3 February 2012

English only

Committee on the Peaceful Uses of Outer Space
Scientific and Technical Subcommittee
Forty-ninth session
Vienna, 6-17 February 2012
Item 11 of the provisional agenda*
Use of nuclear power sources in outer space

UNITED STATES PREPAREDNESS AND RESPONSE ACTIVITIES FOR SPACE EXPLORATION MISSIONS INVOLVING NUCLEAR POWER SOURCES[1, 2]

Abstract

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 as jointly published by the United Nations Committee on the Peaceful Uses of Outer Space 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 potential accidents could occur at the launch site, downrange or out-of-orbit, the plans encompass 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 that 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 extended imposition of protective action measures.

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* A/AC.105/C.1/L.310.

[1] This paper is also available without images, edited and in all official languages of the United Nations, in document A/AC.105/C.1/L.314.

 This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

V.12-50399 (E)

Introduction

The United States of America has been conducting applications of space nuclear power source (NPS) for 50 years.[3] Since 1961, the USA has launched thirty missions involving space radioisotope power system (RPS) applications, including the November 2011 National Aeronautics and Space Administration's (NASA's) Mars Science Laboratory mission with the rover "Curiosity" destined to explore Gale Crater in the Martian southern hemisphere. Consistent with the high priority placed on ensuring the safety in the design and development of each NPS application,[4] the U.S. develops, maintains and implements comprehensive radiological contingency preparedness and response plans for all its space NPS launches.

This paper focuses on outlining the requirements and processes adopted by NASA, with Department of Energy consultation, for ensuring adequate preparedness for a potential launch/mission accident involving an NPS application. After identifying the elements of the model United Nations (UN)/International Atomic Energy Agency (IAEA) Safety Framework for Nuclear Power Source Applications in Outer Space[5] (hereafter referred to as "the UN/IAEA Safety Framework") pertinent to launch/mission radiological contingency preparedness and response, the paper compares the UN/IAEA Safety Framework with the U.S. framework for satisfying preparedness and response activities for space NPS 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 with identifying the key 'lessons learned' by NASA in implementing effective preparedness and response plans.

Elements of Model UN/IAEA Safety Framework Relevant to Emergency Preparedness and Response

All three of the major categories of guidance from the United Nations (UN)/International Atomic Energy Agency (IAEA) Safety Framework, encompassing eight of the ten UN/IAEA Safety Framework's guidelines, have relevant application to developing and implementing an effective emergency preparedness and response capability for NASA space NPS applications (see Figure 1).

- Relevant Governmental Guidance

The guidance provided in Section 3.4 "Emergency preparedness and responses" of the Safety Framework only partially addresses the scope of government guidance NASA relies on for assuring effective emergency preparedness and response capabilities. Documented and enforced safety policies, requirement and processes[6]

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[3] Committee on the Peaceful Uses of Outer Space, Scientific and Technical Subcommittee, Workshop on the Use of Nuclear Power Sources in Outer Space: Safety in the design and development of United States nuclear power source applications in outer space, A/AC.105/C.1/L.313, 14 December 2010.

[4] Ibid.

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

[6] Ibid, Section 3.1.

are as relevant for ensuring adequate emergency preparedness and response activities as they are for ensuring that safety receives a high priority in NPS design and development activities. Similarly, by including reviews of radiological contingency plans in the launch authorization process,[7] NASA helps assure compliance with emergency preparedness and response policies, requirements and processes.

- Relevant Management Guidance

Consistent with Section 4.1 of the Safety Framework,[8] NASA has the primary responsibility within the United States government for implementing effective emergency preparedness and response plans for the agency's NPS launches. Similarly, NASA integrates the responsibility for emergency preparedness and response directly into the organizational structure for the agency's NPS missions. This helps maintain management visibility into the development of effective radiological contingency plans. It also helps sustain a consistent 'safety culture' and high priority for developing effective radiological contingency plans throughout the development phase of the mission.

