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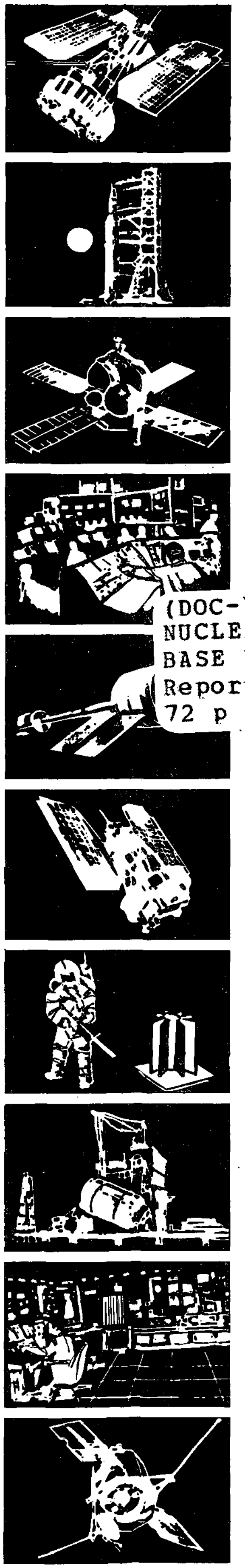

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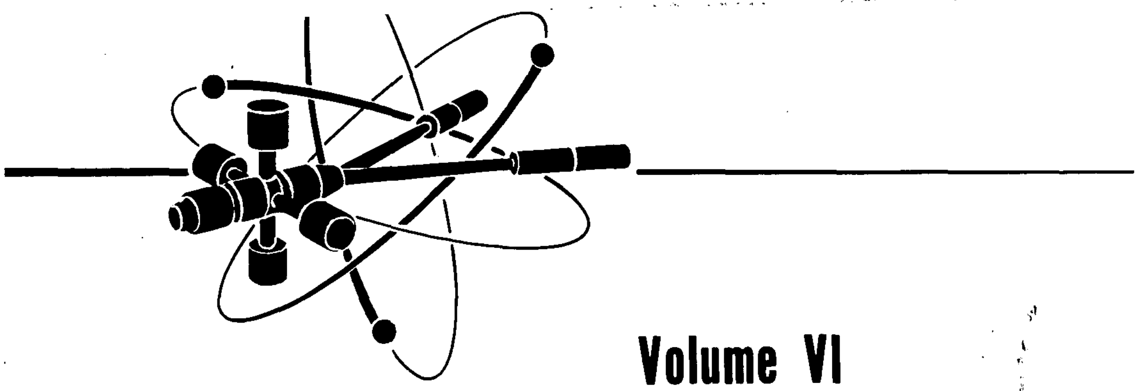

Volume VI

SPACE BASE NUCLEAR SYSTEM SAFETY PLAN

GENERAL ELECTRIC

DOCUMENT NO. 72SD4201-6
JANUARY 1972

FINAL REPORT

MANNED SPACE FLIGHT NUCLEAR SYSTEM SAFETY

VOLUME VI - SPACE BASE NUCLEAR SYSTEM SAFETY PLAN

PERFORMED UNDER
CONTRACT NO. NAS8-26283

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

CONDUCTED BY

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GENERAL ELECTRIC

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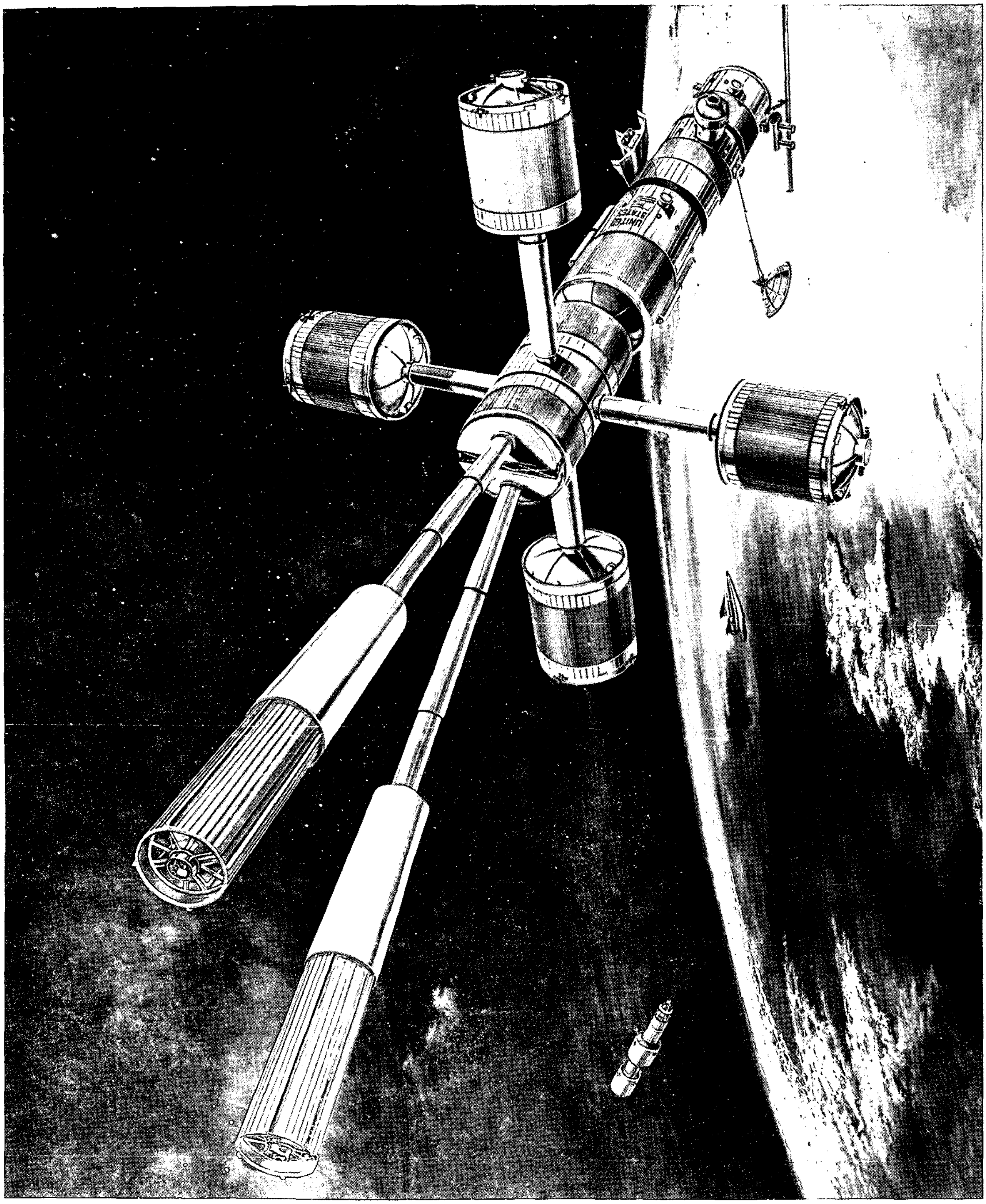
ABSTRACT

The Space Base Nuclear System Safety Plan (Volume VI) of the Manned Space Flight Nuclear System Safety documentation consists of a qualitative identification of the steps required to assure the incorporation of radiological system safety principles and objectives into all phases of a Manned Space Base program. Specific areas of emphasis include:

1. Radiological Program Management
2. Nuclear System Safety Plan implementation
3. Impact on Program
4. Summary of the Key Operation and Design Guidelines and Requirements.

The plan clearly indicates the necessity of considering and implementing radiological system safety recommendations as early as possible in the development cycle to assure maximum safety and minimize the impact on design and mission plans.



FOREWORD

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 A. Manned Space Flight Nuclear System Safety Documentation

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

*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

*□ 4 PRIMARY DISCUSSION

○ SUMMARY OR SUPPLEMENTAL DISCUSSION

*Section number is included where appropriate

STUDY AREAS	DOCUMENTATION														
	VOL I		VOL II		VOL III				VOL IV		VOL V		VOL VI	VOL VII	
	72SD4201-1		72SD4201-2		72SD4201-3				72SD4201-4		72SD4201-5		72SD4201-6	72SD4201-7	
	Part 1 Space Base - Executive Summary	Part 2 Space Shuttle - Executive Summary	Part 1 PSAR-Space Base	Part 2 Appendix (CRD)	Part 1 RDD-Reactor System, Space Base	Part 2 AMD-Reactor System	Part 2A AMD Appendix	Part 3 NSAD-Reactor System	Part 1 Space Shuttle Nuclear Safety	Part 2 Terrestrial Nuclear Safety Analysis	Part 1 Guidelines - Space Base	Part 2 Guidelines - Space Shuttle	System Safety Plan	Part 1 Literature Search and Evaluation	Part 2 ASRDI Forms
SPACE BASE PROGRAM															
Reference Vehicle Data	○		□ 3												
Radiation Limits	○		□ 4,A					○	○						
Radiation Environment/Hazards	○		□ 6			□ 3-5							○ 5		
Radiation Effects	○		□ 6,A												
Mission Support Nuclear Safety	○		□ 5										○ 6		
Orbital Operations Nuclear Safety	○		□ 6,7						○ 3-5						
Design & Operational Considerations	○		□ 5,7					○	○ 3-5						
Guidelines & Requirements	○		○					○			□	○	○ 5		
Reactor System Studies	○		□ 7	□											
Terrestrial Safety Analysis	○														
Reference Design					□				○ ABC						
Accident Models & Source Terms						□	□			○ 2,3					
Risk Analysis								□		○ 2,3					
System Safety Plans													□		
Technology Development Required	○		□ 8					○					○ 7,8		
SPACE SHUTTLE PROGRAM															
Reference Vehicle Data		○							□ ABC						
Nuclear Payload Integration		○							□ 3-5						
Design & Operational Considerations		○	○						□ 3-6						
Guidelines and Requirements		○	○						○ 3-5		○	□			
Terrestrial Safety Analysis		○			○	○		○	○ 6	□					
LITERATURE REVIEW DATA															
Approach and Cross Index														□	
ASRDI Forms															□

