ABSTRACT

This volume of Manned Space Flight Nuclear System Safety contains the Design and Operations Guidelines and Requirements developed in the study of Space Shuttle Nuclear System transportation. Guidelines and Requirements are presented for the Shuttle, nuclear payloads (reactor, isotope-Brayton and small isotope sources), ground support systems and facilities. Cross indices and references are provided which relate guidelines to each other, and to substantiating data in other volumes. The guidelines are intended for the implementation of nuclear safety related design and operational considerations in future space programs.
The establishment and operation of large manned space facilities in earth orbit would constitute a significant step forward in space. Such long duration programs with orbital stay times of up to ten years would benefit the earth's populace and the scientific community by providing:

1. A flexible tool for scientific research.
2. A permanent base for earth oriented applications.
3. A foundation for the future exploration of our universe.

Specifically, the NASA objectives include earth surveys and scientific disciplines of astronomy, bioscience, chemistry, physics and biomedicine, as well as the development of technology for space and earth applications.

Operational and design requirements, of large manned space vehicles, differ from those of the Mercury, Gemini, and Apollo programs. Of particular interest are the radiation survivability and nuclear safety requirements imposed by nuclear power reactors and isotopes and the long term interaction with the natural radiation environment.

The General Electric Company under contract to NASA-MSFC (NAS8-26283) has performed a study entitled "Space Base Nuclear System Safety" for the express purposes of addressing the nuclear considerations involved in manned earth orbital missions. The study addresses both operational and general earth populace and ecological nuclear safety aspects. The primary objective is to identify and evaluate the potential and inherent radiological hazards associated with such missions and recommend approaches for hazard elimination or reduction of risk.
Work performed utilized the Phase A Space Base designs developed for NASA by North American Rockwell and McDonnell Douglas as baseline documentation.

The study was sponsored jointly by NASA's Office of Manned Space Flight, Office of Advanced Research and Technology, and Aerospace Safety Research and Data Institute. It was performed for NASA's George C. Marshall Space Flight Center under the direction of Mr. Walter H. Stafford of the Advanced Systems Analysis Office. He was assisted by a joint NASA and AEC advisory group, chaired by Mr. Herbert Schaefer of NASA's Office of Manned Space Flight.

The results of the study are presented in seven volumes, the titles of which are listed in Table A. A cross-reference matrix of the subjects covered in the various volumes is presented in Table B.

<table>
<thead>
<tr>
<th>Volume</th>
<th>Document No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td></td>
</tr>
<tr>
<td>Part 1</td>
<td>Executive Summary</td>
</tr>
<tr>
<td>Part 2</td>
<td>Space Base Nuclear Safety</td>
</tr>
<tr>
<td>Part 1</td>
<td>Space Shuttle Nuclear Safety</td>
</tr>
<tr>
<td>Part 2</td>
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</tr>
<tr>
<td>Part 2</td>
<td>72SD4201-1-2</td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>Part 1</td>
<td>Space Base Preliminary Nuclear Safety Analysis</td>
</tr>
<tr>
<td>Part 1A</td>
<td>Nuclear Safety Analysis</td>
</tr>
<tr>
<td>Part 1A</td>
<td>Appendix - Alternate Reactor Data (CRD)</td>
</tr>
<tr>
<td>Part 1A</td>
<td>72SD4201-2-1</td>
</tr>
<tr>
<td>III</td>
<td>Reactor System Preliminary Nuclear Safety Analysis</td>
</tr>
<tr>
<td>Part 1</td>
<td>Reference Design Document (RDD)</td>
</tr>
<tr>
<td>Part 2</td>
<td>Accident Model Document (AMD)</td>
</tr>
<tr>
<td>Part 2A</td>
<td>Accident Model Document - Appendix</td>
</tr>
<tr>
<td>Part 3</td>
<td>Nuclear Safety Analysis Document (NSAD)</td>
</tr>
<tr>
<td>IV</td>
<td>72SD4201-3-1</td>
</tr>
<tr>
<td>Part 1</td>
<td>72SD4201-3-2</td>
</tr>
<tr>
<td>Part 2</td>
<td>72SD4201-3-2A</td>
</tr>
<tr>
<td>Part 3</td>
<td>72SD4201-3-3</td>
</tr>
<tr>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Part 1</td>
<td>Space Shuttle Nuclear System Transportation</td>
</tr>
<tr>
<td>Part 2</td>
<td>Space Shuttle Nuclear Safety</td>
</tr>
<tr>
<td>Part 2</td>
<td>Terrestrial Nuclear Safety Analysis (C)</td>
</tr>
<tr>
<td>V</td>
<td>72SD4201-4-1</td>
</tr>
<tr>
<td>VI</td>
<td>72SD4201-4-2*</td>
</tr>
<tr>
<td>VII</td>
<td></td>
</tr>
<tr>
<td>Part 1</td>
<td>Nuclear System Safety Guidelines</td>
</tr>
<tr>
<td>Part 2</td>
<td>72SD4201-5-1</td>
</tr>
<tr>
<td>Part 2</td>
<td>Space Shuttle/Nuclear Payloads Safety</td>
</tr>
<tr>
<td>Part 2</td>
<td>72SD4201-5-2</td>
</tr>
<tr>
<td>VI</td>
<td>72SD4201-6</td>
</tr>
<tr>
<td>VII</td>
<td>Literature Review</td>
</tr>
<tr>
<td>Part 1</td>
<td>Literature Search and Evaluation</td>
</tr>
<tr>
<td>Part 2</td>
<td>ASRDI Forms</td>
</tr>
<tr>
<td>VII</td>
<td>72SD4201-7-1</td>
</tr>
<tr>
<td>Part 2</td>
<td>72SD4201-7-2*</td>
</tr>
</tbody>
</table>

*Limited distribution
This study employs the International system of units and where appropriate the equivalent English units are specified in brackets. A list of Conversion Factors and a Glossary of Terms is included in the back of each volume.

Table B. Study Area Cross Reference

<table>
<thead>
<tr>
<th>STUDY AREAS</th>
<th>DOCUMENTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VOL I</td>
</tr>
<tr>
<td>SPACE BASE PROGRAM</td>
<td></td>
</tr>
<tr>
<td>Reference Vehicle Data</td>
<td></td>
</tr>
<tr>
<td>Radiation Limits</td>
<td></td>
</tr>
<tr>
<td>Radiation Environment/Hazards</td>
<td></td>
</tr>
<tr>
<td>Radiation Effects</td>
<td></td>
</tr>
<tr>
<td>Mission Support Nuclear Safety</td>
<td></td>
</tr>
<tr>
<td>Orbital Operations Nuclear Safety</td>
<td></td>
</tr>
<tr>
<td>Design &amp; Operational Considerations</td>
<td></td>
</tr>
<tr>
<td>Guidelines &amp; Requirements</td>
<td></td>
</tr>
<tr>
<td>Reactor System Studies</td>
<td></td>
</tr>
<tr>
<td>Terrestrial Safety Analysis</td>
<td></td>
</tr>
<tr>
<td>Reference Design</td>
<td></td>
</tr>
<tr>
<td>Accident Models &amp; Source Terms</td>
<td></td>
</tr>
<tr>
<td>Risk Analysis</td>
<td></td>
</tr>
<tr>
<td>System Safety Plans</td>
<td></td>
</tr>
<tr>
<td>Technology Development Required</td>
<td></td>
</tr>
<tr>
<td>SPACE SHUTTLE PROGRAM</td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Guidelines and Requirements</td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
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<td>LITERATURE REVIEW DATA</td>
<td></td>
</tr>
<tr>
<td>Approach and Cross Index</td>
<td></td>
</tr>
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<td>ASRDI Forms</td>
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</tr>
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*Section number is included where appropriate

- ☐ PRIMARY DISCUSSION
- ☐ SUMMARY OR SUPPLEMENTAL DISCUSSION
# ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADM</td>
<td>Add-on Disposal Modules</td>
</tr>
<tr>
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<td>Atomic Energy Commission</td>
</tr>
<tr>
<td>ALS</td>
<td>Advanced Logistic System (Space Shuttle)</td>
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<tr>
<td>AMD</td>
<td>Accident Model Document</td>
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<td>ASRD1</td>
<td>Aerospace Safety Research Data Institute</td>
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<tr>
<td>BOL</td>
<td>Beginning of Life</td>
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<tr>
<td>BPCL</td>
<td>Brayton Power Conversion Loop</td>
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<td>BRU</td>
<td>Brayton Rotating Unit</td>
</tr>
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<td>Department of Defense</td>
</tr>
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<td>Department of Transportation</td>
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<tr>
<td>ECLS</td>
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<tr>
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<td>Electro Magnetic</td>
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<tr>
<td>EOD</td>
<td>Earth Orbital Decay</td>
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<td>End of Life</td>
</tr>
<tr>
<td>EOM</td>
<td>End-of-Mission</td>
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<td>Eastern Test Range</td>
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<td>EVA</td>
<td>Extra Vehicular Activity</td>
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<tr>
<td>FC</td>
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<td>Functional Program Element</td>
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<td>Guidance and Control</td>
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<td>GSE</td>
<td>Ground Support Equipment</td>
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<td>Heat Exchanger</td>
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<tr>
<td>ICRP</td>
<td>International Committee on Radiation Protection</td>
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<tr>
<td>IDM</td>
<td>Integral Disposal Module</td>
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<tr>
<td>INT-21</td>
<td>Intermediate Saturn Stages</td>
</tr>
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</tr>
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<td>Isotope Re-Entry Vehicle</td>
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<td>IU</td>
<td>Instrument Unit</td>
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<tr>
<td>IVA</td>
<td>Intra Vehicular Activity</td>
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<td>Kennedy Space Center</td>
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<tr>
<td>LCC</td>
<td>Launch Control Center</td>
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<tr>
<td>LD</td>
<td>Lethal Dose (% Probability)</td>
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<td>LOX</td>
<td>Liquid Oxygen</td>
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<td>LV</td>
<td>Launch Vehicle</td>
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<td>MCC</td>
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<td>McDonnell Douglas Corporation</td>
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<tr>
<td>MHW</td>
<td>Multi-Hundred Watt</td>
</tr>
<tr>
<td>ML</td>
<td>Mobile Launcher</td>
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<tr>
<td>MFC</td>
<td>Maximum Permissible Concentration</td>
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<tr>
<td>MSC</td>
<td>Manned Spacecraft Center</td>
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<td>MSFC</td>
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<td>Mobile Service Structure</td>
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<td>NAB</td>
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<td>National Committee on Radiation Protection</td>
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<td>NSAD</td>
<td>Nuclear Safety Analysis Document</td>
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<tr>
<td>OPSD</td>
<td>Orbital Propellant Storage Depot</td>
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<td>ORNL</td>
<td>Oak Ridge National Laboratory</td>
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<tr>
<td>PCS</td>
<td>Power Conversion System</td>
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<tr>
<td>PM</td>
<td>Power Module</td>
</tr>
<tr>
<td>PSAR</td>
<td>Preliminary Safety Analysis Report</td>
</tr>
<tr>
<td>RAD</td>
<td>Radiation Absorbed Dose</td>
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</tr>
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<td>Reference Design Document</td>
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<td>Roentgen Equivalent Man</td>
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<td>RMU</td>
<td>Remote Maneuvering Unit</td>
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<td>RNS</td>
<td>Reusable Nuclear Shuttle</td>
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<td>R/S</td>
<td>Reactor/Shield</td>
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<tr>
<td>RSO</td>
<td>Radiation Safety Officer</td>
</tr>
<tr>
<td>RTG</td>
<td>Radiotrace Thermoelectric Generator</td>
</tr>
<tr>
<td>SB</td>
<td>Space Base</td>
</tr>
<tr>
<td>SAR</td>
<td>Safety Analysis Report</td>
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<td>SEHX</td>
<td>Separable Heat Exchanger</td>
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<td>S-1C</td>
<td>First Stage of Saturn V</td>
</tr>
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<td>Second Stage of Saturn V</td>
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<td>SNAP</td>
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<td>SNAPTRAN</td>
<td>Space Nuclear Auxiliary Power Transient</td>
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<tr>
<td>TAC</td>
<td>Turbine Alternator Compressor</td>
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<tr>
<td>TEM</td>
<td>Thermoelastic Electromagnetic Pump</td>
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<tr>
<td>TLD</td>
<td>Thermo Luminescent Dosimeter</td>
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<td>USAF</td>
<td>United States Air Force</td>
</tr>
<tr>
<td>VAB</td>
<td>Vehicle Assembly Building</td>
</tr>
<tr>
<td>Section</td>
<td>Table of Contents</td>
</tr>
<tr>
<td>---------</td>
<td>------------------</td>
</tr>
<tr>
<td>1</td>
<td>INTRODUCTION</td>
</tr>
<tr>
<td>2</td>
<td>GUIDELINES AND REQUIREMENTS DESCRIPTION</td>
</tr>
<tr>
<td></td>
<td>2.1 Number</td>
</tr>
<tr>
<td></td>
<td>2.2 Program Element</td>
</tr>
<tr>
<td></td>
<td>2.3 System-Subsystem Grouping</td>
</tr>
<tr>
<td></td>
<td>2.4 Operation</td>
</tr>
<tr>
<td></td>
<td>2.5 Mission Phase/Event</td>
</tr>
<tr>
<td></td>
<td>2.6 Title</td>
</tr>
<tr>
<td></td>
<td>2.7 Statement</td>
</tr>
<tr>
<td></td>
<td>2.8 Justification</td>
</tr>
<tr>
<td></td>
<td>2.9 Remarks</td>
</tr>
<tr>
<td></td>
<td>2.10 References</td>
</tr>
<tr>
<td></td>
<td>2.11 Cross References</td>
</tr>
<tr>
<td>3</td>
<td>GUIDELINE USAGE</td>
</tr>
<tr>
<td>4</td>
<td>GUIDELINES AND REQUIREMENTS CROSS INDEX</td>
</tr>
<tr>
<td></td>
<td>4.1 Hazard Reduction Sequence Index</td>
</tr>
<tr>
<td></td>
<td>4.1.1 Design for Minimum Hazard</td>
</tr>
<tr>
<td></td>
<td>4.1.2 Safety Devices</td>
</tr>
<tr>
<td></td>
<td>4.1.3 Warning Devices</td>
</tr>
<tr>
<td></td>
<td>4.1.4 Special Procedures</td>
</tr>
<tr>
<td></td>
<td>4.2 Cross Index - Guideline Statements</td>
</tr>
<tr>
<td></td>
<td>4.3 Cross Index - Title</td>
</tr>
<tr>
<td>5</td>
<td>SAFETY GUIDELINES</td>
</tr>
</tbody>
</table>
SECTION 1
INTRODUCTION

The guidelines and requirements developed during the study of the transport of nuclear payloads to and from earth orbit by the Space Shuttle are presented in this Volume. Each guideline describes a design or operational feature which, if implemented, would alleviate or minimize a particular hazard(s) and thereby increase the safety and success of the mission.

A major distinction has been made between a guideline and a requirement. A requirement is only noted as such if it has been classified as a mandatory provision under all circumstances. When any doubt exists, when alternative measures can be taken or when the provision increases the safety of the mission, but may not be required to accomplish the mission objectives, a guideline notation has been given. A majority of the considerations presented fall into the guideline category.

Guidelines prepared for the major Space Base and Terrestrial Safety Study are presented under separate cover - Volume V, Part 1.
Figure 2–1 shows the format used in reporting all guidelines. The content and use of the format is discussed below.

<table>
<thead>
<tr>
<th>SPACE SHUTTLE</th>
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<tbody>
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<td>PROGRAM ELEMENT</td>
<td>SYSTEM-SUBSYSTEM</td>
</tr>
<tr>
<td>MISSION PHASE/EVENT</td>
<td></td>
</tr>
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<td>TITLE:</td>
<td></td>
</tr>
<tr>
<td>STATEMENT:</td>
<td></td>
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<td></td>
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<td>REFERENCES:</td>
<td>CROSS REFERENCES:</td>
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</table>
2.1 NUMBER
The identifying alphanumerical designation consists of two letters followed by a three digit number.

```
Guideline (R - Requirement)
Design Feature (O - Operations Feature)
Numerical Designator
GD-125
```

The first alpha character denotes whether the statement is a guideline (G) or a mandatory requirement (R). The second alpha character distinguishes between design considerations (D) or operational procedures (O). Series 101 to 200 have been reserved for numerical designation of the guidelines and requirements for the Space Shuttle Nuclear System Transportation Study.

2.2 PROGRAM ELEMENT
The program element denotes the major vehicle/program for which the guideline is intended, i.e., Space Base, Space Shuttle, Space Tug, Launch Vehicle, Launch Center, etc.

2.3 SYSTEM-SUBSYSTEM GROUPING
Associated with each program element are various top level groupings of equipment designated as Systems or Subsystems. The system/subsystem groupings designated for this study include the following:

- Shuttle Systems
- Reactor Payload
- Isotope Reentry Vehicle (IRV) - Payload
- Small Isotope Sources - Payload
- Ground Support
- Facilities
2.4 OPERATION
The operation column is used to denote the particular operation or function to which the guideline is directed. Typical operation categories are isotope cooling, Shuttle transport, ground handling, payload monitoring, recovery, etc.

2.5 MISSION PHASE/EVENT
The phase or phases of the mission for which the guideline applies is listed. The various phases of the Shuttle transport mission are shown in Figure 2-2.

![Figure 2-2. Mission Phases](image)

2.6 TITLE
The title is provided to briefly identify the subject matter of the guideline. It is used in the cross index along with the alphanumeric designation to provide the necessary descriptive words to concisely identify the guideline and content.
2.7 **STATEMENT**

The statement contains the guideline, and is usually a brief statement, preferably one sentence, which describes a suggested means by which a hazard may be alleviated or eliminated. All statements for a particular Program/System form a useful checklist for a program manager or designer. Typical examples include:

- Consider use of an inert gas positive pressure liner for encasement of all or portions of a reactor.
- Provide a rapid response back-up isotope cooling system at the launch pad which does not require the opening of Shuttle doors.
- Consider dumping of excess Shuttle propellant prior to landing to minimize explosive potential.

2.8 **JUSTIFICATION**

The justification contains a brief substantiation for the guideline in terms of the nature of the hazards presented. A hazard category column is provided to be used in conformance with the hazard categories listed in NASA office of Manned Space Flight Safety Program Directive No. 1 Revision A. Due to the preliminary nature of this study hazard categories were not assigned to individual guidelines. However, this potential exists and should be reserved for subsequent evaluations.

2.9 **REMARKS**

The remarks column is intended to provide additional information needed to further define the guideline or to indicate techniques worthy of consideration which could be applied or are used in existing systems.

2.10 **REFERENCES**

The key references (supporting data) in the study final reports or other related documents which are used to arrive at the guidelines are listed.

2.11 **CROSS REFERENCES**

The cross reference column lists the related guidelines that should be referred to by the user.
SECTION 3
GUIDELINE USAGE

This particular set of guidelines is intended for use by:

1. Space Shuttle Program/Design personnel in implementing nuclear payload and nuclear safety operational and design considerations in the Shuttle program.

2. Nuclear Payload development personnel in implementing safety related design and operational features for the reactor, isotope-Brayton and Small isotope systems.

3. System safety personnel in planning, establishing priorities, directing and controlling the safety program.

The guidelines can be used to establish requirements on future hardware design and development. They can also be used as a checklist against a preliminary or final design. They also form the basis of trade-off evaluations for the optimization of design when considering safety as related to performance, cost, schedules, etc.

Safety guidelines impact design details, operations and procedures and in some instances can be classified as key configuration drivers. It is important that safety guidelines be reviewed at an early date for implementation on the Shuttle program. Early consideration and implementation will result in a design capable of supporting nuclear hardware missions with minimum perturbations on Shuttle systems and Ground Support.
SECTION 4
GUIDELINES AND REQUIREMENTS CROSS INDEX

This section contains cross indices of all the guidelines and requirements developed.

4.1 HAZARD REDUCTION SEQUENCE INDEX

Table 4-1 contains a summary of the key guidelines in accordance with the hazard reduction sequence of the OMSF Safety Program Directive No. 1, Revision 4. This hazard reduction precedence sequence is as follows:

4.1.1 DESIGN FOR MINIMUM HAZARD
The major effort throughout the design phases shall be to insure inherent safety through the selection of appropriate design features (e.g., fail safe design, redundancy, increased ultimate safety factor).

4.1.2 SAFETY DEVICES
Known hazards which cannot be eliminated through design selection shall be reduced to the acceptable level through the use of appropriate safety devices as part of the system, subsystem, or equipment.

4.1.3 WARNING DEVICES
Where it is not possible to preclude the existence or occurrence of a known hazard, devices shall be employed for the timely detection of the condition and the generation of an adequate warning signal. Warning signals and their application shall be designed to minimize the probability of wrong signals or of improper personnel reaction to the signals.

4.1.4 SPECIAL PROCEDURES
Where it is not possible to reduce the magnitude of an existing or potential hazard through design, or the use of safety and warning devices, special procedures shall be developed to counter hazardous conditions for enhancement of ground and flight crew safety. Precautionary notations shall be standardized in accordance with the direction of the procuring activity.

