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A Technical Review of the U.N. Principles on the Use of Nuclear Power Sources in Outer Space

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Abstract

In 1990 the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) agreed to a set of nonbinding principles governing the use of nuclear power sources (NPS) in outer space. Within the U.S. there was considerable discussion and review of these principles which led to the identification of a number of technical issues that could make the principles as originally stated either unworkable or impractical. As a result of these internal discussions and reviews the U.S. insisted on certain clarifying language and issued several formal statements explaining the U.S. interpretation of the principles before they were adopted during the 1992 meetings of the United Nations (U.N.) Special Political Committee and General Assembly. The U.S. has officially stated that it intends to continue to abide by the proven safety standards of the U.S. This paper summarizes the technical issues that were identified with the principles with particular focus on nuclear reactor operational requirements and radioisotope power source reentry and impact requirements. Suggestions are also made on how the principles could be improved in future revisions so that they would achieve better technical accuracy.

Background

In one forum or another, the United Nations (U.N.) has been discussing the use of nuclear power sources (NPS) in outer space since the 1978 reentry of the Soviet reactor-powered satellite Cosmos 954. 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 subcommittees 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.[1]

The First Technical Consensus on NPS

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 (WGNPS).[2,3] This WGNPS report recognized the technical realities of providing risk reduction within the uncertainties of an accident which is almost by definition an unexpected event that is generally beyond control. The 1981 report described the general safety measures for space reactors and radioisotope power sources while leaving the detailed design features to the discretion of the designers. The report itself was nonjudgmental on the use of NPS stating ". . . that the basis of the decision to use NPS should be technical".[2] The report concluded with the statement that ". . . the Working Group reaffirmed its previous conclusion that NPS can be used safely in outer space, provided that all necessary safety requirements are met".[2] This conclusion represented not only a consensus of international technical experts but a succinct statement of the U.S. position as well.[3]

The Breaking of Consensus

The originally planned progression of the COPUOS work on NPS was to achieve first a technical consensus within the STSC and then have the LSC (in reality usually the same people) use these technical principles as the foundation for a set of legal principles. Unfortunately, several delegations led by the Canadian delegation chose to ignore the 1981 technical agreement they had helped broker during four years of meetings by introducing new papers when they arrived in Geneva for the 1981 meeting of the LSC.[4,5,6] A rumored basis for this break in consensus was Canadian displeasure with plans by the new U.S. administration to change the U.S. position on the Law of the Sea Treaty which Canada strongly supported.[7]

In any case the Canadians made it very clear in private conversations with U.S. delegates over the succeeding years that they were unhappy with the 1981 technical report that they had helped draft and then had formally agreed to and that they planned to develop a new set of principles no matter how many years it took. As a result of this breaking of consensus, the U.S. and several other delegations were forced into a passive role of waiting to see what the Canadian-led effort would produce.

The 1990 "Consensus" on NPS

The Canadian persistence paid off for them in the 1990 STSC meeting when the U.S. delegation, operating without technical input from the U.S. user agencies (NASA and the U.S. Department of Defense [DoD]) and in violation of long-standing U.S. positions, agreed to a set of principles that were greatly at variance with the 1981 consensus report and U.S. policy and practices.[8,9,10] When the U.S. delegation informally proposed the possibility of some changes a month later at the 1990 LSC meeting they were informed by the same delegations which had broken the 1981 consensus that it was not possible to break the new consensus.[11] In a diplomatic effort to put other delegations on notice that the U.S. wanted changes in the principles, the U.S. delegation did formally notify the other delegations ". . . that our agreement to any principle is subject to the understanding that at some stage a complete set of principles will have to be considered in its entirety as was the case with the principles this Subcommittee developed in regard to Remote Sensing. Some changes are inevitable as we understand better the interrelationship between the principles".[12]

Faced with both STSC and LSC approvals of principles which U.S. technical experts found to be technically inaccurate the U.S. Department of State (DOS) informally suggested (as a diplomatic face-saving measure) letting COPUOS approve the principles at its 1990 meeting but with the principles only published as a nonbinding part of the COPUOS report as had been done with the principles on remote sensing. (In effect, the NPS principles would be "buried" as were the remote sensing principles.) As a sop to U.S. technical experts, DOS was willing to allow the U.S. delegation to insert in the U.N. report a written record of the U.S. view to serve (hopefully) as a sort of "legislative history" although DOS was unable to provide a legal opinion on what such a "legislative history" would mean in future applications of the principles.[13]