ABBREVIATIONS

ADM	Add-on Disposal Modules
AEC	Atomic Energy Commission
ALS	Advanced Logistic System (Space Shuttle)
AMD	Accident Model Document
ASRDI	Aerospace Safety Research Data Institute
BOL	Beginning of Life
BPCL	Brayton Power Conversion Loop
BRU	Brayton Rotating Unit
DOD	Department of Defense
DOT	Department of Transportation
ECLS	Environmental Control and Life Support
EM	Electro Magnetic
EOD	Earth Orbital Decay
EOL	End of Life
EOM	End-of-Mission
EPS	Electrical Power System
ETR	Eastern Test Range
EVA	Extra Vehicular Activity
FC	Fuel Capsule
FPE	Functional Program Element
G&C	Guidance and Control
GSE	Ground Support Equipment
HX	Heat Exchanger
ICRP	International Committee on Radiation Protection
IDM	Integral Disposal Module
INT-21	Intermediate Saturn Stages
IR	Infrared
IRV	Isotope Re-Entry Vehicle
IU	Instrument Unit
IVA	Intra Vehicular Activity
KSC	Kennedy Space Center
LCC	Launch Control Center
LD	Lethal Dose (% Probability)
LOX	Liquid Oxygen
LV	Launch Vehicle
MCC	Mission Control Center
MDAC	McDonnell Douglas Corporation
MHW	Multi-Hundred Watt
ML	Mobile Launcher
MPC	Maximum Permissible Concentration
MSC	Manned Spacecraft Center
MSFC	Marshall Space Flight Center
MSS	Mobile Service Structure
NA	Non-Applicable
NAB	Nuclear Assembly Building
NAR	North American Rockwell
NASA	National Aeronautics and Space Administration
NC	Non-Credible
NCRP	National Committee on Radiation Protection
NSAD	Nuclear Safety Analysis Document
OPSD	Orbital Propellant Storage Depot
ORNL	Oak Ridge National Laboratory
PCS	Power Conversion System
PM	Power Module
PSAR	Preliminary Safety Analysis Report
RAD	Radiation Absorbed Dose
RCS	Reaction Control System
RDD	Reference Design Document
REM	Roentgen Equivalent Man
RMU	Remote Maneuvering Unit
RNS	Reusable Nuclear Shuttle
R/S	Reactor/Shield
RSO	Radiation Safety Officer
RTG	Radioisotope Thermoelectric Generator
SB	Space Base
SAR	Safety Analysis Report
SEHX	Separable Heat Exchanger
S-IC	First Stage of Saturn V
S-II	Second Stage of Saturn V
SNAP	Space Nuclear Auxiliary Power
SNAPTRAN	Space Nuclear Auxiliary Power Transient
TAC	Turbine Alternator Compressor
TEM	Thermoelectric Electro Magnetic Pump
TLD	Thermo Luminescent Dosimeter
USAF	United States Air Force
VAB	Vehicle Assembly Building

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SECTION 1
INTRODUCTION

1.1 PURPOSE

The Space Base Nuclear System Safety Plan is designed to assure the timely, systematic and comprehensive incorporation of radiological system safety principles and objectives into all phases and aspects of a Manned Space Base program within the constraints imposed by system requirements and contractual obligations.

The basic radiological system safety principles applied in this program are:

1. The safety program must be thoroughly planned and implemented.
2. Inherent safety should be integrated into the basic design and usage of all hardware that includes the man-media-machine interfaces.
3. Identification and elimination of hazards and safety deficiencies must be pursued and achieved as early as possible in the development cycle and continued throughout the life of the program.

System safety objectives are realized when freedom from actual or potential nuclear/radiological hazards, that can injure the general public, the crew and the ecology, or cause loss of equipment, has been achieved throughout the mission.

As a means for accomplishing this goal, the Space Base Nuclear System Safety Plan is oriented toward a preliminary identification and evaluation of potential hazards to provide a recommended safety organization and key design and procedural engineering objectives for the initial implementation of the safety program.

1.2 SCOPE

This plan encompasses all radiological safety aspects of a Space Base that were identified and their integration into a General Space Base Program System Safety Plan. Specific areas of emphasis include:

1. Implications of nuclear/natural radiological hazards on a Space Base, the general public, the crew, the ecology and interfacing orbital hardware.

2. Impact of the presence of nuclear sources on supporting facilities and operations.

3. Safety constraints on design and operation of associated nuclear hardware.

4. Delineation of nuclear oriented safety operational and design guidelines and requirements for a Space Base Program.

As additional or alternative manned Space Base concept definitions and missions that impact the radiological system safety criteria and analysis becomes available, this Safety Plan should be updated.

SECTION 2
REFERENCE DOCUMENTS

Key reference documents currently applicable toward the implementation of nuclear system safety for manned space vehicles include the following:

DATE	DOCUMENT NUMBER	TITLE	ORIGINATING ORGANIZATION
1969	AFETRM 127-1	Air Force Eastern Test Range Safety Manual	U.S. Air Force (DOD)
1970	AFETRM 160-1	Air Force Eastern Test Range Manual - Medical Service - Radiation Control Program	U.S. Air Force
	KMI 1150.9C	Radiological and Isotopes Safety Committe	NASA-Kennedy Space Center
1970	KMI 1710.1B/SF	The KSC Safety Program	NASA-Kennedy Space Center
1970	KMI 1710, 13A/SF	Safety Review of KSC Technical Operating Procedures	NASA-Kennedy Space Center
1970	KMI 1860.1/IS	Radiation Safety Policies and General Policies	NASA-Kennedy Space Center
1970	KMI 1860.2/IS	Radiation Safety - Personnel Dosimetry	NASA-Kennedy Space Center
1969	KV-0-51	Apollo/Saturn V Launch Operations Plan	NASA-Kennedy Space Center
1969	KV-0-53	Apollo/Saturn V Ground Safety Plan	NASA-Kennedy Space Center
1967	KV-IB-21	Apollo/Saturn IB Launch Operations Plan	NASA-Kennedy Space Center
1971	NCRP-39	Basic Radiation Protection Criteria	National Council for Radiation Protection and Measurement
	NHB 1700	NASA Safety Manual	NASA
1965	NMI 1052.72A and Supplements	NASA-AEC Inter-Agency Agreement Isotopic SNAP Devices	NASA
	NPD 1701.1	Basic Policy on Safety	NASA
1969	ORNL-11C-19	Isotope Users Guide	AEC-Oak Ridge National Laboratory
1971	Radiation Regulation-Title 49	Transportation of Radioactive Materials	US Department of Transportation
1964	SPA-41-S	Radiological Safety Handbook	NASA
1969	SPD No. 1A	System Safety Requirements for Manned Space Flight	NASA-Office of Manned Space Flight
	0500	AEC Manual - Health and Safety	U.S. Atomic Energy Commission
	10CFR20	Standards for Protection Against Radiation	U.S. Government
	10CFR20 20.403	Notification of Incidents	U.S. Government
1972	72SD4201	Manned Space Flight Nuclear System Safety	General Electric Company - Space Division

Reference should be made to the NASA operated Aerospace Safety Research and Data Institute in Cleveland, Ohio, and to Volume VII (72SD4201-7) of this study for additional applicable literature.

SECTION 3
SYSTEM SAFETY MANAGEMENT

3.1 ORGANIZATION

Key to the effective implementation of radiological safety are (1) the placement of responsibility within organizational structures of the NASA and contractor program offices and NASA centers at levels where safety issues are brought to the attention of the Directors and Program Manager and (2) provision of close communication ties between counterpart organizations. Such a typical radiological safety organiational structure is illustrated in Figure 3-1.

The focal point for the review approval and coordination of radiological plans is the Radiological Safety Office which is established within the system safety organization of the NASA Space Base Program Office.

The typical safety responsibilities of the key offices within the NASA organization are discussed below.

A Radiological Safety Office shall be established within the system safety organization of the Space Base Program Office (Figure 3-1). This office will be responsible for providing liaison, review and approval of radiological safety programs, plans and procedures, radiation safety monitoring, and operational radiological safety associated with the definition, design, development, testing and operational phases of the Space Base Program.

A primary requirement for the Radiological Safety Office is that it have a direct line of reporting to the Space Base Program Manager independent of any normal line organization. This requirement will help assure the bringing of radiological safety issues, which have not been resolved to the satisfaction of the safety organization, to the attention of the Program Manager.