4-1/2
Consider touchdown area remote from inhabited facilities.

Provide fixed area of the facility from which the participants can assemble for

Provide temporary shelter for personnel during the mission.

Provide a clean, smooth surface cargo bay interior.

Provide tracking and location aids for nuclear payloads.

Provide a crew and support personnel dose rate minimization capability to defuel the Sh

Provide automatic detection of the cargo bay on arrival after landing.

Minimize the crew and support personnel dose rate.

Minimize the payload mass for nuclear payloads.

Provide tracking and location aids for nuclear payloads.

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4.2 CROSS INDEX - GUIDELINE STATEMENTS
A cross index and useful checklist of all the guideline/requirement statements associated with the Reactor, Isotope Reentry Vehicle, Small Isotope Sources, Shuttle, Ground Support and Facilities is contained in the following pages.

4.3 CROSS INDEX - TITLE
The cross index, by title and applicable system, of all the guidelines and requirements developed is contained in Table 4-2.
REACTOR-GUIDELINE STATEMENTS

RD-105 Provide fireball protection adequate to assure containment of all radioactive material in event of an accident (critical for isotopes; may be necessary for reactors).

RO-103 Minimize overflight of land and continental shelf areas.

RO-104 Provide suitable personnel exclusion area at the launch and landing sites, (4 km fallback area and approximately 13 km administrative control zone).

RO-105 Provide procedures for permanent reactor shutdown prior to separation from Space Base.

RO-107 Establish emergency procedures and decisions (contingency plans) for emergency situations involving nuclear hardware.

GD-101 Provide an inert gas blanket and/or double containment during the prelaunch period to preclude a NaK-oxygen reaction in the event of NaK leak.

GD-102 Consider use of an inert gas positive pressure liner for encasement of all or portions of a reactor power module - considered particularly important for the in-orbit retrieval and landing site removal of a damaged power module.

GD-103 Provide double containment of liquid metal components where feasible.

GD-104 Provide blast overpressure and fragmentation protection adequate to assure containment of all radioactive material in event of an accident (critical requirement for isotopes; may be desirable for reactors).

GD-105 Provide multiple and independent system monitoring and control equipment with instantaneous and recording outputs for all mission phases.

GD-106 Provide NaK loop design which does not require breaking or opening of NaK loops for replacement and maintenance.

GD-107 Provide up to 1 kilowatt of electrical power (either from the Transfer Module or the Shuttle).

GD-108 Assure maximum allowable shuttle crew-nuclear payload separation distance (e.g., provide for the placement of the reactor/shield as far aft in the cargo bay as permitted within shuttle c.g. and power module configuration restrictions).

GD-109 Consider provision of a reactor/shield assembly separable from the radiator at end of mission.
GD-110  Provide for decay heat removal and radiation shielding if a spent reactor is transferred to the Shuttle less than 10 days after shutdown.

GD-111  Provide capability of detecting and alerting the Shuttle crew of a liquid metal leak which would render the power module inoperable and provide potential hazards within the Shuttle cargo bay.

GD-112  Consider provision of liquid metal fire suppression material within the Shuttle.

GD-113  Consider a Shuttle return of only a reactor/shield by a design which permits in-orbit separation of the radiator and other components.

GD-119  Provide certified equipment to handle nuclear payloads.

GD-120  Provide dry $N_2$ purging capability of the Shuttle cargo bay while on the launch pad.

GD-121  Consider use of Transfer Module integration scheme to reduce and simplify Shuttle interfaces and to improve safety in handling nuclear payloads.

GD-122  Prevent propellant boil-off and other undesirable gases from entering Shuttle cargo bay with the doors closed by provision of an environmental enclosure.

GD-123  Provide multiple and independent radiation monitoring equipment with instantaneous and recording outputs.

GD-124  Provide capability of detecting and alerting the Shuttle crew of nuclear payload failures which occur during transport.

GD-125  Provide a free, unobstructed, and directed ejection path for the payload in the event of a Shuttle booster or orbiter explosion on the launch pad.

GD-126  Provide intact reentry and impact capability. Consider use of crush-up materials in Shuttle orbiter cargo bay to minimize damage upon Shuttle land impact.

GD-127  Provide tracking and recovery devices on nuclear payloads.

GD-128  Provide a clean, smooth surface cargo bay to facilitate decontamination and minimize the time required.

GO-101  Provide certified operation plans to store reactor power systems and check out reactor power systems and components.

GO-102  Provide fire alarm and protection system training and procedures capable of supporting hardware containing nuclear material and liquid metals in nuclear facility, transporter and at the launch pad.
GO-103 Provide operational procedures for maintaining an inert gas blanket and/or double containment during the prelaunch period to preclude a NaK-oxygen reaction in the event of NaK leak.

GO-104 Provide a controlled environment liquid metal safing capability at launch and landing sites (reduction of \( O_2 \) sources).

GO-105 Provide certified unloading, decontamination and liquid metal equipment and procedures to handle nuclear reactor power modules subsequent to Shuttle landing.

GO-106 Provide installation, retrieval, and maintenance procedures that do not require breaking or opening of NaK loops.

GO-107 Provide Shuttle crew training with confirmed procedures in the use of multiple and independent system monitoring equipment with instantaneous and recorded outputs for all mission phases.

GO-108 Provide rendezvous and docking positions such that the Shuttle crew locations are within the shadow of the reactor shield to minimize the dose to the crew during docking and replacement operations.

GO-109 Consider allowing at least 10 days after shutdown before enacting Shuttle transfer operations with a spent reactor. If this procedure is not possible, provide for decay heat removal and radiation shielding if the spent reactor is to be transferred to the Shuttle less than 10 days after shutdown.

GO-110 Provide certified operational plans to dispose of or recover a spent reactor power module.

GO-111 Provide a minimum 100 year orbital lifetime for a spent reactor in high earth orbit (250 year orbit is preferred to give 9 half-life decay).

GO-112 Consider capability to install a replaceable or strap-on reactor disposal system by the Shuttle crew.

GO-113 Consider capability of reactor/shield separation from the radiator at end of mission (disposal or recovery).

GO-114 Consider means of long term tracking of reactor power module following boost to a high earth disposal orbit (for possible recovery at a later date).

GO-115 Consider reactor reboost capability to a new long-life orbit by the Shuttle.

GO-125 Provide support personnel and Shuttle crew training with confirmed procedures in the use of multiple and independent radiation monitoring equipment with instantaneous and recorded outputs.
GO-126 Provide recovery gear and procedures for use subsequent to prelaunch accidents.

GO-127 Provide operations in the use of Transfer Modules to protect and reduce handling and packaging requirements of nuclear payloads.

GO-128 Provide Shuttle radiation and liquid metal decontamination capability at the launch and landing sites.

GO-129 Provide emergency capability and procedures for ejection of the payload over deep ocean areas (or continental shelf) or possible ditching of the Shuttle.

GO-130 Provide tracking and location capability for early land and water recovery.

GO-131 Provide for emergency retrieval/recovery of nuclear equipment if jettisoned from the Space Shuttle.

GO-132 Provide trained impact/recovery team and procedures for recovery, fire protection, radiation control and decontamination.

GO-133 Provide launch during unsatisfactory weather conditions, including moderate to high winds blowing towards populated areas.

GO-134 Minimize the crew dose rate throughout all operations (maximum of 150 mrem/day).

GO-135 Minimize radiation dose to crews performing contingency operations (maximum of 150 mrem/day from nuclear sources should be maintained).

GO-136 Consider use of a back-up Shuttle to support repair of a failed Shuttle or transfer or retrieval of the payload in orbit for the continuance of the mission.

GO-137 Provide contingencies for Shuttle orbital stay times of up to 20 days to allow for repairs to be made.

GO-138 Where in-orbit repairs of interfacing non-nuclear hardware (transfer mechanisms, etc.) are unsuccessful, the Shuttle and payload should return to earth.

GO-139 Consider payload ejection through cargo bay doors if doors cannot be opened.

GO-140 Provide certified operational plans to launch and perform orbital transfer operations involving nuclear hardware.

GO-141 Provide positive control of nuclear payloads during all handling operations.

GO-142 Provide nuclear cargo transfer operations that do not involve EVA.
GO-143  Provide direct visual or TV coverage of all nuclear cargo transfer operations.

GO-144  Provide alternate and/or redundant equipment and procedures for nuclear cargo handling.

GO-145  Consider feasibility of uncooperative "tumbling" power module retrieval with Shuttle.

GO-146  Provide Shuttle landing area remote from inhabited facilities.
ISOTOPE RE-ENTRY VEHICLE (IRV) - GUIDELINE STATEMENTS

RD-101 Provide isotope heat source cooling to 420°K (300° F), or less.

RD-102 Provide passive cooling systems, or redundant active systems, throughout all phases of the Shuttle-isotope heat source mission.

RD-103 Provide a redundant active isotope cooling system within the Shuttle cargo bay to be operable on ascent and return/re-entry with at least 24 hours emergency operating time.

RD-104 Provide blast overpressure and fragmentation protection adequate to assure containment of all radioactive material in event of an accident (critical requirement for isotopes; may be desirable for reactors).

RD-105 Provide fireball protection adequate to assure containment of all radioactive material in event of an accident (critical for isotopes; may be necessary for reactors).

RO-101 Provide and confirm procedures for the cooling of isotope payloads for all phases of the Shuttle mission (no identifiable failure modes or provide redundant cooling systems).

RO-102 Provide procedures to assure isotope heat source cooling to 420° K (300° F) or less during prelaunch.

RO-103 Minimize overflight of land and continental shelf areas.

RO-104 Provide suitable personnel exclusion area at the launch and landing sites, (4 km fallback area and approximately 13 km administrative control zone).

RO-106 Provide for Shuttle retrieval and recovery of a heat source with a damaged shield or fuel capsule fractures.

RO-107 Establish emergency procedures and decisions (contingency plans) for emergency situations involving nuclear hardware.

GD-114 Provide a rapid response back-up isotope cooling system at the launch pad which does not require opening of the Shuttle doors.

GD-115 Provide approximately 300 watts of electrical power (either from the Transfer Module or the Shuttle).
GD-116 Provide multiple and independent system monitoring and control equipment with instantaneous and recording inputs for all mission phases.

GD-117 Assure maximum allowable shuttle crew - nuclear payload separation distance. (IRV should be placed with side-on view to crew locations).

GD-118 Consider provision of flotation gear for an isotope-Brayton heat source (possibly time limited).

GD-119 Provide certified equipment to handle nuclear payloads.

GD-120 Provide dry N₂ purging capability of the Shuttle cargo bay while on the launch pad.

GD-121 Consider use of Transfer Module integration scheme to reduce and simplify Shuttle interfaces and to improve safety in handling nuclear payloads.

GD-122 Prevent propellant boil-off and other undesirable gases from entering Shuttle cargo bay with the doors closed by provision of an environmental enclosure.

GD-123 Provide multiple and independent radiation monitoring equipment with instantaneous and recording outputs.

GD-124 Provide capability of detecting and alerting the Shuttle crew of nuclear payload failures which occur during transport.

GD-125 Provide a free, unobstructed, and directed ejection path for the payload in the event of a Shuttle booster or orbiter explosion on the launch pad.

GD-126 Provide intact re-entry and impact capability. Consider use of crush-up materials in Shuttle orbiter cargo bay to minimize damage upon Shuttle land impact.

GD-127 Provide tracking and recovery devices on nuclear payloads.

GD-128 Provide a clean, smooth surface cargo bay to facilitate decontamination, and minimize the time required.

GO-116 Provide certified operational plans to: Receive and store isotope fuel capsules, Load isotope fuel capsules into heat source, Install heat source in IRV and Check out isotope power systems and components.

GO-117 Provide fire alarm and protection system training and procedures capable of supporting isotope hardware at: Nuclear facility, Transporter and Launch pad.
<table>
<thead>
<tr>
<th>GO-118</th>
<th>Provide quick retrieval operations to remove nuclear payload during an emergency.</th>
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<tr>
<td>GO-119</td>
<td>Install the isotope heat source in the Shuttle cargo bay at the last practicable point in the launch countdown sequence.</td>
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<td>GO-120</td>
<td>Provide capability to reduce ignitable propellant fumes around the cargo bay (i.e., drainage of propellant tanks and/or purging immediate payload area).</td>
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<td>GO-121</td>
<td>Avoid or limit operations of the crew which place them in the near vicinity of the heat source and in particular those positions perpendicular to the radiating surface.</td>
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<td>GO-122</td>
<td>Provide Shuttle crew training with confirmed procedures in the use of multiple and independent system monitoring equipment with instantaneous and recorded outputs for all mission phases.</td>
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<td>GO-123</td>
<td>Provide certified removal equipment and procedures to handle the nuclear payload subsequent to Shuttle landing.</td>
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<tr>
<td>GO-124</td>
<td>Provide certified operational plans to retrieve and recover IRV and/or small isotope sources.</td>
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<tr>
<td>GO-125</td>
<td>Provide support personnel and Shuttle crew training with confirmed procedures in the use of multiple and independent radiation monitoring equipment with instantaneous and recorded outputs.</td>
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<td>GO-126</td>
<td>Provide recovery gear and procedures for use subsequent to prelaunch accidents.</td>
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<td>GO-127</td>
<td>Provide operations in the use of Transfer Modules to protect and reduce handling and packaging requirements of nuclear payloads.</td>
</tr>
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<td>GO-128</td>
<td>Provide Shuttle radiation and liquid metal decontamination capability at the launch and landing sites.</td>
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<td>Provide for emergency retrieval/recovery of nuclear equipment if jettisoned from the Space Shuttle.</td>
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</table>
GO-132 Provide trained impact/recovery team and procedures for: Recovery, Fire protection, Radiation control and Decontamination.

GO-133 Prohibit launch during unsatisfactory weather conditions, including moderate to high winds blowing towards populated areas.

GO-134 Minimize the crew dose rate throughout all operations (maximum of 150 mrem/day).

GO-135 Minimize radiation dose to crews performing contingency operations (maximum of 150 mrem/day from nuclear sources should be maintained).

GO-136 Consider use of a back-up Shuttle to support repair of a failed Shuttle for transfer or retrieval of the payload in orbit for the continuance of the mission.

GO-137 Provide contingencies for Shuttle orbital stay times of up to 20 days to allow for repairs to be made.

GO-138 Where in-orbit repairs of interfacing non-nuclear hardware (transfer mechanisms, etc.) are unsuccessful, the Shuttle and payload should return to earth.

GO-139 Consider payload ejection through cargo bay doors if doors cannot be opened.

GO-140 Provide certified operational plans to launch and perform orbital transfer operations involving nuclear hardware.

GO-141 Provide positive control of nuclear payloads during all handling operations.

GO-142 Provide nuclear cargo transfer operations that do not involve EVA.

GO-143 Provide direct visual or TV coverage of all nuclear cargo transfer operations.

GO-144 Provide alternate and/or redundant equipment and procedures for nuclear cargo handling.

GO-145 Consider feasibility of uncooperative "tumbling" power module retrieval with Shuttle.

GO-146 Provide Shuttle landing area remote from inhabited facilities.
SMALL ISOTOPE SOURCES—GUIDELINE STATEMENTS

RD-101 Provide isotope heat source cooling to 420°K (300°F), or less.

RD-102 Provide passive cooling systems, or redundant active systems, throughout all phases of the Shuttle-isotope heat source mission.

RD-103 Provide a redundant active isotope cooling system within the Shuttle cargo bay to be operable on ascent and return/reentry with at least 24 hours emergency operating time.

RD-104 Provide blast overpressure and fragmentation protection adequate to assure containment of all radioactive material in event of an accident (critical requirement for isotopes; may be desirable for reactors).

RD-105 Provide fireball protection adequate to assure containment of all radioactive material in event of an accident (critical for isotopes; may be necessary for reactors).

RO-101 Provide and confirm procedures for the cooling of isotope payloads for all phases of the Shuttle mission (no identifiable failure modes or provide redundant cooling systems).

RO-102 Provide procedures to assure isotope heat source cooling to 420°K (300°F) or less during prelaunch.

RO-103 Minimize overflight of land and continental shelf areas.

RO-104 Provide suitable personnel exclusion area at the launch and landing sites, (4 km fall back area and approximately 13 km administrative control zone).

RO-107 Establish emergency procedures and decisions (contingency plans) for emergency situations involving nuclear hardware.

GD-114 Provide a rapid response back-up isotope cooling system at the launch pad which does not require opening of the Shuttle doors.

GD-115 Provide approximately 300 watts of electrical power (either from the Transfer Module or the Shuttle).

GD-116 Provide multiple and independent system monitoring and control equipment with instantaneous and recording outputs for all mission phases.

GD-117 Assure maximum allowable shuttle crew—nuclear payload separation distance. (IRV should be placed with side-on view to crew locations.)
GD-119  Provide certified equipment to handle nuclear payloads.

GD-120  Provide dry N₂ purging capability of the Shuttle cargo bay while on the launch pad.

GD-121  Consider use of Transfer Module integration scheme to reduce and simplify Shuttle interfaces and to improve safety in handling nuclear payloads.

GD-122  Prevent propellant boil-off and other undesirable gases from entering Shuttle cargo bay with the doors closed by provision of an environmental enclosure.

GD-123  Provide multiple and independent radiation monitoring equipment with instantaneous and recording outputs.

GD-124  Provide capability of detecting and alerting the Shuttle crew of nuclear payload failures which occur during transport.

GD-125  Provide a free, unobstructed, and directed ejection path for the payload in the event of a Shuttle booster or orbiter explosion on the launch pad.

GD-126  Provide intact reentry and impact capability. Consider use of crush-up materials in Shuttle orbiter cargo bay to minimize damage upon Shuttle land impact.

GD-127  Provide tracking and recovery devices on nuclear payloads.

GD-128  Provide a clean, smooth surface cargo bay to facilitate decontamination, and minimize the time required.

GO-116  Provide certified operational plans to: Receive and store isotope fuel capsules, load isotope fuel capsules into heat source, install heat source in IRV, and check out isotope power systems and components.

GO-117  Provide fire alarm and protection system training and procedures capable of supporting isotope hardware at: Nuclear facility, transporter, and launch pad.

GO-118  Provide quick retrieval operations to remove nuclear payload during an emergency.

GO-119  Install the isotope heat source in the Shuttle cargo bay at the last practicable point in the launch countdown sequence.

GO-120  Provide capability to reduce ignitable propellant fumes around the cargo bay (i.e., drainage of propellant tanks and/or purging immediate payload area).

GO-122  Provide Shuttle crew training with confirmed procedures in the use of multiple and independent system monitoring equipment with instantaneous and recorded outputs for all mission phases.
GO-123 Provide certified removal equipment and procedures to handle the nuclear payload subsequent to Shuttle landing.

GO-124 Provide certified operational plans to retrieve and recover IRV and/or small isotope sources.

GO-125 Provide support personnel and Shuttle crew training with confirmed procedures in the use of multiple and independent radiation monitoring equipment with instantaneous and recorded outputs.

GO-126 Provide recovery gear and procedures for use subsequent to prelaunch accidents.

GO-127 Provide operations in the use of Transfer Modules to protect and reduce handling and packaging requirements of nuclear payloads.

GO-128 Provide Shuttle radiation and liquid metal decontamination capability at the launch and landing sites.

GO-129 Provide emergency capability and procedures for ejection of the payload over deep ocean areas (or continental shelf) or possible ditching of the Shuttle.

GO-130 Provide tracking and location capability for early land and water recovery.

GO-131 Provide for emergency retrieval/recovery of nuclear equipment if jettisoned from the Space Shuttle.

GO-132 Provide trained impact/recovery team and procedures for: Recovery, fire protection, radiation control, and decontamination.

GO-133 Prohibit launch during unsatisfactory weather conditions, including moderate to high winds blowing towards populated areas.

GO-134 Minimize the crew dose rate throughout all operations (maximum of 150 mrem/day).

GO-135 Minimize radiation dose to crews performing contingency operations (maximum of 150 mrem/day from nuclear sources should be maintained).

GO-136 Consider use of a back-up Shuttle to support repair of a failed Shuttle or transfer or retrieval of the payload in orbit for the continuance of the mission.

GO-137 Provide contingencies for Shuttle orbital stay times of up to 20 days to allow for repairs to be made.

GO-138 Where in-orbit repairs of interfacing non-nuclear hardware (transfer mechanisms, etc.) are unsuccessful, the Shuttle and payload should return to earth.
GO-139 Consider payload ejection through cargo bay doors if doors cannot be opened.

GO-140 Provide certified operational plans to launch and perform orbital transfer operations involving nuclear hardware.

GO-141 Provide positive control of nuclear payloads during all handling operations.

GO-142 Provide nuclear cargo transfer operations that do not involve EVA.

GO-143 Provide direct visual or TV coverage of all nuclear cargo transfer operations.

GO-144 Provide alternate and/or redundant equipment and procedures for nuclear cargo handling.

GO-145 Consider feasibility of uncooperative "tumbling" power module retrieval with Shuttle.

GO-146 Provide Shuttle landing area remote from inhabited facilities.
SHUTTLE-GUIDELINE STATEMENTS

RD-103 Provide a redundant active isotope cooling system with the Shuttle cargo bay to be operable on ascent and return/reentry with at least 24 hours emergency operating time.

