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Use of nuclear power sources in outer space

Workshop on the Use of Nuclear Power Sources in Outer Space: United States preparedness and response activities for space exploration missions involving nuclear power sources

Paper submitted by the United States of America**

Summary

The United States of America conducts extensive preparedness and response activities for all missions involving the application of nuclear power sources. Consistent with the Safety Framework for Nuclear Power Source Applications in Outer Space, jointly published by the Scientific and Technical Subcommittee and the International Atomic Energy Agency in 2009, these plans encompass planning, training, rehearsals, procedures development, including communication protocols, and the drafting of potential accident notifications. Because accidents could occur at the launch site, downrange or out of orbit, the plans involve multiple government agencies at the federal, state and local levels, and a broad range of resources that are either pre-deployed or readily accessible in the event of an accident. The plans support a rapid response to an accident potentially involving the release of radioactive material. They also facilitate the establishment of systems required for quickly identifying those accidents that do not involve a release of radioactive material — an important capability for avoiding the extended imposition of protective action measures.

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I. Introduction

1. The United States of America has been conducting applications of space nuclear power sources for 50 years (see also A/AC.105/C.1/L.313). Since 1961, the United States has launched 30 missions involving space radioisotope power system applications, including the mission of the Mars Science Laboratory of the National Aeronautics and Space Administration (NASA), involving the launch, in November 2011, of the rover Curiosity, destined to explore Gale Crater in the southern hemisphere of Mars. Consistent with the high priority placed on ensuring safety in the design and development of each nuclear power source application (see also A/AC.105/C.1/L.313), the United States develops, maintains and implements comprehensive radiological contingency preparedness and response plans for all its space nuclear power source launches.

2. This paper focuses on outlining the requirements and processes adopted by NASA, in consultation with the United States Department of Energy, for ensuring adequate preparedness for a potential launch or mission accident involving a nuclear power source application. After identifying the elements of the Safety Framework for Nuclear Power Source Applications in Outer Space (A/AC.105/934) pertinent to launch and mission radiological contingency preparedness and response, the paper compares the Safety Framework with the United States framework for satisfying preparedness and response activities for space nuclear power source applications. The paper then outlines the specific requirements that preparedness and response plans must satisfy prior to launch, followed by an overview of the processes used to satisfy these requirements. Finally, the paper concludes by identifying the key lessons learned by NASA in implementing effective preparedness and response plans.

II. Elements of the Safety Framework for Nuclear Power Source Applications in Outer Space relevant to emergency preparedness and response

3. All three categories of guidance of the Safety Framework (guidance for governments, guidance for management and technical guidance) are relevant to the development and implementation of an effective emergency preparedness and response capability for NASA space nuclear power source applications.

A. Relevant guidance for governments

4. The guidance provided in section 3.4 of the Safety Framework (entitled "Emergency preparedness and response") only partially addresses the scope of the government guidance that NASA relies on for assuring effective emergency preparedness and response capabilities. Documented and enforced safety policies, requirements and processes (which are covered in section 3.1 of the Safety Framework) are as relevant for ensuring adequate emergency preparedness and response activities as they are for ensuring that safety receives high priority in nuclear power source design and development activities. Similarly, by including reviews of radiological contingency plans in the mission launch authorization

process (covered in section 3.3 of the Safety Framework), NASA helps ensure compliance with emergency preparedness and response policies, requirements and processes.

B. Relevant guidance for management

5. Consistent with section 4.1 of the Safety Framework (entitled "Responsibility for safety"), NASA has the primary responsibility within the United States Government for implementing effective emergency preparedness and response plans for the agency's nuclear power source launches. Similarly, NASA integrates the responsibility for emergency preparedness and response directly into the organizational structure for the agency's nuclear power source missions. This helps to maintain management visibility in the development of effective radiological contingency plans. It also helps to sustain a consistent culture of safety and of according high priority to developing effective radiological contingency plans throughout the development phase of the mission.

C. Technical guidance

6. Consistent with section 5.4 of the Safety Framework (entitled "Accident consequence mitigation"), NASA coordinates the development and maintenance of a multiagency accident response infrastructure for rapidly responding to an accident. In addition to the assets dedicated to emergency response (radiation monitors, communication systems etc.), NASA relies on detailed risk assessments (in accordance with section 5.3 of the Safety Framework) to guide the development of accident scenario-specific response plans; it also relies on a wide range of technical experts and trained personnel (risk analysts, health physicists, emergency managers, risk communicators etc.), in accordance with section 5.1 of the Safety Framework (entitled "Technical competence in nuclear safety"), to form an effective organization for responding to potential accidents.

