Part four

Other documents

A. Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space[26]

1. Background

Since the Committee on the Peaceful Uses of Outer Space published its Technical Report on Space Debris in 1999,27 it has been a common understanding that the current space debris environment poses a risk to spacecraft in Earth orbit. For the purpose of this document, space debris is defined as all man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional. As the population of debris continues to grow, the probability of collisions that could lead to potential damage will consequently increase. In addition, there is also the risk of damage on the ground, if debris survives Earth's atmospheric re-entry. The prompt implementation of appropriate debris mitigation measures is therefore considered a prudent and necessary step towards preserving the outer space environment for future generations.

Historically, the primary sources of space debris in Earth orbits have been
(a) accidental and intentional break-ups which produce long-lived debris and
(b) debris released intentionally during the operation of launch vehicle orbital stages and spacecraft. In the future, fragments generated by collisions are expected to be a significant source of space debris.

Space debris mitigation measures can be divided into two broad categories: those that curtail the generation of potentially harmful space debris in the near term and those that limit their generation over the longer term. The former involves the curtailment of the production of mission-related space debris and the avoidance of break-ups. The latter concerns end-of-life procedures that remove decommissioned spacecraft and launch vehicle orbital stages from regions populated by operational spacecraft.

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2. Rationale

The implementation of space debris mitigation measures is recommended since some space debris has the potential to damage spacecraft, leading to loss of mission, or loss of life in the case of manned spacecraft. For manned flight orbits, space debris mitigation measures are highly relevant due to crew safety implications.

A set of mitigation guidelines has been developed by the Inter-Agency Space Debris Coordination Committee (IADC), reflecting the fundamental mitigation elements of a series of existing practices, standards, codes and hand- books developed by a number of national and international organizations. The Committee on the Peaceful Uses of Outer Space acknowledges the benefit of a set of high-level qualitative guidelines, having wider acceptance among the global space community. The Working Group on Space Debris was therefore established (by the Scientific and Technical Subcommittee of the Committee) to develop a set of recommended guidelines based on the technical content and the basic definitions of the IADC space debris mitigation guidelines, and taking into consideration the United Nations treaties and principles on outer space.

3. Application

Member States and international organizations should voluntarily take measures, through national mechanisms or through their own applicable mechanisms, to ensure that these guidelines are implemented, to the greatest extent feasible, through space debris mitigation practices and procedures.

These guidelines are applicable to mission planning and the operation of newly designed spacecraft and orbital stages and, if possible, to existing ones. They are not legally binding under international law.

It is also recognized that exceptions to the implementation of individual guidelines or elements thereof may be justified, for example, by the provisions of the United Nations treaties and principles on outer space.

4. Space debris mitigation guidelines

The following guidelines should be considered for the mission planning, design, manufacture and operational (launch, mission and disposal) phases of spacecraft and launch vehicle orbital stages:

Guideline 1: Limit debris released during normal operations

Space systems should be designed not to release debris during normal operations. If this is not feasible, the effect of any release of debris on the outer space environment should be minimized.

During the early decades of the space age, launch vehicle and spacecraft designers permitted the intentional release of numerous mission-related objects into Earth orbit, including, among other things, sensor covers, separation mechanisms and deployment articles. Dedicated design efforts, prompted by the recognition of the threat posed by such objects, have proved effective in reducing this source of space debris.

Guideline 2: Minimize the potential for break-ups during operational phases

Spacecraft and launch vehicle orbital stages should be designed to avoid failure modes which may lead to accidental break-ups. In cases where a condition leading to such a failure is detected, disposal and passivation measures should be planned and executed to avoid break-ups.

Historically, some break-ups have been caused by space system malfunctions, such as catastrophic failures of propulsion and power systems. By incorporating potential break-up scenarios in failure mode analysis, the probability of these catastrophic events can be reduced.