Figure 1
Elements of Model UN/IAEA Framework Relevant to Emergency Preparedness and Response

Governmental Guidance
- 3.1 Safety policies, requirements and processes
- 3.3 Mission launch authorization
- 3.4 Emergency preparedness and response

Management Guidance
- 4.1 Responsibility for safety
- 4.2 Leadership and management for safety

Technical Guidance
- 5.1 Technical competence in nuclear safety
- 5.3 Risk assessments
- 5.4 Accident consequence mitigation

- Technical Guidance

Consistent with Section 5.4 of the Safety Framework, "Accident consequence mitigation",[9] NASA coordinates the development and maintenance of a multi-agency accident response infrastructure for rapidly responding to an accident. Besides the assets dedicated to emergency response (e.g. radiation monitors,

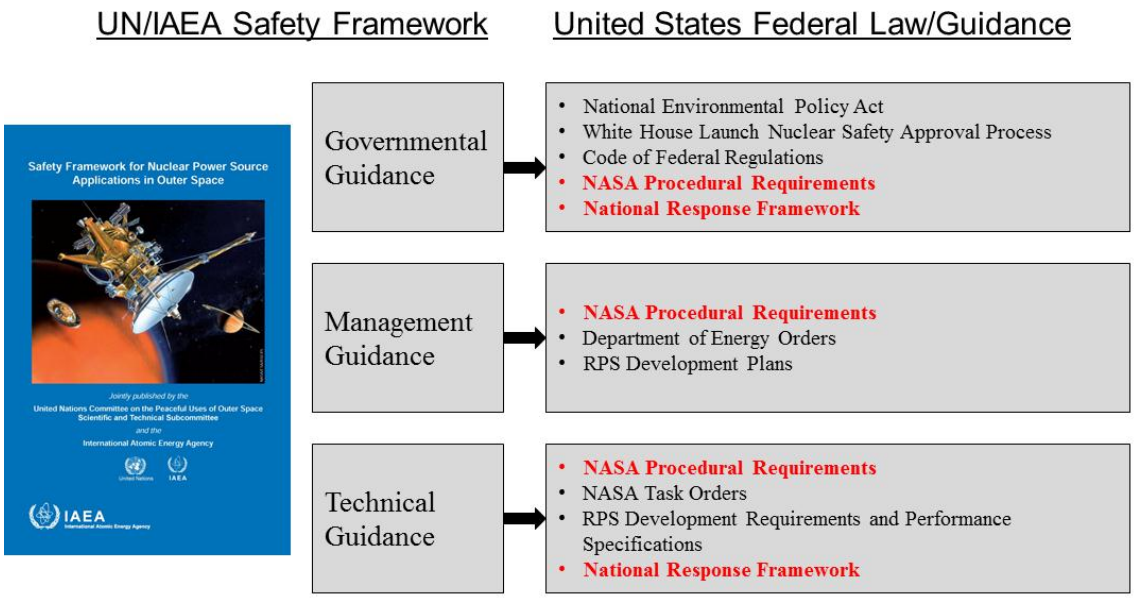
[7] Ibid, Section 3.3.
[8] Ibid, Section 4.1.
[9] Ibid, Section 5.4.

communication systems, etc.), NASA relies on: detailed risk assessments (i.e. Section 5.3, "Risk Assessments"[10]) to guide the development of accident scenario-specific response plans; and a wide range of technical experts and trained personnel (e.g., risk analysts, health physicists, emergency managers, risk communicators, etc.) (i.e., Section 5.1, "Technical competence in nuclear safety"[11]) to form an effective organization for responding to potential accidents.

Comparison of UN/IAEA Safety Framework with the United States' Nuclear Safety Implementation for Space Nuclear Power System Applications

As illustrated in Figure 2, the U.S. has implemented federal laws and guidance that relate directly to the UN/IAEA Safety Framework guidance.[12] In particular, the United States has developed a "National Response Framework" (NRF) that specifically addresses NPS preparedness and emergency response planning. Also, in response to the NRF, NASA has formalized detailed radiological contingency planning requirements specific to space NPS missions.

Figure 2
Mapping of UN/IAEA Safety Framework Guidance to U.S. Federal Law/Guidance



- National Response Framework

The NRF details how the United States responds to all major hazards. The NRF builds "upon scalable, flexible, and adaptable coordinating structures to align key roles and responsibilities across the Nation, linking all levels of government, nongovernmental organizations, and the private sector. It is intended to capture specific authorities and best practices for managing incidents that range from the

[10] Ibid, Section 5.3.
[11] Ibid, Section 5.1.
[12] A/AC.105/C.1/L.313.

serious but purely local, to large-scale terrorist attacks or catastrophic natural disasters."[13]

Consistent with the UN/IAEA Safety Framework, the NRF's term 'response' "includes immediate actions to save lives, protect property and the environment, and meet basic human needs. Response also includes the execution [implementation] of emergency plans and actions to support short-term recovery."[14] The NRF establishes that a "response to an incident is a shared responsibility of governments at all levels, the private sector and [non-governmental organizations] NGOs, and individual citizens."[15] The NRF "commits the Federal Government, in partnership with local, tribal, and State governments and the private sector, to complete both strategic and operational plans,"[16] including ones specific to NPS missions.

