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Information and Best Practices Related to NASA Nuclear Flight Safety for Space Flights Involving Space Nuclear Systems

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FOREWORD

This handbook provides information and best practices associated with NASA's nuclear flight safety activities that fall within NASA's domain (as opposed to that of other Federal authorities). It applies specifically to space nuclear systems, which include radioisotope power systems and fission reactors. It specifically does not cover routine ground processing activities that NASA personnel perform under the technical authority of the Office of the Chief Health and Medical Officer's Ionizing Radiation Protection Program or crew safety activities under human rating requirements.

A NASA Office of Safety and Mission Assurance (OSMA)-led working group developed this document. Members of the working group included NASA civil service, who retained primary responsibility for drafting the document, owning the content, and promoting alignment. The working group members included:

- Anthony Calomino, NASA Space Technology Mission Directorate
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- Matthew Forsbacka, NASA Office of Safety and Mission Assurance
- Kurt Geber, NASA Kennedy Space Center
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Christopher Hallam and Scott Telofski, of the U.S. Environmental Protection Agency participated as interagency partners, ensuring that other-agency interests were considered.

Also, several other contributors participated in the working group by invitation. The other contributor role applied to any contractors (non-Federal employees) who provided advice, with this advice being treated as discretionary (i.e., these individuals specifically did not serve as de facto members). These individuals were:

- Elan Borenstein, NASA Jet Propulsion Laboratory and as a contractor to NASA Glenn Research Center
- Allen Camp, retired and as a contractor to the NASA Power and Propulsion Technical Discipline Team (TDT)
- Andrew Klein, retired and as a contractor to the NASA Power and Propulsion TDT
- Elaine Marshall, as a contractor to the Department of Defense
- Peter McCallum, Aerospace Corporation and as a contractor to NASA Glenn Research Center
- Paul Vandamme, NASA Jet Propulsion Laboratory and as a contractor to NASA Glenn Research Center

The other contributor role was crafted to ensure a diversity of opinion while also ensuring that working group members maintained ultimate responsibility for the document's content.

In addition, the authors benefited from a review performed by three members of the NASA Nuclear Power and Propulsion TDT, as follows:

- Andrew Presby, NASA Glenn Research Center
- Carl Sandifer, NASA Glenn Research Center
- Greg Sullivan, Contractor to the NASA Nuclear Power and Propulsion TDT

Please submit requests for information, corrections or additions to this standard via email to OSMA at Agency-SMA-Policy-Feedback@mail.nasa.gov, or directly to the corresponding author at donald.m.helton@nasa.gov.

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1. SCOPE

1.1 Purpose

The purpose of this handbook is to facilitate a repeatable and robust process that promotes clear and effective interfaces between activities and stakeholders focused on meeting nuclear flight safety requirements for missions utilizing space nuclear systems (SNS), within the context of NASA's broader nuclear-related activities and interfaces. NPR 8715.26, Nuclear Flight Safety, requires that the NASA project manager "incorporate nuclear flight safety considerations starting with program or project formulation through the point at which the SNS or other radioactive material no longer has the potential to affect Earth's biosphere."

NASA's use of SNS inherently involves partnering with other stakeholders to conduct a range of related activities that interface with nuclear flight safety. From a categorical perspective these include: (i) meeting the authorities and licensing requirements for possession and use of nuclear material, as governed by other Federal authorities; (ii) conducting National Environmental Policy Act (NEPA) activities for nuclear-enabled missions; (iii) meeting Federal nuclear launch authorization requirements; (iv) conducting radiological contingency planning activities, including those associated with international commitments; (v) performing risk communication and public outreach activities; and (vi) ensuring decommissioning and disposal strategies reflect National policies and interests. It is the intent of this handbook to promote an effective interface between nuclear flight safety and these interrelated categorical activities.

In addition to activities undertaken with partnering agencies, there are individual nuclear-related activities and programs that have a nexus to nuclear flight safety, and these include: (i) applicable NASA Standing Review Boards; (ii) the US Department of Energy nuclear safety activities conducted in partnership with NASA under Memoranda of Understanding; (iii) the Department of Defense's Range Safety activities; (iv) NASA's general involvement in interagency and international dialogues regarding nuclear safety; (v) the NASA-administered Interagency Nuclear Safety Review Board; (vi) NASA's program and project governance activities and nuclear-specific Technical Discipline Team activities under the Office of the Chief Engineer; and others. It is the intent of this handbook to promote effective leveraging of these additional interrelated organizational activities, as appropriate.

1.2 Applicability

This document is a resource for NASA personnel, including NASA programs and projects that utilize SNS. It is a companion to NPR 8715.26, Nuclear Flight Safety. This document does not dictate how NASA programs and projects organize their responsibilities. The term NASA Project Manager is used throughout the document to refer to actions that may be taken by a Program Executive, Program Manager, Project Manager, or other programmatic authority personnel. NPR 8715.26 addresses the programmatic level at which nuclear flight safety requirements are levied and permits delegation unless specifically prohibited.

2. APPLICABLE AND REFERENCE DOCUMENTS

NSPM-20, National Security Presidential Memorandum on the Launch of Spacecraft Containing Space Nuclear Systems.

SPD-6, Memorandum on the National Strategy for Space Nuclear Power and Propulsion.

NPD 1000.3, The NASA Organization.

NPD 8700.1, NASA Policy for Safety and Mission Success.

NPD 8710.1, Emergency Management Program.

NPD 8020.2, Design and Construction of Facilities.

NPR 1800.1, NASA Occupational Health Program Procedures.

NPR 7120.5, NASA Space Flight Program and Project Management Requirements.

NPR 7120.8, NASA Research and Technology Program and Project Management Requirements.

NPR 7123.1 NASA System Engineering Processes and Requirements.

NPR 1800.1, NASA Occupational Health Program Procedures.

NPR 8000.4, Agency Risk Management Procedural Requirements.

NPR 8580.1, Implementing the National Environmental Policy Act and Executive Order 12114.

NPR 8610.7, Launch Services Risk Mitigation Policy for NASA-Owned and/or NASA-Sponsored Payloads/Missions.

NPR 8621.1, NASA Procedural Requirements for Mishap and Close Call Reporting, Investigating, and Recordkeeping.

NPR 8705.2, Human-Rating Requirements for Space Systems.

NPR 8705.4, Risk Classification for NASA Payloads.

NPR 8715.1, NASA Safety and Health Programs.

NPR 8715.2, NASA Emergency Management Program Procedural Requirements.

NPR 8715.3, NASA General Safety Program Requirements.

NPR 8715.5, Range Flight Safety Program.

NPR 8715.6, NASA Procedural Requirements for Limiting Orbital Debris and Evaluating the Meteoroid and Orbital Debris Environments.

NPR 8715.7, NASA Payload Safety Program.

NPR 8715.24, Planetary Protection Provisions for Robotic Extraterrestrial Missions.

NPR 8715.26, Nuclear Flight Safety.

NPR 8900.1, NASA Health and Medical Requirements for Human Space Exploration.

DAFMAN-91-110, Nuclear Safety Review and Launch Approval for Space or Missile Use of Radioactive Material.

Nuclear/Radiological Incident Annex to the Response and Recovery Federal Interagency Operational Plans.

IAEA, Specific Safety Requirements No. 6 (SSR-6), Regulations for the Safe Transport of Radioactive Material

IAEA, Safety Framework for Nuclear Power Source Applications in Outer Space (2009).

United Nations Convention on Early Notification of a Nuclear Accident (1986).

United Nations Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (1986).

NASA-STD-3001, NASA Spaceflight Human-System Standard.

NASA-STD-8719.24, NASA Payload Safety Requirements.

NASA-STD-8719.24-Annex, Annex to NASA Payload Safety Requirements.

NASA-STD-8719.25, Range Flight Safety Requirements.

NASA-STD-8739.10, Electrical, Electronic, and Electromechanical (EEE) Parts Assurance Standard.

DOE-STD-1189-2016 Integration of Safety into the Design Process.

MIL-STD-882E DOD Standard Practice: System Safety.

Interagency Nuclear Safety Review Board Trial Use Playbook (latest version available at: https://sma.nasa.gov/sma-disciplines/nuclear-flight-safety).

NRC Vision and Strategy: Safely Achieving Effective and Efficient Non-Light Water Reactor Mission Readiness, ADAMS Accession No. ML16356A670.

Helton, D. M. et al., Overview of Past Space Nuclear Reactor Functional Safety Principles in the Context of Recent Policy Changes, Nuclear and Emerging Technologies in Space Topical Meeting, Idaho Falls, May 2023, NTRS No. 20230003898.

3. ACRONYMS AND DEFINITIONS

3.1 Acronyms and Abbreviations

AI&T	Assembly, Integration, and Test
AIM	Assurance Implementation Matrix
ALARA	As Low As Reasonably Achievable
APMC	Agency Program Management Council
ATLO	Assembly, Test, and Launch Operations
CCSFS	Cape Canaveral Space Force Station
CHMO	Chief Health and Medical Officer
CSO	Chief Safety & Mission Assrance Officer
CSpOC	Combined Space Operational Command
DHS	Deparment of Homeland Security
DoD	The United States Department of Defense
DOE	The United States Department of Energy, including the National Nuclear Security Administration (NNSA)
DOS	Department of State
EC	Executive Council
EEE	Electrical, Electronic, and Electromechanical
EOC	Emergency Operations Center
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FRMAC	Federal Radiological Monitoring and Assessment Center
FRR	Flight Readiness Review
FTD	Final Tier Determination
HQ	Headquarters
HSIN	Homeland Security Information Network
IAAs	Internagency Agreements
IAEA	International Atomic Energy Agency
IMAAC	Interagency Modeling and Atmospheric Assessment Center
INSRB	Interagency Nuclear Safety Review Board
KDP	Key Decision Point
KSC	Kennedy Space Center
LCR	Life Cycle Review
LEO	Low-Earth Orbit
LEOC	Launch Emergency Operations Center
LSP	Launch Services Program
LWRHU	Lightweight Radioisotope Heater Unit
MBSE	Model-Based Systems Engineering
MBSMS	Model-Based System and Mission Success
MDAA	Mission Directorate Associate Administrator
MDR	Mission Definition Review
MMRTG	Multi-Mission Radioisotope Thermoelectric Generator
MOAs	Memoranda of Agreement
MOUs	Memoranda of Understanding

NARAC	National Atmospheric Release Advisory Center
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NFSO	Nuclear Flight Safety Officer
NLAP	Nuclear Launch Authorization Plan
NPAS	Nuclear Power Assessment Study
NRC	U.S. Nuclear Regulatory Commission
NSPM	National Security Presidential Memorandum
OCHMO	Office of the Chief Health and Medical Officer
OGC	Office of the General Cousnel
OIIR	Office of International and Interagency Relations
OOCP	On-Orbit Contingency Plan
OPS	Office of Protective Services
OSMA	Office of Safety and Mission Assurance
OSTP	Office of Science and Technology Policy, contained within the Executive Office of the President
PA	Primary Authority
PAR	Primary Authority Representative
PFTD	Provisional Final Tier Determination
PRA	Probabilistic Risk Assessment
PSWG	Payload Safety Working Group
PTD	Preliminary Tier Determination
PTSLR	Prior to Scheduled launch or Reentry
RADCC	Radiological Control Center
RCP	Radiological Contingency Planning
RHU	Radioisotope Heater Unit
RPS	Radioisotope Power System
RSR	Radiological Safety Review
RTG	Radioisotope Thermoelectric Generator
SACM	Structured Assurance Case Metamodel
SAR	Safety Analysis Report
SAS	Safety Analysis Summary
SDR	System Definition Review
SEAM	Systems Engineering and Assurance Modeling
SEMP	Systems Engineering Management Plan
SER	Safety Evaluation Report
SMA	Safety and Mission Assurance
SMAP	Safety and Mission Assurance Plan
S&MS	Safety and Mission Success
SMSR	Safety and Mission Success Review
SNS	Space Nuclear System
SPD	Space Policy Directive
SRB	Standing Review Board
SRATCOM	United States Sratgeic Command
TA	Technical Authority

TED	Total Effective Dose
USAF	United States Air Force

3.2 Definitions

NPR 8715.26 defines most of the terms unique to NASA nuclear flight safety.

Argumentation: This term is used somewhat loosely in this document to refer to the description of connected series of claims used to establish an overall claim; put differently, it is the connective tissue that defines how individual pieces of evidence, claims, and contextual information are aggregated in a logical and understandable way to establish the validity of an overarching claim in a manner so that an independent party can verify that the overall claim has been satisifed by virtue of confirming that the underlying elements have been achieved.

NASA Project Manager: This term is used here as a catchall term to describe the relevant individual within the programmatic authority chain. In reality, the NASA Project Manager may hold the official job title of Program Executive, Program Manager, Project Manager, System Safety Engineer, etc. Since roles and responsibilities may differ across programs and projects, it is the programmatic authorities' responsibility to ensure that roles and responsibilities are clearly defined within the context of their program or project. Delegation or elevation of duties is inherently permitted, given that this Handbook does not (by definition) contain requirements.

Nuclear criticality: The condition in which a nuclear fission chain reaction becomes self-sustaining.

Special nuclear material: See Title I of the Atomic Energy Act of 1954. Within this Handbook, the term generally refers to plutonium and enriched uranium.

4. TECHNICAL AND PROGRAMMATIC GUIDANCE

Note: The following sections are structured in parallel format to address the following topics:

- What is the relevant background in this area?
- What strategies can the responsible personnel employ?
- How can personnel provide argumentation that the strategies employed are effective in meeting both the objectives they support and the overall goal of the program or project?
- Where should personnel document the argumentation to support the assurance case, the basis of compliance, and, if applicable, review success criteria?

4.1 NASA Nuclear Flight Safety Applicability and "Whole-of-Government"

4.1.1 NPR 8715.26 defines the general applicability of NASA nuclear flight safety requirements. However, the NPR also acknowledges that delineation of applicability will not always be clear-cut. In such cases, the NPR requires that NASA personnel consult with the NASA NFSO and NASA OGC when applicability is unclear.

4.1.2 As part of applying NPR 8715.26, the NASA Project Manager and the NFSO can use the following strategies to determine applicability:

4.1.2.1 Use the flowchart provided in Appendix A and obtain OGC concurrence during the formulation phase of each flight project (or program, if relevant).

4.1.2.2 Establish Agreements with other Federal authorities that address how that organization's authority will apply and what mechanism will be used to ensure that all parties (including OSMA) have sufficient insight.

4.1.3 The NASA Project Manager can produce argumentation regarding nuclear flight safety applicability based on the flowchart in Appendix A or otherwise anchored in:

4.1.3.1 The nature of NASA's involvement in the nuclear safety aspects of the flight;

4.1.3.2 Whether the flight will be FAA-licensed;

4.1.3.3 Whether the flight will be launched under DoD authority;

4.1.3.4 Whether the radioactive material falls within an existing nuclear flight safety categorical relief.

4.1.4 The NASA Project Manager can document evidence relevant to nuclear flight safety applicability by:

4.1.4.1 Documenting the basis for applicability in an appropriate project document (e.g., a NLAP or a SMAP), with concurrence by the technical authority.

4.2 Nexus of Nuclear Flight Safety to Mainstream Spaceflight Project Activities

4.2.1 NPR 8715.26 presumes that NASA project managers and SMA personnel understand how nuclear-related activities interface with non-nuclear disciplines and activities. The NPR further presumes that NASA personnel will manage within-NASA, cross-agency, and public-private partnership interfaces effectively.

4.2.2 As part of applying NPR 8715.26 and promoting healthy interfaces, the NASA Project Manager and SMA personnel can use the following strategies:

4.2.2.1 Identifying a primary point of contact for each discipline or activity that can facilitate sharing of information that is of mutual interest (Appendix B provides information to facilitate this strategy);

4.2.2.2 Establishing an SMA roles and responsibilities document that addresses the division of responsibilities between the NFSO, the program or project-level SMA TA of any relevant NASA program offices and flight projects, prime NASA contractor personnel, the PSWG Chair, and others;

4.2.2.3 Establishing a hierarchy of agreements to manage interagency collaboration, such as:

4.2.2.3.1 An interagency memorandum of understanding (MOU) to establish senior leadership alignment;

4.2.2.3.2 Interagency agreements (IAAs) to establish leadership alignment;

4.2.2.3.3 Strategic partnership plans (SPPs) to establish working level alignment.

4.2.3 The NASA Project Manager and SMA personnel do not need to develop formal argumentation to support these strategies; rather, the overall health of the project will ultimately be the indicator of how successful the effort in this area has been.

4.2.4 The NASA Project Manager and SMA personnel can document evidence in this area via:

4.2.4.1 The above-described plans and agreements;

4.2.4.2 SRB findings relative to how well roles and responsibilities are understood and maintained.

4.3 Nuclear Flight Safety and the NASA Program and Project Life-Cycle

Like all other sections of this document, the guidance in this section applies to SNS. The relationships described below between NPR 7120.8 research and development programs and projects and NPR 7120.5 flight projects do not apply to some instances for flight of other radioactive material (e.g., NASA's Sounding Rocket and Scientific Balloon Programs).

4.3.1 NPR 8715.26 contains some requirements that have timing aligned with the NPR 7120.5 project life cycle, along with some additional explanatory information in the appendices about how nuclear flight safety activities fit in to that project life cycle. In reality, multiple project life cycles may be relevant to the flight of a SNS, including the hardware development life cycles of other agencies' activities. An embedded assumption in NPR 8715.26 is that projects will effectively manage their more-detailed activities within all relevant life cycle phases, reviews, and approvals, and that activities that don't fall into NPR 7120.5's purview will still consider downstream implications of the flight on their nuclear technology. The NLAP required by NPR 7120.5 is a key step in ensuring that stakeholders are clear on how nuclear flight safety activities will mesh with a particular spaceflight project's life cycle phase activities. Appendix C provides more information on the NLAP.

4.3.2 As part of integrating nuclear flight safety into the relevant life cycle activities, the NASA Project Manager can use the following strategies:

4.3.2.1 When applicable, devising a strategy to leverage NPR 7120.8 technology and capability development activities when that technology and hardware will be used in a 7120.5 spaceflight project, including consideration of the requirements in NPR 8715.26 or those needed to support an FAA licensing application;

4.3.2.2 Creating a high-level (macro) roadmap showing how nuclear flight safety fits in to the life cycles relevant to nuclear hardware development, spacecraft integration, and mission execution, including how the safety approach will evolve during the life cycle progression (e.g., the design criteria or design principles used in pre-formulation and early formulation leading to the safety posture implicitly or explicitly stated in the NLAP in turn leading to the later safety design strategy and safety basis development);

4.3.2.3 Expanding the macro-level roadmap to develop the specific activities that will be performed in each topical area, along with the associated life cycle elements (Phases, KDPs, LCRs) and, where applicable, the associated entry and success criteria (see NPR 7123.1). Appendix C provides an example of the activities and life cycle stages.

4.3.3 The NASA Project Manager can anchor argumentation for meaningful consideration of nuclear flight safety in all applicable aspects of the lifecycle in:

4.3.3.1 Macro plans and more highly-detailed plans like the ones cited above, backed by illustrations of risk trades performed at different stages that balanced nuclear flight safety risks with cost, schedule, and non-nuclear technical risks to arrive at a design that meets the standard of "how safe is safe enough" without placing an undue burden on the project;

4.3.3.2 Successful completion of LCRs (including SRB reviews), when the SRB Terms of Reference or the LCR review success criteria specifically address the inculcation of nuclear flight safety into the broader mission activities.

4.3.4 The NASA Project Manager can document evidence for the argument via TA concurrence on the plans, documentation of the described risk trades, and findings and observations of the SRB.

4.4 High-Level Safety Assurance Case Development

4.4.1 NPR 8715.26 only requires the use of an assurance case approach in the context of radiological contingency planning. However, the authors anticipate that future versions of the NPR, as well as OSMA directives more broadly, will involve greater use of an assurance case for formulating and implementing safety and mission success activities.

4.4.2 To provide better connectivity between activities and their contribution to the overarching nuclear flight safety goals, the NASA Project Manager can develop and maintain a high-level safety assurance case. Appendix D provides an example of such a case along with supporting information.

4.5 SNS Design, Testing, and Handling as it Relates to Nuclear Flight Safety

4.5.1 NPR 8715.26 requires that the NASA project manager “incorporate nuclear flight safety considerations starting with program or project formulation through the point at which the SNS or other radioactive material no longer has the potential to affect Earth’s biosphere.” The NPR gives examples that include managing radiation exposure to equipment, managing SNS maintenance, managing criticality safety, etc. Personnel make many decisions in this regard prior to integration of a SNS for flight. The current section provides information to help NASA personnel consider nuclear flight safety during design, fabrication, demonstration, testing, and qualification activities.

4.5.2 The NASA Project Manager can use the following strategies to include nuclear flight safety considerations during design, fabrication, demonstration, testing, and qualification activities:

4.5.2.1 Document an expectation that personnel will design SNS to meet the probability and consequence criteria (Safety Guidelines) provided NSPM-20 Section 3 and in compliance with the mission-targeted provisional Tier level;

4.5.2.2 Use NASA system safety resources and relevant external system safety practices (e.g., MIL-STD-882, FAA Advisory Circular 450.103-1) to manage interfaces between spacecraft, launch vehicle, and launch operations system safety and nuclear flight safety;

4.5.2.3 Apply insights from previous development efforts to establish safety-in-design tenets that can guide the identification of system design attributes and risk trades occurring prior to the availability of a radiological risk assessment–safety-in-design tenets would address issues like:

4.5.2.3.1 Decisions to accept single-point failures (SPFs) considering the positive and negative impacts redesign would have on nuclear flight safety;

4.5.2.3.2 Design and construction of a space fission system includes safeguards that prevent inadvertent criticality events that would exceed NSPM-20 Safety Guidelines during all operational phases including ground transportation, launch site processing, launch, and re-entry. Personnel should consider ground or water impact, as well as water submersion or intrusion into the reactor core. Safeguards may include minimizing transient neutron population, using a flight safety system designed to disrupt the reactor, or injecting a neutron absorber (i.e., a poison) into the reactor;

4.5.2.3.3 The reactor control and other control mechanisms have highly reliable designs, as demonstrated through full functionality testing. For example, considerations can include locking the controls in a shutdown position for launch to address payload safety requirements;

4.5.2.4 Assess required cooldown periods for nuclear ground tests of the reactor such that the amount of residual radioactivity during ATLO and at launch meet safety requirements for personnel, facilities, and service equipment.

4.5.2.5 Identify and document required payload safety reviews and approval processes, and factor in the time required to complete these reviews and processes into the overall schedule for the program or project;

4.5.2.6 Document that the ground processing procedures required to address worker safety meet existing and applicable government and industry standards and practices for terrestrial nuclear systems.

4.5.2.7 Appendix E provides more information on some of these topics.

4.5.3 The NASA Project Manager should provide written rationale describing the outcome of the above activities and the rationale for how those activities result in a safe system in accordance with the launch authorization basis strategy discussed later in Section 4.7.

4.5.4 The NASA Project Manager can document evidence to show that team members have adequately addressed and implemented the above activities. Confirmation of adequacy will come from successful completion of system design reviews, authority to proceed following successful gate reviews, Terms of Reference for design and safety reviews, and nuclear launch authorization process documents. In terms of documentation, it will likely be covered to some degree in the NLAP, the SMAP, the SEMP, the nuclear launch authorization basis strategy, and (when applicable) the NSPM-20-mandated Terms of Review for any INSRB review.

4.6 Mission Design as It Relates to Nuclear Flight Safety

4.6.1 NPR 8715.26 does not specify requirements related to mission design at either a broad level (e.g., mission risk classification) or a specific level (e.g., decisions about using Earth gravity assists). However, the authors recognize that these activities and decisions do ultimately affect nuclear flight safety, so they are acknowledged in this section.

4.6.2 The NASA Project Manager can use the following strategies to address the intersection between mission design decisions and nuclear flight safety:

4.6.2.1 Considering nuclear flight safety when setting Level 1 program requirements;

4.6.2.2 Considering the factors that have driven mission radiological risk for similar SNS flights including aspects of spacecraft design, launch vehicle integration, launch operations, and mission architecture. Appendix F provides more information on this topic.

4.6.2.3 Considering nuclear flight safety when developing the initial AIM associated with NPR 8705.4 mission risk classification (i.e., in determining how to tailor requirements in disciplines other than nuclear flight safety that have an indirect impact on nuclear flight safety) or equivalent activities associated with NPR 8705.2 for human-rated missions. Appendix F provides more information on this topic.

4.6.2.4 Considering nuclear flight safety when selecting the launch vehicle (e.g., choosing a launch vehicle that analysts have previously characterized for nuclear launch accident scenarios);

4.6.2.5 Considering nuclear flight safety when performing risk trades for flight trajectory (both prior to insertion into an interplanetary trajectory (where applicable) and during any potential Earth returns (including gravity assists)).

4.6.3 The NASA Project Manager can anchor argumentation for mission design decisions as they relate to nuclear flight safety in the form of a risk-informed decision making and continuous risk management process that considers nuclear flight safety in conjunction with the other sources of risk (cost, schedule, non-nuclear technical risk, etc.).

4.6.4 The NASA Project Manager can produce evidence in this area that takes the form of documented risk trades that consider nuclear flight safety, NFSO concurrence on the AIM, etc.

4.7 Nuclear Launch Authorization Basis Strategy Development

4.7.1 NPR 8715.26 does not set requirements for how NASA personnel structure and package the work to support nuclear flight safety analysis. It only peripherally discusses this aspect of nuclear safety and launch safety basis formulation via discussion in Appendix C (Item C.2.1.1) and an associated table entry (Deliver Safety Design Strategy (SDS) or Equivalent) in Appendix E. NPR 8715.26 also does not set requirements related to the management of the launch authorization basis strategy during the safety analysis and review or after the deciding authority has given authorization to proceed. Meanwhile, the INSRB Trial Use Playbook does give some guidance as to how the INSRB envisions that mission personnel will handle those activities in relation to its safety evaluation, primarily in Section 4.1, Section 5.2, and Appendix G.

4.7.2 The NASA Project Manager can use the following strategies for developing and managing a launch authorization basis strategy:

4.7.2.1 Gathering data and reviewing prior efforts;

4.7.2.2 Establishing an organizational structure to execute the design, development, review, delivery, launch, operations, and the decommissioning and disposal of the SNS and its interdependencies with the spacecraft, launch vehicle, and mission;

4.7.2.3 Generating a plan for implementing the authorization basis strategy;

4.7.2.4 Identifying prior relevant testing and analyses performed by the current program or past programs that could support the authorization basis strategy and determining how safety activities for the SNS will interface with mission activities related to reliability and maintainability, system safety, and risk management;

4.7.2.5 Socializing and maintaining the strategy, and incorporating lessons learned.

4.7.2.6 Appendix G discusses each of the above topics in more detail.

4.7.3 NASA personnel should use argumentation of why the authorization base strategy effectively manages the authorization basis itself in programmatic activities and reviews, including the safety evaluation, the nuclear launch authorization process, and the management of emergent events between the time that mission personnel completes the nuclear flight SAR and when the launch occurs.

4.7.4 Evidence of the activities will take various forms. NASA personnel can document the verification process using the NLAP, the SMAP, the SEMP, the nuclear launch authorization basis strategy, and (when applicable) the NSPM-20-mandated Terms of Review for INSRB reviews. Evidence of confirmations of adequacy can consist of successful completion of system design reviews, authority to proceed following successful gate reviews, the head of the sponsoring agency approving the Terms of Review (when applicable), and nuclear launch authorization itself.