Guideline 3: Limit the probability of accidental collision in orbit

In developing the design and mission profile of spacecraft and launch vehicle stages, the probability of accidental collision with known objects during the system's launch phase and orbital lifetime should be estimated and limited. If available orbital data indicate a potential collision, adjustment of the launch time or an on-orbit avoidance manoeuvre should be considered.

Some accidental collisions have already been identified. Numerous studies indicate that, as the number and mass of space debris increase, the primary source of new space debris is likely to be from collisions. Collision avoidance procedures have already been adopted by some Member

States and international organizations.

Guideline 4: Avoid intentional destruction and other harmful activities Recognizing that an

increased risk of collision could pose a threat to space operations, the intentional destruction of any on-orbit spacecraft and launch vehicle orbital stages or other harmful activities that generate long-lived debris should be avoided.

When intentional break-ups are necessary, they should be conducted at sufficiently low altitudes to limit the orbital lifetime of resulting fragments.

Guideline 5: Minimize the potential for post-mission break-ups resulting from stored energy

In order to limit the risk to other spacecraft and launch vehicle orbital stages from accidental break-ups, all onboard sources of stored energy should be depleted or made safe when they are no longer required for mission operations or post-mission disposal.

By far the largest percentage of the catalogued space debris population originated from the fragmentation of spacecraft and launch vehicle orbital stages. The majority of those break-ups were unintentional, many arising from the abandonment of spacecraft and launch vehicle orbital stages with significant amounts of stored energy. The most effective mitigation measures have been the passivation of spacecraft and launch vehicle orbital stages at the end of their mission. Passivation requires the removal of all forms of stored energy, including residual propellants and compressed fluids and the discharge of electrical storage devices.

Guideline 6: Limit the long-term presence of spacecraft and launch vehicle orbital stages in the low-Earth orbit (LEO) region after the end of their mission

Spacecraft and launch vehicle orbital stages that have terminated their operational phases in orbits that pass through the LEO region should be removed from orbit in a controlled fashion. If this is not possible, they should be disposed of in orbits that avoid their long-term presence in the LEO region.

When making determinations regarding potential solutions for removing objects from LEO, due consideration should be given to ensuring that debris that survives to reach the surface of the Earth does not pose an undue risk to people or property, including through environmental pollution caused by hazardous substances.

Guideline 7: Limit the long-term interference of spacecraft and launch vehicle orbital stages with the geosynchronous Earth orbit (GEO) region after the end of their mission

Spacecraft and launch vehicle orbital stages that have terminated their operational phases in orbits that pass through the GEO region should be left in orbits that avoid their long-term interference with the GEO region.

For space objects in or near the GEO region, the potential for future collisions can be reduced by leaving objects at the end of their mission in an orbit above the GEO region such that they will not interfere with, or return to, the GEO region.

5. Updates

Research by Member States and international organizations in the area of space debris should continue in a spirit of international cooperation to maximize the benefits of space debris mitigation initiatives. This document will be reviewed and may be revised, as warranted, in the light of new findings.

6. Reference

The reference version of the IADC space debris mitigation guidelines at the time of the publication of this document is contained in the annexe to document A/AC.105/C.1/L.260.

For more in-depth descriptions and recommendations pertaining to space debris mitigation measures, Member States and international organizations may refer to the latest version of the IADC space debris mitigation guidelines and other supporting documents, which can be found on the IADC website (www.iadconline.org).

B. Safety Framework for Nuclear Power Source Applications in Outer Space[28]

Preface

Nuclear 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 these missions at great distances from the Sun.

According to current knowledge and capabilities, space NPS are the only viable 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. Past, present and foreseeable space NPS applications include radioisotope power systems (for example, radioisotope thermoelectric generators and radioisotope heater units) and nuclear reactor systems for power and propulsion. 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 require that safety should always be an inherent part of the design and application of space NPS.