The NRF contains a "Nuclear/Radiological Incident Annex" that specifically addresses the release of nuclear/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."[17] The annex's purpose is to:

- "Define the roles and responsibilities of Federal agencies in responding to the unique characteristics of different categories of nuclear/radiological incidents.
- Discuss the specific authorities, capabilities, and assets the Federal Government has for responding to nuclear/radiological incidents that are not otherwise described in the NRF.
- Discuss the integration of the concept of operations with other elements of the NRF, including the unique organization, notification, and activation processes and specialized incident-related actions.
- Provide guidelines for notification, coordination, and leadership of Federal activities."[18]

For incidents involving space NPS 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, NASA has the responsibility for providing the leadership both for the response and for the precursor planning and preparedness activities. Other federal agencies have the responsibility to cooperate with NASA by providing technical assistance and resources. Table 1 lists these "Cooperating Agencies".

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[13] United States Department of Homeland Security, National Response Framework, January 2008, http://www.fema.gov/NRF, Page 1.

[14] Ibid.

[15] Ibid, Page 3.

[16] Ibid.

[17] Ibid, "Nuclear/Radiological Incident Annex", Page 1.

[18] Ibid.

NASA Preparedness and Response Requirements for Space Nuclear Power System Applications

In implementing the NRF for space NPS missions, NASA has developed and formalized requirements for all space NPS application missions. These requirements flow from NASA's responsibility under the NRF to establish contingency plans for all the Agency's missions. The basic, top-level requirements[19] include:

- "Protect lives."
- "Protect the environment."
- "Assist in mitigating hazards and minimizing the effects of natural disasters, technological emergencies and criminal acts including terrorism."
- "Support local state and Federal agencies and appropriate emergency response authorities.
- "Provide for continuous operation or timely resumption of mission critical functions services and infrastructure."
- "Aid in the recovery and timely resumption of normal operations."
- "Minimize loss and damage to NASA resources."

Table 1
U.S. Government Agencies Designated as Cooperating Agencies for Nuclear Incidents Involving NASA Space NPS Applications

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

In addition, NASA has more detailed requirements specific to NPS application missions. The lead organization at NASA Headquarters for an NPS space application and the line management for the mission must ensure:

- "Development of site-specific ground operations and radiological contingency plans commensurate with the risk represented by the planned launch of nuclear materials."

[19] National Aeronautics and Space Administration, NASA Procedural Requirement (NPR) 8715.2A, "NASA Emergency Preparedness Procedural Requirements", Chapter 1 – Basic Emergency Preparedness, Page 6.

- "Contingency planning, as required by the National Response Framework, includes provisions for emergency response and support for source recovery efforts."[20]

NASA launch/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/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 regional Federal, State, territorial, and local emergency management authorities to provide for support to, and coordination with, offsite emergency response elements."
- "Make provisions for special offsite 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 (RADCC[21]) for launches and landings with radioactive sources possessing a significant health or environmental risk, or having an activity of A2[22] mission multiple greater than 1,000 …."
- "Ensure, when required, that the RADCC 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."
- "Ensure, when required, that the RADCC is operational during launch and landing phases anytime there is a potential for an accident that could release radioactive material."
- "Ensure, when required, that the RADCC is staffed commensurate with the risk associated with the radioactive materials present."[23]

In addition, other offices within NASA (e.g. Office of Safety and Mission Assurance) have the responsibility to review the mission's preparedness and response plans to ensure: appropriate coordination with "cooperating agencies" under the NRF; adequate scope of response and recovery efforts; and compliance

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[20] National Aeronautics and Space Administration, NPR 8715.3C, NASA General Safety Program Requirements, Chapter 6 – Nuclear Safety for Launching of Radioactive Materials, Section 6.2.2.

[21] The RADCC is the launch site operations center established and staffed with the multi-agency 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 centers involved in the accident response.

