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Use of nuclear power sources in outer space

Defining the Organizational Structure that Implements a Space Nuclear Power Source Mission Application[1]

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Abstract

Recent work by the Scientific and Technical Subcommittee (STSC) of the United Nations Committee on Peaceful Uses of Outer Space in conjunction with the International Atomic Energy Agency (IAEA) has provided a foundational model safety framework that provides governmental, management and technical guidance for establishing national and international intergovernmental safety frameworks. This guidance, while top-level, provides both "common ground" for facilitating the development of the organizational structure of a multilateral mission but also for providing a benchmark against which the effectiveness of proposed mission-specific organizational structures and processes can be measured.

Introduction

In addition to the United States of America and another member State with decades of experience with space NPS applications, at least two UNCOPUOS member States and an international intergovernmental organization have embarked on developing space nuclear power sources (NPS) and/or space NPS applications. In the process, all have indicated their plan to implement the Safety Framework for Nuclear Power

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* A/AC.105/C.1/L.332.

[1] This paper is also available in all official languages of the United Nations, and formally edited, in document A/AC.105/C.1/L.334.

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Source Applications in Outer Space[3] (hereafter referred to as the "Safety Framework" or "Framework") jointly developed and agreed to by the International Atomic Energy Agency (IAEA) and the Scientific and Technical Subcommittee (STSC) of the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) in 2009. The United States, which strongly supports the Framework, has already implemented it in its entirety.

The Framework provides three types of guidance for member States and international intergovernmental organizations developing space NPS and/or applications: governmental, management and technical. Governmental guidance focuses on: establishing the policies, requirements and processes for ensuring that "safety" receives a high priority in the development, operation and end-of-service phases of a space NPS development and/or application; justifying the rationale for the development and/or application of a space NPS; authorizing the launch and operation of a space NPS application; and ensuring the development and implementation of emergency preparedness and response plans as part of any space NPS application. Management guidance focuses responsibilities for safety on the organization that conducts a space NPS application and emphasizes that safety should be integrated into the structure and culture of that organization. Technical guidance establishes criteria for adequate competence in nuclear safety, integrating safety into design and development processes, conducting risk assessments, and mitigating the potential effects of accidents.

In recent sessions of the UNCOPOUS/STSC annual meetings, certain elements of the "governmental" and "management" guidelines of the Framework have been identified as presenting challenges. One member State indicated that the launch authorization process represents a challenge since the Framework does not explicitly address the case where the launching State and the State responsible for developing/using the space NPS application differ; or for how emergency response and preparedness actions would be coordinated when a space NPS application overflies a country not involved in the application. An international intergovernmental organization has expressed a similar view concerning the organization(s) responsible for emergency preparedness and response plans. This organization has also indicated that, in a mission involving multiple member States, defining the "organization with the prime responsibility for safety" and allocating responsibilities involving authorizing, approving or conducting the mission represents a challenge.

Defining the "Organization that Conducts the Space NPS Mission": The Key to Implementing the Framework for Multilateral Missions

All multilateral space missions, regardless of whether they involve joint development and operation of the spacecraft systems, subsystems, instruments and/or ground systems, require interface agreements between the participating organizations for effective and safe operation. The point in time in a mission's life cycle at which multilateral participation begins typically determines the extent to which the mission's organizational responsibilities, structure and processes have

[3] "Safety Framework for Nuclear Power Source Applications in Outer Space", Jointly published by the United Nations Committee on the Peaceful Uses of Outer Space Scientific and Technical Subcommittee and the International Atomic Energy Agency, A/AC.105/934, 19 May 2009.

been established. If, for example, multilateral participation commences in the conceptual study phase, all mission participants can actively participate in defining the organizational structures, responsibilities and processes for the mission's development. Alternatively, if multilateral participation occurs late in a mission's development phase, then the new multilateral participant will likely be presented with an already-formalized management structure, engineering processes and communication interfaces.