III. Comparison of Safety Framework for Nuclear Power Source Applications in Outer Space with the nuclear safety implementation for space nuclear power system applications of the United States of America

7. The United States has implemented federal laws and guidance that relate directly to the Safety Framework guidance (see also A/AC.105/C.1/L.313). In particular, the United States has developed the National Response Framework, which specifically addresses nuclear power source preparedness and emergency response planning. In response to the National Response Framework, NASA has formalized detailed radiological contingency planning requirements specific to space nuclear power source missions.

National Response Framework

8. The National Response Framework (available from www.fema.gov/emergency/nrf) details how the United States responds to all major hazards. The Framework builds upon "scalable, flexible, and adaptable coordinating structures to align key roles and responsibilities across the nation, linking all levels of government, non-governmental organizations, and the private sector. It is intended to capture specific authorities and best practices for managing incidents that range from the serious but purely local to large-scale terrorist attacks or catastrophic natural disasters."

9. Consistent with the Safety Framework, the term "response", as used in the National Response Framework "includes immediate actions to save lives, protect property and the environment, and meet basic human needs. Response also includes the execution of emergency plans and actions to support short-term recovery." The National Response Framework establishes that "effective response to an incident is a shared responsibility of governments at all levels, the private sector and [non-governmental organizations], and individual citizens." The National Response Framework "commits the federal Government, in partnership with local, tribal, and state governments and the private sector, to complete both strategic and operational plans," including ones specific to nuclear power source missions.

10. The National Response Framework contains the Nuclear/Radiological Incident Annex (available from www.fema.gov/emergency/nrf/incidentannexes.htm), which specifically addresses the release of nuclear and radiological materials from space vehicles. The annex "describes the policies, situations, concepts of operations, and responsibilities of the federal departments and agencies governing the immediate response and short-term recovery activities for incidents involving release of radioactive materials to address the consequences of the event." The purpose of the Annex is to:

- "Define the roles and responsibilities of federal agencies in responding to the unique characteristics of different categories of nuclear and radiological incidents
- Discuss the specific authorities, capabilities and assets the federal Government has for responding to nuclear and radiological incidents that are not otherwise described in the National Response Framework
- Discuss the integration of the concept of operations with other elements of the National Response Framework, including the unique organization, notification and activation processes and specialized incident-related actions
- Provide guidelines for notification, coordination and leadership of federal activities."

11. For incidents involving space nuclear power source applications where NASA either leads or has significant involvement in a space mission, NASA is designated as the “coordinating agency” for the federal response. In this capacity, it is responsible for providing leadership both for the response and for the precursor planning and preparedness activities. The following federal agencies are responsible for cooperating with NASA by providing technical assistance and resources:

- Department of Agriculture
- Department of Commerce
- Department of Defense
- Department of Energy
- Department of Health and Human Services
- Department of Homeland Security
- Department of the Interior
- Department of Justice
- Department of Labor
- Department of State
- Department of Transportation
- Department of Veterans Affairs
- Environmental Protection Agency
- Nuclear Regulatory Commission

IV. National Aeronautics and Space Administration preparedness and response requirements for space nuclear power system applications

12. In implementing the National Response Framework for space nuclear power source missions, NASA has developed and formalized requirements for all space nuclear power source application missions. These requirements flow from the responsibility of NASA, under the National Response Framework, to establish contingency plans for all its missions. The basic, top-level requirements include:

- Protecting lives
- Protecting the environment
- Assisting in mitigating hazards and minimizing the effects of natural disasters, technological emergencies and criminal acts, including terrorism
- Supporting local, state and federal agencies and appropriate emergency response authorities
- Providing for continuous operation or timely resumption of mission-critical functions, services and infrastructure

- Aiding in the recovery and timely resumption of normal operations
- Minimizing loss and damage to NASA resources.

13. In addition, NASA has more detailed requirements specific to nuclear power source application missions. In accordance with chapter 6 (Nuclear safety for launching of radioactive materials) of the NASA General Safety Program Requirements (NPR 8715.3C) (available from http://nodis3.gsfc.nasa.gov), the lead organization at NASA headquarters for a nuclear power source space application and the line management for the mission must ensure, among others:

- The development of site-specific ground operations and radiological contingency plans commensurate with the risk represented by the planned launch of nuclear materials
- That contingency planning, as required by the National Response Framework, includes provisions for emergency response and support for source recovery efforts.