RO-103 Minimize overflight of land and continental shelf areas.

RO-106 Provide for Shuttle retrieval and recovery of a heat source with a damaged shield or fuel capsule fractures.

RO-107 Establish emergency procedures and decisions (contingency plans) for emergency situations involving nuclear hardware.

GD-101 Provide an inert gas blanket and/or double containment during the prelaunch period to preclude a NaK-oxygen reaction in the event of NaK leak.

GD-104 Provide blast overpressure and fragmentation protection adequate to assure containment of all radioactive material in event of an accident (critical requirement for isotopes; may be desirable for reactors)

GD-105 Provide multiple and independent system monitoring and control equipment with instantaneous and recording outputs for all mission phases.

GD-107 Provide up to 1 kilowatt of electrical power (either from the Transfer Module or the Shuttle).

GD-108 Assure maximum allowable shuttle crew-nuclear payload separation distance (e.g., provide for the placement of the reactor/shield as far aft in the cargo bay as permitted within shuttle c.g. and power module configuration restrictions).

GD-110 Provide for decay heat removal and radiation shielding if a spent reactor is transferred to the Shuttle less than 10 days after shutdown.

GD-111 Provide capability of detecting and alerting the Shuttle crew of a liquid metal leak which would render the power module inoperable and provide potential hazards within the Shuttle cargo bay.

GD-112 Consider provision of liquid metal fire suppression material within the Shuttle.

GD-113 Consider a Shuttle return of only a reactor/shield by a design which permits in-orbit separation of the radiator and other components.

GD-114 Provide a rapid response back-up isotope cooling system at the launch pad which does not require opening of the Shuttle doors.
GD-115 Provide approximately 300 watts of electrical power (either from the Transfer Module or the Shuttle).

GD-116 Provide multiple and independent system monitoring and control equipment with instantaneous and recording outputs for all mission phases.

GD-117 Assure maximum allowable shuttle crew - nuclear payload separation distance. (IRV should be placed with side-on view to crew locations.)

GD-120 Provide dry N$_2$ purging capability of the Shuttle cargo bay while on the launch pad.

GD-121 Consider use of Transfer Module integration scheme to reduce and simplify Shuttle interfaces and to improve safety in handling nuclear payloads.

GD-122 Prevent propellant boil-off and other undesirable gases from entering Shuttle cargo bay with the doors closed by provision of an environmental enclosure.

GD-123 Provide multiple and independent radiation monitoring equipment with instantaneous and recording outputs.

GD-124 Provide capability of detecting and alerting the Shuttle crew of nuclear payload failures which occur during transport.

GD-125 Provide a free, unobstructed, and directed ejection path for the payload in the event of a Shuttle booster or orbiter explosion on the launch pad.

GD-126 Provide intact reentry and impact capability. Consider use of crush-up materials in Shuttle orbiter cargo bay to minimize damage upon Shuttle land impact.

GD-127 Provide tracking and recovery devices on nuclear payloads.

GD-128 Provide a clean, smooth surface cargo bay to facilitate decontamination, and minimize the time required.

GO-104 Provide a controlled environmental liquid metal safing capability at launch and landing sites (reduction of O$_2$ sources).

GO-107 Provide Shuttle crew training with confirmed procedures in the use of multiple and independent system monitoring equipment with instantaneous and recorded outputs for all mission phases.

GO-108 Provide rendezvous and docking positions such that the Shuttle crew locations are within the shadow of the reactor shield to minimize the dose to the crew during docking and replacement operations.
GO-110 Provide certified operational plans to dispose of or recover a spent reactor power module.

GO-111 Provide a minimum 100 year orbital lifetime for a spent reactor in high earth orbit (250 year orbit is preferred to give 9 half-life decay).

GO-112 Consider capability to install a replaceable or strap-on reactor disposal system by the Shuttle crew.

GO-115 Consider reactor reboost capability to a new long-life orbit by the Shuttle.

GO-120 Provide capability to reduce ignitable propellant fumes around the cargo bay (i.e., drainage of propellant tanks and/or purging immediate payload area).

GO-122 Provide Shuttle crew training with confirmed procedures in the use of multiple and independent system monitoring equipment with instantaneous and recorded outputs for all mission phases.

GO-124 Provide certified operational plans to retrieve and recover IRV and/or small isotope sources.

GO-125 Provide support personnel and Shuttle crew training with confirmed procedures in the use of multiple and independent radiation monitoring equipment with instantaneous and recorded outputs.

GO-127 Provide operations in the use of Transfer Modules to protect and reduce handling and packaging requirements of nuclear payloads.

GO-128 Provide Shuttle radiation and liquid metal decontamination capability at the launch and landing sites.

GO-129 Provide emergency capability and procedures for ejection of the payload over deep ocean areas (or continental shelf) or possible ditching of the Shuttle.

GO-131 Provide for emergency retrieval/recovery of nuclear equipment if jettisoned from the Space Shuttle.

GO-134 Minimize the crew dose rate throughout all operations (maximum of 150 mrem/day).

GO-135 Minimize radiation dose to crews performing contingency operations (maximum of 150 mrem/day from nuclear sources should be maintained).

GO-136 Consider use of a back-up Shuttle to support repair of a failed Shuttle or transfer or retrieval of the payload in orbit for the continuance of the mission.
GO-137 Provide contingencies for Shuttle orbital stay times of up to 20 days to allow for repairs to be made.

GO-138 Where in-orbit repairs of interfacing non-nuclear hardware (transfer mechanisms, etc.) are unsuccessful, the Shuttle and payload should return to earth.

GO-139 Consider payload ejection through cargo bay doors if doors cannot be opened.

GO-140 Provide certified operational plans to launch and perform orbital transfer operations involving nuclear hardware.

GO-141 Provide positive control of nuclear payloads during all handling operations.

GO-142 Provide nuclear cargo transfer operations that do not involve EVA.

GO-143 Provide direct visual or TV coverage of all nuclear cargo transfer operations.

GO-144 Provide alternate and/or redundant equipment and procedures for nuclear cargo handling.

GO-145 Consider feasibility of uncooperative "tumbling" power module retrieval with Shuttle.

GO-147 Consider dumping of excess Shuttle propellant prior to landing to minimize explosive potential.

GO-148 Provide capability to defuel the Shuttle in nuclear emergencies on the launch pad.
GROUND SUPPORT-GUIDELINE STATEMENTS

RD-102 Provide passive cooling systems, or redundant active systems, throughout all phases of the Shuttle-isotope heat source mission.

RO-101 Provide and confirm procedures for the cooling of isotope payloads for all phases of the Shuttle mission (no identifiable failure modes or provide redundant cooling systems).

RO-104 Provide suitable personnel exclusion area at the launch and landing sites, (4 km fallback area and approximately 13 km administrative control zone).

RO-107 Establish emergency procedures and decisions (contingency plans) for emergency situations involving nuclear hardware.

GD-114 Provide a rapid response back-up isotope cooling system at the launch pad which does not require opening of the Shuttle doors.

GD-119 Provide certified equipment to handle nuclear payloads.

GD-120 Provide dry $N_2$ purging capability of the Shuttle cargo bay while on the launch pad.

GD-125 Provide a free, unobstructed, and directed ejection path for the payload in the event of a Shuttle booster or orbiter explosion on the launch pad.

GO-101 Provide certified operational plans to store reactor power systems and check out reactor power systems and components.

GO-102 Provide fire alarm and protection system training and procedures capable of supporting hardware containing nuclear material and liquid metals in nuclear facility, transporter and launch pad.

GO-104 Provide a controlled environment liquid metal safing capability at launch and landing sites (reduction of $O_2$ sources).

GO-105 Provide certified unloading, decontamination and liquid metal equipment and procedures to handle nuclear reactor power modules subsequent to Shuttle landing.

GO-114 Consider means of long term tracking of reactor power module following boost to a high earth disposal orbit (for possible recovery at a later date).
GO-116 Provide certified operational plans to receive and store isotope fuel capsule, load isotope fuel capsules into heat source, install heat source in IRV and check out isotope power systems and components.

GO-117 Provide fire alarm and protection system training and procedures capable of supporting isotope hardware at nuclear facility, transporter and launch pad.

GO-118 Provide quick retrieval operations to remove nuclear payload during an emergency.

GO-119 Install the isotope heat source in the Shuttle cargo bay at the last practicable point in the launch countdown sequence.

GO-123 Provide certified removal equipment and procedures to handle the nuclear payload subsequent to Shuttle landing.

GO-126 Provide recovery gear and procedures for use subsequent to prelaunch accidents.

GO-128 Provide Shuttle radiation and liquid metal decontamination capability at the launch and landing sites.

GO-132 Provide trained impact/recovery team and procedures for: recovery, fire protection, radiation control and decontamination.

GO-133 Prohibit launch during unsatisfactory weather condition, including moderate to high winds blowing towards populated areas.

GO-146 Provide Shuttle landing area remote from inhabited facilities.

GO-148 Provide capability to defuel the Shuttle in nuclear emergencies on the launch pad.
FACILITY-GUIDELINE STATEMENTS

GD-129 Provide certified facilities to store reactor power modules, checkout reactor power modules and components and perform radiological monitoring and control functions.

GD-130 Provide certified facilities to store isotope fuel capsules, load isotope fuel capsules into heat sources, install heat source in IRV, checkout isotope power systems and components and perform radiological monitoring and control functions.

GO-104 Provide a controlled environment liquid metal safing capability at launch and landing sites (reduction of O₂ sources).
### Table 4-2. Shuttle Nuclear System Safety

#### Guideline Cross Index

<table>
<thead>
<tr>
<th>NUMBER</th>
<th>TITLE</th>
<th>REACTOR</th>
<th>SMALL BOOSTER</th>
<th>SHUTTLE</th>
<th>GROUND SUPPORT</th>
<th>FACILITIES</th>
<th>REACTOR</th>
<th>SMALL BOOSTER</th>
<th>SHUTTLE</th>
<th>GROUND SUPPORT</th>
<th>FACILITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>G001</td>
<td>ENVIRONMENTAL PROTECTION</td>
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<tr>
<td>G002</td>
<td>USE OF PROPANE</td>
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<td>G003</td>
<td>ISSUING COMPARTMENT</td>
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<td>G005</td>
<td>PAYLOAD STATUS MONITORING EQUIPMENT</td>
<td></td>
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<td>G006</td>
<td>NUCLEAR LOOP</td>
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<tr>
<td>G007</td>
<td>AUXILIARY POWER - REACTOR PAYLOAD</td>
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<tr>
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<td>SHUTTLE CREW - NUCLEAR PAYLOAD SEPARATION (REACTOR)</td>
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<td>DEDICATED REACTOR REACTOR ACTIVITY</td>
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<td>STAND-BY PAYLOAD</td>
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<td>REACTOR DECEPTION/RECOVERY</td>
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<td>ON-PAD BOOSTER PAYLOAD</td>
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<td>PAYLOAD STATUS MONITORING</td>
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<td>G022</td>
<td>RADAR MONITORING EQUIPMENT</td>
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<td>DETECTION OF NUCLEAR PAYLOAD PAYLOAD POWER</td>
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<td>IMPACT RESISTENCY AND IMPACT CHARACTERISTICS</td>
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<td>TRACKING AND RECOGNITION PAYLOAD PAYLOAD</td>
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<td>G027</td>
<td>DECOMMISSIONING</td>
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<td>NUCLEAR FACILITIES</td>
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<td>NUCLEAR FACILITIES (REACTOR)</td>
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SECTION 5
SAFETY GUIDELINES

This section contains the complete set of guidelines and requirements arranged in the following order:

Requirements
   Design Requirements                RD-101 - RD-105
   Operations Requirements            RO-101 - RO-107

Guidelines
   Design Guidelines                  GD-101 - GD-130
   Operations Guidelines              GO-101 - GO-148
**SPACE SHUTTLE - NUCLEAR SYSTEM SAFETY GUIDELINE**

<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>IRV, Small Isotope Source</td>
<td>Isotope Cooling at Launch Pad</td>
</tr>
</tbody>
</table>

**MISSION PHASE/EVENT**

Prelaunch

**TITLE:** ON PAD COOLING OF ISOTOPE HEAT SOURCE

**STATEMENT:** Provide isotope heat source cooling to 420°K (300°F), or less.

**JUSTIFICATION:** On a standard day at sea level, the radiating surface of the isotope heat source will reach an equilibrium temperature of 867°K (1100°F). This would present a hazard in the presence of hydrazine and other booster fuels, and would also cause structural damage to the heat source and fuel capsules due to refractory alloy oxidation.

**REMARKS:** Cooling during prelaunch can be accomplished by pumping cold nitrogen or some other cryogenic fluid over the heat source. The cold nitrogen would be supplied by existing Ground Support Equipment (GSE) located in the Mobile Launcher.

**REFERENCES:**

72SD4201-4-1 Section 4, 5, Appendix C

**CROSS REFERENCES:**

GD-114 RO-102

RD-102
TITLE: ISOPOKE COOLING SYSTEMS

STATEMENT: Provide passive cooling systems, or redundant active systems, throughout all phases of the Shuttle-isotope heat source mission.

JUSTIFICATION: An isotope heat source provides a continuous flow of heat energy and radiation throughout its lifetime. The heat must be removed in a manner that maintains the temperature of the heat source and nearby equipment at acceptably low levels. Inadequate heat removal will result in excessive temperatures that can render equipment unoperative and the heat source capsule unable to contain the isotope fuel.

REMARKS: During the prelaunch period, the heat source is cooled to about 420°K with a flow of cold nitrogen which is supplied by GSE located in the Mobile Launcher. During orbital and reentry phases of the mission, cooling of the heat source must be accomplished by other means. Either a passive or active thermal control system can be employed, depending to a large extent upon the type of environmental shielding. If a hemispherical environmental shield is used, passive cooling (direct radiation to space) can be employed once the Shuttle is out of the earth's atmosphere and the Shuttle doors opened. During reentry operations when the Shuttle doors are closed, cooling of the heat source to an acceptable temperature of perhaps 650° or 700°K can be accomplished by a low temperature nitrogen system similar to that used during prelaunch, but carried aboard the Shuttle. A water boil-off system could also be used to reduce the heat source temperature. Upon landing, the heat source could once again be cooled by GSE. If a 4π environmental shield is employed, cooling could be accomplished by a redundant cold gas system, or by a pumped loop, rejecting the heat to space by means of a radiator mounted externally on the Shuttle. During reentry, a cold gas or water boil-off system must be relied upon. For small isotope systems, cooling requirements during prelaunch of less than 420°K still exist, but the thermal output may be low enough to negate the need for auxiliary cooling.

REFERENCES:
72SD4201-4-1 Section 4, 5; Appendix C
72SD4201-2-1 Section 5

CROSS REFERENCES:
GO-119
RD-101
RD-103
GD-114
### Title: Isotope Cooling During Shuttle Transport

**Statement:** Provide a redundant active isotope cooling system within the Shuttle cargo bay to be operable on ascent and return/reentry with at least 24 hours emergency operating time.

**Justification:** One of the large potential hazards that arises when transporting an isotope heat source is the constant emission of heat. This heat energy must be removed to prevent excessive temperatures that can render equipment unoperative and the heat source capsule unable to contain the isotope fuel. To maintain allowable temperatures during the ascent and on-orbit operations, the heat source may be capable of radiating directly to space with the cargo bay doors open, however, during reentry when the cargo bay doors are closed, provisions must be made for a redundant active cooling system with a 24-hour emergency operating capability. This redundant active cooling system should also be provided for during ascent and on-orbit operations to serve as a back-up if the Shuttle cargo bay doors fail to open. (For small isotope sources, cooling requirements during prelaunch of less than 420°K still exist but the thermal output may be low enough to negate the need for auxiliary cooling. However, in the event of a contingency situation, a redundant active cooling system could be employed.)

**Remarks:** A cold gas system or a water boil-off system should be considered. A pumped loop system using perhaps an organic fluid and rejecting the heat to space by means of a radiator mounted externally on the Shuttle orbiter can be used during ascent and orbital operations, but cannot be used during reentry when high Shuttle skin temperatures exist. However, suitable controls can permit the pumped loop to act as a water boil-off system when desired.

**References:**
72SD4201-4-1 Section 4, 5, 6; Appendix C

**Cross References:**
RD-102
TITLE: BLAST AND FRAGMENTATION PROTECTION (ISOTOPE)

STATEMENT: Provide blast overpressure and fragmentation protection adequate to assure containment of all radioactive material in event of an accident (critical requirement for isotopes; may be desirable for reactors).

JUSTIFICATION: The proximity of the isotope payload in the Shuttle cargo bay to the Shuttle fuel tankage will result in extremely high blast overpressures and fragment velocities in the event of a tankage explosion. To prevent breaking of the nuclear fuel capsules and the release of radioactive material to the environment, extensive shielding will be required. (The size and weight of blast and fragmentation shielding for small isotope sources will be minor compared to that for an IRV.)

REMARKS: Three possible approaches to the design of an environmental shield (protection of heat source capsules from the blast overpressure, high velocity fragments, and fireball temperatures that might ensue in the event of an explosion of the Shuttle main tankage) are:

- Hemispherical environmental shield-interface shielding between the heat source and Shuttle tankage; permits passive thermal control
- $4\pi$ environmental-heat source is completely protected by shielding
- Augmented hemispherical shield-shielding nearly encompasses the heat source, but has an opening (away from probable source of explosion) that permits radiation of sufficient heat to maintain acceptable heat source temperatures.

An alternative approach that permits the use of lighter and simpler environmental shielding is to increase the separation distance between the heat source and the source of explosion. Blast overpressure and fragment velocities are rapidly reduced as the separation distance increases. To achieve this, the heat source could be transported in a pod mounted externally on the Shuttle, or it might even be located in the nose of the Shuttle.

REFERENCES:
72SD4201-4-1 Section 4, 5; Appendix A
72SD4201-4-2 Appendix A

CROSS REFERENCES:
GD-104
RD-105
**TITLE:** FIREBALL PROTECTION

**STATEMENT:** Provide fireball protection adequate to assure containment of all radioactive material in event of an accident (critical for isotopes; may be necessary for reactors).

**JUSTIFICATION:** Fireball temperatures in the aftermath of a launch pad Shuttle explosion are expected to reach a maximum temperature of approximately 2980°K (4900°F) immediately after the explosion and level off to approximately 1250°K (1800°F) within 10-14 seconds following the explosion. The isotope fuel capsules or fuel elements of a nuclear reactor must be designed to survive this thermal environment without releasing any radioactive material to the atmosphere or environmental shielding must be provided to perform this function.

**REMARKS:** Fireball protection is critical for isotope payloads with inherently large curie inventories that could be released, whereas the fireball protection requirement is not as critical for a reactor system because of the small core fission product inventory (generated during preflight low power acceptance testing) that exists prior to reactor startup in orbit. However, if the reactor system is to be returned to earth following in-orbit power operation, fireball protection must be provided because of the potentially large core fission product inventory generated during the reactor's operational lifetime.

**REFERENCES:**
72SD4201-4-1 Section 3, 4, 5; Appendix A
72SD4201-4-2 Appendix A

**CROSS REFERENCES:**
RD-104
PROCEDURES TO ASSURE ISOTOPE COOLING

STATEMENT: Provide and confirm procedures for the cooling of isotope payloads for all phases of the Shuttle mission (no identifiable failure modes or provide redundant cooling systems).

JUSTIFICATION: The isotope payload generates heat throughout its useful lifetime. The heat must be removed in a fashion that maintains fuel capsule and surrounding equipment temperatures within acceptable limits; failure to do so can result in equipment breakdowns, fuel capsule failures, and a possibility of increased fuel dispersion in the event of a subsequent accident and independent reentry. Equipment and procedures aboard the Shuttle must remove the heat generated, and must indicate that allowable temperatures exist.

REMARKS: During a normal launch/ascent, the heat generated by the isotope fuel is largely taken up by the heat source structure. The temperature of the device increases only slightly from the 420°K to which it is cooled prior to launch during the approximately eight minutes required to penetrate the earth's atmosphere. After this time, the Shuttle cargo bay doors can be opened and the heat source can radiate directly to space. The IRV heat source temperature will rise slowly to its equilibrium temperature of 865°K.

During reentry at the end of mission when the IRV is being returned to earth, a redundant active system should be capable of providing cooling. Prior to actual removal of the IRV from the cargo bay following landing, inert gas cooling will be introduced to cool the heat source, using the same inert gas cooling systems that cooled the heat source prior to lift-off. For small isotope systems, prelaunch cooling requirements of less than 420°K still exist, but the thermal output may be low enough to negate the need for auxiliary cooling.

REFERENCES:
72SD4201-2-1 Section 5
72SD4201-4-1 Section 4, 5; Appendix C

CROSS REFERENCES:
RD-102
<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>IRV, Small Isotope Source</td>
<td>Launch Pad Cooling</td>
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**MISSION PHASE/EVENT**

Prelaunch

**TITLE:** ISOTOPE HEAT SOURCE COOLING PROCEDURES FOR PRELAUNCH

**STATEMENT:** Provide procedures to assure isotope heat source cooling to $420^\circ K$ ($300^\circ F$) or less during prelaunch.