The implementation of the Safety Framework, while critical to ensuring safe space NPS applications, does not require the replacement of organizational structures or processes that typically exist for multilateral (non-NPS) missions. If NPS safety requirements (e.g. establishment of a nuclear safety culture) exist at a mission's earliest stage of development, then the definition of the organization that conducts the mission will incorporate NPS safety. Even a multilateral mission that considers adding a space NPS application after the mission's development phase has been initiated would face a challenge similar to adding a spacecraft subsystem or instrument that was not part of the original design. In such a case, engineering and configuration management processes would immediately be available for evaluating the impact of the NPS on the existing design and vice versa. New and changed requirements would be defined and, if necessary, the mission's organizational structure, processes, and participants and their respective responsibilities could be modified.

The key point here is that countries and international intergovernmental organizations considering or initiating involvement in space NPS applications should integrate space NPS safety into their existing organizational structures and processes. The existing Safety Framework greatly facilitates this process by identifying the scope of requirements that will need to be encompassed.

At the highest level, the Framework's safety objective of "… protect[ing] people and the environment in Earth's biosphere from potential hazards associated with relevant launch, operation and end-of-service phases of space nuclear power source applications" is the focal point for defining safety policies, requirements and processes. The Framework's technical guidance specifies that the technical basis for a mission's authorization and approval process should be supported by a nuclear safety design, test and analysis capability that applies to the space NPS, spacecraft, launch system, mission design and flight rules. The Framework further specifies that this capability should be applied throughout all mission phases and be focused on rigorously defining both NPS normal operating conditions and potential accident scenarios, understanding the consequences of potential accidents, and identifying and assessing any engineering features that could mitigate risks to people and the environment.

This technical guidance translates into "requirements" and "criteria" that can be incorporated into existing mission organizational and requirements structures and engineering review processes. To the extent that typical (i.e. non-NPS mission) authorization and approval processes lack the expertise or participation of governmental agencies/officials necessary to adequately address the breadth of potential requirements or issues involved in ensuring a mission's nuclear safety, mission managers should identify organizations with the requisite capabilities that also have a responsibility in the "nuclear safety" portion of the launch authorization process. In this way, additional participant organizations (i.e., those not normally associated with mission development and launch), incremental analytical requirements and processes not part of non-NPS missions can be expeditiously

identified and integrated with more typical mission organizational structures, requirements and processes.

Development, Launch and Use of an NPS Application All Involve NPS Safety Responsibilities

The Safety Framework emphasizes that important nuclear safety considerations exist in all elements and phases of a space NPS application:

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

Both the developer of the NPS and the developer of the NPS application have responsibility for optimizing nuclear safety. The NPS developer can engineer inherent design safety features that will both help to keep occupational exposures as low as reasonably achievable during the production and integration of NPS with a spacecraft, and reduce the probability, amount and environmental impact of a potential NPS fuel release. Similarly, the NPS application developer can modify and optimize spacecraft and mission designs and/or integration processes to manage occupational exposures, mitigate or reduce the probability or severity of potential failures that could lead to potential NPS fuel releases, and mitigate or reduce the potential hazards to NPS fuel containment in pre-launch processing, launch or mission accidents. In addition, the NPS application launcher can mitigate or reduce the probability or severity of pre-launch processing or launch accidents that threaten NPS fuel containment by increasing launch vehicle reliability, and by adding safety systems and/or flight rules that reduce the probability or severity of potential NPS fuel releases in launch accidents.

Multilateral Agreements: The Governing Instruments for Allocating NPS Safety Responsibilities

Given the potential range of NPS, spacecraft, mission and launch designs and configurations — many of which are unique — it is not immediately apparent or intuitive to determine with high confidence the primary threats to NPS fuel containment. Invariably, the likelihood of making an error increases when assumptions are made by one element of the mission team about another mission element without first verifying the validity of those assumptions with the other team. As a result, all participants in a mission with an NPS application have some level of responsibility for nuclear safety. This characteristic of space NPS missions should be addressed by incorporating nuclear safety considerations in the governing instruments for multilateral missions. For example, mission participants should explicitly agree to support, as appropriate, the definition and satisfaction of the mission's nuclear safety "requirements" and "criteria" that are incorporated into the mission's organizational and requirements structures and engineering review processes.

The Framework explicitly encompasses this approach by specifying that "[f]or multinational or multi-organizational missions, governing instruments should define

clearly the allocation of … responsibilities" for "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."

