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**Use of nuclear power sources in outer space**

## **Possible General Safety Recommendations to implement the Safety Framework for Nuclear Power Source Applications in Outer Space**

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### **Introduction**

In an earlier paper (A/AC.105/C.1/L.342) [ref 1] a trial set of Safety Recommendations to implement the Guidance for Governments section of the Safety Framework for Nuclear Power Source Applications (A/AC.105/934) [ref 2] — the *Safety Framework* — was presented. In this paper, the trial set has been updated and amended to incorporate Recommendations in relation to the other two sections of the *Safety Framework*, namely:

- The management responsibilities of organizations involved in space NPS applications; and
- Technical guidance for organizations involved in space NPS applications.

This paper has been drafted to promote discussion within the United Kingdom and with other partners in the European Space Agency (ESA) about the best way to provide a more detailed interpretation of the *Safety Framework* for policy makers, mission designers, managers, scientists and engineers. It should be emphasised that this trial set of *Safety Recommendations* is intended for the United Kingdom situation (as a member of ESA) and is at a very preliminary stage of development. It

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is presented to the Working Group at this early stage for information and to seek comments on the approach being adopted and the level and comprehensiveness of the Recommendations proposed.

## **Development of this Trial Set of General 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. Any detailed *Safety Recommendations* should be governed by this safety objective and the three "Guidance" sections of the *Safety Framework*. In the Appendix to this paper, draft *Safety Recommendations* are proposed for all three of these "Guidance" sections.

As in the earlier work, close attention has been paid in developing these *Safety Recommendations* to information provided by the two member States (the United States of America and the Russian Federation) with decades of experience in using space NPS applications. A recent paper in *Acta Astronautica* (The International Safety Framework for nuclear power source applications in outer space — Useful and substantial guidance by Summerer, Wilcox, Bechtel and Harbison) [ref 3] has provided much useful information from which to deduce general recommendations in relation to the management and technical issues associated with the safe use of NPS applications.

In deriving these updated *Safety Recommendations* the IAEA's Safety Requirements have been used as a template, particularly General Safety Requirements Part 1 (GSR Part 1) [ref 4]. However, the recommendations related to management and technical issues have not yet been developed to the level of those for Governmental activities.

Another consideration in developing these *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 [ref 5] — the *Principles*. A brief comparison of the *Principles* with the *Safety Framework* has been carried out and 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), 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) — that should be mentioned specifically in the *Guidance for Governments* section of the trial *Safety Recommendations*. (See Recommendation 1 b). The Working Group's considered view on the relationship between the *Principles* and the *Safety Framework* would be welcomed as an important input into the further development of these *Safety Recommendations*. This issue has already been raised by the delegation of France in a non-paper in 2013.

Finally, it is clear that, while it is vital to ensure that the trial *Safety Recommendations* are as complete and comprehensive as possible, there needs to be appropriate recognition of the limited involvement of some member States, such as the United Kingdom, in the actual launch of space NPS missions. Consequently,

Recommendation 1 has been modified to indicate that any Government's policy for NPS safety should be "suitable and sufficient" for the intended NPS programme of the country in question. This is especially important when the member State is a member of an international intergovernmental organization such as ESA where it is vital to avoid unnecessary duplication of roles and responsibilities.

## Conclusions

The trial set of *Safety Recommendations* developed to implement the *Guidance for Governments* section of the *Safety Framework* has been extended to include the other two sections of the *Safety Framework*, namely, *Guidance for Management* and *Technical Guidance*. It is intended specifically for the United Kingdom (as a member of ESA) and is at a very preliminary stage of development. The comments of the members of the NPS Working Group on this document would be very welcome.