4.8 NSPM-20 Mission Tiering

4.8.1 Section 3 of NPR 8715.26 describes the process for tiering NASA missions that fall under the purview of NSPM-20. Tier determination is necessary at up to three stages due to NSPM-20's multi-faceted tiering approach, which includes consideration of nuclear flight safety analysis-generated risk estimates. Appendix H provides more information in this regard.

4.8.2 To support the multi-staged tiering concept required by NSPM-20's approach and its implementation for NASA missions in NPR 8715.26, the NASA Project Manager can use the following strategies:

4.8.2.1 Evaluating the final tier determination for similar past missions;

4.8.2.2 Establishing mission requirements that would drive mission risk toward the desired end state (see Section 4.6 for more information on mission design activities);

4.8.2.3 Making a conservative assumption (e.g., assuming the final outcome will be Tier III) to provide the mission maximum flexibility in making risk trades.

4.8.3 Argumentation will evolve through the three stages of tier determination.

4.8.3.1 NASA personnel can anchor the argumentation for the Preliminary Tier Determination in a combination of the mission's risk posture (as it relates to promoting flexibility in making risk trades versus driving toward a particular tiering outcome) and available information from past missions with sufficient similarity. Once available, the authors may add examples of prior Preliminary Tier Determinations to Appendix H..

4.8.3.2 NASA personnel can anchor argumentation for the Provisional Final Tier Determination in the preliminary nuclear flight safety analysis results available at that time. Once available, the authors may add examples of Provisional Final Tier Determinations to Appendix H.

4.8.3.3 NASA personnel can anchor argumentation for the Final Tier Determination in the final nuclear flight safety analysis results (i.e., the mission SAR). Once available, examples of prior Final Tier Determinations may be added to Appendix H.

4.8.4 NASA personnel can establish evidence of well-substantiated argumentation in this area by documenting technical authority concurrence on the three tiering determinations.

4.9 Nuclear Flight Safety Analysis and the Mission SAR

4.9.1 Safety and launch approval for SNS is now focused on ensuring conformance with NSPM-20, including the Safety Guidelines therein. While this Handbook provides discussion related to meeting the criteria provided in NSPM-20, Section 3, the document is not intended to be prescriptive as to the ways in which the mission adheres to NSPM-20. Future efforts will develop accepted standards in this regard. NSPM-20 requires a nuclear safety analysis to support nuclear launch authorization decision-making, and it establishes the very high-level expectation as to how the results from the associated nuclear SAR will be compared with the NSPM-20 Safety Guidelines (maximum dose as a function of exposure likelihood exceedance). The required safety analysis should also contain, “the likelihood of an accident resulting in an exposure in excess of 5 rem TED to any member of the public; the number of individuals who might receive such exposure in an accident scenario; and comparisons of potential exposure levels to other meaningful measures such as nuclear space launch safety guidelines, background radiation, average public exposure from natural and manmade sources, and other relevant public safety standards.” Beyond this, the policy does not prescribe the contents of the safety analysis. NPR 8715.26 carries these requirements forward. Meanwhile, DAFMAN 91-110 and the INSRB Playbook provide additional information on this subject from the perspective of DoD Range Safety and the interagency review body. Nuclear authorities’ agency-specific guidance will also heavily influence work in this area. NASA customarily sponsors the nuclear flight safety analysis (which culminates in the mission SAR). Normally, NASA personnel and contractors perform activities related to the launch vehicle, launch operations, and characterization of the potential launch accident environments. Meanwhile, DOE personnel and contractors usually carry out all other aspects, including the overarching management of the analytical modeling and the documentation. Appendix I provides some additional clarifying information.

4.9.2 The NASA Project Manager can use various strategies for supporting the development and completion of the nuclear flight safety analysis and mission SAR. These include:

4.9.2.1 Relying on existing guidance and standards where available and applicable (See below for more on applicable guidance and standards);

4.9.2.2 Engaging early with review entities, and establishing clear terms of review;

4.9.2.3 Determining mission phases to be analyzed, including considering how mission phase definitions that are convenient for the nuclear flight safety analysis (and mission SAR) mesh with potentially differing mission phase definitions used by upstream analysts (e.g., system safety for ground operations, launch provider reliability analyses) and downstream end-users (e.g., radiological contingency planning).

4.9.3 The NASA Project Manager can provide argumentation in this area in the technical analysis performed. The Project Manager can anchor argumentation related to quality and scope by relating the analysis to other guidance and standards relevant to that portion of the analysis. Some examples of guidance and standards that have limited and specific relevance to nuclear flight safety analysis and the mission SAR include:

4.9.3.1 DOE standards, such as DOE-STD-1189 on safety-in-design, and DOE-STD-3009 and DOE-STD-1237 on content of terrestrial documented safety analyses;

4.9.3.2 FAA Advisory Circulars related to non-nuclear flight safety analysis (such as 450.113-1 and 450.115-1) and population exposure assessment (450.123-1).

4.9.4 The NASA Project Manager can provide evidence of effective argumentation in the form of reviewer reports. These include the technical peer review required by NSPM-20, agency reviews (such as DOE or NRC safety evaluation reports related to the nuclear system or NASA radiological safety reviews related to the flight of the nuclear system), and, when applicable, safety evaluation by the INSRB.

4.10 Nuclear Flight Safety Review

4.10.1 NPR 8715.26 contains a series of requirements and recommendations that largely carry forward requirements or recommendations from NSPM-20 itself. In addition, NPR 8715.26 extrapolates the relevant concepts to Tier I missions. In this case, RSR performed by the NFSO (rather than the INSRB) replaces the SER. The NFSO also identifies any significant gaps in the safety analysis and provides these to the safety analysis preparer prior to mission SAR completion, analogous to the task performed by the INSRB for Tier II and Tier III missions.

4.10.2 The NASA Project Manager, NFSO, the INSRB representative and others can use the following strategies in this area:

4.10.2.1 The NASA Project Manager should work with the NFSO to ensure that early planning activities associated with the NLAP consider the involvement of INSRB (Tier II and Tier III) or the NFSO (Tier I), such that this early planning results in a process and schedule that can support NSPM-20's expectations. Appendix J provides more detailed information in this regard, including a recommendation for a meeting prior to Key Decision Point-C (KDP-C) to bring all relevant parties together to align expectations.

4.10.2.2 The NASA Project Manager should assure alignment amoung all stakeholders on the terms of review for the INSRB review (Tier II and III) or the NFSO review (Tier I). The NASA Project Manager should use Project governance, this Handbook, and the INSRB

Playbook, along with the key material relative to a particular mission review, to formulate a "Terms of Review" document for Executive approval.

4.10.2.3 In providing optional recommendations to the NASA Project Manager on areas for additional analysis when gaps are identified, the NASA INSRB representative (Tier II or III) or the NFSO (Tier I) should generally provide these around the time that a draft Nuclear Safety Analysis is provided, and should consult the NFSO or the Program or Project-level SMA TA (as applicable) to understand whether INSRB recommendations harmonize with, or are in tension with, other risk management drivers for the mission (to provide context and not to inhibit INSRB recommendations).

4.10.2.4 In providing the required omissions or gaps identified by the INSRB during its review, the NASA INSRB representative (Tier II or III) or NFSO (Tier I) should ensure delivery of these omissions or gaps ahead of the mission SAR issuance and should ensure that NASA SMA TA stakeholders are aware of the findings.

4.10.2.5 Concurrent with the transmission of the SER to the NASA Project Manager, the NASA INSRB representative (Tier II and III) or the NFSO (Tier I) should provide a publicly-available Executive Summary for the SER to the Chief, SMA along with a specified timeline for release that includes the predecisional nature prior to an Administrator or Presidential decision.

4.10.2.6 In performing reviews, the NASA INSRB representative (Tier II or III) or the NFSO (Tier I) should seek to leverage existing standards whenever available and applicable. Appendix J, Section J.3 provides a survey of available standards and other guidance, including insight into their applicability.

Note: At present, the community has not developed a consensus definition of "gap," and the nuclear safety review would benefit from such a definition.

4.11 Interface with Payload and Range Safety Activities

4.11.1 Although NPR 8715.26 establishes a framework to allow other requirements, guidance, and processes to be integrated into the overall nuclear flight safety process, such as payload and launch vehicle safety requirements, it does not describe how they are integrated, nor the multiple paths in which they can be integrated. The way in which payload and launch vehicle safety requirements flow down to payload and launch vehicle providers is of the utmost importance to ensure protection of flight hardware, facilities, and people. There exist two primary paths in which payloads and launch vehicles gain approval to launch, either through an existing U.S. federal range (DoD or NASA) or through an FAA licensed launch. An FAA licensed launch could occur from the U.S. or a foreign country. The payload and launch vehicle safety requirements may vary based on these two approaches, but, in essence, the requirements focus on achieving the same end state, which is the identification and mitigation of hazards to an acceptable level. Note that an FAA launch license specifically addresses risk to the public, so other range safety requirements still apply when needed to protect personnel involved in the project and high-value assets.

4.11.2 For NASA payload safety requirements, the NASA Project Manager should follow the NPR 8715.7, NASA Payload Safety Review Process to ensure:

4.11.2.1 Appropriate system safety representatives are involved in the adjudication of the applicable payload safety requirements. For example, personnel responsible for payload safety should form a PSWG (or equivalent) to include representation from the launch vehicle provider, Range safety, etc.

4.11.2.2 Explicit safety requirements associated with flight hardware containing ionizing radiation sources are properly levied, per NASA-STD-8719.24 Annex (for NASA or DoD Ranges), or equivalent.

4.11.2.3 Explicit requirements under 14 CFR are levied (for FAA-licensed flights). (Note: The FAA will also accept an existing federal launch range's safety process if the federal launch range's process meets the applicable FAA subparts.)

4.11.3 The launch vehicle provider safety requirements are similar to the payload safety requirements. The NASA program procuring the launch service should have insight into the implementation of these safety requirements, with the requirements themselves being under the purview of the FAA or the existing federal launch range manager. To support this, the NASA Project Manager should:

4.11.3.1 Acquire, via the launch service provider contract(s), the necessary safety deliverables described under the FAA subparts or under the existing federal launch range's safety requirements.

4.11.3.2 Review these launch vehicle safety deliverables to ensure the launch vehicle hazards associated with integrating and launching a payload with an SNS are appropriately identified and mitigated.

4.11.3.3 Assess the launch vehicle provider's reliability report and products to ensure the reliability of the launch vehicle is commensurate with the potential risk associated with launching a payload with an SNS.

4.11.3.4 Work in concert with the launch vehicle provider to develop a launch vehicle Interface Control Document (ICD) to capture any safety requirements or hazards shared across the launch vehicle to payload interface to ensure they are adequately communicated and addressed. Examples include separation interface electrical connector inhibits or loop backs, environmental cooling systems or redundancy, acceptable radiofrequency environment or limits, avionics hardware radiation limits, etc.

4.11.3.5 Work in concert with NASA Range Flight Safety to maintain insight regarding the launch vehicle provider's overall flight risk criteria associated with NPR 8715.5, NASA Range Flight Safety Program, and NASA-STD-8719.25, Range Flight Safety Requirements. NASA Range Flight Safety should work closely with the existing federal ranges for the flight aspect of the mission to ensure NASA is not exceeding any risk criteria requirements.

4.11.3.6 Request, per the NASA Governance model, that an independent technical authority (i.e., SMA CSO) assess launch vehicle technical problems and risks to mission success. Any identified launch vehicle mission assurance or safety risks will be reported via the independent path through the CSO to OSMA and to the NASA programmatic authority.

4.12 Nuclear Launch and (When Applicable) Return Authorization

4.12.1 Section 4.4 of NPR 8715.26 addresses launch authorization requirements, which largely flow directly from NSPM-20. The launch authorization process culminates in a nuclear launch authorization decision, which is distinct from, but related to, the programmatic determination of flight readiness and the Range Commander authorization. For a NASA-sponsored mission flying SNS, the nuclear launch authorization must come from the NASA Administrator (Tier I or II) or the President or their designee (Tier III).

4.12.2 The NASA Project Manager can use the following strategies to facilitate the nuclear launch authorization process:

4.12.2.1 Providing sufficient resources, access, and engagement for conducting the nuclear safety analysis and review activities;

4.12.2.2 Considering (at least conceptually) the projected content of the launch authorization briefings such that personnel can complete all needed inputs in a timely fashion (including any needed contingency timing associated with a late-breaking change in the mission tier);

4.12.2.3 Considering the recommendations in Appendix L regarding the information to be provided to the NASA Administrator and the pathway for providing that information;

4.12.2.4 Taking advance actions to coordinate with the Executive Council and, when relevant, OSTP staff to understand their expectations;

4.12.2.5 Ensuring that recommendations regarding additional analysis, insights related to omissions in information, or information related to knowledge gaps is routed to all relevant parties, and acted upon, as discussed further in Appendix L;

4.12.2.6 Coordinating with related stakeholders, including the PSWG.

4.12.3 The NASA Project Manager can anchor argumentation regarding the request for nuclear launch authorization in information stemming from:

4.12.3.1 The nuclear flight safety analysis and, most notably, the mission SAR;

4.12.3.2 The nuclear safety review, i.e., the INSRB SER (Tier II and III) or the RSR (Tier I) and any associated reviews performed by other internal processes (e.g., NASA Standing Review Boards) or external processes (e.g., the process of the terrestrial nuclear authority);

4.12.3.3 The payload safety and range flight safety activities;

4.12.3.4 Radiological contingency planning, etc.

4.12.4 The NASA Project Manager can document evidence showing whether the mission personnel effectively argued the case for nuclear launch authorization using the positive or negative decision by the nuclear launch authority, along with any feedback therein.

4.13 Radiological Contingency Planning and Coordination

4.13.1 NPR 8715.26 implements a flexible approach to radiological contingency planning and execution to support a high degree of coordination while also encouraging a scaling of the needed capabilities that considers the specific characteristics of a given mission. In particular, NPR 8715.26 requires the development and execution of a negotiated mission-specific plan for addressing radiological contingency that has defined content commensurate with a mission's scope and context. The NASA Mission Directorate (as the lead programmatic authority) and the Center Director (as the lead institutional authority) lead the development of the negotiated plan in coordination with OSMA. The team develops this plan in cooperation with several other key NASA HQ offices, the preparer of the nuclear safety analysis used for launch approval, relevant US government agencies, relevant local and State authorities, and any international partners. The features of the plan include the development of a radiological contingency risk posture consistent with the broader principle of using established risk postures to implement a risk leadership philosophy toward the goal of increasing decision velocity, as described in Section 3.4.1 of NPD 1000.0. The plan's features also include the development, reporting, independent review, and acceptance by relevant authorities of an assurance case tailored to the defined risk posture to substantiate that sufficient radiological contingency controls and mishap preparedness capabilities exist.

4.13.2 The NASA Project Manager can utilize the following strategies in this area:

4.13.2.1 Beginning planning early start by identifying organizations, resources, and facilities that support RCP activities;

4.13.2.2 Establishing a risk posture to guide the scaling of capabilities;

4.13.2.3 Holding a workshop (or equivalent) to bring together the diverse set of stakeholders and to familiarize them with the concepts of RCP (see Appendix M, Section M.1 for more information) and the preliminary mission risk posture;

4.13.2.4 Creating an integrated schedule to ensure readiness sufficiently early to train, exercise, and improve, as necessary prior to launch;

4.13.2.5 Establishing the launch and flight phase breakdown that will be used for RCP, and assessing how this breakdown meshes with breakdowns used in critical upstream analyses and, most notably, the mission SAR (see Appendix M, Section M.2 for more information);

4.13.2.6 Determining the personnel to fill the key RCP roles described in Appendix M, Section M.3;

4.13.2.7 Assigning the personnel with the primary responsibility for developing and approving the key RCP documents, nominally those described in Appendix M, Section M.4 and Section M.5.

4.13.3 The NASA Project Manager can anchor argumentation of adequacy in this area in the use and tailoring of past precedents and lessons learned, as there is not an accepted standard for performing RCP for SNS launches. In some cases, it may be possible to invoke specific portions of existing terrestrial nuclear emergency management standards, while some aspects of the National Response Framework dictate some aspects of RCP.

4.13.4 The NASA Project Manager can document evidence of successful completion of work in this area primarily in technical and institutional authority concurrences on the associated assurance case envisioned by NPR 8715.26, as well as exercising capabilities prior to the scheduled launch.

4.14 Life-Cycle Activities Relevant After Launch Authorization

4.14.1 NPR 8715.26, Section 4.6.2, establishes the best practice that the NFSO "should ensure that the results of the nuclear safety analysis and nuclear safety review are factored into SMA oversight after launch authorization, including consideration of the safety guidelines in NSPM-20."

4.14.2 The NFSO can use the following strategies to accomplish this best practice (Appendix N provides further detail):

4.14.2.1 Leveraging an already-established, mission-owned change control process;

4.14.2.2 Establishing a critical analysis assumptions list;

4.14.2.3 Performing dedicated monitoring.

4.14.3 The NFSO can demonstrate effective argumentation in this area by traceably tracking emergent issues that develop after the decision authority has granted nuclear launch authorization, and showing how these issues have been assessed and communicated.

4.14.4 The NFSO can document activities in this area in ways that are relevant to the particular mission context. For example, the NFSO can upload explanatory notes the OSMA Flight Projects database for minor issues and issue memoranda to the Chief, Safety and Mission Assurance, for significant issues.

4.15 SNS Decommissioning and Disposal

4.15.1 NPR 8715.26 contains one requirement related to decommissioning and disposal, contained in Section 4.6.3. That requirement responds to the federal policy statement for safe disposal contained in SPD-6. Otherwise, decommissioning and disposal activities related to the SNS are addressed in either mission-specific requirements levied by the terrestrial nuclear authority (DOE, NRC, or EPA) or via broader decommissioning and disposal mission activities such as: (i) the NPR 7120.5 requirement that the SMAP address decommissioning and disposal,

(ii) the End-of-Mission Plan requirements in NPR 8715.6 related to orbital debris, (iii) the Disposal Plan required by NPR 7123.1, and (iv) unique considerations identified during planetary protection activities or related to the tenets of the Outer Space Treaty.

4.15.2 The NASA Project Manager can use the following strategies to develop the decommissioning and disposal plan (Appendix O provides additional information):

4.15.2.1 Structuring the disposal strategy to mitigate the impact to the public, astronauts, existing mission operations, and any planned or envisioned future missions;

4.15.2.2 Demonstrating through analysis that the operation and disposal of the SNS meets the intent of SPD-6, and showing how the risks of exposure to the public from accidents compare to the Safety Guidelines in NSPM-20;

4.15.2.3 Using reliability and maintainability, system safety, and risk management standard practices when addressing the transfer of an operating or hot SNS between orbits;

4.15.2.4 Addressing non-proliferation and security concerns when addressing disposal for SNS using special nuclear material;

4.15.2.5 Fulfilling the requirements of NASA-STD-3001 regarding crews' anticipated exposures from the disposed SNS.

4.15.3 The NASA Project Manager can demonstrate effective argumentation in this area by developing a consensus position in collaboration with partners and stakeholders regarding the adopted approach and the competing constraints.

4.15.4 The NASA Project Manager can document activities in this area in some combination of the SMAP, the End of Mission Plan, and the Disposal Plan. Approval of these plans, successful completion of KDPs, and successful completion of the FRR and the SMSR serve as the final evidence of consensus (and the basis of compliance).

4.16 Internal and External Reporting

4.16.1 NPR 8715.26 identifies three requirements to be carried out by the NFSO in this area. The first relates to internal communications and it directs the NFSO to transmit copies of specific documents to the NASA HQ NEPA Manager and the Chief Health and Medical Officer to support cross-coordination between nuclear-related responsibilities at the NASA HQ level. The second and third are specific requirements that NSPM-20 levies upon NASA regarding reporting to the White House on launches of SNS.

4.16.2 The NFSO can use the following strategies when carrying out these requirements:

4.16.2.1 For internal communications:

4.16.2.1.1 The identified parties (NASA HQ NEPA Manager and CHMO) are the minimum subset of recipients, and the NFSO should also consider copying other relevant

NASA HQ and Center-level personnel or posting them (when appropriate from an information security perspective) to shared IT platforms;

4.16.2.1.2 The OSMA Flight Projects system is an appropriate place to capture these documents;

4.16.2.2 For the external communications:

4.16.2.2.1 Specific points-of-contact should be identified within affected Mission Directorates and other NASA HQ Offices in order to ensure the products reflect an agency view;

4.16.2.2.2 The Office of International and Interagency Relations should handle the transmission of the completed products to the White House and should coordinate briefings with the White House;

4.16.2.2.3 The NFSO should upload products transmitted to the White House into the OSMA Flight Projects Database.

4.16.2.3 Appendix P provides additional information.

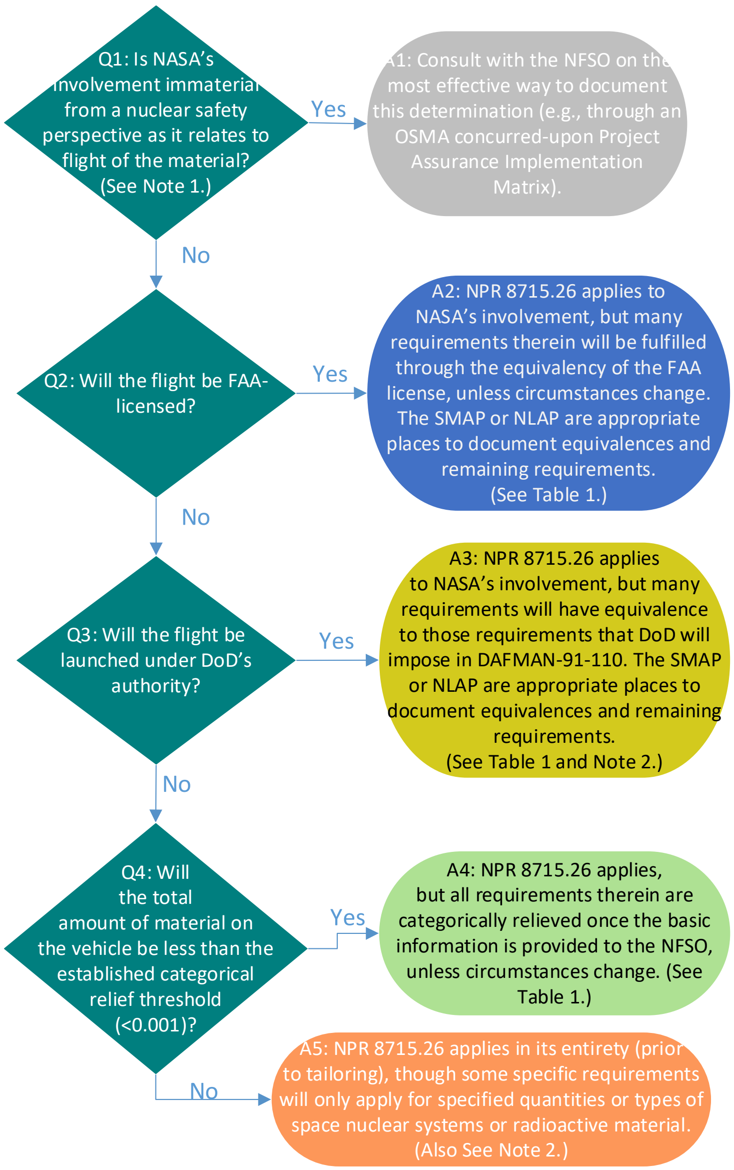
4.16.3 The NFSO can demonstrate effective argumentation in this area by soliciting and receiving feedback on an annual basis as to whether internal stakeholders agree that they are properly informed. For external communications, and in years when a briefing occurs to OSTP on an ongoing mission, the NFSO should solicit feedback from OSTP staff regarding their satisfaction on the level and mode of engagement.

4.16.4 The NFSO can document activities in these areas through uploading the relevant materials to the OSMA Flight Projects repository and conveying feedback received to OSMA management during the annual state-of-the-program review.

APPENDIX A. NASA Nuclear Flight Safety Applicability and "Whole of Government"

To help frame the discussions that occur in this regard, Figure 1 presents a decision-making rubric for NASA nuclear flight safety applicability. This is not a definitive means of making this determination, but by providing an anchor for discussions, it will help to make the outcomes of such discussions more predictable and repeatable. While the scope of this document is SNS missions, this decision-making rubric is also generally useful for flights involving other radioactive material (e.g., small radioactive sources used for calibration of scientific devices).

Ongoing discussions with terrestrial nuclear authorities, range safety authorities, and other relevant government agencies will lead to additional opportunities to refine this rubric and to more effectively leverage equivalences with other agencies' processes.



Note 1: In this context, "immaterial" means no direct or indirect responsibility for managing activities that will affect protection of the public, the NASA workforce, or high-value assets (on Earth), during launch or flight. Answer "no" if the nuclear or other radioactive material will be under a NASA NRC or Agreement State license during pre-launch processing, if the launch/return will occur under the direction of a NASA launch Center/Range, if NASA is providing launch services, or if NASA has a substantial involvement in development of the vehicle. "No" is the default answer (exceptions and equivalencies are addressed later in the process). Answer "yes" if NASA is only contributing non-nuclear and non-radiological services or supplies (such as deep space communications services) to a spaceflight for which NASA otherwise has no involvement. Even in this case, it may still be prudent to develop a communication plan so that relevant parties are briefed in advance of NASA's involvement and are armed with appropriate talking points in the case of a mishap.

Note 2: If the nuclear or other radioactive material in question is under DOE authorization, then the NASA program or project may choose to utilize an interagency agreement to codify distribution of responsibilities, and to ensure that DOE's nuclear authority is being appropriately respected.

Table 1

	FAA License	DoD-Authorized Launch	NASA Categorical Relief
Characteristics for the Purposes of Nuclear Flight Safety			
Space Nuclear System Tiering	Addressed by the FAA launch/reentry license*	Addressed by the DoD authorization process in DAFMAN-91-110*	N/A
Categorization for Other Missions with Radioactive Material			Notify NFSO of basic flight info (e.g., see NPR 8715.26 App. F)
Other Foreseen Circumstances	*Catchall to consult with OSMA/OGC if applicability of nuclear flight safety requirements is unclear*		
Nuclear Flight Safety Requirements			
Nuclear Safety Analysis	Addressed by the FAA launch/reentry license*	Addressed by the DoD authorization process in DAFMAN-91-110*	N/A
Nuclear Safety Review			
Launch and Reentry Authorization or Concurrence			
Contingency Planning and Coordination (when applicable)	Case-dependent		
Life-Cycle Activities Relevant After Launch Authorization	Case-dependent	Case-dependent	
Internal and External Reporting	Only contains OSMA actions		

*OSMA situational awareness is still needed to facilitate responding to inquiries

Figure 1: Guide for Assessing Whole-of-Government Effects on Nuclear Flight Safety Applicability

APPENDIX B. Nexus of Nuclear Flight Safety to Mainstream Spaceflight Activities

B.1 Overview of General Touchpoints

B.1.1 Nuclear flight safety compliments routine NASA processes to address the specific aspects that are relevant to the spaceflight of an SNS. In practice, the degree to which the nuclear flight safety activities integrate directly into these more routine processes versus the degree to which the nuclear flight safety activities are an additional layer of activity varies. Table 1 provides a very simplified overview as a starting point for making connections between nuclear and nonnuclear disciplines and activities that rely upon each other. In general, NASA personnel use interagency agreements to establish and manage roles and responsibilities when multiple government agencies are involved. NASA personnel use varying process tools to manage the transfer of work products across organizational interfaces. Process tools may include an Interface Control Document, Compliance Matrix, End Item Data Package, and Buy-Off meeting to manage the transfer of an RTG from DOE’s fabrication facilities to the NASA launch center.

