A/AC.105/C.1/2008/CRP.10
19 February 2008

Original: English

COMMITTEE ON THE PEACEFUL USES OF OUTER SPACE
Scientific and Technical Subcommittee
Forty-fifth session
Vienna, 11-22 February 2008
Agenda item 11
Use of nuclear power sources in outer space

DRAFT SAFETY FRAMEWORK FOR NUCLEAR POWER SOURCE APPLICATIONS IN OUTER SPACE

1. At its forty-fourth session, held in Vienna from 12 to 23 February 2007, the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space endorsed the recommendation of its Working Group on the Use of Nuclear Power Sources in Outer Space that, in order to prepare and publish the safety framework for nuclear power source (NPS) applications in outer space, a partnership be established between the Subcommittee and the International Atomic Energy Agency (IAEA) by means of a joint experts group, consisting of representatives of the Subcommittee and of IAEA (A/AC.105/890, para. 113).

2. The text of the draft safety framework was made available by the Secretariat to the Subcommittee before its current session in document A/AC.105/C.1/L.292.

3. At the current, forty-fifth session, of the Subcommittee the Joint Experts Group continued its work on the text of the draft framework and provided a number of amendments on it. These amendments have been introduced on the basis of discussion held in the Joint Experts Group, as well on the basis of comments received from the Working Group on NPS of the Subcommittee.

4. The present document contains the updated text of the draft safety framework for the purpose of informing the Subcommittee about the introduced changes. The text will be made available by the Secretariat as document A/AC.105/C.1/L.292/Rev.1 in all official languages of the United Nations in March 2008.

V.08-51167 (E)

Draft Safety Framework for Nuclear Power Source Applications in Outer Space (Revision D, as of 10 December 2007)

Preface

Historically, nNuclear power sources (NPS) for use in outer space have been developed and used in space applications where unique mission requirements and constraints on electrical power and thermal management precluded the use of non-nuclear power sources. Such missions have included interplanetary missions to the outer limits of the solar system, for which solar panels were not suitable as a source of electrical power because of the long duration of the mission at great distances from the Sun.

According to current knowledge and capabilities, space NPS are the only available energy option to power some space missions and significantly enhance others. Several ongoing and foreseeable missions would not be possible without the use of space NPS. The designs of NPS for use in outer space have included radioisotope (for example, radioisotope thermoelectric generators) and nuclear reactor systems. In addition, small radioisotope heater units have been used to provide local heating of spacecraft components. Reactors for power or propulsion are contemplated for scientific and exploration missions, specifically for the Moon, Mars, and other Solar System destinations. Earth orbital missions requiring high power (e.g., communications, inter-orbital space tugs) are also foreseeable. The presence of radioactive materials or nuclear fuels in space NPS and their consequent potential for harm to people and the environment in Earth's biosphere mean that safety should always be an inherent part of their design and application.

Nuclear power sources for applications in outer space have unique safety considerations compared to terrestrial applications. Unlike many terrestrial nuclear applications, space applications tend to be used infrequently and their requirements can vary significantly depending upon the specific mission. Mission launch and outer space operational requirements impose size, mass, and other space environment limitations not present for many terrestrial nuclear facilities. For some applications, space nuclear power sources must operate autonomously at great distances from the Earth in harsh environments. Potential accident conditions resulting from launch failures and inadvertent re-entry ~~have the potential to~~could expose the nuclear power source to extreme ~~environments~~physical conditions. These and other unique safety considerations for the use of space nuclear power sources are significantly different from those for terrestrial nuclear systems and are not addressed in safety guidance for terrestrial nuclear applications.

After a period of initial discussion and preparation, the Scientific and Technical Subcommittee (STSC) of the UN Committee on the Peaceful Uses of Outer Space and the International Atomic Energy Agency (IAEA) agreed in 2007 to partner in the drafting of a safety framework for ~~the safe use of~~ nuclear power source applications in outer spaces for space applications. This partnership integrated the STSC's expertise in the use of space nuclear power sources with the IAEA's well-established procedures for developing safety standards pertaining to nuclear safety and radiation protection of terrestrial applications. The Safety Framework for Nuclear Power Source Applications in Outer Space represents a technical consensus of both organizations.

The Safety Framework for Nuclear Power Source Applications in Outer Space is intended to be utilized as a guide for national purposes. As such, it provides voluntary guidance and is not legally binding under international law.