[22] A2 is the maximum activity of any radioactive material other than special form radioactive material that can be transported in a Type A package" (IAEA Glossary, http://www-ns.iaea.org/downloads/ standards/glossary /glossary- english-version2point0-sept-06-12.pdf).

[23] NPR 8715.3C, Chapter 6 – Nuclear Safety for Launching of Radioactive Materials, Section 6.2.2.

with 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 can be reviewed as part of the launch authorization process.

Processes for Satisfaction of Preparedness and Response Requirements

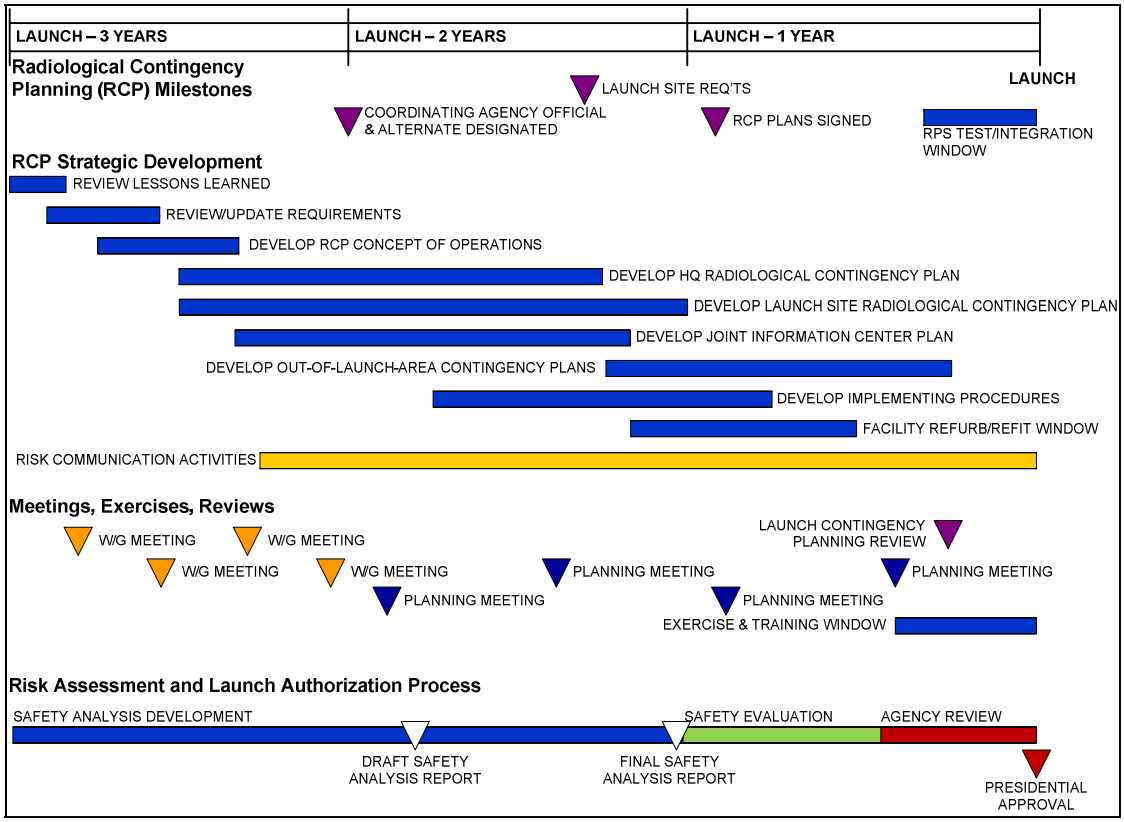
The United States processes for satisfying preparedness and response requirements for a NPS space application typically begin several years before launch and are coordinated with the risk assessment and launch authorization processes. Figure 3 provides a typical timeline of: radiological contingency planning (RCP) milestones; RCP processes, meetings exercises and reviews; and the relevant interfaces with ongoing mission nuclear risk assessments and the launch authorization process.

Three years before a planned launch, the mission initiates RCP efforts. As the United States has conducted several space NPS missions, the first activity involves reviewing 'lessons learned', detailed requirements and plans from previous space NPS mission applications for applicability to the planned mission. A multi-agency working group involving federal, state and local agencies is established that collaboratively defines a "concept of operations" consistent with the NRF and agency requirements (outlined in the previous section of this paper).

