United Nations A/AC.105/C.1/L.256/Rev.1

General Assembly

Distr.: Limited
6 March 2002

Original: English

Committee on the Peaceful Uses of Outer Space
Scientific and Technical Subcommittee
Thirty-ninth session
Vienna, 25 February-8 March 2002
Agenda item 7
Use of nuclear power sources in outer space

A review of international documents and national processes potentially relevant to the peaceful uses of nuclear power sources in outer space

Report of the Working Group on the Use of Nuclear Power Sources in Outer Space

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V.02-51903 (E) 070302 070302

I. Introduction

1. Having taken into account the international experience and some unintended events in the use of space nuclear power sources, the Committee on the Peaceful Uses of Outer Space in 1980 established the Working Group on the Use of Nuclear Power Sources in Outer Space. The Working Group consisted of national experts charged with examining, as an initial step, the practice of using nuclear power sources in outer space. In 1983, the Working Group's mandate was changed to require it to produce technical criteria for the safe use of nuclear power sources in space.

2. In 1992, after about a decade of discussions and negotiations in the Committee on the Peaceful Uses of Outer Space and its two subcommittees, recognizing the need for goals and guidelines to ensure the safe use of nuclear power sources in outer space, a set of principles was established. Those principles were endorsed by the General Assembly in its resolution 47/68 of 14 December 1992, entitled "Principles Relevant to the Use of Nuclear Power Sources in Outer Space".[1]

3. In adopting resolution 47/68, the General Assembly recognized, as noted in the preamble to the resolution, that the principles would require future revision in view of emerging nuclear power applications and evolving international recommendations on radiological protection. During the thirty-fourth session of the Scientific and Technical Subcommittee in 1997, it was agreed to reconvene the Working Group on the Use of Nuclear Power Sources in Outer Space in 1998 to identify and study the current international technical standards pertinent to the use of nuclear power sources. During the thirty-fifth session of the Subcommittee, the Working Group convened and a work plan for developing a framework for safety assurance processes and standards for nuclear power sources in outer space was adopted. The Subcommittee agreed during that session that, at the present time, revision of the Principles was not warranted. The Subcommittee further agreed that, until a firm scientific and technical consensus had been reached, it would be inappropriate to pass on the topic to the Legal Subcommittee.

4. The adopted work plan focused on establishing a process and framework for developing information or data that would facilitate future discussions of safety processes and standards for nuclear power sources. It included the following schedule of work:

Year	*Activity*
1998	Adopt schedule of work. Invite Member States and international organizations to submit information to the United Nations on the topics for 2000 and 2001.
1999	Review and discuss progress in responding to work plan, as appropriate.
2000	Identify terrestrial processes and technical standards that may be relevant to nuclear power sources, including factors that distinguish nuclear power sources in outer space from terrestrial nuclear applications.
2001	Review national and international processes, proposals and standards, and national working papers relevant to the launch and peaceful use of nuclear power sources in outer space.

Year	*Activity*
2002	Prepare a report which provides the information to the Scientific and Technical Subcommittee.
2003	Scientific and Technical Subcommittee to determine whether to take or not take any additional steps concerning the information contained in the report of the Working Group.

5. The Working Group met three times during the thirty-seventh session of the Scientific and Technical Subcommittee (in 2000), five times during the thirty-eighth session (in 2001) and [...] times during the thirty-ninth session (in 2002) with the objective of producing the report called for in the work plan. In addition, a number of informal consultations took place among interested delegations to ensure continued progress in the work of the Working Group. During the course of the meetings and informal consultations, the Working Group considered 16 working papers and additional materials (see annex I). The present report represents the consensus reached by the Working Group on the basis of its deliberations and was prepared by the Working Group for submission to the Scientific and Technical Subcommittee as called for in the work plan.

II. Factors that differentiate nuclear power sources in outer space from terrestrial nuclear applications

6. When assessing the potential relevance of various terrestrial processes and technical standards to space nuclear power sources, it is important to consider the factors that differentiate between space and terrestrial power sources. The present section identifies some of these distinguishing factors as called for in the work plan and serves as a precursor to the information on potentially relevant documents provided in section III below.

7. The extent of differences and similarities between the use of nuclear power sources in outer space and terrestrial applications depends upon the specific nature of the application in each case and the peculiarities of the nuclear power sources being considered.

8. Some similarities at a fundamental level that exist between terrestrial and nuclear power sources in outer space include:

(a) The use of radioactive materials to provide benefits to humankind;

(b) The advanced science and engineering involved in designing nuclear power sources and developing associated technologies;

(c) The emphasis on safety (and related issues of public perception) associated with the use of radioactive materials;

(d) The potential, in some cases, for consequences from certain accident scenarios to cross international boundaries;

(e) The high level of reliability applied to system operation and protection of workers, the public and the environment;

(f) Some degree of commonality between analytical and engineering methods and processes used to support design, safety and risk assessment.

9. Activities involving nuclear power sources in outer space can be viewed as consisting of two sequential categories: (a) terrestrial-based operations including development, assembly and testing of the nuclear power sources in outer space and transportation to the launch site; and (b) operations of nuclear power sources in outer space that can affect flight nuclear safety, including launch, deployment and use as part of a space mission. The existing terrestrial procedures that are most directly applicable to nuclear power sources in outer space relate to the first set of activities, whereas activities in the latter set are unique to nuclear power sources in outer space and direct application of terrestrial standards in those cases is likely to be limited.

10. The following classes of terrestrial nuclear power sources or processes were initially identified by the Working Group as having potential relevance to nuclear power sources in outer space:

(a) Nuclear reactors (stationary and mobile);

(b) The use of radioactive sources in terrestrial applications;

(c) Packaging and transport of radioactive materials.

11. In considering the relevance of each of the above-mentioned classes to the use of nuclear power sources in outer space, a number of other factors need to be taken into account, including the following:

(a) Nature of the applications;

(b) Operating environment;

(c) Nature and autonomy of operation of systems;

(d) Quantity of radioactive material;

(e) Frequency and duration of use;

(f) Distance to, and the effects of normal operation and potential accidents on, populated areas;

(g) Complexity and designed reliability of systems;

(h) Use of passive and/or active systems;

(i) End of service.

12. The above factors lead to fundamental technical differences between space and terrestrial nuclear power sources with regard to their design and use, for example:

(a) The uniqueness and very short time duration of the launch of nuclear power sources into space, coupled with the relatively low number of launches that have taken place to date;

(b) Design for autonomous or remote operation of the nuclear power sources in the environment of outer space;

(c) Long-term presence of nuclear power sources in outer space after shutdown.

The differences in the design and use of space and terrestrial nuclear power sources also give rise to differences in the risks and benefits associated with their use.

13. It should be noted that space nuclear power sources are of either the radioisotope or the nuclear reactor type. Radioisotope systems use the energy released by the natural decay of a radioisotope to produce thermal or electrical power, whereas fission reactor systems primarily derive their power from the energy released through controlled and sustained nuclear fission reactions.

14. Mission reliability requirements, smaller power requirements, launch vehicle and spacecraft mass limitations and related technical constraints drive space nuclear power sources to be much smaller and to involve fewer subsystems than terrestrial power reactors. For instance, the main features of space reactors are determined by the basic requirement for a minimal reactor size and mass for a given power level and operating life, which, together with the radiation shield and thermal-to-electrical power conversion system, needs to permit overall dimensions and mass that are tolerable for the space object.

15. With regard to terrestrial nuclear power sources, significant attention has been focused on land-based nuclear power plants. It is important to note that although there are some commonalties with space reactors regarding the physical principles related to operation, control and analytical methods, there are still vast differences between the two applications, and even more so between land-based nuclear power plants and space radioisotope systems.

16. Unlike typical terrestrial reactors used for power generation, space nuclear reactors are typically characterized by a much smaller (1,000-10,000 times less) thermal power level, and minimal dimensions and mass (through use of uranium highly enriched in the isotope 235). Differences in reactor core design and types of accident scenarios that need to be addressed also exist between the two applications.

17. Due in part to their greater radioactive inventories and closer proximity to the surrounding human population and Earth environment, terrestrial power reactors have a greater need for multiple engineered safety features than do smaller space nuclear reactors designed to stay inactive until started in outer space. The great distances at which nuclear power sources in outer space typically operate are very beneficial from a safety standpoint in reducing any consequences arising from a malfunction during operations. However, the remote nature of operations has the disadvantage of precluding, or making quite inconvenient, the performance of any maintenance, safety enhancements, or equipment upgrades.

18. Space radioisotope power systems are generally even smaller in power level and size. For example, each of the space radioisotope power system units used on recent science missions to explore Jupiter, Saturn and other parts of our solar system occupies a volume of less than a quarter of a cubic metre and produces less than 300 watts of electricity as compared with the approximately one billion watts produced by a typical terrestrial civilian power reactor.