The Safety Framework for Nuclear Power Source Applications in Outer Space is not a publication in the IAEA's Safety Standards Series, but is intended to complement the Safety Standards Series by providing high-level guidance that addresses unique safety considerations for relevant phases of launch, operation, and end-of-service disposition for space nuclear power sources. The development of theis framework takes into consideration applicable conventions, principles, and international law. It and is intended to be complementary to existing national and international safety guidance and standards pertaining to terrestrial activities that involve the design, manufacture, testing and transportation of space nuclear power sources.

The unique focus of this framework is the protection of people and the environment in Earth's biosphere from potential hazards associated with relevant launch, operation, and end-of-service disposition mission phases of space nuclear power source applications. As such, the protection in space of humans in space involved in the operational phase of missions that use space nuclear power source applications is beyond the scope of this framework.

In summary, the purpose of the framework is to promote the safety of NPS applications in outer space; as such this framework applies to all NPS application without prejudice.

The STSC and IAEA wish to express their appreciation to all those who assisted in the drafting and review of this text and in the process of reaching consensus.

Contents

1. Introduction

1.1. Background

Nuclear power sources (NPS) for use in outer space have been developed and used on spacecraft where unique mission requirements and constraints on electrical power and thermal management precluded the use of non-nuclear power sources. Such missions have included interplanetary missions to the outer limits of the solar system, for which solar panels were not suitable as a source of electrical power because of the long duration of the mission at great distances from the Sun.

The designs of space NPS have included radioisotope power systems (including radioisotope thermoelectric generators and radioisotope heater units) and nuclear reactor systems. Radioisotope power systems are currently in use, and their continued use is expected. Foreseeable missions to Mars by space agencies might use space radioisotope power systemssources. Reactors for power or propulsion are contemplated for scientific and exploration missions, specifically for the Moon, Mars, and other Solar System destinations. Earth orbital missions requiring high power (e.g., communications, inter-orbital space tugs, etc.) may also use nuclear reactors. According to current knowledge and capabilities, space NPS are the only available energy option to power some space missions and significantly enhance others. Several ongoing and foreseeable missions would not be possible without the use of space NPS.

The environments for Bboth normal operating and potential accident conditions conditions for space NPS applications, from launch through operation to end_-of_-service disposition, are radically different from the environments conditions for terrestrial applications. The launch and outer space environments create very different safety design and operational criteria for space NPS. Furthermore, space mission requirements lead to unique mission-specific designs for space NPS, spacecraft, launch systems, and mission operations.

The presence of radioactive materials or nuclear fuels in space NPS and their consequent potential for harm to people and the environment in Earth's biosphere due to an accident mean that safety must always be an inherent part of their design and application. It is important to recognize that safety (i.e., protection of people and the environment[1]) should focus on the entire application and not simply on the space NPS component. All elements of the application could affect the nuclear aspects of safety. Therefore, safety needs to be addressed in the context of the entire space NPS application, which includes the space NPS, spacecraft, launch system, mission ~~plan~~design, and flight rules~~, and other appropriate elements~~.

1.2. Purpose

The purpose of this publication is to provide high-level guidance in the form of a model safety framework. The framework provides a foundation for the development of national and international intergovernmental safety frameworks while allowing for flexibility in adapting such frameworks to specific space NPS applications and organizational structures. Such national and international intergovernmental frameworks should include both technical and programmatic elements to mitigate risks arising from the use of space NPS. Implementation of such frameworks would provide assurance to the global public that space NPS applications would be launched and used in a safe manner, and could facilitate bilateral and multilateral cooperation on space missions using NPS. This guidance reflects an international consensus on measures needed to achieve safety and is intended for both radioisotope power systems and nuclear reactor systems.

1.3. Scope

This framework focuses on safety for relevant launch, operation, and end-of-service ~~disposition~~ phases of space NPS applications. High-level guidance is provided for both the programmatic and technical aspects of safety, including the design and application of space NPS. However, detailed usage of this guidance depends on the particular design and application. The guidance provided in this framework would supplement existing standards that cover other aspects of ~~the~~ space NPS applications. For example, activities occurring during the terrestrial phase of space NPS applications, such as development, testing, manufacturing, handling, and transportation, are addressed in national and

[1] Use of the phrase "people and the environment" throughout this document is synonymous with the phrase, "people and the environment in Earth's biosphere."

international standards relating to terrestrial nuclear installations and activities. Similarly, non-nuclear safety aspects of space NPS applications are addressed in national government and international intergovernmental organization (e.g., regional space agency) safety standards pertaining to these aspects.