## References

1. A trial set of Safety Recommendations to implement the Guidance for Governments section of the Safety Framework. A/AC.105/C.1/L.342.
2. Safety Framework for Nuclear Power Source Applications in Outer Space. Jointly published by the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space and the International Atomic Energy Agency, 2009, A/AC.105/934.
3. The International Safety Framework for nuclear power source applications in outer space — Useful and substantial guidance, L. Summerer, R. E. Wilcox, R. Bechtel, S. Harbison. *Acta Astronautica* 111 (2015) 89-101.
4. INTERNATIONAL ATOMIC ENERGY AGENCY, Governmental, Legal and Regulatory Framework for Safety, IAEA Safety Standards Series No. GSR Part 1, IAEA, Vienna (2010).
5. Principles Relevant to the Use of Nuclear Power Sources in Outer Space, adopted by the United Nations General Assembly on 12th December 1992. <http://www.unoosa.org/oosa/en/ourwork/spacelaw/principles/nps-principles.html>.

## **Appendix**

### **Possible General Safety Recommendations for Nuclear Power Source Applications in Outer Space (Guidance for governments and management, and technical guidance)**

#### **Background**

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.

Therefore, safety needs to be addressed in the context of the entire space 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 NPS.

This 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.

#### **Objective**

The objective of this 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 (IIO) that does so;
- the management responsibilities of organizations involved in space NPS applications; and
- 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 between 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.

The technical 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.

### Scope

This 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 IIOs;
- (c) Those support services necessary for providing emergency preparedness and response, nuclear security and the State 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 NPS 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, para3), 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 and provision for human and financial resources;

(e) The provision 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 NPS 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 NPS in outer space;

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

(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 where 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 achievement 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 competency for ensuring safety;
- (l) Responsibilities and obligations with respect to the end of life phase of any space mission involving a 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.

Where 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 NPS 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 make arrangements to provide all necessary safety related information, including information from suppliers, and access for inspection to 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 in the use of nuclear power source applications in outer space to the person or organization “authorized” by it for such use.**

The legal framework for the safe use of space NPS applications should be established in such a way that there is always a party responsible for safety and the “authorized party” retains the prime responsibility for safety for the duration of the activity. The “authorized party” should not be able, by itself, to delegate this prime responsibility. Responsibility for safety may be transferred to a different “authorized party” in the chain of responsibility for the overall space NPS application provided that the transfer has been declared in advance and approved under formal arrangements mandated by the government.

**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 provisions for the effective coordination of their safety assurance functions, to avoid any omissions or undue duplication and to avoid conflicting requirements being placed on “authorized parties”.**

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 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 NPS applications**

**Any government that authorizes or approves space missions with NPS applications should ensure that adequate provision is 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: Competency for safety**

**The government should make provision for building and maintaining the competency of all parties having responsibilities in relation to the safe use of NPS 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 competency of an appropriate number of suitably qualified and experienced staff.

The building of competency 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 competency 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 for increasing, maintaining and regularly verifying the technical competency of persons working for authorized parties.

**Recommendation 8: International obligations and arrangements for international cooperation**

**The government should fulfil its respective international obligations, participate in the relevant international arrangements and promote international cooperation to enhance safety in the use of space NPS 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 NPS 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 safety significant events.

**Recommendation 10: Establish a policy and strategy for justifying the use of space NPS applications**

**Any government that authorizes or approves space NPS missions should establish a policy and strategy for justifying the use of space NPS 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 timeframe 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 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 NPS 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 for justification 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 appropriate organizations or persons 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, the government should specify clearly the responsibilities and functions of each authority within the governmental, legal and assurance framework for justification.

**Recommendation 12: Establishment of a policy and strategy for authorization**

**Any government that authorizes the launch of space NPS 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 timeframe 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 operations for space NPS 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 nuclear power source 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 appropriate organizations or persons 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 management organization conducting the mission as the basis for its authorization request.

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

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

**Any government that authorizes or approves space NPS missions should establish a national policy and strategy for emergency preparedness and response 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 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 and provision for human and financial resources;
- (f) The provision 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**

**The government 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 promulgate such legal instruments as are necessary to 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 territories 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 persons or organizations 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 persons or organizations responsible for the space NPS mission for the immediate notification of an emergency to the competent authorities;

(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: Identification of the organization that has prime responsibility for safety in the use of any NPS application in outer space**

The managements of the various organizations involved in any mission incorporating space NPS applications should agree on which organization will assume prime responsibility for safety. Formal relations should be established early in any space project's formulation phase between all the participants in the mission in order to ensure that the fundamental safety objective of the Safety Framework is achieved.

