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Use of nuclear power sources in outer space

Safety recommendations for nuclear power source applications in outer space

Working paper submitted by the United Kingdom of Great Britain and Northern Ireland[1]

I. Introduction

The Safety Framework for Nuclear Power Source Applications in Outer Space[2] sets out a model for the development of national and international intergovernmental safety frameworks while allowing for flexibility in adapting such frameworks to specific nuclear power source (NPS) applications and organizational structures. Previous papers[3] have chronicled the development, within the United Kingdom of Great Britain and Northern Ireland, of a trial set of safety recommendations to implement the Safety Framework. The present paper outlines the conclusions of that development work, based on discussions within the United Kingdom and with other international partners in the European Space Agency (ESA) and elsewhere about the best way to provide a more detailed interpretation of the Safety Framework for government officials, policymakers, mission designers, managers, scientists and engineers. Although this trial set of safety recommendations is intended for the situation in the United Kingdom (as a member of ESA), it is hoped that it may be of interest to other member States seeking to develop their own national frameworks to implement the Safety Framework.

[1] Prepared by Sam Harbison, consultant to the United Kingdom Space Agency.
[2] Jointly drafted by the Scientific and Technical Subcommittee and the International Atomic Energy Agency, and published in 2009 (see A/AC.105/934).
[3] Paper submitted by the United Kingdom of Great Britain and Northern Ireland on a trial set of Safety Recommendations to implement the Guidance for Governments section of the Safety Framework (A/AC.105/C.1/L.342); and conference room paper on possible general safety recommendations to implement the Safety Framework for Nuclear Power Source Applications in Outer Space (A/AC.105/C.1/2016/CRP.6).

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II. Development of a trial set of safety recommendations

The fundamental safety objective of the Safety Framework 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 NPS applications. The detailed Safety Recommendations in the annex to the present document are governed by this safety objective and by the three "guidance" sections of the Safety Framework.

In developing these safety recommendations, close attention has been paid to information provided by the two member States (United States of America and Russian Federation) with decades of experience in using space NPS applications. A paper in *Acta Astronautica*[4] has also provided useful information concerning management and technical issues associated with the safe use of NPS applications.

In deriving these safety recommendations, the Safety Requirements of the International Atomic Energy Agency have been used as a template, particularly Part 1 of the General Safety Requirements.[5] Consideration has also been given to Part 2 (Leadership and Management for Safety)[6] and Part 4 (Safety Assessment for Facilities and Activities) of the General Safety Requirements.[7] Even so, it is recognized that the recommendations relating to management and technical issues are not yet as well developed as those related to guidance for Governments.

Another consideration in developing the present safety recommendations has been to ensure that they do not conflict with the Principles Relevant to the Use of Nuclear Power Sources in Outer Space.[8] From a brief comparison of the Principles with the Safety Framework, it has been concluded that, while most of the provisions of the Principles can be considered to be subsumed within the more general requirements of the Safety Framework, there are three areas — prior notification of the intended launch of an NPS mission (principle 4, para. 3), notification of any possible re-entry of an NPS into the Earth's atmosphere (principle 5) and the requirements for States to provide information to, consult with and assist States that might be affected by such a re-entry (principles 6 and 7) — that should be mentioned specifically in the "Guidance for Governments" section of the safety recommendations (see recommendation 1 (b) below).

These safety recommendations have been drafted to be as complete and comprehensive as possible, but the limited extent of the involvement of member States, such as the United Kingdom, in the actual launch of space NPS missions needs to be recognized and taken into account. Consequently, recommendation 1 indicates that the policy of any Government with regard to NPS safety should be "suitable and sufficient" for the intended NPS programme of the country in question. This is especially important if the member State is a member of an international intergovernmental organization such as ESA, in which case it is vital to avoid unnecessary duplication of roles and responsibilities.

[4] L. Summerer and others, "The international safety framework for nuclear power source applications in outer space — useful and substantial guidance", in *Acta Astronautica*, vol. 111 (2015), pp. 89-101.

[5] International Atomic Energy Agency (IAEA), Governmental, Legal and Regulatory Framework for Safety, IAEA Safety Standards Series No. GSR Part 1 (Rev. 1) (Vienna, 2016).

[6] International Atomic Energy Agency (IAEA), Leadership and Management for Safety, IAEA Safety Standards Series No. GSR Part 2 (Vienna, 2016).

[7] International Atomic Energy Agency (IAEA), Safety Assessment for Facilities and Activities, IAEA Safety Standards Series No. GSR Part 4 (Rev. 1) (Vienna, 2016).

[8] General Assembly resolution 47/68.