A substantial body of knowledge exists for establishing a space NPS application safety framework for people and the environment in Earth's biosphere. However, comparable scientific data does not yet exist that would provide a technically sound basis for developing a space NPS application framework for protecting humans in the unique conditions in space and beyond Earth's biosphere. Therefore, ~~This safety framework does not address small radiation sources used for science instruments. However, the framework would apply for missions that use large quantities of such sources. Further, t~~the protection in space of humans involved in ~~the operational phase of~~ missions that use space nuclear power source applications is beyond the scope of this framework~~.~~

2. Safety Objective

The fundamental safety objective is to protect people and the environment in Earth's biosphere from potential hazards associated with relevant launch, operation, and end-of-service ~~disposition~~ phases of space nuclear power source applications.

Government(s) and organizations responsible for authorizing, approving or conducting space NPS applications should take measures to ensure that ~~the risk to~~ people (individually and collectively) and the environment in Earth's biosphere ~~is as low as reasonably achievable~~are protected without unduly limiting the beneficial uses of space NPS applications.

Guidance, for~~To~~ satisfying the fundamental safety objective, ~~a set of functions needs to be performed for space NPS applications. These functions are~~ is grouped into three categories: Governmental ~~Elements~~, Managerial~~ement Elements~~, and Technical ~~Elements~~. ~~The first group of functions, the~~ Guidance for Governments~~al Elements~~ (Section 3)~~, specifies functions that~~ applies~~y~~ to governments and relevant international intergovernmental organizations responsible for authorizing, approving, or conducting space NPS missions. ~~The~~ Guidance for ~~The second group,~~ Management ~~Elements~~ (Section 4)~~,~~ provides guidance to the management of the organization that conducts space NPS missions. ~~The third group,~~ Technical Guidance~~Elements~~ (Section 5)~~,~~ provides ~~technical~~ guidance that is pertinent to design, development, and mission phases of ~~a~~ space NPS applications.

3. Guidance for Governments~~al Elements~~

This section provides guidance ~~and identifies functions that should be performed by~~for government(s) and relevant international intergovernmental organizations (e.g., regional space agencies) responsible for authorizing, approving or conducting space NPS missions. These governmental ~~functions~~ responsibilities include establishing safety policies, requirements, and processes; ensuring compliance with these policies, requirements, and processes; ensuring that there is an acceptable justification for using a space NPS when weighed against other alternatives; establishing a formal mission launch authorization process; and preparing for and ~~to~~ responding to emergencies. For multi-national or multi-organizational missions, governing instruments should define the allocation of these ~~functions~~ responsibilities clearly.

3.1. Safety Policy, Requirements, and Processes

Governments responsible for authorizing, approving or conducting space nuclear power source missions should establish safety policies, requirements, and processes.

National governments and relevant international intergovernmental organizations responsible for authorizing, approving or conducting space NPS missions, whether such activities are carried on by governmental agencies or by non-governmental entities**,** should establish and ensure compliance with their respective safety policies, requirements, and processes to achieve the fundamental safety objective and fulfill their safety requirements.

3.2. Justification for Space Nuclear Power Source Applications

The government's mission approval process should ~~confirm~~verify that the rationale for using the space nuclear power source application has been~~is~~ appropriately justified~~s should be appropriate~~[A1].

Space NPS applications may introduce risk to people and the environment. For this reason, the government(s) and relevant international intergovernmental organizations responsible for authorizing, approving, or conducting the space NPS mission should ensure that the rationale for the space NPS application considers alternatives and is appropriately justified ~~acceptable~~[A2] ~~relative to other alternatives~~. The process~~is determination~~ should consider ~~the~~ benefits and risks to people and the environment ~~during the~~related to relevant launch, operation, and end-of-service ~~disposition~~ phases of the space NPS application.

3.3. Mission Launch Authorization

A mission launch authorization process for space nuclear power source applications should be established and sustained.

The national government that oversees and authorizes the launch operations for space NPS missions should establish a mission launch authorization process focused on nuclear safety aspects.

The process should include an evaluation of all relevant information and considerations from ~~the~~ other participating organizations. This mission launch authorization process should supplement the authorization processes covering non-nuclear and terrestrial aspects of launch safety. An independent safety evaluation (i.e., a review, independent of the management organization conducting the mission, of the adequacy and validity of the safety case) should be an integral part of the authorization process. The independent safety evaluation should consider the entire space NPS application--including the space NPS, spacecraft, launch system, mission design~~plan~~, and flight rules~~, and other appropriate elements~~--in assessing the risk to people and the environment from relevant launch, operation and end-of-service ~~disposition~~ phases of the space mission.