**JUSTIFICATION:** On a standard day at sea level, the radiating surface of the isotope heat source will reach an equilibrium temperature of $867^\circ K$ ($1100^\circ F$). This would present a hazard in the presence of hydrazine and other booster fuels and would also cause structural damage to the heat source and fuel capsules due refractory alloy oxidation. For small isotope sources, the cooling requirements of less than $420^\circ K$ still exist, but the thermal output may be low enough to negate the need for auxiliary cooling.

**REMARKS:** Cooling during prelaunch can be accomplished by pumping cold nitrogen or some other cryogenic fluid over the heat source. The cold nitrogen would be supplied by GSE located in the Mobile Launcher.

**REFERENCES:**
72SD4201-4-1 Section 4, 5; Appendix C

**CROSS REFERENCES:**
RD-101
GD-114
PROGRAM ELEMENT: Shuttle
SYSTEM-SUBSYSTEM: Reactor, IRV, Small Isotope Sources, Shuttle
OPERATION: Shuttle Transport

MISSION PHASE / EVENT: Launch/Ascent

TITLE: LAND AND CONTINENTAL SHELF OVERFLIGHT

STATEMENT: Minimize overflight of land and continental shelf areas.

JUSTIFICATION: The hazard association with earth impact of a nuclear payload is greatly reduced if it occurs in a deep ocean area where the population exposure is the smallest and the payload can sink to the ocean bottom. Therefore, the mission should be planned to minimize land and continental shelf overflight during launch/ascent and during descent/reentry operations.

REFERENCES:
72SD4201-4-1 Section 3, 4, 5, 7
72SD4201-4-2 Section 4

CROSS REFERENCES:
TITLE: PERSONNEL EXCLUSION AREA

STATEMENT: Provide suitable personnel exclusion area at the launch and landing sites, (4 km fallback area and approximately 13 km administrative control zone).

JUSTIFICATION: An on-pad accident could result in the release of radioactive material in the immediate vicinity of the launch pad. To prevent the ground crew and observers from being exposed to a potential nuclear hazard, provisions must be made for maintaining suitable personnel exclusion area surrounding the launch site during the fueling and countdown operations.

REMARKS: The 4 km fallback distance is based on the locus of isopleths (0.15 rem whole body dose which is equivalent to the yearly natural background level) from a 100 MW-sec reactor excursion on the launch pad for Pasquill F weather (worst case). The isopleths are within the KSC boundary and do not extend to the Vehicle Assembly Building (VAB) and Launch Control Center where launch control and observers are located.

The currently controlled area at KSC with a radius of about 13 km appears to be adequate for missions involving nuclear hardware. This is the area within which all personnel are under direct administrative control. The 13 km radius from the perimeter of nuclear facilities remains within the boundaries of KSC and the Eastern Test Range.

REFERENCES:
72SD4201-4-1 Section 3, 4, 5, 7
72SD4201-4-2 Section 4
TITLE: PERMANENT REACTOR SHUTDOWN OPERATIONS

STATEMENT: Provide procedures for permanent reactor shutdown prior to separation from Space Base.

JUSTIFICATION: It is conceivable that a reactor upon impacting the earth's surface could go critical due to a combination of control drum motion and core compaction (land impact) or over moderation caused by water reflection of neutrons (water immersion). To prevent such an occurrence and eliminate the nuclear hazards involved, permanent reactor shutdown should be provided.

REMARKS: Control drum lockouts and core poisons are possible permanent shutdown mechanisms. A third approach is to force the hydrogen moderator out of the fuel elements. This can be done by reducing the coolant flow, thereby increasing the core temperature enough to induce fuel cladding failure.

REFERENCES:
72SD4201-4-1 Section 3, 7; Appendix B
72SD4201-4-2 Section 2
TITLE: ISOTOPE RETRIEVAL/RECOVERY

STATEMENT: Provide for Shuttle retrieval and recovery of a heat source with a damaged shield or fuel capsule fractures.

JUSTIFICATION: As a back-up recovery mode, the isotope reentry vehicle (IRV) has its own reentry protection to assure a successful independent reentry of the heat source. This back-up recovery mode should be particularly avoided if fuel capsule fractures are present or if the reentry shield is damaged. If these conditions exist, there is a high probability that upon reentry, a fuel release will occur. Therefore, the Shuttle should be considered as the prime mode of retrieval/recovery of an isotope heat source with a damaged shield or fuel capsule fractures.

REMARKS: With a failure in fuel capsule containment, the resultant radiation due to release of fines should not be a hazard to the crew, but a thorough decontamination of the Shuttle cargo bay upon landing will be required. Clean, smooth cargo bay surfaces, free from protrusions and crevices would enhance decontamination procedures. A sealed crew compartment (separate ECLS) should be a design objective to assure radioactive vapor from fractured capsules does not enter the compartment.

REFERENCES:
72SD4201-4-1 Section 6

CROSS REFERENCES:
GO-124
GD-128
**TITLE:** CONTINGENCY PLANS

**STATEMENT:** Establish emergency procedures and decisions (contingency plans) for emergency situations involving nuclear hardware.

**JUSTIFICATION:** Abnormal and/or emergency situations involving nuclear payloads could result during the mission. If remedial steps are not taken in these situations, the mission could be curtailed and potential hazards to the crew, equipment, the general public, and the ecology could result. The implementation of contingency modes and emergency operating procedures could eliminate or substantially reduce the adverse effects on the mission and the risks to personnel.

**REMARKS:** The results of a qualitative contingency analysis of Shuttle/nuclear payload transport missions indicate that the implementation of emergency procedures is effective for three situations: (1) where remedial actions contain and control the emergency situation and normal operations can be resumed, (2) where a diminished operating mode can be established until the normal operational conditions are reestablished and (3) where crew and/or equipment abort procedures can be enacted to effect recovery of the crew and/or safe disposal or recovery of the nuclear source. Each situation is a deviation from the normal mode of operations and could require unanticipated implementation.

Effective contingency implementation requires careful planning, procedural preparation, and training, which must be performed in parallel with hardware design, development, and mission planning.

**REFERENCES:**

72SD4201-4-1 Section 3, 4, 5, 6, 7
72SD4201-4-2 Section 4

**CROSS REFERENCES:** RD-103
RD-106
GD-102, 103, 111, 112, 113, 114, 118, 120, 124, 125, 126, 127, 128
TITLE: ENVIRONMENTAL PROTECTION

STATEMENT: Provide an inert gas blanket and/or double containment during the prelaunch period to preclude a NaK-oxygen reaction in the event of NaK leak.

JUSTIFICATION: Reactors that may be transported by the Shuttle use NaK as the heat transfer medium to remove heat from the reactor core. Some systems also use NaK in the heat rejection (radiator) loop. Because there is a possibility of a NaK leak, and because NaK reacts violently with oxygen, an inert gas blanket coupled with double wall containment must be provided to prevent the presence of moisture and other oxygen sources from coming in contact with the NaK coolant.

REMARKS: An added safety precaution involves sealing off the cargo bay from the rest of the Shuttle, especially from the LO$_2$ and LH$_2$ vapor boil-off of propellant tanks or fuel cell storage bottles.

The requirements for an inert gas environmental enclosure are significantly increased if a liquid metal NaK coolant is used in the primary heat rejection loop rather than an organic coolant (i.e., Dow Corning 200).

REFERENCES:
72SD4201-4-1 Section 3
MISSION PHASE/EVENT
Prelaunch, Launch/Ascent, On-Orbit Operations, End of Mission

TITLE: INERT GAS PRESSURE LINER

STATEMENT: Consider use of an inert gas positive pressure liner for encasement of all or portions of a reactor power module - considered particularly important for the in-orbit retrieval and landing site removal of a damaged power module.

JUSTIFICATION: Reactors that may be transported by the Space Shuttle use NaK as the heat transfer medium to remove heat from the reactor core. Some systems also use NaK in the heat rejection (radiator) loop. Because there is a possibility of a NaK leak and because NaK reacts violently with oxygen, the use of an inert gas positive pressure liner for encasement of all or portions of a reactor power module should be considered to protect the Shuttle cargo bay and provide safety advantages in the unloading and Shuttle refurbishment operations at the launch/landing site.

REMARKS: The inert gas positive pressure liner would be placed around the reactor/shield assembly or the entire power module prior to or during installation in the cargo bay. This liner could be designed to contain a NaK leak and also maintain a positive inert gas pressure until the power module is within the controlled environment of the liquid metal servicing building.

REFERENCES:
72SD4201-4-1 Section 6

CROSS REFERENCES:
GD-101, 103, 122
GO-104, 105
# SPACE SHUTTLE NUCLEAR SYSTEM SAFETY GUIDELINE

<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>Reactor</td>
<td>Contingencies</td>
</tr>
</tbody>
</table>

## MISSION PHASE / EVENT
Prelaunch, Launch/Ascent, On-Orbit Operations, End of Mission

## TITLE: DOUBLE CONTAINMENT

**STATEMENT:** Provide double containment of liquid metal components where feasible.

**JUSTIFICATION:** Reactors that may be transported by the Space Shuttle use NaK as the heat transfer medium to remove heat from the reactor core. Some systems also use NaK in the heat rejection (radiator) loop. Because there is a possibility of a NaK leak and because NaK reacts violently with oxygen, double wall containment of liquid metal components should be provided where feasible.

**REMARKS:** Another protective device based on the principle of double containment involves the use of a positive pressure liner which would be placed around the reactor/shield assembly or the entire power module prior to or during installation in the cargo bay. This liner could be designed to contain the NaK leak and also maintain a positive inert gas pressure until the module is within the controlled environment of the liquid metal servicing facility.

**REFERENCES:**
72SD4201-4-1 Section 3, 6
**TITLE:** BLAST AND FRAGMENTATION PROTECTION (REACTOR)

**STATEMENT:** Provide blast overpressure and fragmentation protection adequate to assure containment of all radioactive material in event of an accident (critical requirement for isotopes; may be desirable for reactors)

**JUSTIFICATION:** The proximity of the nuclear reactor payload in the Shuttle cargo bay to the Shuttle fuel tankage will result in extremely high blast overpressures and fragment velocities in the event of a tankage explosion. To prevent breaking of the nuclear fuel elements and the release of radioactive material to the environment, extensive shielding will be required.

**REMARKS:** Prior to initial reactor startup in orbit, little or no blast and fragmentation protection will be required due to the small fission product inventory present in the core. However, following reactor operation in space and the resultant buildup of a relatively large fission product inventory, blast and fragmentation protection must be provided if the spent reactor is to be returned to earth.

**REFERENCES:**
72SD4201-4-1 Section 3, Appendix A
72SD4201-4-2 Appendix A

**CROSS REFERENCES:**
RD-104
TITLE: PAYLOAD STATUS MONITORING EQUIPMENT

STATEMENT: Provide multiple and independent system monitoring and control equipment with instantaneous and recording outputs for all mission phases.

JUSTIFICATION: Knowing the condition of the reactor power module within the Shuttle orbiter cargo bay permits an assessment by the crew of the "go/no-go" status of the payload (1) prior to launch, (2) prior to final rendezvous and docking, and (3) prior to initiating the re-entry, final approach and landing upon returning a spent reactor power module to the earth's surface. A detected failure condition, such as a liquid metal or radiator coolant leak would eliminate the need for docking and the subsequent removal (from the cargo bay) of a damaged power module. A detected failure condition of the power module which is deemed a hazard upon landing could result in the emergency ejection of the power module into a deep ocean area prior to earth landing.

REMARKS: Provisions must be made for the recording and/or display of a maximum of 80 data points (sensors) for maintaining periodic and, in some cases, continuous system status of power module integrity, radiation levels, NaK leaks, power module and cargo bay temperatures, etc. In addition to the monitoring equipment, some 20 separate control signals are required to provide environmental control regulation, handling, attachment and deployment controls from the Shuttle.

REFERENCES: 72SD4201-4-1 Section 3

CROSS REFERENCES: GO-107 GD-111
**Program Element:** Shuttle  
**System-Subsystem:** Reactor  
**Operation:** In orbit operations, maintenance

**Title:** NaK Loop Integrity  
**Statement:** Provide NaK loop design which does not require breaking or opening of NaK loops for replacement and maintenance.

**Justification:** NaK, used as the primary coolant in most reactor systems, reacts violently in the presence of oxygen (which may be leaking or otherwise being discharged from the Space Base or Space Shuttle) and is very corrosive. If NaK is released in orbit, it may vaporize and then condense on external surfaces and the vapor could contaminate the surrounding environment. Therefore, the NaK loops should be designed to retain their integrity during orbital operations.

**Remarks:** If NaK loops are broken, an EVA will most likely be required if repair is to be attempted. Since NaK is probably not compatible with the space suits worn by the astronauts, EVA may be hazardous.

**References:**  
72SD4201-4-1 Section 3, Appendix B

**Cross References:**  
GO-106
TITLE: AUXILIARY ELECTRIC POWER - REACTOR PAYLOAD

STATEMENT: Provide up to 1 kilowatt of electrical power (either from the Transfer Module or the Shuttle).

JUSTIFICATION: Reactors that may be transported by the Space Shuttle use NaK as the heat transfer medium to remove heat from the reactor core. NaK-78 freezes at approximately 260°K (12°F) and is subject to freezing temperatures during launch/ascent and while in orbit prior to operation. Severe freezing can cause coolant loop damage. Frozen loops also become difficult to thaw in order to permit circularization and cooling of the reactor. Up to 200 watts of electrical power may be required to provide radiant heat to prevent NaK freeze-up.

At the end of mission, if the spent reactor power module is placed in the cargo within a very few days after shutdown, the fission product afterheat may have to be removed. Approximately 500 watts of electrical power may be needed for operation of coolant pumps for the removal of fission product decay heat.

REMARKS: These electrical power requirements can be substantially reduced if:

- The NaK heating requirement is placed on the Space Base rather than on the Space Shuttle (NaK would be heated subsequent to mating of the reactor power module to the Space Base and prior to reactor start-up);
- A short wait time of approximately two days is observed for thermal cooling prior to placing the shutdown, spent reactor in the cargo bay.

The electrical power required could be supplied by batteries that are mounted on the transfer module or by the Space Shuttle Electrical Power System.

REFERENCES:

CROSS REFERENCES:

72SD4201-4-1 Section 3

GD-115
# Shuttle Crew - Nuclear Payload Separation (Reactor)

**Title:** Shuttle crew - Nuclear Payload Separation (Reactor)

**Statement:** Assure maximum allowable shuttle crew-nuclear payload separation distance (e.g., provide for the placement of the reactor/shield as far aft in the cargo bay as permitted within shuttle c.g. and power module configuration restrictions).

**Justification:** The maximum allowable dose rate to the Shuttle crew is 150 mrem/day per study groundrule. This dose rate will not be exceeded when transporting a "clean" reactor power module that has not been operated; however, when transporting a shutdown, spent reactor module during the end of mission operations, the 150 mrem/day dose rate will be exceeded (with no additional gamma shielding) unless the reactor/shield assembly is placed as far aft in the Shuttle cargo bay as permitted within Shuttle payload center-of-gravity and power module configuration restrictions. Maximum separation distance will reduce shielding requirements in applications where additional gamma shielding is necessary.

**Remarks:** Even though the maximum allowable Shuttle crew dose rate will not be exceeded if a clean reactor power module is transported with the reactor/shield assembly placed forward in the cargo bay, it is desirable to perform all transport operations with the reactor/shield assembly positioned aft in the cargo bay as is required if a shutdown, spent reactor power module. Shuttle transport operations will be simplified by always transporting reactor power modules in the same relative position in the cargo bay.

**References:**
72SD4201-4-1 Section 3, Appendix B

**Cross References:**
GO-109, 135
TITLE: DESIGN OF SEPARABLE REACTOR/SHELl ASSEMBLY

STATEMENT: Consider provision of a reactor/shield assembly separable from the radiator at end of mission.

JUSTIFICATION: If the selected reactor disposal scheme is the placement of the spent reactor in high earth orbit, its orbital lifetime at a given altitude will increase considerably as its ballistic coefficient \( \frac{W}{C_D A} \) increases. The ballistic coefficient can be substantially increased by separating the radiator from the reactor/shield assembly and boosting only the latter to high earth orbit. This provision eliminates the transport of the radiator back to the earth via the Shuttle.

REMARKS: Separation of the reactor/shield assembly from the rest of the power module can be accomplished by using a "separable heat exchanger". The separable heat exchanger permits separation of the reactor, with its primary liquid metal coolant loop, from the power conversion system and its secondary liquid metal coolant loop, without breaking any liquid metal coolant lines.

REFERENCES:

72SD4201-4-1 Section 3, Appendix B

CROSS REFERENCES:

GO-113
GD-113
**PROGRAM ELEMENT:** Shuttle  
**SYSTEM-SUBSYSTEM:** Reactor, Shuttle  
**OPERATION:** Shuttle Transport

**MISSION PHASE/EVENT:** On-Orbit Operations, End of Mission

**TITLE:** SPENT REACTOR DECAY HEAT REMOVAL AND RADIATION PROTECTION

**STATEMENT:** Provide for decay heat removal and radiation shielding if a spent reactor is transferred to the Shuttle less than 10 days after shutdown.

**JUSTIFICATION:** The radiation field created by the fission products in a shutdown reactor is rapidly reduced in strength during the first several days following shutdown. With no additional gamma shielding for the Shuttle crew, a minimum wait time (from reactor shutdown to initiation of replacement/recovery operations) of approximately 10 days is required for the dose rate (with the reactor/shield assembly positioned aft in the cargo bay) to decay below the maximum allowable 150 mrem/day (reactor power history: 5 yrs at 125 kWt). The fission product after heat generation in a reactor that has operated at 125 kWt for 5 yrs decays to approximately 250 w after 10 days (500 w two days after shutdown). Therefore, if the reactor is to be transferred to the Shuttle during the first 10 days after shutdown, additional nuclear radiation shielding for the Shuttle crew must be provided and an afterheat removal system may be required.

**HAZARD CATEGORY**

**REMARKS:** Scattered (reflected) radiation from hardware located in the near vicinity of the reactor can be a major contributor to the total radiation received by the Shuttle crew. If radiation protection is required for the Shuttle crew, the mass of additional shielding depends on the reactor fission product inventory and the location chosen for shield placement. The radiation impact on Shuttle components is related to the integrated dose and hence is mission dependent. Consideration can be given to localized shielding for critical components (i.e., solid state electronic devices, etc.), and hardening techniques can be applied where required. Since, the afterheat generation is relatively low several days after shutdown, it is possible that no special reactor/shield heat removal apparatus would be needed since the heat capacity and natural heat loss from the Shuttle itself may be sufficient.

**REFERENCES:**
72SD4201-4-1 Section 3, Appendix B

**CROSS REFERENCES:**
GO-109, 134
**SPACE SHUTTLE**
**NUCLEAR SYSTEM SAFETY GUIDELINE**

<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>Reactor, Shuttle</td>
<td>Contingencies</td>
</tr>
</tbody>
</table>

**DATE** JAN 72  
**NO.** GD-111

**MISSION PHASE/EVENT**
Prelaunch, Launch/Ascent, On-Orbit Operations, End of Mission

**TITLE:** DETECTION OF NaK LEAK IN CARGO BAY

**STATEMENT:** Provide capability of detecting and alerting the Shuttle crew of a liquid metal leak which would render the power module inoperable and provide potential hazards within the Shuttle cargo bay.

**JUSTIFICATION:** During Shuttle transport of a reactor system, a NaK leak in a reactor coolant loop could occur. If provisions are not made for detecting and alerting the Shuttle crew to this situation, the mission could be curtailed and potential hazards to the crew, equipment, the general public, and the ecology could result. If the NaK leak is detected and the Shuttle crew alerted, contingency modes and emergency operating procedures can be implemented which could eliminate or substantially reduce the adverse effects on the mission and the risks to personnel.

**REMARKS:** Consider use of pressure measurements in the NaK coolant loops.

**REFERENCES:**
72SD4201-4-1 Section 6

**CROSS REFERENCES:**
GO-107
# Liquid Metal Fire Suppression

**Title:** Liquid Metal Fire Suppression

**Statement:** Consider provision of liquid metal fire suppression material within the Shuttle.

**Justification:** Following an accident during the Launch/Ascent Phase of the mission (or at the end of mission if the spent reactor is being returned to the earth's surface), an emergency Shuttle landing may be attempted. A hard landing could rupture liquid metal components and if environmental containment is not maintained, a liquid metal reaction could result. Readily accessible quantities of liquid metal fire suppression material should be provided in the Shuttle, as this material would probably not be available at an unplanned landing site.

**Remarks:** Fires are generally extinguished by the removal of oxygen. Extinguishing materials normally used must not be applied to liquid metal fires because if the reaction with common extinguishers such as water, carbon tetrachloride, carbon dioxide, and sodium bicarbonate. The exclusion of oxygen can be effected by covering the burning metal with such materials as dry alkali metal chlorides, graphite, or soda ash (calcium carbonate). Met-L-X dry powder is an impregnated sodium chloride which is free flowing and not susceptible to moisture pickup. Another commercial material is Pyrene G-1 powder. This is a graphite-base material. Yellow is the adopted color for liquid metal fire extinguishers and all equipment used for this purpose should be painted yellow for easy identification.

