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Summary of the U.S. Ad-Hoc Working Group Meeting on Revising the U.N. Principles on the Use of Nuclear Power Sources in Outer Space

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SUMMARY OF THE U.S. AD-HOC WORKING GROUP MEETING ON REVISING THE U.N. PRINCIPLES ON THE USE OF NUCLEAR POWER SOURCES IN OUTER SPACE

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Abstract

In 1990 the U.N. Committee on the Peaceful Uses of Outer Space adopted a draft set of principles relevant to the use of nuclear power sources (NPS) in outer space. Unfortunately, this draft set of principles contained some technical flaws which would have made them unworkable as written. As a result, U.S. technical experts convened an ad-hoc working group meeting on 8 January 1991 to develop a more technically accurate and consistent set of principles. This working group followed the 1990 draft U.N. principles paragraph by paragraph in developing its technical changes. The working group adopted the guiding principle of only making the minimum number of changes even though the majority of U.S. technical experts recognized that the entire U.N. set of principles needed to be rewritten to be technically accurate, realistic, and consistent. The output of this meeting served as one of the major inputs for U.S. policy makers in working within the U.N. to modify or clarify the 1990 draft principles so that they would be technically realistic and accurate. This paper summarizes the work of the ad-hoc working group of U.S. experts in an effort to provide some of the historical supporting documentation for the reasons that the U.S. changed its approach on the NPS principles at the United Nations from 1990 to 1991.

Introduction

Following the adoption by the United Nations (U.N.) Committee on the Peaceful Uses of Outer Space (COPUOS) of a draft set of principles relevant to the use of nuclear power sources (NPS) in outer space in 1990, U.S. technical experts, most of whom had not been consulted by the U.S. delegation during the adoption process, convened a meeting on 8 January 1991 in Albuquerque, New Mexico to discuss the draft principles. The meeting, which became known as the (U.S.) Ad-Hoc Working Group Meeting, was held because the technical experts had learned in late 1990 that the draft principles were to be incorporated into a U.N. General Assembly (UNGA) resolution, contrary to earlier promises from representatives of the U.S. Department of State (DOS) that they would ensure that the principles were buried in a report.[1]

The Ad-Hoc Working Group Meeting, which was held in conjunction with the Eighth Symposium on Space Nuclear Power Systems in Albuquerque, New Mexico, was designed to familiarize U.S. technical experts with the principles and, where necessary, to develop corrective language to make the politically motivated principles technically valid. Both because of time constraints and its critical nature, the U.S. Ad-Hoc Working Group elected to focus exclusively on Principle 3: "Guidelines and criteria for safe use". The plan was to take the revised technical language developed on Principle 3 in this meeting to the policy organizations in the U.S. Department of Energy (DOE), the U.S. Department of Defense (DoD), and the National Aeronautics and Space Administration (NASA) for further action.

Representatives from DOE, DoD, and NASA attended along with people from various government laboratories and contractors. The U.S. Department of State (DOS) had been invited to participate but declined. Earlier, DOS representatives had said they would abide by whatever technical agreements were reached jointly by DOE, DoD, and NASA. The list of attendees is given in Appendix 1.

The author was asked to chair the meeting and to provide background information on the earlier U.N. work on developing NPS principles. The source for much of this background material can be found in Ref. 2. The attendees then reviewed the 1990 draft set of U.N. principles, specifically focusing on Principle 3 ("Guidelines and criteria for safe use"). For reference purposes the 11 principles as finally adopted by UNGA are (1) Applicability of international law; (2) Use of terms; (3) Guidelines and criteria for safe use; (4) Safety assessment; (5) Notification of re-entry; (6)Consultations; (7) Assistance to States;

(8) Responsibility; (9) Liability and compensation; (10) Settlement of disputes; and (11) Review and revision (see also Appendix 4).[3]

Mindful of the admonition from various policy organizations that it might not be possible to make any changes in the draft principles, the Ad-Hoc Working Group adopted as a fundamental ground rule that only a very minimal set of substantive changes in Principle 3 would be allowed so that the policy people could focus on the "hard points", i.e., the most technically inaccurate of the language in the U.N. draft Principle 3. Each proposed change had to be defended by the proposer and if it could not be defended as an essential change then it was dropped by the Ad-Hoc Working Group. Thus, while many of the attendees expressed dissatisfaction with the entire draft set of U.N. principles and said all of the principles should be completely rewritten to be technically accurate and consistent, they did agree in a spirit of compromise to the minimal set of revisions to Principle 3 provided in Appendix 2 of this paper.[4]