19. Additional differences exist between terrestrial and space systems. Terrestrial systems must provide engineering and design features that minimize risk to the general public over the lifetime of the facility (for example, typically 40 years or more), accommodate potential human operational errors, and ensure proper equipment maintenance over that time period. Because these are terrestrial facilities,

various large-scale (relative to space applications) backup or emergency systems are often employed to protect the public, environment and capital investment. Because of differences in size and application, terrestrial systems tend to be more complex than those used in space. Although more recent designs for terrestrial nuclear power plants have focused on simplicity and passive safety features, the current generation of operating plants relies on numerous active systems for normal operation and safety. Furthermore, there are several hundred terrestrial nuclear power sources operating around the world, most of which operate at fixed locations for their entire service life. Space systems, however, are less frequently used, traverse specified trajectories, and spend virtually all of their operating life at great distances from Earth.

20. Interactions between space nuclear power sources and the space object that carries them are also fundamentally different from those between terrestrial nuclear power sources and their environment (for example, the grid network, earthquakes and flooding). Terrestrial systems are generally operated directly by humans, whereas space systems operate autonomously or remotely. These give rise to differences in safety provisions to prevent and minimize the consequences of any internal failures as well as externally induced events. For example, several site-related environmental and safety aspects of terrestrial nuclear power plants, such as periodic inspection and maintenance requirements and evaluation of natural and human-related hazards over the life of the plant, apply for terrestrial but not space nuclear power sources. In contrast, safety and environmental analyses of space nuclear power sources address the response of the nuclear power sources to various physical environments induced by such factors as launch system or space vehicle failure over a wide range of postulated accident scenarios.

21. One potential accident scenario unique to space nuclear power sources relates to the risk of collision of space debris with Earth-orbiting nuclear power sources. The consequences depend on the particular scenario considered, the most serious one of which involves an impact by a space debris fragment to the spacecraft with nuclear power sources leading to damage of the spacecraft and nuclear power sources, followed by premature re-entry into the Earth's atmosphere. In general the probability and consequences of collisions between space debris particles and nuclear power sources on space objects depend on a number of factors, such as the height of the orbit, the physical dimensions of the debris particle and the space object, and their relative velocities. For example, the calculations and theoretical research of the Russian Federation presented in working papers A/AC.105/C.1/L.233 and L.246 show that the probability of collision with a space debris particle sufficient to result in severe damage or fragmentation may be numerically around 0.01 in 100 years (at altitudes of 700 km to 1,100 km). Even if a collision did occur, it would be highly unlikely to result in the re-entry of nuclear power source fragments, in particular larger-sized fragments, with significant associated radiological consequences. The issues associated with space debris are currently being addressed within the Scientific and Technical Subcommittee in a broader context.

III. International conventions, standards and documents of a technical nature having potential relevance to space nuclear power sources and procedures for their development

22. As indicated in the introduction to the present report, the Scientific and Technical Subcommittee, at its thirty-fourth session, agreed to reconvene the Working Group on the Use of Nuclear Power Sources in Outer Space to identify and study current international technical standards pertinent to the use of nuclear power sources (A/AC.105/672, paras. 69-87). The work plan (A/AC.105/C.1/L.222) presented during the thirty-fifth session was developed to support that activity. Accordingly, a review was conducted to identify various international documents, in addition to the existing Principles Relevant to the Use of Nuclear Power Sources in Outer Space, of potential relevance to space nuclear power sources, including conventions, standards, recommendations and other technical documents. The objective of this activity was to garner information that could be useful in facilitating any future discussions on safety processes and standards relating to nuclear power sources.

23. During the course of its work, the Working Group undertook a review of the following documents in order to identify with more specificity those documents or parts of documents which might be of particular relevance to nuclear power sources in outer space:

(a) The provisions of the Convention on Nuclear Safety,[2] the Convention on Early Notification of a Nuclear Accident,[3] the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency[4] and the Convention on the Physical Protection of Nuclear Material;[5]

(b) The recommendations of the International Commission on Radiological Protection (ICRP);

(c) The relevant Safety Series publications of the International Atomic Energy Agency (IAEA);

(d) The reports of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

24. The existence of technical documents produced by the International Maritime Organization addressing nuclear activities was called to the attention of the Working Group. Those documents were not reviewed by the Working Group as they were considered generally not to be of direct relevance to space nuclear power source activities. However, they may be of some value from a fundamental point of view in comparing the high seas and outer space, both of which share a common interest for all humankind.

25. A preliminary review of most of the documents mentioned in paragraph 24 above was performed and discussed during the thirty-eighth session of the Scientific and Technical Subcommittee in 2001. A listing of the specific documents included in each area is provided in the form of a database in annex II to the present report. Particular documents and types of documents examined by the Working Group are discussed in the present section. A summary of the procedures used by IAEA and ICRP for developing technical standards, recommendations and other guidance documents is also included at the end of the present section.

A. Existing international conventions

26. There are a number of high-level international instruments of a general nature that, while not necessarily citing nuclear power sources within their text, still may be relevant to activities involving space nuclear power sources. They include the following:

(a) The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies;

(b) The Convention on International Liability for Damage Caused by Space Objects;

(c) The Convention on Registration of Objects Launched into Outer Space;

(d) The Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space.

The latter Agreement may regulate the transfer of space nuclear power sources or parts thereof from the country that has been affected by re-entry of the nuclear power sources back to the originating country.

27. The Working Group decided to focus on those international instruments of a less general nature and more specific to nuclear power sources. It also focused its attention on the technical aspects of relevant conventions and procedures. With that in mind, the Group identified the following conventions that might be relevant to the safety of nuclear power sources in outer space:

(a) The Convention on Early Notification of a Nuclear Accident;

(b) The Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency;

(c) The Convention on Nuclear Safety;

(d) The Convention on the Physical Protection of Nuclear Material. This Convention was also examined, although its potential relevance relates to protecting or safeguarding nuclear material in international transport either prior to launch or subsequent to accidental re-entry (rather than being related to launch nuclear safety per se).

The four above-mentioned international conventions are inherently high-level documents, the first two of which are generic in nature, the third being developed specifically for civil land-based nuclear power plants, and the fourth being developed to address international transport of nuclear material between States. Specific information on each of the conventions is provided in the following paragraphs.

28. The Convention on Early Notification of a Nuclear Accident (the Early Notification Convention) entered into force in October 1986. The facilities and activities to which the Convention relates include, inter alia, “any nuclear reactor wherever located” and “the use of radioisotopes for power generation in space objects” (article 1). The Convention applies in the event of any accident involving any such facility or activity under the jurisdiction or control of a State party “from which a release of radioactive material occurs or is likely to occur and which has

resulted or may result in an international transboundary release that could be of radiological significance for another State" (article 1). In the event of such an accident, the relevant State party shall "forthwith notify … those States which are or may be physically affected … of the nuclear accident, its nature, the time of its occurrence and its exact location where appropriate; and promptly provide [those] States … with such available information relevant to minimizing the radiological consequences in those States, as specified in Article 5" (article 2). Each State party is also required by the Convention to make known to the other States parties "its competent authorities and point of contact [responsible] for issuing and receiving the notification and information" (article 7). In each case, States parties may provide notification and information directly or through IAEA.

29. The main procedure vitally important for addressing the emergency return to Earth of a space object with nuclear power sources on board is the earliest possible exchange of information related to trajectory parameters, the forecast related to space object entry in the upper layers and the possible geographical location of fallen nuclear power sources and space object. This procedure of cooperation among Member States of the United Nations and IAEA member States that have relevant means of outer space control and space object tracking in near-Earth orbits will ensure the receipt of objective information related to a possible re-entry of nuclear power sources and the timely preparation for it, using all available ways and means to spot the location, and retrieve the nuclear power sources and/or some of their parts from the territory of a country that has been affected by the fall.

30. The procedure that exists for sharing information related to safety of nuclear power sources even before launch is a much more simple procedure, with States providing the Secretary-General of the United Nations with information on the results of the safety assessment prior to launch of a spacecraft with nuclear power sources.

31. The Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (the Assistance Convention) entered into force in February 1987. The Convention requires the States parties to "cooperate between themselves and with the International Atomic Energy Agency … to facilitate prompt assistance in the event of a nuclear accident or radiological emergency to minimize its consequences and to protect life, property and the environment from the effects of radioactive releases" (article 1). Although many of the specific obligations concern the provision of assistance by States parties to other States parties, the Convention requires IAEA to "respond, in accordance with its Statute and as provided for in this Convention, to a requesting State Party's or a Member State's request for assistance in the event of a nuclear accident or radiological emergency" (article 2).

32. In addition to the reactive functions set out in the Assistance Convention under article 5, States parties or Member States may request IAEA:

(a) To collect and disseminate information concerning experts, equipment and materials that could be made available in the event of an emergency and on relevant methodologies, techniques and research findings;

(b) To assist States on request in preparing emergency plans and appropriate legislation and in developing training or radiation monitoring programmes.

33. The Convention on Nuclear Safety entered into force in October 1996. It is somewhat different in nature from the Early Notification Convention and the Assistance Convention, in that its main focus is on encouraging parties to pursue agreed nuclear safety objectives by fulfilling specific safety obligations at the national level. The international dimension takes the form of peer review: each contracting party is required to report periodically on the steps that it has taken with regard to the specific obligations set out in the Convention, and those reports are reviewed by the other contracting parties.