Two years prior to launch, NASA designates the mission lead RCP individual, referred to as the "coordinating agency representative" (CAR). The CAR oversees the development of mission-specific RCPs — both for the launch area and for out-of-orbit accidents – and the preparation of joint agency communication plans. During this period of time, the working group uses early risk assessment results to develop scenario-specific response plans, initiate preparation of scenario-specific government, media and public notifications, scope preparedness resource requirements, develop implementing procedures, and plan preparedness exercises/rehearsals and training activities.

In the year prior to launch, multi-agency review and approval processes focus on finalizing and obtaining signature-approval for the RCPs, conducting training programs, pre-deploying and testing RCP resources (e.g. radiation detectors) and procedures, implementing multiple rehearsals/exercises, and supporting launch authorization process nuclear safety reviews.

Figure 3
Processes and Activities for Satisfying Preparedness and Response Requirements



Lessons Learned from NASA Space NPS Applications

Over the last five decades of launching space NPS applications, the United States has gained significant experience in preparing multi-agency 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 RCPs. Key lessons learned from previous missions include the following:

- Exercises and rehearsals identify gaps

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

- Integrate RCP into standard emergency response management structures and contingency plans; build on existing infrastructure

NPS applications on space missions typically occur only once to 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. While consistent with the overall strategy of the NRF, this approach facilitates the development of cost-effective detailed plans and procedures at the launch site where, to a large extent, response/preparedness communication networks, notification trees and procedures, response/recovery teams, meteorological sensors and models, and inter-governmental working interfaces and procedures already exist. While NPS mission applications still require significant augmentation of non-radiological preparedness/response plans, procedures and resources, the United States has avoided substantial uncertainty and organizational resistance to the development of RCPs by relying on existing preparedness/response systems that get regularly reviewed and practiced for routine launches.

- Co-locate (physically or 'virtually') the technical, management and public information elements of the emergency response organizations

Successful implementation of a radiological contingency plan for a space NPS 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 NPS 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/assessment, public information collection/dissemination, and response management – and facilitating internal and external communication among these three elements, facilitates the flow of accurate information to decision makers and the public. 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. Co-locating public information personnel (e.g. media affairs, legislative affairs, public affairs, international affairs, etc.) in close physical proximity to the inter-governmental 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.

- Include emergency preparedness reviews for all levels of government 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 NPS application. The federal government conducts both intra- and interagency safety reviews, and numerous briefings involving state and local governments. The ultimate decision on the safety of the mission, however, does not rest with NASA, but instead 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 stands as an important consideration in determining whether nuclear launch safety approval will be granted. By including emergency preparedness/response plans in the launch authorization process, the United States government has raised the level of attention and priority for these plans during the development phase of the mission.

- Recognize that the emergency preparedness function includes not only determining and implementing the appropriate protective actions in the event of an accident, but also includes 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 purposeful termination of a mission: such termination events appear spectacular and can easily promote the perception that a significant radioactive material release has occurred. It is just as important to emergency response managers to verify that a release of radioactive material has not occurred for such accidents as it is to determine whether a release has, in fact, occurred. Protective action measures (e.g. sheltering-in-place), while important for minimizing potential public exposures to radioactive releases, also can create health consequences, economic hardships and significant costs to local governments if maintained for extended time periods. For this reason, accident response plans should (1) place a high priority on determining if, where and to what degree any release of radioactive material has occurred, (2) scope associated protective action measures to a reasonably conservative estimate of potential releases based on a rigorous risk assessment, and (3) rapidly communicate this information to the appropriate governmental authorities and to the public.

Conclusion

The United States government requires detailed multi-agency emergency preparedness/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's preparedness/response plans encompass both small radioactive releases limited to the launch site and to larger releases that could migrate off-site to populated areas. Due to the emphasis on nuclear safety across all mission design/development phases and launch system elements[24] (i.e., launch vehicle, spacecraft, mission design, ground system, flight rules), the majority of accidents do not involve releases of radioactive materials. However, this design/development 'success' has not diminished the rigor and scope of emergency preparedness/response plans for United States space NPS 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 NPS application, NASA conducts multiple exercises and rehearsals to verify the adequacy of preparedness/response plans. This extensive effort, implemented for each launch of a space NPS application, both helps assure public safety and build public trust and support for the safe conduct of future United States space NPS applications.

[24] A/AC.105/C.1/L.313.