Making Sense of the 1990 "Consensus"

However, when it became clear in the fall of 1990 that certain other COPUOS delegations planned to have the principles adopted as a U.N. General Assembly (UNGA) resolution, U.S. technical experts began a concerted effort within the U.S. Government (USG) to transform the principles into a form that was technically realistic. Beginning in 1991, efforts were made by USG officials to reopen the principles to correct the technical deficiencies.[14,15]

As a first step in developing a minimal set of changes by the technical experts an ad-hoc working group of U.S. technical experts met on 8 January 1991 in Albuquerque, New Mexico during the Eighth Symposium on Space Nuclear Power Systems. The report of this group, which was designed to provide the smallest number of changes (even though the U.S. technical experts agreed the entire U.N. set of principles needed to be rewritten to be technically accurate), helped provide a common basis for the technical agencies's opposition to the 1990 principles.[16] As a result, this paper relies heavily upon that report for the technical evaluation that appears in the following sections.

The Path to Adoption of the Principles

Despite the good-faith work of the U.S. technical experts, DOS, citing other unrelated diplomatic concerns, was unwilling to allow the U.S. delegation to pursue more than a minimal set of peripheral changes in the principles in the effort to get the principles to approach technical accuracy. (In fact, DOS, following the lead of other COPUOS delegations, was unwilling to support any changes to Principle 3 ["Guidelines and criteria for safe use"], the most controversial and technically inaccurate principle, preferring that any changes be made in the other principles. As we shall see, the DOS approach ultimately led to the adoption of a set of principles that are both technically inaccurate and inconsistent.)

Following two more years of discussions at various levels in the USG and the U.N., the Special Political Committee (SPC), meeting during the 47th session of UNGA, adopted on 30 October 1992, by consensus, the resolution concerning the NPS principles (essentially the same principles as adopted by COPUOS in 1990 with some clarifying definitions). Subsequently on 14 December 1992, UNGA adopted these principles in resolution 47/68.

The U.S. View of the Principles

Faced with the known concerns of U.S. technical experts, the U.S. delegation formally expressed reservations about the technical validity of these principles to the SPC on 28 October 1992 as follows: "The United States did not block the consensus recommendation of the Committee to forward the principles to the General Assembly, nor will the United States oppose their adoption here. On some points, however, it remains our view that the principles related to safe use of nuclear power sources in outer space do not yet contain the clarity and technical validity appropriate to guide safe use of nuclear power sources in outer space. The United States has an approach on these points which it considers to be technically clearer and more valid and has a history of demonstrated safe and successful application of nuclear power sources. We will continue to apply that approach".[17]

Within the U.S. Government, the USG official responsible for approval of the launches of NPS notified the Secretary of Defense, the Administrator of NASA and the Secretary of Energy by official memorandum that "On October 30, 1992, the United Nations Special Political Committee adopted by consensus a set of principles related to safe use of nuclear power sources in outer space. Over the past 2 years, the United States has worked diligently to improve the scientific and technical validity of these principles, as well as to ensure their consistency with established U.S. safety practices. On some points, however, it is our view that the principles do not yet contain the clarify and sound technical standards necessary to serve as a basis for decision making in this area."[18]

In continuing, the official stated in the memorandum "As our delegation made clear, pending necessary technical revisions, the U.S. Government will not look to these flawed principles as standards of review for space launches involving nuclear power sources".[18]

The memorandum closed with "The United States will continue to employ its stringent design and operational flight safety measures to protect the public and the environment under normal operations and postulated accident scenarios. The overall safety review conducted under PD/NSC-25 by an independent Interagency Nuclear Safety Review Panel (INSRP) will continue to ensure that nuclear power sources undergo a thorough safety assessment prior to launch, and will serve as the standard by which the safety of these launches is determined".[18]

Subsequently, the new U.S. Administration conducted a review of the U.S. position and it was determined that "U.S. policy and practice in the use of nuclear power sources in outer space is fully consistent with the overall objective and intent of the Principles. The U.S. has a rigorous safety review process prior to launch of nuclear power sources, and intends to continue to apply that approach. The Principles will not affect currently planned U.S. missions with NPS on board".[19] In particular it was noted ". . . that the proposed position **does not** confer U.S. approval of any specific provisions of the Principles, but only declares that U.S. policy and practice is consistent with their **overall objective and intent**, which is the safe use of NPS in outer space" [emphasis in original].[19] In view of the unwillingness of other U.N. delegations to reopen the principles to correct their technical inaccuracies even as they are simultaneously seeking to promote new, unreviewed principles (which, in effect, reopen the principles), the U.S. delegation has been pushing for either a reduced allocation of time for the discussion of NPS or outright elimination of the topic on the COPUOS agenda.[19]

The following sections describe the safety criteria and guidelines contained in the U.N. principles followed by a technical assessment and the officially delivered U.S. reservations as contained in formal statements by U.S. representatives. The focus of this paper is essentially on Principle 3 ("Guidelines and criteria for safe use").