III. Conclusions

The present paper provides a trial set of safety recommendations aimed at presenting a more detailed interpretation of the Safety Framework for government officials, policymakers, mission designers, managers, scientists and engineers. While it has been developed specifically for the United Kingdom (as a member of ESA), it is hoped that it may be of interest to other member States seeking to develop their own national frameworks to implement the Safety Framework.

Annex

Safety recommendations for nuclear power source applications in outer space

Background

The presence of radioactive materials or nuclear fuels in space nuclear power sources and the consequent potential for harm to people and the environment in Earth's biosphere resulting from an accident require that safety must always be an inherent part of the design and application of space nuclear power sources.

Therefore, safety needs to be addressed in the context of the entire space nuclear power source (NPS) application, which includes the design, development, construction and testing of the space NPS, and its incorporation into the spacecraft, launch system, mission design and flight rules. This means that mission planners should use the existing processes for ensuring the protection of hardware, personnel and the public against non-nuclear hazardous materials, such as propellants, as the starting point for addressing the additional requirements arising from the use of nuclear power sources.

The present document establishes recommendations that support and amplify the safety objective and guidance provided in the Safety Framework for Nuclear Power Source Applications in Outer Space, and takes account of relevant provisions in the Principles Relevant to the Use of Nuclear Power Sources in Outer Space.[9]

Objective

The objective of the present document is to establish recommendations in relation to:

- The responsibilities of Governments that authorize, approve or conduct space NPS missions or are part of an international intergovernmental organization that does so
- The management responsibilities of organizations involved in space NPS applications
- Technical guidance for organizations involved in space NPS applications.

Governmental responsibilities include establishing safety policies, requirements and processes; ensuring compliance with those policies, requirements and processes; ensuring that there is 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 multi-organizational missions, governing instruments should define clearly the allocation of responsibilities among the different parties.

In the context of the Safety Framework, management should comply with governmental and relevant intergovernmental 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.

Technical guidance is pertinent to the design, development and mission phases of space NPS applications. It encompasses the following key areas, which provide the

[9] General Assembly resolution 47/68.

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.

Scope

The present document covers the essential aspects of the governmental, legal, management and technical frameworks needed to ensure the effective control of safety during relevant launch, operation and end-of-service phases of space NPS applications. Other responsibilities and functions are also considered, such as ensuring efficient and effective compliance with:

(a) Existing standards that cover other aspects of space NPS applications, e.g. activities that occur during the terrestrial phase of space NPS applications, such as development, testing, manufacturing, handling and transportation;

(b) Non-nuclear safety aspects of space NPS applications that are addressed in relevant safety standards of Governments and international intergovernmental organizations;

(c) Those support services necessary for providing emergency preparedness and response, nuclear security and the State's system for accounting for, and control of, nuclear material.

Part 1: Guidance for Governments

Recommendation 1: Establishment of a policy and strategy for safety in the use of nuclear power source applications in outer space

Any Government that authorizes or approves space nuclear power source missions should establish a national policy and strategy for safety to achieve the fundamental safety objective and to apply the fundamental safety principles established in the Safety Framework for Nuclear Power Source Applications in Outer Space.

The policy and strategy for safety should express a long-term commitment to safety. The policy should be promulgated as a statement of the Government's intent and should be suitable and sufficient for the intended NPS programme of the country in question. The strategy should set out the mechanisms for implementing the policy. In the policy and strategy, account should be taken of the following:

(a) The fundamental safety objective and the fundamental safety principles established in the Safety Framework for Nuclear Power Source Applications in Outer Space;

(b) Relevant international legal instruments, such as conventions, principles and other international instruments. In particular, the Government should establish appropriate mechanisms for fulfilling the provisions of the Principles Relevant to the

Use of Nuclear Power Sources in Outer Space in relation to the prior notification of the intended launch of an NPS mission (principle 4, para. 3), the notification of any possible re-entry of an NPS into the Earth's atmosphere (principle 5) and the requirements for States to provide information to, consult with and assist States that might be affected by such a re-entry (principles 6 and 7);

(c) The specification of the scope of the Government's legal and assurance framework for safety;

(d) The need for and provision of human and financial resources;

(e) The provision of and framework for research and development;

(f) Adequate mechanisms for taking account of societal and economic developments;

(g) The promotion of leadership and management for safety, including safety culture.

Recommendation 2: Establishment of a framework for safety in the use of nuclear power source applications in outer space

Any Government that authorizes or approves space nuclear power source missions should establish and maintain an appropriate legal and assurance framework for safety, within which responsibilities are clearly allocated.