NPS applications in outer space have unique safety considerations compared with 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 NPS must operate autonomously at great distances from Earth in harsh environments. Potential accident conditions resulting from launch failures and inadvertent re-entry could expose NPS to extreme physical conditions. These and other unique safety considerations for the use of space NPS are

28Endorsed by the Committee on the Peaceful Uses of Outer Space at its fifty-second session and contained in A/AC.105/934.

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 of the Committee on the Peaceful Uses of Outer Space of the United Nations and the International Atomic Energy Agency (IAEA) agreed in 2007 to jointly draft a safety framework for NPS applications in outer space. This partnership integrated the expertise of the Scientific and Technical Sub-committee in the use of space NPS with the well-established procedures of IAEA for developing safety standards pertaining to the nuclear safety of terrestrial applications. The Safety Framework for Nuclear Power Source Applications in Outer Space represents a technical consensus of both bodies.

The Safety Framework 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 is not a publication in the IAEA Safety Standards Series, but it is intended to complement the Safety Standards Series by providing high-level guidance that addresses unique nuclear safety considerations for relevant launch, operation and end-of-service mission phases of space NPS applications. It complements existing national and international safety guidance and standards pertaining to terrestrial activities that involve the design, manufacture, testing and transportation of space NPS. The Safety Framework has been developed with due consideration of relevant principles and treaties. The Safety Framework does not supplement, alter or interpret any of those principles or treaties.

The focus of the Safety 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 mission phases of space NPS applications. The protection of humans in space is an area of ongoing research and is beyond the scope of the Safety Framework. Similarly, the protection of environments of other celestial bodies remains beyond the scope of the Safety Framework.

Safety terms used in the Safety Framework are defined in the IAEA Safety Glossary. As used herein, the term “nuclear safety” includes radiation safety and radiation protection. Additional terms specific to space NPS applications are defined in the section of the Safety Framework entitled “Glossary of terms”.

In summary, the purpose of the Safety Framework is to promote the safety of NPS applications in outer space; as such, it applies to all space NPS applications without prejudice.

The Scientific and Technical Subcommittee and IAEA wish to express their appreciation to all those who assisted in the drafting and review of the text of the Safety Framework and in the process of reaching a consensus.

Introduction

Background

Nuclear power sources (NPS) for use in outer space22 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.

Past, present and foreseeable space NPS applications include radioisotope power systems (including radioisotope thermoelectric generators and radio-isotope heater units) and nuclear reactor systems for power and propulsion. Space NPS have enabled several ongoing missions. According to current knowledge and capabilities, space NPS are the only viable energy option to power some foreseeable space missions and significantly enhance others.

Both normal operating and potential accident conditions for space NPS applications, through the launch, operation and end-of-service phases, are radically different from the 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 require that safety must always be an inherent part of the design and application of space NPS. Safety (i.e. protection of people and the environment)30 should focus on the entire application and not only 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 design and flight rules.

22As used herein, the term "outer space" is synonymous with "space".

30As used herein, the term "people and the environment" is synonymous with the term "people and the environment in Earth's biosphere".

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 inter-national intergovernmental frameworks should include both technical and programmatic elements to mitigate risks arising from the use of space NPS. Implementation of such frameworks not only would provide assurance to the global public that space NPS applications would be launched and used in a safe manner, but could also facilitate bilateral and multilateral cooperation on space missions using NPS. The guidance provided herein reflects an international consensus on measures needed to achieve safety and applies to all space NPS applications without prejudice.

Scope

The Safety Framework for Nuclear Power Source Applications in Outer Space focuses on safety for relevant launch, operation and end-of-service phases of space NPS applications. High-level guidance is provided for both the pro-grammatic 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. Implementation of the guidance provided in the Safety Framework would supplement existing standards that cover other aspects of 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 international standards relating to terrestrial nuclear installations and activities. Similarly, non-nuclear safety aspects of space NPS applications are addressed in relevant safety standards of governments and international intergovernmental organizations (e.g. regional space agencies).

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 do 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, the protection in space of humans involved in missions that use space NPS applications is beyond the scope of the Safety Framework. Similarly, the protection of environments of other celestial bodies remains beyond the scope of the Safety Framework.