3.4. Emergency Preparedness and Response

Preparations should be made to respond to potential ~~accidents~~ emergencies involving a space nuclear power source.

Government(s) and relevant international intergovernmental organizations responsible for authorizing, approving, or conducting the space NPS application should be prepared to respond rapidly to launch and mission ~~accidents~~ emergencies that may result in radiation exposure to people and radioactive contamination of Earth's environment. The emergency preparedness activities include emergency planning, development of procedures, training, rehearsals, and ~~development~~ drafting of potential accident notifications. The ~~accident~~ emergency response plans should be designed so as to restrict~~, to the extent feasible,~~ radioactive contamination and radiation exposure.

4. Guidance for Management ~~Elements~~

This section provides guidance for management of the organizations that use space NPS. In the context of this framework, management should comply with governmental and relevant intergovernmental safety policies, requirements, and processes to achieve the fundamental safety objective. Management ~~functions~~ responsibilities include accepting prime responsibility for safety and creating a robust "safety culture" within the organization.

4.1. Responsibility for Safety

The prime responsibility for safety should rest with the organization that conducts the space nuclear power source mission.

The organization that conducts the space NPS mission has the prime responsibility for safety. This organization should include, or have formal arrangements with, all relevant participants in the mission (e.g., spacecraft provider, launch vehicle provider, NPS provider, launch site, etc.) for satisfying the safety requirements established for the space NPS application.

Specific safety responsibilities for management should include the following:

- Establishing and maintaining the necessary technical competencies;
- Providing adequate training and information to all relevant participants;
- Establishing procedures to promote safety under all reasonably foreseeable conditions;
- Developing specific safety requirements, as appropriate, for missions that use space NPS;
- Performing and documenting safety tests and analyses as input to the governmental mission launch authorization process;
- Considering credible opposing views on safety matters; and
- Providing accurate and timely information to the public.

4.2. Leadership and Management for Safety

Effective leadership and management for safety should be established and sustained in the organization that conducts the space nuclear power source mission.

Leadership in safety matters should be demonstrated at the highest levels in the organization that conducts the mission. Management of safety should be integrated with the overall management of the mission. Management should develop, implement, and maintain a safety culture that ensures safety and satisfies the requirements of the governmental mission launch authorization process.

The safety culture should include the following:

- Clear lines of authority, responsibility, and communication;
- Active feedback and continuous improvement;
- Individual and collective commitment to safety at all levels of the organization;
- Accountability of organization and of individuals at all levels for safety; and
- A questioning and learning attitude to discourage complacency with regard to safety.

5. Technical ~~Elements~~Guidance

This section provides the framework's technical guidance pertinent to the design, development, and mission phases of space NPS applications relevant to achieving the safety objective. To ensure a satisfactory technical basis for the government's authorization and approval processes and for emergency preparedness and response, gGuidelines are specifieduidance is provided in four key areas for organization(s) involved in conducting space NPS applications:

- Establishing and maintaining a nuclear safety design, test, and analysis capability;
- Applying this capability in the design, qualification, and mission launch authorization processes of the space NPS application (i.e., space NPS, spacecraft, launch system, mission design, and flight rules);
- Assessing the radiation risks to people and the environment arising from potential accidents and ensuring that the risk is acceptable and as low as reasonably achievable; and
- Taking actions to manage the consequences of potential accidents.

5.1. Technical Competence in Nuclear Safety

Technical competence in nuclear safety should be established and maintained for space nuclear power source applications.

Having technical competence in nuclear safety is vital for achieving the safety objective. From the earliest point in the development of a space NPS application, the organization(s) conducting the space NPS applications should establish, consistent with their responsibilities, nuclear safety design, test, and analysis capabilities, including qualified individuals and facilities, as appropriate. These capabilities should be maintained for the duration of the relevant phases of the space NPS mission(s).

The nuclear safety competence should include the capability to:

- Define space NPS application accident scenarios, and their estimated probabilities, in a rigorous manner;
- Characterize the physical environments conditions that the space NPS and its components could be exposed to in normal operationsconditions, as well as potential accidents;
- Assess the potential consequences to people and the environment from potential accidents; and
- Identify and assess inherent and engineered safety features to reduce the risk of potential accidents to people and the environment.

5.2. Safety in Design and Development

Design and development processes should provide the highest level of safety that can reasonably be achieved.