The Government should promulgate such legal instruments as are necessary to provide for an effective legal and assurance framework for safety in the use of NPS applications in outer space. This framework should set out the following:

(a) The principles for protecting people (individually and collectively) and the environment in the Earth's biosphere from the risks associated with the use of nuclear power sources in outer space;

(b) The types of activities that are included within the scope of the framework;

(c) The type of authorization that is required for the conduct of all relevant activities associated with the preparation and launch of space missions with NPS applications, in accordance with a graded approach;

(d) Provision for the involvement of interested parties and for their input to decision-making;

(e) Provision for assigning legal responsibility for safety to the persons or organizations responsible for the activities, and for ensuring the continuity of responsibility when activities are carried out by several persons or organizations successively;

(f) The establishment of appropriate assurance mechanisms to provide an independent oversight of the safety achievements of the persons or organizations responsible for safety;

(g) Provision for the review, assessment and inspection, through the established assurance mechanisms, of activities, in accordance with a graded approach;

(h) Provision for preparedness for, and response to, a nuclear or radiological emergency involving a space NPS application and for the timely notification of other States that may be affected;

(i) Provision for an appropriate interface with nuclear security entities;

(j) Provision for an interface with the system of accounting for, and control of, nuclear material;

(k) Provision for acquiring and maintaining the necessary competence for ensuring safety;

(l) Responsibilities and obligations with respect to the end-of-life phase of any space mission involving an NPS application;

(m) Provision for controls on the import and export of nuclear material and radioactive material, and for tracking authorized import and export of radioactive sources.

When several authorities are involved, the Government should specify clearly the responsibilities and functions of each authority within the governmental, legal and assurance framework for safety.

Recommendation 3: Establishment of an appropriate safety assurance regime

The Government, through its legal system, should establish and maintain an appropriate safety assurance regime, with the independence, competence and resources necessary to fulfil its statutory obligations in relation to overseeing the safety of activities associated with the use of nuclear power sources in outer space.

In this context, the term "safety assurance regime" means all the systems, procedures and resources applied by a Government to provide an assessment and verification, independent of the designers and operators, of the safety of any NPS application.

The Government should ensure that the safety assurance regime has sufficient authority and resources to allow it to discharge its assigned responsibilities in a competent and timely manner without undue pressure or constraint.

The Government should confer on the safety assurance regime the legal authority to require the persons or organizations responsible for the safety of NPS applications to provide all necessary safety-related information, including information from suppliers, and facilitate inspection of the premises of any designer, supplier, manufacturer, constructor, contractor or operating organization associated with the NPS application.

Recommendation 4: Prime responsibility for safety in the use of nuclear power source applications in outer space

The Government should expressly assign the prime responsibility for safety to the organization that conducts the space nuclear power source mission.

In the legal framework for the safe use of space NPS applications, the organization that conducts a space NPS mission has the prime responsibility for safety. That organization has the legal responsibility to make appropriate arrangements with all other participating organizations for ensuring that the safety requirements established for the mission are met at all times.

Recommendation 5: Coordination of different authorities with responsibilities within the safety assurance regime for the use of nuclear power source applications in outer space

Where several authorities have responsibilities within the safety assurance regime for the use of nuclear power source applications in outer space, the Government should make provision for the effective coordination of their safety assurance functions.

Where several authorities have responsibilities for safety within the safety assurance regime, the responsibilities and functions of each authority should be clearly specified in the relevant regulations. The Government should ensure that there is appropriate coordination of and liaison between the various authorities in areas such as:

(a) Safety of workers and the public;

(b) Protection of the environment;

(c) Emergency preparedness and response;

(d) Management of radioactive waste;

(e) Liability for nuclear damage (including under relevant conventions);

(f) Nuclear security;

(g) Accounting for, and control of, nuclear material;

(h) Safety in the transport of nuclear and radioactive material;

(i) Controls on the import and export of nuclear and radioactive material.

Recommendation 6: Provision for the safe management of the end-of-service phases of space missions with nuclear power source applications

When authorizing or approving space missions with nuclear power source applications, the Government should ensure that adequate provision has been made for the safe management of the end-of-service phases of such missions.

The safe management of the end-of-service phases of space missions with NPS applications should constitute an essential element of the governmental policy and strategy. The policy should reflect all relevant international conventions and agreements, and include appropriate interim targets and end states. The Government should enforce continuity of responsibility between successive authorized parties. The Government should make provision for appropriate research and development programmes in relation to the end-of-service phases of space NPS missions.

Recommendation 7: Competence for safety

The Government should make provision for building and maintaining the competence of all parties having responsibilities in relation to the safe use of nuclear power source applications.

As an essential element of the national policy and strategy for safety in the use of NPS applications in outer space, arrangements should be made to achieve and maintain the competence of an appropriate number of suitably qualified and experienced staff.

The building of competence should be required for all parties with responsibilities for the safety of NPS activities, including authorized parties, the safety assurance regime and organizations providing services or expert advice on matters relating to safety.