Table 1: Relationship of Nuclear Flight Safety Activities to Broader Spaceflight Activities

Area of Activity	**Other NASA TA Directives and Activities**	**Nexus with Nuclear Flight Safety**
NEPA	NPR 8580.1	There is no direct nexus as described in the Preface of NPR 8715.26; however, cooperation with these activities is appropriate.
Facility System Safety for Ground Testing	NPD 8820.2	The relevant DOE or NRC directives would apply to DOE or commercial facilities; NASA would clearly be involved for NASA facilities (e.g., launch center processing facilities), and there is little experience base for processing fission reactors at a launch facility (nevertheless, the nuclear flight safety team is an interested party, and not an owner, of this safety area).
Life Cycle and Project Management Establishment	NPR 7120.5	NPR 7120.5 specifies that a SNS mission must be Project Category 1.
Risk Classification	NPR 8705.2 or 8705.4	Tailoring in other disciplines implicitly affects nuclear flight safety, but nuclear flight safety requirements are not themselves tailored on the basis of risk classification or human rating.
Establishment of Independent Review	NASA Standing Review Board, per NPR 7120.5	The NASA Standing Review Board performs activities in accordance with NPR 7120.5. Meanwhile, NPR 8715.26 contains requirements specific to NASA's involvement with the INSRB required by NSPM-20 for Tier II and III missions.
Establishment of SMA Requirements	Established through the SMAP	NPR 8715.26 contains requirements specific to the nuclear flight safety program.
Establishment of an S&MS Assurance Case	Not currently required	This handbook includes a general assurance case for nuclear flight safety for illustration, but such an assurance case is not a requirement at this time.
Safety Culture	NPD 8700.1	NPD 8700.1 contains policy tenets for safety culture, in general.
System Safety	NPR 8715.3, Chapter 2	NASA does not have nuclear-specific requirements in this area. NRC or DOE requirements may apply (prior to launch or upon return).
Risk Management	NPR 8000.4	NASA does not have nuclear-specific requirements in this area; NRC or DOE requirements may apply (prior to launch or upon return).
Orbital Debris	NPR 8715.6, SPD-6	SPD-6 includes requirements related to the disposal of SNS in some contexts; beyond the invocation of these requirements in NPR 8715.26, there are no nuclear-specific orbital debris requirements.
Planetary Protection	NPR 8715.24	The Team considers thermal and radiation effects specific to nuclear devices within the planetary protection activities. Disposal may be affected by planetary protection considerations (as was the case for Cassini).
Other disciplines--EEE Parts, Quality, Reliability & Maintainability, Software Assurance	Applicable directives vary by topic	NASA does not have nuclear-specific requirements in most of these areas; some requirements do have dual-relevance (e.g., NASA-STD-8739.10's radiation hardness assurance items); NRC or DOE requirements may apply (prior to launch or upon planned return).

Area of Activity	Other NASA TA Directives and Activities	Nexus with Nuclear Flight Safety
Launch Vehicle Risk Mitigation Policy	NPR 8610.7 for NASA-provided Launch Services	NPR 8610.7 specifies that Class A payloads (per 8705.4) will launch on Risk Category 3 (low risk) vehicles, while Class B payloads may launch on either Risk Category 3 or Risk Category 2 (medium risk) vehicles.
Health and Medical for Human Space Exploration	NPR 8900.1, including NASA-STD-3001	NASA-STD-3001, Volume 1, Revision B, Section 4.8.4 includes specific requirements for crew radiation limits for nuclear technologies.
Terrestrial Nuclear Safety Analysis	N/A	Follows the requirements of DoD, DOE or NRC, as applicable.
NASA Flight Safety Analysis	NPR 8715.5 and NASA-STD-8719.25 address Range Flight Safety	NPR 8715.26 addresses the nuclear flight safety requirements for NASA SNS missions, which flow down from NSPM-20 and heavily leverage the nuclear safety analysis, as adapted to the spaceflight situation.
Interagency Review of the Nuclear Flight Safety Analysis	Varies, depending on the participating parties and generally relies on the Agency Flight Safety Analysis	NPR 8715.26 addresses the nuclear flight safety requirements for SNS missions, which flow down from NSPM-20 and involve the INSRB for Tier II and III missions.
Payload Safety, including Ground Systems Requirements	NPR 8715.7 and NASA-STD-8719.24 and NASA-STD-8719.24-Annex	NASA-STD-8719.24-Annex, Volume 3, Chapter 9 addresses payload and ground system requirements for ionizing radiation sources. NASA-STD-8719.24-Annex, Volume 6, Chapter 9 addresses ground and launch personnel, equipment, systems, and material operations safety requirements for ionizing radiation source operations; the comments under "Facility System Safety for Ground Testing" also apply here.
Center Institutional Safety & Health	NPR 8715.1 and NPR 1800.1	NPR 8715.1 Chapter 11 addresses radiation safety requirements for protecting the public and workforce from risks associated with the handling, use, and storage of radioactive material and radiation generating equipment by pointing to NPR 1800.1 (Sections 4.13–4.15 address radiation and radioactive materials).
Other Nuclear-Centric Aspects of AI&T and ATLO	N/A	SNS launches have occurred only from KSC in recent decades. NASA developed site-specific and mission-specific plans.
Flight Readiness	Certification of Flight Readiness Process	NPR 8715.26 contains requirements related to the Federal launch authorization process in NSPM-20. Separately, the OSMA NFSO reports Nuclear Flight Safety readiness to the Chief, SMA during the SMSR, as part of the overall NASA HQ flight readiness activities.
Mishap Preparedness, Contingency Planning, and Emergency Response	NPD 8710.1, NPR 8715.2, NPR 8621.1	NPR 8715.26 contains requirements specific to an SNS launch, including consideration of the Nuclear/Radiological Incident Annex to the Response and Recovery Federal Interagency Operational Plans. This planning effort involves an extensive amount of coordination with entities identified in NPR 8715.26 and in this Handbook
Monitoring and Requests for Relief During Pre-Launch, Launch, and Subsequent Operation	NPR 8715.3, the PSWG, and the Range Safety Risk Management Process	NPR 8715.26 contains recommended practices to ensure that the NFSO is aware of emergent issues that may impact radiological risk. A nuclear-specific subject matter expert can participate in the PSWG, but this is not currently required. DoD or FAA may have additional applicable requirements

Area of Activity	Other NASA TA Directives and Activities	Nexus with Nuclear Flight Safety
End of Mission Planning and Execution	NPR 7120.5 and NPR 8715.6	NPR 8715.26 includes a nuclear-specific requirement that flows from SPD-6. Beyond this, the Team addresses these issues via routine processes.

B.2 Specific Areas of Commonality and Misunderstanding

B.2.1 Launch Vehicle Reliability and Failure Estimates

B.2.1.1 Activities that address the likelihood that a launch vehicle will successfully perform its function, or conversely that it will fail to perform its function, appear in differing contexts that present opportunities for both leveraging resources and introducing confusion.

B.2.1.2 **Launch vehicle provider reliability studies**–Launch vehicle providers perform reliability and system safety activities to inform the design, development, and operation of their launch vehicles to understand and manage technical and competitive or commercial risks. These activities utilize assumptions regarding data and methods that are largely dictated by the entities' own needs and decision-making. These entities typically use MIL-HDBK-217F2/ANSI-VITA 51.1 and NASA/SP-2009-569 (Bayesian Inference) to develop fault tree models. The modelers often develop and execute these models in a tool like SAPHIRE (Systems Analysis Program for Hands on Integrated Reliability Evaluations) to provide an overall vehicle and mission reliability estimate. The overall estimate encompasses multiple phases of a mission profile. Examples of analyzed phases include (but are not limited to): ground processing, individual vehicle stage performance, subsystem components, and spacecraft and interface accommodations. Modelers typically use reliability predictions that are based on worst case vehicle configuration(s) and mission timelines. Given the nature of Bayesian updating, reliability estimates are constantly in flux as a vehicle or family of vehicles gains additional flight experience.

B.2.1.3 **NASA Launch Services Program vehicle certification activities**–NASA's Launch Services program uses its own set of data and methods to perform vehicle certification activities, which is outlined in NPD 8610.7. Non-recurring mission assurance (or certification) is NASA's launch service risk mitigation policy. The attributes of each candidate launch vehicle for prospective NASA sponsored missions are individually evaluated to determine a risk category level. Attributes studied include flight experience, design evaluation, and process-driven elements. The aforementioned categories are further broken out into specific areas of evaluation that include (but are not limited to): flight margin verification, system and sublevel component hardware and software qualification, system safety, design reliability, risk management, and launch vehicle analysis. The process elements determine whether repeatable practices are in place to ensure that the LV is designed, manufactured, assembled, and tested in a way consistent with industry experience and LSP requirements and specifications. In addition, NPD 8610.7 is meant to complement NPD 8610.23 which refers to NASA's recurring mission assurance and launch vehicle technical insight and oversight. LSP's technical strength lies in a broad range of engineering disciplines with an end-to-end systems engineering perspective. The overall objective is to decrease mission risk through review and verification of mission unique requirements and analyses, and relevant fleet issues. LSP technical disciplines further coordinate with mission-specific integration engineers, vehicle system engineers, and The Office of the Chief Engineer for final technical authority. Finally, the SMA technical authority performs an independent assessment of the LSP and launch service contractor's decisions.

B.2.1.4 **Common Standards Working Group Probability of Failure working group**–The tri-agency (NASA, FAA, DoD) Common Standards Working Group also estimates launch vehicle probability of failure for the purposes of informing the ground and flight safety analysis performed for each launch. This analysis addresses issues like debris hazards and distance focused over-pressure.

B.2.1.5 **Nuclear Vehicle/Mission Databook accident probability analysis**–During the development of Databooks for use in nuclear launch authorization activities, LSP and its contractors develop PRAs that include estimates of the probability that a launch vehicle will experience one or more failures. The purpose of a PRA is to define and quantify accident scenarios (accident initiating conditions-AICs and accident outcome conditions–AOCs) that a given launch vehicle poses that could adversely influence or damage a nuclear payload. The assessments cover each phase of the mission including pre-launch, early-launch, late-launch, sub-orbital, orbital, and interplanetary. Analysts typically develop numerous fault trees and event sequence diagrams in conjunction with Bayesian updating, similar to launch vehicle provider reliability studies. Analysts quantify the accident sequence models using a combination of reliability data obtained from launch vehicle success and failure history and data provided by the launch vehicle manufacturer. Analysts then use the data provided by the launch vehicle manufacturer to derive initial estimates of basic initiating events and AIC probabilities. Next, the analysts use the launch vehicle success and failure history data to obtain "posterior" AIC probability estimates via Bayesian updating techniques. These estimates often contain certain conservatism, such as human error contributions and immaturity discounting, and should not be interpreted as reliability estimates for the launch vehicle itself. The nuclear safety analysis team then uses this information and the associated probability data generated by the analysis as inputs for the nuclear safety analysis.

APPENDIX C. Nuclear Flight Safety and the NASA Program and Project Life Cycle

C.1 General Information

C.1.1 Table 2 provides a listing of the major nuclear-specific documents discussed in this Handbook. Figure 2 provides an overview of nuclear flight safety-related activities within an overarching life cycle. This is intended as a starting point for a nuclear-enabled Program or Project to develop a mission-specific equivalent. If a mission chooses to use this type of presentation as a means of tracking assurance case evidence, personnel could expand each topical area into its own separate chart to enable evidence tracking. This presentation approach could also form the basis for developing content for the NLAP and an associated compliance matrix if that is desired. This template schedule may be expanded in future versions of this Handbook to link in other content within this Handbook and the assurance case concept itself.

C.1.2 Table 3 provides the layout for a companion LCR entrance and success criteria table that would support the above-described activities.

Table 2: Primary Nuclear-Specific Documentation

Document Name	Origin	Suggested Mission Life Cycle Phase	Convening Authority	Decision Authority	Internal Concurrers	External Concurrers
NLAP	NPR 7120.5	Baseline in Phase A	MDAA	PM	OSMA Chief (incl. input from NASA INSRB Member and NFSO)	
Nuclear Launch Authorization Basis Strategy (NLABS)[1]	This Handbook, INSRB Playbook	Baseline in Phase B	MDAA	PM	NFSO	Nuclear Authority
Launch Vehicle Databook	Common practice	Baseline in Phase B or C	PM	PM, Launch Center Inst. Auth.	Launch Services	-
Nuclear Launch Authorization Terms of Review	NSPM-20, NPR 8715.26	Baseline in Phase B or C	MDAA	NASA Adm.	PM, OSMA Chief	Nuclear Authority, INSRB
Mission Nuclear Safety Analysis Report (SAR)	NSPM-20, NPR 8715.26	Complete in Phase D	MDAA, Nuclear Authority	PM, Nuclear Authority	NFSO	-
Nuclear Authority Nuclear SER	Nuclear Authority	Complete in Phase D	Nuclear Authority	Nuclear Authority	-	-
INSRB Nuclear SER	NSPM-20, NPR 8715.26	Complete in Phase D	NASA Adm.	INSRB	-	INSRB Review Group
Nuclear Launch Authorization	NSPM-20, NPR 8715.26	Complete in Phase D	NASA Adm.	NASA Adm. or EOP	OSMA Chief, Launch Center Director	Nuclear Authority
Radiological Contingency Plans	NPR 8715.26	Complete in Phase D	MDAA, Launch Center Director	MDAA, Launch Center Director	OCHMO, OIIR, OPS	Nuclear Authority

[1] This item is intended to generally encompass a Safety Design Strategy (SDS) when an SDS is used as a part of the system safety basis.

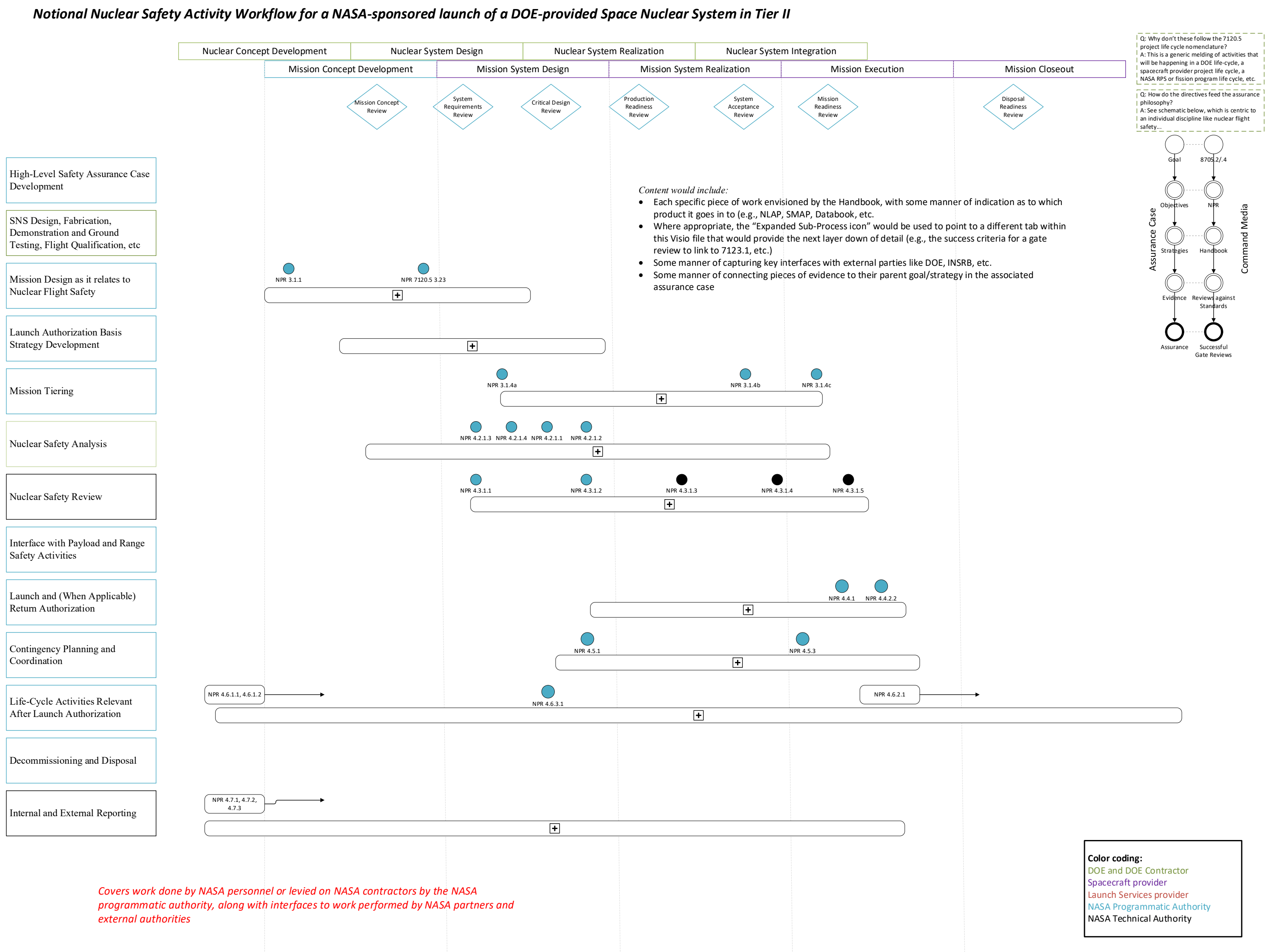


Figure 2: Nuclear Flight Safety Activities Within the Overall Life Cycle - Example

Table 3: LCR Entrance and Success Criteria

Entrance Criteria	Success Criteria
Mission Concept Review	
1. The mission baseline includes the intent to use an SNS and the Mission Directorate has notified the NFSO.	1. The mission has presented evidence that demonstrates that nuclear flight safety considerations (such as those discussed in Section 4.6.1.1 of NPR 8715.26) are addressed in all relevant activities, including risk trades. 2. The mission has presented evidence that demonstrates that radiation exposures from the SNS are addressed in mission planning (where applicable).
System Requirements Review	
…	…

C.2 Information on the NLAP

C.2.1 The purpose of this section is to provide an example of the notional flow of the top-level processes and deliverables associated with obtaining launch authorization as put in practice for a genericized SNS mission. The signed mission-specific NLAP codifies the process. The purpose of this document is to outline the project's support for ensuring the U.S. Government Nuclear Flight Safety and Launch Authorization Process proceeds smoothly and is completed prior to the launch date for the mission. The plan identifies the top-level expected project support for the Nuclear Flight Safety and Launch Authorization Approval process per NPR 8715.26, Nuclear Flight Safety, and NSPM-20. For each milestone product, the plan will indicate which organization is responsible for developing and delivering that product. The following are examples of the information included in the NLAP for an SNS-enabled mission.

C.2.1.1 Core Team Members and Process

C.2.1.1.1 In this example, the mission specific core launch authorization team consists of the following members: Program Executive (mission specific), an executive from the entity providing the SNS and the SAR, NASA nuclear launch authorization lead, flight project launch authorization lead (mission specific), LSP representative, and a nuclear safety subject matter expert (such as from the Department of Energy). Additional effort in supporting meetings and pre-work by support contractors is expected.

C.2.1.2 Preliminary Tier Determination

C.2.1.2.1 As the plan is developed and updated for mission PDR, the mission has the option of using the NLAP to serve as the preliminary tier determination (PTD) documentation. This PTD is made immediately preceding KDP-C, as that life cycle gate is defined in NPR 7120.5. The team will make the PTD based predominantly on the material-at-risk (A2 mission multiple–see Appendix D in NPR 8715.26). The team will also consider information related to the potential radiation exposure levels and associated likelihoods from the safety analyses of relevant past missions. This determination serves to provide initial alignment and clarity as to whether the team should engage the INSRB and who the team should identify as the authorizing official for the launch. This determination also serves to lock in the IAEA-issued A2 values applicable to the mission. Also, for example, during an RPS-enabled mission, DOE, as the terrestrial nuclear authority, provides an official correspondence calculating the mission's overall activity. This is used as a basis for the PTD and the NASA team can include this as an appendix in the NLAP.

C.2.1.3 Required Documentation

C.2.1.3.1 The launch authorization required documents listed below are described in the NLAP:

C.2.1.3.1.1 Mission SAR

C.2.1.3.1.2 INSRB SER

C.2.1.3.1.3 Radiological Contingency Plans

C.2.1.3.1.4 Launch Authorization Package for Administrator Concurrence

C.2.1.3.1.5 Launch Authorization Package for OSTP Concurrence (Tier III)

C.2.1.4 Additional Supporting Documentation

C.2.1.4.1 To meet NPR 8715.26 requirements and to support the documents listed in Section C.2.1.3, personnel will develop the following documents:

C.2.1.4.1.1 Preliminary Tiering Determination (if not included in the NLAP)

C.2.1.4.1.2 SDS

C.2.1.4.1.3 INSRB Terms of Review

C.2.1.4.1.4 Mission SAR Databook

C.2.1.4.1.5 Terrestrial Nuclear Authority SER

C.2.1.4.1.6 Provisional Tiering Determination

C.2.1.4.1.7 Final Tiering Determination

C.2.1.4.1.8 Agency Views, if applicable

C.2.1.5 NLAP Milestones and Deliverables Schedule

C.2.1.5.1 This section provides a comprehensive schedule for all milestones and deliverables in the NLAP.

APPENDIX D. High-Level Safety Assurance Case Development

Over the past few years, OSMA has been moving towards objective-driven methods of safety and mission success assurance in which programs and projects are encouraged to make a positive argument supported by evidence that the program or project have met the objectives of the life cycle phase and that the program or project is on track to meet stakeholder expectations. Nevertheless, the approach documented in the current version of NPR 8715.26 uses a more detailed and prescriptive format, with the notable exception of the approach to radiological contingency planning. The expectation is that the next revision of NPR 8715.26 will move further toward the objective-driven approach. Meanwhile, this Handbook generally supports the case-assured model, in terms of structuring each topical area in terms of strategies, argumentation, and evidence. To further support this evolution, this appendix presents an example of a top-level assurance case for nuclear flight safety shown in Figure 3.

From this example, NASA personnel could develop a mission-specific to guide nuclear flight safety activities, including the potential to drill down to the point of linking specific spaceflight project activities (like those discussed throughout this Handbook) to these higher-level strategies and objectives. This would be particularly relevant if a spaceflight project team adopted an MBSE or MBSMS approach. The example here is simply a static schematic. Existing tools like AdvoCATE and the Systems Engineering and Assurance Modeling tool (modelbasedassurance.org) can handle more complex assurance cases, including linking to other project elements (e.g., MBSE). NASA personnel can obtain additional information on assurance cases from references like:

1) Adelard Safety Case Development Manual, 1998

2) A CubeSat-Payload Radiation-Reliability Assurance Case using Goal Structuring Notation, R.A. Austin et al., RAMS, 2017

3) SACM, Version 2.1, 2020

4) SEAM: A Web-based Solution for Integrated Mission Assurance, K.L. Ryder et al., *Electronics and Energetics* Vol. 34, No 1, March 2021, pp. 1-20

For now, this Handbook only provides the example in Figure 3 and the above information to stimulate discussion. NASA personnel are developing a NASA Technical Standard for preparing Safety and Mission Success Assurance Cases and expect that the template assurance case in Appendix D of this handbook will evolve significantly as norms in this area evolve within NASA.

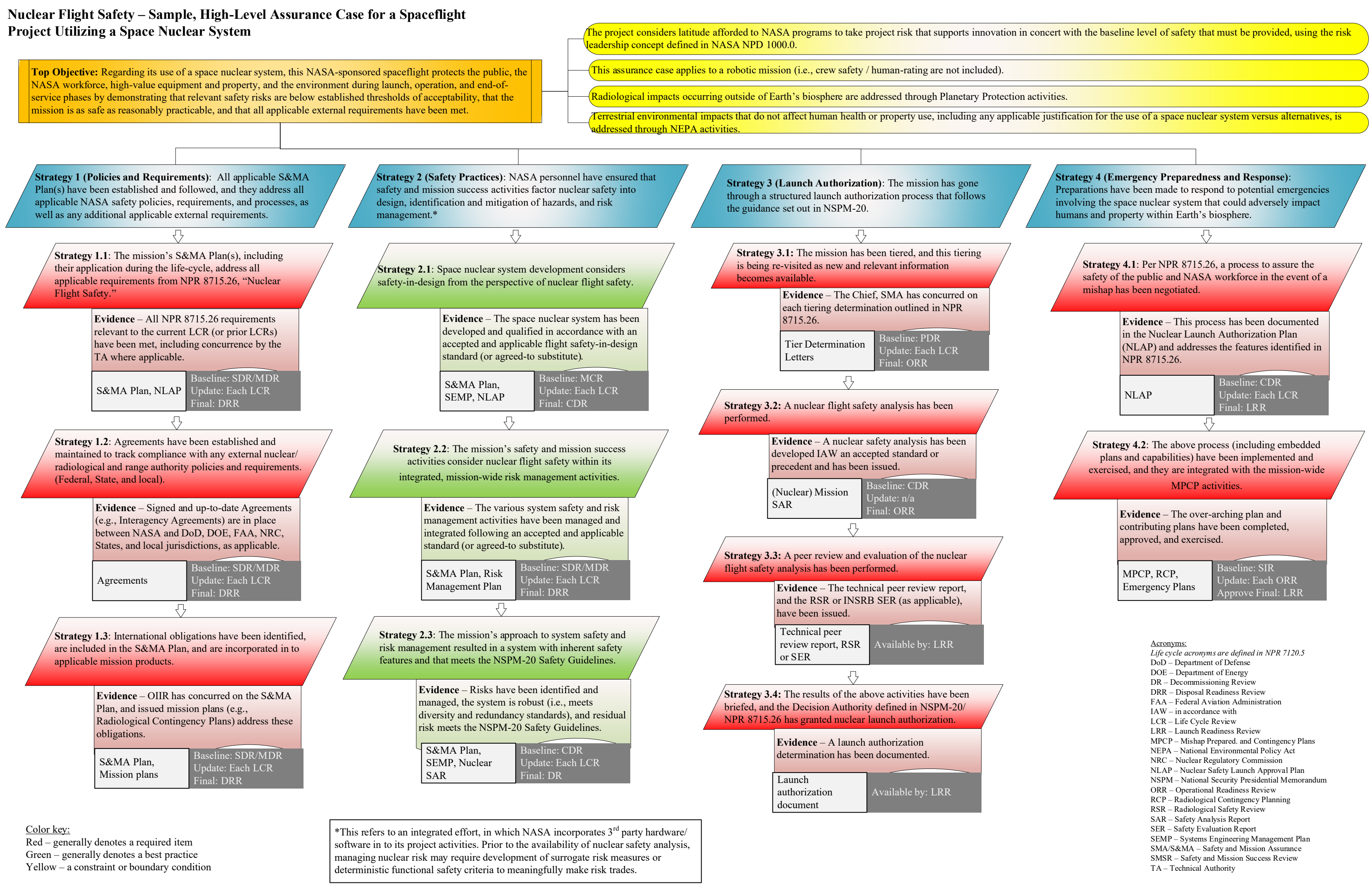


Figure 3: Example High-Level Assurance Case

APPENDIX E. SNS Design, Testing, and Handling as it Relates to Nuclear Flight Safety

E.1 Safety-in-Design

E.1.1 Considerations in Developing Functional Safety-in-Design Criteria

Personnel typically develop the risk assessment model used to support the safety case for nuclear flight safety during a period of time spanning one to three years before the scheduled launch. This means that a draft sufficient for providing risk insights related to nuclear flight safety is not typically available until roughly two years before the scheduled launch. By this time, personnel have made virtually all major design decisions for both the system and the mission. As such, the project often make these system and mission design decisions based on risk trades that do not utilize the radiological risk assessment (though personnel can use insights from past risk assessments when applicable). For this reason, personnel often use deterministic criteria as an effective way of ensuring that they are considering broad nuclear flight safety interests at these earlier stages.