34. The scope of the Convention on Nuclear Safety is explicitly restricted to land-based civil nuclear power plants and associated on-site handling, treatment and storage facilities. The Convention does not, therefore, apply to nuclear power sources in outer space, and contains no provision for reporting on or reviewing safety measures taken in relation to such sources. Nevertheless, the articles under the "General Safety Considerations" section of the Convention covering such areas as quality assurance, radiation protection and emergency preparedness, have potential relevance to space nuclear power sources with the possible exception of article 12 addressing human factors.

35. The Convention on the Physical Protection of Nuclear Material entered into force on 8 February 1987. The Convention applies to nuclear material used for peaceful purposes while in international transport from one State to another. The Convention contains provisions on the physical protection of the material from theft, robbery or any other unlawful taking, as well as legal provisions related to the prosecution of offenders.

36. As this Convention was developed for international transport between States, it was not intended to apply to the launch of space nuclear power sources. Space nuclear power sources have historically used uranium-235 (for nuclear reactors) or plutonium-238 (for radioisotope power systems). The Convention does not apply to most radioisotopes, including plutonium-238 of the purity typically used in space radioisotope power systems. The Convention would apply, however, to international shipments of uranium-235 that may be used in space fission reactor power systems.

37. An interesting case concerns the applicability of this Convention as it relates to re-entry of a space nuclear reactor with uranium-235 fuel. Obviously, the Convention cannot practically be applied in the event of aerodynamic destruction of the nuclear fuel and the fallout in the atmosphere of small, dispersed fuel particles. However, in the event of the return to Earth of an undamaged or partly damaged reactor, the Convention may be applicable, beginning with the moment of tracing the reactor location and its seizure from the impact area.

B. International standards and other technical documents potentially relevant to space nuclear power sources

38. The present section focuses on those technical documents including standards, recommendations and reports of three organizations that are generally recognized authorities in atomic energy and radiation effects and protection at the international level: IAEA, ICRP and UNSCEAR. The following short, descriptive summaries of the organizations are presented for those readers who may not be as familiar with them:

(a) *IAEA*, established under the auspices of the United Nations, is authorized to establish or adopt standards of safety in the field of atomic energy in collaboration with other organizations within the United Nations system and specialized agencies concerned. IAEA establishes its safety standards based on advice provided by its safety standards committees and the International Nuclear Safety Advisory Group, health effects estimates made by UNSCEAR and recommendations made by a number of international organizations, principally ICRP;

(b) *ICRP* is an international advisory body providing recommendations and guidance on radiation protection. It has official relationships with the World Health Organization (WHO) and IAEA. The most important contribution of ICRP is in the areas of establishing a basic radiation protection philosophy; establishing radiation dose limit guidelines for occupational workers and the general public; providing guidance on the development and use of health effects estimators (relating radiation exposure and the potential for health effects); and developing of internal dosimetry models and internal dose conversion factors;

(c) *UNSCEAR* periodically evaluates the latest studies on the health effects of ionizing radiation and makes recommendations on values and application of health effects estimators in assessing the radiation risks.

39. For each of the three above-mentioned organizations, a listing of the technical documents initially considered as potentially relevant to flight nuclear safety of space nuclear power sources was developed and is included in annex II to the present report. The three international conventions discussed previously are also listed for completeness in section A of annex II.

40. In assessing relevance, it is important to note, as mentioned in section II, that an activity related to space nuclear power sources can be viewed as falling into one of two categories: terrestrial-based operations including development, assembly, testing and transportation; and operations unique to space nuclear power sources that affect nuclear safety, including operations related to launch, deployment and use as part of a space mission. International technical standards established for terrestrial nuclear operations would generally be relevant to the first set of activities. The focus of the current assessment was therefore applied with regard to the second category of operations. A document is then considered to be potentially relevant if it has the potential of providing a benefit or value as a technical resource or reference for launch and operational nuclear safety activities of space nuclear power sources.

41. A total of 57 documents were identified as potentially relevant to flight nuclear safety of space nuclear power sources. These consist of four international conventions; 24 IAEA-related entries; 26 ICRP publications; and three UNSCEAR documents.

42. Individual documents identified were categorized based on potential relevance and level of guidance or detail as described in annex II. For each set of documents (conventions, IAEA-related, ICRP and UNSCEAR), the documents were grouped into the following topical categories:

(a) Nuclear safety (focusing on system safety);

(b) Radiation protection (focusing on the protection of individuals);

(c) Emergency planning, intervention and mitigation;

(d) Potential exposure situations;

(e) Transportation.

43. The listing consists of a mixture of high-level and detailed documents. Most of the documents identified (35 in number) are potentially relevant to any type of nuclear facility, system, or material, including space nuclear power sources. A lesser number of documents (21) were developed specifically for terrestrial nuclear power sources, but may contain some elements potentially relevant to space nuclear power sources. Only one document out of those surveyed, a safety practice issued by IAEA[6] entitled "Emergency planning and preparedness for re-entry of a nuclear powered satellite", was developed specifically for space nuclear power sources. Each set of technical documents, not including the conventions, is discussed below.

44. The IAEA documents contain a mixture of both high-level and detailed documents, the majority of which are focused on terrestrial applications, in particular nuclear power plants.

45. The IAEA safety standards fall into three categories:

(a) Safety Fundamentals, which present basic objectives, concepts and principles of safety and protection in the development and application of nuclear energy for peaceful purposes;

(b) Safety Requirements, which establish the requirements that must be met to ensure safety;

(c) Safety Guides, which recommend actions, conditions or procedures for meeting safety requirements.

In addition to the IAEA safety standards, there are other IAEA-related reports, not considered standards but which still address safety, including safety practices publications and advisory group publications.

46. In the area of nuclear safety, the IAEA Safety Fundamentals publication entitled "The safety of nuclear installations"[7] sets out the basic objectives, concepts and principles for ensuring safety of nuclear installations. In describing the scope of the publication, it is stated that: "These principles, since they are fundamental in nature, are applicable to a broad range of nuclear installations, but their detailed application will depend on the particular technology and the risks posed by it. In addition to nuclear power plants, such installations may include: research reactors and facilities; fuel enrichment, manufacturing and reprocessing plants; and certain facilities for radioactive waste treatment and storage" (para. 104). This publication, although written in a general nature, does not appear to have formally considered space nuclear power sources in the context of its development. Existing IAEA safety standards in the Safety Requirements and Safety Guides categories primarily address either nuclear power plants or research reactors. Some of the general principles derived from the Safety Fundamentals for nuclear installations may be relevant to the safety of nuclear power sources in outer space, in particular nuclear reactors, but the more detailed Safety Requirements and Safety Guides under this topical area are likely to be less useful.

47. The IAEA radiation safety standards are set forth in the IAEA Safety Fundamentals publication entitled “Radiation protection and the safety of radiation sources”[8] and in the IAEA Safety Requirements publication entitled “International basic safety standards for protection against ionizing radiation and for the safety of radiation sources”[9]—commonly referred to as the Basic Safety Standards. Both sets of standards are sponsored by IAEA and five other international organizations (International Labour Organization (ILO), Food and Agriculture Organization of the United Nations (FAO), WHO, Pan American Health Organization (PAHO) and Nuclear Energy Agency of the Organisation for Economic Cooperation and Development (OECD/NEA). The publications set out, respectively, the basic objectives, concepts and principles of radiation protection (controlling exposure to radiation sources) and radiation safety (keeping radiation sources under control and preventing accidents) and the requirements necessary to comply with those principles. Of particular relevance in the context of nuclear power sources in outer space are the principles and requirements for both the safety of radiation sources and intervention. Intervention is a radiation protection term to refer to actions taken to prevent or reduce radiation exposure, for example, in the event of an accident that results in a radiation source being out of control, and to mitigate the consequences thereof. The principles of and requirements for intervention therefore underpin the more specific requirements and guidance for emergency preparedness and response.

48. The IAEA safety standards on preparedness for and response to nuclear and radiological emergencies are currently being revised. It is envisaged that a Safety Requirement publication (sponsored by FAO, WHO, PAHO, IAEA and OECD/NEA) and two Safety Guides—covering, respectively, preparedness (sponsored by WHO, IAEA and OECD/NEA) and criteria for planning the response to an emergency—will be issued in 2002 or 2003. Those publications will provide specific recommendations and guidance, building upon the general requirements of the Basic Safety Standards, in particular those related to intervention, and will supersede the existing safety standards specifically concerned with emergencies.

49. Turning now to the other two document sets, the ICRP and UNSCEAR documents identified are primarily generic with respect to application, but detailed with regard to technical content. The generic aspects of the documents also have potential relevance to nuclear power sources in outer space. One example is the estimation of cancer risks following exposure to ionizing radiation, on which UNSCEAR has submitted a recent major report[10] to the General Assembly. The report shows an encouraging level of consistency in the estimates of radiation-induced cancer mortality with the conclusions of previous reports; that supports the risk estimates used in ICRP-60.[11] The Working Group noted the intention of UNSCEAR, as part of its future work programme, to evaluate the health effects of radiation exposure to heavy particles present in cosmic radiation at high altitudes and in outer space. This reflects the UNSCEAR view that, in years to come, the potential radiation hazard from these natural sources to space travellers should receive additional consideration.