NPS Principles

The principles begin with a preamble which recognizes that for some missions NPS are essential and affirms that the principles only apply to NPS ". . . devoted to generation of electric power on board space objects for non-propulsive purposes, which have characteristics generally comparable to those of systems used and missions performed at the time of the adoption of the Principles. . ."[20] In other words, the principles do not apply to nuclear propulsion systems or to new NPS. This clarification, which is also discussed in the following technical assessments, is one of the concessions given to the U.S. in recognition of the technical limitations of the principles. The preamble also recognizes ". . . that this set of Principles will require future revision in view of emerging nuclear-power applications and of evolving international recommendations on radiological protection".[20] This change was a recognition of the U.S. position that trying to legislate rigid standards of radiological protection (such as citing soon-to-be outdated international standards) was inconsistent with the evolving national and international standards of radiological protection.

The 11 principles consist of:[20]

Principle 1 - *Applicability of international law* - basically states that the use of NPS will be carried out in accordance with international law

Principle 2 - *Use of terms* - defines a number of terms, in particular ". . . 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". In addition the definition of the term "general concept of defence-in-depth" allows flexibility in achieving this goal by allowing consideration of ". . . 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". Finally, the term "made critical" mentioned in paragraph 2 (a) of Principle 3 ". . . does not include actions such as zero-power testing [prior to the launch of the reactor] which are fundamental to ensuring system safety".

These definitions, which are discussed in the context of the technical assessments presented later in this paper, were included at the request of the U.S. as a way to correct some of the technical flaws in Principle 3 without actually changing Principle 3 (which the other delegations did not want changed no matter how many technical flaws it contained).

Principle 3 - *Guidelines and criteria for safe use* - this principle begins with a somewhat negative preamble (it is the only principle with its own preamble) and then sets forth general goals for radiation protection and nuclear safety followed by specific safety criteria for nuclear reactors and for radioisotope generators. This is the principle that was and still is of the most concern to U.S. technical experts and, as such, it is the principle which is both discussed further and technically assessed in the next section.

Principle 4 - *Safety assessment* - requires a "thorough and comprehensive" safety assessment which is to be made publicly available prior to each launch. Principle 4 states that "This assessment shall respect the guidelines and criteria for safe use contained in principle 3".

Principle 5 - *Notification of reentry* - requires a timely notification of the reentry of radioactive materials to the Earth and provides a format for such notification.

Principle 6 - *Consultations* - requires States providing information under Principle 5 to respond promptly to requests for further information or consultations sought by other States.

Principle 7 - *Assistance to States* - requires States with tracking capabilities to provide information to the Secretary-General of the U.N. and to the State concerned and requires the launching State to promptly offer assistance. After reentry, other States and international organizations with relevant technical capabilities should also provide assistance to the extent possible when requested by the affected State.

Principle 8 - *Responsibility* - states that States shall bear international responsibility for their use of NPS.

Principle 9 - *Liability and compensation* - holds the launching State and the State procuring such a launch internationally liable for any damage, including restoration ". . . to the condition which would have existed if the damage had not occurred". Compensation includes ". . . reimbursement of the duly substantiated expenses for search, recovery and clean-up operations, including expenses for assistance received from third parties". (Note: In view of the reentry of the Soviet Cosmos 954 satellite over Canada, this was an interesting Principle for Canada to support because Canada neither achieved this level of clean up nor did it request or get full reimbursement from the Soviet government.)

Principle 10 - *Settlement of disputes* - states that disputes ". . . shall be resolved through negotiations or other established procedures for the peaceful settlement of disputes, in accordance with the Charter of the United Nations".

Principle 11 - *Review and revision* - states that "These Principles shall be reopened for revision by the Committee on the Peaceful Uses of Outer Space no later than two years after their adoption". This principle was sold to the U.S. technical experts as the mechanism for U.S. technical concerns to be addressed eventually.

The next section focuses specifically on Principle 3, "Guidelines and criteria for safe use" and on a technical assessment followed by a summary of U.S. concerns as officially expressed at the U.N.