14. In accordance with chapter 6 of the NASA General Safety Program Requirements, NASA launch and landing site managers are required to:

- Develop and implement site-specific ground operations and radiological contingency plans to address potential ground handling accidents and potential launch and landing accident scenarios and to support source recovery operations commensurate with the radioactive materials
- Exercise contingency response capabilities as deemed necessary to ensure adequate readiness of participants and adequacy of planning to protect the public, site personnel and facilities
- Ensure appropriate and timely coordination with federal, state, territorial and local emergency management authorities to provide for support to and coordination with off-site emergency response elements
- Make provisions for special off-site monitoring and assistance in recovery of radioactive materials that could spread into areas outside the geographical boundaries of the launch site
- Establish a radiological control centre[1] for launches and landings with radioactive sources possessing a significant health or environmental risk, or having an activity of A_2[2] mission multiple greater than 1,000
- Ensure, when required, that the radiological control centre provides technical support and coordination with other federal, state, territorial and local agencies in the case of a launch or landing accident that may result in the release of radioactive materials

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[1] A radiological control centre is a launch site operations centre established and staffed with the multiagency technical expertise to: determine whether a radioactive material release has occurred; formulate and recommend protective action measures for public officials; and coordinate the activities of emergency centres involved in the accident response.

[2] A_2 is the maximum activity of any radioactive material other than special form radioactive material that can be transported in a Type A package (International Atomic Energy Agency, *IAEA Safety Glossary* (Vienna, 2006). Available from www-ns.iaea.org/standards/safety-glossary.asp?s=11&l=87.

- Ensure, when required, that the radiological control centre is operational during launch and landing phases any time there is a potential for an accident that could release radioactive material
- Ensure, when required, that the radiological control centre is staffed commensurate with the risk associated with the radioactive materials present.

15. In addition, other offices within NASA (such as the Office of Safety and Mission Assurance) are responsible for reviewing the mission's preparedness and response plans to ensure: appropriate coordination with "cooperating agencies" under the National Response Framework; adequate scope of response and recovery efforts; and compliance with the relevant regulatory requirements of other government agencies with respect to the use of radioactive materials in a space launch. Further, any and all of these requirements may be reviewed as part of the launch authorization process.

V. Processes for satisfaction of preparedness and response requirements

16. The United States processes for satisfying preparedness and response requirements for a nuclear power source space application typically begin several years before launch and are coordinated with the risk assessment and launch authorization processes. Early activities focus on forming an inter-agency working group consisting of federal, state and local representatives. The working group reviews lessons learned from previous nuclear power source missions and updates radiological contingency planning requirements for the next mission. After establishing the "concept of operations" for responding to an accident, scenario-specific plans and procedures are developed. As safety analysis results become available, scenario-specific exercises are conducted and as launch approaches, response plans and exercise results are reviewed as part of the launch authorization process.

17. Three years before a planned launch, the mission initiates radiological contingency planning efforts. As the United States has conducted several space nuclear power source missions, the first activity involves reviewing lessons learned, detailed requirements and plans from previous space nuclear power source mission applications for applicability to the planned mission. A multiagency working group involving federal, state and local agencies is established that collaboratively defines a "concept of operations" consistent with the National Response Framework and agency requirements (outlined in sect. IV above).

18. Two years prior to launch, NASA designates the mission-lead radiological contingency planning individual, referred to as the coordinating agency representative. The coordinating agency representative oversees the development of mission-specific radiological contingency planning — both for the launch area and for out-of-orbit accidents — and the preparation of joint agency communication plans. During this period, the working group uses early risk assessment results to develop scenario-specific response plans, initiate the preparation of scenario-specific government, media and public notifications, assess preparedness

resource requirements, develop implementing procedures and plan preparedness exercises, rehearsals and training activities.

19. In the year prior to launch, multiagency review and approval processes focus on finalizing and obtaining signature approval for the radiological contingency planning and for conducting training programmes, pre-deploying and testing radiological contingency planning resources (e.g. radiation detectors) and procedures, implementing multiple rehearsals and exercises, and supporting launch authorization process nuclear safety reviews.

VI. Lessons learned from National Aeronautics and Space Administration space nuclear power source applications

20. Over the last five decades of launching space nuclear power source applications, the United States has gained significant experience in preparing multiagency radiological contingency plans. As part of every mission, NASA requires a post-launch preparation of "lessons learned". These lessons have helped establish a process for continuing enhancements to mission radiological contingency planning. Key lessons learned from previous missions include the following:

(a) Exercises and rehearsals identify gaps. Exercises and rehearsals help establish whether preparedness and response plans and procedures are complete and reasonably achievable within the time frame of a mission incident potentially involving the release of radioactive material. They also are critical to identifying gaps or conflicts in plans and procedures in interfaces between organizations involved in contingency operations and deficiencies in training and/or communication resources. While partial exercises and rehearsals are easier to coordinate and conduct than full-scale accident simulations, the benefits of rehearsing with the entire contingency response team provides the highest level of confidence to government officials with regard to the adequacy of preparedness and response plans;

