit. In any case ultimate disposal is necessary.

Assessment

The second sentence should be broadened to allow for the use of other safe disposal methods (e.g., solar orbits or escape trajectories). The term "ultimate disposal" is meaningless.

Section 3.2

Radioisotope generators shall be protected by a containment system that is designed and constructed to withstand the heat and aerodynamic forces of re-entry in the upper atmosphere under foreseeable orbital conditions, including highly elliptical or hyperbolic orbits where relevant. Upon impact, the 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.

Assessment

As a minimal change in this sentence, U.S. technical experts proposed this wording: "Upon impact, the containment system and the physical form of the isotope should minimize radioactive material release into the environment so that the debris can be retrieved". In 1991, the U.S. delegation formally proposed changes to the wording of Section 3.2 ". . . to take into account the fact that the probability of accidental re-entry from a hyperbolic or highly elliptical orbit can be reduced to a very low value by mission design and operations" and to recognize ". . . the fact that the practical design objective for RTG containment systems is localization rather than zero release under all circumstances, and that there are practical limits from a cost-versus-risk standpoint on 'complete' clearing of radioactivity by a recovery operation". To date these concerns have not been reflected in the principles. In the only case of an NPS reentering over land (Cosmos 954 in 1978) the Canadian government did not completely clear the radioactivity and it accepted less than the full cost of cleanup from the Soviet government.

Concluding Remarks

The U.S. delegation has consistently made clear its interpretation of the principles and their legal status ("non-binding" and "recommendatory") and that it intends to continue to use the proven U.S. approach to space nuclear safety. The U.S. view was perhaps best summed up in a 1992 statement given by the head of the U.S. delegation to the Scientific and Technical Subcommittee of the U.N. Committee on the Peaceful Uses of Outer Space:

"The United States stands ready to finalize the principles, provided that our concerns with respect to their technical accuracy, their appropriateness and the scope of their coverage are adequately addressed. We continue to believe that the principles will only be as strong as their scientific and technical underpinnings, and that the recommendations of this Subcommittee should reflect the best and most current data available. Only in this way will the principles derived from them . . . be a credible contribution to the safe use of nuclear power sources in space".