U. N. Safety Criteria and Guidelines

Principle 3 begins with a preamble that states that ". . . 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".[20]

Given that Principle 3 has to have its own preamble, the U.S. technical experts proposed an improved preamble which stated "In order to enhance the safety of nuclear power sources (NPS), which includes nuclear reactors and radio-isotope power sources used for space power or propulsion, the decision to use NPS should be based on the technical merits with due consideration for safety and environmental aspects".[16] During the discussions in the STSC the U.S. delegation made clear that ". . . we believe that it 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".[21] Unfortunately, other delegations did not support this reasonable and modest proposal.

The U.S. delegation also made clear its views on the legal status of the principles when it stated that "Throughout the recommendations, 'shall' and 'must' should be replaced with 'should'. In our view, this is clearly consistent with the non-binding, recommendatory nature of the principles".[21,22]

The U.S. delegation made an additional clarification when it stated that "We would also recommend another clarification to be made throughout the text, replacing the word 'foreseeable' with the word 'credible'. The United States safety assessments which cleared the Ulysses and Galileo spacecraft for launch limited the universe of hypothetical accident scenarios to those with reasonable probability of occurrence. This set of scenarios was thus labelled as 'credible'. This change brings the usage in the recommendations into conformity with this established formulation".[22] As noted earlier, clarification of the terms "foreseeable" and "all possible" was eventually achieved through the definitions in Principle 2. Regarding the "shall" versus "should" selection, the U.S. is proceeding at the operational level with the interpretation that "should" is the correct word.

As noted in the previous section, Principle 3 is divided into three main sections or "paragraphs" which are summarized below according to the numbering system of Principle 3, followed by (1) a technical assessment based mainly on the report of the U.S. technical experts and (2) the official U.S. response.

1. General goals for radiation protection and nuclear safety

Section 1.1 requires launching States to protect individuals, population and the biosphere against radiological hazards and to keep hazards in foreseeable operational or accidental circumstances below acceptable levels as defined in paragraphs 1 (a) and (c). This section also requests avoidance of a significant contamination of outer space.

Technical Assessment: Wherever it appears, the word "hazards" should be replaced with the word "risks". The word "hazards" is not quantitatively defined and it is pejorative. The term "risks" has a quantitative definition accepted internationally in the safety community. 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. If all "foreseeable" operational or accidental circumstances have to be considered then it is doubtful if a reasonable NPS can ever be built just as one could not build a reasonable automobile if all foreseeable accidents had to be mitigated by the design. A better and more useful word than "foreseeable" would be 'credible". This concern about "foreseeable" and "credible" was eventually reflected in the definitions provided in Principle 2 in response to these U.S. concerns.

Finally, since most technically responsible governments (including the U.S. Government) do not have official dose limits for accidents (nor, for that matter, do they have limits for nonradiological accidents such as airplane and automobile crashes) the reference to dose limits should be deleted and replaced with a concept used internationally in radiation health physics, namely, "as low as reasonably achievable" (ALARA).

In general, wherever it occurs, the word "shall" should be replaced with the word "should".

Section 1.2 requires meeting the appropriate radiation protection objective for the public as recommended by the International Commission on Radiological Protection (ICRP) for both normal operation and reentry from a sufficiently high orbit.

Technical Assessment: Section 1.2 is misleading at best and disingenuous at worst because there is no "appropriate radiation protection objective for the public" for reentry accidents just as there are no limits on other kinds of accidents (e.g., airplane crashes, ship sinkings, etc.). Like most technically responsible 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 requires consideration of relevant and generally accepted international radiological protection guidelines in the design and construction of NPS in order to limit exposure in accidents. Specifically Section 1.3 states that "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". Section 1.3 goes on to require that "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".

Technical Assessment: The use of dose limits for accidents or potential exposure situations is *not* consistent with current ICRP guidance (i.e., ICRP Publication 60). Since it is not possible to control accidents (accidents are, as noted earlier, 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 applying injury and/or death limits to airplane or automobile crashes. Moreover, the establishment of dose limits is contrary to the philosophy of probabilistic risk assessments which is the generally accepted international basis for assessing the risk of either terrestrial or space nuclear power sources. Finally, because space accidents are usually caused by propulsion or spacecraft malfunctions, the design of the NPS is not usually a factor in the probability of accidents so this requirement is technically meaningless.