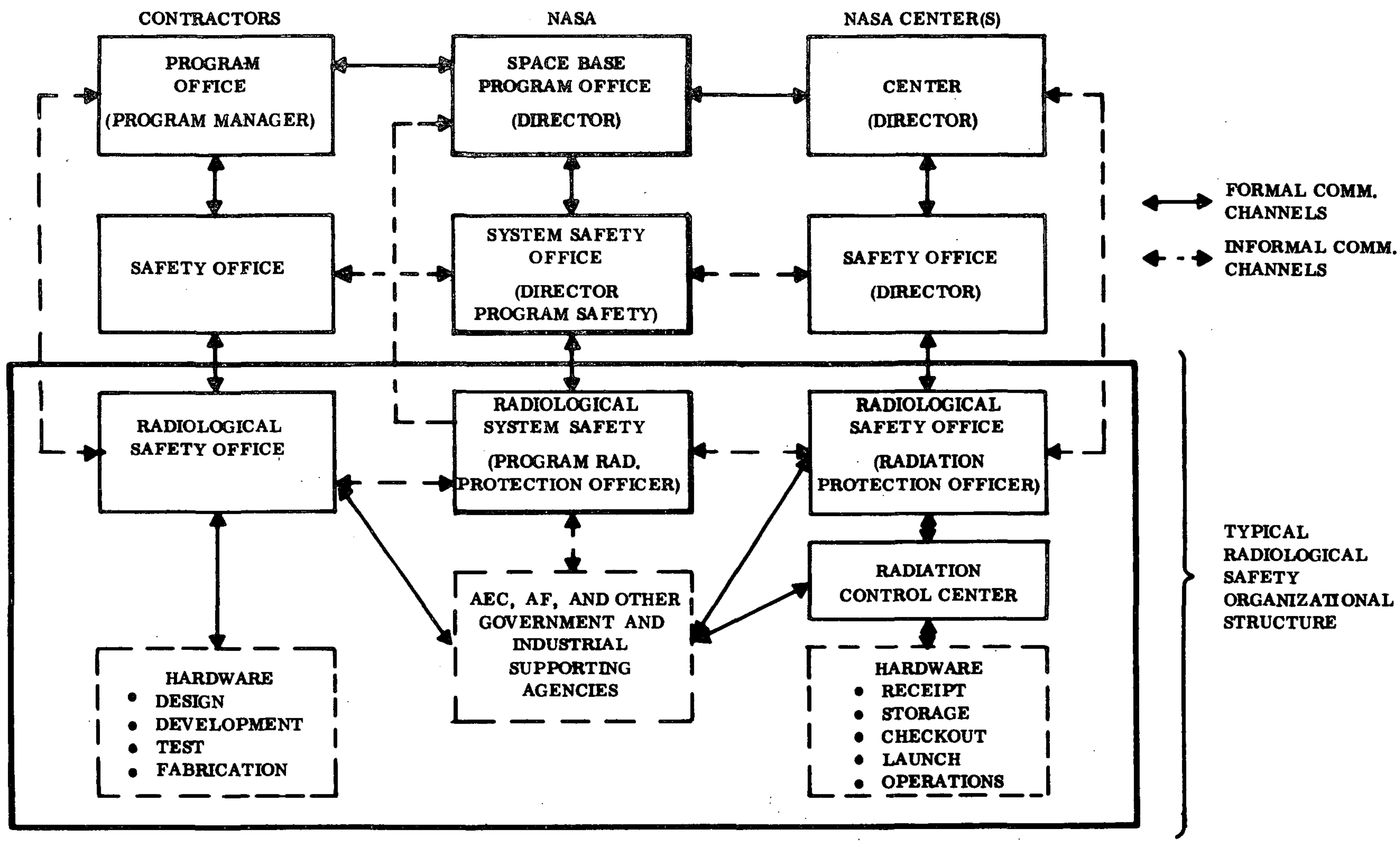


Figure 3-1. Typical Space Base Program Radiological Safety Organizational Structure

It is essential that pre-planned assessments and contingency plans be available for the inherent potential radiological hazards and aspects associated with the Space Base Mission operations involving nuclear or radioisotope devices. This will ensure that proper preventative, remedial, rescue or recovery procedures can be effectively implemented in the event of an accident or incident where radioactive material is involved.

3.2 DIRECTOR, PROGRAM SYSTEM SAFETY OFFICE

A Director, Program System Safety Office, will report directly to the Program Director and will be responsible for directing the overall Safety Program. The Safety Program Director will have basic responsibility for the adequacy of safety planning in all matters of safety. His responsibility will not abrogate the overall safety responsibility of the Commander of the Air Force Eastern Test Range (AFETR) or Director, Center Safety Offices. Among the many responsibilities of the Director, Program System Safety Office, is radiation safety. The unique characteristics of radioactive materials, sources and ionizing radiation producing devices with their potential and subtle impact on environmental health requires a point of formal contact and coordination to comply with State and Federal regulations and pertinent health and safety standards.

3.3 PROGRAM RADIATION PROTECTION OFFICER

A Program Radiation Protection Officer, reporting to the Director, Program System Safety Office, shall be designated the point of formal contact and coordination during Program Phases A, B, C and D on radiological safety and health matters of the program. Responsibilities will not include flight hardware or operational hardware at Centers and formal interfaces with the Atomic Energy Commission, other governmental agencies, radiological and isotopes safety committees, contractors and Center Safety Offices. He shall be responsible for (1) implementing, review and approval of program level radiological safety programs, plans and procedures, (2) providing monitoring and surveys to assure compliance with the implemented programs, (3) providing advice on levels and types of training and experience required for personnel to handle or use radiation sources and (4) maintainence of data and location inventory of radioactive materials assigned to contractors or Centers on the program.

3.4 CENTER(S) RADIATION PROTECTION OFFICER

A Radiation Protection Officer, reporting to the Director, Center Safety Office, shall be designated the point of formal contact and coordination on radiological safety and health matters at the Center(s). He shall be responsible for (1) interfacing with the Atomic Energy Commission, other governmental agencies, Center and Program Safety Offices, (2) implementing Center radiological safety programs, (3) providing monitoring and surveys to assure compliance with implemented programs (4) providing advice on levels and types of training and experience required for center personnel authorized to handle or use radiation sources, and (5) maintain data, location and inventory of radioactive materials at the center.

The Launch Center Radiation Protection Officer shall assume control and initiate action in radiological emergencies located at the Launch Center during the interval between hardware arrival at the Launch Center and orbital insertion. The Mission Control Center Radiation Protection Officer shall assume control and initiate action in radiological emergencies of flight hardware from orbital insertion through disposal of the radioactive materials. To facilitate the liaison with interfacing government agencies and Center functions in radiological safety and health matters and emergencies, the Center Radiation Protection Office(s) shall operate a Radiological Control Center(s) and provide space for the following personnel:

1. AFETR Representative (Launch Center Only)
2. Recovery Team Chief Representative
3. AEC/Albuquerque Operations Coordinator
4. AEC/Headquarters Safety Chief
5. Public Health Service Operations Team
6. Public Affairs Office Coordinator
7. Meteorologists
8. Consultants

9. Environmental Protection Agency Representative

10. State Department or Executive Office Representative.

3.5 INTERFACES WITH CONTRACTORS AND GOVERNMENT AGENCIES

Interfaces will be established with (1) contractors performing definition and assessment studies or hardware design and development of radioactive devices on board the Space Base, and (2) government agencies furnishing equipment or facilities to assure the compatibility with the Space Base radiological safety program. Interface control documents and the normal channels established for design interfaces will be used to the full extent possible.

3.6 INTERFACES WITH INDUSTRIAL AND PUBLIC SAFETY

Radiological safety interfaces will be established between contractors furnishing or operating nuclear hardware and industrial and public safety to (1) ensure compliance with state and federal government regulations, (2) ensure that permissible dosage is not exceeded, and (3) establish pre-planned contingency procedures and necessary training for use in the event of radiological emergencies.

3.7 RADIOLOGICAL SAFETY AUDITS AND SURVEYS

Periodic audits and surveys should be conducted by the Center Safety Offices and supported by contractors operating, developing and assembling radioactive devices to assure compliance with the radiological safety requirements of the Space Base program and applicable state and federal regulations for protection against radiation. Audits at the Launch Center shall be assigned to the KSC Health Physics Contractor subject to review by KSC, RPO and by the AEC.

SECTION 4
NUCLEAR SAFETY PLAN

This nuclear system safety plan is intended for the entire life cycle of a Space Base program which spans the definition, design, development, operational and end of mission phases. The recommended radiological safety milestones shown in Table 4-1 are established to provide timely inputs to enhance safety and reflect safety program elements contained in NASA Safety Program Directive No. 1A.

4.1 PRELIMINARY RADIOLOGICAL SAFETY ANALYSIS REPORTS

These reports identify and evaluate the potential radiological hazards to the crew, onboard equipment and earth's populace and ecology.