- **United States NPS Mission Experiences Involving Multilateral Contributions**

While not as complex as potential multilateral missions under consideration by other member States and international intergovernmental organizations, past and current United States NPS mission applications involving multinational partners have inherently involved multiple government agencies. While the National Aeronautics and Space Administration (NASA) is responsible for the spacecraft and mission, the Department of Energy (DOE) provides the NPS, the Department of Defense (DOD) controls the launch vehicle safety design and launch range, and the Environmental Protection Agency (EPA) would oversee clean-up activities in the event of an accident that releases NPS fuel.

While each of these government agencies is independent of each other, they work closely with each other for the purposes of mission success as a single organization, using formally established requirements and processes. For example, in the design and development phase of the mission, NASA, DOE and DOD all participate in ground operations and mission integration working groups that are formally integrated into the mission's organizational and engineering review/approval structure and processes. Additionally, all four agencies cooperate with each other as part of an ad hoc Interagency Nuclear Safety Review Panel that evaluates the mission's nuclear safety for an incremental added component — i.e., unique to missions involving NPS — of the standard non-NPS launch authorization process.

In all cases to date, the international partners on United States NPS missions have contributed spacecraft subsystems, components, and/or science instruments built to requirements controlled by interface control documents (ICDs). These ICDs were subject to definition, review and approval processes that ensured that the international contributions did not create a credible or significant accident initiation or NPS containment threat under normal or accident conditions. As a result, United States launch authorization processes for missions involving NPS have not needed to directly involve international partners in launch nuclear safety analyses or approval processes. Further, because standard engineering review processes ensure that no credible threat to NPS containment has been presented by the foreign partner's contribution, the United States has been able to effectively indemnify foreign contributors from launch accidents involving space NPS fuel releases.

Building on Non-NPS Mission Infrastructure: The Key to Effective Implementation of Space NPS Safety

The entire 50+ year history of United States space NPS applications demonstrates that an effective nuclear safety framework can be implemented by using and augmenting existing non-NPS organizational structures, requirements and processes.

Space NPS missions in the United States have been conducted only about once to twice a decade. At such a low rate relative to non-NPS missions, it would be

extremely difficult and expensive to build and maintain an effective infrastructure for NPS missions separate from that for non-NPS missions.

As a result, the United States has built its NPS mission infrastructure in specific areas, but primarily as augmented aspects to existing non-NPS mission infrastructure. In the context of the UN/IAEA Safety Framework, for example, the United States does not change the basic organization of a mission's organization because the mission involves an NPS application. The technical capabilities are augmented in specific areas to adequately inform design trades and conduct nuclear safety analysis, building upon existing capabilities.

For example, launch system reliability and failure effects analysis and modelling delves further into the physical environments created by and the sequence of potential threats to NPS containment resulting from a launch accident. The environmental impacts of releases of radioactive material are assessed using the same meteorological databases and, in some cases, highly similar models for understanding the impacts of accidents involving large-scale accidental releases of launch vehicle propellants. NPS contingency plans follow standard protocols for responding to any large accident that would potentially involve multiple levels of government and agencies.[4]

Similarly, mission contingency operations rely on existing non-NPS launch accident contingency response plans, communication systems, and operations protocols, etc. as the starting point for addressing any mission-unique requirement posed by having an NPS mission application. NPS-specific safety reviews and approvals are handled as incremental requirements for standard mission approvals. For example, while the nuclear safety review and approval process culminates with a decision from the Office of the President of the United States, that decision is limited to the mission's nuclear safety. As such, it is simply an additional "gate" that the mission must pass through prior to entering the standard launch safety and approval process at the launch site.

In summary, any multilateral mission involving different contributors for the launch system, the spacecraft and/or the power system — regardless of whether NPS is used — requires agreed-to configuration management, interface control, and engineering review processes for a mission's design, development, assembly, test, launch and operation. These standard processes ensure protection of mission hardware and personnel, and the public, when hazardous materials such as propellants are involved. Mission planners can and should use these existing processes as the starting point for addressing additional requirements arising from the use of NPS.

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[4] "United States preparedness and response activities for space exploration missions involving nuclear power sources", by Reed Wilcox (United States of America), A/AC.105/C.1/L.314, 16 December 2011.