The Government should:

(a) Stipulate a necessary level of competence for persons with responsibilities in relation to the safety of NPS activities;

(b) Make adequate arrangements for the safety assurance regime to build and maintain its expertise in the disciplines necessary for the discharge of its responsibilities;

(c) Make adequate arrangements to regularly verify the technical competence of persons working for authorized parties.

Recommendation 8: International obligations and arrangements for international cooperation

The Government should fulfil its relevant international obligations, participate in relevant international arrangements and promote international cooperation to enhance safety in the use of space nuclear power sources globally.

A Government that authorizes or approves space NPS missions should actively seek to promote a global safety regime for such activities through such things as:

(a) International treaties, conventions and principles that establish common obligations and mechanisms for ensuring the safety of NPS missions;

(b) The Safety Framework for Nuclear Power Source Applications in Outer Space and any recommendations and other guidance developed to support and expand it;

(c) Multilateral and bilateral cooperation that enhances safety by means of harmonized approaches, as well as increasing the quality and effectiveness of safety reviews.

Recommendation 9: Sharing of operational experience

The Government should make arrangements for analysis to be carried out to identify lessons to be learned from operational experience with space nuclear power source applications, including experience in other States, and for the dissemination of the lessons learned and for their use by authorized parties, the safety assurance regime and other relevant authorities.

The Government should establish and maintain a means for receiving information from other States and from authorized parties in relation to their experiences with space NPS applications, as well as a means for making available to others the lessons it has learned from its own operating experiences. Through its safety assurance regime, the Government should require appropriate corrective actions to be carried out to prevent the recurrence of significant safety events.

Recommendation 10: Establishment of a policy and strategy for justifying the use of space nuclear power source applications

Any Government that authorizes or approves space nuclear power source missions should establish a policy and strategy for justifying the use of space nuclear power source applications on such missions.

The policy and strategy for justifying the use of space NPS applications should express a commitment to explore all the viable alternative options that may be available. The policy should be promulgated as a statement of the Government's intent. The strategy should set out the mechanisms for implementing the policy. In the policy and strategy, account should be taken of the following:

(a) The fundamental safety objective and the fundamental safety principles established in the Safety Framework for Nuclear Power Source Applications in Outer Space;

(b) Relevant international legal instruments, such as conventions and other international instruments;

(c) The specification of the scope of the governmental and legal framework for justification;

(d) The specification of the process and procedures to be used to consider the justification for using space NPS applications in specific missions and who has the responsibility for making justification decisions;

(e) The time frame for reaching decisions on the justification for using space NPS applications in specific missions;

(f) The scope of the information required in order for a justification decision to be made, and who is responsible for providing it;

(g) The provision and framework for obtaining additional information or for carrying out additional research to underpin a justification decision;

(h) Adequate mechanisms for taking account of social and economic developments.

Recommendation 11: Establishment of a framework for justification

Any Government that authorizes or approves space nuclear power source missions should establish and maintain an appropriate governmental, legal and assurance framework for justification within which responsibilities are clearly allocated.

The Government should promulgate laws and statutes to make provision for an effective governmental, legal and assurance framework for justification. This framework should set out the following:

(a) The basic principles that are to be applied when considering and deciding on the justification for using space NPS applications compared with possible alternatives;

(b) The type of justification that is required for using space NPS applications in different types of space mission;

(c) The rationale for justifying the use of space NPS applications in different situations;

(d) Provision for the involvement of interested parties and for their input to decision-making;

(e) Provision for assigning legal responsibility to the organization responsible for any space NPS mission to provide sufficient information to allow the justification decision to be made;

(f) Provision for review of any justification decision if substantial new evidence is acquired about the efficacy or consequences (to people or the environment in the Earth's biosphere) of using any particular NPS application on any specific mission.

Where several authorities are involved in the governmental, legal and assurance framework for justification, the Government should specify clearly the responsibilities and functions of each such authority.

Recommendation 12: Establishment of a policy and strategy for authorization

Any Government that authorizes the launch of space nuclear power source missions should establish a national policy and strategy for authorization.

The policy and strategy for authorization should express a long-term commitment to safety. The policy should be promulgated as a statement of the Government's intent. The strategy should set out the mechanisms for implementing the policy. In the policy and strategy, account should be taken of the following:

(a) The fundamental safety objective and the fundamental safety principles established in the Safety Framework for Nuclear Power Source Applications in Outer Space;

(b) Relevant international legal instruments, such as conventions and other international instruments;

(c) The specification of the scope of the governmental and legal framework for authorization;

(d) The specification of the process and procedures to be used to determine whether to authorize the launch of missions using space NPS applications and who makes the final decision on authorization;

(e) The time frame for reaching decisions on the authorization of missions using space NPS applications;

(f) The scope of the information required in order for an authorization decision to be made, and who is responsible for providing it;

(g) The provision and framework for obtaining additional information or carrying out additional research to underpin an authorization decision;

(h) Adequate mechanisms for taking account of the authorization processes covering non-nuclear and terrestrial aspects of launch safety;

(i) Adequate mechanisms for taking account of social and economic developments.