**Recommendation 17: Making formal arrangements between all relevant participants in a space NPS mission 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 stage of a mission's development. This is particularly relevant for multilateral missions, such as those organized by IIOs. 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 NPS should work to the nuclear safety standards established for that mission.

**Recommendation 18: Establishing and maintaining the necessary technical competences**

In any organization considering or initiating involvement 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 actions 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 19: Establishing procedures to promote safety under all reasonably foreseeable circumstances**

In any organization considering or initiating involvement 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 20: Developing specific safety requirements, as appropriate, for missions that use space NPS**

In any organization considering or initiating involvement 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 NPS, 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.

**Recommendation 21: Performing and documenting safety tests and analyses as input to the governmental mission launch authorization process**

In any organization considering or initiating involvement in a space NPS mission the senior management should ensure that appropriate safety tests and analyses are

performed and documented in order 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 22: Generating the technical information required to support a decision to use an NPS on any specific space mission**

The senior management of the organization that has prime responsibility for safety should make appropriate arrangements to generate the technical information required to support a decision to use an NPS on any specific space mission and inform interested parties about this intended use. The management should make appropriate arrangements to consider credible opposing views about the safety implications of such use. If any or all of this responsibility is to be delegated to another organization involved in the proposed space NPS mission, the delegation should be subject to formal agreement and approval. The senior management of the relevant organization 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 23: Providing relevant, accurate and timely information to the public**

The senior management of the organization that has prime responsibility for safety should make appropriate arrangements for providing relevant, accurate and timely information to the public about any space NPS mission. If any or all of this responsibility is to be delegated to another organization involved in the proposed space NPS mission, the delegation should be subject to formal agreement and approval.

**Recommendation 24: Establishing and maintaining effective leadership and management for safety in the organizations involved in the space NPS mission**

In any organization considering or initiating involvement in a space NPS mission the senior management 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.

**Recommendation 25: Developing, implementing and maintaining a safety culture that ensures safety and satisfies the requirements of the governmental mission launch authorization process**

In any organization considering or initiating involvement in a space NPS mission the senior 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 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.

### **Part 3: Technical Guidance**

#### **Recommendation 26: Technical competence should be established and maintained for defining space NPS application accident scenarios and their estimated probabilities**

In any organization considering or initiating involvement in a space NPS mission the technical competence should be established and maintained for defining the space NPS application accident scenarios 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: Technical competence should be established and maintained for characterizing the physical conditions to which the space NPS and its components could be exposed in both normal operation and potential accidents**

In any organization considering or initiating involvement in a space NPS mission the technical competence should be established and maintained for characterizing the physical conditions to which the space NPS and its components could be exposed in both normal operation and potential accidents. This implies detailed engineering competence to model and emulate 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: Technical competence should be established and maintained for assessing the consequences to people and the environment from potential accidents with space NPS applications**

In any organization considering or initiating involvement in a space NPS mission the technical competence should be established and maintained for assessing the consequences to people and the environment from potential accidents with space NPS applications. This includes the competence to translate the conditions that might arise in potential accidents (such as extreme temperatures and pressures, chemical reactions and impacts) into responses of the NPS in terms of radioactive release probabilities and the potential amount, form and location of a release.

**Recommendation 29: Technical competence should be established and maintained for identifying and assessing inherent and engineered safety features to reduce the risk of potential accidents to people and the environment**

In any organization considering or initiating involvement in a space NPS mission the technical competence should be established and maintained 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: The design and development process for space NPS applications should provide the highest level of safety that can reasonably be achieved**

Any organization considering or initiating involvement in a space NPS mission should commit to meeting the fundamental safety objective of the Safety Framework through 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 fully NPS safety considerations into the overall safety of all phases of the mission.