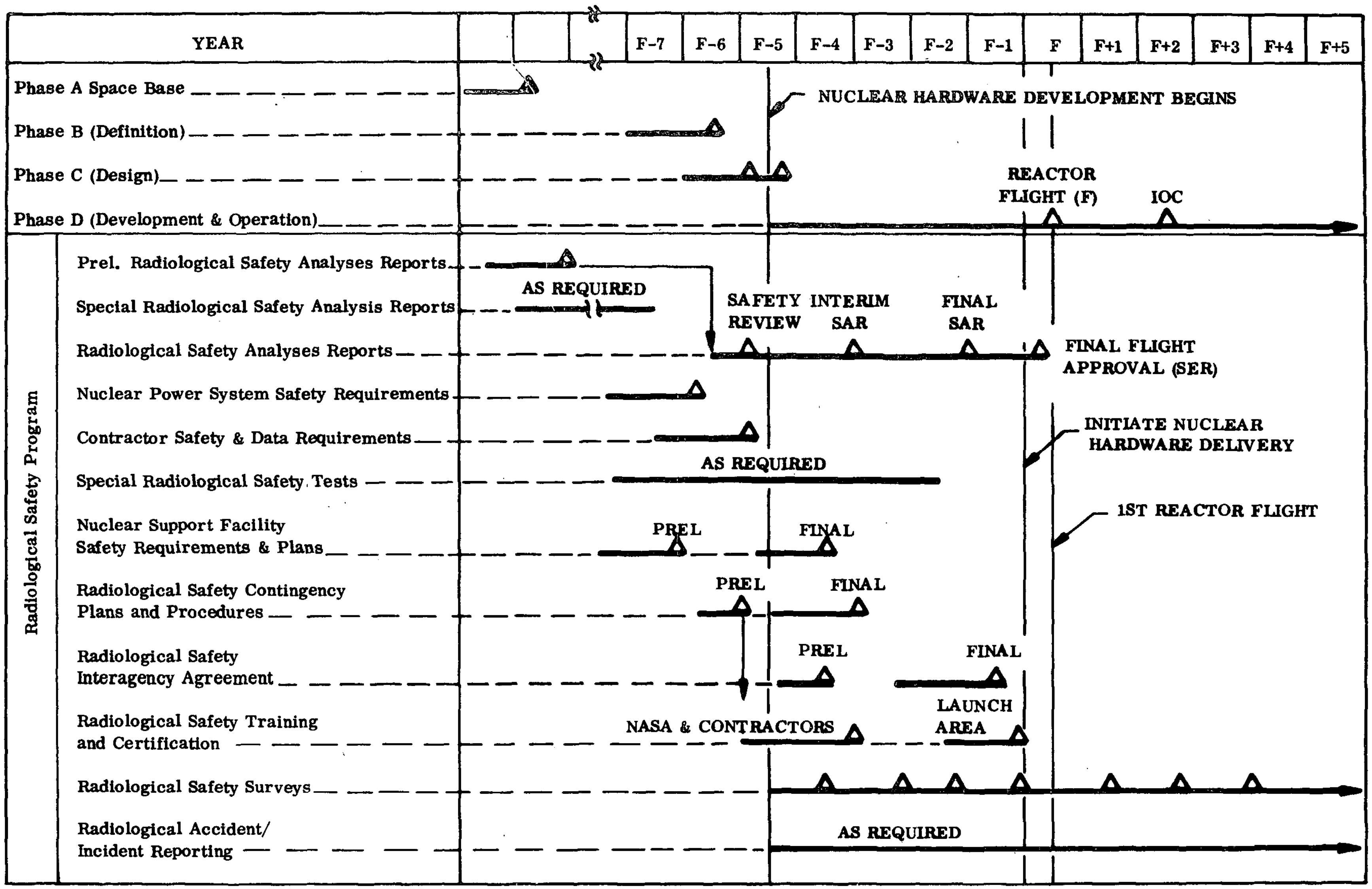
One report entitled "Preliminary Safety Analysis Report (PSAR) - Reactor System" provides preliminary nuclear safety data for the AEC and consists of a series of three parts:

1. Reference Design Document
2. Accident Model Document
3. Nuclear Safety Analysis Document.

The PSAR is intended to provide NASA and the AEC with a preliminary analysis of the potential risk to the general public imposed by the nuclear power modules of a Space Base. This report also contains recommendations for preventative measures and areas of additional study in improving the nuclear safety of the mission related to the nuclear power modules. The report will also serve as a point of departure for the more comprehensive Safety Analysis Report (SAR) and Safety Evaluation Report (SER) ultimately required for flight approval.

The second report is entitled, "Preliminary Safety Analysis Report - Space Base". The intent of this report is to identify those potential and inherent radiological hazards of a Space Base Program (crew, subsystems, experiments, ground support operations, etc.)

Table 4-1. Space Base Radiological System Safety Milestone Chart



and recommend approaches for their elimination or reduction to acceptable risk levels. This report can serve as a checklist for further safety efforts during the design and development program and the foundation for the formulation and implementation of the nuclear safety oriented guidelines and requirements.

4.2 SPECIAL RADIOLOGICAL SAFETY STUDIES

Safety areas may be identified that require further study to determine the feasibility of radiological safety enhancement. An example of such areas include the feasibility of using the Shuttle as a means of transporting and disposing of nuclear hardware, attaching ablative shields to a reactor after end-of-life shutdown to provide intact reentry capability for disposal etc.

4.3 RADIOLOGICAL SAFETY ANALYSES REPORTS

Comprehensive safety analyses of nuclear systems are required prior to actual flight. Interim Safety Analysis Reports should be prepared after the Phase B definitions are completed. Submittal should occur no later than two years before flight.

The Safety Analysis Report - Reactor System is an update of the preliminary and interim reports. The analysis shall be based on firm design, mission and operational data to provide a most realistic evaluation of the mission radiological risk to the earth's general populace. This document, to be submitted a minimum of six months prior to flight, is used as a data base by NASA and the AEC in developing the Safety Evaluation Report (SER). The SER, used in obtaining flight approval, is required no later than three months prior to actual flight. It is necessary that the SAR and SER reports be updated to reflect design or operational changes which significantly eliminate, mitigate, or increase potential hazards.

Flight approval documentation will also be required for other hardware made a part of a Space Base program which contains potentially hazardous quantities of nuclear material.

4.4 NUCLEAR ELECTRICAL POWER SYSTEM SAFETY REQUIREMENTS

Refinement of radiological safety requirements associated with the Space Base nuclear electrical power system is dependent on the type and configuration of the reactor, heat exchanger, and power conversion system selected. Specific characteristics and operations requirements for a particular nuclear power system impacts radiological safety. These radiological safety requirements shall be refined prior to a preliminary design review during the design phase and contain the criteria for the safety requirements.

4.5 CONTRACTOR SAFETY AND DATA REQUIREMENTS

Safety requirements for a contractor's product or service are usually specified for procurement purposes. These requirements are often required to be exhibited in forms of analysis results, plans, reports, organizational responsibility, procedures, constraints, safety devices or features, redundant or alternate performance modes and configurations. The basic outline used in this system safety plan is also a suggested outline for the contractor's safety plan.

4.6 SPECIAL RADIOLOGICAL SAFETY TESTS

Safety devices are often incorporated in hardware designs to enhance personnel and/or equipment safety. Usually it is required that the effectiveness of these devices be demonstrated with tests. An example of such a safety device is a reactor control drum lockout mechanism. Evaluation demonstrations should be considered for any untested safety devices prior to their incorporation into the Space Base design and flight hardware.

4.7 NUCLEAR SUPPORT FACILITY SAFETY REQUIREMENTS AND PLANS

The safety requirements for support facilities associated with the nuclear power system and radioisotopes for use on a Space Base should be delineated so that their impact on facilities plans can be incorporated in their design and construction. Examples of nuclear safety requirements for support facilities may be a radiation monitoring system and partial pressure systems that would contain any radioactive particles in the event of an accidental radioactive material release. Special liquid metal handling and fire fighting equipment would also be required.

4.8 RADIOLOGICAL SAFETY CONTINGENCY PLANS AND PROCEDURES

Contingency plans and procedures shall be provided that will cope with any type of radiological emergency that can arise on a Space Base program. If rescue and recovery actions are warranted, organizational element responsibilities should be designated so that training and demonstrated proficiency can be completed prior to the possible occurrence of the potential radiological hazard.

4.9 RADIOLOGICAL SAFETY INTERAGENCY AGREEMENTS

Support and assistance required by NASA from other governmental agencies in the event of a potential radiological emergency, shall be formally agreed to by responsible personnel in those governmental agencies involved. Such formal agreements facilitate those delegated agency elements in training and providing the needed assistance in a timely manner during any Space Base radiological emergency. An example may be the support of NASA in the detection and recovery of released radioactive material by the U.S. Atomic Energy Commission.

4.10 RADIOLOGICAL SAFETY TRAINING AND CERTIFICATION

Skills in operating a nuclear reactor, conducting tests with reactor coolants, handling radioisotopes, and operating radiation detection and monitoring equipment usually requires special training. Such training provides appreciation of the potential hazards and establishes remedial actions required in the event of radiological emergencies in addition to proficiency in operation of equipment and monitoring systems. Usually this training and certification requirement is completed prior to the construction or fabrication of the radiological equipment for operational use.

4.11 RADIOLOGICAL SAFETY SURVEYS

Periodic surveys provide a means for determining the adequacy of prepared safety plans and procedures and their implementation toward achieving the radiological safety goals of the Space Base program. The necessity of periodic safety surveys is usually desirable because of personnel changes and possible degradation of implemented safety practices and skills with time when they are not used frequently. These periodic surveys also provide a means for determining the progress made from the safety efforts on the program.