The underlying approach to meeting the safety objective should be to reduce the risks from normal operations and potential accidents to as low a level as is reasonably achievable by establishing design and development processes that incorporate safety considerations in the context of the entire space NPS application (i.e., space NPS, spacecraft, launch system, mission design, and flight rules). Nuclear and radiation safety should be considered from the earliest stages of design and development, and throughout all mission phases. The design and development processes should:

- Incorporate lessons learned from prior experience;
- Evaluate and implement preventive measures, features, and controls that:
  - Reduce the probability of potential accidents that could release radioactive material, and
  - Reduce the magnitude of potential releases and their potential consequences;
- Verify and validate design safety features and controls through tests and analyses, as appropriate;
- Use risk analysis to assess the effectiveness of design features and controls and provide feedback to the design process; and
- Use design reviews to provide assurance of the safety of the design.

5.3. Assessment of Risk

Risk assessments should be conducted to characterize the radiation risks to people and the environment.

The radiation risks to people and the environment from potential accidents during the launch and use of space NPS should be assessed and uncertainties quantified to the extent possible. Risk assessments are an integral componentessential of for the governmental mission authorization process.

5.4. Accident Consequence Mitigation

All practical efforts should be made to mitigate the consequences of potential accidents.

As part of the safety process for the space NPS application, measures should be evaluated to mitigate the consequences of accidents with the potential to release radioactive material and radiation into Earth's environment. The necessary capabilities Actions should be established and made available, as appropriate, for supporting taken by the appropriate organization(s) to mitigate potential accident consequences mitigation activities in a timely manner, including:

- Developing and implementing contingency plans to interrupt accident sequences that could lead to radiation hazards;
- Determining whether a release of radioactive material has occurred;
- Characterizing the location and nature of the release of radioactive material;
- Characterizing the areas contaminated by radioactive materials;
- Recommending protective measures to Llimiting exposure of population groups by implementing protective measures in the affected areas; and
- Providing information to the appropriate government(s), organizations, and entities regarding those areas affected by the accident.

6. Glossary of Terms

~~This section provides a glossary of terms that are unique to the safety of space nuclear power sources.~~~~*Launch* – A set of actions at the launch site, which leads to the delivery of a spacecraft to a pre-determined orbit or flight trajectory.~~

~~*Launch Phase* – The period of time that includes the following: pre-launch preparation at the launch site, lift-off, ascent, operation of upper (or boost) stages, payload deployment and any other action associated with delivery of a spacecraft to a pre-determined orbit or flight trajectory.~~

~~*Launch Vehicle* – Any propulsive vehicle including upper (or boost) stages constructed for placing a payload into space.~~

~~*Launch System* – The launch vehicle, launch site infrastructure, supporting facilities, equipment, and procedures required for launching a payload into space.~~

~~*Mission Authorization* – [DEFINITION TO BE PROVIDED]~~

~~*Space Nuclear Power Source* – A device that uses radioisotopes or a nuclear reactor for electrical power generation, heating, or propulsion in a space application.~~

~~*Space Nuclear Power Source Application* – The overall system of elements (i.e., space nuclear power source, spacecraft, launch system, mission plan, flight rules, etc.) involved in conducting a space mission involving a space nuclear power source.~~ This section provides a glossary of terms that are unique to the safety of space nuclear power sources. General nuclear safety terms in this framework are defined in the IAEA Safety Glossary.

Flight Rules - A collection of pre-planned decisions to minimize the amount of real-time decision ~~making requiredmaking~~ making required for nominal and off-nominal situations affecting ~~a missiona~~a mission.

Launch – A set of actions at the launch site, which leads to the delivery of a spacecraft to a pre-determined orbit or flight trajectory.

Launch Phase – The period of time that includes the following: pre-launch preparation at the launch site, lift-off, ascent, operation of upper (or boost) stages, payload deployment and any other action associated with delivery of a spacecraft to a pre-determined orbit or flight trajectory.

Launch Vehicle – Any propulsive vehicle including upper (or boost) stages constructed for placing a payload into space.

Launch System – The launch vehicle, launch site infrastructure, supporting facilities, equipment, and procedures required for launching a payload into space.

Mission – Launch and, operation (including end-of-service aspects) of a payload (e.g., spacecraft) beyond Earth's biosphere for a specific purpose.

Mission Approval – The permission by a governmental authority for activities to proceed for preparing a mission for launch and operation.

Mission Launch Authorization – The permission by a governmental authority to launch and operate a mission.

Space Nuclear Power Source – A device that uses radioisotopes or a nuclear reactor for electrical power generation, heating, or propulsion in a space application.

Space Nuclear Power Source Application – The overall system of elements (i.e., space nuclear power source, spacecraft, launch system, mission design, flight rules, etc.) involved in conducting a space mission involving a space nuclear power source.