**Recommendation 31: The design and development process for space NPS applications should identify, evaluate and implement design features, controls and preventive measures to reduce both the probability of potential accidents that could release radioactive material and the magnitude and consequences of such potential releases**

Any organization considering or initiating involvement in a space NPS mission should establish a design and development process which identifies, evaluates and implements design features, controls and preventative measures to reduce both the probability of potential accidents that could release radioactive material and the magnitude and consequences of such potential releases. This implies establishing and exercising a risk analysis capability early enough in the mission design process to allow alternative designs to be compared and design safety features developed for the selected design. 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 32: The design and development process for space NPS applications should incorporate lessons learned from previous experience**

Any organization considering or initiating involvement in a space NPS 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 33: The design and development process for space NPS applications should verify and validate design safety features and controls through tests and analyses, as appropriate**

Any organization considering or initiating involvement in a space NPS mission should ensure that its design and development process has the capability to verify and validate design safety features and controls through appropriate tests and analyses. Based on US experience, 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 characterisation tests. In addition, because the range of possible accident conditions is much larger than those that 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 34: The design and development process for space NPS applications should use risk analysis to assess the effectiveness of design features and controls, and to provide feedback to the design process**

Any organization considering or initiating involvement in a space NPS mission should ensure that its 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. These are fed into a suitable risk analysis code which provides 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.

**Recommendation 35: Risk assessments should be conducted to characterize the radiation risks to people and the environment from space NPS applications and to facilitate comparison against targets of acceptability**

Any organization considering or initiating involvement in a space NPS mission should ensure that appropriate risk assessments are conducted to characterize the radiation risks to people and the environment from the space NPS application and to facilitate comparison against relevant targets of acceptability. The final product of such risk assessments should contain calculated “best estimates” of the probability of each accident scenario, the probability of a release given such an accident, the possible consequences in terms of potential individual and population radiation doses and land contamination, overall risk (i.e. probability multiplied by consequences) calculations, and uncertainty distributions around the various estimates. The calculated risks should be compared against the relevant targets of

acceptability<sup>2</sup> and design improvements carried out if the targets are not met. The results of the risk assessments and their comparison against the relevant targets of acceptability should be included in the documentation provided in support of the mission launch authorization request.

**Recommendation 36: All practical efforts should be made to mitigate the consequences of potential accidents arising from the use of space NPS applications**

Any organization considering or initiating involvement in a space NPS mission should ensure that all practical efforts are made to mitigate the consequences of potential accidents arising from the use of space NPS applications. 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 in practice. In such cases the mission planners should demonstrate that effective alternative arrangements have been made in the design of the space NPS application to achieve the overall ALARA requirement, i.e. that the risk from potential accidents will be kept as low as reasonably achievable.

**Recommendation 37: Contingency plans should be developed and implemented to deal with any space NPS accident sequences that could lead to radiation hazards**

Any organization considering or initiating involvement in a space NPS mission should ensure that it is appropriately involved in the development and implementation of contingency plans to deal with any space NPS 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 38: The capability should be established and maintained to determine whether a release of radioactive material has occurred from a space NPS accident, to characterise its nature and location, and to determine the areas likely to be contaminated by the radioactive materials released**

Any organization considering or initiating involvement in a space NPS mission should ensure that it establishes and maintains the capability to:

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<sup>2</sup> 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 NPS 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. The targets of acceptability for each specific space NPS application should be derived from the safety principles promulgated by the government.

- determine whether a release of radioactive material has occurred from a space NPS accident;
- characterize the location and nature of the release of radioactive material from such a space NPS accident;
- characterize the areas contaminated by radioactive materials released during such a space NPS accident.

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 39: The capability should be established and maintained to recommend protective measures to limit exposure of population groups in the areas affected by a space NPS accident**

Any organization considering or initiating involvement in a space NPS mission should ensure that it establishes and maintains the capability to recommend protective measures to limit exposure of population groups in the areas affected by a space NPS accident. 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 40: The capability should be established and maintained to prepare relevant information regarding any space NPS accident for dissemination to the appropriate governments, international organizations, non-governmental entities and to the general public**

Any organization considering or initiating involvement in a space NPS mission should ensure that it establishes and maintains the capability to prepare relevant information regarding any space NPS accident for dissemination to the appropriate governments, international organizations, 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.

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