50. ICRP has published a number of documents in the past decade that are potentially relevant to nuclear power sources in outer space. The most notable is ICRP-60, which provided the 1990 Recommendations, addressed potential exposure situations, introduced the concept of “constraint”, and differentiated between “practices” and “interventions”. ICRP has also published recent documents on

protection from potential exposure[12] and the protection of the public in situations of prolonged radiation exposure[13] that are potentially relevant to nuclear power sources in outer space.

51. Additional examination would be required to identify what particular sections are potentially relevant, if any, for each document listed in the annex. However, the listing, along with the discussion above addressing a number of the more notable documents, should provide a useful resource for facilitating any future discussions that may take place on space nuclear power sources.

C. Procedures for developing and agreeing to international nuclear safety and radiation protection documents

52. The Working Group believed it would be useful to include a summary of the processes used to develop and obtain consensus on international technical documents in related areas, namely those of IAEA and ICRP. A description of each of these processes is therefore provided in the present subsection.

1. Safety standards of the International Atomic Energy Agency

53. Article III of the Statute establishing IAEA authorizes the agency "to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property …". All IAEA safety standards are prepared and reviewed in accordance with a uniform process.[14] This process is designed to ensure the technical quality and consistency of the safety standards, but also to ensure that they reflect the consensus views of the member States.

54. A set of four committees with harmonized terms of reference assists the secretariat in preparing and reviewing all standards. The committees are standing bodies, made up of senior regulatory officials from member States plus participants from relevant international organizations. The respective members of the four committees have technical expertise in: the safety of nuclear installations; radiation protection and safety of radiation sources; the safety of radioactive waste management; and the safety of transport of radioactive materials.

55. A Commission on Safety Standards assists the secretariat in coordinating the activities of the committees. The Commission is a standing body of senior government officials holding national responsibilities in relation to nuclear, radiation, waste and transport safety. The Commission has a special oversight role with regard to the IAEA safety standards.

56. The uniform preparation and review process for each safety standard can be summarized briefly as follows. An outline and work plan must first be approved by the appropriate committee (or committees, if the subject cuts across different areas of safety). Experts from member States then prepare a draft document. The draft is reviewed by the relevant committees and the secretariat. When the draft has been agreed upon by the committees, it is sent to all IAEA member States for comment. A revised draft, taking into account comments of member States, is prepared and reviewed again by the relevant committees. When the draft has been approved by

the committees, it is again reviewed by the secretariat and forwarded to the IAEA Publications Committee and to the Commission for endorsement. Safety Guides can then be published. For the higher-level standards—Safety Fundamentals and Safety Requirements—the draft endorsed by the Commission is submitted to the IAEA Board of Governors for approval.

57. As mentioned previously, under article III of its Statute, the IAEA establishes its safety standards "in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned". Accordingly, several safety standards are formally co-sponsored by other international organizations. Some other standards are prepared in close consultation with other international organizations, but not formally co-sponsored. In addition, advice provided by the International Nuclear Safety Advisory Group is taken into account, and recommendations made by a number of international bodies—including UNSCEAR, ICRP and the International Commission on Radiation Units and Measurements—are used as a basis in the preparation and review of the IAEA safety standards.

58. In the case of development of an IAEA standard that is either co-sponsored or prepared in close consultation with other international organizations, IAEA usually takes the lead in arranging for the preparation of a standard according to its established procedures, employing experts in the appropriate fields on a consultancy basis to draft and revise documents, and providing for review of the drafts by specialist committees and by the IAEA member States. The other organizations involved are encouraged to participate fully throughout the process by providing or recommending experts and by reviewing drafts. Various specific mechanisms are available and can be used as appropriate for a specific standard or group of standards. They include the following:

(a) Reference to standing inter-agency committees (at present, such committees exist on radiation safety and on emergency preparedness and response);

(b) Establishment of ad hoc inter-agency committees;

(c) Participation by representatives of other organizations in the relevant Agency committees.

IAEA obtains formal approval for publication of a standard through its usual internal mechanisms, and normally publishes it in its Safety Standards Series. However, co-sponsoring organizations also need to formally endorse the standard in accordance with their own procedures.

2. Recommendations of the International Commission on Radiological Protection

59. The main objective of ICRP is to provide recommendations on an appropriate standard of protection for people without unduly limiting the beneficial practices giving rise to radiation protection. ICRP recognizes that providing an appropriate standard of protection, rather than the best possible standard regardless of costs and benefits, cannot be achieved on the basis of scientific concepts alone. Members of ICRP and its committees have responsibility for supplementing their scientific knowledge by value judgements about the relative importance of different kinds of risk and about the balancing of risks and benefits. ICRP understands the importance

of making the basis for such judgements clear, so that readers can understand how decisions have been reached.

60. ICRP plays a different role to that of IAEA in that ICRP has always been an advisory body. It offers its recommendations to regulatory and advisory agencies at international, regional and national levels, mainly by providing guidance on the fundamental principles on which appropriate radiological protection can be based. ICRP does not aim to provide regulatory texts. Authorities are expected to develop their own texts in the context of their own regulatory structures. Nevertheless, ICRP believes that the regulatory texts should be developed from, and have aims that are broadly consistent with, its guidance.

61. ICRP is composed of a Main Commission and four standing committees dealing respectively with: radiation effects; derived limits; protection in medicine; and the application of ICRP recommendations. The Main Commission consists of 12 members and a chairman. They are elected by ICRP itself, under its rules, which are subject to the approval of the International Society of Radiology. ICRP appoints the committee members and each committee is chaired by an ICRP member. ICRP uses task groups and working parties to prepare reports to be discussed by the committees and finally approved by the Main Commission. A Scientific Secretary coordinates the activities of ICRP and its committees.

62. ICRP has also recently expanded and formalized its consultation processes. Traditionally, the members of task groups preparing new reports had informally circulated draft versions of their reports to colleagues before submitting them to the relevant committee. The 1990 recommendations of ICRP were also subjected to quite extensive consultations before they were finally adopted. However, the new consultation policy includes some additional features. Probably the most important of these is that ICRP now provides advance information to and solicits comments from all interested persons.

IV. Summary of national space nuclear power source launch approval processes

A. Russian Federation procedures

63. In the Russian Federation, the procedure for obtaining a permit to launch a nuclear power source into outer space takes into account the following phases of the nuclear power source construction:

(a) Making a decision by governmental decree with regard to development and construction of nuclear power sources on the basis of a proposal by an interested ministry, agency, institute or entity, depending on how important the nuclear power source is, its capacity and complexity and the length of the project requiring the operation of a spacecraft with a nuclear power source;

(b) Analysis of the safety issues associated with any specific nuclear power source, the solutions to and development of which are implemented under the control of the relevant ministries and agencies.

64. After a decision has been made to use a nuclear power source, an inter-agency commission is established to verify nuclear power source safety. The commission

consists of representatives of various Ministries (Ministry of Health, Ministry for Atomic Energy, Ministry of Defence and Ministry of Civil Defence, Emergencies and Disaster Management and various agencies (such as the Russian Aviation and Space Agency and the Academy of Sciences), the nuclear power source developer and manufacturer, the control bodies (the State Environmental Protection Agency, the state sanitary supervision agencies and the State Nuclear and Radioactive Safety Supervision Inspection), as well as the participation of third-party experts.

65. The inter-agency commission, headed by the representative of the State Nuclear and Radioactive Safety Supervision Inspection, ensures the independent verification of the following nuclear power source documents developed at various stages of the nuclear power source construction, as well as documents related to the safety of the space-based nuclear power sources:

(a) A preliminary safety report, including the concept for safe use of nuclear power sources and general technical requirements developed on the basis of international documents and national rules and regulations, also the analysis of possible safety systems and structural components of nuclear power sources related to safety;

(b) An interim safety report, including the choice of safety systems and structural components of nuclear power sources and the safety assurance document compiled on the basis of experimental testing;

(c) A final safety report, including the assurance of effectiveness and reliability of the safety systems and structural components of nuclear power sources;

(d) A report containing the nuclear power source safety evaluation, which is made available to the United Nations and IAEA.

66. The inter-agency commission is required to evaluate the nuclear power source safety and, if necessary, to make additions to the information contained in the documents on the basis of its own research and data evaluation.

67. The final decision on the nuclear power source launch as part of a space object is made by the state commission on launching space objects that is appointed by governmental decision. The latter commission is required to consider the independent evaluation of risk connected with the nuclear power source launch and its operation prepared by the inter-agency commission.

B. United States of America procedures

68. Space nuclear safety review by the United States comprises two separate processes: the National Environmental Policy Act process and the nuclear safety launch approval process. The National Environmental Policy Act process ensures early consideration both of the potential environmental impacts of launching the mission and of a range of reasonably viable alternatives for achieving mission objectives. The nuclear safety launch approval process ensures a coordinated inter-agency review of a mission's nuclear safety prior to the decision of whether to grant nuclear safety launch approval.