Recommendation 13: Establishment of a framework for authorization

Any Government that authorizes the launch of space nuclear power source missions should establish and maintain an appropriate governmental, legal and assurance framework for mission launch authorization within which responsibilities are clearly allocated.

The Government should promulgate laws and statutes to make provision for an effective governmental, legal and assurance framework for mission launch authorization of space NPS applications. This framework should set out the following:

(a) The safety principles for protecting people (individually and collectively) and the environment in the Earth's biosphere from the risks associated with the launch of an NPS application on a space mission;

(b) The type of authorization that is required for the launch of space missions with NPS applications, in accordance with a graded approach;

(c) The rationale for the authorization of space missions incorporating NPS applications, as well as the applicable decision-making process;

(d) Provision for appropriate interfaces with the authorization processes covering non-nuclear and terrestrial aspects of launch safety;

(e) Provision for the involvement of interested parties and for their input to decision-making;

(f) Provision for assigning legal responsibility to the organization responsible for any space NPS mission to provide sufficient information to allow the authorization decision to be made;

(g) The establishment of an appropriate safety assurance mechanism to provide an independent evaluation of the adequacy and validity of the safety case presented by the organization conducting the mission.

Where several authorities are involved in the governmental, legal and assurance framework for authorization, the Government should specify clearly the responsibilities and functions of each such authority.

Recommendation 14: Establishment of a policy and strategy for emergency preparedness and response

Any Government that authorizes or approves space nuclear power source missions should establish a national policy and strategy for emergency preparedness and response.

The policy and strategy for emergency preparedness and response should express a long-term commitment to ensuring the safety of people and protecting the environment. The policy should be promulgated as a statement of the Government's intent. The strategy should set out the mechanisms for implementing the policy. In the policy and strategy, account should be taken of the following:

(a) The fundamental safety objective and the fundamental safety principles established in the Safety Framework for Nuclear Power Source Applications in Outer Space;

(b) Relevant international legal instruments, such as conventions and other international instruments;

(c) The specification of the scope of the governmental, legal and assurance framework for emergency preparedness and response;

(d) The assignment of responsibilities, within the overall framework, for preparing emergency response plans and for making arrangements for emergency preparedness and response;

(e) The need for and provision of human and financial resources;

(f) The provision of and framework for research and development;

(g) Adequate mechanisms for taking account of social and economic developments.

Recommendation 15: Establishment of a framework for emergency preparedness and response

Any Government that authorizes or approves space nuclear power source missions should establish and maintain an appropriate governmental, legal and assurance framework for emergency preparedness and response within which responsibilities are clearly allocated.

The Government should make provision for an effective governmental, legal and assurance framework for emergency preparedness and response. This framework should set out the following:

(a) The safety principles for protecting people (individually and collectively) and the environment in the Earth's biosphere from the risks associated with potential accidents resulting from space missions incorporating NPS applications;

(b) The system, including emergency response arrangements, for protecting people (individually and collectively) and the environment in the Earth's biosphere from a nuclear or radiological emergency declared as a consequence of an accident involving a space NPS application within or outside the territory and jurisdiction of the State;

(c) The types of facilities and activities that are to be included within the scope of the framework for emergency preparedness and response;

(d) Provision for assigning legal responsibility to the organization responsible for the space NPS mission for preparing an emergency response plan and for making arrangements for emergency preparedness and response;

(e) Provision for assigning legal responsibility to the organization responsible for the space NPS mission for the immediate notification of the competent authorities in the event of an emergency;

(f) Designation of competent authorities that will have the responsibility and resources necessary to make preparations and arrangements for dealing with the consequences of an emergency involving a space NPS application, both during the emergency and in its aftermath;

(g) Provision for specifying and assigning clear responsibilities for decision-making in an emergency, and for ensuring effective liaison between all authorized parties and the competent authorities;

(h) Provision for an effective means of communication with affected parties, particularly the general public, during the course of an emergency involving a space NPS application;

(i) Provision for the review, assessment and inspection, through the established assurance mechanisms, of the emergency response plans of organizations responsible for space NPS missions and of their state of preparedness for such emergencies;

(j) Provision for acquiring and maintaining the necessary competence nationally for ensuring an appropriate, continuing level of emergency preparedness and response.

Part 2: Guidance for management

Recommendation 16: Establishment and maintenance of the necessary management structure, policies and competences

Any organization involved in space nuclear power source applications should establish and maintain the management structures, policies and competences necessary to implement the Government's policy and strategy for the safe use of such applications in outer space.