These revisions to Principle 3 were taken back to DOE, DoD, and NASA Headquarters for further action. Since these revisions to Principle 3 provided a minimum common agreement among the technical experts from the three agencies the revised Principle 3 became the de facto common technical underpinning for some of the subsequent U.S. statements and U.S.-initiated changes to the draft U.N. principles. While the U.S. decided for political reasons not to change the most controversial principle (Principle 3: "Guidelines and criteria for safe use"), the thinking behind the Ad-Hoc Working Group's revisions to Principle 3 can be found in U.S.-initiated revisions to other paragraphs and the overall preamble of the U.N. principles as adopted by the U.N. General Assembly (UNGA) in 1992 in which most of the meaning of Principle 3 was changed or clarified.

The following section explains the changes which the U.S. Ad-Hoc Working Group proposed to the draft 1990 U.N. Principle 3. The complete text of the revised version of Principle 3 developed by the Ad-Hoc Working Group is given in Appendix 2.[4]

Explanation of Proposed Changes in Principle 3: Guidelines and Criteria for Safe Use

The following subsections provide background information (in the author's words based on notes taken during the Ad-Hoc Working Group meeting) on some of the reasons for the changes which the U.S. Ad-Hoc Working Group made in Principle 3 ("Guidelines and criteria for safe use") of the 1990 U.N. "Draft Principles Relevant to the Use of Nuclear power Sources in Outer Space". The explanations are keyed to the numbering system used in the 1990 U.N. draft version of Principle 3 that was available to the U.S. Ad-Hoc Working Group. Principle 3 is divided into three main sections or "paragraphs" which follow the preamble (Principle 3 is the only principle with its own preamble). The full text of Principle 3 as adopted by the U.N. in 1992 is given in Appendix 3.

Preamble

The 1990 preamble, which focused on restricting the use of NPS, was judged to be extremely negative toward the use of nuclear power in space. Unlike the original 1981 U.N. technical consensus on principles governing the use of NPS in outer space which the U.S. delegation and all other COPUOS delegations had supported, the preamble to the 1990 Principle 3 would force users to find any other "reasonable way" to power spacecraft.[3] In contrast, the 1981 U.N. Working Group report said that the decision to use NPS in outer space should be a technical one (all other factors equal).[5,6] The proposed new preamble listed in Appendix 2 puts the safety goal in a positive vein, that is, enhancing safety and environmental protection.[4] (Author's note: Given the naturally occurring and very high nuclear radiation of the Van Allen Belts, solar flares, Jovian radiation belts, etc., many of the attendees found it incongruous that the U.N. was attempting "to minimize the quantity of radioactive material in space" as stated in the Preamble.[3])

1. General goals for radiation protection and nuclear safety

Section 1.1 uses the word "hazards" which is not quantitatively defined.[3] The term "risks" was substituted in the second sentence by the U.S. Ad-Hoc Working Group because it has a quantitative definition (basically probability multiplied by consequences). (In keeping with the objective of minimizing changes the word "hazards" was left in the first sentence.)

Section 1.1 also requires that any "hazards" be kept below "acceptable levels" in "foreseeable operational or accidental circumstances".[3] The Ad-Hoc Working Group judged that the term "foreseeable" connotes everything one can envision beforehand. In U.S. 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 nuclear power source can ever be built just as one could not build a reasonable automobile if all foreseeable accidents had to be mitigated by design.

Since the U.S. Government does not have official dose limits for accidents (just as it does not have accident limits on airplane or automobile crashes) the reference to dose limits was deleted by the Ad-Hoc Working Group and replaced with a concept used in radiation health physics, namely, "as low as reasonably achievable". (It is interesting to note that less than two months after the Ad-Hoc Working Group meeting the representative from the International Atomic Energy Agency to COPUOS independently supported the U.S. Ad-Hoc Working Group's position by stating that "The sole use of the individual-related dose limits, rather than the complete ICRP [International Commission on Radiological Protection] 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".[7])

Regarding the last sentence of Section 1.1, several of the attendees at the Ah-Hoc Working Group Meeting observed, as noted earlier regarding the Preamble, that the prohibition of the U.N. principles against "a significant contamination of outer space" was inconsistent with the fact that many parts of outer space are already highly filled with radiation (e.g., Van Allen radiation belts, solar storms, etc.)