4.12 RADIOLOGICAL ACCIDENT/INCIDENT REPORTING

Any incidents or accidents that result in excessive exposure of personnel to radiation or the release of radioactive material shall be reported and carefully documented. It is essential that the responsible personnel in the governmental agencies involved (i.e., NASA, AEC, DOD) be informed of such accident/incidents for providing information as requested to the executive and legislative branches of the government as well as the public. Reporting procedures which may be used as references are:

1. Title 10 Code of Federal Regulations 20.403 (AEC)
2. NASA Management Instruction 1052.72A
3. NASA Safety Manual NHB 1700.1, Volume I, Chapter 9
4. Apollo/Saturn V Ground Safety Plan, KSC SNAP-27 Radiological Control Plan, K-V-053, Volume II, Supp. 11
5. The KSC Safety Program KMI 1710.1B/SF.

SECTION 5
SPACE BASE NUCLEAR SYSTEM SAFETY STUDY

This section contains data from the Space Base Nuclear System Safety Study performed under NASA Contract NAS 8-26283 considered pertinent in the implementation of a Nuclear System Safety Plan.

5.1 RADIOLOGICAL GOALS

The Space Base program shall have as radiological safety goals (1) minimizing radiological exposure to humans, (2) not exceeding established maximum allowable exposure limits to humans (Tables 5-1 and 5-2), and minimize mission aborts or loss of equipment attributed to radiological emergencies.

Table 5-1. Dose Limits for Crew and Ground Radiation Workers

Currently in Use (10 CFR 20)

Exposure	Condition	Dose (rem)
• Whole Body - Head, trunk, active blood-forming organs, gonads. lens of eye	Accumulated Quarterly	5 (N-18 yr) 1.25
• Skin - of whole body	Year Quarterly	30.00 7.50
• Hands - and forearms, feet and ankles	Year Quarterly	75.00 18.75

Recommended (NCRP-39) Jan. 15, 1971

Exposure	Condition	Dose (rem)
• Whole Body	Long Term Accumulated	5 (N-18 yr) 5/Year
• Skin	Year	15
• Hands, Feet & Ankles	Year Quarterly	75 25
• Forearms	Year Quarterly	30 10
• Other Organs	Year Quarterly	15 5

Crew Radiation Limits (rem)

Area Depth	1 Yr Avg Daily	30 Day	Quarter	Year	Career
Skin (0.1 mm)	0.6	75	105	225	1200
Eye (3 mm)	0.3	37	52	112	600
Marrow (5 cm)	0.2	25	35	75	400

Table 5-2. Dose Guidelines for General Populace

Permitted Exposure Standards (10 CFR 20)

Exposure	Dose Rate
• Whole Body	0.002 rem/hr 0.100 rem/wk 0.500 rem/yr

Accident Exposure Guidelines

Exposure	Dose (rem)
External	
• Whole Body	25*
Internal	
• 70 Year Bone Dose	150**
• Thyroid	300**
• Lower Large Intestine	75**

*10 CFR-100
**DML 50-268

5.2 REFERENCE CRITERIA

The general criteria and significant system features associated with the radiological program of the reference Space Base are listed in Table 5-3.

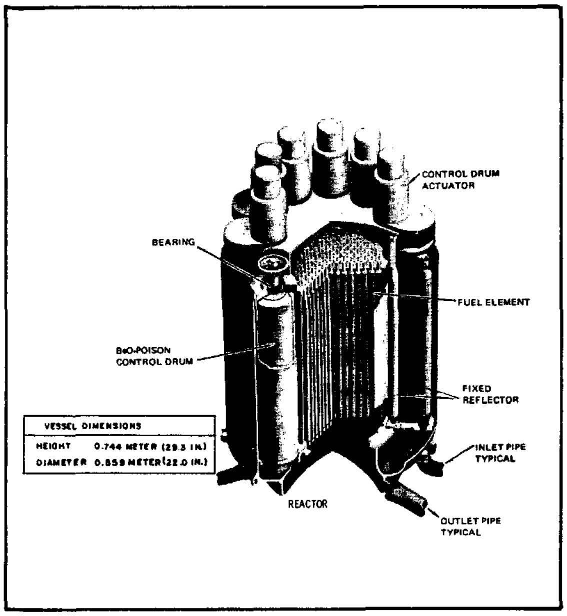
Table 5-3. Space Base System Features

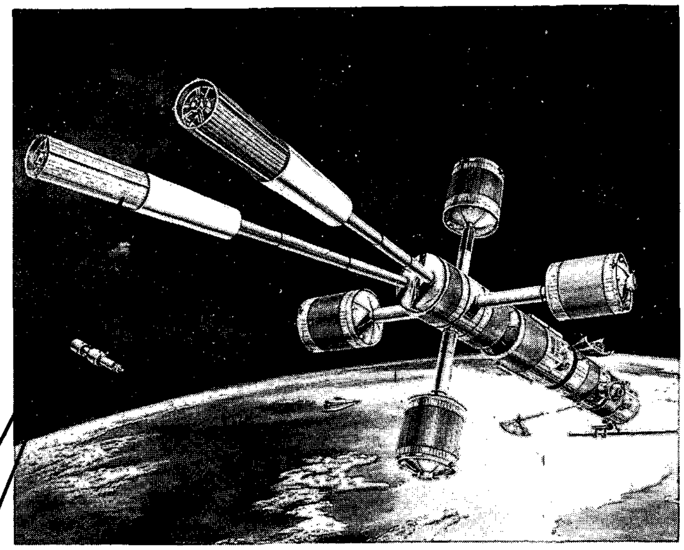
Reactor System	2-ZrH reactor-Brayton power modules, each with 330 kWt (50 kWe) nominal rating-600 kWt maximum
Configuration	Power modules on extendable booms of zero-g core. Art-g rotating hubs.
Orbit	500 km (273 nm), 55^{o} inclination
Launch Vehicle	Saturn INT-21 (launch of 1 or 2 power modules)
Launch Trajectory	46^{o} launch azimuth from KSC; Eurasian over-fly
Lifetimes	Mission - 10 years, reactor - nominally 5 years, power conversion system - nominally 2.5 years
Crew Size	50 (nominal) with 90 to 180 day crew rotation cycle
Experiments	Extensive on-board and orbiting subsatellite program
Logistics	Space Shuttle - primary logistics vehicle, Space Tug - final rendezvous and docking of power module
Power Module Disposal	Boost by integral Disposal System to 990 km high altitude disposal orbit.
Reactor Shield	Shaped 4π lithium hydride neutron shield, tungsten gamma shield — 1 mrem/hr at nearest habitable interface
Space Base Definition	North American Rockwell and McDonnell Douglas Phase A studies.

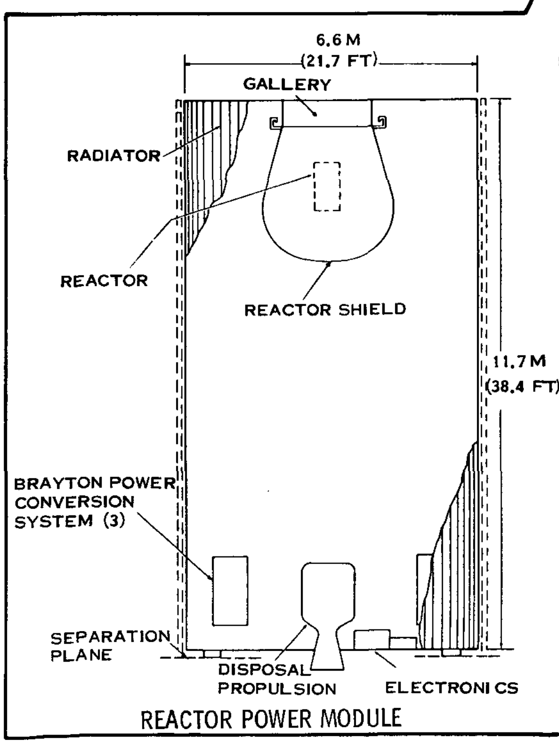
Figure 5-1 illustrates the Space Base reactor power module concept.

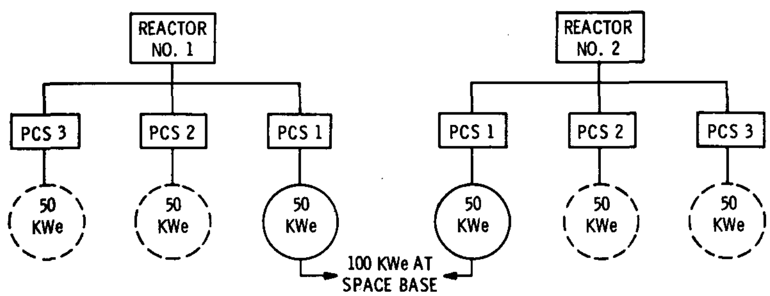
5.3 RADIOLOGICAL ANALYSES

Safety analyses oriented to radiological safety of a program such as the Space Base were applied in the Space Base Nuclear System Safety Study. The overall study, development of data and principal conclusions are intended as a point of departure for subsequent phases









ITEM	CONCEPT REMARKS
REACTOR	2 ZrH, 295 FUEL ELEMENTS
CONTROL	10 DRUMS
POWER CONVERSION	3–50 KW_E BRAYTON UNITS/REACTOR
NORMAL POWER LEVEL	330 KW_T
EMERG POWER LEVEL	600 KW_T (ASSUMED FOR STUDY)
SHIELD	SHAPED 4 π LiH
RADIATION LEVELS	1 MR/HR SB INTERFACE
LIFETIME	5 YEARS

Figure 5-1. Reactor Power Modules Details

of manned space flight programs where similar radiological hazards will be encountered. Basic assumptions and reference design data were clearly defined and in some instances parametric data supplied to assist in the extrapolation of results when deviations from the reference are made.