It is the responsibility of the management of any organization involved in a space NPS mission to ensure that the organization has the necessary policies, structure and competences to implement fully the relevant government policy and strategy. This entails having a complete understanding of the government policy and strategy, especially the legal requirements related to justification and authorization of the use of nuclear power sources and the framework for emergency preparedness and response, and having the resources, systems and staff to fulfil the organization's legal responsibilities.

Recommendation 17: Establishment and maintenance of effective leadership and management for safety

Any organization involved in space nuclear power source applications should establish and maintain effective leadership and management for safety.

The senior management of any organization involved in a space NPS mission should establish and maintain effective leadership and management for safety throughout the organization. This involves developing individual values, institutional values and behavioural expectations for the organization to support the implementation of the management system. Within the management system, safety should be paramount, overriding all other demands. The senior management should develop, implement and maintain a 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 continual improvement
- Individual and collective commitment to safety at all levels in the organization
- Safety accountability of the organization and of individuals at all levels
- A questioning and learning attitude to discourage complacency with regard to safety.

Recommendation 18: Identification of the organization that has prime responsibility for safety

The organization that conducts the space nuclear power source mission has the prime responsibility for safety.

The management of the organization that conducts any space NPS mission should recognize its prime responsibility for safety. For multilateral space NPS missions, it will be necessary for the management of each of the various participating organizations to agree which one will assume prime responsibility for safety.

Recommendation 19: Making formal arrangements for satisfying the safety requirements for any space nuclear power source mission

Organizations involved in any space nuclear power source mission should make formal arrangements for satisfying the safety requirements established for that mission.

The guidance provided by the Safety Framework implies that nuclear safety considerations need to be taken into account in the governing instruments for space NPS applications. This means that NPS safety requirements should be incorporated into such instruments at the earliest possible stage of a mission's development. This is particularly relevant for multilateral missions, such as those organized by international intergovernmental organizations. The formal arrangements should identify the organization which has the prime responsibility for safety while also recognizing that all participants in the mission have some level of responsibility for nuclear safety. All participants in a mission incorporating space nuclear power sources should work according to the nuclear safety standards established for that mission.

Recommendation 20: Establishment and maintenance of necessary technical competences

Organizations involved in any space nuclear power source mission should establish and maintain the technical competences necessary for carrying out the mission safely.

In any organization involved in a space NPS mission, the senior management should determine the technical competence requirements for individuals at all levels in the organization and should provide training or take other action to achieve the required level of competence. An evaluation should be conducted of the effectiveness of the actions taken. Suitable proficiency should be achieved and maintained.

Recommendation 21: Establishment of procedures to promote safety under all reasonably foreseeable circumstances

Organizations involved in any space nuclear power source mission should establish and maintain procedures to promote safety under all reasonably foreseeable circumstances.

In any organization involved in a space NPS mission, the senior management should establish procedures to promote safety under all reasonably foreseeable circumstances. Relevant individuals at all levels in the organization should receive appropriate training on the relevance and importance of these procedures and understand how they contribute to safety in achieving the space NPS mission.

Recommendation 22: Development of specific safety requirements for missions that use space nuclear power sources

Organizations involved in any space nuclear power source mission should develop and maintain appropriate specific safety requirements for that mission.

In any organization involved in a space NPS mission, the senior management should develop specific safety requirements for the organization's safety responsibilities, recognizing the unique safety aspects of space nuclear power sources, and ensure that these requirements are harmonized with those of other participating organizations and reflect the overall safety requirements for the mission. Senior management should ensure that regular reviews are carried out of the level of compliance with the organization's safety requirements and take action to address any deviations therefrom.

Recommendation 23: Generation of the technical information required to support a decision to use a nuclear power source on any specific space mission

Organizations involved in any space nuclear power source mission should generate the technical information needed to support a decision to use a nuclear power source on the mission in question.

The organization that has prime responsibility for safety should make appropriate arrangements, with its partner organizations involved in the space NPS mission, to generate the technical information required to support a decision to use an NPS on the mission, and inform interested parties about this intended use. Appropriate arrangements should be made to consider credible opposing views about the safety implications of such use. The senior management should ensure that the consideration of credible opposing views is thorough and exhaustive, properly documented and made available to those who submitted the views.

Recommendation 24: Performance and documentation of safety tests and analyses as input to the governmental mission launch authorization process

Organizations involved in any space nuclear power source mission should perform and document appropriate safety tests and analyses to provide input into the launch approval process.