**References:**
72SD4201-4-1 Section 6
TITLE: REACTOR DISPOSAL/RECOVERY

STATEMENT: Consider a Shuttle return of only a reactor/shield by a design which permits in-orbit separation of the radiator and other components.

JUSTIFICATION: Reactors that may be transported by the Space Shuttle use NaK as the heat transfer medium to remove heat from the reactor core. Some systems also use NaK in the heat rejection (radiator) loop. Because there is a possibility of a NaK leak and because NaK reacts violently with oxygen, the less NaK that is present in the system, the better. Therefore, if the reactor system has a NaK radiator, consideration should be given to providing a design which will allow separation of the reactor/shield assembly from the radiator and other power conversion components. Such a design will allow the Shuttle to return only the reactor/shield assembly rather than the entire power module. This will reduce the potential for liquid metal fires and should facilitate ground handling procedures.

REMARKS: Separation of the reactor/shield assembly from the rest of the power module can be accomplished by using a "separable heat exchanger". The separable heat exchanger permits separation of the reactor, with the primary liquid metal coolant loop, from the power conversion system and its secondary liquid metal coolant loop, without breaking any liquid metal coolant lines.

In addition, if the selected means of reactor disposal is boost to high earth orbit, the higher ballistic coefficient (W/CDA) of the reactor/shield configuration as compared to that of the entire power module means considerably longer orbital lifetimes for a given disposal altitude. This means that the fission products generated during operation aboard the Space Base will have a longer time to decay to insignificant levels.

REFERENCES:

72SD4201-4-1 Section 3, 6; Appendix B

CROSS REFERENCES:

GD-109
GO-113
**PROGRAM ELEMENT**
Shuttle

**SYSTEM-SUBSYSTEM**
IRV, Small Isotope Sources, Ground Support, Shuttle

**OPERATION**
Contingencies

**MISSION PHASE/EVENT**
Prelaunch

**TITLE:** ON-PAD ISOPOPE COOLING

**STATEMENT:** Provide a rapid response back-up isotope cooling system at the launch pad which does not require opening of the Shuttle doors.

**JUSTIFICATION:** Normal cooling of an isotope payload to at least 420°K (300°F) is required on the launch pad to eliminate the isotope heat source as a potential Shuttle propellant vapor ignition source. Loss of on-pad cooling of an isotope heat source contained within the Shuttle cargo bay will result in an immediate rise in heat source temperature. If the Shuttle doors are opened to allow the heat source to radiate directly to space, propellant fumes could enter the cargo bay and ignite. To reduce the possibility of inadvertent propellant ignition, a rapid response back-up isotope cooling system should be provided at the launch pad which does not require opening of the Shuttle cargo bay doors.

**REMARKS:** Cooling during prelaunch can be accomplished by pumping cold nitrogen or some other cryogenic fluid over the heat source. Incorporating redundancy into this system could provide the suggested emergency back-up. The cold nitrogen would be supplied by existing Ground Support Equipment (GSE) located in the Mobile Launcher.

**REFERENCES:**
72SD4201-4-1 Sections 4, 5, 6; Appendix C

**CROSS REFERENCES:**
RD-101
GO-120
PROGRAM ELEMENT  SYSTEM-SUBSYSTEM  OPERATION
Shuttle          IRV, Small Isotope Sources, Shuttle  Shuttle Transport

MISSION PHASE/EVENT
Launch/Ascent, On-Orbit Operations, End of Mission

TITLE: AUXILIARY POWER - ISOTOPE PAYLOAD

STATEMENT: Provide approximately 300 watts of electrical power (either from the Transfer Module or the Shuttle).

JUSTIFICATION: One requirement of the large isotope-Brayton systems is that heat be removed at all times. This is accomplished by direct radiation to space when possible, but there are periods in the mission when a heat rejection loop must be employed. The loop pump will require approximately 300 watts of power. Minor amounts of power are also required for the isotope-Brayton system status monitoring instrumentation and the system controls.

REMARKS: The total energy requirement should not exceed two or three kilowatt-hours. This power could be supplied by batteries mounted on the transfer module or by the Shuttle electrical power and distribution system.

REFERENCES: 72SD4201-4-1 Sections 4, 5; Appendix C

CROSS REFERENCES: GD-107
SPACE SHUTTLE

NUCLEAR SYSTEM SAFETY

GUIDELINE

DATE

JAN 72

NO.

GD-116

PROGRAM ELEMENT

Shuttle

SYSTEM-SUBSYSTEM

IRV, Small Isotope Sources, Shuttle

OPERATION

Payload Monitoring

MISSION PHASE/EVENT

Prelaunch, Launch/Ascent, On-Orbit Operations, End of Mission

TITLE: PAYLOAD STATUS MONITORING EQUIPMENT

STATEMENT: Provide multiple and independent system monitoring and control equipment with instantaneous and recording outputs for all mission phases.

JUSTIFICATION: The thermal control system associated with isotope systems is the critical system to be monitored because the heat generated by fuel decay must be dissipated without developing excessive temperatures in the heat source or elsewhere in the Shuttle orbiter cargo bay that could result in equipment damage. To prevent such occurrences, instrumentation must be provided to monitor both the payload and the auxiliary systems (such as thermal control and electrical power) required to service the payload.

REMARDS: The number of sensors and controls will be a function of the types of thermal control system that are employed and the thermal control system selection is in turn dependent upon the environmental shielding approach. For a 4π environmental shielding approach and an active pumped loop, an estimated 62 data points (sensors) are required for maintaining periodic and, in some cases, continuous system status of heat source integrity, radiation levels, heat source and cargo bay temperatures, etc. In addition to the monitoring equipment, an estimated 32 control devices are required to provide thermal control regulation, handling, attachment, and deployment controls from the Shuttle.

REFERENCES:

72SD4201-4-1 Sections 4, 5

CROSS REFERENCES:

GO-122
SPACE SHUTTLE NUCLEAR SYSTEM SAFETY GUIDELINE

DATE JAN 72
NO. GD-117

PROGRAM ELEMENT Shuttle
SYSTEM-SUBSYSTEM IRV, Small Isotope Sources, Shuttle
OPERATION Shuttle Transport

MISSION PHASE/EVENT Prelaunch, Launch/Ascent, On-Orbit Operations, End of Mission

TITLE: SHUTTLE CREW - NUCLEAR PAYLOAD SEPARATION (ISOPOE)

STATEMENT: Assure maximum allowable shuttle crew - nuclear payload separation distance. (IRV should be placed with side-on view to crew locations.)

JUSTIFICATION: The maximum allowable radiation dose rate to the Shuttle crew is 150 mrem/day per study groundrule. This requirement can be met by locating the nuclear payload as far as possible from the astronauts. Maximum separation distance will reduce shielding requirements in applications where shielding is necessary.

REMARKS: With the IRV presenting a side-on view (of the planar array heat source) to the crew location, the radiation exposure will be reduced through self shielding by the fuel, the capsules, and the heat source structure. If a crewman is required to be positioned side-on to the heat source, he could remain within about 2 m of its center for 3 hrs. or at about 5 m for nearly an entire day without exceeding the allowable dose.

REFERENCES: 72SD4201-4-1 Sections 4, 5; Appendix C

CROSS REFERENCES: GO-121, 134
<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>IRV</td>
<td>Contingencies</td>
</tr>
</tbody>
</table>

**MISSION PHASE / EVENT**
Lauch/Ascent, End of Mission

**TITLE:** FLOTATION GEAR

**STATEMENT:** Consider provision of flotation gear for an isotope-Brayton heat source (possibly time limited).

**JUSTIFICATION:** Due to the relatively high monetary value of the isotope inventory in a large heat source, recovery is generally the prime aim at end of mission. Therefore, recovery provisions such as possible flotation gear are important safety design features in the event of an abort during descent/reentry (or launch/ascent).

**REFERENCES:**
72SD4201-4-1 Section 6
Title: Payload Handling

Statement: Provide certified equipment to handle nuclear payloads.

Justification: The specialized requirements and precautions that must be observed in connection with handling nuclear payloads (such as thermal control, radiation protection, environmental enclosures, etc.) indicate that certified equipment should be provided to reduce the possibility of an accident involving the nuclear hardware.

Remarks: The provision of ground support and handling equipment which minimizes and simplifies handling of the nuclear hardware reduces the chances of damage and accident potential during prelaunch. The "transfer module" integration scheme is well suited for this type of application. It offers added ease in safely handling nuclear systems. For example, a reactor power module can be mounted on the transfer module at the manufacturer's site and not be removed until the power module transfer operations are initiated in orbit.

References:
72SD4201-4-1 Sections 3, 4, 5

Cross References:
GO-123
<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>Reactor, IRV, Small Isotope Sources, Ground Support, Shuttle</td>
<td>Contingencies</td>
</tr>
</tbody>
</table>

**MISSION PHASE/EVENT**

Prelaunch

**TITLE:** ON-PAD NITROGEN PURGING OF CARGO BAY

**STATEMENT:** Provide dry N₂ purging capability of the Shuttle cargo bay while on the launch pad.

**JUSTIFICATION:** Providing the capability to purge the cargo bay with dry N₂ or inert gas will (1) help prevent a potential liquid metal fire if a liquid metal leak from a reactor Nak coolant loop is detected, and (2) will reduce the ignition potential if a loss of on-pad cooling of an isotope payload occurs.

**REMARKS:** The dry nitrogen can be supplied by existing Ground Support Equipment (GSE) located in the Mobile Launcher.

**REFERENCES:**
72SD4201-4-1 Sections 3, 4, 5, 6

**CROSS REFERENCES:**
GD-122
TITLE: TRANSFER MODULE INTEGRATION SCHEME

STATEMENT: Consider use of Transfer Module integration scheme to reduce and simplify Shuttle interfaces and to improve safety in handling nuclear payloads.

JUSTIFICATION: Nuclear payloads have unique support requirements such as radiation shielding, thermal control, blast and fragmentation shielding, instrumentation, and auxiliary power. A Transfer Module can meet these requirements and, in addition, can afford a safe means for handling the payload and mounting it in the Shuttle cargo bay.

REMARKS: The transfer module is simply a carriage-type of assembly in which the nuclear payload is placed prior to being installed in the Shuttle orbiter. The entire nuclear payload/transfer module assembly is placed in the Shuttle cargo bay. The key advantage in using a transfer module is that it not only reduces the impact on the nuclear payload of being transported by the Space Shuttle, but it reduces the impact on the Shuttle when transporting a nuclear payload. When a transfer module is used, much of the necessary auxiliary equipment can be incorporated into the transfer module rather than being mounted to the Shuttle directly. The capability of emergency payload ejection into a deep ocean area could be provided by the transfer module. There are, however, disadvantages associated with this concept. The weight of the transfer module must be included in the total payload weight and the transfer module will occupy some of the allowable payload space.
**Title:** SHUTTLE ENVIRONMENTAL ENCLOSURE  

**Statement:** Prevent propellant boil-off and other undesirable gases from entering Shuttle cargo bay with the doors closed by provision of an environmental enclosure.

**Justification:** Reactors that may be transported by the Space Shuttle use NaK as the heat transfer medium to remove heat from the reactor core. Because NaK reacts violently with oxygen, LO₂ propellant boil-off should be prevented from entering the cargo bay.

The isotope heat source in the IRV generates 52 kw of thermal power. During prelaunch, the heat source is cooled to at least 420°K to preclude the ignition of substances such as hydrazine fumes that may exist in the launch pad area. Undesirable fumes and vapors should be kept from entering the cargo bay should a cooling malfunction occur.

**Remarks:** Preventing propellant boil-off and other undesirable gases from entering the cargo bay can be accomplished by providing a positive pressure inert gas cover blanket or by sealing off the cargo bay from the rest of the Shuttle.

**References:**  
72SD4201-4-1 Sections 3, 4, 5

**Cross References:**  
GD-101, 102, 120  
GO-103
**TITLE:** RADIATION MONITORING EQUIPMENT  

**STATEMENT:** Provide multiple and independent radiation monitoring equipment with instantaneous and recording outputs.

**JUSTIFICATION:** Nuclear radiation emanating from a reactor or isotope heat source being transported in the cargo bay of the Shuttle can result in injury to the Shuttle crew. Existing requirements call for a maximum of 150 mrem per day exposure. Radiation monitoring equipment is required to determine the actual exposure of each crew member.

**REMARKS:** Provisions must be made within the Shuttle crew compartment for the recording and/or display of approximately 6 radiation monitoring sensors to assess the radiation environment within the cargo bay and the crew compartment.

**REFERENCES:**  
72SD4201-4-1 Sections 3, 4; Appendices B, C

**CROSS REFERENCES:**  
GO-125
**SPACE SHUTTLE NUCLEAR SYSTEM SAFETY GUIDELINE**

<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>Reactor, IRV, Small Isotope Sources, Shuttle</td>
<td>Contingencies</td>
</tr>
</tbody>
</table>

**MISSION PHASE/EVENT**

Prelaunch, Launch/Ascent, On-Orbit Operations, End of Mission

**TITLE:** DETECTION OF NUCLEAR PAYLOAD FAILURES DURING TRANSPORT

**STATEMENT:** Provide capability of detecting and alerting the Shuttle crew of nuclear payload failures which occur during transport.

**JUSTIFICATION:** Failures and/or hazardous conditions of nuclear payloads in the cargo bay could result during the mission. If provisions are not made for detecting and alerting the Shuttle crew to these situations, the mission could be curtailed and potential hazards to the crew, equipment, the general public, and the ecology could result. If failures and/or hazardous conditions of the nuclear hardware are detected, contingency modes and emergency operating procedures can be implemented which could eliminate or substantially reduce the adverse effects on the mission and the risks to personnel.

**REMARKS:** System status monitoring and liquid metal leak detectors will provide a means of detecting some failures in nuclear payloads prior to docking to the Space Base.

With isotope payloads, the thermal control system is the critical system to be monitored because the heat generated by fuel decay must be dissipated without developing excessive temperatures in the heat source or elsewhere in the cargo bay.

**REFERENCES:**

72SD4201-4-1 Section 6

**CROSS REFERENCES:**

GD-105, 111, 116
GO-107, 122
**TITLE:** DIRECTED EJECTION OF PAYLOAD

**STATEMENT:** Provide a free, unobstructed, and directed ejection path for the payload in the event of a Shuttle booster or orbiter explosion on the launch pad.

**JUSTIFICATION:** The severe blast overpressures resulting from an on-pad explosion of the Shuttle fuel tankage are so high that it precludes the use of any material that will withstand the blast loading. In all likelihood in the event of a Shuttle explosion on the launch pad, the nuclear payload will be thrown or blasted out of the cargo bay by the resultant overpressures. It is desirable to position the launch vehicle on the launch pad and design the payload mounting devices such that the payload is provided with a free, unobstructed, and directed ejection path.

**REMARKS:** If the nuclear payload is thrown or blasted out of the Shuttle cargo bay by a launch pad Shuttle explosion, it then becomes a matter of protecting the nuclear payload from the primary and secondary fragmentation following such an explosion. A Shuttle launch configuration concept which positions the orbiter between the booster and the Mobile Launcher (ML) is particularly undesirable due to the possibility of slamming the nuclear payload against the ML tower in the event of a launch pad explosion.

**REFERENCES:**
72SD4201-4-1 Sections 3, 4, 5, 6
**SPACE SHUTTLE**  
**NUCLEAR SYSTEM SAFETY GUIDELINE**

<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>Reactor, IRV, Small Isotope Sources, Shuttle</td>
<td>Contingencies</td>
</tr>
</tbody>
</table>

**MISSION PHASE / EVENT**

Launch/Ascent, On-Orbit Operations, End of Mission

**TITLE:** INTACT REENTRY AND IMPACT CAPABILITY OF NUCLEAR PAYLOAD

**STATEMENT:** Provide intact reentry and impact capability. Consider use of crush-up materials in Shuttle orbiter cargo bay to minimize damage upon Shuttle land impact.

**JUSTIFICATION:** The release of radioactive material can be minimized by maximizing the intact impact capability of the nuclear payload and/or by providing crush-up structure in the Shuttle orbiter cargo bay.

**REMARKS:** Some type of honeycomb structure could be provided for in the Shuttle orbiter cargo bay to take some of the impact forces that are generated if a Shuttle crash landing occurs.

**REFERENCES:**
72SD4201-4-1 Sections 3, 4, 5, 6, 7
72SD4201-4-2 Section 4
### SPACE SHUTTLE NUCLEAR SYSTEM SAFETY GUIDELINE

<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>Reactor, IRV, Small Isotope Sources, Shuttle</td>
<td>Contingencies</td>
</tr>
</tbody>
</table>

**MISSION PHASE/EVENT**
Launch/Ascent, On-Orbit Operations, End of Mission

**TITLE:** TRACKING AND RECOVERY DEVICES FOR NUCLEAR PAYLOAD

**STATEMENT:** Provide tracking and recovery devices on nuclear payloads.

**JUSTIFICATION:** In the event of an in-orbit accident, the nuclear payload may be jettisoned or released from the Shuttle orbiter cargo bay. It is desirable to retrieve or recover the payload as quickly and as safely as possible to reduce the hazard that it represents. Therefore, tracking and recovery devices on the nuclear payload should be provided to aid in locating and rendezvousing with the payload.

**REMARKS:** Transponders, beacons, etc. can be considered. In addition, special grappling devices on the nuclear payload may be desirable. Shuttle compatible receiving hardware must be supplied.

**REFERENCES:**
72SD4201-4-1 Section 6

**CROSS REFERENCES:**
GO-114, 131
TITLE: SHUTTLE DECONTAMINATION

STATEMENT: Provide a clean, smooth surface cargo bay to facilitate decontamination, and minimize the time required.

JUSTIFICATION: Clean, smooth cargo bay surfaces, free from protrusions and crevices would enhance decontamination procedures, thus reducing the possibility of a radiation hazard or liquid metal fire.

REMARKS: If there are sections in the cargo bay which may be inaccessible to decontamination, equipment, such sections must be protected so that no liquid metal or radioactive debris could get into them.

Decontamination should be performed in an environmentally controlled area, such as would be provided by the nuclear check-out facility or liquid metal servicing building.

Clean, unobstructed surfaces should be a design objective.

REFERENCES:
72SD4201-4-1 Section 6

CROSS REFERENCES:
GO-128
RO-106
**SPACE SHUTTLE**  **NUCLEAR SYSTEM SAFETY**  **GUIDELINE**

<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>Facilities (Reactor)</td>
<td>Ground Handling, Storage and Checkout</td>
</tr>
</tbody>
</table>

**MISSION PHASE / EVENT**

Prelaunch, End of Mission (Return to Earth's Surface)

**TITLE:** NUCLEAR FACILITIES (REACTION)

**STATEMENT:** Provide certified facilities to:

- Store reactor power modules
- Checkout reactor power modules and components
- Perform radiological monitoring and control functions

**JUSTIFICATION:** The specialized requirements and precautions that must be observed in connection with reactor power systems and components (such as radiation detection and protection, assuring NaK containment, etc.) indicate that a special facility must be provided.

**REMARKS:** Existing facilities at KSC such as the pyrotechnic facility could be used on a temporary or near term basis where only relatively small amounts of nuclear hardware are involved. However, with programs involving large amounts of nuclear hardware (i.e., several reactor power modules), new facilities should be provided because the cost of modifying existing facilities may be greater than constructing new facilities. The only new facilities that have been identified are (1) a nuclear system check-out building, and (2) a liquid metal servicing building. Depending on the amounts of liquid metals involved, the liquid metal servicing building may be small, and in fact, could possibly be a portioned off section of the nuclear check-out building.

**REFERENCES:**
72SD4201-4-1 Section 3

**CROSS REFERENCES:**
GO-101
**SPACE SHUTTLE NUCLEAR SYSTEM SAFETY GUIDELINE**

<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>Facilities (Isotope)</td>
<td>Ground Handling, Storage, and Checkout</td>
</tr>
</tbody>
</table>

**MISSION PHASE/EVENT**

Prelaunch, End of Mission

**TITLE:** NUCLEAR FACILITIES (ISOPOTE)

**STATEMENT:** Provide certified facilities to:
- Store isotope fuel capsules
- Load isotope fuel capsules into heat sources
- Install heat source in IRV
- Checkout isotope power systems and components
- Perform radiological monitoring and control functions

**JUSTIFICATION:** The specialized requirements and precautions that must be observed in connection with isotope power systems, heat sources, and components (such as radiation detection and protection, thermal control, etc.) indicate that a special facility must be provided.

**REMARKS:** Existing facilities at KSC such as the pyrotechnic facility could be used on a temporary or near term basis where only relatively small amounts of nuclear hardware are involved. However, with programs involving large amounts of nuclear hardware (i.e., several isotope heat sources), new facilities should be provided because the cost of modifying existing facilities may be greater than constructing a new facility. The only new facility that has been identified for applications involving isotope systems is a nuclear system check-out building.