69. The National Environmental Policy Act process provides opportunities for public review and comment on the potential environmental impact of the launch of the mission early in the mission's development phase. Public interest groups, private citizens and both federal and non-federal agencies are offered the opportunity to review, as appropriate, an environmental assessment or environmental impact statement prepared by the agency proposing the mission.

70. The environmental document presents the purpose of and need for the mission, a description of the mission and a comparative evaluation of the reasonable alternatives for accomplishing the mission's objectives and potential environmental impacts. Potential impacts assessed include estimated health effects and land contamination that could occur from postulated launch accident scenarios involving the proposed nuclear power system. The documents are based on the best available data from nuclear safety tests and analyses.

71. Prior to completing the National Environmental Policy Act environmental impact statement process, the agency proposing the mission documents the response to all public review comments in a final environmental impact statement. Finally, the agency prepares, as appropriate, a final determination or record of decision that describes how environmental considerations entered into the agency's decision-making process prior to launching the proposed mission.

72. In total, the National Environmental Policy Act process usually takes over two years to complete.

73. The nuclear safety launch approval process requires preparation of a nuclear safety analysis report, inter-agency coordination, a safety evaluation report and presidential approval prior to launch. An ad hoc inter-agency nuclear safety review panel—comprised of designated coordinators from the National Aeronautics and Space Administration, the United States Department of Energy, the United States Environmental Protection Agency and the United States Department of Defense—conducts a detailed review of the safety analysis report and prepares a safety evaluation report. The safety analysis report, safety evaluation report and other relevant information provide the database on which the mission agency decides (in consultation with the member agencies of the inter-agency nuclear safety review panel) whether to proceed with the mission and to request presidential nuclear safety launch approval. The Director of the Office of Science and Technology Policy is authorized to give approval for such launchings, unless it is considered advisable to forward the matter to the President for a decision.

74. The safety analysis report documents the results of a probabilistic risk assessment of the estimated response of the nuclear power system to accidents specified by the proposing mission agency. Accidents are specified in terms of accident scenarios, their associated probabilities and the physical environments created when an accident occurs (i.e. blast, fragment, impact, thermal and re-entry). The safety analysis report estimates the probability and characteristics of potential fuel release, if any, associated with a given accident scenario. Postulated fuel releases are characterized in terms of amount, location, particle size distribution, transport of material, final location and form of released material. Potential consequences are estimated using internal dosimetry models of the International Commission on Radiological Protection. Both the accident environment

specifications and the nuclear power system response estimates are derived from testing and analysis programmes that simulate actual accident conditions.

75. In total, the nuclear safety launch approval process takes about five years to complete. Overall, the completion of both the National Environment Policy Act and nuclear safety launch approval processes takes between five and seven years.

76. In addition to the National Environmental Policy Act document(s), safety analysis report and safety evaluation report, the sponsoring or mission agency prepares radiological contingency plans that are coordinated with state, local and federal government officials. Those plans characterize the potential for releases of radioactive material and establish recommendations and protective action guides for implementation in the event of a launch accident.

V. Potential future developments relevant to nuclear power sources in outer space

77. Nuclear power sources have been used on a variety of different missions to date, either in the form of radioisotope thermal or electrical generators or nuclear reactors. Below is a summary discussion of a conceivable range of technologies and applications that may be studied or developed in the future. The feasibility, justification and timing of any particular technology development activities and potential applications have yet to be determined and are subject to decision-making at the national level.

78. Nuclear power sources on board space objects can be used as a source of heat for direct use, for electricity generation and/or propulsion. For conversion of thermal energy to electric power, those systems may use direct (for example, thermoelectric or thermionic) or dynamic (for example, Rankine, Brayton or Stirling) conversion technology.

79. Radioisotope sources can be employed to generate electricity with a power generally in the range of milliwatts to about one kilowatt. They may be also used as thermal units with a thermal power of approximately 1-1,000 W to provide heat for spacecraft equipment.

80. Radioisotope systems were initially used on navigational, meteorological and communication satellites in Earth orbit. At present, they are used for sensing seismic activity and on missions conducting science experiments on the Moon and Mars and in support of deep space missions exploring other celestial bodies. Some missions are still sending signals back to Earth on their way out of the solar system over 20 years after launch. Small radioisotope heaters have also been used to provide the thermal energy needed to keep spacecraft equipment operating in the cold environments of space.

81. Future developments for radioisotope systems may include the development of advanced systems with improved performance for powering spacecraft in collecting information on other celestial bodies. Advanced systems may also, for example, be developed for use in powering surface vehicles for extended scientific study and may possibly even be used to energize small submersibles searching for life in oceans existing beneath the frozen surface of certain celestial bodies.

82. To date, nuclear reactors have been used on board spacecraft carrying out experimental and observational missions. Bimodal (used for both propulsion and electrical power generation) nuclear electric propulsion systems may be used to provide electricity for spacecraft systems, including thrusters or engines for orbital correction and transfer from the reference near-Earth orbit to a higher operational orbit and as far as geostationary orbit. In the future, advanced systems with higher power capability on the order of tens to hundreds of kilowatt electric are possible. Such nuclear reactors could provide the electricity needed for thrusters on nuclear electric propulsion vehicles to reach various destinations within our solar system and to enable orbital missions of the outer planets, supplying abundant power on arrival for data gathering and transmittal. Nuclear reactors could be used to provide a power-rich environment for advanced robotic missions on planetary bodies in which deep drilling operations, in situ propellant generation and other power-intensive activities are performed. Those reactors, capable of higher power levels, could be used to sustain life for human exploration missions on the surface of the Moon and Mars.

83. Nuclear reactor power could also be used to provide direct thermal heating of propellant, making it possible to create a propulsion engine with about twice the specific impulse of chemical engines, and with higher thrust than electrical propulsion engines. Such systems could provide the capability for more rapid travel of cargo and perhaps eventually piloted missions to planetary destinations, reducing cosmic radiation exposure to astronauts en route. Alternatively, very high power nuclear electric propulsion systems could be developed for interplanetary transport.

VI. Conclusions

84. Although there are some similarities at a fundamental level between terrestrial nuclear power sources or systems and space nuclear power sources, there are significant differences with regard to their design and use that are relevant to safety processes and standards.

85. The two member States of the Committee on the Peaceful Uses of Outer Space that have launched and operated space nuclear power sources employ launch approval processes in which safety analysis reports are prepared to address various safety considerations involving the space nuclear power sources proposed. Those safety analysis reports are then independently evaluated by an inter-agency commission or panel, after which approval is required by a separate office or commission functioning at a high level within the Government prior to launch of the space objects with nuclear power sources.

86. Current international conventions, recommendations, standards and other technical documents on nuclear safety and radiation protection are primarily focused on terrestrial applications. As such, they are generally relevant to terrestrial-based activities involving space nuclear power sources. However, their direct application to the launch and operational nuclear safety of space nuclear power sources is limited.

87. Nearly 60 international documents in addition to the existing Principles Relevant to the Use of Nuclear Power Sources in Outer Space were identified as having portions potentially relevant to space nuclear power source launch and

operational nuclear safety. Most of those publications are generic in nature and were not written for a specific type of nuclear power application. All but one of the remaining documents were developed for specific terrestrial applications.

88. Recommendations and publications of ICRP are focused on radiological protection and those documents usually do not distinguish between different applications of nuclear energy and ionizing radiation. However, an orientation towards terrestrial applications can be found in particular cases. The ICRP Recommendations are updated periodically and take into account the latest thinking with regard to radiation protection philosophy and approaches.

89. IAEA has a well-established process for generating safety standards, but historically the experience of the Agency in standards development has been with terrestrial applications of nuclear energy. The Agency establishes safety standards in consultation and, where appropriate, in collaboration with competent entities of the United Nations system and with other specialized bodies concerned. Various specific mechanisms are available and can be used as appropriate for preparing a specific standard or group of standards. Thus, potential options could exist for cooperation between the Committee on the Peaceful Uses of Outer Space and IAEA in the area of standards development.

Notes

1 The text of the Principles is also reproduced in the booklet “United Nations Treaties and Principles on Outer Space (A/AC.105/722/Add.1 (Arabic, Chinese, French, Russian and Spanish versions) and A/AC.105/572/Rev.3 (English)).

2 “Convention on Nuclear Safety”, International Atomic Energy Agency, INFCIRC/449.

3 United Nations, *Treaty Series*, vol. 1439, No. 24404.

4 Ibid., vol. 1457, No. 24643.

5 International Atomic Energy Agency, INFCIRC/274/Rev.1, May 1980.

6 “Emergency planning and preparedness for re-entry of a nuclear powered satellite”, International Atomic Energy Agency Safety Series No. 119 (STI/PUB/1014) (1996).

7 “The safety of nuclear installations: a safety fundamental”, International Atomic Energy Agency Safety Series No. 110 (STI/PUB/938) (1993).