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 phases of space nuclear power source applications.

Governments, international intergovernmental organizations and non-governmental entities that are involved in space NPS applications should take measures to ensure that people (individually and collectively) and the environment are protected without unduly limiting the uses of space NPS applications.

Guidance for satisfying the fundamental safety objective is grouped into three categories: guidance for governments (section 3 below) applies to governments and relevant international intergovernmental organizations that authorize, approve or conduct space NPS missions; guidance for management (section 4 below) applies to the management of the organization that conducts space NPS missions; and technical guidance (section 5 below) applies to the design, development and mission phases of space NPS applications.

Guidance for governments

This section provides guidance for governments and relevant international intergovernmental organizations (e.g. regional space agencies) that authorize, approve or conduct space NPS missions. Governmental responsibilities include establishing safety policies, requirements and processes; ensuring compliance with those 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 responding to emergencies. For multinational or multiorganizational missions, governing instruments should define clearly the allocation of these responsibilities.

Safety policies, requirements and processes

Governments that authorize or approve space nuclear power source missions should establish safety policies, requirements and processes.

Governments and relevant international intergovernmental organizations that authorize or approve space NPS missions, whether such missions are conducted by governmental agencies or by non-governmental entities, should establish and ensure compliance with their respective safety policies, requirements and processes to satisfy the fundamental safety objectives and fulfil their safety requirements.

Justification for space nuclear power source applications

The government's mission approval process should verify that the rationale for using the space nuclear power source application has been appropriately justified.

Space NPS applications may introduce risk to people and the environment. For this reason, governments and relevant international intergovernmental organizations that authorize, approve or conduct space NPS missions should ensure that the rationale for each space NPS application considers alternatives and is appropriately justified. The process should consider benefits and risks to people and the environment related to relevant launch, operation and end-of- service phases of the space NPS application.

Mission launch authorization

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

The 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 other participating organiza- tions. The mission launch authorization process should supplement the authori- zation 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 and flight rules—in assessing the risk to people and the environment from relevant launch, opera- tion and end-of-service phases of the space mission.

Emergency preparedness and response

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

Governments and relevant international intergovernmental organizations that authorize, approve or conduct space NPS missions should be prepared to respond rapidly to launch and mission emergencies that may result in radiation exposure of people and radioactive contamination of Earth's environment. Emergency preparedness activities include emergency planning, training, rehearsals and development of procedures and communication protocols, including the drafting of potential accident notifications. Emergency response plans should be designed so as to restrict radioactive contamination and radiation exposure.

Guidance for management

This section provides guidance for management of the organizations involved in space NPS applications. In the context of the Safety Framework, management should comply with governmental and relevant intergovern- mental safety policies, requirements and processes to satisfy the fundamental safety objective. Management responsibilities include accepting prime responsibility for safety, ensuring the availability of adequate resources for safety and promoting and sustaining a robust safety culture at all organizational levels.

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. That organization should include, or have formal arrangements with, all relevant participants in the mission (spacecraft provider, launch vehicle provider, NPS provider, launch site provider etc.) for satisfying the safety requirements established for the space NPS application.

Specific safety responsibilities for management should include the following:

(a) Establishing and maintaining the necessary technical competencies;

(b) Providing adequate training and information to all relevant participants;

(c) Establishing procedures to promote safety under all reasonably foreseeable conditions;

(d) Developing specific safety requirements, as appropriate, for missions that use space NPS;

(e) Performing and documenting safety tests and analyses as input to the governmental mission launch authorization process;

(f) Considering credible opposing views on safety matters;

(g) Providing relevant, accurate and timely information to the public.

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:

(a) Clear lines of authority, responsibility and communication;

(b) Active feedback and continuous improvement;

(c) Individual and collective commitment to safety at all organizational levels;

(d) Safety accountability of the organization and of individuals at all levels;

(e) A questioning and learning attitude to discourage complacency with regard to safety.