The 2015 NPAS study states, "Before the design of a U.S. space nuclear system can proceed in earnest, clear safety criteria must be in place to guide designers and mission planners." Personnel have used such criteria throughout decades of developing RPS systems. Personnel working on fission development efforts also typically relied on such criteria. A structured approach to safety adapted from (Sholtis, 2005) may involve steps like:

1. Establishing a safety philosophy and risk posture for the mission;

2. Establishing the unique safety issues relevant to the mission and a strategy for addressing those issues;

3. Establishing a minimum set of intent-based safety principles that can address those safety issues and promote eventual conformance with the NSPM-20 Safety Guidelines and the tiering criteria for the intended NSPM-20 tier level; and

4. Establishing binding design and operational safety specifications to guide efforts and assure safety.

(Helton, 2023) discusses this topic in more detail and provides information related to potential fission system design criteria.

E.1.2 Inadvertent Criticality During the Ascent Phase

The authors will developed this section at a later time. In the interim, example considerations are provided as follows:

- For neutron-moderated, low-enriched uranium-fueled SNS, an assessment of inadvertent criticality would include analyses and evaluations to demonstrate that long prompt neutron lifetime and U-238 Doppler feedback, when considered with safety devices, cannot produce inadvertent and sustained criticality.

- Regarding the use of the flight safety system as a means of precluding inadvertent criticality, one proposed criterion is to use the flight safety system approach if it cannot be shown that the occurrence of less than 10^{20} fissions has a probability of less than 1 in 10,000.

E.2 Demonstration and Ground Testing Impacts on Nuclear Flight Safety

E.2.1 Zero- or Low-power Physics Testing

The authors will develop this content at a later time.

E.2.2 Assessing the Needed Cool-down Period for Ground-Tested Fission Systems

The authors will develop this section at a later time. In the interim, example considerations include the following:

- If a fission system is ground tested prior to ATLO and launch operations, analysts need to consider the additional hazard (beyond issues like inadvertent criticality and hot reentry) posed by the radioactive fission products. Ground safety, payload safety, and nuclear flight safety would all be relevant, but this document focuses primarily on the nuclear flight safety aspects.

- In some cases, it may be simplest to demonstrate that the fission products generated during ground testing are *de minimis* relative to other common flight risks. For instance, if analysts can show that the system has an A2 mission multiple below 0.001 (the current NASA categorical relief threshold) then they can reasonably argue that the system would not present an elevated risk from a nuclear flight safety perspective. To make this determination, the analysts would need to estimate the fission products and their quantity.

- In other situations, it may be appropriate to specify an *a priori* total radioactivity limit (e.g., less than 10 Curies of total fission products) and justify by analysis that this quantity is not likely to contribute significantly to the dose exceedance risks in the NSPM-20 Safety Guidelines.

E.3 Flight Qualification Impacts on Nuclear Flight Safety

Many flight qualification activities are focused on engineering, performance, and mission assurance, and do not have a nexus to nuclear flight safety. Meanwhile, NASA guidance (for non-nuclear and space nuclear aspects) or the terrestrial nuclear authority (for all aspects germane to that authority's activities) generally dictates the specifications, standards, and other conditions relevant to flight qualification. Nevertheless, some aspects of flight qualification are germane, in that they provide the design basis of the system. It is the system's design basis that will either prevent accident scenarios from progression to radiological release, or that will be defeated by beyond-design basis accident environments. Design-basis testing and analysis establishes a baseline system response to accident environments that are within, or just outside, of that design basis. In particular, the following typical flight qualification tests will likely provide useful information for the nuclear safety analysis, and there may be opportunities to make minor adjustments in these test campaigns that provide significant additional information relevant to the technical basis of that nuclear safety analysis:

- Thermal testing– This testing includes establishing empirical or analytical correlations that personnel use to estimate the temperatures of key components during pre-launch and launch as part of material response modeling.

- Random vibration tests–This testing addresses damage that may occur to the SNS's engineering safety features in the early portion of a mishap, before later and more significant damage from an impact, blast, or fire environment.

- Quasi-static load tests–Similar to the thermal and random vibration testing described above.

- Pyroshock tests– Similar to the thermal and random vibration testing described above.

E.4 Integration of the Nuclear Components into the SNS

The authors have not developed material for this section yet. A future revision of the Handbook may describe considerations related to insertion of the radioactive material into the SNS (for RPS) or the reactor core into the SNS (for reactors). This step could occur prior to transport to the launch site (wherein storage or aging effects may be relevant), at the launch site (wherein competing demands with planetary protection cleanliness standards, personnel radiation safety, or security may be relevant), or in-space (wherein there might be no relevance to nuclear flight safety). In all cases, the interest here is with the nexus of these activities to nuclear flight safety.

E.5 Storage and Transport Impacts on Nuclear Flight Safety

The authors have not developed material for this section yet. The following are examples of they type of information that the authors may choose to include in future revisions of this Handbook:

- Aging issues during storage (such as the plutonium aging issue investigated during past radioisotope power system activities);

- Terrestrial nuclear authorities (specifically those of the Department of Energy, the Department of Transportation, and the Nuclear Regulatory Commission) address safety issues related to transportation to the launch site. An effect of ground transportation on nuclear flight safety may occur if engineers must permanently alter the designed and fabricated SNS to accommodate an emergent ground transportation-related issue. Since that emergent issue may arise after completion of the mission nuclear safety analysis and review, it is important to assess this possibility in advance (to increase the likelihood that the as-analyzed system is sufficiently equivalent to the as-flown system and to minimize unnecessary major change control process issues after the nuclear safety analysis is complete).

E.6 Launch Facility Assembly, Integration, and Test Impacts on Nuclear Flight Safety

E.6.1 Managing Competing Safety and Mission Demands

The authors have not yet developed material in this section. The following are examples of considerations that the authors may choose to include in future revisions of this Handbook:

- Potential managing of competing risks as nuclear flight safety pushes toward careful integration and testing of ground cooling, planetary protection pushes for cleanliness in flight hardware, and personnel safety pushes for keeping doses ALARA;

- Nuclear flight safety guidelines may push personnel to keep the device within a certain temperature regime to promote advantageous material properties (e.g. ductility, moderator temperature), but the thermal needs of other hardware within the payload faring may push engineers to consider different thermal environments.

- Redundancy and resiliency in GSE may have a bearing on pre-launch accident scenarios.

E.6.2 Spacecraft Integration Considerations

The authors have not yet developed material in this section. An example of a consideration that the authors may choose to include in future revisions of this Handbook is the implication that installing the device as late as possible has on vehicle integration facility design (additional platforms) and payload fairing design (potential need for additional access points).

E.6.3 Prelaunch System Maintenance and Monitoring

The authors have not yet developed material in this section. An example of a considerations that the authors may choose to include in future revisions of this Handbook is addressing cooling needs for RTGs or moderator exclusion needs for reactors while the spacecraft is buttoned up.

APPENDIX F. Mission Design as It Relates to Nuclear Flight Safety

At present, this appendix focuses predominantly on mission risk classification. Future revisions may expand to other mission-related considerations.

F.1 Mission Risk Classification Relative to Nuclear Flight Safety

F.1.1 Background

Traditionally, NASA has only flown SNS for flagship missions. With the further maturation of the technology, updates to streamline the launch authorization process, and more focus on risk leadership (as defined in NPR 1000.0), there is an apparent trend toward using SNS on a wider range of missions. NASA is committed to supporting the use of space nuclear power and propulsion systems, consistent with the 2020 National Space Policy.

F.1.2 Past Risk Classification of SNS Programs and Projects

The modern era of robotic mission risk classification began in 2004 with the issuance of NPR 8705.4. At that time, the Pluto New Horizons mission was well underway, so it did not undergo a robotic mission risk classification stage during pre-formulation. NASA originally classified the Mars Science Laboratory mission as a Class B mission and later reclassified it as a Class A mission. The Mars 2020 mission was a Class A mission throughout its entire life cycle. At no point during this time did NASA policy prescribe a risk classification based on the use of a SNS.

Meanwhile, the two major ongoing Radioisotope Power System Program Office projects of relevance, the Next Generation Radioisotope Thermoelectric Generator project and the Dynamic Radioisotope Power System project, are both Class B projects. In both cases, NASA personnel are working to ensure that any gaps are well understood if these systems were to fly on a spaceflight with a mission classification of Class A.

F.1.3 Landmarks for Current Federal and NASA Requirements

NSPM-20 establishes tiering criteria, and these are discussed further in Section 4.8 and Appendix H. Importantly, the new policy also establishes Safety Guidelines, or a measure of "How Safe Is Safe Enough?" These guidelines are based on the probability of exceeding a dose and, over time, it will be possible to leverage these guidelines to make decisions about whether project risks are affecting nuclear safety in an inadvisable manner. However, at present there is insufficient experience with use of these guidelines and insufficient alignment on how to perform the safety analysis and comparison to the guidelines. So, for the time being, analysts must judge the impact of relaxing these requirements more subjectively. Beyond establishing the safety guideline thresholds, the Federal policy relies on underlying agency-specific guidance for the details of implementation, as well as the purview of related activities (e.g., radiological contingency planning).

For NASA, NPR 8705.4 does not tie risk classification to the presence of radioactive or nuclear material, though there is some natural correlation between the other characteristics (e.g., complexity, cost) and the use of a SNS. Meanwhile, NPR 7120.5 does have such a tie, in that missions with a significant amount of radioactive material must be Project Category 1 (the least risk-tolerant category). Meanwhile, for missions subject to NPR 8610.7, there is no consideration specific to radioactive material, and a mission could fly on a Category 2 launch vehicle (the middle risk-tolerant category) if it had a mission risk classification of B or C.

Finally, nothing in NPR 8715.26 ties nuclear flight safety requirements to risk classification. All requirements applicable to the type of SNS or other radioactive material flown apply, regardless of mission risk classification, prior to tailoring or a request for relief.

F.1.4 Potential Impacts of Risk Classification on Nuclear Safety

A risk posture that accepts more organizational risk does not inherently correlate to a concerning degradation of safety. However, the application of standards that promote greater risk tolerance in some disciplines (e.g., quality, reliability and maintainability, software assurance) could have such an effect. Efforts in this area should focus on exploring the identification of such circumstances. Generically, there are two overarching areas that apply to all missions.

The first area relates to the launch vehicle selection. In general, SNS should launch on Category 3 vehicles (i.e., the least risk tolerant category). Absent that, personnel should perform an upfront analysis that justifies why a Category 2 or Category 1 vehicle is expected to provide either a comparable level of overall nuclear safety or a level of safety that clearly results in a favorable comparison to the NSPM-20 Safety Guidelines. While programs and projects are encouraged to manage risk in a way that might warrant selection of a lower-category vehicle, doing so when a SNS is present, barring justification, may result in an unacceptable challenge to mission success and an undue pressure on the nuclear flight safety analysis, review, and authorization process.

The second situation relates to the project risk management plan. Historically, NASA has performed loss-of-mission-focused PRAs, while the nuclear hardware provider has performed nuclear risk PRAs. Given the potential that relaxations in other discipline areas may have an adverse effect on nuclear flight safety in a way that is not readily identifiable by other means, other-than-Class A or human-rated missions that meet the NSPM-20 Tier II or Tier III criteria (i.e., typical radioisotope thermoelectric generator or fission device missions) should address radiological risk in a manner that directly relates to the NASA spaceflight project's system safety and risk management activities and compliments the use of deterministic criteria earlier in the life-cycle (see Appendix E, Section E.1). Such an activity must fully respect the other agency's authority in ensuring nuclear safety, and thus it must focus on managing radiological risk for those parts of the mission within NASA's purview.

A permutation of the above is the situation where NASA develops an SNS under a Class B risk classification and then seeks to fly that system as a Class B payload on a Class D mission. In such a situation, it is important to distinguish between those requirements that are unaffected by mission risk classification (e.g., the requirements in NPR 8715.26, which are tailored based on mission circumstances and not mission risk classification) versus those that are linked to mission risk classification. During the tailoring process specific to mission risk classification, evaluators may notice that some elements for the Class B payload have already been completed and that these elements are wholly unaffected by the system's use on a Class D mission. Meanwhile, the tailoring process can affect other elements (such as those related to payload integration and use), so engineers tailoring these requirements will need to take the risk classifications of both the payload and the mission into account. For SNS developed by other entities and used by NASA in turn-key commercial delivery situations, it will be important that the acquisition strategy acknowledges and addresses how external regulatory processes obviate the need for NASA projects and programs to comply with Federal requirements and NASA requirements (i.e., establishing equivalences between those external regulatory actions and the analogous NASA requirements).

F.2 Factors That Explicitly Impacted Mission Design in the Past

Future revisions of this Handbook may provide information on past lessons learned related to nuclear flight safety in mission design, including items like:

- Galileo's change of its Earth fly-by trajectory;
- Ulysses' and Galileo's use of a different upper stage than originally envisioned;
- Cassini's reduction in the size of its propellant tanks and modification of its flyby trajectory;
- Pluto New Horizons' addition of an auto-destruct system to the solid upper stage;
- Curiosity's use of a larger battery in the spacecraft to ensure that it could have a targeted reentry should it fail to leave Earth's orbit.

APPENDIX G. Nuclear Launch Authorization Basis Strategy Development

G.1 Data Gathering and Prior Effort Review

One of the first steps in preparing the authorization basis strategy is capitalizing on the lessons learned from prior missions. The NASA Project Manager should document the conceptual designs (or aspects thereof) considered and then engage in researching previous missions for information applicable to authorization basis strategy. The program needs to capture all relevant information, which will need to include not only NASA's missions, but also missions conducted by other organizations, government and commercial. Information initially captured should undergo a secondary review to ensure it is still current, given changes to policy.

Such information is likely to be derived from several sources including NASA archives, DOE activities, DoD activities, INSRB (or its predecessor's) activities, etc. Once identified, this information should become part of the program documentation. After it is reviewed, personnel should annotate the information to explain its usefulness.

G.2 Organization Structure

The NASA Project Manager should establish an organizational structure to execute the design, development, review, delivery, launch, operations, decommissioning, and disposal of the SNS and its interdependencies with the spacecraft, launch vehicle, and mission. This plan should:

1) Clearly establish the roles, responsibilities, accountabilities, and authorities for all aspects of the Program;
2) Include Program and Project management, engineering, review, safety, independent evaluations, approving authority, and any other organizational elements necessary to complete the activity;
3) Include discussion on how the Program will establish and maintain an effective safety culture;
4) Clearly establish the interconnections and reporting relationships between the various organizational elements of the activity (e.g., through organizational charts and discussion); and
5) Clearly establish the data products, information, reports, documentation, and other materials that should pass between these organizations.

G.3 Safety Plan

The NASA Project Manager should generate a plan (which might have some nexus to or overlap with the NLAP) for implementing the authorization basis strategy. Such a plan should include the program's approach to:

1) General design principles or general design criteria;
2) Safety strategy;
3) Approach for hazard analysis and mitigation;

4) Approach and requirements for transportation, integration, waste handling, and quality assurance to the extent that they affect launch authorization or flight safety through design or operation constraints;
5) Approach and requirements for safety (SMAP) and system engineering (SEMP) with expected tailoring relative to the appropriate standards;
6) Approach to validating and verifying safety methods and models;
7) Identification of relevant launch vehicle databooks and any data gaps that need to be addressed (e.g., data used to generate the mission-specific SAR from a pre-existing system-specific SAR).

The NASA Project Manager should complete this plan early enough in the mission planning process, ideally by MCR, to assure its thorough application during the development process. The plan should also identify and consider the Program's approach to addressing radiological hazards to the public and range safety environmental hazards associated with the mission.

G.4 Informing Safety Through Testing and Analysis

The NASA Project Manager should review the INSRB Playbook for activities that could inform the Safety Plan. Specifically, the NASA Project Manager should identify prior relevant testing and analyses performed by the current program or past programs that could support the Safety Plan. The NASA Project Manager could summarize and report those activities to provide evidence of the Project's readiness to proceed with flight system development. Some potential activities that the NASA Project Manager could use to assess the incoming safety case include:

1) System-Specific Safety Analysis Report
2) System-Specific Safety Basis
3) System-to-Mission Gap Closure
4) Mission Requirements and Specifications
5) Nuclear Design and Operational Safety Criteria
6) Nuclear Testing and Analysis
7) Validation and Verification
8) Hardware Manufacture
9) Flight Software Development
10) Launch Vehicle Selection
11) Launch Vehicle Inputs and Accident Environments

The NASA Project Manager should use the results of the above review to establish a safety testing campaign that identifies key additional tests that are needed to inform the Safety Plan.

In addition, the NASA Project Manager, in coordination with the SMA Technical Authority, should:

1) Initiate a preliminary hazards assessment that identifies key Program-level hazards and proposed activities to mitigate those hazards;
2) Determine the appropriate risk assessment technique (e.g., PRA, 5x5, etc.) to inform the Program-level risk management process, as it relates to nuclear flight safety; and

3) Identify credible launch accident and reentry scenarios to inform the Program-level risk management process and provide guidance on key areas for nuclear safety analysis.

G.5 Data Dissemination and Feedback Loop

After the Authorization Basis Strategy is defined and implemented, the NASA Project Manager should:

1) Disseminate the Authorization Basis Strategy to relevant stakeholders, including the NASA Nuclear Flight Safety Officer (Tier I) or NASA INSRB Member (Tier II or III),;
2) Update the plan as relevant program inputs evolve and as the safety analysis and safety review proceed;
3) Use the plan as the platform to translate the outcomes of the launch authorization process into the information that will guide incorporation of the launch authorization into launch and flight; and
4) Document lessons learned for use by future missions.

To further elaborate, it is inevitable that changes will occur in mission formulation that affect the Authorization Basis Strategy. Such changes could be brought on by drivers such as new knowledge, new constraints, and organizational changes. The Authorization Basis Strategy should account for these changes in a manner that is traceable and transparent to both the programmatic authority and the institutional authorities (including the technical authority and federally required external reviewers). Beyond document control, the NASA Project Manager (or their designee) should use standing tag-ups and risk management boards to clearly communicate substantive changes.

APPENDIX H. NSPM-20 Mission Tiering

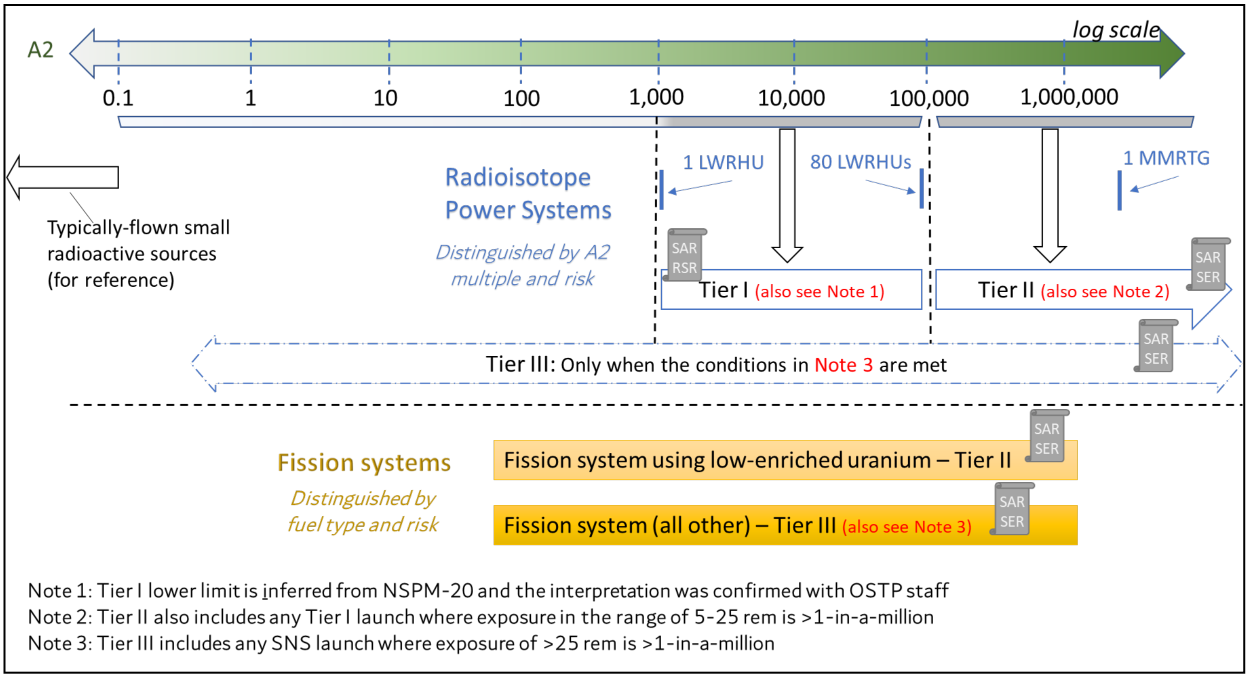
Note: How the team calculates maximum individual dose exceedance in the safety analysis and how that information is translated (e.g., phase-by-phase versus grouped-by-affected population) can affect mission tiering, just as it can affect the comparison to the NSPM-20 Safety Guidelines. To the extent that this Handbook addresses those issues prior to the adoption of a consensus approach, that topic is reserved for Section 4.9 and Appendix I.

H.1 Background

The revised Federal policy for nuclear launch authorization (NSPM-20) uses a set of tiering criteria to establish a high-level risk posture. Missions with radioisotope heater units would be Tier I missions and missions with radioisotope thermoelectric generators would be Tier II missions by default or Tier III if the associated mishap risk crosses specified thresholds for the technology currently in use. For different technologies on the horizon, the categories above could be different for radioisotope power systems. Space fission systems will likely be Tier II for missions using low-enriched uranium or Tier III for missions using highly enriched uranium (with additional caveats on use of highly enriched uranium specified in SPD-6) again, unless the mission exceeds specified risk thresholds.

H.2 Further Clarifying Information on NSPM-20 Tiering

NSPM-20 sets tier boundaries based on material-at-risk, technology, and radiological risk estimates stemming from the nuclear safety analysis. Therefore, NASA makes the final determinations after completion of the nuclear safety analysis. Because the characteristics of safety analysis review depend on the tier, the NASA Project Manager must also do an earlier evaluation of the likely tiering outcome. Figure 4 provides an illustration of the NSPM-20 tiering criteria, while Table 4 provides a tabular capturing of the same criteria.



(LWRHU = Light-weight radioisotope heater unit; MMRTG = Multi-mission radioisotope thermoelectric generator; SAR = Safety Analysis Report; SER = Safety Evaluation Report; SNS = Space nuclear system)

Figure 4: Illustration Showing NSPM-20 Tiering Factors

Table 4: NSPM-20 Tiering Criteria

Tier	Criteria for SNS
Tier I	• Quantity of radioactive material is ≥ 1,000×A2 but ≤ 100,000×A2
Tier II	• Quantity of radioactive material is > 100,000×A2, or • Any Tier I launches where the associated safety analyses determine that the probability of an accident during launch or subsequent operation resulting in an exposure in the range of 5 rem to 25 rem TED to any member of the public is equal to or greater than 1 in 1,000,000, or • Nuclear fission systems and other devices with a potential for criticality using low-enriched uranium.
Tier III	• Any spacecraft containing a SNS for which the associated safety analyses determine that the probability of an accident during launch or subsequent operation resulting in an exposure more than 25 rem TED to any member of the public is equal to or greater than 1 in 1,000,000, or • Nuclear fission systems and other devices with a potential for criticality where such systems utilize any nuclear fuel other than low-enriched uranium.

H.2.1 Features of NSPM-20 implementation within this directive that warrant elaboration:

H.2.1.1 NSPM-20 clearly states in Section 1 that it "updates the process for launches of spacecraft containing SNS," while later using the terminology "radioactive sources" in the definitions of Tier I and Tier II. NASA NPR 8715.26 only applies NSPM-20 to SNS with the expectation that no other payload would have an A2 mission multiple greater than 1,000, while the nuclear safety analysis would need to consider any additional radioactive material in the payload (in addition to the SNS). Other requirements in this directive ensure nuclear flight safety for all other missions.

H.2.1.2 While the term spacecraft is used in both NSPM-20 and NPR 8715.26, the NASA Project Manager would also need to consider any radioactive material on the integrated launch vehicle aside from the spacecraft, acknowledging that this would be atypical for a NASA mission.

H.2.1.3 The lower bound of Tier I is treated to equate to an A2 mission multiple of 1,000. This is effectively the lower end of historical SNS flown and comports with NSPM-20's reporting requirement bounds codified in Section 6 of that document.

H.2.2 There is a possibility that an SNS (that is not a fission reactor system) with an A2 mission multiple of less than 1,000 could surpass the NSPM-20 Tier III criterion associated with a greater than 1 in 1 million probability of an exposure in excess of 25 rem. This Handbook's tiering approach only addresses this possibility to the extent that the NASA Project Manager or the technical authority can reasonably foresee this potential at the Preliminary Tier Determination stage. Nevertheless, the authors do not anticipate this situation to occur in practice given existing SNS designs and mission profiles, and subject to the current state-of-knowledge in radiological risk modeling.

APPENDIX I. Nuclear Flight Safety Analysis and the Mission SAR

Note: The authors may update this appendix in the future to provide suggested contents for the Databook (leveraging information in the MMRTG Users Guide and Appendix G of the Trial Use INSRB Playbook) and the mission SAR (leveraging DAFMAN-91-110, Appendix G of the Trial Use INSRB Playbook, information from DOE standards related to the development of Documented Safety Analyses, etc.). It may also eventually be the place for pointing to a consensus document on how the analysis results will be packaged for comparison to the NSPM--20 Safety Guidelines and tiering criteria.

I.1 Contextual Information About Safety Analysis Preparation Practices.

I.1.1 While the NASA Project Manager will use other guidance to inform details of the mission SAR schedule, the mutually agreed upon schedule would typically address: the planned analysis schedule; a technical interface document between NASA and the safety analysis preparer; base assumptions, analysis limitations and bounds, and model descriptions associated with the mission SAR development; and the development of a draft or initial mission SAR well in advance of (e.g., one year prior to) the final mission SAR. The NASA Project Manager can capture this and related information in an SDS, Safety Architecture, Safety Case, or equivalent product.

I.1.2 While the NASA Project Manager will use other guidance to inform details of the mission SAR content, the scope of the mission SAR typically includes prelaunch and launch activities, as well as all operational phases where the SNS or other radioactive material could result in significant exposure of a member of the public in the event of an accident. The consideration of accident impacts would typically be sufficiently broad to support the nuclear safety review; the nuclear launch or reentry authorization or concurrence process (comparison to NSPM-20's safety guidelines, the specific items described in Section 5(b) of NSPM-20, and mission tiering); range safety uses; mishap preparedness and contingency planning activities; and public risk communications. To baseline the contents of the mission SAR, the NASA Project Manager would typically utilize a recognized standard or precedent (NRC or DOE guidance, INSRB guidance, a NASA Technical Standard, a consensus standard) or an appropriate precedent (e.g., the mission SAR from a contemporary mission with a similar payload and mission design), adjusted as necessary to address the specifics of the SNS context and the mission at hand.