8 Food and Agriculture Organization of the United Nations, International Atomic Energy Agency, International Labour Organization, Nuclear Energy Agency of the Organization for Economic Cooperation and Development, Pan American Health Organization and World Health Organization, “Radiation protection and the safety of radiation sources: a safety fundamental”, International Atomic Energy Agency Safety Series No. 120 (STI/PUB/1000) (1996).

9 Food and Agriculture Organization of the United Nations, International Atomic Energy Agency, International Labour Organization, Nuclear Energy Agency of the Organization for Economic Cooperation and Development, Pan American Health Organization and World Health Organization, “International basic safety standards for protection against ionizing radiation and for the safety of radiation sources: a safety standard”, Safety Series No. 115 (STI/PUB/996) (1996).

10 United Nations Scientific Committee on the Effects of Atomic Radiation, *Sources and Effects of Ionizing Radiation*, 2000 report (United Nations publication, Sales No. E.00.IX.3).

11 International Commission on Radiological Protection, “1990 recommendations of the

International Commission on Radiological Protection", publication 60, *Annals of the ICRP*, Nos. 1-3 (1991).

[12] International Commission on Radiological Protection, "Protection from potential exposure: a conceptual framework", publication 64, *Annals of the ICRP*, No. 1 (1993) and "Protection from potential exposures: application to selected radiation sources", publication 76, *Annals of the ICRP* (1997).

[13] International Commission on Radiological Protection, "Principles for the protection of the public in situations of prolonged radiation exposure", publication 82, *Annals of the ICRP* (2000).

[14] These formal procedures apply only to the preparation of the IAEA safety standards, that is, publications of a regulatory nature issued pursuant to article III.A.6 of the IAEA Statute. Other safety-related IAEA publications are issued pursuant to articles III.A.3 and VIII of the Statute, to foster the international exchange of information on safety-related matters. Those publications are not safety standards, and are not subject to the same preparation and review process.

Annex I

Documents before the Working Group on the Use of Nuclear Power Sources in Outer Space

Document number	*Title or description*
A/AC.105/731	Note by the Secretariat on national research on space debris, safety of nuclear-powered satellites and problems of collisions of sources with space debris
A/AC.105/751	Note by the Secretariat on national research on space debris, safety of space objects with nuclear power sources on board and problems of their collisions with space debris
A/AC.105/754	Report by the International Atomic Energy Agency on the preliminary review of international documents relevant to the safety of nuclear power sources in outer space
A/AC.105/770 and Add.1	Note by the Secretariat on national research on space debris, safety of space objects with nuclear power sources on board and problems relating to their collision with space debris
A/AC.105/C.1/L.229	Working paper submitted by the United States of America on the review of safety processes and standards for the United States space and terrestrial nuclear power systems
A/AC.105/C.1/L.231	Working paper submitted by the United Kingdom of Great Britain and Northern Ireland on technical processes and technical standards relevant to nuclear power sources in space: the position of the United Kingdom of Great Britain and Northern Ireland
A/AC.105/C.1/L.233	Working paper submitted by the Russian Federation on collisions between nuclear power sources and space debris
A/AC.105/C.1/L.234	Working document submitted by the Russian Federation on the identification of terrestrial processes and technical standards with a possible relevance to nuclear power sources, including factors distinguishing the use of nuclear power sources in outer space from terrestrial nuclear power applications
A/AC.105/C.1/L.242	Working paper submitted by the United Kingdom of Great Britain and Northern Ireland on the Convention on Nuclear Safety and the Safety Fundamentals of the International Atomic Energy Agency: a common approach to the safety of terrestrial nuclear power sources

Document number	*Title or description*
A/AC.105/C.1/L.244	Working paper submitted by the United States of America on a database of international documents of potential relevance to nuclear power sources in outer space
A/AC.105/C.1/L.245	Working paper submitted by the United Kingdom of Great Britain and Northern Ireland on the review of international documents on radiation protection of particular relevance to nuclear power sources in space
A/AC.105/C.1/L.246	Working paper submitted by the Russian Federation on collisions between nuclear power sources and space debris
A/AC.105/C.1/L.247	Working paper submitted by the Russian Federation on national research on the safety of space objects carrying nuclear power sources, including information on national procedures for obtaining final authorization to launch such objects
Other materials	
State/organization	*Title*
United States of America	International documents of potential relevance to nuclear power sources in outer space
United States of America	Nuclear power source launch approval process in the United States of America
International Atomic Energy Agency	An overview of the procedures and mechanisms currently utilized by the International Atomic Energy Agency to prepare and review safety standards for terrestrial nuclear applications

Annex II

List of international documents of potential relevance to nuclear power sources in outer space

1. The present annex contains a listing of international documents of potential relevance to nuclear power sources in outer space, as described in section III the report, that can serve as a database to facilitate any future discussions on nuclear power sources. Section A of the present annex lists very high-level documents consisting of international conventions. Section B presents potentially relevant International Atomic Energy Agency (IAEA)-related documents. Those documents include: IAEA Safety Standards, which have undergone a formal IAEA review process and represent an international consensus; other IAEA publications that provide information, methodologies and examples of good practice; and reports by the International Nuclear Safety Advisory Group. Sections C and D present potentially relevant publications of the International Commission on Radiological Protection and reports of the United Nations Scientific Committee on the Effects of Atomic Radiation, respectively, that support and/or form the basis of a number of the IAEA documents presented in section B.

2. The documents have been categorized in terms of degree of relevance, using a scale of 1 to 3, and level of guidance or detail, using an A or B designator. The criteria used in assigning these categories are as follows:

(a) Potential relevance:

Designator

1 The document is directly relevant only to space nuclear power sources in outer space;

2 The document is potentially relevant to any nuclear application, including nuclear power sources in outer space;

3 The document was developed specifically for terrestrial nuclear applications, but contains some elements potentially relevant to nuclear power sources in outer space;

(b) Level of guidance and detail:

Designator

A The document addresses high-level nuclear safety or radiation protection concepts, fundamentals, principles or philosophy. These documents also include high-level international conventions;

B The document provides detailed information in the form of specific guidance, technical data, results of studies and analyses, and recommended methodologies, including modelling or analytical methods.

3. A number of IAEA and International Commission on Radiological Protection documents prepared in the past have been clearly superseded by more recent documents. In those cases, only the more recent documents are retained, with a few

exceptions, where it was believed worth retaining the earlier documents for reference purposes only.

A. International conventions of potential relevance

Number	*Reference*	*Title*	*Comments*	*Designator*
Nuclear safety				
1	International Atomic Energy Agency (IAEA) INF/CIRC/449 (1996)	Convention on Nuclear Safety	This Convention commits participating States operating land-based nuclear power plants to maintain a high level of safety by setting international benchmarks to which States would subscribe. The obligations are based to a large extent on the principles contained in the IAEA Safety Fundamentals document "The safety of nuclear installations" (annex II, sect. B, document no. 1) and cover siting, design, construction, operation, the assessment and verification of safety, quality assurance and emergency preparedness.	3A
Radiation protection				
		[None identified.]		
Emergency planning, intervention and mitigation				
2	IAEA INF/CIRC/335 (1986); United Nations, *Treaty Series*, vol. 1439, No. 24404	Convention on Early Notification of a Nuclear Accident	This Convention establishes a notification system for nuclear accidents that have the potential for international transboundary release that could be of radiological safety significance for another State. It requires States to report the accident's time, location, radiation releases and other data essential for assessing the situation.	2A
3	IAEA INF/CIRC/336 (1987); United Nations, *Treaty Series*, vol. 1457, No. 24643	Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency	This Convention sets out an international framework for cooperation among States and with IAEA to facilitate prompt assistance and support in the event of nuclear accidents or radiological emergencies. It requires States to notify IAEA of their available experts, equipment and other materials for providing assistance.	2A
Potential exposure situations				
		[None identified.]		
Transportation				
4	IAEA INF/CIRC/274/Rev.1 (1980)	Convention on the Physical Protection of Nuclear Material	This Convention establishes measures for the physical protection of nuclear material during international transport and sets forth legal provisions related to theft, robbery or any other unlawful taking of such material and prosecution of offenders.	3A