The U.S. technical experts proposed the following *minimal* set of changes to Paragraph 1.3:

"To limit exposure in accidents, the design and construction of the NPS systems shall [should] take into account relevant and generally accepted international radiological protection guidelines.

"The probability of accidents with potentially serious radiological consequences shall [should] be kept extremely small by virtue of the design of the system."

Obviously much more would need to be done to develop a logically consistent and technically accurate text.

U.S. Response: In 1991, the U.S. delegation pointed out that Principle 3 should address risk (probability of exposure times consequence) rather than numerical dose limits.[21,22] In particular, the U.S. delegation made the point that ". . . this modification, by taking into account the probabilistic concept of risk, which is a central feature of a thorough safety assessment, relates the recommendation directly to the well-proven space NPS practices of the United States".[22] Again, in 1992, the U.S. delegation observed that "One significant example [of the need for technical accuracy] is in the area of dose limits. In November 1990 the International Commission on Radiological Protection has published new recommendations in the form of ICRP-60, which supersede the approach taken in Principle 3 when it was developed earlier that year".[23]

IAEA Response: The International Atomic Energy Agency (IAEA) independently supported the U.S. position by stating that "The sole use of the individual-related dose limits, rather than the complete ICRP system of radiation protection (including source-related constraint), is, in the Agency's view, inappropriate and does not conform with the aims of the ICRP recommendations . . . Secondly, as the ICRP has recently issued new recommendations on dose limitation . . . It might, therefore, be problematic to issue guidelines and criteria of safe use of NPS in outer space that would be outdated from their inception".[24]

Section 1.4 states that "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." Section 1.4 goes on to state that "The reliability of systems important for safety shall be ensured, inter alia, by redundancy, physical separation, functional isolation and adequate independence of their components".

Technical Assessment: Defense in depth is a concept that was originally developed for large terrestrial power reactors which can operate for 40 years in one location and, as such, makes no provisions for the special nature and time-limited risk of NPS. Defense in depth involves the use of multiple, successive barriers to prevent the release of radioactivity from nuclear facilities.[25,26] Typically three levels of safety are invoked and some design provisions are aimed at helping ". . . to prevent undue challenges to the integrity of the physical barriers, to prevent the failure of a barrier if it is jeopardized, and to prevent consequential damage of multiple barriers in series".[26]

Since this section requires application of defense in depth to all "foreseeable safety-related failures or malfunctions" (something not done on terrestrial nuclear facilities) it is technically infeasible. (The redefinition of the word "foreseeable" to mean essentially "credible" in Principle 2 helps somewhat.) Some NPS, such as radioisotope thermoelectric generators (RTGs), are passive devices with proven passive safety features. Since passive safety features are generally considered to be superior to active safety systems (everything else being equal) the requirement for active safety systems is not appropriate and may actually reduce the level of safety (since active safety systems have some failure probability of their own). This requirement of Section 1.4 could be achieved by stating that "credible safety-related failures or malfunctions should be corrected by design or counteracted by an action or a procedure, possibly automatic". The clarification of the term "general concept of defence-in-depth" achieved by the U.S. in Principle 2 met some of these concerns of the U.S. technical experts.

In general the word "foreseeable" should be replaced with the word "credible" and "*inter alia*" should be replaced by words such as "by consideration of". (To some extent this was eventually accomplished with the definitions incorporated in Principle 2.)

U.S. Response: The U.S. proposed clarifying language in 1991 with the statement that "We believe that this clarification removes any doubts as to the intent behind the application of the term 'defence-in-depth'. As was clear at the time that the Legal Subcommittee reached consensus on this principle, the Subcommittee did not intend to apply the terrestrial standards as such to space systems. The second sentence of paragraph 1.4, as it now appears, makes no provision for passive systems, such as RTGs, or for the preferred solution, in the case of either passive or active systems, of countering risks by system or mission design".[22] The U.S. delegation also stated that ". . .'inter alia' should be replaced with 'for example'. It is our view that 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. The United States expressed this view in joining the consensus on principle 3 in the Legal Subcommittee and wishes to reconfirm that view here".[22] As noted earlier, the discussion in Principle 2, which the U.S. delegation helped develop, helps alleviate these concerns.

2. Nuclear reactors

Section 2.1 states that "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."

Technical 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. (When COPUOS adopted an overall preamble that excluded nuclear propulsion this helped correct some of the problems with Section 2.1.)

Section 2.2 states that "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".

Technical 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 NPS in orbit about the Earth could probably be found to be in violation of Principle 3.