Technical guidance

This section provides technical guidance for organizations involved in space NPS applications. This guidance is pertinent to the design, development and mission phases of space NPS applications. It encompasses the following key areas for developing and providing the technical basis for the authorization and approval processes and for emergency preparedness and response:

(a) Establishing and maintaining a nuclear safety design, test and analysis capability;

(b) Applying that 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);

(c) 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;

(d) Taking action to manage the consequences of potential accidents.

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 satisfying the safety objective. From the earliest point in the development of a space NPS application, organizations should establish, consistent with their responsibilities, nuclear safety design, test and analysis capabilities, including qualified individuals and facilities, as appropriate. Those capabilities should be maintained for the duration of the relevant phases of the space NPS missions.

Competence in nuclear safety should include:

(a) Defining space NPS application accident scenarios and their estimated probabilities in a rigorous manner;

(b) Characterizing the physical conditions to which the space NPS and its components could be exposed in normal operations, as well as potential accidents;

(c) Assessing the potential consequences to people and the environment from potential accidents;

(d) Identifying and assessing inherent and engineered safety features to reduce the risk of potential accidents to people and the environment.

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 satisfying 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 comprehensive design and development processes that integrate safety considerations in the context of the entire space NPS application (i.e. space NPS, spacecraft, launch system, mission design and flight rules). Nuclear safety should be considered from the earliest stages of design and development and throughout all mission phases. The design and development processes should include:

(a) Identifying, evaluating and implementing design features, controls and preventive measures that:

- (i) Reduce the probability of potential accidents that could release radioactive material;
- (ii) Reduce the magnitude of potential releases and their potential consequences;

(b) Incorporating lessons learned from prior experience;

(c) Verifying and validating design safety features and controls through tests and analyses, as appropriate;

(d) Using risk analysis to assess the effectiveness of design features and controls and to provide feedback to the design process;

(e) Using design reviews to provide assurance of the safety of the design.

Risk assessments

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 relevant launch, operation and end-of-service phases of space NPS applications should be assessed and uncertainties quantified to the extent possible. Risk assessments are essential for the mission launch authorization process.

Accident consequence mitigation

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

As part of the safety process for space NPS applications, measures should be evaluated to mitigate the consequences of accidents with the potential to release radioactive material into Earth's environment. The necessary capabilities should be established and made available, as appropriate, for timely support of activities to mitigate the consequences of accidents, including:

(a) Developing and implementing contingency plans to interrupt accident sequences that could lead to radiation hazards;

(b) Determining whether a release of radioactive material has occurred;

(c) Characterizing the location and nature of the release of radioactive material;

(d) Characterizing the areas contaminated by radioactive materials;

(e) Recommending protective measures to limit exposure of population groups in the affected areas;

(f) Preparing relevant information regarding the accident for dissemination to the appropriate governments, international organizations and nongovernmental entities and to the general public.

Glossary of terms

The glossary below defines terms that are specific to space NPS applications. General safety terms used in the Safety Framework are defined in the *IAEA Safety Glossary, 2007 Edition.*31

End-of-service phase: the period of time after the useful life of a spacecraft

Flight rules: a collection of pre-planned decisions to minimize the amount of real-time decision-making required for nominal and off-nominal situations affecting a mission

Launch: a set of actions at the launch site leading to the delivery of a spacecraft to a predetermined 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 predetermined 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: permission by a governmental authority for activities to proceed for preparing a mission for launch and operation

Mission design: the design of a space mission's trajectory and manoeuvres based on mission objectives, launch vehicle and spacecraft capabilities and mission constraints

Mission launch authorization: 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 (space nuclear power source, spacecraft, launch system, mission design, flight rules etc.) involved in conducting a space mission involving a space nuclear power source.

31International Atomic Energy Agency, *IAEA Safety Glossary: Terminology Used in Nuclear Safety and Radiation Protection, 2007 Edition* (Vienna, 2007).