B. International Atomic Energy Agency and related documents of potential relevance

Number	*Reference: document number*	*Title*	*Comments*	*Designator*
Nuclear safety				
1	Safety Series No. 110 (1993); STI/PUB/938	"The safety of nuclear installations"	Safety Fundamental. Standard on nuclear safety fundamentals. Presents an international consensus on the basic concepts and principles for the regulation, management of safety and operation of nuclear installations. Forms a top-level publication in the hierarchy of the IAEA Safety Series. In conjunction with this publication, Safety Standards, Safety Guides and Safety Practices provide requirements, guidance and information for activities relating to siting, design, quality assurance, operation and regulation of nuclear installations. Addresses safety objectives, legislative and regulatory framework, management of safety, technical aspects of safety, verification of safety, the concept of risk, and methods of risk evaluation and limitation.	3A
2	50-C/SG-Q (1996); STI/PUB/1016	"Quality assurance for safety in nuclear power plants and other nuclear installations"	This revised Safety Code and its corresponding Safety Guides replace Safety Series Nos. 50-C-QA (Rev.1) and 50-SG-QA1-11. Presents basic requirements and implementation methods for quality assurance, including recommendations to regulatory bodies in establishing requirements and verifying implementation; identifies the responsibilities of the licensee in achieving improved quality and safety performance; and gives guidance on methods for fulfilling the basic requirements.	3B
3	Safety Series No. 106 (1992); STI/PUB/911	"The role of probabilistic safety assessment and probabilistic safety criteria in nuclear power plant safety"	Establishes guidelines on the role probabilistic safety assessment (PSA) can play as part of an overall safety assurance programme in nuclear power plants. It describes a framework for probabilistic safety criteria (PSC) and provides guidance for the establishment of PSC values.	3A
4	50-P-1 (1990); STI/PUB/819	"Application of the single failure criterion"	Addresses the relationship between the single failure criterion (addressed in Safety Series No. 50-C-D (Rev.1)) and system performance reliability with respect to the scope of the criterion's application. Discusses the application principles, the relation to common cause failures, exemptions to the criterion and single failure analysis methodology.	3B

Number	*Reference: document number*	*Title*	*Comments*	*Designator*
5	50-P-4 (1992); STI/PUB/888	"Procedures for conducting probabilistic safety assessments of nuclear power plants (Level 1)"	Provides information on how to conduct a Level-1 PSA for a nuclear-power plant. Emphasis is placed on the procedural steps rather than on detailed methods. Addresses sources of radioactive releases and accident initiators, accident sequence modelling, parameter estimation, accident sequence quantification and documentation.	3B
6	50-P-8 (1995); STI/PUB/969	"Procedures for conducting probabilistic safety assessments of nuclear power plants (Level 2)"	Provides information on how to conduct a Level-2 PSA for a nuclear power plant. Emphasis is placed on procedural steps rather than on detailed methods. Addresses accident progression, containment analysis, source terms for severe accidents and documentation.	3B
7	50-P-12 (1996); STI/PUB/1009	"Procedures for conducting probabilistic safety assessments of nuclear power plants (Level 3)"	Provides information on how to conduct a Level-3 PSA for a nuclear power plant. Addresses approaches to and current developments in probabilistic consequence analysis. Discusses the relative importance of accident prevention and mitigative measures with respect to accident consequences, the relative effectiveness of emergency response planning aspects of off-site accident management and their economic impacts.	3B
8	75-INSAG-4 (1991); STI/PUB/882	"Safety culture"	Publication of the International Nuclear Safety Advisory Group. Describes the concept of "safety culture" in connection with nuclear plant safety in relation to both organizations and individuals engaged in nuclear power activities. Provides a basis for judging the effectiveness of the safety culture in specific cases in order to identify their potential improvements.	3A
9	75-INSAG-6 (1992); STI/PUB/916	"Probabilistic safety assessment"	Advisory Group publication. Describes how PSA has contributed significantly to the understanding of how best to ensure the safety of nuclear power plants. Reviews general basis of PSA, emphasizing its merits and limitations as well as the general lines of future PSA developments and their applications.	3A
10	75-INSAG-10 (1996); STI/PUB/1013	"Defence in depth in nuclear safety"	Advisory Group publication. Addresses the concept of defence in depth in nuclear and radiation safety, discussing its objectives, strategy, implementation and future development.	3A

Number	Reference: document number	Title	Comments	Designator
Radiation protection				
11	Safety Series No. 115 (1996); STI/PUB/996	"International basic safety standards for protection against ionizing radiation and for the safety of radiation sources: a safety standard"	Current IAEA standard on requirements related to radiation protection. Jointly sponsored by the Food and Agriculture Organization of the United Nations, IAEA, the International Labour Organization, the Organisation for Economic Cooperation and Development/Nuclear Energy Agency and the World Health Organization and the Pan American Health Organization. The standards are based on the latest assessments of the biological effects of ionizing radiation made by the United Nations Scientific Committee on the Effects of Atomic Radiation and the recommendations of the International Commission on Radiological Protection (ICRP). The standards represent an international consensus on qualitative and quantitative requirements for protection and safety for planned practices such as nuclear power generation and the use of radiation and radioactive materials in medicine and industry; intervention in existing situations such as chronic exposure to natural sources of radiation or exposure following an accident; control of radiation sources, including notification and authorization; and criteria for exemption. Consensus guidance is also given on occupational radiation protection, medical exposure, protection of members of the public from exposure to radioactive materials released to the environment, prevention of incidents giving rise to potential exposure and intervention in a radiological emergency.	2B
12	Safety Series No. 120; STI/PUB/1000	"Radiation protection and the safety of radiation sources: a safety fundamental"	Safety Fundamental. Provides a set of objectives and principles for protection against ionizing radiation and ensuring safety in the use of radiation sources. The principles applied to achieve protection and safety objectives provide the basis for the requirements in IAEA Safety Standards for the control of occupational, public and medical exposures and for the safety of sources.	2A
13	Safety Series No. 100 (1989); STI/PUB/835	"Evaluating the reliability of predictions made using environmental transfer models: a safety practice"	Provides information on the available methods for evaluating the reliability of environmental transfer model predictions used in dose assessments. Provides an introduction to the subject and supplements existing IAEA publications on environmental dose assessment methodology.	2B

Number	*Reference: document number*	*Title*	*Comments*	*Designator*
14	Safety Reports Series No. 19 (2001); STI/PUB/1103	"Generic models for use in assessing the impact of discharges of radioactive substances to the environment"	Presents simple models intended to be applied for use at the pre-operational stage of a nuclear installation to assess local doses from planned releases. Directed at national regulatory bodies and technical personnel responsible for performing environmental impact analyses, in particular for generic assessments of doses to most exposed individuals from routine radioactive releases to the environment.	3B
15	STI/PUB/1030 (1998)	"Low doses of ionizing radiation: biological effects and regulatory control, invited papers and discussions"	Addresses the latest research regarding low-level radiation dose effects.	2B
Emergency planning, intervention and mitigation				
16	IAEA-INES-2001	"INES: The International Nuclear Event Scale User's Manual"	User's Manual to be used as part of the reporting requirements under the Convention on Early Notification of a Nuclear Accident.	2B
17	Safety Series No. 109 (1994); STI/PUB/900	"Intervention criteria in a nuclear or radiation emergency"	Provides international consensus and understanding on principles for intervention and numerical values for generic intervention levels. The recommendations are the basis for the standards and numerical guidance related to intervention contained in Safety Series No. 115 (document no. 11 above)	2B
18	Safety Series No. 73 (1985)	"Emergency preparedness exercises for nuclear facilities: preparation, conduct and evaluation"	Provides information for operating organizations and public authorities on planning, organizing and conducting emergency preparedness exercises and utilizing their results to improve current emergency plans and preparedness. It also provides methods for reviewing emergency plans, procedures, equipment and facilities with a view to maintaining a satisfactory level of emergency preparedness.	3B
19	TECDOC-955 (1997) and TECDOC-1162 (2000)	"Generic assessment procedures for determining protective actions during a reactor accident" and "Generic procedures for assessment and response during a radiological emergency"	Provides practical support to the information contained in IAEA Safety Series No. 109 (document no. 17 above). Provides methods on relating measurement results made in environmental materials and in foodstuffs following a nuclear accident or radiological emergency to levels of projected dose at which it may be necessary to introduce relevant protective measures. These derived intervention levels (DILs) need to be determined for the radionuclides of potential radiological importance. Information is provided on the principles, procedures and methodologies relevant to the evaluation of DILs.	2B

Number	Reference: document number	Title	Comments	Designator
20	Safety Series No. 119 (1996); STI/PUB/1014	"Emergency planning and preparedness for re-entry of a nuclear-powered satellite"	Prepared to assist States in planning for possible re-entry events involving nuclear-powered satellites and to provide international consensus practices for responding to such a situation. Provides guidance on specific actions to be taken from the time of the announcement of an impending re-entry event through the locating, monitoring and recovery phases.	1B
Potential exposure situations				
21	Safety Series No. 104 (1990); STI/PUB/834	"Extension of the principles of radiation protection to sources of potential exposure"	The principles of radiation protection recommended by ICRP in ICRP-60 (document no. 2 in sect. C below) for the normal operation of a radiation source constitute a dose limitation system that has three components: the justification of a practice, the optimization of radiation protection and the limitation of individual doses. This report describes how the application of those principles may be extended to unexpected or accidental (potential exposure) situations by changing from the dose-based system of radiation protection to a unified approach within a probabilistic framework.	2A
22	75-INSAG-9 (1995); STI/PUB/992	"Potential exposure in nuclear reactor safety"	Advisory Group publication. Addresses the concept of potential exposure in nuclear and radiation safety, policy aspects, safety assessments, risk considerations and probabilities. Discusses the implications of low probabilities and includes a section on probability theory and its application in PSAs.	3A
Transportation				
23	Safety Series No. 6 (1990); STI/PUB/866	"Regulations for the safe transport of radioactive material: 1985 edition (as amended 1990)"	Presents international regulations on the packaging and transport of radioactive materials for shipment by truck, rail, ship and air. Current packaging and transport regulations of the United States Department of Transportation, the United States Nuclear Regulatory Commission and the United States Department of Energy are based on this document. Superseded by ST-1 (document no. 24 below).	3B
24	TS-R-1 (ST-1, Revised) (2000); STI/PUB/1098	"Regulations for the safe transport of radioactive material"	Supersedes Safety Series No. 6 (document no. 23 above). Presents the latest IAEA regulations and standards for the packaging and transport of radioactive materials.	3B