The safety analyses consisted of the tasks as illustrated in Figure 5-2.

Task A, Program Management, provided overall technical and financial control for the total program.

Tasks B, 1.0 and 2.0 made up the definition and supporting phases of the study. The Baseline Definition provided the reference vehicle and mission information required to perform a safety evaluation of the two Space Base concepts. The Literature Review identified and made available for use existing reports, computer programs and unpublished data that were potentially applicable to the study. Pertinent information was provided on ASRDI forms for use by NASA's Aerospace Safety Research and Data Institute at LeRC. Task 2.0 identified the radiation limits for the hardware and personnel associated with the Space Base Program. Task 3.0 involved the identification and characterization of potential nuclear and nuclear related hazards associated with the Space Base program.

An operational safety evaluation of the Space Base program was performed in Task 4.0. The hazards identified in Task 3.0 were evaluated to determine their potential effect and impact on Space Base hardware, personnel and operations. Development of hazard fault and failure sequence trees were included. Subtasks 4.2 and 4.3 identified design and operational guidelines, procedures and requirements that will reduce or eliminate the hazards identified.

A detailed nuclear safety evaluation of the reference reactor power system was performed in Task 5.0. Trade-off studies were performed in Subtask 5.1 to determine the effects on safety of alternate power system configurations.

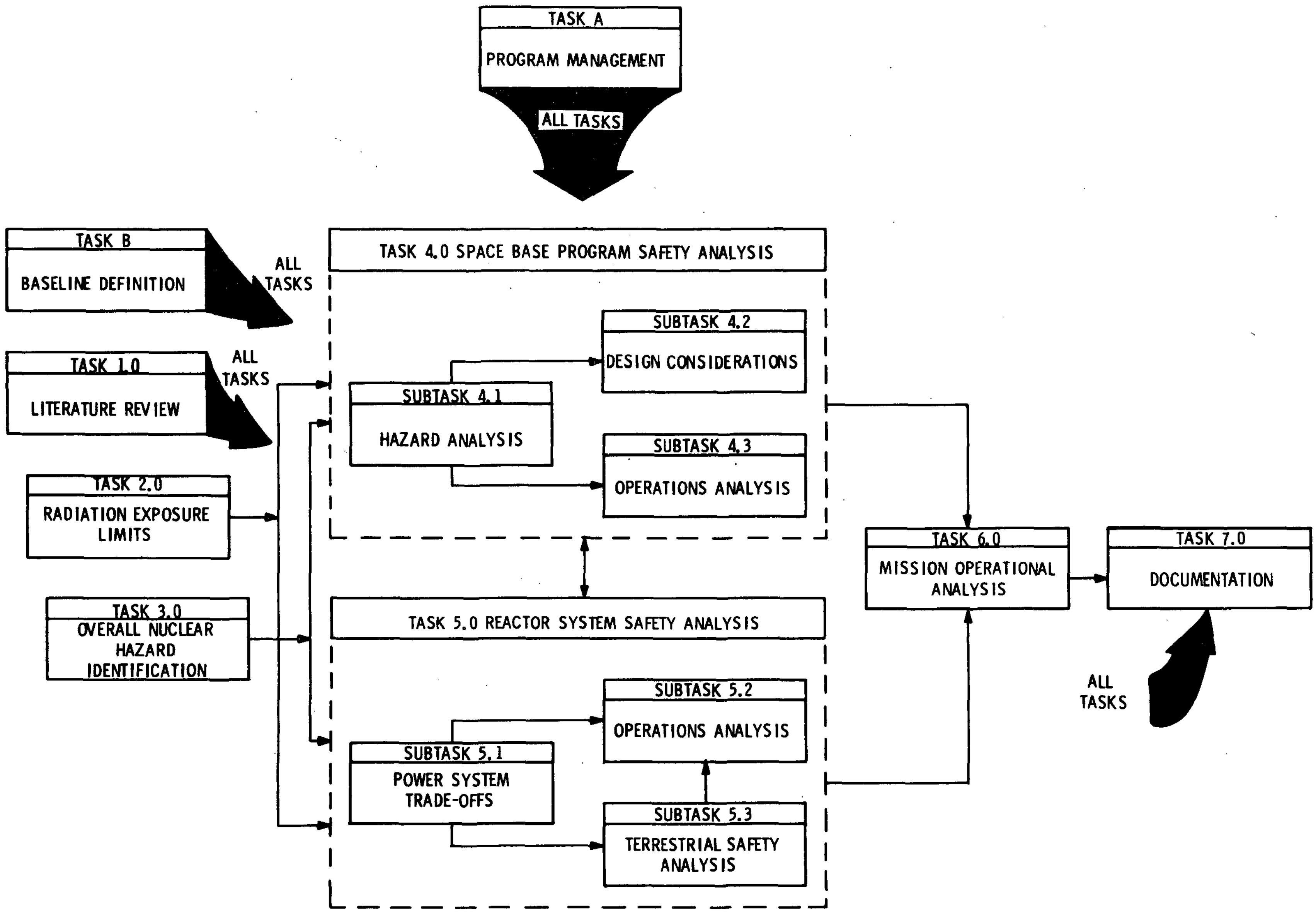


Figure 5-2. Study Approach

Operational analyses performed in Subtask 5.2 provided guidelines and procedures for the operation, repair, replacement and disposal of the power module. Subtask 5.3 provided a terrestrial nuclear safety analysis of the reactor power modules to determine the hazards and degree of risk to the general populace and ecology.

Task 6.0 provided radiological safety guidelines and procedures for the mission support functions of the program such as launch, range safety, orbital support, and recovery. Documentation of all work including PSAR's, guidelines and the nuclear safety plan was carried out in Task 7.0. Reference should be made to the other volumes of this report for detailed analysis and results of all the tasks.

The mission phases applied in the analyses are listed in Figure 5-3.

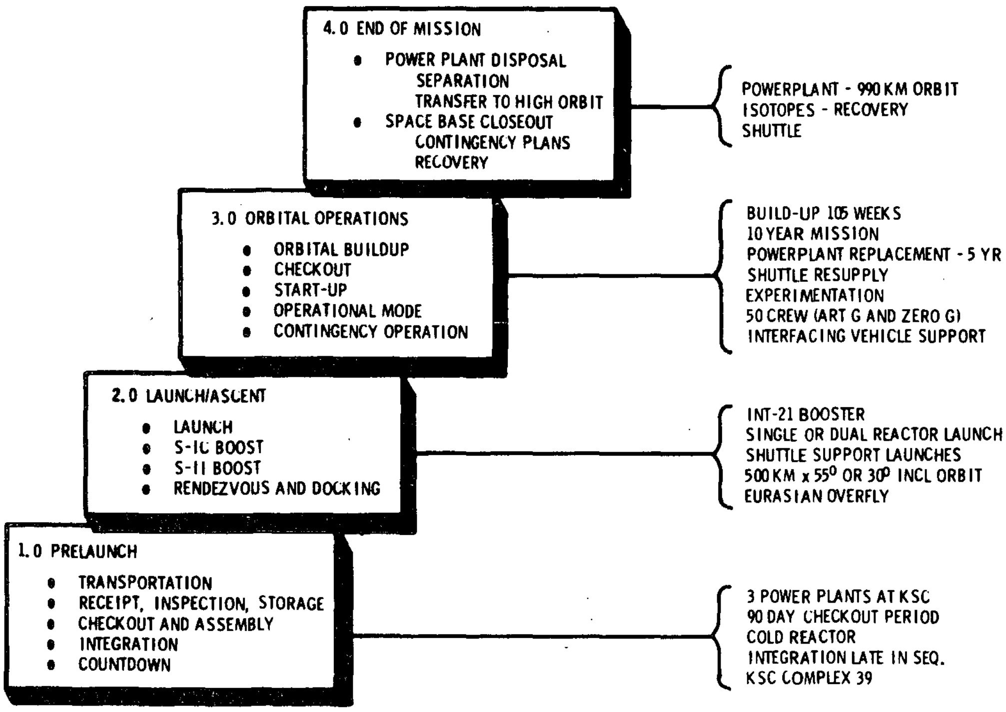


Figure 5-3. Mission Phases

The radiation sources considered in the radiological hazard analysis throughout the Space Base mission phases are those identified in Table 5-4.