**REFERENCES:**
72SD4201-4-1 Sections 4, 5; Appendix C

**CROSS REFERENCES:**
GO-116
## NUCLEAR SYSTEM SAFETY GUIDELINE

<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
<th>DATE</th>
<th>NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>Reactor, Ground Support</td>
<td>Ground Handling, Storage, and Checkout</td>
<td>JAN 72</td>
<td>GO-101</td>
</tr>
</tbody>
</table>

### MISSION PHASE EVENT

- Prelaunch, End of Mission (Return to Earth's Surface)

### TITLE: NUCLEAR OPERATIONAL PLANS (REACTOR)

**STATEMENT**: Provide certified operational plans to:

- Store reactor power systems
- Check out reactor power systems and components

**JUSTIFICATION**: The specialized requirements and precautions that must be observed in connection with reactor power systems and components (such as radiation detection and protection, assuring NaK containment, etc.), indicate that special operational plans must be provided.

### REFERENCES:

- 72SD4201-4-1 Section 3, Appendix B

### CROSS REFERENCES:

- GD-129
TITLE: FIRE ALARM AND PROTECTION (REACTOR)

STATEMENT: Provide fire alarm and protection system training and procedures capable of supporting hardware containing nuclear material and liquid metals in:

- Nuclear facility
- Transporter
- Launch pad

JUSTIFICATION: Fires involving the reactor system or its supporting equipment can present serious nuclear hazards in addition to destroying expensive and hard to replace equipment. Fire alarm and protection systems, and the proper training can reduce these possibilities.

REMARKS: To preclude the possibility of a NaK-oxygen reaction that could result in a catastrophic fire, an inert gas (Argon, Helium, or Nitrogen) environmental cover gas blanket should be provided for all the reactor components that contain NaK.

As can be determined the fire protection provisions at KSC may not be adequate of supporting a nuclear reactor system. In addition, known incompatibilities of presently used substances with liquid metals exist. The effective control and prompt extinguishment of liquid metal fires at KSC can be accomplished through a program which includes special design considerations as well as careful adherence to procedures, use of trained personnel, and provision of proper equipment. In order to implement such a program, a thorough study is recommended with emphasis on the VAB and launch pad.

REFERENCES:
72SD4201-4-1 Sections 3, 7
72SD4201-4-2 Section 4

CROSS REFERENCES:
TITLE: ENVIRONMENTAL PROTECTION OPERATIONS

STATEMENT: Provide operational procedures for maintaining an inert gas blanket and/or double containment during the prelaunch period to preclude a NaK-oxygen reaction in the event of NaK leak.

JUSTIFICATION: Reactors that may be transported by the Shuttle use NaK as the heat transfer medium to remove heat from the reactor core. Some systems also use NaK in the heat rejection (radiator) loop. Because there is a possibility of a NaK leak, and because NaK reacts violently with oxygen, an inert gas blanket coupled with double wall containment must be provided to prevent the presence of moisture and other oxygen sources from coming in contact with the NaK coolant.

REMARKS: An added safety precaution involves sealing off the cargo bay from the rest of the Shuttle, especially from the LO₂ and LH₂ vapor boil-off of propellant tanks or fuel cell storage bottles.

The requirements for an inert gas environmental enclosure are significantly increased if a liquid metal NaK coolant is used in the primary heat rejection loop rather than an organic coolant (i.e., Dow Corning 200).

REFERENCES:
72SD4201-4-1 Section 3
<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>Reactor, Shuttle, Ground Support, Facilities</td>
<td>Contingencies</td>
</tr>
</tbody>
</table>

**MISSION PHASE/EVENT**

Prelaunch, End of Mission (Return to Earth's Surface)

**TITLE:** LIQUID METAL SAFING CAPABILITY

**STATEMENT:** Provide a controlled environment liquid metal safing capability at launch and landing sites (reduction of $O_2$ sources).

**JUSTIFICATION:** Reactors that may be transported by the Space Shuttle use NaK as a coolant. Because there is a possibility of a NaK leak and because NaK reacts violently in the presence if oxygen, the proper equipment and techniques to safe the system and reduce the liquid metal hazards should be provided.

**REMARKS:** A positive pressure liner could be placed around the reactor/shield assembly or the entire power module prior to or during installation in the cargo bay. This liner could be designed to contain the NaK leak and also maintain a positive inert gas pressure until the power module is within the controlled environment of the liquid metal servicing facility.

A complete liquid metal servicing facility capable of liquid metal charging and purification may not be necessary, but should be a definite consideration if extensive nuclear activities or several programs are to be supported.

**REFERENCES:**

72SD4201-4-1 Section 3, 6

**CROSS REFERENCES:**

GD-102
GO-103, 105
TITLE: PAYLOAD REMOVAL (REACTOR)

STATEMENT: Provide certified unloading, decontamination and liquid metal equipment and procedures to handle nuclear reactor power modules subsequent to Shuttle landing.

JUSTIFICATION: The equipment and procedures employed to remove the nuclear reactor payload from the Shuttle after its landing must be capable of:

- Monitoring for radioactivity
- Decontaminating the cargo bay if necessary
- Removing, if necessary, heat generated by the reactor payload
- Maintaining suitably low levels of radioactivity at stations occupied by ground and flight personnel
- Protecting the radioactive payload from fire and other potentially dangerous environments.
- Removing or rendering inactive the liquid metals carried by the reactor power module.

REMARKS: The removal of the reactor payload from the Shuttle cargo bay should be performed in a controlled environment. This could be afforded by a nuclear checkout facility and/or a liquid metal servicing building located at the landing site.

REFERENCES:
72SD4201-4-1 Section 3

CROSS REFERENCES:
GO-104
GD-102
**TITLE:** NaK LOOP INTEGRITY DURING ORBITAL OPERATIONS

**STATEMENT:** Provide installation, retrieval, and maintenance procedures that do not require breaking or opening of NaK loops.

**JUSTIFICATION:** NaK, used as the primary coolant in most reactor systems, reacts violently in the presence of oxygen (which may be leaking or otherwise being discharged from the Space Base or Space Shuttle) and is very corrosive. If NaK is released in orbit, it may vaporize and then condense on external surfaces and the vapor could contaminate the surrounding environment. Therefore, installation and maintenance procedures must not involve the opening or breaking of NaK loops.

**REMARKS:** If NaK loops are broken, an EVA will most likely be required if repair is to be attempted. Since NaK is probably not compatible with the space suits worn by the astronauts, EVA may be hazardous.

**REFERENCES:**
72SD4201-4-1 Section 3, Appendix B
**SPACE SHUTTLE**

**NUCLEAR SYSTEM SAFETY**

**GUIDELINE**

<table>
<thead>
<tr>
<th>DATE</th>
<th>NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>JAN 72</td>
<td>GO-107</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>Reactor, Shuttle</td>
<td>Payload Monitoring</td>
</tr>
</tbody>
</table>

**MISSION PHASE / EVENT**

Prelaunch, Launch/Ascent, On-Orbit Operations, End of Mission

**TITLE:** PAYLOAD STATUS MONITORING PROCEDURES

**STATEMENT:** Provide Shuttle crew training with confirmed procedures in the use of multiple and independent system monitoring equipment with instantaneous and recorded outputs for all mission phases.

**JUSTIFICATION:** Knowing the condition of the reactor power module within the Shuttle orbiter cargo bay permits an assessment by the crew of the "go/no-go" status of the payload (1) prior to launch, (2) prior to final rendezvous and docking, and (3) prior to initiating the reentry, final approach and landing upon returning a spent reactor power module to the earth's surface. A detected failure condition, such as a liquid metal or radiator coolant leak, would eliminate the need for docking and the subsequent removal (from the cargo bay) of a damaged power module. A detected failure condition of the power module which is deemed a hazard upon landing could result in the emergency ejection of the power module into a deep ocean area prior to earth landing.

**REMARKS:** Provisions must be made for the recording and/or display of a maximum of 80 data points (sensors) for maintaining periodic and, in some cases, continuous system status of power module integrity, radiation levels, NaK leaks, power module and cargo bay temperatures, etc. In addition to the monitoring equipment, some 20 separate control signals are required to provide environmental control regulation, handling, attachment and deployment controls from the Shuttle.

**REFERENCES:**

72SD4201-4-1 Section 3

**CROSS REFERENCES:**

GD-105
TITLE: USE OF SHADOW SHIELDING DURING TRANSFER OPERATIONS

STATEMENT: Provide rendezvous and docking positions such that the Shuttle crew locations are within the shadow of the reactor shield to minimize the dose to the crew during docking and replacement operations.

JUSTIFICATION: Radiation exposure guidelines specify crew exposure limits of 150 mrem/day. Reactor docking and replacement procedures involving movement of the spent reactor such that the Shuttle crew remains within the shadow of the reactor shield will assist in meeting the 150 mrem/day limitation.

REMARKS: In examining the NAR and MDAC Shuttle orbiters and their selected cargo transfer mechanisms (manipulator arms and 90° rotation, respectively) it was found that the crew locations in the MDAC Shuttle may be outside the shadow of the reactor shield (depending on the reactor power module configuration) during the docking and replacement operations. The crew may therefore receive some amounts of direct radiation.

Orienting the spent reactor in a fashion that shadow shields the Shuttle crew may expose the Space Base crew to direct radiation. A compromise may be necessary.

REFERENCES:
72SD4201-4-1 Section 3, Appendix B

CROSS REFERENCES:
GO-134, 135
TITLE: SPENT REACTOR HANDLING

STATEMENT: Consider allowing at least 10 days after shutdown before enacting Shuttle transfer operations with a spent reactor. If this procedure is not possible, provide for decay heat removal and radiation shielding if the spent reactor is to be transferred to the Shuttle less than 10 days after shutdown.

JUSTIFICATION: The radiation field created by the fission products in a shutdown reactor is rapidly reduced in strength during the first several days following shutdown. With no additional gamma shielding for the Shuttle crew, a minimum wait time (from reactor shutdown to initiation of replacement/recovery operations) of approximately 10 days is required for the dose rate (with the reactor shield assembly positioned aft in the cargo bay) to decay below the maximum allowable 150 mrem/day (reactor power history: 5 yrs at 125 kWt). The fission product afterheat generation in a reactor that has operated at 125 kWt for 5 yrs decays to approximately 250 W after 10 days (500 W two days after shutdown). Therefore, if the reactor is to be transferred to the Shuttle during the first 10 days after shutdown, additional nuclear radiation shielding for the Shuttle crew must be provided and an afterheat removal system may be required.

REMARKS: Scattered (reflected) radiation from hardware located in the near vicinity of the reactor can be a major contributor to the total radiation received by the Shuttle crew. If radiation protection is required for the Shuttle crew, the mass of additional shielding depends on the reactor fission product inventory and the location chosen for shield placement. The radiation impact on Shuttle components is related to the integrated dose and hence is mission dependent. Consideration can be given to localized shielding for critical components (i.e., solid state electronic devices, etc.), and hardening techniques can be applied where required. Since, the afterheat generation is relatively low several days after shutdown, it is possible that no special reactor/shield heat removal apparatus would be needed since the heat capacity and natural heat loss from the Shuttle itself may be sufficient.

REFERENCES: 72SD4201-4-1 Section 3, Appendix B

CROSS REFERENCES: GD-110, 135
TITLE: DISPOSAL/RECOVERY OPERATIONS (REACTOR)

STATEMENT: Provide certified operational plans to dispose of or recover a spent reactor power module.

JUSTIFICATION: Because of the potentially large and hazardous fission product inventory present in the reactor core at the end of operation, certified operational plans are necessary for the safe disposal of the spent reactor power module.

REMARKS: The in-orbit transfer operations involved with the disposal or recovery of a spent reactor power module should be performed within the following constraints:

- No EVA is required in normal operations
- All hardware is secured at all times. No objects are permitted to "float" free in space, nor is a simple tether an acceptable restraint.
- Transfer operations are performed by crew members of the Space Shuttle and/or Space Base who are able to observe the transfer directly.

REFERENCES:
72SD4201-4-1 Section 3, Appendix B
TITLE: REACTOR DISPOSAL ALTITUDE

STATEMENT: Provide a minimum 100 year orbital lifetime for a spent reactor in high earth orbit (250 year orbit is preferred to give 9 half-life decay).

JUSTIFICATION: Disposal of the spent reactor power module in a high earth orbit with an orbital lifetime of at least 100 years will give the majority of the core fission products adequate time to decay to insignificant, non-hazardous radiation levels. However, since it is generally accepted that an orbital decay time of approximately ten half lives of the longest fission product is preferable from a nuclear safety standpoint, a 250 year orbital decay time is preferred.

REMARKS: The reference Space Shuttle has the capability to boost a reactor payload to a maximum circular disposal altitude of 835 km (450 n mi) resulting in an estimated 250 year orbital lifetime. This represents approximately 10 half lives of the dominant long-lived core fission products (Cs-137 and Sr-90 with half-lives of 30 yrs and 28 yrs, respectively).
### SPACE SHUTTLE NUCLEAR SYSTEM SAFETY GUIDELINE

<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>Reactor, Shuttle</td>
<td>Contingencies</td>
</tr>
</tbody>
</table>

#### MISSION PHASE/EVENT
End of Mission (Boost to High Earth Orbit)

#### TITLE: REACTOR DISPOSAL SYSTEM INSTALLATION BY SHUTTLE

**STATEMENT:** Consider capability to install a replaceable or strap-on reactor disposal system by the Shuttle crew.

**JUSTIFICATION:** The Space Shuttle may be required to dispose of or recover a previously damaged power module. The action taken is dependent on the extent of the damage. It is therefore important that the damage be known prior to commitment of the Shuttle so that the proper action can be taken. If damage is of such an extent that considerable hazards would be presented to the Shuttle and crew or placement within the cargo bay would be impossible, it would be advisable to enact a separate (apart from the Shuttle) disposal to high earth orbit. If a disposal system were not part of the power module or the existing disposal system were inoperable, the Shuttle could be called upon to bring up a replaceable or strap-on disposal package.

**REMARKS:** Time spent in these operations should be minimized as the damaged power module would possibly remain attached to the Space Base, necessitating a reduction in Space Base power.

Precaution should be taken during this contingency operation to not exceed the Shuttle crew maximum allowable dose rate from the nuclear payload of 150 mrem/day.

**REFERENCES:**
72SD4201-4-1 Section 6
TITLE: SEPARATION OF R/S ASSEMBLY FROM PCS

STATEMENT: Consider capability of reactor/shield separation from the radiator at end of mission (disposal or recovery).

JUSTIFICATION: If the selected reactor disposal scheme is the placement of the spent reactor in high earth orbit, its orbital lifetime at a given altitude will increase considerably as its ballistic coefficient \( \frac{W}{C_D A} \) increases. The ballistic coefficient can be substantially increased by separating the radiator from the reactor/shield assembly and boosting only the latter to high earth orbit. This provision eliminates the transport of the radiator back to the earth via the Shuttle.

REMARKS: Separation of the reactor/shield assembly from the rest of the power module can be accomplished by using a "separable heat exchanger". The separable heat exchanger permits separation of the reactor, with the primary liquid metal coolant loop, from the power conversion system and its secondary liquid metal coolant loop, without breaking any liquid metal coolant lines.

REFERENCES:
72SD4201-4-1 Section 3, Appendix B

CROSS REFERENCES:
GD-109, 113
TITLE: TRACING OF SPENT REACTOR POWER MODULE

STATEMENT: Consider means of long term tracking of reactor power module following boost to a high earth disposal orbit (for possible recovery at a later date).

JUSTIFICATION: After the reactor has completed its operational lifetime (or in the event of a non-reparable system failure) it is necessary to dispose of the spent reactor power module in a way that will not present a nuclear hazard to the earth's populace and ecology. This can be accomplished by using the Space Shuttle to transport the power module to a high earth disposal orbit, thereby increasing the orbital lifetime of the power module, giving the core fission products adequate time to decay to insignificant, non-hazardous radiation levels. However, if no permanent reactor shutdown mechanism has been employed, the reactor may still be able to undergo a destructive excursion upon random reentry by orbital decay and earth impact. To reduce the risks to the general public of such an event, long term tracking of the spent reactor power module should be considered for possible Shuttle recovery and re-boost at a later date or return to the earth's surface.

REMARKS: Analysis indicates that "perfectly reliable" Shuttle re-boosts of a spent reactor power module to high earth disposal orbits rather than allowing random reentry following orbital decay from the initial high earth disposal orbit (orbital lifetime = 250 yrs) can reduce the risk to the general populace by approximately three orders of magnitude.

A beacon employed on the reactor power module would enhance tracking by ground and space radar. Reliability of such a device under the thermal, radiation, and long life environment needs to be evaluated.
THE TITLE:

**REACTOR DISPOSAL TO HIGH EARTH ORBIT**

**STATEMENT:** Consider reactor reboost capability to a new long-life orbit by the Shuttle.

**JUSTIFICATION:** As long as it may be possible for a destructive excursion to occur on earth impact of a reactor, random reentry from earth orbit is not acceptable from a nuclear safety standpoint. Therefore, if a spent reactor power module is boosted to a long-life high earth for disposal, consideration should be given to providing reactor reboost capability (at a later date) to a new long-life high altitude disposal orbit.

**REMARKS:** Analysis indicates that "perfectly reliable" Shuttle reboosts of a spent reactor power module to new long-life disposal orbits rather than allowing random reentry following orbital decay from the initial high earth disposal orbit (orbital lifetime = 250 yrs) can reduce the risk to the general populace by approximately three orders of magnitude.
**SPACE SHUTTLE NUCLEAR SYSTEM SAFETY GUIDELINE**

**DATE**
JAN 72

**NO.**
GO-116

<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>IRV, Small Isotope Sources, Ground Support</td>
<td>Ground Handling, Storage, and Checkout</td>
</tr>
</tbody>
</table>

**MISSION PHASE/EVENT**
Prelaunch, End of Mission

**TITLE:** NUCLEAR OPERATIONAL PLANS (ISOTOPE)

**STATEMENT:** Provide certified operational plans to:
- Receive and store isotope fuel capsules
- Load isotope fuel capsules into heat source
- Install heat source in IRV
- Check out isotope power systems and components

**JUSTIFICATION:** The specialized requirements and precautions that must be observed in connection with isotope power systems, heat sources, and components (such as radiation detection and protection, thermal control, etc.), indicate that special operational plans must be provided.

**REFERENCES:**
72SD4201-4-1 Sections 4, 5; Appendix C

**CROSS REFERENCES:**
GD-130
TITLE: FIRE ALARM AND PROTECTION (ISOTOPE)

STATEMENT: Provide fire alarm and protection system training and procedures capable of supporting isotope hardware at:

- Nuclear facility
- Transporter
- Launch pad

JUSTIFICATION: Fires involving an isotope system or its supporting equipment can present serious nuclear hazards in addition to destroying expensive and hard to replace equipment. Firm alarm and protection systems, and the proper training can reduce these possibilities.

REMARKS: The isotope heat source should be cooled to 420°K (300°F) to keep the heat source temperature below the ignition point of any propellant fumes which may be in the launch pad area.

REFERENCES:

72SD4201-4-1 Sections 4, 5, 7
72SD4201-4-2 Section 4
TITLE: QUICK RETRIEVAL OPERATIONS INVOLVING ISOTOPE PAYLOADS

STATEMENT: Provide quick retrieval operations to remove nuclear payload during an emergency.

JUSTIFICATION: Nuclear payloads, particularly isotope heat sources, present a potential nuclear safety hazard when they are in the Shuttle cargo bay during the prelaunch period (or subsequent to landing). This hazard can be reduced if equipment is available to quickly remove the nuclear payload from the Shuttle cargo bay in the event of an emergency, such as a fire at the pad or upon landing.
TITLE: ISOTOPE HEAT SOURCE INSTALLATION IN SHUTTLE

STATEMENT: Install the isotope heat source in the Shuttle cargo bay at the last practicable point in the launch countdown sequence.

JUSTIFICATION: The isotope heat source in the IRV generates 52kW of thermal power and produces a radiation field of approximately 600 mrem/hr at a distance of one meter. Because of these considerations plus the fact that the heat source temperature must be maintained at 420 K (to preclude the ignition of substances such as hydrazine fumes that may exist in the launch pad area), integration with the Shuttle on the launch pad should occur as late in the countdown as possible.

REMARKS: A minimum amount of functional tests need be performed on the isotope system while on the launch vehicle. Compatibility tests prior to installation on the launch vehicle could for the most part be performed with a payload simulator.

REFERENCES:
72SD4201-4-1 Sections 4, 5; Appendix C

CROSS REFERENCES:
RD-101
TITLE: IGNITION POTENTIAL ON LAUNCH PAD

STATEMENT: Provide capability to reduce ignitable propellant fumes around the cargo bay (i.e., drainage of propellant tanks and/or purging immediate payload area).

JUSTIFICATION: Normal cooling of the heat source to at least 420°C is required to eliminate the isotope heat source as a potential Shuttle propellant vapor ignition source. Loss of on-pad cooling of an isotope heat source contained within the Shuttle cargo bay will result in an immediate rise in heat source temperature. The potential for oxidation of the heat source refractory metals increases as the temperature rises. A maximum design temperature of approximately 700°C in ambient conditions is suggested. A heat source cooling system failure with Shuttle doors closed would result in a heat source temperature rise to 550°C within a half-hour and 700°C in approximately one hour. Repair of the prime cooling system on the Mobile Launcher or start-up of an auxiliary back-up cooling system should be accomplished within this time frame. Failure to do so would require opening of the cargo-bay doors to permit use of external cooling systems and prevent damage to the Shuttle. Draining of the propellant tanks and/or purging of the cargo bay area with dry N₂ may be advisable in this event to reduce the ignition potential that exists on the launch pad.