Section 2.3 states that "Nuclear reactors shall use only highly enriched uranium 235 as fuel. The design shall take into account the radioactive decay of the fission and activation products".

Technical Assessment: Where it occurs, the word "shall" should be replaced with the word "should". U.S. technical experts were concerned that this section eliminated consideration of less than "highly enriched uranium 235 as fuel" and that it precluded the use of other fissionable materials.

Section 2.4 states that "Nuclear reactors shall not be made critical before they have reached their operating orbit or interplanetary trajectory".

Technical 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. By eventually clarifying in Principle 2 the term "made critical", the other delegations acknowledged the concerns of the U.S. technical experts.

U.S. Response: The U.S. delegation 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".[22] The U.S. delegation proposed some alternative language which eventually became part of Principle 2.

Section 2.5 requires that the nuclear reactor not become critical before reaching the operating orbit including consideration of the effects of all possible events such as explosions, reentry, impact and water immersion.

Technical 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 requires the use of ". . . a highly reliable operational system to ensure an effective and controlled disposal of the reactor" in the event the reactor is operated ". . . in an orbit with a lifetime less than in the sufficiently high orbit (including operations for transfer into the sufficiently high orbit) . . ."

Technical Assessment: The U.S. 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).

3. Radioisotope generators

Section 3.1 states that "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".

Technical 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 states that "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".

Technical Assessment: This section sets a more rigorous standard for radioisotope power sources than for reactors which presumably are allowed to scatter radioactive materials in the environment. Moreover, this section does not consider the use of mission design and operation to minimize the reentry probability nor does it consider the internationally accepted practice of using probabilistic risk analyses to perform safety assessments. A glaring technical inconsistency between Section 3.2 and Section 1.3 can been seen in the fact that even if current generation RTGs met all of the requirements of Section 3.2 (e.g. remaining intact and not releasing any radioactive material), the natural radioactive emissions of the radioisotope fuel would still violate the somewhat arbitrary radiation dose limits of Section 1.3.

The history of RTGs has shown that it is always possible to find some "foreseeable" hypothetical accident in which the RTG is postulated to impact some hard, sharp surface in a manner that could potentially cause breaching of the containment in some fashion. Similarly, one can postulate "foreseeable" hypothetical reentry accidents that could ablate the reentry shield. During the safety review of the Galileo RTGs there was a disagreement between the DOE project office and INSRP on some of these points. Clearly, then, Section 3.2 is an impossible requirement unless clarification is achieved, perhaps through the terrestrial practice of first defining "design basis accidents" before establishing the safety requirements.

Given an accident with the release of radioactive materials it may be difficult for the impact area to "be completely cleared of radioactivity by a recovery operation". In fact, as noted previously, the Canadian government, which pushed strongly for this principle, showed through analyses that it did not need to completely clear the radioactive debris from Cosmos 954; moreover, the Canadian government accepted less the full cost of cleanup from the Soviet government.[27]

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 shall [should] minimize radioactive material release into the environment so that the debris can be retrieved". Obviously, the U.S. technical experts would have preferred even more realistic wording.

U.S. Response: In 1991 the U.S. delegation 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".[22] To date these concerns have not been reflected in the principles.

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 STSC statement: "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".[23]

However, from a policy standpoint, the U.S. reaped what it had sown on the NPS issue. Beginning in the early 1980s, a handful of low-level DOS personnel used the continuing U.N. discussion of NPS to avoid the addition of new agenda items for COPUOS and ". . . to expose the shortcomings of the Soviet space nuclear power programme and to embarrass the USSR".[28] By 1988, when the Soviet reactor-power satellite Cosmos 1900 threatened to reenter, these same DOS employees suddenly wanted the USG to agree to have the U.N. quickly conclude a set of principles no matter what the technical content. Apparently the objective was either to show that DOS had seriously wanted progress all along or to remove NPS from the COPUOS agenda (or both). Unfortunately, the Soviet delegation had deciphered the DOS game plan and quit objecting to the principles (see Ref. 28) and, in its haste, DOS fell into the trap so patiently laid by Canada and other delegations. The irony is, as one long-time observer noted, that despite the failures in interagency communication which led to the embarrassing reversal on Principle 3, the U.S. delegation almost by accident achieved the emasculation of the U.N. principles -- the principles as adopted are so technically inaccurate and inconsistent they provide almost no useful guidelines.[28]

To achieve technically sound safety principles, it is hoped that in any future U.N. work the technical decisions can be made by proven NPS technical experts rather than by the policy people who have created and continued the current confusing situation.

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