Section 1.2 applies the "appropriate radiation protection objective for the public recommended by the International Commission on Radiological Protection (ICRP)" to the normal operation of an NPS including reentry.[3] Consistent with the policy-dictated objective of preparing only a minimal number of changes the Ad-Hoc Working Group added a clarifying phrase "to the public" at the end of the paragraph to make it clear that the ICRP standards apply only to the general public and then only in normal operation situations. Astronauts and radiation workers, for example, have different (and higher) radiation standards. The Ad-Hoc Working Group was well aware that the ICRP had no rigid standards for accidents because accidents are almost by definition events that are out of control.

Section 1.3 established for the first time radiation exposure limits for accidents.[3] The Ad-Hoc Working Group deleted the paragraph on dose limits because the U.S. Government (and all other rational agencies) have no official dose limits for accidents. In any of the radiation protection standards the Ad-Hoc Working Group was aware of, no limits were set for accidents because (as noted above) by definition an accident is an unintentional event, one that is out of control or off-normal. Just as there are no regulations restricting injuries or fatalities in automobile crashes or airplane crashes there are no dose limits for radiation accidents.

Section 1.4 requires that "Systems important for safety shall be designed, constructed and operated in accordance with the general concept of defence-in-depth" and that "foreseeable safety-related failures or malfunctions must be capable of being corrected or counteracted by an action or a procedure, possibly automatic".[3]

The U.S. Ad-Hoc Working Group replaced the word "foreseeable" with the word "credible" for the same reasons discussed in Section 1.1.

Based on the text of Section 1.4, the Ad-Hoc Working Group judged that the draft 1990 U.N. Principle 3 intended to apply the terrestrial concept (and not some new space concept) of "defense-in-depth" to space nuclear power. In one of the U.S. definitions of defense-in-depth for terrestrial nuclear power facilities three independent levels of safety are required.[8] As an example of the potential impact of Section 1.4, such a definition would require that a new cladding physically separated from and redundant to the existing fuel cladding be developed for the current U.S. radioisotope thermoelectric (RTG) heat source design which has already shown itself to be the safest RTG yet flown. Similarly, at a minimum, the then-planned U.S. design for the SP-100 space nuclear reactor power system, which already had multiple safety features, would have had to be drastically modified to include a heavy containment vessel in addition to the fuel cladding and the pressure vessel in order to meet the requirements of Section 1.4. All other identified U.S. and Russian space nuclear reactor designs would have suffered similar drastic design changes. (The reader interested in the RTG and SP-100 safety features is referred to Ref. 9.)

Adding to the confusion of Section 1.4 is that unlike most reactors, RTGs are passive devices with no moving parts so there should not be a requirement for them to have active safety systems when passive safety systems have been shown to do the job; hence, the Ad-Hoc Working Group changed the U.N. words to "corrected by design". (In fact, a case could be made that adding active safety systems to an RTG could degrade the safety margin because, for example, active safety systems have some probability of failure.)

The other changes made by the Ad-Hoc Working Group (e.g., changing "must" to "should", "*inter alia*" to "consideration of" and "shall" to "may") basically make the paragraph more realistic; some things (e.g., reality) just cannot be legislated.

2. Nuclear reactors

Section 2.1 limits the use of nuclear reactors to interplanetary missions, sufficiently high orbits (SHO) and low-Earth orbits (LEO).[3] The Ad-Hoc Working Group replaced the phrase "in low Earth orbits" with the phrase "in any orbit or flight trajectory" to allow the use of other than low-Earth orbit and also to allow for nuclear propulsion missions which may need to use a "flight trajectory" rather than an "orbit".