I.1.3 The level of detail and content of the mission SAR will be commensurate with the mission radiological risk. Per NSPM-20, "a mission SAR may incorporate a system-specific SAR that establishes a safety basis for the space nuclear system," and NSPM-20 goes on to describe this relationship. In cases where launch vehicles, configurations, mission characteristics, and SNS are similar and the safety analysis and review stakeholders determine that a comparative analysis will appropriately estimate the radiological risk of the mission, a comparative analysis can be utilized. RHU and RTG risk assessments have demonstrated over time that a fairly mature understanding of mission phase radiological risk contributions exists for these devices, while also demonstrating shifts in the relative importance of phenomena associated with both changes to state-of-knowledge (e.g., breach modeling, dispersion modeling) and mission characteristics (e.g., clad temperature, launch window climatological conditions).

I.1.4 Where multiple entities are providing nuclear or radioactive materials, MDAAs may choose to provide either a single safety analysis document or multiple safety analysis documents. Depending on the specifics of the circumstances, the MDAA may need to justify why they can reasonably treat the radiological risks in an additive fashion when using multiple mission SARs. Some consequence metrics do not scale linearly with the activity of released material.

I.2 Accompanying Safety Analysis Summaries

I.2.1 As mentioned above, some launches may involve other radioactive material that, by itself, would not necessitate a SAR. Typically, this other radioactive material has fallen into categories with a sufficiently low enough hazard level such that this additional radioactive materials does not require a SAS (see NPR 8715.26), but this may not always be the case. When a SAS is required, it could follow a graded approach (i.e., have features similar to a SAR but with reduced rigor). References like DOE-STD-3009-2014 and Table 2 of Appendix A to 10 C.F.R. 830, Subpart B offer guidance on how to scale the degree of rigor to remain commensurate with the potential hazard (i.e., assuring that the facility or system has acceptable safety provisions without requiring unnecessary information or analysis). The NRCaddresses this issue in a somewhat similar vein in its deliberations on the content of its 10 CFR 53 Rulemaking, and the FAA likewise has similar concepts in features of its regulatory implementation of 14 CFR 450.

APPENDIX J. Nuclear Flight Safety Review

J.1 Tier II and Tier III Missions:

The Nuclear Safety Review for Tier II and Tier III NASA missions leverages the INSRB evaluation required by NSPM-20. For this reason, NASA activities in this area depend heavily on the NASA INSRB member's involvement (meant here to refer to the standing Board member or the NASA Chair of the INSRB Review Group if the same individual does not hold both positions). By design, the NASA Chair of the INSRB Review Group is not the NFSO, when circumstances permit, since both positions require different levels of access and insight.

Requirement 4.3.1.1 of NPR 8715.26 states that the NASA Project Manager “shall engage the INSRB early in the safety analysis process, typically to occur prior to KDP-C and after the conceptual design of the mission is generated, in accordance with NSPM-20’s requirement for INSRB engagement early in the safety analysis process.” To accomplish this, the NASA Project Manager should consider the following salient points:

1) A NASA spaceflight project following an NPR 7120.5 project life cycle will reach the KDP-C project life-cycle gate immediately after completion of the Preliminary Design Review (PDR) cycle review.

2) The NASA Project Manager, and the Program and Project-level SMA Technical Authority, participate in the Preliminary Design Review. Meanwhile, the NFSO and NASA INSRB representative should already be aware of the need for a potential INSRB review well in advance of PDR, based on the project notifying the NFSO prior to MDR or SDR.

3) The NASA Project Manager may delegate the responsibility to manage this type of interaction, and the NFSO and the NASA INSRB representative should align with the programmatic authority to ensure clear roles and responsibilities for managing this early interaction between the NASA program and spaceflight project with the INSRB.

4) To fulfill this particular engagement requirement, the NASA Project Manager should convene a meeting prior to KDP-C whose express purpose is to bring the identified parties together for a discussion about the standup of an INSRB review. This discussion should identify any initial concerns with how the project is conducting business relative to INSRB practices and guidance. The NASA Project Manager should report the outcome of this meeting to program management and the NASA INSRB representative should report the outcome to the INSRB. In addition, the NASA Project Manager and the NASA INSRB representative should agree on a timeline and approach to resolving any disconnects.

Requirement 4.3.1.2 of NPR 8715.26 states, “The NASA Project Manager, with concurrence by the INSRB, the Chief, SMA, and the cognizant MDAA, shall document the terms of the INSRB review, including any estimated costs of the review.” To accomplish this, the NASA Project Manager should consider the following salient points:

1) The programmatic authority will maintain a plan regarding the nuclear safety launch approval process via the NLAP required by NPR 7120.5 (unless tailored). The NASA Project

Manager baselines this plan at SDR or MDR (which occurs well in advance of KDP-C in a NASA spaceflight project life cycle). Per NPR 7120.5, the requirement owner is OSMA.

2) The INSRB Playbook lays out a process in which the NASA program (meaning NASA and the relevant interagency and commercial partners) develops a Launch Authorization Basis Strategy, which is then used by the INSRB to develop a mission-specific review plan. That plan lays out the terms and conditions for review, including any costs. The Terms of Review document, which the sponsoring agency uses to align all stakeholders on the plan for interagency review, distills the key aspects of the Launch Authorization Basis Strategy and the Mission-specific Review Plan.

3) NSPM-20 intends that the NASA Administrator will approve the terms of the INSRB review, so it is noteworthy that NPR 8715.26 delegates this responsibility to the Chief of Safety and Mission Assurance and the Mission Directorate Associate Administrator. Such alignment must include agreement as to which NASA Agency Council(s) to engage.

Requirement 4.3.1.3 of NPR 8715.26 recommends that the NASA INSRB representative “may, as the designated interface between the INSRB and the NASA mission, provide recommendations to the NASA Project Manager on areas for additional analysis when gaps are identified, and do so in a timeframe that allows mission planners to address them without creating unnecessary delays in the launch timeline, in accordance with NSPM-20.” To accomplish this, the NASA INSRB representative should consider the following salient points:

1) This step, in concert with other requirements, comes from Section 5(c) of NSPM-20, and specifically the idea that INSRB “may recommend areas for additional analysis where it identifies gaps, but it is not tasked with repeating or conducting its own analysis,” as part of its early engagement, and prior to advising the NASA Administrator of any gaps or omissions.

2) Timing-wise, the INSRB representative communicates these recommendations after the mission-specific review plan has been approved (and thus after the INSRB has developed insight in the ongoing review), but well before advising the NASA Administrator of any significant gaps or omissions (so that the program and project personnel can take the INSRB recommendations under consideration and take any desired action). Though circumstances will dictate this timing, the INSRB representative will typically communicate these recommendations around the same time that the Mission SAR for Interim Review (or the draft SAR) is provided to INSRB.

3) Since INSRB has no means of handling documents with the formality of a government agency, the NASA INSRB member (or the NFSO on their behalf) should transmit any such INSRB recommendations in a NASA memo from the NASA INSRB member (or NFSO) to the NASA Project Manager and should copy all program and project personnel involved in supporting the INSRB review.

4) When INSRB provides recommendations that may already be under investigation by the program, or by the project’s SRB, the NASA INSRB representative should work with the NFSO and the program and project-level SMA Technical Authority to understand the

relationship, if any, between INSRB recommendations and the project's risk management activities or SRB interactions. The overlap, if any, need not influence INSRB's recommendations, but may provide an opportunity to point out relationships that will better frame these recommendations and drive toward their resolution. It may also highlight instances where INSRB recommendations may be in tension with other risk management drivers.

Requirement 4.3.1.4 of NPR 8715.26 requires that the NASA INSRB representative "shall, as the designated interface between the INSRB and the NASA mission, ensure that any omissions or gaps identified by the INSRB during review of a NASA mission, along with any recommendations for corrective actions, are provided to the NASA Administrator (or their designee) prior to completion of the mission SAR, in accordance with NSPM-20." To accomplish this, the NASA INSRB representative should consider the following salient points:

1) This step, in concert with other requirements, comes from Section 5(c) of NSPM-20, and specifically the idea that, "Before completion of the mission SAR, the INSRB shall advise the head of the sponsoring agency of any omissions or gaps that the INSRB has identified in analysis that is planned or underway, and may provide recommendations for corrective action."

2) Timing-wise, there is a clear need here to balance the maturity of the analysis and review (to avoid false alarms) against the requirement that this reporting occurs prior to completion of the mission SAR. It should occur after the program office has had the opportunity to consider and respond to the recommendations described in the previous requirement. Although circumstances will dictate the specific timeline, for this reason, the NASA INSRB representative should plan to communicate these gaps or omissions roughly halfway between the Mission SAR for Interim Review and the Mission SAR for Launch Approval.

3) Since INSRB has no means of handling documents with the formality of a government agency, the NASA INSRB member (or the NFSO on their behalf) should transmit the INSRB-developed report as a NASA memo. The NASA INSRB representative will need to decide whether to transmit this memo up through the OSMA management chain or through the Mission Directorate and whether to transmit the memo to the Administrator or a designee. Prior to transmittal, the NASA INSRB member should brief the NASA Program Manager and program and project personnel involved in supporting the INSRB review, so that they are aware of the information sent.

When INSRB provides recommendations that may already be under investigation by the program, or by the project's SRB, the NASA INSRB representative should work with the NFSO and the program and project-level SMA Technical Authority to understand the relationship, if any, between INSRB recommendations and the project's risk management activities or SRB interactions. The overlap, if any, need not influence INSRB's recommendations, but may provide an opportunity to point out relationships that will better frame these recommendations and drive toward their resolution. It may also highlight instances where INSRB recommendations may be in tension with other risk management drivers.

Requirement 4.3.1.5 of NPR 8715.26 states that the NASA INSRB representative "shall, in coordination with the INSRB, ensure that the SER is ready in the timeframe identified in Table 1, and that a publicly available Executive Summary is produced." To accomplish this, the NASA INSRB representative should consider the following salient points:

1) The NASA Project Manager transits the SER to the NASA Administrator alongside the mission SAR. The NASA INSRB representative (or the NFSO on their behalf) should transmit the SER to the NASA Project Manager via a memo. The NASA Project Manager would then provide both the SAR and SER to the Administrator through the relevant Agency Council. (See Section 4.12 for more information on this subject.)

2) The SER is an INSRB product, as opposed to a NASA product. Therefore, it does not require some treatments that may be customary for NASA products (such as meeting a specific NASA format). These are the responsibilities of the INSRB. Conversely, NASA cannot handle products if they do not meet certain Federal or Agency requirements, so NASA may subject the SER to a NASA-led information security review and marking if the process followed by INSRB does not conform to NASA's requirements.

3) The NASA INSRB representative (or the NFSO on their behalf) should transmit the summary to be made publicly available in stand-alone form to the Chief, Safety and Mission Assurance, coincident with transmittal of the SER and with a specified timeline for release. This timeline should account for providing the SAR and SER to the Administrator and should generally be made public only after the Administrator (or the President for a Tier III mission) has made their decision.

J.2 For Tier I Missions:

Per NSPM-20, Tier I missions do not require an INSRB evaluation. Thus, the NFSO manages activities in this area leveraging the Technical Authority activities and other NASA reviews already occurring for the mission. NPR 8715.26 applies these requirements to missions that contain radiological material with an A2 mission multiple greater than one, even if they do not qualify as an SNS for NSPM-20 purposes, and the following information may be useful to guiding such reviews. However, consistent with the scope of this Handbook, the authors provide the information below specifically in the context of NSPM-20 Tier I missions.

Requirement 4.3.2.1 of NPR 8715.26 requires that the NFSO "shall perform an RSR to include a publicly-available Executive Summary, in accordance with the timeframe identified in Table 1 of NPR 8715.26. Appendix A of NPR 8715.26 describes the general form of the RSR." In Appendix A, the NPR defines an RSR as:

> "A review of a planned launch or return to Earth (fly-by or reentry) of radioactive material (sometimes evaluating a nuclear safety analysis and sometimes serving as a stand-alone nuclear flight safety review) that qualitatively or semi-quantitatively addresses the radiological risk of the mission, by describing the form and quantity of radioactive material being launched or reentered, describing the relevant mission profile, providing an analysis of the probabilities of launch and in-flight accidents which could result in the terrestrial release of radioactive materials (surface and air), providing a

realistic and a pessimistically-biased estimate of the health and other effects due to a radioactive material release in the considered accident scenarios, and providing mission-specific information that would be relevant for contingency planning and material recovery. The scope and depth of the RSR would be tailored and scaled to the risk, and would be less intensive than the effort needed to develop a SER."

To accomplish this, the NFSO should consider the following salient points:

1) The intent is not to perform new analysis. Rather, the intent is to review the analysis already performed in this spaceflight project, to consider readily available information from other sources, and to evaluate this information as part of NASA's systems of check and balances to support well-informed decision-making.

2) Much, if not all, of the information needed to undertake such an assessment will typically be contained in:

    a) The nuclear safety analysis required by NSPM-20 for all Tier I missions;

    b) The NASA spaceflight project system safety work performed to support each major aspect of the project and the integration of all aspects (NASA typically performs this work in concert with its partnering agencies and its commercial providers);

    c) Launch vehicle information developed during the launch vehicle selection process, and subsequent launch services activities;

    d) Launch approval engineering and management activities that seek to address the unique aspects of processing and launching a SNS; and

    e) Past information relevant to nuclear flight safety of SNS that are typical of Tier I missions includes safety analysis and review performed for the following past missions:

        i) Mars Pathfinder (Sojourner rover);

        ii) Mars Exploration Rovers A&B (Spirit and Opportunity rovers);

        iii) The Programmatic Environmental Assessment of Launches Involving Radioisotope Heater Units.

Requirement 4.3.2.2 of NPR 8715.26 requires that the "NASA Program or Project Manager, in coordination with the NFSO, shall ensure that significant gaps in the safety analysis are identified and provided to the safety analysis preparer, prior to mission SAR completion." To accomplish this, the NASA Project Manager should consider the following salient points:

1) This step chronologically occurs before the preceding requirement for a given mission. The NPR ordering reflects that this additional requirement only applies to Tier I missions (it is required by NSPM-20).

2) NPR 8715.26 does not specify who will perform the evaluation of significant gaps in the safety analysis. In theory, this could be any individual or group that has a sufficient degree of independence including the NFSO (at the program's request), the Program or project-level SMA TA (if experienced in nuclear matters), the program or project SRB, or a party from the nuclear safety authority that does not a have a conflict with participation in the SAR development.

3) The NASA Project Manager should forward the document identifying gaps to OSMA to inform the RSR (in cases where the document wasn't developed by the NFSO).

J.3 Other General Nuclear Safety Review Guidance:

During reviews, it is often instructive to consider how other entities have addressed similar issues. Table 5 provides a potentially useful reference in this regard. These are simply references of note; they don't obviate the need to meet all applicable Federal, State, and local requirements.

Table 5: Specific References of Potential Relevance to Performing Nuclear Safety Reviews

Topical Area	Reference
General Nuclear Safety	DOE Report for Grant DE-FG01-94NE32180 (1995) ONSP-1 (1982)–F*ocuses on space nuclear reactors* Marshall et al. (1993)–F*ocuses on nuclear propulsion* NASA Nuclear Power Assessment Study (2015) NASA Tech Memo 105711-F*ocuses on nuclear propulsion* NASA-CR-2020-220569 (2020)–F*ocuses on space nuclear reactors*
Inadvertent Reentry	NASA-CR−2019-220397
Packaging of Radioactive Material for Transport	49 CFR 173, IAEA SSR-6 (& SSG-26)
Standard Review Plans (Not for Space Reactors)	NUREG-0800 (Power Reactor SRP), NUREG-1520 (Fuel Cycle Facility SRP), NUREG-1537 (Non-Power Reactor)
Other	

Often during a review, it is helpful to consult with subject matter experts within NASA who are not vested in the mission or its review to better understand whether a specific technical issue warrants further probing. Table 6 provides a list of experts, acknowledging that in some contexts these organizations might already be supporting the NASA program office.

Table 6: NASA Agency Subject Matter Expertise

Subject Matter Expertise	Org Title	Org Code
Ionizing Radiation Effects on Humans Inside NASA Facilities	OCHMO Environmental Health	OCHMO
Ionizing Radiation Effects on Humans In Space	Space Radiation Analysis Group	JSC-SD
Nuclear Power and Propulsion Technology	Nuclear Power and Propulsion Tech. Discipline Team	OCE (NESC)
Radiation Effects on EEE Parts	NASA Radiation Effects Analysis Group	GSFC-5600
Radioisotope Power Systems	Radioisotope Power Systems Program Office	GRC-MR
Reliability and Risk Modeling	Reliability and Maintainability Tech. Discipline Team System Safety Tech. Discipline Team	OSMA (NSC) OSMA (NSC)
Range Flight Safety Analysis	KSC Launch Services Program Office KSC Center SMA	KSC-VA KSC-SA

During reviews, the NFSO should brief out the radiological (nuclear flight safety) activities with OSMA counterparts that manage non-radiological-specific disciplines to promote a culture where nuclear flight safety is an additional layer of activity rather than a stand-alone activity. This out-brief should include the relevant program and project-level SMA Technical Authorities, who intrinsically have SMA responsibility across many of these same areas, as well as the spaceflight project personnel responsible for managing across these areas. Appendix B provides a useful overview of potential touchpoints. In addition to those topical areas, the NFSO should also consider other interfacing disciplines such as fire protection, human factors, lifting devices, and quality.

APPENDIX K. Interface with Payload and Range Safety Activities

In the future, Appendix K may elaborate on the aspects of the interface between nuclear flight safety, range safety, and payload safety not included otherwise in this document. This additional information may serve to improve the efficiency of the workflow across this interface. Examples of topics that might fall into this category are:

- Addressing the relationship between specific design criteria developed as part of the terrestrial nuclear system safety activities (e.g., those associated with DOE authorization for possession and use of the SNS during KSC processing) and the nuclear launch authorization safety activities (e.g., specific design features arising from the nuclear launch authorization safety basis) within the context of the payload system safety activities (e.g., applicability of NASA-STD-8719.24-Annex, Volume 3, Section 3.2, regarding specification of dual fault tolerance for system failures that can lead to a catastrophic hazard if not otherwise covered).

- Efficiently managing the inclusion of non-NASA nuclear-related range flight safety requirements, specifically the risk constraint, dose goal, and contamination impact statement activities in DAFMAN-91-110.

APPENDIX L. Nuclear Launch and (When Applicable) Return Authorization

The NASA Project Manager should provide sufficient resources, access, and engagement for conducting the nuclear safety analysis and review. As discussed in earlier topical areas, that individual should coordinate with the NFSO, INSRB, LSP, DOE, and the spacecraft provider early in the flight project development to formulate a nuclear safety design strategy and nuclear safety authorization approach to appropriately scope the required resources.

L.1 Launch and Reentry Authorization Roles and Responsibilities – Tier 1

The NSPM-20 section on launch authorization states:

"Authorization for launches of spacecraft containing space nuclear systems shall follow a three-tiered process based upon the characteristics of the system, the level of potential hazard, and national security considerations…

(a) Tier I shall apply to launches of spacecraft containing radioactive sources of total quantities up to and including 100,000 times the A2 value listed in Table 2 of the International Atomic Energy Agency's Specific Safety Requirements No. SSR-6 (Rev. 1), Regulations for the Safe Transport of Radioactive Material, 2018 Edition. For Federal Government missions in Tier I, the head of the sponsoring agency shall be the launch authorization authority."

Thus, the first step in the authorization process is to determine the amount of radioactive material proposed to be launched. If the total amount is less than 100,000 times the A2 value, then the mission <u>may</u> be Tier I. However, the NASA Project Manager must oversee completion of an analysis to determine the risk level. Tiering is discussed in more detail in Section 4.8. NSPM-20 goes on to state:

"(b) Tier II shall apply to:

(i) launches of spacecraft containing radioactive sources in excess of 100,000 times the A2 value referenced above;

(ii) any Tier I launches where the associated safety analyses determine that the probability of an accident during launch or subsequent operation resulting in an exposure in the range of 5 rem to 25 rem TED to any member of the public is equal to or greater than 1 in 1,000,000; and

(iii) any launches of spacecraft containing nuclear fission systems and other devices with a potential for criticality (defined as the condition in which a nuclear fission chain reaction becomes self-sustaining), when such systems utilize low-enriched uranium (less than 20 percent uranium-235 enrichment)."

Therefore, if the amount of radioactive material is less than 100,000 times the A2 value <u>and</u> the risk is less than the criteria in (b)(ii) above and does not include fission systems, then the launch will be Tier I.

For a Tier I launch, the MDAA shall request and obtain authorization from the NASA Administrator. Per NPD 1000.3 and NPR 8715.26, the authorization request would include an informational briefing to the APMC by the applicable MDAA, the nuclear safety analysis preparer, and the INSRB on the mission SAR, the SER, and the radiological contingency plans (both launch site area and out-of-orbit reentry). The Agency Program Management Council (APMC) then make their recommendation for authorization for launches containing SNS to the Administrator or Executive Council (EC). The Administrator, using the EC, will make the decision on authorization.

If the mission includes a planned return to Earth (reentry or fly-by), that would be part of the mission profile addressed by the mission SAR, and thus covered by the launch authorization.

L.2 Launch and Reentry Authorization Process – Tier II

Tier II launches are as defined above in Section L.1. Briefly, they are launches with greater than 100,00 times the A2 value, Tier I launches with risks as defined in criteria (b)(ii), or fission systems using low-enriched uranium. Tier II launches require review by the INSRB and approval by the NASA Administrator.

For SNS in Tier II, the MDAA shall request and obtain authorization from the NASA Administrator. The authorization request will include a briefing by the applicable MDAA, the nuclear safety analysis preparer, and the INSRB on the mission SAR, the SER, and the radiological contingency plans. If a Tier II mission included a planned return to Earth (reentry or fly-by) that would be part of the mission profile addressed by the mission SAR, and thus covered by the launch authorization.

NASA personnel should consider the content of the launch authorization briefings, at least conceptually (aside from the detailed project launch authorization schedule), early in the launch authorization process. Doing so ensures all the necessary information is available for consideration during the launch authorization briefing and review process and that the process can be completed in a timely fashion (even in the potential circumstance that NASA determines that it needs to elevate the launch authorization decision to the Executive Office of the President, for instance when the review process indicates a late change or ambiguity in tiering).

For both Tier I and Tier II launches wherein the NASA Administrator is the Authorizing Official for nuclear launch authorization, the assessment of risks associated with launching or reentering SNS and other radioactive material provided to the Administrator should:

1) First be briefed to the applicable MDAA and appropriate senior MDAA managers;

2) Include an assessment of potential consequences to a maximally exposed individual member of the public in accident scenarios (NSPM20.10, from Table 10);

3) Address launch and any subsequent stages when accidents may result in radiological effects on the public or the environment, for instance, in an unplanned reentry from Earth orbit or during an Earth fly-by (NSPM20.11, from Table 10);

4) Include an assessment of risks to the public, NASA workforce, high-value property, and the environment from potential harm as a result of normal and accident situations (NPR8700.1, Table 10);

5) Utilize the APMC and EC path previously discussed.

L.3 Launch and Reentry Authorization Process – Tier III

NSPM-20 states:

> "Tier III shall apply to launches of any spacecraft containing a space nuclear system for which the associated safety analyses determine that the probability of an accident during launch or subsequent operation resulting in an exposure in excess of 25 rem TED to any member of the public is equal to or greater than 1 in 1,000,000.
>
> . . . Tier III shall also apply to launches of spacecraft containing nuclear fission systems and other devices with a potential for criticality when such systems utilize any nuclear fuel other than low-enriched uranium."

Tier III launches require review by the INSRB and approval by the President (or the Director of OSTP, if authority is delegated).

See and follow guidance in Section L.2 in terms of the briefing by the MDAA through the NASA Administrator. In the case of Tier III, the outcome is a decision by the NASA Administrator to seek White House authorization.

The MDAA should coordinate with appropriate directorates and offices for planning briefings with OSTP (and any other White House Offices deemed appropriate, such as the National Space Council).

L.4 Recommendations, Gaps, and Omissions Within the Launch Authorization Process

Section 4.3 of NPR 8715.26 discusses best practices and requirements related to:

- The optional step of the INSRB (Tier II and III) providing recommendations to the NASA Project Manager on areas for additional analysis when gaps are identified early (e.g., Phase B and prior to the SAR review) and

- The compulsory step of the INSRB (Tier II or III), or the NASA Project Manager in coordination with the NFSO (Tier I), providing any omissions or gaps identified during review of a NASA mission, along with any recommendations for corrective actions, to the NASA Administrator.

Section 4.10 and Appendix J of this Handbook elaborate on these review activities. The text below further elaborates on them, specific to the feedback loop that is anticipated as part of the launch authorization process.

In executing these actions:

- If the NASA Project Manager receives early recommendations for additional analysis when gaps are identified, they should consider the information in a timely way so that mission planners can address this information without creating unnecessary delays in the launch timeline and to potentially mitigate radiological risks as appropriate (NSPM-20.24, from Table 10).

- If the NASA Administrator receives notifications from the INSRB related to omissions in information or knowledge gaps potentially relevant to nuclear launch safety before completion of the mission SAR, the NASA Administrator should direct the MDAA to consider this information in a timely way so that the NASA Project Manager can consider potential corrective actions (NSPM-20.25, from Table 10).

Separately, if the NASA Project Manager receives notifications and information related to omissions in information or knowledge gaps potentially relevant to future missions, they should provide that information to the appropriate Program Director and Program Manager for that technology. Initiating a risk within the program's risk management process is an effective means of ensuring that the issue is retained and resolved in a way that is timely for managing risks relevant to protecting the public, NASA workforce, high-value property, and the environment from potential harm as a result of NASA activities and operations (N8700.1-1, from Table 10) (IAEA-6, 7, 9, 10, 11, from Table 10).

L.5 Additional Information

When a NASA Project Manager incorporates nuclear flight safety considerations from program or project formulation through the point at which the SNS no longer has the potential to affect Earth's biosphere, these elements should:

- Protect the public, NASA workforce, high-value property, and the environment from potential harm as a result of NASA activities and operations, (NSPM20-3, 4, from Table 10) (N8700.1-x) and strive to achieve the highest level of safety that is reasonably practicable (IAEA-9, from Table 10) and

- Be described in a NLAP and be conducted within the normal NPR 7120.5 practices, requirements, and, lifecycle reviews by which NASA formulates and implements space flight programs and projects (NPR 7120.5, from Table 10).

Relating to the information provided elsewhere in this Handbook, as it interfaces with the launch authorization process, the NASA Project Manager should:

- Ensure that briefings throughout the authorization process include radiological contingency concept of operations (discussed in Section 4.13) covering both launch area accident contingency plans and out of launch area contingency plans. Conversely, NASA personnel and relevant interagency partners should brief a summary of the radiological risk analyses performed for the mission (i.e., for Nuclear

Flight Safety NPR compliance) to launch site area emergency responders and state government emergency response officials.

- Consider Strategy 4 of the Nuclear Flight Safety High-Level Assurance Case for Space Flight Project Utilizing an SNS (see Appendix D) in formulating launch authorization plans.

- Coordinate with the applicable PSWG early in its formulation (typically before launch vehicle selection) to ensure that the NASA project Manager shares information regarding payload hazards with all stakeholders (per NPR 8715.7B). The goal is to ensure the PSWG can coordinate across the multiple stakeholder organizations, advise the Payload Project Manager, and advise their respective organizations on strategies for early hazard abatement, mitigation, or resolution. The NASA Project Manager should consider possible relevant external requirements and guidance (e.g., DAFMAN-91-110).