The organization that has prime responsibility for safety should make appropriate arrangements, with its partner organizations involved in the space NPS mission, to perform and document appropriate tests and analyses to establish the reliability of the space NPS application and to provide input to the governmental mission launch approval process. The specific competences, expertise, resources and time needed to carry out and document such tests and analyses need to be included in the overall planning for the mission.

Recommendation 25: Provision of relevant, accurate and timely information to the public

Organizations involved in any space nuclear power source mission should provide relevant, accurate and timely information to the public.

The organization that has prime responsibility for safety should make appropriate arrangements, with its partner organizations involved in the space NPS mission, to provide relevant, accurate and timely information to the public about any space NPS mission. The specific resources and time needed to carry this out should be included in the overall planning for the mission.

Part 3: Technical guidance

Recommendation 26: Establishment and maintenance of the technical competence for defining scenarios for accidents that involve nuclear power source applications and their estimated probabilities

Organizations involved in any space nuclear power source mission should establish and maintain the technical competence for defining scenarios for accidents that involve nuclear power source applications and their estimated probabilities.

The identification of accident scenarios in the early phases of a mission can influence the design of the NPS and help inform design trade-offs involving the spacecraft and/or launch system. In the later phases of the mission's development, refined accident scenario descriptions and sequences are used to estimate the residual probabilities of accidents which could lead to a potential release of NPS radioactive material.

Recommendation 27: Establishment and maintenance of the technical competence for characterizing the physical conditions to which the space nuclear power source and its components could be exposed in both normal operation and potential accidents

Organizations involved in any space nuclear power source mission should establish and maintain the technical competence for characterizing the physical conditions to which the nuclear power source and its components could be exposed in both normal operation and potential accidents.

This implies that the organizations need the detailed engineering competence to model and simulate the physical conditions anticipated in normal operation plus the competence to carry out sophisticated modelling of the propagation of effects from initiating accidents, such as extreme temperatures and pressures, chemical reactions and impacts.

Recommendation 28: Establishment and maintenance of the technical competence for assessing the consequences to people and the environment from potential accidents with space nuclear power source applications

Organizations involved in any space nuclear power source mission should establish and maintain the technical competence for assessing the consequences to people and the environment from potential accidents with space nuclear power source applications.

This implies that the organizations need the detailed scientific and engineering competence to translate the conditions that might arise in potential accidents (such as extreme temperatures and pressures, chemical reactions and impacts) into the expected

responses of the NPS in terms of radioactive release probabilities and the potential amount, form and location of a release.

Recommendation 29: Establishment and maintenance of the technical competence for identifying and assessing inherent and engineered safety features to reduce the risk of potential accidents to people and the environment

Organizations involved in any space nuclear power source mission should establish and maintain the technical competence for identifying and assessing inherent and engineered safety features to reduce the risk of potential accidents to people and the environment.

Maintaining this competence includes maintaining functioning, iterative information exchange processes between the different entities responsible for the design of the NPS, the spacecraft, the launch system, the overall mission and the flight rules.

Recommendation 30: Establishment and maintenance of a design and development process for space nuclear power source applications

Organizations involved in any space nuclear power source mission should establish and maintain a design and development process that provides the highest level of safety that can reasonably be achieved.

This implies that the organizations should commit to meeting the fundamental safety objective of the Safety Framework by implementing a design and development process for space NPS applications that provides the highest level of safety that can reasonably be achieved. To do this, the design and development process needs to integrate NPS safety considerations fully into the overall safety of all phases of the mission.

Recommendation 31: Provision for incorporating lessons learned from previous experience into the design and development process for space nuclear power source applications

Organizations involved in any space nuclear power source mission should establish a process for identifying, evaluating and implementing relevant lessons learned from previous experience.

While the requirement to incorporate lessons learned from previous experience is a standard element of all space missions, there are some aspects of space NPS missions, such as their relative infrequency and the heightened public perception associated with them, which add an extra imperative to this requirement. The relevance of lessons learned from previous experience and their impact on the selected design of the NPS application should be covered in the documents prepared for justification and launch authorization decisions.

Recommendation 32: Provisions in the design and development process for verifying and validating design safety features and controls through tests and analyses, as appropriate

Organizations involved in any space nuclear power source mission should ensure that the design and development process has the capability to verify and validate design safety features and controls through appropriate tests and analyses.

Based on the experience of the United States, the following tests are likely to be needed to calibrate NPS response models: explosive overpressure tests; fragment projectile tests; drop tests; impact tests; large fragment and flyer plate tests; and solid propellant fire characterization tests. In addition, because the range of possible accident conditions is much larger than those which can be tested, a substantial part of

the analysis has to rely on computer simulations. The validation of these mathematical models and codes is an integral part of the design and development process for space NPS applications.