Section 2.2 requires that "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".[3] The Ad-Hoc Working Group changed this sentence to give the mission planner sufficient flexibility while still requiring consideration of orbital debris. Since there will probably be orbital debris everywhere (particularly when future missions have to be considered) the original U.N. paragraph was not practical. If taken literally, Section 2.2 means that many existing NPS in orbit about the Earth violate 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".[3] While the Ad-Hoc Working Group was aware that in 1990 the choice of "shall" or "should" had yet to be decided by the U.N., the Ad-Hoc Working Group believed rather strongly that in this instance the word should be "should" in order to give some flexibility in the choice of fuel (e.g., Section 2.3 excludes low-enriched uranium 235 which is not a problem). For certain futuristic mission scenarios other fissionable materials might be desirable.

Section 2.4 states that "Nuclear reactors shall not be made critical before they have reached their operating orbit or interplanetary trajectory".[3] As written, this section 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 ("zero") power that there is very little fission product buildup. The original U.N. paragraph would have had the effect of forcing a country to launch multi-million dollar reactors on multi-billion-dollar spacecraft with no assurance that the flight reactors would work. In some mission scenarios, the reactor would be needed to boost the satellite (via some form of nuclear propulsion) to a SHO so if the reactor did not operate because of the failure to perform preflight zero-power checkout tests then SHO could not be reached. The Ad-Hoc Working Group changed this sentence to allow for zero-power testing to ensure the operability and safety of the flight reactor(s).

Section 2.5 states that "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".[3] The changes proposed by the Ad-Hoc Working Group acknowledge the use of nuclear reactors in nuclear thermal propulsion or nuclear electric propulsion; hence, such systems may need to be operated in the "flight trajectory" and not just in orbit. The phrase "all possible events" would lead to an unending list of anything anyone can think of no matter how far-fetched; therefore, the word "credible" was used to bring this sentence into the real world.

Section 2.6 requires "a highly reliable operational system to ensure an effective and controlled disposal of the reactor".[3] In keeping with the objective of minimizing changes, the Ad-Hoc Working Group made no changes to this section (paragraph), although some of the attendees noted that the word "disposal" was not defined and so could mean anything.

3. Radioisotope generators

Section 3.1 states where radioisotope generators may be used and calls for "ultimate disposal".[3] In keeping with the objective of minimizing changes, the Ad-Hoc Working Group made no changes to this section (paragraph). Some of the attendees at the Ad-Hoc Working Group Meeting noted that the term "ultimate disposal" was not defined and so could mean anything, including leaving the NPS in orbit.

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".[3]

The Ad-Hoc Working Group replaced the word "foreseeable" with the word "credible" for the reasons discussed in Section 1.1 (see also the discussion on Section 2.5). The Ad-Hoc Working Group recognized that absolute containment cannot be guaranteed in all "foreseeable" accidents so it used words to give the designers some flexibility to minimize the consequences of postulated accidents while preserving the overall safety goals. For similar reasons the IAEA and the ICRP recognize the impossibility of absolute containment and complete cleanup in terrestrial nuclear facilities in all "foreseeable" accidents. Such a requirement is akin to requiring absolute protection of all passengers in an airplane crash.

It is interesting to note that in the case of the Soviet reactor-powered satellite Cosmos 954, which reentered over Canada in 1978, the Canadian government eventually quit trying to clean up the debris and concluded that what was estimated to be left was not worth the expense of cleaning up.[10] Similar flexibility must be given to future decision makers.

Consequences of the Ad-Hoc Working Group Meeting

As a result of the meeting of the Ad-Hoc Working Group the knowledgeable technical experts in the U.S. Government became united around a specific document (Appendix 2) which allowed them to press their respective policy organizations to argue for the necessary changes to make Principle 3 technically realistic and meaningful. Following the meeting on 8 January 1991, the U.S. delegation insisted on a number of changes to the overall principles. Since other delegations would not countenance changes to Principle 3 no matter how necessary, the U.S.-led changes were made in other paragraphs and the overall preamble to the principles.