REFERENCES:
72SD4201-4-1 Section 6

CROSS REFERENCES:
GD-114
GO-119
RD-101
**SPACE SHUTTLE NUCLEAR SYSTEM SAFETY GUIDELINE**

<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>IRV</td>
<td>Shuttle Transport</td>
</tr>
</tbody>
</table>

**MISSION PHASE/EVENT**

Prelaunch, Launch/Ascent, On-Orbit Operations, End of Mission

**TITLE:** CREW OPERATIONS IN VICINITY OF IRV

**STATEMENT:** Avoid or limit operations of the crew which place them in the near vicinity of the heat source and in particular those positions perpendicular to the radiating surface.

**JUSTIFICATION:** The maximum allowable radiation dose rate to the Shuttle crew is 150 mrem/day per study groundrule. If a crewman is required to be positioned side-on to the heat source, he could remain within about 2m of its center for 3 hours or at about 5m for nearly an entire day without exceeding the allowable dose. Dose rates along the planes perpendicular to the radiating face of the heat source are somewhat higher. Such an orientation of the heat source with respect to the Shuttle crew should be avoided, or if necessary, limited to only brief periods during transfer operations.

**HAZARD CATEGORY**

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<thead>
<tr>
<th>CAT.</th>
<th>CRIT.</th>
<th>MARG.</th>
<th>NEG.</th>
</tr>
</thead>
</table>

**REMARKS:** With the IRV presenting a side-on view (of the planar array heat source) to the crew location, the radiation exposure will be reduced through self shielding by the fuel, the capsules, and the heat source structure.

**REFERENCES:**

<table>
<thead>
<tr>
<th>CROSS REFERENCES:</th>
</tr>
</thead>
<tbody>
<tr>
<td>72SD4201-4-1 Section 4, Appendix C</td>
</tr>
<tr>
<td>GD-117</td>
</tr>
</tbody>
</table>
TITLE: PAYLOAD STATUS MONITORING PROCEDURES

STATEMENT: Provide Shuttle crew training with confirmed procedures in the use of multiple and independent system monitoring equipment with instantaneous and recorded outputs for all mission phases.

JUSTIFICATION: The thermal control system associated with isotope systems is the critical system to be monitored because the heat generated by fuel decay must be dissipated without developing excessive temperatures in the heat source or elsewhere in the Shuttle orbiter cargo bay that could result in equipment damage. To prevent such occurrences, instrumentation must be provided to monitor both the payload and the auxiliary systems (such as thermal control and electrical power) required to service the payload.

REMARKS: The number of sensors and controls will be a function of the types of thermal control systems that are employed and the thermal control system selection is in turn dependent upon the environmental shielding approach. For a $4\pi$ environmental shielding approach and an active pumped loop, an estimated 62 data points (sensors) are required for maintaining periodic and, in some cases, continuous system status of heat source integrity, radiation levels, heat source and cargo bay temperatures, etc. In addition to the monitoring equipment, an estimated 32 control devices are required to provide thermal control regulation, handling, attachment, and deployment controls from the Shuttle.

REFERENCES:
72SD4201-4-1 Section 4, 5

CROSS REFERENCES:
GD-116
**Title:** Payload Removal (Isotope)

**Statement:** Provide certified removal equipment and procedures to handle the nuclear payload subsequent to Shuttle landing.

**Justification:** The equipment and procedures employed to remove the isotope payload from the Shuttle after its landing must be capable of:

- Monitoring for radioactivity
- Decontaminating the cargo bay if necessary
- Removing, if necessary, the heat generated by the isotope payload
- Maintaining suitably low levels of radioactivity at stations occupied by ground and flight personnel.
- Protecting the radioactive payload from fire and other potentially dangerous environments.

**Remarks:** The removal of the isotope payload from the Shuttle cargo bay should be performed in a controlled environment. This could be afforded by a nuclear check-out facility located at the landing site.

**References:**

72SD4201-4-1 Sections 4, 5

**Cross References:**

GD-119
**TITLE:** RETRIEVAL/RECOVERY OPERATIONS (ISOTOPE)

**STATEMENT:** Provide certified operational plans to retrieve and recover IRV and/or small isotope sources.

**JUSTIFICATION:** Because of the relatively small quantities of the plutonium fuel available, its high cost, and the potentially adverse radiological consequences if a fuel release would occur, certified operational plans to retrieve and recover isotope payloads are necessary.

**REMARKS:** The in-orbit transfer operations involved with the retrieval and recovery of nuclear payloads should be performed within the following constraints:

- No EVA is required in normal operations
- All hardware is secured at all times. No objects are permitted to "float" free in space, nor is a simple tether an acceptable restraint.
- Transfer operations are performed by crew members of the Space Shuttle and/or Space Base who are able to observe the transfer directly.

**REFERENCES:**

72SD4201-4-1 Sections 4, 5; Appendix C
**SPACE SHUTTLE NUCLEAR SYSTEM SAFETY GUIDELINE**

**DATE**
JAN 72

**NO.**
GO-125

<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>Reactor, IRV, Small Isotope Sources, Shuttle</td>
<td>Radiation Monitoring</td>
</tr>
</tbody>
</table>

**MISSION PHASE/EVENT**
Prelaunch, Launch/Ascent, On-Orbit Operations, End of Mission

**TITLE:** RADIATION MONITORING PROCEDURES

**STATEMENT:** Provide support personnel and Shuttle crew training with confirmed procedures in the use of multiple and independent radiation monitoring equipment with instantaneous and recorded outputs.

**JUSTIFICATION:** Nuclear radiation emanating from a reactor or isotope heat source being transported in the cargo bay of the Shuttle can result in injury to the Shuttle crew. Existing requirements call for a maximum of 150 mrem per day exposure. Radiation monitoring equipment is required to determine the actual exposure of each crew member.

**HAZARD CATEGORY**

**REMARKS:** Provisions must be made within the Shuttle crew compartment for the recording and/or display of approximately 6 radiation monitoring sensors to assess the radiation environment within the cargo bay and the crew compartment.

**REFERENCES:**
72SD4201-4-1 Sections 3, 4; Appendices B, C

**CROSS REFERENCES:**
GD-123
TITLE: RECOVERY GEAR AND PROCEDURES

STATEMENT: Provide recovery gear and procedures for use subsequent to prelaunch accidents.

JUSTIFICATION: Prelaunch accidents such as the explosion of the Shuttle orbiter fuel tankage could leave the nuclear payload damaged and in an unsafe condition. It can also result in the payload being ejected some distance from the launch pad. The payload could be buried in debris or submerged in water. It is necessary to identify all possible payloads conditions subsequent to prelaunch accidents, and to provide the necessary equipment for recovery of the payload.

REFERENCES:
72SD4201-4-1 Sections 3, 4, 5, 7; Appendices B, C
TITLE: TRANSFER MODULE OPERATIONS

STATEMENT: Provide operations in the use of Transfer Modules to protect and reduce handling and packaging requirements of nuclear payloads.

JUSTIFICATION: Nuclear payloads have unique support requirements such as environmental protection, radiation shielding, thermal control, blast and fragmentation shielding, instrumentation, and auxiliary power. A Transfer Module can meet these requirements and, in addition, can afford a safe means for handling the payload and mounting it in the Shuttle cargo bay.

REMARKS: The transfer module is simply a carriage-type of assembly in which the nuclear payload is placed prior to being installed in the Shuttle orbiter. The entire nuclear payload/transfer module assembly is placed in the Shuttle cargo bay. The key advantage in using a transfer module is that it not only reduces the impact on the nuclear payload of being transported by the Space Shuttle, but it reduces the impact on the Shuttle when transporting a nuclear payload. When a transfer module is used, much of the necessary auxiliary equipment can be incorporated into the transfer module rather than being mounted to the Shuttle directly. The capability of emergency payload ejection into a deep ocean area could be provided by the transfer module. There are, however, disadvantages associated with this concept. The weight of the transfer module must be included in the total payload weight and the transfer module will occupy some of the allowable payload space.

REFERENCES:
72SD4201-4-1 Sections 3, 4, 5

CROSS REFERENCES:
GD-121
## Shuttle Decontamination

**Title:** Shuttle Decontamination  
**Statement:** Provide Shuttle radiation and liquid metal decontamination capability at the launch and landing sites.  
**Justification:** To reduce the nuclear hazards involved with transporting a damaged or faulty nuclear payload, provisions should be made for Shuttle radiation and liquid metal decontamination capability at the launch/landing site.  
**Remarks:** Decontamination should be performed in an environmentally controlled area, such as would be provided by the nuclear check-out facility or liquid metal servicing building. Clean, smooth cargo bay surfaces, free from protrusions and crevices would enhance decontamination procedures. A sealed crew compartment (separate ECLS) should be a design objective to assure radioactive vapor from fractured fuel capsules/fuel elements does not enter the compartment.

**References:**  
72SD4201-4-1 Section 6  
**Cross References:**  
GD-128
### TITLE: PAYLOAD EJECTION

**STATEMENT:** Provide emergency capability and procedures for ejection of the payload over deep ocean areas (or continental shelf) or possible ditching of the Shuttle.

**JUSTIFICATION:** Should a known malfunction of the Space Shuttle increase the risk of a crash on landing (at end of mission recovery or from a mission abort during ascent), emergency ejection of the payload at sea or ditching of the Shuttle should be considered. Ditching should be beyond the continental shelf if safe nuclear payload recovery is not possible. Ditching at sea would reduce the risk of general populace exposure to very low levels.

**REMARKS:** The most desirable situation would be to ditch in shallow waters in such a manner that isotope or fission product containment would not be breached at impact. Safe recovery would then be possible and eventual release to the sea would be avoided. If there is a high risk or radioactive release in continental shelf waters, ditching should be in the deep ocean areas beyond the continental shelf. A release in deep ocean areas should present no discernible hazard to the general public.

**REFERENCES:**
- 72SD4201-4-1 Sections 3, 4, 5, 6, 7
- 72SD4201-4-2 Section 4
TITLE: TRACKING AND LOCATION AIDS

STATEMENT: Provide tracking and location capability for early land and water recovery.

JUSTIFICATION: In the event of an abort during Launch/Ascent or Descent/Reentry, the nuclear payload may be jettisoned from the Shuttle and permitted to reenter in a random fashion. It is desirable to recover the payload as quickly as possible to reduce the hazard that it represents. Therefore, tracking and location aids should be provided.

REMARKS: Transponders, pingers, dye markers, etc., can be considered. Reliability over the years of lifetime in a wide range of temperatures and severe radiation environment must be an important design tool.

REFERENCES:
72SD4201-4-1 Sections 3, 4, 5, 7
72SD4201-4-2 Section 4
TITLE: EMERGENCY PAYLOAD RETRIEVAL/RECOVERY

STATEMENT: Provide for emergency retrieval/recovery of nuclear equipment if jettisoned from the Space Shuttle.

JUSTIFICATION: A nuclear power system such as a reactor or an isotope heat source could inadvertently be jettisoned from the Space Shuttle cargo bay. A retrieval/recovery system should be devised for use in such instances because an unrecovered nuclear system would reenter and impact randomly, with greater hazard to the earth’s populace than if it were returned by the Space Shuttle.

REMARKS: The Shuttle emergency retrieval/recovery system must be capable of grappling an uncontrolled, tumbling piece of nuclear hardware. If the nuclear system has been damaged, additional hazards may be involved (such as increased radiation field and/or released radioactive material) which warrant additional precautions.

REFERENCES:
72SD4201-4-1 Sections 3, 4, 5

CROSS REFERENCES:
GD-127
### SPACE SHUTTLE NUCLEAR SYSTEM SAFETY GUIDELINE

<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>Reactor, IRV,</td>
<td>Earth Impact/Recovery</td>
</tr>
<tr>
<td></td>
<td>Small Isotope Sources, Ground Support</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MISSION PHASE/EVENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch/Ascent, End of Mission</td>
</tr>
</tbody>
</table>

### TITLE: IMPACT/RECOVERY TEAM

**STATEMENT:** Provide trained impact/recovery team and procedures for:

- Recovery
- Fire protection
- Radiation control
- Decontamination

**JUSTIFICATION:** A nuclear reactor or an isotope heat source that has impacted on the earth's surface following a Shuttle abort must, if possible, be recovered to reduce the nuclear safety hazard to the general populace. Recovery operations will entail radiation control and probably decontamination of the impact area. Trained personnel are required for these operations.

**REFERENCES:**

- 72SD4201-4-1 Sections 3, 4, 5, 7
- 72SD4201-4-2 Section 4
TITLE: WEATHER RESTRICTIONS

STATEMENT: Prohibit launch during unsatisfactory weather conditions, including moderate to high winds blowing towards populated areas.

JUSTIFICATION: If an accident occurs on the launch pad or during lift-off, radioactive material may be released. Adverse weather conditions can result in widespread dispersion of the radioactive debris. To reduce the risk to the general public of such an event, launches during unsatisfactory weather (including moderate to high winds blowing towards populated areas) should be prohibited.

REMARKS: The contamination of facilities and KSC property and the potential risk to personnel resulting from a launch pad accident can be minimized by scheduling Shuttle launches with nuclear payloads when winds are blowing out to sea.

REFERENCES:
72SD4201-4-1 Section 3, 4, 5, 7
72SD4201-4-2 Section 4
### SPACE SHUTTLE
**NUCLEAR SYSTEM SAFETY GUIDELINE**

<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>Reactor, IRV, Small Isotope Sources, Shuttle</td>
<td>Shuttle Transport</td>
</tr>
</tbody>
</table>

**DATE**: JAN 72  
**NO.**: GO-134

**MISSION PHASE/EVENT**:  
Launch/Ascent, On-Orbit Operations, End of Mission

**TITLE**: NUCLEAR RADIATION PROTECTION

**STATEMENT**: Minimize the crew dose rate throughout all operations (maximum of 150 mrem/day).

**JUSTIFICATION**: The allowable exposure limit currently in use by NASA is a yearly average of 200 mrem/day to the bone marrow (5cm depth) from all radiation sources. Cosmic, galactic, and trapped radiation contribute approximately 50 mrem/day. Therefore, the Shuttle crew dose rate should be minimized with a maximum allowable dose rate from the nuclear payload of 150 mrem/day.

**REMARKS**: The 150 mrem/day maximum allowable dose rate from the nuclear payload is based on yearly averages. Since most crew time durations are short, higher dose rates may be permissible for short periods of time.

**REFERENCES**:  
72SD4201-4-1 Sections 3, 4, 5; Appendices A, B, C

**CROSS REFERENCES**:  
GO-108, 135  
GD-108, 117
<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>Reactor, IRV, Small Isotope Sources, Shuttle</td>
<td>Contingencies</td>
</tr>
</tbody>
</table>

**MISSION PHASE/EVENT**

Launch/Ascent, On-Orbit Operations, End of Mission

**TITLE:** NUCLEAR RADIATION PROTECTION DURING CONTINGENCIES

**STATEMENT:** Minimize radiation dose to crews performing contingency operations (maximum of 150 mrem/day from nuclear sources should be maintained).

**JUSTIFICATION:** The allowable exposure limit currently in use by NASA is a yearly average of 200 mrem/day to the bone marrow (5cm depth) from all radiation sources. Cosmic, galactic, and trapped radiation contribute approximately 50 mrem/day. Therefore, the Shuttle crew dose rate should be minimized during all contingency operations with a maximum allowable dose rate from the nuclear payload of 150 mrem/day.

**REMARKS:** The 150 mrem/day maximum allowable dose rate from the nuclear payload is based on yearly averages. Since most crew time durations are short, higher dose rates may be permissable for short periods of time.

**REFERENCES:**

72SD4201-4-1 Sections 3, 4, 5, 6; Appendices A, B, C

**CROSS REFERENCES:**

GO-134
TITLE: BACK-UP SHUTTLE CAPABILITY

STATEMENT: Consider use of a back-up Shuttle to support repair of a failed Shuttle or transfer or retrieval of the payload in orbit for the continuance of the mission.

JUSTIFICATION: If an in-orbit accident renders the Shuttle orbiter incapable of completing the intended mission, a back-up Shuttle should be considered to support repair of the failed Shuttle or to transfer or retrieve the nuclear hardware for the successful continuance of the mission. This contingency action increases the probability that the crew and the payload can be rescued, and eliminates or substantially reduces the adverse effects on the mission and the risks involved in allowing the failed Shuttle and/or nuclear hardware to reenter from low earth orbit with relatively short orbital decay times.

REMARKS: The Shuttle handling equipment and cargo transfer mechanisms must be capable of grappling a randomly tumbling piece of hardware that could weigh several metric tons.

REFERENCES: 72SD4201-4-1 Sections 4, 5, 6
TITLE: Extended Orbital Stay Time

STATEMENT: Provide contingencies for Shuttle orbital stay times of up to 20 days to allow for repairs to be made.

JUSTIFICATION: The primary contingency plan should include consideration for repair if it is found impossible to remove the nuclear payload from the Shuttle orbiter cargo bay due to failures in the transfer mechanisms or docking of the nuclear hardware cannot be completed due to interface problems. If repair is possible, a back-up Shuttle should be available within approximately 12 days (time allowed for hardware preparation and launch preparation) to provide the necessary logistic and maintenance support. These operations would necessarily require a Shuttle orbital stay time of up to 20 days.

REMARKS: The Shuttle, with its nuclear payload, could be docked to the Space Base and powered down in the interim with the Shuttle crew billeted in the Space Base. Radiation limits for the Shuttle crew should be carefully controlled to minimize the radiation doses to the crew.
TITLE: IN-ORBIT REPAIRS

STATEMENT: Where in-orbit repairs of interfacing non-nuclear hardware (transfer mechanisms, etc.) are unsuccessful, the Shuttle and payload should return to earth.

JUSTIFICATION: When non-reparable equipment failures preclude in-orbit docking and transfer operations, it is desirable to recover the nuclear payload and return it to earth rather than jettisoning the nuclear payload in low earth orbit (for possible recovery at a later date) or to boost the payload to a high earth disposal orbit. Therefore, when in-orbit repairs are unsuccessful, the Shuttle and payload should return to the landing site. The nuclear payload can be stored at the launch/landing site for use at a later date.

REMARKS: Positive control of the nuclear payloads should be maintained at all times to prevent a possibly hazardous and undesired event such as uncontrolled, random reentry.
EMERGENCY PAYLOAD EJECTION THROUGH CARGO BAY DOORS

STATEMENT: Consider payload ejection through cargo bay doors if doors cannot be opened.

JUSTIFICATION: The nuclear payload emergency ejection mode may involve the opening of the Shuttle cargo bay doors. If the doors fail to open, consideration should be given to emergency ejection through the doors. If the emergency ejection were done over the ocean, this would reduce the nuclear hazard potential involved with a Shuttle/nuclear payload crash.

REMARKS: The cargo bay doors should be designed such that an impact of this type on the doors would cause severance of door hinges or other attachments so that damage can remain isolated from the Shuttle proper. The design and aerodynamic implications of these situations must be addressed.

REFERENCES: 72SD4201-4-1 Section 6
TITLE: LAUNCH AND IN-ORBIT TRANSFER OPERATIONS (REACTOR)

STATEMENT: Provide certified operational plans to launch and perform orbital transfer operations involving nuclear hardware.

JUSTIFICATION: The critical nature of nuclear hardware and the potential radiological hazards that could occur during a mission involving a nuclear payload warrant specially certified operational plans for launch and all in-orbit transfer operations.

REMARKS: The launch trajectory should minimize overflight of land and the continental shelf to reduce the nuclear hazard potential if an accident occurs. The contamination of facilities and KSC property and the potential risk to personnel resulting from a launch pad accident can be minimized by scheduling Shuttle launches with nuclear payloads when winds are blowing out to sea.

All in-orbit transfer operations should be performed such that (1) the maximum allowable Shuttle crew dose rate of 150 mrem/day is not exceeded, and (2) positive handling control of the nuclear system is maintained.

REFERENCES:
72SD4201-4-1 Sections 3, 4, 5; Appendices B and C

CROSS REFERENCES:
GO-141, 142, 143
**Title:** NUCLEAR CARGO TRANSFER  

**Statement:** Provide positive control of nuclear payloads during all handling operations.

**Justification:** The nuclear radiation, high temperatures, and sometimes large mass associated with nuclear power systems present various hazards when handling operations are involved. The isotope inventory of a large heat source or the fission product inventory of a spent reactor, represents a potential hazard to the earth's populace if the system is allowed to reenter the earth's atmosphere and impact the earth's surface in a random fashion. For these reasons, positive control of the nuclear payloads is required during all in-orbit handling operations.

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**References:**

72SD4201-4-1 Sections 3, 4, 5

**Cross References:**

GO-140
TITLE: NUCLEAR CARGO TRANSFER OPERATIONS

STATEMENT: Provide nuclear cargo transfer operations that do not involve EVA.