APPENDIX M. Radiological Contingency Planning and Coordination

M.1 Familiarity with RCP Concepts

M.1.1 Overview of RCP

SNS launches present unique hazards because of the potential for release of radioactive material (or inadvertent criticality) in the event of a mishap. Designated missions use comprehensive RCP to prepare for mitigating the effects of any launch-related radiological release and recovering radioactive sources. Radioactive material receives special attention and consideration because of the potential long-term health, environment, and operational consequences of a mishap and the public perception of such. Through RCP, NASA and its partners prepare for taking prompt actions to protect the public, NASA workforce, high value property, and the environment in accordance with NASA NPD 8700.1. For launch authorization NASA factors in the extent to which the risks related to a radiological release can have adverse effects and the extent to which NASA can mitigate these effects. Contingency planning and coordination requirements contained in NPR 8715.26, Nuclear Flight Safety, describe implementation of a graded, risk-informed, performance-based process to assure safety in the event of a mishap. This section presents the RCP concepts developed for the most recent missions Mars Science Laboratory (MSL) and Mars 2020 as best practices for meeting the NPR 8715.26 RCP requirements. Experience shows that planning should begin early with identification of organizations, resources, and facilities that support RCP activities. NASA personnel should facilitate planning with an integrated schedule to ensure readiness sufficiently early to train staff, exercise capabilities, and improve readiness as necessary prior to launch.

The goal of RCP is to protect the people, the environment, and high-value property from radiological hazards from three general types of possible launch mishaps: (1) prelaunch, launch area, and near offshore accidents; (2) sub-orbital accidents; and (3) orbital accidents. Sub-orbital accidents can impact international waters or land in a foreign country. An orbital accident could result in spacecraft atmospheric reentry with the spacecraft in a controlled or uncontrolled state. Therefore, before launching any spacecraft that includes an SNS, NASA develops plans to make sure it can effectively respond to a launch or flight accident that could affect Earth's biosphere. NASA develops these plans under the Department of Homeland Security's (DHS) National Response Framework (NRF) and the Nuclear/Radiological Incident Annex (NRIA) to the Response and Recovery Federal Interagency Operational Plans (FIOPS). In making these plans, NASA coordinates with other organizations that would respond in a radiological emergency. These organizations include the DOE and other Federal agencies, the applicable State and county, and local governmental organizations. For accidents involving NASA-managed spacecraft with a radiological payload, NASA is the designated Primary Authority (PA) for all required elements of any Federal response.

In the event of a launch area accident with a release of nuclear material, response activities are intended to satisfy the following goals:

1) Verify whether a release of radioactive material has occurred;

2) Quantify the magnitude and character of any radioactive material released to the environment;

3) Predict the dispersion of any released radioactive material;

4) Formulate appropriate and prudent protective actions to be taken on-site and provide protective action recommendations for off-site agencies;

5) Generate public information releases on the status of a launch accident that are accurate, timely, consistent, and communicate relative level of risk;

6) Provide a response mode that will support smooth transition to the Federal response model in accordance with the NRF.

To effectively achieve these goals, NASA established a launch area functional organization known as the RADCC to control the response architecture, so that NASA and the Federal, State, and local government partners can coordinate radiological assessment expertise, response management, and information and messaging decisions.

M.1.2 Probabilities and Consequences in the Context of RCP

NASA has a long history of successfully launching SNS. Yet, however small, each launch has some probability greater than zero of a launch failure. RCP develops responses for those small, but finite probabilities.

A mission nuclear risk assessment establishes the probability and consequence data that drive RCP and influence early accident response assumptions and actions. DOE typically develops this mission nuclear risk assessment, which is closely related to the safety analysis performed for launch authorization, for NASA. This risk assessment considers: 1) potential accidents associated with the launch and their probabilities and accident environments; 2) the response of the SNS hardware to accident environments with respect to source terms (that portion of the release that becomes airborne) and their probabilities, and 3) the radiological consequences associated with such releases.

The mission nuclear risk assessment assesses accident scenarios over all launch phases from pre-launch operations through escape from Earth orbit and consequences are assessed for both the regional population near the launch site and the global population. Analysts calculate estimates of source term by modeling the response of flight hardware in the accident environment unique to each of these phases and they estimate radiological consequences from the subsequent release and dispersion of the source term. Section M.2 provides a typical breakdown of launch and flight phases for the purposes of RCP.

Analysts calculate radiological consequences of a given accident that results in a release of radioactive material in terms of radiation doses and potential health effects to humans and land area potentially impacted at or above specified levels.[1] Analysts estimate these radiological consequences from atmospheric transport and dispersion simulations incorporating both worldwide and launch-site specific meteorological and population data. Missions have historically expressed health consequences in terms of maximum individual dose, collective dose to the potentially exposed population, and the associated risk of health effects. Typically expressed in units of rem, the maximum individual dose is the maximum dose delivered to a single individual assumed to be outside without shelter during the time of radiological exposure for each accident. Collective dose (also called a population dose) is the sum of the radiation dose received by all individuals exposed to radiation from a given release[2]. Health effects represent statistically estimated additional latent cancer fatalities resulting from an exposure to a release of radioactive material calculated over a 50 year period following the exposure. Analysts often develop these estimates assuming no mitigation, such as sheltering in place.

RCP develops the methods and strategies that combine available accident information, meteorological conditions, and field monitoring data to inform mitigations and protective actions to minimize these consequences.

M.1.3 Interagency Coordination and Key Planning Personnel

Planning must provide for a flexible, scalable response which will always involve Federal, State and local emergency management agencies, but may also include international coordination for scenarios beyond the geographic, jurisdictional boundaries of the United States. Planning requires a cooperative effort among NASA, DOE, DoD, State and county emergency management (EM) organizations, and other participating agencies (e.g., EPA, FEMA). Agencies achieve interagency coordination and cooperation through established agreements and committed multiagency teams working closely and meeting regularly to ensure alignment of their organizations' roles and responsibilities with those of NASA. Figure 5 shows this situation pictorially for a NASA launch involving DOE-authorized material occurring from KSC. This coordination is often facilitated by MOUs, MOAs, or IAAs, such as the 2016 NASA and DOE MOU, Memorandum of Understanding between the National Aeronautics and Space Administration and the Department of Energy Concerning Radioisotope Power Systems, and the MOA between Space Launch Delta 45, KSC, and the Brevard County Emergency Management Office, which establishes roles, responsibilities, policies, and procedures for the operation of the Eastern Range (ER) Risk Assessment Center (RAC).

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[1] Historically, a value of 0.2 microcuries per square meter ($\mu Ci/m^2$) has been used, but there are specific concerns and limitations with using this value as a surrogate for the more complex decisionmaking process that would affect the actual response to a radiological release. The appropriateness of the 0.2 μCi m-2 value is currently being reevaluated by the Environmental Protection Agency (EPA).

[2] When calculating collective dose, care must be taken not to aggregate very small doses over very large populations.

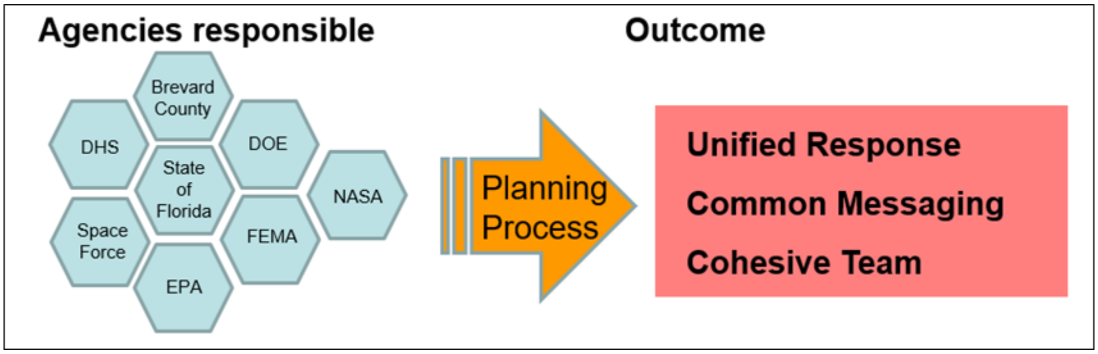

Figure 5: Representation of Interagency RCP Coordination

The RCP architecture relies on the leadership of six key roles for the development and implementation of plans which address the various launch accident scenarios. On launch day, the individuals in these roles are prepared to transition to a response role and implement their respective plans directly at or through liaisons physically at the launch area RADCC. These roles are:

1) The NASA launch site primary authority representative (PAR);

2) The NASA OPS planning lead;

3) The NASA launch site RCP lead;

4) The DOE Planning Coordinator;

5) The NASA Joint Information Center (JIC) manager;

6) The NASA OIIR planning lead.

Section M.3 provides a description of each of these roles.

M.1.4 Primary RCP Documents, Plans, and Procedures

As described earlier, NASA bases it's RCP framework on requirements drawn from the National Response Framework and the Nuclear/Radiological Incident Annex to the Response and Recovery FIOPS and NASA and other Federal, State, local, and tribal planning documents. NASA fully coordinates this framework across participating Federal, State, and local agencies. Approximately seven higher-level RCP documents provide the interagency organizational structure, relationships, and actions needed for comprehensive radiological contingency planning, response, and recovery. For the recent missions, which launched from KSC, these plans include those listed below (Section M.4 describes each in more detail):

1) The NASA HQ Radiological Contingency Plan

2) The KSC-PLN-1903, KSC Radiological Contingency Plan for Major Radiological Source Missions

3) The NASA HQ JIC Plan

4) The OIIR Communications Plan

5) The Project On-Orbit Contingency Plan (OOCP)

6) The Project Debris Impact Footprint Definition Plan

7) The DOE Accident Recovery and Transportation Plan

Figure 6 illustrates the interrelationship between these higher-level primary RCP and other NASA, launch site, and federal, state, and county documents.

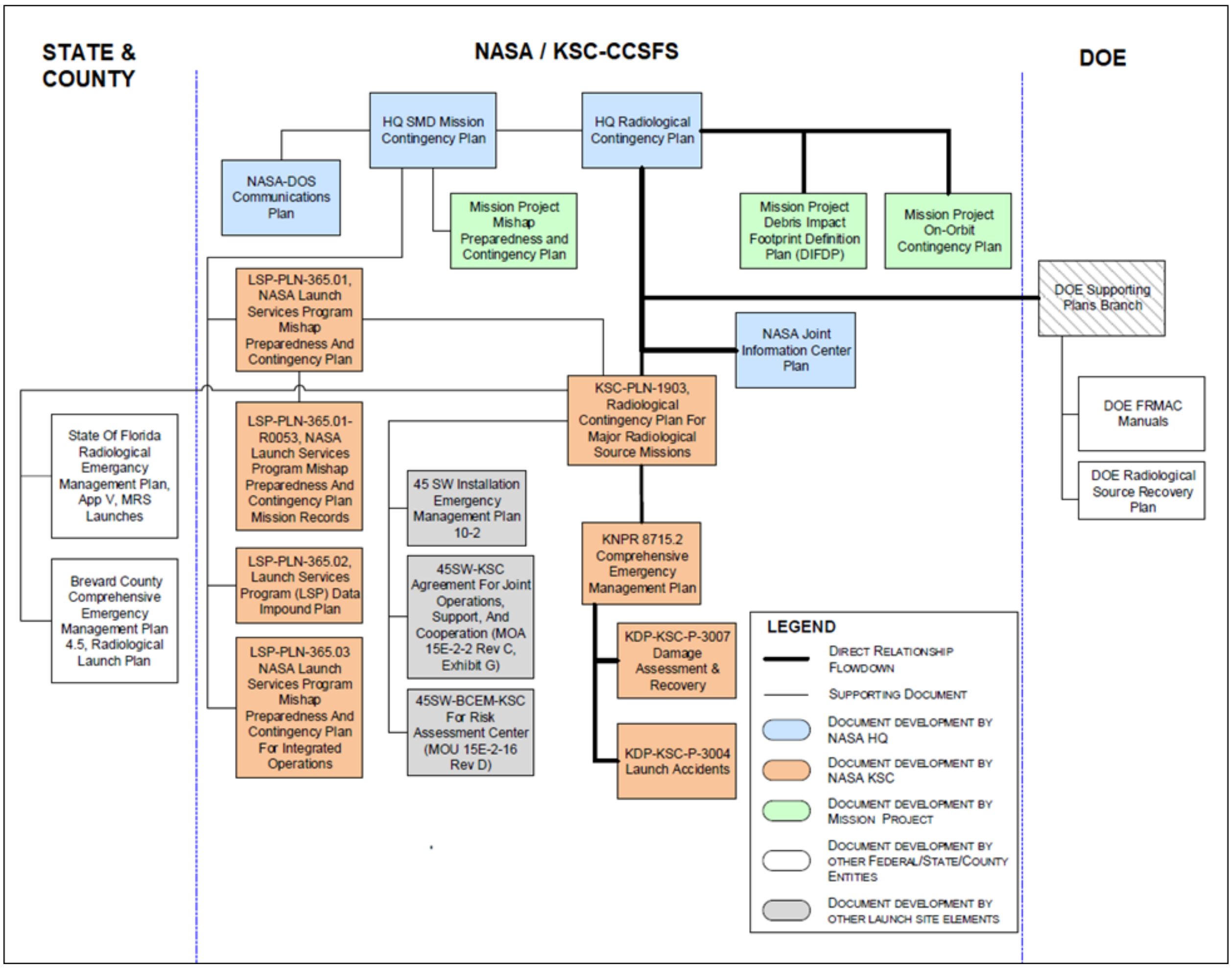

Figure 6: Sample RCP Document Tree for a KSC Launch of a DOE RPS

Personnel experienced in radiological emergency response operations staff the RADCC. The RADCC compiles field monitoring data, estimates the path and direction of any potential releases, and assesses the monitoring data to formulate advisories and status reports relating to radiological emergency response activities and recommendations to provide to the Primary Authority Management Group (PMG). The RADCC Operations Manual describes the concept of operations for the RADCC; the methodology and assessment strategy employed to derive protective action recommendations; communication nets and protocols; procedures and criteria for readiness; and checklists. RADCC activities are highly checklist-driven.

Many additional plans and procedures are necessary to address response elements such as: Field team composition, staffing, and resourcing; radiological monitoring instrumentation and sampling; and the continuous environmental air monitor (ECAM) network, to name a few. Section M.5 provides a list of launch area RCP implementing plans and procedures.

M.1.5 RCP Planning and Milestones

RCP is a multi-year process that typically begins about three years prior to launch for an RTG launch. Historically, several years have elapsed between nuclear missions. Among other important changes between missions are organizational and staffing changes, and possibly missions and concept of operations evolutions. Personnel must assess facilities, equipment, and other resources. Reconstituting the multiagency RCP team must start early, and this may coincidentally align with when the INSRB begins actively engaging with a mission. This is the time when NASA appoints the new PAR and JIC manager, personnel review lessons learned from the previous nuclear mission, and the first working group meetings occur. Figure 7 depicts a notional high-level RCP schedule.

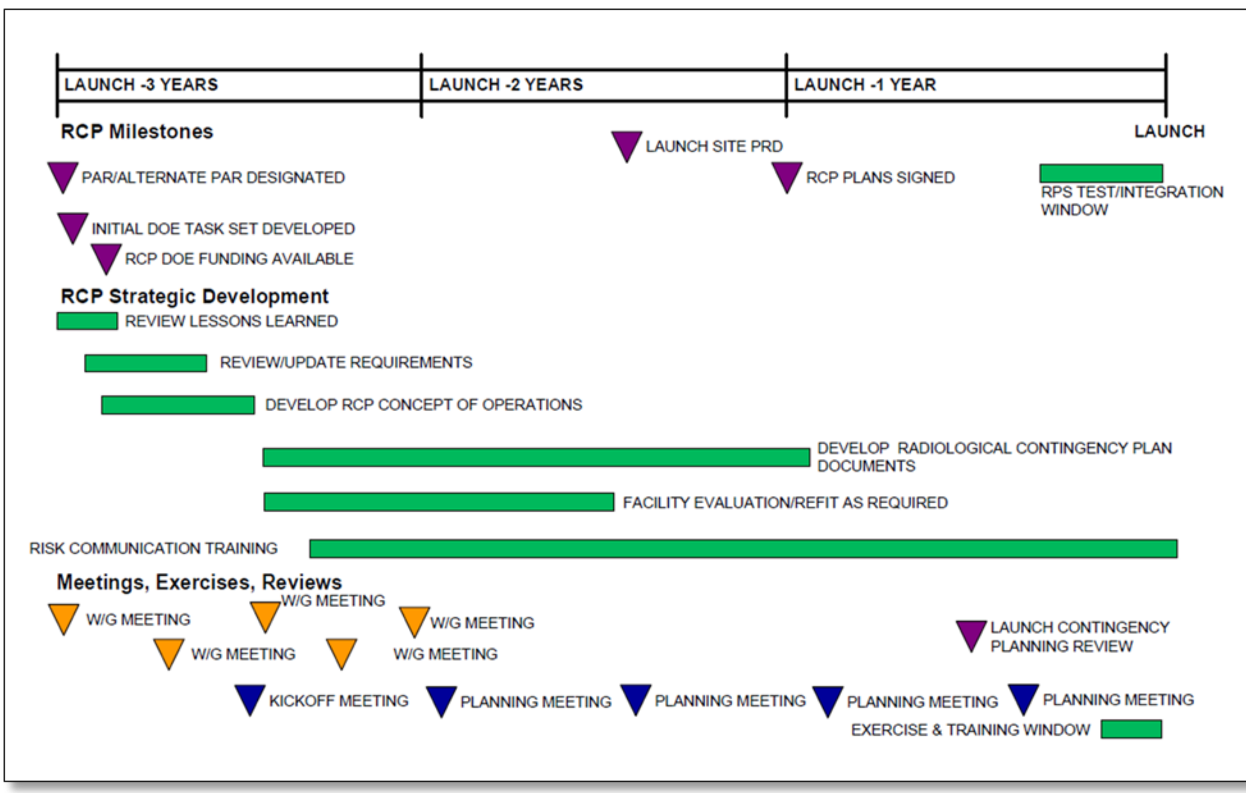

Figure 7: Sample High-Level RCP Preparation Timeline

M.1.6 Response Elements, Critical Considerations, and Recovery

RCP also relies on various elements, critical considerations, and recovery capabilities. Many of these are referenced in the preceding discussion, and they include things like:

1) A RADCC

2) Field monitoring assets

3) A general RCP decision making process

4) A set of critical considerations

5) Recovery capabilities

6) Atmospheric modeling capabilities, etc.

Section M.7 describes some of these elements further, and the reader should refer to the Mars 2020 mission documentation, the Nuclear/Radiological Incident Annex, and other relevant documentation for further detail.

M.2 Typical Launch and Flight Phase Breakdown for RCP

A typical breakdown of the launch and flight phases is provided below. The nuclear safety analysis performed for launch authorization, which is customarily a key input to RCP, typically influences this breakdown.

- Phase 0 (Pre-Launch): T < t1, from installation of the SNS to just prior to start of the Stage 1 rocket engines at t1. A launch-related accident during this period could result in ground impact in the launch area.

- Phase 1 (Early Launch): t1 < T < tx, from start of Stage 1 engines to just prior to tx, where tx is the time after which there would be no potential for debris or intact vehicle configurations resulting from an accident to impact land in the launch area, and water impact would occur.

- Phase 2 (Late Launch): tx < T when the launch vehicle reaches an altitude of nominally 30,480 m (100,000 ft), an altitude above which reentry heating could occur. A launch accident during this period would lead to debris landing in the Atlantic Ocean (assuming launch on the Eastern Range).

- Phase 3 (Suborbital): Suborbital Reentry, from nominally 30,480 m (100,000 ft) altitude to the end of Stage 2 burn 1 and Command Destruct System (CDS) is disabled. A launch accident during this period prior to reaching Earth parking orbit could lead to prompt suborbital reentry within minutes.

- Phase 4 (Orbital): Orbital Reentry, from end of Stage 2 burn 1 to Stage 2 spacecraft separation. A launch accident that occurs after attaining parking orbit could result in orbital decay reentries from minutes to years after the accident.

- Phase 5 (Long-Term Reentry): Long-Term Reentry, after spacecraft separation until no chance of Earth reentry.

M.3 Description of Key RCP Leadership Roles

The RCP architecture relies on the leadership of the following six key individuals, as described below.

M.3.1 NASA Launch Site PAR

The PAR is the single point of contact for the overall RCP effort and implementation and is accountable to NASA HQ. The PAR is a member of launch site management designated by the launch site Center Director and tasked with decision-making authority for the radiological response element in an accident involving an SNS. The general responsibilities of the KSC PAR are the five general management responsibilities for the PAR as described by the National Response Framework. Upon receiving notification of a launch accident from the Launch Director, the PAR will initiate a response and notify appropriate Federal, State, and local agencies as required. The PAR will manage initial response actions and coordinate those actions, as necessary, with Federal, State, and local EM organizations, with the goal of determining if any radiological material has been released. In coordination with the DOE Senior Science Advisor and Senior Response Official, the PA will formulate radiological protective actions and develop recommendations for Launch Emergency Operations Center (LEOC) entry to the launch accident site and provide recommendations for off-site protective actions through the State and county emergency management liaisons in the RADCC.

M.3.2 NASA OPS Planning Lead

The OPS Planning Lead develops and implements the NASA HQ RCP and works closely with the PAR and launch site RCP Lead to ensure the launch site and NASA HQ plans are consistent, and to coordinate with FEMA to ensure familiarity with the NASA HQ and launch site RCP. The OPS planning lead:

1) Works with the DHS to ensure compliance with the National Response Framework and the Nuclear/Radiological Incident Annex;

2) Provides necessary coordination with the DoD, NASA OIIR, DOE, and FEMA, ensuring concurrence of the On-Orbit Contingency Plan (OOCP);

3) Coordinates with OIIR in the development of the Department of State (DOS) Communications Plan;

4) Coordinates with U.S. Air Force (USAF) and U.S. Strategic Command (STRATCOM) personnel to obtain support for on-orbit contingency response, including the USAF’s

Combined Space Operations Command (CSpOC) for additional DoD assets that may aid in defining the accident scenario;

5) Ensures that the NASA HQ Radiological Contingency Response Plan complements and is consistent with other mission contingency plans;

6) Coordinates with the OIIR and the DOE to notify DOS regarding which foreign countries could expect debris, if any, consistent with the applicable Launch Center plan; and

7) Leads the programmatic coordination with the CSpOC and the Space Systems Command to ensure that agreements are in place such that the PAR receives tracking and reentry analysis results.

M.3.3 NASA Launch Site RCP Lead

The Center Planning Lead is the Center Radiation Protection Officer and fulfills the role of the Center RADCC Operations Director to manage the overall radiological contingency response planning effort for NASA at the launch site. In cooperation with the PAR; the NASA HQ OPS Planning Lead; the DOE Planning Coordinator; and the JIC Manager, the Center Planning Lead develops contingency response details including, but not limited to:

1) Launch site response plans and procedures;

2) RADCC staffing and equipment requirements;

3) Size and deployment of onsite and offsite field teams;

4) Field radiation monitoring equipment requirements;

5) Communication and organizational interfaces; jointly agreed protective action guides (PAGs);

6) Radiological release evaluation strategy to formulate protective action recommendations; and

7) Contingency plan development and planning activities with Federal, State, local, or tribal organizations and agencies.

M.3.4 DOE Planning Coordinator

If an accident were to occur, NASA would use the expertise of the DOE in planning the response and obtaining and assessing field measurements. The DOE Planning Coordinator serves both a management and technical role in support of NASA RCP activities, including coordinating with the Center Planning Lead and RADCC Director in the development and delivery of specialized training for field team personnel, and developing and implementing an exercise plan to assess response readiness. During the planning phase, the DOE Planning Coordinator provides the Center Planning Lead and RADCC Director information and insight into DOE resources, assets, and capabilities to support NASA in evaluating any potential releases from a launch accident and developing an assessment and monitoring strategy. The DOE Planning Coordinator provides a schedule of DOE support tasks that enables the overall NASA contingency planning timeline, coordinates with the RADCC Director to assess DOE staffing requirements for prelaunch response contingencies, and designates communications and technical representatives to provide JIC support, including developing the JIC Plan and joint public messaging, as necessary.

M.3.5 NASA JIC Manager

The JIC Manager directs the overall planning effort for public affairs support of emergency response activities at the launch site. Working with the NASA PAR, the OPS Planning Lead, and the DOE Planning Coordinator, the JIC Manager leads development of approved contingency response messaging including, but not limited to, launch site public affairs response plans and procedures to support JIC operations in accordance with the NRF. The JIC Manager defines JIC staffing and equipment requirements and communication and organizational interfaces. The JIC Manager ensures JIC personnel are trained and exercised in execution of the JIC Plan and related procedures for contingency response. In addition, the JIC Manager is responsible for the development, coordination, and approval of JIC products and activities required to support contingency response activities, including preparation for and rehearsal of prompt and regular media briefings.

M.3.6 NASA OIIR Planning Lead

When the OIIR planning lead develops a plan to address a launch mishap beyond the launch area that could lead to an impact in international waters or a foreign country, OIIR works with the DOS to inform foreign governments and the United Nations (UN), including the IAEA and Committee on the Peaceful Uses of Outer Space (COPUOS). In addition, OIIR would work with DOS to provide the initial offer of U.S. Government (USG) assistance to any nations affected by the launch anomaly.

M.4 Description of the Key RCP Plans

The following are descriptions of the key plans that guided RCP activities during recent SNS launches.

M.4.1 NASA HQ Radiological Contingency Plan

NASA derives all supporting plans from the NASA HQ Radiological Contingency Plan which is the overarching NASA radiological contingency plan developed by the NASA HQ OPS based on NPD 8710.1, NASA Emergency Management Program; NPR 8715.2, NASA Emergency Management Program; and NPR 8715.26, Nuclear Flight Safety). The NASA HQ plan sets forth the required organizational actions both within NASA and between NASA and other Federal, State, local, and tribal organizations, and describes the top-level contingency response requirements that govern the development of launch site specific radiological contingency plans.

M.4.2 KSC-PLN-1903, KSC Radiological Contingency Plan for Major Radiological Source Missions

This plan is the launch area RCP for accidents during the prelaunch, launch, early ascent phases, and reentry from orbit of a SNS mission. It integrates with the launch area KNPR 8715.2,: Comprehensive Emergency Management Plan (CEMP), and the NASA LSP, Mishap Preparedness and Contingency Plan. It describes the coordination and procedures required to respond effectively to such an accident. It describes the roles and interfaces of the participants in the RADCC and coordination with the Cape Canaveral Space Force Station (CCSFS) LEOC for the accident entry and recovery teams, which include health physics responders. Due to the situation-specific nature of recovery operations, this plan provides only a general framework for source and facility recovery operations.

M.4.3 NASA HQ JIC Plan

NASA, as the Primary Authority, is responsible for being the primary Federal source of information regarding any launch accidents and their potential effects, including the status of conditions on-site at NASA KSC and CCSFS, and off-site. This plan describes the collaborative, multi-agency public communication effort involved in planning, developing, and conducting an effective JIC. The purpose of the JIC is to coordinate and disseminate approved information about the status of a launch accident, potential resulting radiological conditions, and any recommended safety actions to all external audiences. These audiences include the general public, space center workers and visitors, the news media, and other stakeholders, including potentially affected regions in other countries.

M.4.4 OIIR Communications Plan

The OIIR communication plan facilitates DOS' issuance of pre-coordinated cables to overseas DOS missions to international organizations, Embassies, and consulates in potentially affected countries to provide appropriate guidance and information. OIIR coordinates all communications with the DOS from the JIC and NASA HQ in the event of any mishap immediately before or during the launch. The PAR is the central point of coordination and dissemination of information during launch operations and must approve all communications prior to release.