The overall preamble to the 11 U.N. principles (not the specific preamble to Principle 3) was changed to a more positive and specific preamble with these words:[3]

"The General Assembly,

"Recognizing that for some missions in outer space nuclear power sources are particularly suited or even essential due to their compactness, long life and other attributes,

"Recognizing that the use of nuclear power sources in outer space should focus on those applications which take advantage of the particular properties of nuclear power sources,

"Recognizing that the use of nuclear power sources in outer space should be based on a thorough safety assessment, including probabilistic risk analysis, with particular emphasis on reducing the risk of accidental exposure of the public to harmful radiation or radioactive material,

"Recognizing the need, in this respect, for a set of principles containing goals and guidelines to ensure safe use of nuclear power sources in outer space,

"Affirming that this set of Principles applies to nuclear power sources in outer space 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,

"Recognizing that this set of Principles will require future revision in view of emerging nuclear power applications and of evolving international recommendations on radiological protection,

"Adopts the Principles Relevant to the Use of Nuclear Power Sources in Outer Space as set forth below."

The third paragraph of U.N. Principle 2 ("Use of terms") was changed to state that "For the purposes of principle 3, 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. 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. For the purposes of paragraph 2.4 of principle 3, the term 'made critical' does not include actions such as zero-power testing which are fundamental to ensuring system safety".[3]

These and other U.S.-developed changes had the effects of

- Making the use of NPS a technical decision as the 1981 U.N. technical report[5] stated.
- Eliminating nuclear propulsion and future

NPS (those not currently in existence) from the Principles

- Requiring future revisions to recognize that trying to legislate rigid standards of radiological protection was inconsistent with the evolving national and international standards of radiological protection.
- Defining the terms "foreseeable" and "all possible" to mean, in effect, "credible".
- Defining the term "defense-in-depth" to give the necessary flexibility for space applications.
- Defining the term "made critical" to allow zero-power testing of reactors before launch.

The preamble also brings in the basic concept that the principles are to provide safety goals and guidelines rather than (by inference) arbitrary numerical dose limits that have no relationship to accidents. The preamble also mentions the term "risk" rather than the undefined word "hazards" and the preamble describes the need for probabilistic risk assessments (which is the U.S. approach).

In a number of formal statements, the U.S. has stated its view that the principles are non-binding and recommendatory only and that the words "shall" and "must" should be replaced by the word "should".[11,12] The U.S. delegation has also taken exception to rigid dose limits applied to any accident.[11,12,13]

While the U.S. reluctantly went along with the principles for political reasons it formally expressed its reservations and interpretation in this statement during the final adoption process: "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".[14]

In effect, the U.S. is going to continue to follow its own proven safety practices which it believes are consistent with the overall *goals* of the U.N. principles. The U.S. will not necessarily be guided by the specifics of the U.N. principles since as this paper has shown many of the specifics are technically inaccurate or misleading. Unfortunately, because certain delegations would not accept the U.S.-proposed changes that would have made the principles technically accurate, realistic, and consistent, the U.N. now has a set of principles which are inaccurate, inconsistent and unworkable, a fact that has been noted rather forcefully elsewhere.[15,16]

Concluding Remarks

Overall, the meeting of the (U.S.) Ad-Hoc Working Group achieved its objective of providing a common set of changes to U.N. draft Principle 3 ("Guidelines and criteria for safe use"). Most of this minimal set of changes requested by the Ad-Hoc Working Group was incorporated into the overall principles (generally in the overall preamble or in Principle 2 ["Use of terms"]). In other areas where the U.S. was not able to make the requested specific changes (e.g., "shall" versus "should", Section 1.3, Section 3.2, etc.), U.S. delegates presented formal statements describing how the U.S. intended to interpret the principles. This process also showed that it is possible for knowledgeable, rational technical experts to work together to correct a political document that contained many technical flaws. As the author has stated elsewhere, "Whether the issue is NPS, remote sensing, orbital debris, the definition and delimitation of outer space, or direct broadcast satellites, it is essential that qualified technical experts be involved in the development of any international principles affecting that area".[16]

Acknowledgments

The author acknowledges his gratitude to the attendees of the Ad-Hoc Working Group Meeting (see Appendix 1) for taking the time to discuss, debate, and agree on a minimal set of changes and then to take these changes to their respective agency policy groups for implementation. Specifically, the author would like to thank George C. Allen of Sandia National Laboratories for providing excellent and rapid administrative support to the meeting.