Table 5-4. Space Base Program Nuclear Sources

	Nuclear Sources	Remarks
Baseline	Reactor(s)	Space Base Nuclear Shuttle Nuclear Propellant Depot
	Radioactive Tracers	Experiment Labs
	X-Ray Equipment	Experiment Labs
	Natural Environment	Earth Trapped/Cosmic Radiation, Solar Flares
Perturbations	Isotope Brayton Power	Back-up Electrical Power Candidate
	Radioisojet Thrusters	Orbit Adjust System
	Isotope Heated Waste Management System	Advanced Technology Experiment

An additional task was performed which addressed nuclear safety aspects of transporting nuclear hardware to an from a Space Base by a Space Shuttle. Results from that task are not a part of this System Safety Plan, although implementation of the radiological safety program for the Shuttle would require similar activities. Reference should be made to study documentation 72SD4201-4 for further details.

5.4 HAZARD IDENTIFICATION AND CATEGORIZATION

The specific potential radiological sources and hazards identified in the Space Base Nuclear System Safety Study are summarized in Tables 5-5 and 5-6 to provide a starting point for continuing safety efforts of Manned Space Flight Programs.

Categorization of these radiological hazards are consistent with the hazard categories listed in the NASA Office of Manned Space Flight Safety Program Directive No. 1, Revision A. Since many of these identified potential hazards could occur in different degrees of severity, the rationale used in categorizing these hazards was to list a potential range of the occurrence or the "worst case" or most severe condition.

The probability of occurrence in most cases is or can be made very low. Reference should be made to Volumes II, III and IV of the study documentation where the hazards are discussed, probabilities are determined, risks evaluated and design and operational features are recommended to minimize and in some cases prevent these hazards from occurring.

Table 5-5. Space Base Operations – Hazard Sources by Mission Phase (Ground and Flight Personnel and Mission Hardware

NORMAL CONDITIONS			MISSION PHASES			
Hazard Source	Source Condition	Potential Hazard	Prelaunch	Launch/Ascent	Orbital Oper.	End-of-Mission
Natural Radiation Environment Geomagnetically Trapped Protons, Electrons and Galactic Cosmic Rays	Varying Degree of Intensity Depending on Orbit Position	Excessive Radiation	N/A	Neg	Neg	Neg
Solar Radiation	Solar Flare	Excessive Radiation	N/A	Neg → Marg	Neg → Marg	Neg → Marg
Reactor Power System	Shutdown (No Operating History)	Excessive Radiation	Neg	Neg	Neg	N/A
	Shutdown (Post Operation)	Excessive Radiation	N/A	N/A	Neg	Neg
	Normal Operating Power	Excessive Radiation Thermal Interference	N/A N/A	N/A N/A	Neg Neg → Marg	N/A N/A
	Emergency Operating Power	Excessive Radiation Thermal Interference	N/A	N/A N/A	Neg → Marg Neg → Marg	N/A N/A
Interfacing Vehicles *Reusable Nuclear Shuttle	Shutdown (Post Operation)	Excessive Radiation	N/A	N/A	Neg	N/A
	Normal Power (Thrusting)	Excessive Radiation	N/A	N/A	Neg	N/A
*Orbital Propellant Depot (Reactor Power System	Shutdown (Post Operation)	Excessive Radiation	N/A	N/A	N/A	N/A
	Normal Operating Power	Excessive Radiation	N/A	N/A	Neg	N/A
Experiment Laboratories X-ray Equipments	As Installed	Excessive Radiation	Neg	N/A	Neg	N/A
Open Radioisotope Sources/Tracers	Stored	Excessive Radiation	Neg	Neg	Neg	Neg
	In Use	Radioactive Contamination	N/A	N/A	Neg	N/A
Closed Isotope Sources/Capsules	As Installed As Installed	Excessive Radiation Excessive Radiation	Neg Neg	Neg Neg	Neg Neg	Neg Neg
ACCIDENT CONDITIONS						
Space Base Reactor Power System	Damaged Reactor Shield	Excessive Radiation Tritium Release	Neg Neg	Neg Neg	Crit Marg	Crit Marg
	NaK Coolant Release	Excessive Radiation (Activated NaK) Structural Corrosion Equipment Contamination Personnel Contamination	Neg Neg Neg Neg	Neg Neg Neg Neg	Neg → Marg Neg → Crit Neg → Crit Neg → Crit	Neg → Marg Neg → Crit. Neg → Crit Neg → Crit
	Fission Product and NaK Coolant Leak	Excessive Radiation Structural Corrosion Equipment Contamination Personnel Contamination	Neg Neg Neg Neg	Neg Neg Neg Neg	Neg → Crit Neg → Crit Neg → Crit Neg → Crit	Neg → Crit Neg → Crit Neg → Crit Neg → Crit
	Non-Destructive Excursion	Excessive Radiation	Marg	Marg	Marg	Marg
	Destructive Excursion	Excessive Radiation Structural Corrosion Equipment Contamination Radioactive Debris	Crit → Cat Crit → Cat Crit → Cat Crit → Cat	Crit → Cat Crit → Cat Crit → Cat Crit → Cat	Crit → Cat Crit → Cat Crit → Cat Crit → Cat	Crit → Cat Crit → Cat Crit → Cat Crit → Cat
Interfacing Vehicles *Reusable Nuclear Shuttle	Fission Products in Plume	Excessive Radiation	N/A	N/A	Neg	Neg
	Reactor Disassembly	Excessive Radiation	N/A	N/A	Marg	N/A
	Loss of Attitude Control	Excessive Radiation	N/A	N/A	Marg	N/A
*Orbital Propellant Service Depot	(Same as Space Base Reactor Power System)	(Same as Space Base Reactor Power System)	N/A	N/A	Marg	N/A
Experiment Laboratories X-ray Equipment/ Dynamic Generators	Inadvertent Turn-On	Excessive Radiation	Neg → Marg	N/A	Neg → Marg	Neg → Marg
Isotope Tracers/ Open Sources	Release to Space Base Environment	Internal Exposure of Critcal Body Organs	N/A	N/A	Neg → Cat	Neg → Cat
Closed Sources/ Isotope Capsules	Shielding Failure/ Removal	Excessive Radiation	Neg → Marg	Neg → Marg	Neg → Marg	Neg → Marg
	Encapsulation Failure	Internal Exposure of Critical Body Organs	N/A	N/A	Neg → Marg	Neg → Marg

*Prelaunch and launch of these vehicles is not included.

Legend: N/A - Not Applicable; Neg - Negligible; Marg - Marginal; Crit - Critical; Cat - Catastrophic

Table 5-6. Potential Reactor Terrestrial Radiological Hazards

Hazard Source	Source Condition (Arising From)	Potential Hazard
Reactor, Ground Level	Non-destructive Excursion, Ground Level	Prompt neutron and gamma radiation (Relatively low level with shield around reactor)
	Quasi-Steady State Critical	Prompt neutron and gamma radiation which may be attenuated due to shielding from water or partial burial
	Shutdown Radiation	Gamma radiation from fission product decay and activated materials.
	Destructive Excursion, Ground Level	Prompt neutron and gamma radiation.
Airborn Fission Products and/or Activated Materials	Destructive Excursion, Ground Level	Gamma and beta radiation from a cloud of radioactive material contributing direct radiation to the body and inhalable particles.
	Reactor Disassembly on Impact	Same as above
	Reentry Heating/Burn-up	Gamma and beta radiation from radiative material in the stratosphere or mesosphere with potential of wide dispersal at relatively low dose levels.
Ground Deposited Fission Products and/or Activated Materials	Destructive Excursion, Ground Level	Gamma and beta radiation at ground level
	Reactor Disassembly on Impact	Gamma and beta radiation at ground level. Dose levels dependent on fission product decay time.
	Reentry Heating/Burn-up	Low level radiation deposited on the ground over a relatively wide area from an atmospheric burn-up.
Bare Fuel Elements and/or Activated Structural Materials	Destructive Excursion, Ground Level	Direct gamma and beta radiation from ground deposited and scattered fuel elements and materials.
	Reactor Disassembly on Impact	Same as above.
	Re-entry Heating/Burn-up	Direct gamma and beta radiation from impacted fuel elements and materials.
Fission Products and/or Activated Materials Deposited in Drinking Water	Destructive Excursion in Water Supply	Gamma and beta radiation (S_r90, I^{131} etc.) deposited in water supply and ingested into body.
	Reentry Heating, Material Deposited in Water Supply	Same as above - possibly smaller quantities.
Fission Products and/or Activated Materials Deposited in Waters Containing Edible Marine Life	Destructive Excursion (Over Moderation)	Gamma and beta radiation (S_r90, etc.) deposited in water, consumed by marine life and subsequently ingested into human body.
	Reentry Heating, Material Deposited in Water	Same as above - possibly smaller quantities.
Fission Products Released in Orbit	Destructive Excursion in Orbit	Possible direct radiation and inhalable and ingestionable particles from airborne or ground/water deposited fission products and materials.

5.5 HAZARDS ANALYSES

5.5.1 MISSION SUPPORT OPERATIONS

Mission support operations analyses conducted in the Space Base Nuclear System Safety Study of the identified radiological hazards resulted in these significant results:

1. The reactor can be designed to present minimum hazards during prelaunch operations at the launch center. Fission product inventories should be negligible with minimum criticality tests performed at the point of manufacture and no such tests at the launch center.

2. Liquid metal fire protection is incompatible with present fire suppression at the launch center. Modifications in present fire protection techniques are required including the addition of liquid metal fire suppressants, isolation barriers and sumps etc. Liquid metal fire hazards can be minimized by use of nonliquid metal radiators, provision of double wall containment and use of inert gas blankets.