M.4.5 Project OOCP

The OOCP addresses the specialized cases where a healthy and controllable spacecraft would have separated from the launch vehicle and NASA would have the ability to influence reentry location. The purpose of this Plan is to delineate the roles, responsibilities, and activities that would need to occur in response to on-orbit launch vehicle failures whereby the spacecraft has separated from the launch vehicle and is in a commandable state. Transmission of the command sequence to de-orbit the stranded spacecraft requires NASA approval. The objective of the contingency commanding is to target a reentry point such that the SNS impacts the ocean at least 370 km (200 nautical miles) from foreign landmasses and at least 50 km (27 nautical miles) from the continental U.S., territories of the U.S., and the permanent ice pack of Antarctica.

M.4.6 Project Debris Impact Footprint Definition Plan

This plan describes the process by which personnel estimate an Earth impact footprint in the event of a suborbital or orbital reentry of the SNS due to a launch vehicle failure. The estimated footprint describes a region, generally in the shape of an ellipse, within which personnel expect the SNS to impact. This plan also identifies the participants in the footprint estimation process and their roles and responsibilities relative to the implementation of this task. This plan describes the necessary coordination that would need to take place between NASA HQ, the Project, the NASA Launch Services Team, the U.S. Space Force–Space Launch Delta 45, and the DOE, and related contractors. The U.S. STRATCOM, through its CSpOC, has procedures in place and tracking assets to aid in determining the orbit of the spacecraft hardware following an accident and may also be able to provide an independent debris footprint estimate.

M.4.7 DOE Accident Recovery and Transportation Plan

This source recovery plan provides an upper-level strategy summarizing how the DOE would approach: identifying SNS components in the accident debris field, immediate and intermediate storage of SNS components, and repackaging and transporting SNS components should there be a catastrophic mission accident. A key assumption in the DOE source recovery plan is that NASA Center health physics personnel and security forces will provide support in accordance with the DOE and NASA MOU for Radioisotope Power Systems, as well as availability of the NASA Center SNS Facility for operations attendant to packaging and shipping.

M.5 Launch Area RCP Implementing Plans and Procedures

Table 7 and Table 8 provide lists of RCP implementation plans and procedures applicable to the Mars 2020 situation.

Table 7: Launch Site Radiological Contingency Implementing Plans

Launch Site Radiological Contingency Implementing Plans
KSC-PLN-1903.1, Radiological Contingency Field Team Deployment Plan for Major Radiological Source Missions
KSC-PLN-1903.2, KSC Health Physics Logistics Plan for Major Radiological Source (MRS) Missions
KSC-PLN-1903.3, Data Management Plan for Major Radiological Source (MRS) Missions
KSC-PLN-1903.4, Major Radiological Source Field Team Health and Safety Plan
KSC-PLN-1903.5, KSC Radiation Protection Program Dose Assessment / Management Plan for Major Radiological Source Missions
KSC-PLN-1903.6, Major Radiological Source Ground Operations Health Physics Support Plan
KSC-PLN-1903.7, Major Radiological Source Respiratory Protection Plan for Radiological Monitoring Team Personnel
KSC-PLN-1903.8, Health Physics Major Radiological Source Mission Roles & Responsibilities

Table 8: Launch Site Radiological Contingency Field Monitoring Team Procedures

Launch Site Radiological Contingency Field Monitoring Team Procedures
KTI 8715.1, Collection of Radiological Air Samples
KTI 8715.2, Radiological Sample Packaging and Labeling
KTI 8715.3, Collection of Human Food and Animal Feed Samples
KTI 8715.6, Collection of Radiological Soil Samples
KTI 8715.7, Collection of Radiological Water Samples
KTI 8715.8, Field Monitoring Procedure
KTI 8715.9, Ludlum Model 3 Alpha Survey Meter Operating Instruction
KTI 8715.10, Ludlum Model 2221 Ratemeter with FIDLER Operating Instruction
KTI 8715.11, Ludlum Model 12-4 Neutron Survey Meter Operating Instruction
KTI 8715.12, Canberra Radiagem 4000 Portable Survey Meter/Probes Operating Instruction
KTI 8715.14, Garmin GPS Operating Instruction
KTI 8715.15, Motorola APX 1000 (Model 1.5) Handheld Radio Operating Instruction
KTI 8715.17, EPD Easy Issue Database
KTI 8715.18, Instrument Identification Plan
KTI 8715.19, Anti-C Protective Clothing Donning & Doffing
KTI 8715.20, Radiation Hotline Set-Up & Operation
KTI 8715.21, Personnel Monitoring for Radioactive Contamination
KTI 8715.22, Personnel Decontamination
KTI 8715.24, Monitoring and Release of Radiologically Contaminated Materials / Equipment
KTI 8715.25, Medical Emergency Response Instructions for Incidents Involving Radiation Radioactive Material
KTI 8715.26, Hurricane Preparation Procedure for Radiological Response Personnel & Assets
KTI 8715.27, Environmental Continuous Air Monitor (ECAM) Deployment Strategy
KTI 8715.29, Environmental Continuous Air Monitor (ECAM) Assembly & Commissioning
KTI 8715.30, Environmental Continuous Air Monitor (ECAM) Filter Change / Performance Test Procedure

M.6 Information on the KSC RADCC

The RADCC is the launch site physical and functional command and control entity staffed by multiagency personnel experienced in radiological emergency response operations. The overall purpose of the RADCC is to provide a decision-making framework to assess the status of a potential emergency involving a mission that would carry an SNS. The functions of the RADCC include the ability to monitor and direct data gathering and assessment activities and guide response efforts, including providing recommendations for potential protective actions, and timely and accurate information. The RADCC also provides a means to issue authorized releases of information and status reports to the media, the public, and other stakeholders about the accident.

The KSC RADCC is located on the fourth floor of the Neil Armstrong Operations & Checkout Building. The RADCC is composed of three colocated operational units: the Data Assessment Center (DAC), the Primary Authority Management Group (PMG), and JIC. Each unit functions independently and synergistically to accomplish specific tasks in support of the common RCP goals. Each center leverages technology to inform continuous situational awareness and a common operating picture to function as a unified team. Technology is a key component to allow for the separate operational centers to execute their individual objectives and to maintain communications between themselves and externally to the separate external authorities represented at each console position (e.g., State and county emergency operations center, KSC, EOC, and CCSFS Launch Emergency Operations Center, FEMA National Operations Center and National Watch Center, and EPA Emergency Operations Center).

The DAC collects field monitoring data, assesses that data, and generates advisories and status reports relating to on-site and off-site radiological conditions resulting from a pre-launch accident or launch area anomaly with a release of radioactive material. Personnel generate assessment products and recommend protective actions to the PAR in the PMG. The KSC RADCC Director (KSC Radiation Protection Officer) leads the DAC.

The PMG provides a forum for senior management monitoring of data collection and assessment activities and discussion and decision-making regarding development of protective action recommendations to State and local agencies in the event of an accident in the launch area. The PMG is also the central coordination point for contact with applicable Federal agency HQs and field offices via liaison positions seated in the PMG. The PAR, a NASA senior manager designated by the launch site Center Director, leads the PMG.

The JIC provides a collaborative multiagency system to coordinate all accident information for timely and regular release to the news media and the public for missions carrying an SNS. The JIC is led by the NASA JIC Manager.

The RADCC compiles field monitoring data, estimates the path and direction of any potential releases, and assesses the monitoring data to formulate advisories and status reports relating to radiological emergency response activities, recommendations, and decisions. In the early phase of an accident response, very little factual information may be available, so personnel make recommendations and decisions based on information extrapolated from what is known or can be inferred (e.g., a source term based on an apparent representative accident scenario). Precautionary sheltering-in-place is the default action until the DAC receives and analyzes field monitoring data. Figure 8 describes the general process.

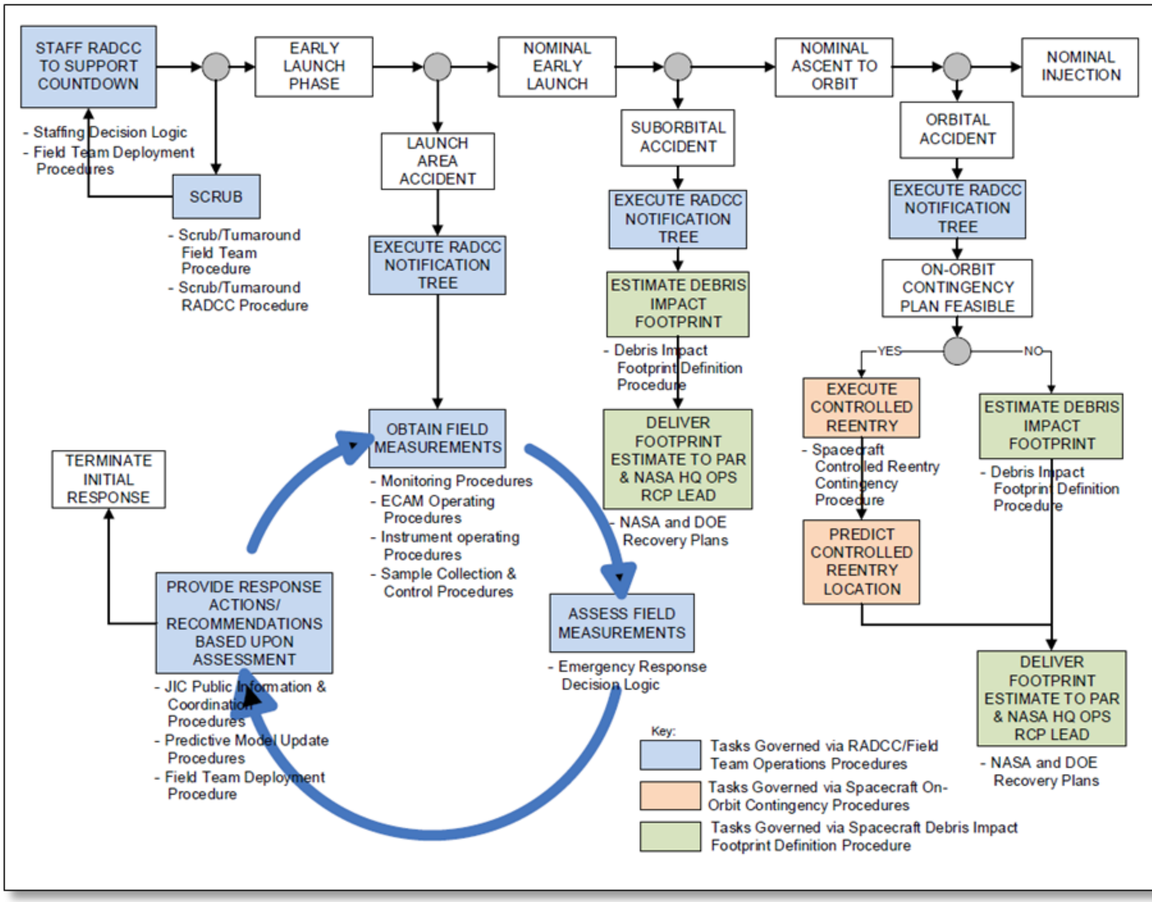

Figure 8: General Radiological Contingency Response Decision Flow Diagram

M.7 Other Critical Assessment and Response Considerations

Spacecraft altitude at time of the accident, size and rise of fireball, meteorological conditions, status of destruct systems, and other factors affect the time between a release of radioactive material and a confirmation by alarm or increased count-rate on an ECAM. Deployed field monitoring teams equipped with specialized instrumentation to measure radioactive material validate ECAM indications with ground deposition measurements. DOE assessment scientists and atmospheric release modeling scientists in the RADCC, supported by additional reach back capability called the DOE Consequence Management Home Team and National Atmospheric Release Advisory Center on phone bridges consume the data and create assessment products for the RADCC director to use in field monitoring team movement, delivering briefings to the PMG for decision-making, and tailoring pre-scripted messaging releases coordinated and released by the JIC following PAR approval.

In a launch accident, personnel assume radioactive material release until proven otherwise. It may be hours before the LEOC sends in the initial entry team. If human lives are not at risk, the LEOC commander will likely let the fires from unburnt solid and liquid fuel burn out first. The RADCC provides two trained radiological monitors each embedded with the accident site Entry and Recovery teams (RADMON 1E and 1R, respectively) to measure ground deposition and support hotline decontamination efforts at the crash site. In addition, a spacecraft specialist and an SNS specialist embed within the team to identify components of their respective hardware.

NASA uses a network of 26 stationary and 4 mobile ECAMs strategically located around the launch area to detect slight increases in background airborne radioactivity levels indicative of release confirmation. The RADCC continuously receives ECAM data for analysis. ECAM alarms are verified with ground deposition measurements by RADMON teams equipped with specialized detection equipment for detection of special nuclear material (i.e., Pu-238 in the case of RPS launches). The typical field monitoring force offsite consists of three 2-person RADMON teams and two 2-person mobile ECAM teams. In addition to the RADMON teams supporting the LEOC, seven more 2-person RADMON teams and two 2-person mobile ECAM teams support monitoring of onsite conditions. All data is transmitted to the RADCC and quality checked before analysis by the assessment scientists. Additional teams are dedicated to support ECAMs, RADMON instrumentation, sample transport, and personnel and medical decontamination teams.

Response refers to those activities and capabilities commonly identified as consequence management, and the term consequence management describes those activities that include securing the incident site, assessing the dispersal of radioactive material, enhancing first responder capabilities, ensuring availability of decontamination and site remediation resources, providing radiological medical triage capabilities, and increasing population resilience and recovery capabilities.

In the event of an accident, the radioactive plume from airborne releases may reach areas distant from the point of release and local air and surface contamination concentrations may rapidly change in intensity and area coverage (based on weather conditions and radioactive decay) until the plume has passed. Response to a large incident will depend on the extent of radiological deposition from the plume and personnel may required to conduct certain operations in contaminated areas over multi-jurisdictional and multi-state regions. Meteorological conditions and weather forecasts throughout the incident will likely play a significant role in decision making, including determining evacuation routes, locations for staging areas and shelters, and incident response zones.

Responders use PAGs and Derived Response Levels to protect the public during the short-term and intermediate response phase of an incident. In small incidents, standards may be set more conservatively than such guidelines require. Though these guidelines are not necessarily applicable to the types of accidents in question here, for the sake of completeness, in catastrophic incidents immediate health and life safety issues may necessitate allowing more exposure for both responders and the public to save the most lives. The primary protective actions for reducing or eliminating exposure during a radiological incident are:

1) Shelter in place, evacuation, self-decontamination;

2) Food and water restrictions; and

3) Long-term relocation and remediation.

Any workers deployed to a radiation area must receive radiation safety training before deployment and should receive radiation measurement training. Response teams should not enter affected areas until radiation safety experts determine and can readily monitor radiation levels, and personnel must receive pre-entry briefings (in addition to any other required training) before entering such areas. In general, neither responders nor members of the public should exceed Occupational Safety and Health Administration or NRC dose limits; however, in catastrophic incidents, certain emergency activities (such as those associated with critical infrastructure protection or restoration, lifesaving actions, and protection of large populations) may justify an individual exceeding such limits. In these cases, doses over the established limits must be unavoidable, doses must be monitored, and all reasonable steps must be taken to provide appropriate protection and minimize doses during emergency activity.

Operating safely in a hazardous environment requires appropriate policies, plans, equipment, training, and expertise. Employers, including federal agencies, must also adequately assess worksite hazards and develop site-specific health and safety plans for controlling those hazards. In radiation-contaminated zones and other hazardous environments, collection and reporting of relevant information to track responders, their health status, and accumulated dose data helps protect workers. Federal agencies should comply with their own worker safety and health policies, including instances where those policies prohibit federal personnel from entering contaminated environments.

If a personnel establish a national defense or national security area or exclusionary zone, response assets may have limited access to the incident area. Further, personnel will treat the location of a suspected or actual deliberate incident as a federal crime scene. The preservation and collection of evidence is critical to determine the identity of culpable parties or information about additional planned attacks. Therefore, it is important to ensure that Response and Recovery personnel understand and recognize possible access restrictions to crime scenes. Further, the Response and Recovery missions should collaborate with the Prevention mission to establish joint priorities to save lives, protect property, and conduct Prevention activities.

When the Federal Radiological Monitoring and Assessment Center (FRMAC) transfers to the EPA, the EPA assumes responsibility for coordination of radiological monitoring and assessment activities. A transfer most likely will occur in the recovery phase of a response, when response personnel have largely completed immediate emergency operations. The EPA is then responsible for the transition into long-term monitoring and assessment. Although it is difficult to specify in advance when the transfer of this coordination responsibility will occur, certain conditions must be met prior to this transfer. DOE may request that the EPA consider the transfer when the DOE believes it is practical and appropriate to do so, and the EPA will consider this request.

The response team will activate the Interagency Modeling and Atmospheric Assessment Center (IMAAC) for incidents requiring a coordinated federal response to coordinate and develop federal atmospheric modeling tools, activities, and results. The Center will provide the Federal Government's common operating picture for atmospheric modeling. Once activated, the Center will provide initial modeling analysis through the FEMA National Watch Center and available on The Homeland Security Information Network (HSIN) within 30 minutes and will continue to update models as required by the release and weather conditions. The National Atmospheric

Release Advisory Center (NARAC) will produce official atmospheric modeling products for the Federal Government in the event of a radiological release.

APPENDIX N. Life Cycle Activities Relevant After Launch Authorization

N.1 SMA Nuclear Flight Safety-Related Oversight Following Launch Authorization

The authors recommend that NASA personnel use one of the three approaches outlined below, or some combination therein, as the means of managing nuclear flight safety-related technical authority after the authorizing official grants launch authorization. These approaches will support effective insight leading up to the SMSR.

N.1.1 Alternative 1–Mission-Owned Change Control Process

As part of the overall management of the safety basis for the nuclear launch authorization, the mission may choose to implement a change control process that supports the broad needs of all stakeholders (including the terrestrial nuclear authority and the nuclear launch authority). If that process provides sufficient access and insight to the safety and mission assurance technical authority stakeholders (including the NFSO, PSWG, and radiological contingency planners), no additional activity is necessary.

N.1.2 Alternative 2–Critical Analysis Assumptions List

The NFSO, in coordination with the NASA Project Manager, the PSWG Chair, the Project-Level SMA TA, and the INSRB (when applicable) can use the results of the nuclear safety analysis and nuclear safety review to construct and formally issue a nuclear-specific and mission-specific critical analysis assumptions list to the PSWG Chair and relevant SMA TAs for use within the routine launch services and mission execution processes. This list would, in effect, serve as an amendment to the NPR 8719.24 compliance matrix and would serve to facilitate the monitoring of any anticipatable issues that would cause the mission to likely exceed (or further exceed by a significant amount) NSPM-20’s safety guidelines or that would cause a significant degradation of defense-in-depth (e.g., fission product barriers). In this way, the list serves as a tool to codify nuclear flight safety-specific factors into these stages of NASA’s routine risk management processes.

N.1.3 Alternative 3–Dedicated NFSO Monitoring

Barring adoption of the above, the NFSO could periodically monitor available information streams or consult with the applicable SMA interface for that phase of the mission in order to identify events and conditions that significantly deviate from the assumptions of the SAR during periods leading up to launch and subsequent operation (that are within scope of the SAR) for Tier I, II, and III missions, and which are also prior to the spacecraft entering interplanetary flight with no plan for return or Earth gravity assist. In cases where NASA personnel could reasonably expect identified events to cause the mission execution to exceed (or further exceed by a significant additional quantity) NSPM-20’s safety guidelines or requirements (e.g., Department of the Air Force risk constraint), the NFSO will perform a simple, scoping-level qualitative or semi-quantitative assessment of the impact of the event or condition and document this assessment in a Note to File. In cases where the NFSO finds a specific event or condition to exceed (or further exceed by a significant additional quantity) the safety guidelines or a quantitative requirement, the NFSO will capture this finding in a memo and discuss it with the relevant SMA interface. By this means, NASA personnel can factor the finding into safety and mission success activities (e.g., a PSWG Safety Review, the SMSR).

Depending on the circumstances, the appropriate interface might be the Project-level SMA TA, a Program-affiliated SMA TA, the SMA Launch Services Division Mission Safety Engineer, the Payload Safety Program Executive, the Range Safety Program Executive, or the PSWG Chair. In some cases, the monitoring of information sources (e.g., the Launch Services Portal where the PSWG posts spacecraft non-compliances after signing the Payload Safety Compliance documentation) may be a suitable replacement to contacting the interface.

The appropriate periodicity of monitoring the mission will vary greatly depending on the phase of the mission execution (e.g., more frequently during the period following SNS integration into the integrated launch vehicle and prior to launch versus less frequently during spaceflight). Examples of relevant events and conditions are: (a) a two-fold increase in the time window in which the ground support equipment cools the SNS relative to that assumed in the SAR, (b) a significant deficiency identified in the performance of a safety-relief valve that personnel cannot mitigate and which effectively results in an increase in launch vehicle unreliability, and (c) a spacecraft malfunction while in Earth orbit that significantly increases the likelihood of not achieving a sufficiently high orbit when the mission reaches end-of-life.

APPENDIX O. SNS Decommissioning and Disposal

O.1 Background

Of particular interest in this area is the requirement in SPD-6, which states:

> "The operation and disposition of SNPP systems shall be planned and conducted in a manner that protect[s] human and environmental safety and national security assets. Fission reactor SNPP systems may be operated on interplanetary missions, in sufficiently high orbits, and in low-Earth orbits if they are stored in sufficiently high orbits after the operational part of their mission. In this context, a sufficiently high orbit is one in which the orbital lifetime of the spacecraft is long enough for the fission products to decay to a level of radioactivity comparable to that of uranium-235 by the time it reenters the Earth's atmosphere, and the risks to existing and future space missions and of collision with objects in space are minimized. Spacecraft operating fission reactors in low-Earth orbits shall incorporate a highly reliable operational system to ensure effective and controlled disposition of the reactor."

This language adopts a tenet in the 1992 UN Safety Principles that had similar wording. The Administration has not elaborated on how to interpret this passage in technical analysis. Currently, analysts and reviewers must independently determine how to implement terms like "sufficiently high," "comparable to that of uranium-235," and "highly reliable." For instance, Alfonsi (2022) presents three different interpretations of the radioactive decay aspects arriving at three distinctly different outcomes.

Analysts could perform analysis to estimate how long it would take the fission products (as opposed to actinides) to decay to activity levels where their contribution to the overall system radioactivity is negligible, and such a basis would be consistent with the specific wording in SPD-6. The key underlying premise is that fission products have shorter half-lives (and therefore designers can mitigate the risk that they pose by delaying reentry), whereas the half-lives of many actinides are too long to lend themselves to risk mitigation in this way. Most fission products have half-lives on the order of hours, days, or a few years. However, some have relatively longer half-lives of decades or higher. The premise of the SPD-6 passage is to encourage mission designers and reviewers to seek out disposal orbits that mitigate the manageable risks, acknowledging that the risks associated with the long-lived actinides are not mitigatable (short of taking the flight system entirely out of orbit, which poses its own challenges for mission design and risk).

Because prominent fission products like Cs-137 have a 30 year half-life, a significant amount of fission product radioactive decay will occur after several hundred years. To make a rigorous case regarding the safe disposal tenet, analysts would need to estimate fission product abundances and model the relevant controlling exposure accidents (those reentry accident scenarios with a combination of likelihood and consequence that makes them most important to overall risk) to arrive at a time-dependent estimate of risk, where the orbital decay lifetime (the timing of reentry) is the ordinate. Such an estimate would be more meaningful than the more typical assessment performed, in which analysts look at the total activity of all fission products and actinides as a function of time because different radioisotopes have lesser or greater impact on human health. Such an assessment would result in a monotonically decreasing risk, so analysts would need to define an accepted threshold or construct an optimization to balance this radiological risk mitigation against the orbital mechanics aspects. Analysts would still need to address the “highly reliable” tenet through other means, potentially anchoring to state-of-practice reliability and maintainability standards.

Note, analysts may need to revalidate past declarations of what constitutes a sufficiently high orbit given the issuance of SPD-6, if they are to be used as a basis for future missions. For instance, the 2009 Mars Design Reference Architecture Addendum (NASA/SP–2009–566-ADD) states, “750 km (405 nmi) and 1,000 km (540 nmi) are considered sufficiently high for launching systems that contain nuclear material.”

O.2 Strategies

O.2.1 For missions that operate or disposition an SNS in low Earth orbit, the NASA Project Manager should demonstrate through analysis that the operation or disposal of the SNS is in an orbit where the rate of orbital decay and potential for Earth reentry is sufficient to meet the public exposure risk requirements of the Tiered mission and NSPM-20. The NASA Project Manager should plan and conduct operation and disposition of the SNS in a manner that protects human and environmental safety and national security assets. Missions operating fission SNS in cis-lunar orbits should place the SNS in a sufficiently high orbit as part of the planned mission such that the risk of radiological hazard complies with NSPM-20. In this context, a sufficiently high orbit is one where the orbital lifetime of the spacecraft has a life duration that allows fission products to decay to a level of radioactivity comparable to uranium-235 by the time it reenters the Earth’s atmosphere. Mission designers should minimize risks to existing and future space missions from collisions with space objects. Spacecraft operating fission reactors in low-Earth orbits should incorporate a highly reliable operational system to ensure effective and controlled disposition of the reactor.

O.2.2 Missions that plan to transfer an operating or hot SNS between orbits or to a disposal orbit should ensure that inadvertent disposition of the SNS due to a potential operational failure meets the approved mission NSPM-20 Tier risk.

O.2.3 For SNS using highly enriched levels of nuclear material, mission designers should avoid a reliance on a partial burnup and dispersal strategy of the core material given the overriding security concerns and potential requirement to retrieve dispersed, or residual, nuclear material. Rather, the vehicle configuration should be designed to ensure intact reentry of the nuclear material to facilitate retrieval.

O.2.4 The decommissioning and disposal strategy for a surface nuclear power system having the potential for human exposure should anchor its decommissioning and disposal strategy in the permissible exposure levels defined in NASA-STD-3001.

APPENDIX P. Internal and External Reporting

P.1 More Information on Annual NSPM-20 Reporting

P.1.1 NSPM-20 Directs Heads of Sponsoring Agencies to:

P.1.1.1 "On an annual basis… provide a report to the Director of OSTP listing all launches that the agency has sponsored or licensed in the past calendar year of spacecraft using radioactive sources containing total quantities in the range of 1,000 times to 100,000 times the A2 value listing all such launches planned for the coming calendar year." [Sect. 6(a)], and

P.1.1.2 "Any agency planning Tier II or Tier III launches shall provide an annual briefing to OSTP and the National Science and Technology Council on the status of safety analysis for any such planned missions…" [Sect. 6(b)]

P.1.2 At a minimum, a letter leveraging the prior year's format will report mission names, estimated launch dates, and preliminary tier identifications (when available) using a tabular format. In general, the Section 6(b) activity will include a briefing on the safety analysis status. However, if there are no missions for which nuclear safety analysis has begun in earnest, NASA and OSTP staff may conclude on the basis of informal discussion that a letter acknowledging the status of mission planning is sufficient.