(b) Radiological contingency planning should be integrated into standard emergency response management structures and contingency plans and existing infrastructure should be utilized. Nuclear power source applications on space missions typically occur only once or twice a decade in the United States. As a result, radiological contingency plans have been built on the foundation of existing non-radiological contingency plans and infrastructure for routine space launches. As well as being consistent with the overall strategy of the National Response Framework, this approach facilitates the development of cost-effective detailed plans and procedures at the launch site, where, to a large extent, response and preparedness communication networks, notification trees and procedures, response and recovery teams, meteorological sensors and models and intergovernmental working interfaces and procedures already exist. While nuclear power source mission applications still require significant augmentation of non-radiological preparedness and response plans, procedures and resources, the United States has avoided substantial uncertainty and organizational resistance to the development of radiological contingency planning by relying on existing preparedness and response systems that are regularly reviewed and practised for routine launches;

(c) The technical, management and public information elements of the emergency response organizations should be located near to each other (physically or virtually). Successful implementation of a radiological contingency plan for a space nuclear power source application relies primarily on effective and efficient communication during the contingency. Unlike most accidents and contingencies faced by national Governments, the precise time and place of potential incidents involving space nuclear power source applications is largely known. Expert teams and response resources can be organized and co-located prior to a potential incident. The United States has found that, by organizing response teams into three major elements (radiological monitoring and assessment, public information collection and dissemination, and response management) and facilitating internal and external communication among those three elements, the flow of accurate information to decision makers and the public is facilitated. Extensive use of information technology (e.g. computer server-based and Internet-accessible applications and data storage, and satellite communications) allows on-site experts to quickly gather, process and share field data; communicate with colleagues at remote sites; and access additional sources of information. Locating public information personnel (media affairs, legislative affairs, public affairs, international affairs etc.) in close physical proximity to the intergovernmental management team responsible for managing a contingency helps minimize the time lag between making and implementing decisions that have the most direct impact on public safety. Similarly, it also facilitates response managers being made aware of information (or misinformation) being circulated by the press that could influence the effectiveness of response plans;

(d) Emergency preparedness reviews for all levels of government should be included as part of the launch authorization process. The United States launch nuclear safety approval process involves a multi-year process of rigorous reviews that encompass every phase and safety aspect of a space nuclear power source application. The federal Government conducts both intra- and inter-agency safety reviews and numerous briefings involving state and local governments. The ultimate decision on the safety of the mission does not, however, rest with NASA; it rests with the President of the United States. Further, the decision on whether a mission's nuclear safety is adequate does not rest strictly on the mission's nuclear risk estimate. The adequacy of radiological contingency plans is an important consideration in determining whether nuclear launch safety approval will be granted. By including emergency preparedness and response plans in the launch authorization process, the United States Government has raised the level of attention to and priority for those plans during the development phase of the mission;

(e) It should be recognized that the emergency preparedness function includes not only determining and implementing the appropriate protective actions in the event of an accident, but also the capability to verify whether a release of radioactive material has occurred. Since most launch accidents, especially those close to the launch site, would involve the activation of destruct systems to ensure that accident debris remains in a controlled area, mission anomalies will typically lead to the purposeful termination of a mission: such termination events can appear spectacular and can easily promote the perception that a significant radioactive material release has occurred. It is just as important for emergency response managers to verify that a release of radioactive material has not occurred in such accidents as it is to determine whether a release has occurred. Protective action

measures (e.g. sheltering in place), while important for minimizing potential public exposures to radioactive releases, can also create health consequences, economic hardships and significant costs for local governments if maintained for extended time periods. For this reason, accident response plans should: place a high priority on determining if, where and to what degree any release of radioactive material has occurred; assess associated protective action measures to a reasonably conservative estimate of potential releases based on a rigorous risk assessment; and rapidly communicate this information to the appropriate governmental authorities and the public.

VII. Conclusion

21. The United States Government requires detailed multiagency emergency preparedness and response plans that cover the credible range of potential launch accidents involving potential releases of radioactive materials. Consistent with federal requirements, NASA builds these plans on the foundation of a national incident framework for responding to national emergencies. NASA preparedness and response plans encompass both small radioactive releases limited to the launch site and to larger releases that could migrate off site to populated areas. Owing to the emphasis on nuclear safety across all mission design and development phases and launch system elements (see A/AC.105/C.1/L.313) (i.e. launch vehicle, spacecraft, mission design, ground system and flight rules), the majority of accidents do not involve releases of radioactive materials. However, this design and development "success" has not diminished the rigour and scope of emergency preparedness and response plans for United States space nuclear power source applications. In addition to extensive multi-year efforts to develop plans, procedures, communication protocols and pre-scripted notifications prior to the launch of a space nuclear power source application, NASA conducts multiple exercises and rehearsals to verify the adequacy of preparedness and response plans. This extensive effort, implemented for each launch of a space nuclear power source application, helps to both ensure public safety and build public trust and support for the safe conduct of future United States space nuclear power source applications.