Recommendation 33: Provision in the design and development process for using risk analysis to assess the effectiveness of design features and controls, and to provide feedback to the design process

Organizations involved in any space nuclear power source mission should ensure that the design and development process uses risk analysis to assess the effectiveness of design features and controls, and to provide feedback to the design process.

The results of physical tests and computer simulations, as well as relevant operational experience, should be used to evaluate the response characteristics and reliabilities of NPS design features and controls in both normal operation and under potential accident conditions. When fed into a suitable risk analysis code, these help to provide detailed information about the effectiveness of the NPS design features and controls. This information is then fed back into the design and development process to seek to improve the design of the NPS application. Multiple technical iterations are normally required during all design and development phases of the space NPS mission in order to identify the optimum design solution.

Recommendation 34: Provision for conducting risk assessments to characterize the radiation risks to people and the environment from space nuclear power source applications, and to demonstrate the acceptability of those risks

Organizations involved in any space nuclear power source mission should ensure that appropriate risk assessments are conducted to characterize the radiation risks to people and the environment from space nuclear power source applications, and to demonstrate the acceptability of those risks.

The final product of such risk assessments should contain calculated "best estimates" of the probability of each accident scenario, the probability of a release in the event of such an accident, the possible consequences in terms of potential individual and population radiation doses and land contamination, calculations of overall risk (i.e. probability multiplied by consequences), and uncertainty distributions around the various estimates. The calculated risks should be shown to be acceptable[10] or design improvements should be carried out to make them acceptable. The results of the risk assessments and the extent to which acceptability has been demonstrated should be included in the documentation provided in support of the mission launch authorization request.

Recommendation 35: Provision for ensuring that all practical efforts are made to mitigate the consequences of potential accidents arising from the use of space nuclear power source applications

Organizations involved in any space nuclear power source mission should ensure that all practical efforts are made to mitigate the consequences of potential accidents arising from the use of space nuclear power source applications.

[10] In accordance with recommendation 2, it is the Government's responsibility to provide a legal and assurance framework which, inter alia, sets out the safety principles for protecting people (individually and collectively) and the environment in the Earth's biosphere from the risks associated with the use of nuclear power sources in outer space and establishes an appropriate assurance mechanism to provide an independent oversight of the safety achievement of the persons or organizations responsible for safety. For each specific space NPS application, the safety principles should be used to determine the acceptable level of risk, taking all relevant factors into account.

The fundamental principle of "defence in depth" should be applied in the design of the space NPS application. The redundancy principle that would ensure that "no single technical, human or organizational failure could lead to harmful effects" (IAEA Fundamental Safety Principles) may not be always achievable for space NPS applications. In such cases, the mission planners should demonstrate that effective alternative arrangements have been made in the design to achieve the overall ALARA requirement, i.e. that the risk from potential accidents will be kept as low as reasonably achievable.

Recommendation 36: Provision for developing and implementing contingency plans to deal with any space nuclear power source accident sequences that could lead to radiation hazards

Organizations involved in any space nuclear power source mission should ensure that contingency plans are developed and implemented to deal with any space nuclear power source accident sequences that could lead to radiation hazards.

The development of these radiological contingency plans should be based on the data and safety analyses submitted in the documentation for the launch approval process of the space NPS application. The radiological contingency plans should be coordinated among all the entities that would need to be involved in the event of an accident. The capability of the relevant entities to implement the contingency plans efficiently and effectively should be demonstrated prior to the launch of the space NPS application.

Recommendation 37: Provision for establishing and maintaining the capability to determine the size, nature and consequences of any release of radioactive material from a space nuclear power source accident

Organizations involved in any space nuclear power source mission should ensure that the capability is established and maintained to determine whether a release of radioactive material has occurred from an accident involving a space nuclear power source, to characterize its location and nature and to determine the areas likely to be contaminated.

The necessary technical competence, instrumentation, telemetry, flight details and predicted state of the NPS should be available in order to allow such a characterization to be made in a reliable and timely manner.

Recommendation 38: Provision for establishing and maintaining the capability to recommend protective measures

Organizations involved in any space nuclear power source mission should ensure that they establish and maintain the capability to recommend protective measures to limit exposure of population groups in the areas affected by an accident involving a space nuclear power source.

The necessary technical competence, instrumentation and telemetry should be available in order to allow such protective measures to be determined and communicated in a reliable and timely manner.

Recommendation 39: Provision for establishing and maintaining the capability to prepare relevant information regarding any accident involving a space nuclear power source

Organizations involved in any space nuclear power source mission should ensure that they establish and maintain the capability to prepare relevant information regarding any accident involving the space nuclear power source for

dissemination to the appropriate Governments, international organizations and non-governmental entities, and to the general public.

The necessary competences, in the technical and communications fields should be available in order to allow such information to be prepared and communicated in a reliable and timely manner.