C. International Commission on Radiological Protection publications of potential relevance

Number	*Reference*	*Title*	*Comments*	*Designator*
Nuclear safety				
		[None identified except in terms of the other areas covered by the database.]		
Radiation protection				
1	ICRP-26 (1977)	"Recommendations of the International Commission on Radiological Protection", 2nd ed.	Superseded by ICRP-60 (document no. 2 below).	2A
2	ICRP-60 (1991)	"1990 Recommendations of the International Commission on Radiological Protection"	Current ICRP recommendations on radiation protection and health effects of ionizing radiation. Addresses three principles of radiation protection in terms of justification of a practice, the optimization of radiation protection and the limitation of individual doses. Presents recommendations on dose limits for workers and the general population for normal operations. Presents health effect estimators for workers and the general population based on latest health effect studies as of 1990.	2A
3	ICRP-29 (1979)	"Radionuclide release into the environment: assessment of doses to man"	Outlines a high-level methodology for assessing the consequences of planned and unplanned releases of radioactive materials to the environment. Addresses the use of dose predictions in decision-making.	2B
4	ICRP-30 (1979-1989)	"Limits for intakes of radionuclides by workers" (8-vol. set with index)	Presents a detailed methodology for estimating radiation doses resulting from the inhalation and ingestion of radionuclide materials. Dose factor results by radionuclide are presented for the adult worker. The results are used to derive worker annual limits on intake (ALI) values for each radionuclide. Source of internal dose factors currently used by the United States Environmental Protection Agency, the United States Nuclear Regulatory Commission and the United States Department of Energy.	2B
5	ICRP-37 (1983)	"Cost-benefit analysis in the optimization of radiation protection"	Addresses the use of cost-benefit analyses in evaluating alternative approaches to radiation protection and optimizing the approach selected.	3B
6	ICRP-38 (1983)	"Radionuclide transformation: energy and intensity of emissions"	Basic data on radionuclide-specific transformations used in radiation protection, monitoring, internal dosimetry and external dosimetry.	2B

Number	Reference	Title	Comments	Designator
7	ICRP-41 (1984)	"Non-stochastic effects of ionizing radiation"	Reviews non-stochastic biological and health effects of ionizing radiation, with reference to their implications for dose limits in radiation protection.	2B
8	ICRP-42 (1984)	"A compilation of the major concepts and quantities in use by ICRP"	Basic definitions of quantities used in radiation protection, monitoring and dosimetry.	2B
9	ICRP-43 (1984)	"Principles of monitoring for the radiation protection of the population"	Describes the general principles on which monitoring programmes should be based, consistent with current radiation protection philosophy, and extends the scope to all types of monitoring affecting the public outside the workplace.	3A
10	ICRP-45 (1986)	"Quantitative bases for developing a unified index of harm"	Outlines approaches to establishing acceptable levels of risk. Develops dose limit recommendations for normal operations based on a risk-based approach.	2B
11	ICRP-48 (1986)	"The metabolism of plutonium and related elements"	Forms basis for the parameters used to describe the metabolic characteristics of plutonium compounds (and those of related elements) in internal dosimetry models presented in ICRP-30 and ICRP-66 (documents nos. 4 above and 16 below, respectively).	2B
12	ICRP-51 (1988)	"Data for use in protection against external radiation"	Presents basic data used in external radiation monitoring, dose estimates and protection.	2B
13	ICRP-55 (1989)	"Optimization and decision-making in radiological protection"	Considers various techniques associated with optimization and decision-making in radiation protection and their application to problems at different levels of complexity.	2B
14	ICRP-56 (1990)	"Age-dependent doses to members of the public from intake of radionuclides: Part 1"	The internal dosimetry models and radionuclides presented in ICRP-30 (document no. 4 above) are for the adult worker. This report extends the ICRP-30 methodology to members of the general public and presents age-dependent internal dose factors by radionuclides.	2B
15	ICRP-58 (1990)	"RBE for deterministic effects"	Summarizes information used to provide the latest estimates of the relative biological effectiveness (RBE) of each type of radiation.	2B
16	ICRP-66 (1994)	"Human respiratory tract model for radiological protection"	New ICRP internal dosimetry model that could replace the ICRP-30 model in the future.	2B
17	ICRP-67 (1994)	"Age-dependent doses to members of the public from intake of radionuclides: Part 2, Ingestion dose coefficients"	Age-dependent ingestion dose factors. Uses revised organ weighting factors based on ICRP-60.	2B

Number	*Reference*	*Title*	*Comments*	*Designator*
18	ICRP-69 (1995)	"Age-dependent doses to members of the public from intake of radionuclides: Part 3, Ingestion dose coefficients"	Extends the age-dependent ingestion dose factors originally developed in ICRP-56 and -67 to include additional radionuclides.	2B
19	ICRP-72 (1996)	"Age-dependent doses to the members of the public from intake of radionuclides: Part 4, Inhalation dose coefficients"	Revised age-dependent inhalation dose conversion factors based on the ICRP-66 model, updating the factors presented in ICRP-56 based on the ICRP-30 model.	2B
20	ICRP-72 (1996)	"Age-dependent doses to the members of the public from intake of radionuclides: Part 5, Compilation of ingestion and inhalation dose coefficients"	Summarizes and updates age-dependent inhalation and ingestion dose factors originally presented in ICRP-56, -67, -68, -69 and -71 (documents nos. 14, 17 (not listed here), 18 and 19 above). Adopted by IAEA in Safety Series No. 115, "International Basic Safety Standards for Protection Against Ionizing Radiation", and for the "Safety of radiation sources: a safety standard".	2B
21	ICRP-74 (1996)	"Conversion coefficients for use in radiological protection against external radiation"	Provides an extensive and authoritative set of data related to the measurements and estimates used for radiation protection against external radiation.	2B
22	ICRP-79 (1999)	"Genetic susceptibility to cancer"	Provides an extensive discussion of hereditary variations in the susceptibility to cancer and the possible implications of such susceptibility variations for radiation protection.	2B
Emergency planning, intervention and mitigation				
23	ICRP-63 (1993)	"Principles for intervention for protection of the public in a radiological emergency"	Presents general principles for planning intervention after an accident over short times generally near the accident location, continuation following periodic review over prolonged timescales lasting years and intervention over larger areas. Supersedes ICRP-40 (not listed here).	2A
24	ICRP-82 (2000)	"Protection of the public in situations of prolonged radiation exposure"	Addresses the application of radiation protection principles to the control of prolonged exposures resulting from practices and intervention in the case of prolonged exposure situations. The report considers, among others, the intervention following an accident releasing radioactive materials and the global marketing of commodities for public consumption that contain radioactive substances.	2A

Number	*Reference*	*Title*	*Comments*	*Designator*
Potential exposure situations				
25	ICRP-64 (1993)	“Protection from potential exposure: a conceptual framework”	ICRP recommendations presented in ICRP-60 (document no. 2 above) primarily address normal exposure situations. ICRP-64 supplements ICRP-60 regarding potential exposure situations, reflecting the probabilistic aspects of unplanned events and accidents. Addresses radiation protection aspects of potential exposure situations in terms of probability of exposure, dose received given the exposure and approaches to establishing acceptable envelopes of probability of exposure versus dose received as part of design objectives.	2A
26	ICRP-76 (1997)	“Protection from potential exposures: application to selected radiation sources”	Expands approach to potential exposure situations addressed in ICRP-64 (document no. 25 above). Addresses potential exposure primarily affecting individuals who are also subject to exposures in normal practices, either occupationally, as members of the public or as patients. As such, it deals with “common smaller accidents”.	3B
Transportation				
		[None identified.]		

D. United Nations Scientific Committee on the Effects of Atomic Radiation reports of potential relevance

Number	*Reference*	*Title*	*Comments*	*Designator*
Nuclear safety				
		[None identified.]		
Radiation protection				
1	UNSCEAR (1988)	“Sources and effects of ionizing radiation, 1988 Report”	Forms part of the basis for the health effect estimators presented in ICRP-60 (document no. 2 in sect. C above).	2B
2	UNSCEAR (1994)	“Sources and effects of ionizing radiation, 1994 Report”	Addresses research on the effects of ionizing radiation at low levels.	2B
3	UNSCEAR (2000)	“Sources and effects of ionizing radiation: 2000 Report”	Addresses the latest information on the sources and effects of ionizing radiation.	2B
Emergency planning, intervention and mitigation				
		[None identified.]		
Potential exposure situations				
		[None identified.]		
Transportation				
		[None identified.]		