P.1.3 OSMA will coordinate the content of the letter or report with all Mission Directorates with planned or ongoing nuclear-enabled projects, as well as OIIR. The Mission Directorate representatives will ensure that relevant Program Managers are aware of the reporting. The applicable Mission Directorate representative(s), OIIR, or OSMA, as appropriate, will ensure that other agencies that are either partnering with NASA in this area (e.g., DOE) or have a reportable mission (e.g., DoD, FAA) are also made aware. The NASA Chief of Safety and Mission Assurance will sign the resulting report as the agency signatory, having notified the Administrator through OSMA's routine communications with the Office of the Administrator. OSMA will ensure that the above parties are copied on the letter. (Note: In March 2021, OACS staff validated that this annual report does not rise to the level of warranting Agency Council involvement.)

P.1.4 The requirement is for an annual report, but there are no deadlines specified in NSPM-20. Based on precedent, an April letter is the goal. The typical steps leading up to this letter will include:

P.1.4.1 A kickoff discussion with the relevant NASA parties;

P.1.4.2 Initial drafting of the letter;

P.1.4.3 Technical editing;

P.1.4.4 Routing for broader (i.e., outside of the immediate authorship) comment;

P.1.4.5 Formal concurrence and circulating the draft final letter to other affected agencies for awareness;

P.1.4.6 Notifying the Associate Administrator and the Administrator's Office of the pending issuance and signing the letter.

P.1.5 The NFSO will post letters and briefings in response to this reporting requirement on NASA's nuclear flight safety webpage (https://sma.nasa.gov/sma-disciplines/nuclear-flight-safety), either internally or externally. NASA will determine public availability on a case-by-case basis.

APPENDIX Q. Constraints Relevant to Nuclear Flight Safety

Table 10 provides a list of all constraints that the authors identified relative to nuclear flight safety. This table provides a potentially useful resource to those attempting to catalogue applicable overarching constraints.

Table 9: Constraints Relevant to NASA Nuclear Flight Safety

Ident.	Constraint	Binding?
Overview and Framing – This table attempts to capture constraints that specifically have the potential to influence NASA nuclear flight safety guidance. The general approach is to identify unique constraints at their lowest (and thus most implementable) level. However, since different institutions have drilled down on the relevant authorities and directions to widely varying degrees and in varying ways, there is significant heterogeneity in this regard. This is the reason that some aspects are at a very high level (e.g., the Atomic Energy Act), while others are at a much lower level (e.g., NASA Directives).		
US Statutes and Regulations–Atomic Energy Act of 1954 (as amended), including other relevant successors such as the Energy Reorganization Act of 1974		
AEA-1	Establishes the authorities for atomic energy activities (in modern day involving the US Department of Energy, the US Nuclear Regulatory Commission, and the US Environmental Protection Agency)–N*one of these agencies have promulgated Rules explicitly covering space applications, and so a more detailed breakdown of binding and non-binding elements and auspices is less straight-forward and should involve OGC. Such an exercise has been conducted on a few occasions over the years, resulting in MOUs capturing specific suites of activity, such as the 2016 NASA and DOE MOU entitled, "Memorandum of Understanding Between the National Aeronautics and Space Administration and the Department of Energy Concerning Radioisotope Power Systems." In the meantime, two simple derivatives are captured below from the discussions surrounding NSPM-20 and a potential new SNPP Policy.*	Yes
AEA-2	A person may not own, possess, or transfer a production facility, a utilization facility, special nuclear material, source material, or byproduct material without a license from the NRC or an authorization from the DOE, or an authorization extended from the Secretary of Energy to the Department of Defense – for NASA, this has historically been addressed by having NASA in a DOE contractor relationship, via a DOE/NASA MOU.	Yes
AEA-3	AEA authority applies "under or within the jurisdiction of the United States," commonly interpreted to mean that it does not apply to spaceflight (e.g., see NUREG-1556, Volume 19, Revision 1, Section 2.10 regarding material licensing reciprocity for commercial launch operations).	Yes
US Statutes and Regulations–14 CFR, including the Sept. 2020 Rulemaking entitled, "Streamlined Launch and Reentry License Requirements" (applicable to FAA-licensed launches)		
14CFR-1	450.45 - The FAA will evaluate the launch or reentry of any radionuclide on a case-by-case basis…For any radionuclide on a launch or reentry vehicle, an applicant must—(i) identify the type and quantity; (ii) include a reference list of all documentation addressing the safety of its intended use; and (iii) describe all approvals by the Nuclear Regulatory Commission for pre-flight ground operations.	Yes
National Policy–Presidential Directive/NSC-25 (1977)		
PDNSC-1	Para. 8 - To the extent that it is consistent with national security, and subsequent to approval of the experiment, there should be early and widespread dissemination of public information explaining the purpose, benefits, and assessments of impacts.	No
Recall that only Paragraph 9 of PD/NSC-25 is superseded by later documents (most notably NSPM-20)		

Ident.	Constraint	Binding?
National Policy–National Security Presidential Memorandum 20 (2019)		
NSPM20-1	The United States shall develop and use SNS when such systems safely enable or enhance space exploration or operational capabilities.	Yes
NSPM20-2	The Secretary of Energy shall maintain, on a full cost recovery basis, the capability and infrastructure to develop, furnish, and conduct safety analyses for SNS for use in United States Government space systems.	Yes
NSPM20-3	Executive departments and agencies (agencies) shall seek to ensure that safe application of SNS is a viable option for Federal Government and commercial space activities.	Yes
NSPM20-4	All United States Government entities involved in the launch of spacecraft containing SNS (including in the licensing of non-Government launches) shall seek to ensure safe operation.	Yes
NSPM20-5	For any mission that includes a SNS, mission planners and launch authorization authorities should, as appropriate, seek to ensure that: (i) normal operation of the SNS is consistent with applicable Federal, State, and local requirements. (Conditions (ii) – (iv) specify quantitative Safety Guidelines via a piece-wise linear dose-vs-likelihood function.)	No
NSPM20-6	Authorization for launches of spacecraft containing SNS shall follow a three-tiered process based upon the characteristics of the system, the level of potential hazard, and national security considerations. (the NSPM goes on to define Tier I, Tier II, and Tier III.)	Yes
NSPM20-7	Issuance of a launch authorization or license as described in this memorandum shall not relieve the mission sponsor or licensee of its obligations with respect to other applicable laws, regulations, policies, or agreements that may apply to its activities.	Yes
NSPM20-8	The President's authorization shall be required for Federal Government launches in Tier III.	Yes
NSPM20-9	The head of the sponsoring agency shall request the President's authorization for the launch through the Director of OSTP.	Yes
NSPM20-10	Safety analysis should include an assessment of potential consequences to a maximally exposed individual member of the public in accident scenarios.	No
NSPM20-11	Safety analysis should address launch and any subsequent stages when accidents may result in radiological effects on the public or the environment, for instance, in an unplanned reentry from Earth orbit or during an Earth flyby.	No
NSPM20-12	To the extent possible, safety analyses and reviews should incorporate previous mission and review experience.	No
NSPM20-13	For Federal Government missions in all tiers, the head of the sponsoring agency shall be responsible for ensuring compliance with requirements under the National Environmental Policy Act (NEPA), 42 U.S.C. 4321 et seq.	Yes
NSPM20-14	For Federal Government missions in all tiers, the head of the sponsoring agency shall ensure that a mission Safety Analysis Report (SAR) be prepared.	Yes
NSPM20-15	The mission SAR shall demonstrate that safety analysis incorporates technical peer review, and shall include a concise, high-level summary of key risk information.	Yes
NSPM20-16	This summary [alluding to the above] should include: the likelihood of an accident resulting in an exposure in excess of 5 rem TED to any member of the public; the number of individuals who might receive such exposure in an accident scenario…	No
NSPM20-17	When appropriate, a mission SAR may incorporate a system-specific SAR that establishes a safety basis for the SNS. In such cases, the mission SAR must either: (i) demonstrate that the mission is within the safety basis envelope…or (ii) supplemental safety analysis for any deviations that are outside of the established safety basis envelope…	No
NSPM20-18	Agencies responsible for system-specific SARs should review them annually and update them as necessary.	No
NSPM20-19	Within 180 days of the date of this memorandum, the NASA Administrator shall establish an Interagency Nuclear Safety Review Board (INSRB).	Yes

Ident.	Constraint	Binding?
NSPM20-20	The INSRB shall consist of representatives from the Departments of State, Defense, Energy, and Transportation, the Environmental Protection Agency, NASA, and, as appropriate, the Nuclear Regulatory Commission.	Yes
NSPM20-21	Each of these agencies shall designate technically qualified personnel to the INSRB.	Yes
NSPM20-22	For…Tier II and Tier III, the head of the sponsoring agency shall request of the NASA Administrator that the INSRB review the nuclear safety analysis, ultimately including the mission SAR, and report its findings, in the form of a Safety Evaluation Report, to the head of the sponsoring agency…	Yes
NSPM20-23	The INSRB shall evaluate the quality of the safety analysis and identify any significant gaps in analysis.	Yes
NSPM20-24	The INSRB may recommend areas for additional analysis where it identifies gaps, but it is not tasked with repeating or conducting its own analysis.	No
NSPM20-25	The INSRB shall engage early in the safety analysis process, after the conceptual design of the mission is generated, to identify gaps in time for mission planners to address them without creating unnecessary delays in the launch timeline.	Yes
NSPM20-26	Before completion of the mission SAR, the INSRB shall advise the head of the sponsoring agency of any omissions or gaps that the INSRB has identified in analysis that is planned or underway, and may provide recommendations for corrective action.	Yes
NSPM20-27	At the request of the Secretary of Transportation, the INSRB shall review any nuclear safety analysis associated with a potential commercial launch of a SNS under review by the Secretary of Transportation.	Yes
NSPM20-28	The terms of any INSRB review, including the costs of such review, shall be agreed upon between the NASA Administrator and the head of the agency requesting INSRB review.	Yes
NSPM20-29	On an annual basis, the recipients of this memorandum shall provide a report to the Director of OSTP listing all launches that the agency has sponsored or licensed in the past calendar year of spacecraft using radioactive sources containing total quantities in the range of 1,000 times to 100,000 times the A2 value…and listing all such launches planned for the coming calendar year.	Yes
NSPM20-30	Any agency planning Tier II or Tier III launches shall provide an annual briefing to OSTP and the National Science and Technology Council on the status of safety analysis for any such planned missions.	Yes
National Policy–Space Policy Directive 6 (2020)–*focused on those aspects with direct relevance to nuclear flight safety*		
SPD6-1	Fission reactor SNPP systems may be operated on interplanetary missions, in sufficiently high orbits, and in low-Earth orbits if they are stored in sufficiently high orbits after the operational part of their mission. In this context, a sufficiently high orbit is one in which the orbital lifetime of the spacecraft is long enough for the fission products to decay to a level of radioactivity comparable to that of uranium-235 by the time it reenters the Earth's atmosphere, and the risks to existing and future space missions and of collision with objects in space are minimized. Spacecraft operating fission reactors in low-Earth orbits shall incorporate a highly reliable operational system to ensure effective and controlled disposition of the reactor.	Yes

Ident.	Constraint	Binding?
SPD6-2	The use of highly enriched uranium (HEU) in SNPP systems should be limited to applications for which the mission would not be viable with other nuclear fuels or non-nuclear power sources. Before selecting HEU or, for fission reactor systems, any nuclear fuel other than low-enriched uranium (LEU), for any given SNPP design or mission, the sponsoring agency shall conduct a thorough technical review to assess the viability of alternative nuclear fuels. The sponsoring agency shall provide to the respective staffs of the National Security Council, the National Space Council, the Office of Science and Technology Policy, and the Office of Management and Budget a briefing that provides justification for why the use of HEU or other non-LEU fuel is required and any steps the agency has taken to address nuclear safety, security, and proliferation-related risks. The Director of the Office of Science and Technology Policy shall ensure, through the National Science and Technology Council, that other relevant agencies are invited to participate in these briefings.	Yes (in terms of requiring justification if HEU is used)
SPD6-3	Cost-effectiveness. The heads of relevant agencies should pursue SNPP development and use solutions that are cost-effective while also consistent with the principles of safety and security. For any program or system, the heads of such agencies should seek to identify the combination of in-space and ground-based testing and certification that will best qualify the system for a given mission while ensuring public safety.	No
SPD6-4	The Administrator of NASA shall conduct and support activities associated with development and use of SNPP systems to enable and achieve United States space science and exploration objectives. The Administrator of NASA shall establish the performance requirements for SNPP capabilities necessary to achieve those objectives.	Yes
National Policy–Nuclear Radiological Incident Annex (2016)–*likely not exhaustive*		
NRIA-1	Radioactive Materials in Space Vehicles Impacting the United States that are…Managed by the National Aeronautics and Space Administration (NASA) – the Primary Authority for Federal Response is NASA [Table 1].	Yes
NRIA-2	For radiological incidents involving nuclear material in NASA custody, NASA may establish a Security Area per 14 CFR Part 1203a. NASA will manage the response within the boundaries of the Security Area and will coordinate with state and local officials to ensure appropriate public health and safety actions are taken outside the Security Area.	No
NRIA-3	In the event that the DHS assumes overall management of the federal response under Homeland Security Presidential Directive 5 to an inadvertent incident involving NASA space vehicles, NASA will support the DHS under the NRF and NIMS.	Yes
NRIA-4	For incidents in which there is no Stafford declaration, the agency with primary authority should respond in a standard NIMS, Incident Command System structure.	No
NRIA-5	If DHS does not assume federal leadership for the coordination of the consequence management response, the agency with primary authority may request that FEMA activate NRF or NDRF elements to support response and recovery activities.	No
NRIA-6	The agency with primary authority may request assistance from other federal agencies.	No
NRIA-7	The agency with primary authority will also be represented in appropriate positions within the Command Staff in the Incident Command and Unified Command structure (as defined by the NIMS), coordinates federal radiological response and recovery activities at appropriate field facilities, and provides personnel to other sections of the Incident Command and Unified Command as needed.	Yes
NRIA-8	The FRMAC is established at or near the incident location in coordination with FEMA, the Federal agency with primary authority, other Federal agencies, and State and local governments	Yes

Ident.	Constraint	Binding?
Agency Policy–NPR 8700.1-NASA Policy for Safety and Mission Success–*focusing on the policy tenets most closely tied to NASA's nuclear flight safety program*		
Lead-in text to the following policies	It is NASA policy to protect the public, NASA workforce, high-value property, and the terrestrial, orbital, and planetary environments from potential harm due to NASA activities and operations by:	
N8700.1-1	Managing safety as an integral aspect and objective of the program, project, facility, and center operations and activities.	Yes, but this is broad
N8700.1-2	Complying with statutes, regulations, and directives, and meeting external obligations.	Yes, but this is broad
N8700.1-3	Adopting effective and responsible safety standards, guidelines, and industry best practices to manage hazards requiring control, while prioritizing performance-based approaches.	Yes, but this is broad
N8700.1-4	When there is no accepted standard to manage novel or unique hazards, consulting with subject matter experts on strategies to ensure an acceptable level of risk.	Yes, but this is broad
N8700.1-5	Obtaining the authorization or consent of an authorized official representing entities exposed to potential harm unless consent is established by adherence to applicable standards or policy.	Yes, but this is broad
Agency Policy–Dept. of the Air Force Manual 91-110 – Nuclear Safety Review and Launch Approval for Space or Missile Use of Radioactive Material and Nuclear Systems–*Applicable when NASA uses a DoD Range*		
The below focuses on the aspects of the Dept. of the Air Force Manual that arise as additional items not otherwise covered by the invocation of the Federally mandated interagency process in NSPM-20 or the equivalent NASA Procedural Requirements Document.		
DAFMAN-1	PCancerC. Assess the PCancerC as 1.2 times the Probability of a Latent Cancer Fatality (PLCF). (T-1) This value provides the PCancerC associated with a projected 50-year cumulative increase in risk for fatal and non-fatal cancers (i.e., a casualty). This PCancerC is not aggregated with other mission risks. (T-1) General public risk that exceeds a PCancerC of 1 × 10-6 requires the Space Launch DEL/CC waiver approval. (T-1) When the general public risk exceeds a PCancerC of 100 × 10-6, FLDCOM Commander or equivalent approval is required. (T-1) The DEL/CC shall notify AFSEC/SES before allowing launches that exceed a PCancerC of 1 × 10-6 (T-1)	Yes
DAFMAN-2	Dose Goal. The overall mean maximum individual effective dose is the mean of the calculated maximum effective doses, based on various launch vehicle failure modes resulting in release of radioisotopes, received by the maximally exposed individual for a given mission. Each mission should not exceed the overall mean maximum individual total effective dose goal of 100 mrem. (T-3) However, if a mission exceeds the dose goal, the Space Launch DEL/CC may approve the launch after additional safety analysis. The DEL/CC must consider how the additional radiological risk contributes to the overall launch risks, any additional safety analyses, and contingency plans. (T-3) This includes but is not limited to the impacts of planned mitigation efforts and target organs of the mission radioisotopes. (T-3)	Yes, in terms of being performed, however the threshold is a goal and not a requirement
DAFMAN-3	Contamination Impact Statement. A contamination impact statement estimates radiological risk to range assets and operations beyond the immediate exposures at the time of the mishap required to be considered per AFI 91-202 Sec. 10.7.2.1. The range user will provide the estimates of range contamination levels under credible scenarios and other information deemed necessary to the Range Safety Office. (T-3) The Range Safety Office will prepare the contamination impact statement for the Space Launch DEL/CC. (T-3)	Yes, in terms of being performed

Ident.	Constraint	Binding?
International Policy–The Outer Space Treaty (1967)		
OST-1	States Parties to the Treaty shall pursue studies of outer space…and conduct exploration of them so as to avoid their harmful contamination…If a State Party to the Treaty has reason to believe that an activity or experiment planned by it or its nationals in outer space, including the moon and other celestial bodies, would cause potentially harmful interference with activities of other States' Parties in the peaceful exploration and use of outer space, including the moon and other celestial bodies, it shall undertake appropriate international consultations before proceeding with any such activity or experiment.	Yes
International Policy-UN Convention on Early Notification of a Nuclear Accident (1986)		
In the context of this Convention pertaining to NASA nuclear flight safety, nuclear accident below refers to "any accident involving"…the "use of radioisotopes for power generation in space objects"…from "which a release of radioactive material occurs or is likely to occur and which has resulted or may result in an international transboundary release that could be of radiological safety significance for another State." [Note that USG did take exception to Article 11 (https://www-legacy.iaea.org/Publications/Documents/Conventions/cenna_reserv.pdf) (not included below) in adopting the Convention.]		
UN-EN-1	…the State Party shall notify directly, or through the IAEA, "those States which are or may be physically affected, …its nature, the time of its occurrence and its exact location…" as well as, "information relevant to minimizing the radiological consequences…"	Yes
UN-EN-2	"The information to be provided…shall comprise the following data as then available to the notifying State Party: (a) The time, exact location where appropriate, and the nature of the nuclear accident; (b) The facility or activity involved; (c) The assumed or established cause and the foreseeable development of the nuclear accident…(d) the general characteristics of the radioactive release…(e) Information on current and forecast meteorological and hydrological conditions…(f) The results of environmental monitoring…(g) The off-site protective measures taken or planned…(h) The predicted behavior over time of the radioactive release.	Yes
UN-EN-3	"Such information shall be supplemented at appropriate intervals by further relevant information on the development of the emergency situation, including its foreseeable or actual termination."	Yes
UN-EN-4	"A State Party providing information pursuant to sub-paragraph (b) of article 2 shall, as far as is reasonably practicable, respond promptly to a request for further information or consultations sought by an affected State Party with a view to minimizing the radiological consequences in that State."	Yes
UN-EN-5	"Each State Party shall make known to the Agency [IAEA] and to other States Parties, directly or through the Agency, its competent authorities and point of contact responsible for issuing and receiving the notification and information referred to in article 2. Such points of contact and a focal point within the Agency shall be available continuously. Each State Party shall promptly inform the Agency of any changes that may occur in the [foregoing] information…"	Yes
International Policy–UN Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (1986)		
The below focuses on instances where NASA or USG would be providing assistance. There are separate requirements for instances where NASA or USG would be requesting assistance (e.g., in the case of an inadvertent reentry of another State Party's spacecraft with the potential to affect US territories. Note that most of these obligations are handled through the routine interactions of the Department of State, the Department of Energy, the US Nuclear Regulatory Commission, and the IAEA. Exceptions taken by the US during signing can be found at https://www.iaea.org/sites/default/files/infcirc335a1-infcirc336a2.pdf, but generally don't affect the capturing below.		
UN-ACNA-1	"The States Parties shall cooperate between themselves and with the…[IAEA]…to facilitate prompt assistance in the event of a nuclear accident or radiological emergency to minimize its consequences and to protect life, property, and the environment from the effects of radioactive releases."	Yes

Ident.	Constraint	Binding?
UN-ACNA-2	"Each State Party to which a request for such assistance is directed shall promptly decide and notify the requesting State Party, directly or through the Agency, whether it is in a position to render the assistance requested, and the scope and terms of the assistance that might be rendered."	Yes
UN-ACNA-3	"States Parties shall, within the limits of their capabilities, identify and notify the Agency of experts, equipment and materials which could be made available for the provision of assistance to other States Parties in the event of a nuclear accident or radiological emergency as well as the terms, especially financial, under which such assistance could be provided."	Yes
UN-ACNA-4	"The assisting party should, where the assistance involves personnel, designate in consultation with the requesting State, the person who should be in charge of and retain immediate operational supervision over the personnel and the equipment provided by it. The designated person should exercise such supervision in cooperation with the appropriate authorities of the requesting State"	No
UN-ACNA-5	"a State Party providing assistance in response to a request…shall co-ordinate that assistance within its territory."	Yes
UN-ACNA-6	*Article IV contains language very similar to that captured earlier under UN-EN-5*	Yes
UN-ACNA-7	"The requesting State and the assisting party shall protect the confidentiality of any confidential information that becomes available to either of them in connection with the assistance in the event of a nuclear accident or radiological emergency. Such information shall be used exclusively for the purpose of the assistance agreed upon. The assisting party shall make every effort to coordinate with the requesting State before releasing information to the public on the assistance provided in connection with a nuclear accident or radiological emergency."	Yes
UN-ACNA-8	"Each State Party shall, at the request of the requesting State or the assisting party, seek to facilitate the transit through its territory of duly notified personnel, equipment and property involved in the assistance to and from the requesting State."	Yes
UN-ACNA-9	"The States Parties shall closely cooperate in order to facilitate the settlement of legal proceedings and claims under this article."	Yes
International Policy-UN Resolution 47/68-The United Nations Principles Relevant to the Use of Nuclear Power Sources in Outer Space		
UN47/68-1	Principle 1–2 cover applicability of international law and use of terms; for the latter, NASA's practices are generally consistent with the provided context around all of these terms, which include, "launching State," "foreseeable," "all possible," "general concept of defense-in-depth," and "made critical."	No[1]
UN47/68-2	Principle 3–Item 1–Establishes an expectation for meeting general goals in radiation protection and nuclear safety, to protect individuals, populations, and the biosphere through the mitigation of hazards. It also promotes ensuring no significant contamination of outer space. During normal operations, including reentry from a sufficiently high orbit, the appropriate radiation protection objective to the public recommended by ICRP is to be observed, and there will be no significant radiation exposure. Accident limits of 100 mrem/yr and 500 mrem/yr are cited but are not applicable to low-probability accident with potentially serious radiological consequences. Systems important to safety require defense-in-depth in design, construction, and operation. Similarly, systems important to safety require reliability founded in redundancy, physical separation, functional isolation, and adequate independence.	No[1]

Ident.	Constraint	Binding?
UN47/68-3	Principle 3–Item 2-Permits operation of reactors in interplanetary missions, in sufficiently high orbits, or in LEO if boosted to a sufficiently high orbit. It goes on to give a qualitative definition of sufficiently high orbit, which includes features of radioactive decay, orbital debris, and no-harm to other missions. It states that nuclear reactors will only use HEU, will not be made critical until reaching interplanetary flight or their operating orbit, that design and construction will preclude criticality in any accidents (including reentry and submersion), and the use of a highly reliable operational system to ensure an effective and controlled disposal.	No[1]
UN47/68-4	Principle 3–Item 3–Asserts that RTGs may be used in interplanetary missions or in a high orbit, and that they shall be protected by a containment system that is designed to withstand re-entry, and that upon impact will ensure no radioactive release (to facilitate recovery and cleanup).	No[1]
UN47/68-5	Principle 4–Promotes the performance of "a thorough and comprehensive safety assessment," prior to launch, covering "all relevant phases of the mission" and "all systems involved." The assessment is to be "made publicly available prior to each launch," and the UN Secretary-General is to be informed on how States may obtain results of the safety assessment.	No[1]
UN47/68-6	Principle 5–Involves the notification of an imminent or ongoing reentry accident, including specific information to be provided	No[1]
UN47/68-7	Principle 6–Consultations and Principle 7–Assistance to States is both generally comparable to the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency	No[1]
UN47/68-8	The remaining principles are generally broader, and predominantly legal or administrative aspects that are not of direct relevance to OSMA's management of nuclear flight safety activities. As such, they are not addressed further here.	No[1]
International Policy–IAEA and UN-STSC Safety Framework for Nuclear Power Source Applications in Outer Space (2009)		
IAEA-1	Section 2 – Safety objectives - The fundamental safety objective 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 nuclear power source applications. Note that the ensuing text refers to protecting people individually and collectively.	No
IAEA-2	Section 3.1-Governments that authorize or approve space nuclear power source missions should establish safety policies, requirements, and processes.	No
IAEA-3	Section 3.2-The government's mission approval process should verify that the rationale for using the space nuclear power source application has been appropriately justified.	No
IAEA-4	Section 3.3-A mission launch authorization process for space nuclear power source applications should be established and sustained… The independent safety evaluation should consider the entire space NPS application–including the space NPS, spacecraft, launch system, mission design, and flight rules–in assessing the risk to people and the environment from relevant launch, operation, and end-of-service phases of the space mission.	No
IAEA-5	Section 3.4-Preparations should be made to respond to potential emergencies involving a space nuclear power source.	No
IAEA-6	Section 4.1-The primary responsibility for safety should rest with the organization that conducts the space nuclear power source mission. Note that this section goes on to list seven features including technical competence, training, procedures, requirements development, testing and analysis, opposing views, and public information sharing.	No

Ident.	Constraint	Binding?
IAEA-7	Section 4.2-Effective leadership and management for safety should be established and sustained in the organization that conducts the space nuclear power source mission. Note that this goes on to discuss elements of safety culture, including clear roles, continuous improvement, commitment to safety, accountability, and a questioning attitude.	No
IAEA-8	Section 5.1-Technical competence in nuclear safety should be established and maintained for space nuclear power source applications. Note that this section goes on to discuss assessment of accident scenarios and consequences and managing risk.	No
IAEA-9	Section 5.2-Design and development processes should provide the highest level of safety that can reasonably be achieved. Note that this section goes on to discuss (i) Identifying, evaluating, and implementing design features, controls, and preventive measures that reduce the probability and consequences of accidents; (ii) incorporating lessons learned; (iii) verifying and validating design features and controls; (iv) using risk assessments; and (v) using design reviews.	No
IAEA-10	Section 5.3-Risk assessments should be conducted to characterize the radiation risks to people and the environment.	No
IAEA-11	Section 5.4-All practical efforts should be made to mitigate the consequences of potential accidents. This section goes on to cite: (i) developing and implementing contingency plans to interrupt accidents sequences that could lead to radiation hazards; (ii) determining whether a release of radioactivity has occurred, (iii) characterizing the location and nature of the release, etc.	No

[1] In adopting the UN Resolution, the US stated, "The proposed position does not confer U.S. approval of any specific provisions of the Principles, but only declares that U.S. policy and practice is consistent with their overall objective and intent, which is the safe use of NPS in outer space."