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3. "Report of the Legal Subcommittee on the Work of its Thirty-First Session, Chairman's text, Principles Relevant to the Use of Nuclear Power Sources in Outer Space", U.N. Document A/AC.105/L.198, 23 June 1992. A partial listing of the principles (U.N. Document A/47/20) is presented in the *Journal of Space Law*, Vol. 20, No. 2, pp. 211-215, 1992. The final form of the U.N. principles, as passed by the Special Political Committee of UNGA on 30 October 1992, is in U.N. document A/47/610.

4. "Revision to the Draft Principles Relevant to the Use of Nuclear Power Sources in Outer Space" prepared at the Ad-Hoc Working Group Meeting held during the Eighth Symposium on Space Nuclear Power Systems in Albuquerque, New Mexico, 8 January 1991.

5. "Report of the Working Group on the Use of Nuclear Power Sources in Outer Space on the Work of its Third Session", Annex II of Report of the Scientific and Technical Subcommittee on the Work of its Eighteenth Session, U.N. Document A/AC.105/287, United Nations, 13 February 1981.

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14. K. Hodgkins, "Statement by Kenneth Hodgkins, United States Adviser to the 47th Session of the United Nations General Assembly, in the Special Political Committee, on Item #72, International Cooperation on the Peaceful Uses of Outer Space, October 28, 1992", USUN Press Release #116-(92), United States Mission to the United Nations, New York, New York, 28 October 1992.

15. S. Aftergood, "Space nuclear power and the UN, A growing fiasco", *Space Policy*, pp. 9-12, February 1992.

16. G. L. Bennett, "Reaching the outer planets -- with or without the U.N.", *Aerospace America*, pp. 26-30, 43, July 1996.

Appendix 1
List of Attendees at
Ad-Hoc Working Group Meeting

(Note: The organizational listings are for identification purposes only and do not imply any organizational endorsement. These listings are those of the attendees at the time of the meeting on 8 January 1991.)

Douglas M. Allen, SDIO/TNK
George C. Allen, Sandia National Laboratories (SNLA)
Hal Bengelsdorf, ERCE
Gary L. Bennett, NASA Headquarters
Colette Brown, DOE Headquarters
Hatice Cullingford, NASA/LMEPO
Leven Gray, NASA Headquarters
Lt. Col. Ernest D. Herrera, USAF/PL/TAP
Frank Jankowski, USAF/PL/TAPN
Inara Kuck, USAF/PL/TAP
Stephen J. Lanes, DOE Headquarters
Robert G. Lange, DOE Headquarters
Jim Lee, SDIO/TNK
Lt. Col. Roger X. Lenard, SDIO/TNG
Al Marshall, SNLA
Bill McCulloch, SNLA
Greg Reck, NASA Headquarters
J. C. Sawyer, NASA Headquarters
Lt. Col. Joseph Sholtis, AFISC/SNRA
Greg Sullivan, Xerad, Inc.
Earl J. Wahlquist, DOE Headquarters
Abe Weitzberg, NUS Corporation
Col. Robert Winchester, AFISC/SNR

Appendix 2
Revision to Principle 3 of the 1990 Draft Principles Relevant to the Use of Nuclear Power Sources in Outer Space

The following is the revision to the 1990 U.N. draft Principle 3 ("Guidelines and criteria for safe use") prepared at the (U.S.) Ad-Hoc Working Group Meeting held on 8 January 1991 in Albuquerque, New Mexico during the Eighth Symposium on Space Nuclear Power Systems.[4] It must be emphasized that the Ad-Hoc Working Group operated under the rigid guideline of making only a very few substantiative changes. Many of the attendees believed that all of the principles (not just Principle 3) needed to be completely rewritten to be technically accurate, realistic, and consistent. At the Ad-Hoc Working Group meeting, it was recommended that additional text from the 1981 U.N. working group guidelines[5] be added to the preamble. The text was not available when this revision was typed and so that text is not included here.

Author's note: The Ad-Hoc Working Group assumed that the U.S. delegation would be successful in changing "shall" and "must" to "should" or "may". Since those changes were not accomplished, this text contains those modifications. Some minor editorial changes of a grammatical nature have also been made. An additional change from Ref. 4 is the author's highlighting through italics or brackets where the changes were made (including where, for convenience, the Ad-Hoc Working Group used acronyms as was done in the 1990 draft U.N. text instead of spelling out the phrases as in the 1992 U.N. final text).