JUSTIFICATION: Nuclear cargo such as isotope heat sources and reactors present a safety hazard to crew members who might be involved in EVA associated with transfer of such cargo. Hazards result from the radiation emanating from the nuclear device, from the high surface temperatures that may exist, and from the mass of equipment such as reactors and large isotope sources. Therefore, EVA should be avoided, and transfer operations using remote handling equipment and special transfer devices should be planned.
TITLE: NUCLEAR CARGO TRANSFER VISIBILITY

STATEMENT: Provide direct visual or TV coverage of all nuclear cargo transfer operations.

JUSTIFICATION: Since the transfer of nuclear cargo is to be by the use of remote handling gear, and since certain hazards are involved in the transfer operations, direct visual or TV coverage must be provided to reduce the risks as much as possible.
### Title: Alternate Payload Handling Operations

**Statement:** Provide alternate and/or redundant equipment and procedures for nuclear cargo handling.

**Justification:**

The nuclear radiation and heat generation associated with nuclear payloads make it essential that planned handling operations be carried out promptly and with precision. To accomplish this, alternate and/or redundant handling mechanisms must be provided to permit the continuation of transfer operations.

**References:**

72SD4201–4–1 Sections 3, 4, 5
**SPACE SHUTTLE NUCLEAR SYSTEM SAFETY GUIDELINE**

<table>
<thead>
<tr>
<th>PROGRAM ELEMENT</th>
<th>SYSTEM-SUBSYSTEM</th>
<th>OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle</td>
<td>Reactor, IRV, Small Isotope Sources, Shuttle</td>
<td>Contingencies</td>
</tr>
</tbody>
</table>

**DATE** JAN 72  
**NO.** GO-145

**MISSION PHASE/EVENT**  
On-Orbit Operations, End of Mission

**TITLE:** EMERGENCY IN-ORBIT RETRIEVAL

**STATEMENT:** Consider feasibility of uncooperative "tumbling" power module retrieval with Shuttle.

**JUSTIFICATION:** If an in-orbit accident results in the release of the nuclear payload, emergency retrieval operations must be initiated to prevent the nuclear hazard potential associated with an uncontrolled, random reentry of nuclear hardware from low earth orbit. In all likelihood, the released nuclear payload will not be stable, but will be tumbling in a random fashion. Therefore, the feasibility of employing retrieval/grappling techniques to retrieve uncooperative "tumbling" payloads should be considered.

**REMARKS:** Tracking devices (transponders, beacons, etc.) on the nuclear payload should aid in location and rendezvous.

**REFERENCES:** 72SD4201-4-1 Sections 3, 6

**HAZARD CATEGORY**

<table>
<thead>
<tr>
<th>CAT.</th>
<th>CRIT.</th>
<th>MARG.</th>
<th>NEG.</th>
</tr>
</thead>
</table>

**CROSS REFERENCES:**
**TITLE:** SHUTTLE LANDING AREA  

**STATEMENT:** Provide Shuttle landing area remote from inhabited facilities.

**JUSTIFICATION:** Because of the potential exposure to radioactive materials that could occur as the result of a mishap prior to or at touchdown of the Shuttle orbiter carrying a spent reactor or an isotope power system, the area should be cleared of human habitation.

**REMARKS:** The touchdown location on the runway should be approximately 4 km from KSC inhabited facilities to minimize the risk from a potential release of radioactive material.
TITLE: DUMPING OF EXCESS SHUTTLE PROPELLANT

STATEMENT: Consider dumping of excess Shuttle propellant prior to landing to minimize explosive potential.

JUSTIFICATION: If an equipment failure is detected early in the Launch/Ascent Phase which aborts the mission, it may be necessary to consider dumping of Shuttle fuel to meet landing weight limits and to avoid landing with a large and potentially explosive fuel load. Therefore, if an explosion were to occur on landing, the blast and fragmentation environment would be significantly less severe, thereby reducing the potential for a release of radioactive material.
**TITLE:** SHUTTLE DEFUELING

**STATEMENT:** Provide capability to defuel the Shuttle in nuclear emergencies on the launch pad.

**JUSTIFICATION:** The blast overpressures resulting from a launch pad explosion of the Shuttle fuel tankage are so high that it precludes the use of any material that would withstand the blast loading. In all likelihood, in the event of a Shuttle explosion on the launch pad, the nuclear payload will be thrown or blasted out of the cargo bay by the resultant overpressures. Because of this severe blast and fragmentation environment, radioactive debris may be released in the immediate vicinity of the launch pad. Therefore, if there are indications that an explosion of the Shuttle fuel tankage is imminent, provisions should be made for emergency defueling.

**REMARKS:** Other reasons for providing emergency defueling capabilities are:

- A NaK leak in a reactor coolant loop is detected after the power module has been installed in the Shuttle orbiter cargo bay (an explosion could result because of the violent reaction when NaK comes in contact with oxygen).

- On-pad cooling for an isotope payload malfunction resulting in increased heat source temperatures (ignition of propellant fumes could occur).

**REFERENCES:**

72SD4201–4–1 Sections 3, 6; Appendix A

**HAZARD CATEGORY**

- CAT.
- CRIT.
- MARG.
- NEG.
## CONVERSION FACTORS
### INTERNATIONAL TO ENGLISH UNITS

<table>
<thead>
<tr>
<th>Physical Quantity</th>
<th>International Units</th>
<th>English Units</th>
<th>Conversion Factor Multiply By</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration</td>
<td>m/sec²</td>
<td>ft/sec²</td>
<td>3.281</td>
</tr>
<tr>
<td>Area</td>
<td>m²</td>
<td>ft²</td>
<td>10.764</td>
</tr>
<tr>
<td>Density</td>
<td>Kg/m²</td>
<td>lb/ft³</td>
<td>9.479 x 10⁻⁴</td>
</tr>
<tr>
<td>Energy</td>
<td>Joule</td>
<td>Btu</td>
<td>2.248 x 10⁻¹</td>
</tr>
<tr>
<td>Force</td>
<td>Newton</td>
<td>lbf</td>
<td>2.205</td>
</tr>
<tr>
<td>Length</td>
<td>m</td>
<td>ft</td>
<td>5.399 x 10⁻⁴</td>
</tr>
<tr>
<td>Mass</td>
<td>Kg</td>
<td>lbm</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>watt</td>
<td>Btu/sec</td>
<td>9.488 x 10⁻⁴</td>
</tr>
<tr>
<td>Pressure</td>
<td>Newton/m²</td>
<td>Atmosphere</td>
<td>3.413</td>
</tr>
<tr>
<td>Speed</td>
<td>m/sec</td>
<td>ft/sec (fps)</td>
<td>3.281</td>
</tr>
<tr>
<td>Temperature</td>
<td>K</td>
<td>F</td>
<td>(9/5 - 459.67/tK)</td>
</tr>
<tr>
<td>Volume</td>
<td>m³</td>
<td>in³</td>
<td>6.097 x 10⁴</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ft³</td>
<td>35.335</td>
</tr>
</tbody>
</table>
# Glossary of Terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abort</td>
<td>Premature and abrupt termination of an event or mission because of existing or imminent degradation or failure of hardware. (In the safety analysis, no distinction is made between an accident and abort.)</td>
</tr>
<tr>
<td>Accident</td>
<td>An undesirable unplanned event which may or may not result from a system failure or malfunction.</td>
</tr>
<tr>
<td>Airborne Material</td>
<td>Radioactive gases, vapors and particulates released to the air.</td>
</tr>
<tr>
<td>Breached</td>
<td>Fuel elements, coolant loops, pressure vessel, core, or radiation shield are (a) physically torn by thermal or mechanical stresses, (b) cut open by fragmentation or (c) split open by internal pressures.</td>
</tr>
<tr>
<td>Bulk Damage (Radiation)</td>
<td>Radiation causing atomic displacement in semiconductor devices - sometimes commonly referred to as &quot;crystal&quot; damage.</td>
</tr>
<tr>
<td>Contamination</td>
<td>A condition where a radioactive material is mixed or adheres to a desirable substance or where radioactivity has spread to places where it may harm persons, experiments or make areas unsafe.</td>
</tr>
<tr>
<td>Control Drum Motion</td>
<td>Rotation of the control drums or drum toward or away from the most reactive position within a reactor. (As used in safety analysis results in a reactor excursion.)</td>
</tr>
<tr>
<td>Core Compaction</td>
<td>The act of increasing the density of the core which results in increased reactivity and possible criticality.</td>
</tr>
<tr>
<td>Cover Gas</td>
<td>A gas blanket used to provide an inert atmospheric environment around hardware to minimize potential reactions which can give rise to accident situations.</td>
</tr>
<tr>
<td>Credible</td>
<td>An event having a relative or cumulative probability of occurrence of $&gt;10^{-12}$</td>
</tr>
<tr>
<td>Criticality</td>
<td>The act of obtaining and sustaining a chain reaction.</td>
</tr>
<tr>
<td>Critical Mass</td>
<td>The mass of fissionable material necessary to obtain criticality.</td>
</tr>
<tr>
<td>Cumulative Probability</td>
<td>Sometimes referred to as &quot;Mission probability&quot; is the overall probability of a sequence of events occurring (product of &quot;relative probabilities&quot; of the individual events along a path of an abort sequence tree).</td>
</tr>
<tr>
<td>Damaged</td>
<td>Same as &quot;Breached&quot;.</td>
</tr>
<tr>
<td>Decontamination</td>
<td>The removal of undesired dispersed radioactive substances from material, personnel, rooms, equipment, air, etc. (e.g., washing, filtering, chipping).</td>
</tr>
<tr>
<td>Destructive Excursion</td>
<td>An excursion (safety analysis assumes ~ 100 MW-sec) accompanied by a complete disassembly of the reactor, a prompt radiation emission and release of fission product gases, vapors and particulates.</td>
</tr>
<tr>
<td>Disassembly/Disassembled</td>
<td>Nuclear hardware (e.g., reactor) which has been violently broken or separated into parts and not capable of forming a critical mass.</td>
</tr>
<tr>
<td>Disposal</td>
<td>The planned discarding or recovery of nuclear hardware.</td>
</tr>
<tr>
<td>Distributed Material</td>
<td>The spread of nuclear fuel and radioactive debris on the earth's surface following impact or destructive excursion.</td>
</tr>
<tr>
<td>Dose Guidelines</td>
<td>Established radiation levels used in the nuclear safety analysis for evaluating number of exposures and in determining operating limits and boundaries.</td>
</tr>
<tr>
<td>Dosimetry</td>
<td>Techniques used in the measurement of radiation.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Dynamic Interference</td>
<td>An experiment radiation effect where the flux rate above some threshold (a fraction of the experiment signal-to-noise ratio at maximum sensitivity, for electronic detectors) causes noticeable degradation of data quality.</td>
</tr>
<tr>
<td>Early Reactor Disposal</td>
<td>Attempted disposal of the reactor prior to its successful completion of 5 years operational lifetime.</td>
</tr>
<tr>
<td>Electrical Power System</td>
<td>All components (heat source, regulation, control, power conversion and radiators) necessary for the development of electrical power. The reactor electrical power system includes all hardware associated with the Power Module with the exception of the Disposal System.</td>
</tr>
<tr>
<td>End of Mission</td>
<td>Generally associated with the termination of the mission or flight. Is also used to define those activities involved with disposal and recovery of hardware after intended lifetime.</td>
</tr>
<tr>
<td>Excursion</td>
<td>A rapid and usually unplanned increase in thermal power associated with the operation of a power reactor.</td>
</tr>
<tr>
<td>Exposure Limit</td>
<td>Total accumulated or time dependent radiation exposure limits imposed on personnel by regulatory agencies or limits which preclude equipment damage.</td>
</tr>
<tr>
<td>Fission Products</td>
<td>The nuclides (quite often radioactive) produced by the fission of a heavy element nuclide such as U-235 or Pu-239.</td>
</tr>
<tr>
<td>Fuel</td>
<td>Fissionable material in a reactor or radioisotopes in a heat source used in producing energy.</td>
</tr>
<tr>
<td>Fuel Element/Capsule</td>
<td>A shaped body of nuclear fuel prepared for use in a reactor or heat source. Common usage involves some form of encapsulation.</td>
</tr>
<tr>
<td>Fuel Element Ablation</td>
<td>Fuel element clad and/or fuel removed by reentry heating, releasing fission products to the atmosphere.</td>
</tr>
<tr>
<td>Fuel Element Burial</td>
<td>Individual fuel elements beneath the ground surface completely covered by soil.</td>
</tr>
<tr>
<td>Gallery</td>
<td>The compartment of the reactor shield which houses the major primary loop components.</td>
</tr>
<tr>
<td>Ground Deposited Particles</td>
<td>Particles deposited on the ground from radioactive fallout.</td>
</tr>
<tr>
<td>Hazard</td>
<td>An existing situation caused by an unsafe act or condition which can result in harm or damage to personnel and equipment.</td>
</tr>
<tr>
<td>Hazard Source</td>
<td>The location and/or origin of the hazard.</td>
</tr>
<tr>
<td>Immediate Reentry</td>
<td>Very early reentry of the reactor (e.g., misaligned thrust vector which causes firing of the reactor disposal rockets toward earth resulting in 1-2 day reentry).</td>
</tr>
<tr>
<td>Impact in Deep Ocean</td>
<td>Reentering and/or impact of nuclear material in the ocean, beyond the Continental Shelf where contamination of the food chain is extremely remote.</td>
</tr>
<tr>
<td>Impact in Reservoir</td>
<td>Reentering and/or impact of nuclear material in reservoir containing potable drinking water.</td>
</tr>
<tr>
<td>Impact in Water Containing Edible Marine Life</td>
<td>Reentering and/or impact of nuclear material on the Continental Shelf or in a body of water such as a lake, river or stream where contamination of the food chain is likely.</td>
</tr>
<tr>
<td>Intact Reentry/Reactor</td>
<td>A nuclear system that retains its integrity upon impact and in the case of a reactor is capable of undergoing an excursion.</td>
</tr>
<tr>
<td>Integrated/Cumulative Dose</td>
<td>The total dose resulting from all or repeated exposures to radiation.</td>
</tr>
<tr>
<td>Interacting Vehicle</td>
<td>Any defined module, spacecraft, booster or logistic vehicle which may have an interaction with the Manned Space Base.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Ionization Damage</td>
<td>Radiation causing surface damage in materials (e.g., the fogging of film).</td>
</tr>
<tr>
<td>Land Impact</td>
<td>Nuclear hardware which impacts land at terminal velocities following reentry and lower velocities during prelaunch or early in the launch/ascent phase.</td>
</tr>
<tr>
<td>Loss of Coolant</td>
<td>Loss of organic or liquid metal coolant in reactor coolant loops due to failure/accident.</td>
</tr>
<tr>
<td>Mission Support</td>
<td>Supporting functions provided the Space Base Program by ground personnel and interfacing vehicles throughout all mission phases.</td>
</tr>
<tr>
<td>Moderator</td>
<td>Material used in a nuclear reactor to slow down neutrons from the high energies at which they are released to increase the probability of neutron capture: Water and hydrogen are moderators in a thermal reactor.</td>
</tr>
<tr>
<td>NaK-78</td>
<td>An alloy of sodium (22% by weight) and potassium (78%) used as a liquid metal heat transfer fluid.</td>
</tr>
<tr>
<td>No Discernible Hazard</td>
<td>Represents no hazard to the general populace.</td>
</tr>
<tr>
<td>Non-credible</td>
<td>An event having a relative or cumulative probability of occurrence of $&lt; 10^{-12}$. Considered not worthy of concern.</td>
</tr>
<tr>
<td>Non-destructive Excursion</td>
<td>A temperature excursion which may rupture the primary coolant loop and release fission products to the environment but leaves the reactor shield essentially intact.</td>
</tr>
<tr>
<td>Normal Operations</td>
<td>Planned and anticipated mission activities and events.</td>
</tr>
<tr>
<td>Over Moderation</td>
<td>Immersion of reactor in an hydrogenous medium (moderator) resulting in increased neutron reflection into the core causing a reactor excursion.</td>
</tr>
<tr>
<td>Permanent Shutdown</td>
<td>Enacting provisions which preclude reactor criticality under all foreseeable circumstances.</td>
</tr>
<tr>
<td>Poison</td>
<td>A material that absorbs neutrons and reduces the reactivity of a reactor.</td>
</tr>
<tr>
<td>Power Module</td>
<td>The complete reactor/shield, radiator, power conversion system and disposal system unit as provided on the Space Base.</td>
</tr>
<tr>
<td>Premature Reentry</td>
<td>Any reentry of the reactor from Earth orbit with orbital lifetimes less than the planned (1167 year) orbital decay time of the 990 km disposal altitude.</td>
</tr>
<tr>
<td>Pre-poison</td>
<td>A poison which is added to the reactor fuel for purposes of controlling reactivity. Sometimes referred to as &quot;burnable poison&quot;.</td>
</tr>
<tr>
<td>Prompt Radiation</td>
<td>The neutron and gamma radiation released coincident with the fission process as opposed to the radiation from fission product decay. Commonly associated with an excursion event.</td>
</tr>
<tr>
<td>Quasi-Steady State</td>
<td>A term used to describe the condition when a reactor periodically goes critical and then sub-critical due to water surging in and out of the core.</td>
</tr>
<tr>
<td>Radiological Consequences</td>
<td>The radiation exposure effect on personnel and the ecology from a radiation release accident or event.</td>
</tr>
<tr>
<td>Radiological Hazards</td>
<td>Hazards associated with radiation as differentiated from other sources.</td>
</tr>
<tr>
<td>Radiological Risk</td>
<td>The term used to define the average number of people anticipated to be affected by radiation in a given mission or phase thereof.</td>
</tr>
<tr>
<td>Random Reentry</td>
<td>The uncontrolled non-directed reentry of a vehicle from orbit.</td>
</tr>
<tr>
<td>Reactivity</td>
<td>A measure of the departure of a reactor from critical such that positive values correspond to reactors super-critical and negative values to reactors which are sub-critical. (Usually expressed in multiples of a dollar.)</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Reactor Fails to Survive Reentry</td>
<td>Reactor/shield is completely disassembled by reentry heating, releasing individual fuel elements and structural debris to the atmosphere.</td>
</tr>
<tr>
<td>Reactor Survives Reentry</td>
<td>Reactor is not disassembled by reentry heating; radiation shield may be damaged.</td>
</tr>
<tr>
<td>Reactor/Shield</td>
<td>A system containing the reactor, control drums, gallery and surrounding LiH and Tungsten shield.</td>
</tr>
<tr>
<td>Relative Probability</td>
<td>Probability of the occurrence of a particular event given a defined set of choices.</td>
</tr>
<tr>
<td>Repair/Replacement</td>
<td>Consists of (a) physically repairing all faulty systems, or (b) complete replacement of the faulty system(s).</td>
</tr>
<tr>
<td>Ruptured</td>
<td>Same as &quot;Breached&quot;.</td>
</tr>
<tr>
<td>Safety</td>
<td>Freedom from chance of injury or loss to personnel, equipment or property.</td>
</tr>
<tr>
<td>Safety Catastrophic</td>
<td>Condition(s) such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem or component malfunction will severely degrade system performance, and cause subsequent system loss, death, or multiple injuries to personnel (SPD-1A).</td>
</tr>
<tr>
<td>Safety Critical</td>
<td>Condition(s) such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem or component malfunction will cause equipment damage or personnel injury, or will result in a hazard requiring immediate corrective action for personnel or system survival (SPD-1A).</td>
</tr>
<tr>
<td>Safety Marginal</td>
<td>Condition(s) such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem failure or component malfunction will degrade system performance but which can be counteracted or controlled without major damage or any injury to personnel (SPD-1A).</td>
</tr>
<tr>
<td>Safety Negligible</td>
<td>Condition(s) such that personnel error, design characteristics, procedural deficiencies, or subsystem failure or component malfunction will not result in minor system degradation and will not produce system functional damage or personnel injury (SPD-1A).</td>
</tr>
<tr>
<td>Scram System</td>
<td>A separate, possibly automatic, mechanism used to rapidly shut down a reactor.</td>
</tr>
<tr>
<td>System Safety</td>
<td>The optimum degree of risk management within the constraints of operational effectiveness, time and cost attained through the application of management and engineering principles throughout all phases of a program.</td>
</tr>
<tr>
<td>Space Base Program</td>
<td>All aspects of the Space Base mission including all prime and support hardware and personnel both on the ground, at sea or in orbit, which are required throughout all mission phases.</td>
</tr>
<tr>
<td>Space Debris</td>
<td>Uncontrolled radioactive or non-radioactive man-made objects in space; these objects may present collision and radiation hazards to earth orbital missions.</td>
</tr>
<tr>
<td>Space Shuttle</td>
<td>The manned vehicle used for the transportation of cargo to and from earth orbit. A separately launched vehicle (booster) on which the Shuttle is placed provides the initial first stage thrust.</td>
</tr>
<tr>
<td>Source Terms</td>
<td>Characterization of a radiation hazard with regard to (a) location, (b) magnitude, and (c) exposure mode.</td>
</tr>
<tr>
<td>Tracer</td>
<td>Material in which isotopes of an element may be incorporated to make possible observation of the course of the element through a chemical, biological or physical process.</td>
</tr>
</tbody>
</table>