Principle 3: Guidelines and criteria for safe use

In order to *enhance the safety of nuclear power sources (NPS), which include nuclear reactors and radioisotope 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.*

1. General goals for radiation protection and nuclear safety

1.1 States launching space objects with *NPS* on board *should* endeavour to protect individuals, populations and the biosphere against radiological hazards. The design and use of space objects with *NPS* on board *should* ensure, with a high degree of confidence, that the *risks* in [*Deletion*] operational or accidental circumstances, are kept *as low as reasonably achievable (ALARA).*

Such design and use *should* also ensure with high reliability that radioactive material does not cause a significant contamination of outer space.

1.2 During the normal operation of space objects with *NPS* on board, including re-entry from the sufficiently high orbit *(SHO)* as defined in paragraph 2.2, the appropriate radiation protection objective for the public recommended by the International Commission [on] Radiological Protection (ICRP) *should* be observed. During such normal operation there *should* be no significant radiation exposure *to the public.*

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

[*Deletion of dose limits.*]

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

Future modifications of the guidelines referred to in this paragraph *should* be applied as soon as practicable.

1.4 Systems important for safety *should* be designed, constructed and operated in accordance with the general concept of defence-in-depth *for aerospace systems.* Pursuant to this concept, *credible* safety-related failures or malfunctions *should* be [*Deletion*] corrected *by* *design* or counteracted by an action or a procedure, possibly automatic.

The reliability of systems important for safety *should* be ensured *by consideration of* redundancy, physical separation, functional isolation and adequate independence of their components.

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

2. Nuclear reactors

2.1 Nuclear reactors may be operated:

(i) On interplanetary missions;
(ii) In sufficiently high orbits (SHO) as defined in paragraph 2.2;
(iii) *In any orbit or flight trajectory* if they are stored in *SHO* after the operational part of their mission.

2.2 The *SHO* 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 selection of the SHO should take into consideration* the risks to existing and future outer space missions and [*Deletion*] collision with other space objects [*Deletion*]. The necessity for the parts of a destroyed reactor also to attain the required decay time before re-entering the Earth's atmosphere *should* be considered in determining the *SHO* altitude.

2.3 Nuclear reactors *should* use only highly enriched uranium 235 as fuel. The design *should* take into account the radioactive decay of the fission and activation products.

2.4 Nuclear reactors *should* not be *operated at power, except for zero-power testing* before they have reached their operating orbit or [*Deletion*] trajectory.

2.5 The design and construction of the nuclear reactor *should* ensure that it cannot become critical before reaching the operating orbit *or flight trajectory considering credible launch accidents*, including rocket explosion, *inadvertent* re-entry, impact on ground or water, submersion in water or water intruding into the core.

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 *SHO* (including operations for transfer into the *SHO*), there *should* be a highly reliable operational system to ensure an effective and controlled disposal of the reactor.

3.1 Radioisotope generators

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.

3.2 Radioisotope generators *should* 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 *credible* orbital conditions, including highly elliptical or hyperbolic orbits where relevant. 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.*

Appendix 3
UN Principle 3: Guidelines and criteria for safe use

[The following is the text of Principle 3 as taken from Reference 3. Note that the numbering system of the subparagraphs is different from that of Appendix 2 because the U.N. text that Ad-Hoc Working Group was given had used Arabic numbers rather than lower case letters for the subparagraphs.]

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.

1. General goals for radiation protection and nuclear safety

(a) 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.

(b) 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.

(c) 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.

Future modifications of the guidelines referred to in this paragraph shall be applied as soon as practicable.

(d) 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 be also be taken to raise the level of safety.

2. Nuclear reactors

(a) Nuclear reactors may be operated:

(i) On interplanetary missions;

(ii) In sufficiently high orbits as defined in paragraph 2 (b);

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

(b) 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.

(c) 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.

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

(e) 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.

(f) 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.

3. Radioisotope generators

(a) 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.

(b) 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.

Appendix 4
List of U.N. Principles Relevant to the Use of Nuclear Power Sources in Outer Space

The 11 principles consist of:[3]

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 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 this paper.

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 cleanup 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.