3. The necessity and desirability of integrating and testing the reactor power module within the Vehicle Assembly Building is questionable. Consideration should be given for a direct transfer of the power module from the Nuclear Assembly Building to the Launch Pad.

4. Extensive use can be made of existing facilities at KSC. A nuclear assembly and storage facility, and a minimum liquid metal servicing facility are required.

5. A universal reactor power module transport and storage trailer provided with environmental protection and status monitoring can serve in transport, storage, checkout and integration operations to minimize handling functions and potentially hazardous situations.

6. Isotope heat sources require redundant prelaunch cooling and should be integrated with the launch vehicle as late in the countdown sequence as feasible.

7. Mission Control can assist in the radiological monitoring and control of the crew and provide supporting diagnostic data for the rapid maintenance and/or replacement of nuclear hardware.

8. Quick response recovery and decontamination teams are required at KSC. A mobile team coupled with advance warning of impending impact can minimize the potential hazard to the general populace.

9. Relatively high inclinations (55°) may require Eurasian overfly prior to orbital insertion. Destruct systems could be safed to minimize Eurasian impact potential.

5.5.2 ORBITAL OPERATIONS

Orbital operations analyses, conducted in the Space Base Nuclear System Safety Study, of the identified radiological hazards resulted in these significant results:

1. The natural space radiation environment in typical Space Base earth orbits can present a more severe hazard to the crew and space subsystems than a shielded operating reactor. The dose rate from the reactors at the nearest crew module is approximately 1 mrem/hr contrasted to 3 mrem/hr obtained from the natural space radiation environment in a 500 km 55 degree inclination orbit.

2. Ten year orbital missions with crew stay-times of one year are feasible. Predicted solar flare activity and practical Space Base module shielding necessitate storm shelter provisions for crew stay-times of over one year. The eye dose limits as defined by the National Academy of Sciences appears to make the eyes the limiting body organ. Increased shielding in headgear can help to reduce the doses to the eyes.

3. The normal space base reactor environment allows for Space Shuttle and Tug rendezvous at any view angle if loiter times are minimized and breaking gate times and velocities are maintained within currently planned specifications. A crewman flying a rendezvous with the flight path directly head-on to the power module (worst case) was calculated to receive a maximum integrated dose of approximately 24 mrem.

4. The radiation limits on the storage and usage of film may present one of the most frequent resupply requirements. High speed films stored or contained within 20 gm/cm^2 shielding will have lifetimes of 25 to 50 days, provided no solar flares occur. A solar flare could eliminate the entire stored film supply.

5. Several of the experiments identified in the "NASA Blue Book" are susceptible to dynamic interference which can be attributed to the radiation environment. Dynamic interference is assumed to exist where signal to noise ratios greater than 1:10 result from the radiation received. Solar flares, high radiation belts such as the South Atlantic anomaly, or radiation from the Space Base and interfacing vehicle reactors can be sources of this problem. Although shielding can, in some instances, minimize the problem, in many cases the best solution is an operational restriction which calls for a temporary termination of experimentation. Location changes and distance restrictions can also be made.

6. Dynamic interference thresholds of the sub-satellite experiments require nominal separation distance from the Space Base reactors of from several meters to several kilometers.

7. Typical susceptible experiments to dynamic interference are the Grazing Incidence X-ray Telescope, Functional Program Element (FPE) 5.1, and the High Energy Stellar Survey Experiment, FPE 5.5. During operation, they are relatively susceptible to gamma and neutron radiation emitted by the reactor and should be considered candidates for detached modules orbiting at distances of several kilometers from the reactor interface.

8. In addition to the nuclear power reactors and the natural environment, there are several additional potential sources of radiation. It is important that the isotope heat sources and isotope tracers contained in the modules be properly shielded and contained to prevent contamination of the Space Base and minimize the integrated doses to the crew in the event of a release.

9. Subsystems of the Space Base are not severly affected by the combined reactor and space radiation environment over the 10 year mission. However, where threshold damage to electronics may result, piece part selection, and if necessary, radiation hardening can be performed to minimize if not eliminate the problem.

10. The reactor shield of the Space Base is designed to maintain very low radiation levels at the nearest habitable module (< 1 mrem/hr). Relatively heavy shielding away from the Space Base is also provided. Lighter reactor shields and higher operating thermal power levels will increase the radiation levels and likewise increase the hazards to the crew, subsystems and experiments.

11. Biological experiments (specimens) exhibit a wide range of radiation sensitivity. The radiation protection required is dependent on the specimen, type, age, and the experiment objective. Monitoring the radiation dose to sensitive bioscience experiments is recommended.

12. A reactor shield leak in orbit can result in increased radiation which increases with time. Compartmentalized and/or increased shield cladding combined with leak detection instrumentation can minimize the hazard and allow more time for repair.

13. The presence of a reactor(s) on the Space Base Mission requires a minimum of additional radiological control support. It is estimated that in a crew of 50, an averaged time of at least 3 men are required to support the entire radiological control program, the direct support of the reactors accounting for only 1/2 of a crewman.

5.5.3 REACTOR POWER MODULE STUDIES

Significant results of several qualitative studies of the nuclear safety implications concerned with the reactor power module configuration and operation include the following:

1. The servicing, replacement and operating characteristics of multiple reactor power modules are enhanced by providing adequate power module to Space Base core separation distances. Rendezvous corridors should also be considered in the configuration layout.

2. The Brayton and organic Rankine cycle power conversion systems permit relatively low temperature operation which in turn allows the use of non-liquid metal radiators. Toxic, corrosive and explosive coolants should be avoided where feasible.

3. Several Power Conversion System (PCS) features can increase nuclear safety: (1) multiple operating PCS units are preferred for safe shutdown and to minimize temperature transients, and (2) a separable heat exchanger allows for a modular powerplant and permits significant increases in the reentry ballistic coefficient thereby extending reactor orbital lifetimes by as much as a factor of 10.

4. The ZrH thermal reactor exhibits several inherent safety features: (1) desirable negative temperature coefficient, (2) compact minimum void space, reducing fuel load susceptibilty to core compaction accidents, and (3) release of hydrogen within core upon a temperature excursion provides inherent shutdown capability.

5. Disposal of a reactor power module is best accomplished by boosting to a long life (> 100 year decay) high earth orbit or recovery via the Space Shuttle. Random reentry and/or burn up in the earth's atmosphere are politically, if not radiologically, unacceptable.

6. Positive and permanent shutdown is recommended. Neutron poison injection coupled with drum lockouts are feasible techniques.

7. Maintenance operations involving the PCS and other life limited components within a pressurized and temperature controlled engine room located in the aft section of the power module, was determined to be feasible and crew radiation limits would not be exceeded with both reactors operating. Repair of the primary loop, shield and reactor systems during or after operation is deemed not feasible.

5.5.4 TERRESTRIAL SAFETY

A preliminary terrestrial safety analysis (safety of the earth's general populace) was performed for all phases of the Space Base mission (Reference Volume III (72SD4201-3) of the Study). These analyses resulted in these significant results:

1. The overall Space Base mission radiological risk to the general populace is low and can be further reduced by the incorporation of several design and procedural features:

   a. Design for no excursion

   b. Assure shield reentry capability

   c. Provide for intact reentry

   d. Consider use of Shuttle for recovery.

2. Minimum risk exists during the early phases of the mission (e.g., KSC prelaunch operations) due to the low fission product inventory of the reactor. Radiological exposure and contamination is confined within the KSC boundary.

3. Present fallback/exclusion areas and KSC boundaries (4 km and 13 km, respectively) are adequate for the mission.

4. Deep ocean impact presents negligible risk. A slightly higher risk results from impact along the Continental Shelf.

5. The most significant reactor radiological source terms result from (1) a destructive excursion, (2) distributed fuel elements, structural debris and deposited fission products from an impacted reactor, (3) quasi-steady state operation of the reactor after impact.

6. Low level radiation over large areas result from a reentry burnup. Radiological consequences are small but political implications should be considered.

7. The LiH radiation/heat shield exhibits questionable reentry capability.

8. Fission product inventories are high immediately after shutdown of a reactor that has been operating at full power for months and years. Decay time of > 10 days allows rendezvous and transport by Space Shuttle.

9. Fission product inventories decay to insignificant values for time periods greater than 100 years after shutdown.

10. The dominant risk occurs during the disposal phase due to disposal failures which result in relatively early reentries and the eventual reentry and impact or landing on the earth's surface in all situations.

5.6 HAZARD REDUCTION

Specific recommendations for eliminating or mitigating those radiological hazards identified in the Space Base Nuclear System Safety Study are summarized in consonance with the hazard reduction precedence sequence of the OMSF Safety Program Directive No. 1, Revision 4. This hazard reduction precedence sequence is as follows:

5.6.1 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).

5.6.2 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.

5.6.3 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.

5.6.4 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.

Residual hazards for which safety or warning devices and special procedures cannot be developed or provided for counteracting the hazard shall be specifically identified to safety and program management. Continuation of effort to eliminate or reduce such hazards shall be accomplished throughout the program by maintaining awareness of new safety technology or devices being developed and their application to the residual hazards. Justification for the retention of residual hazards shall be documented.

5.7 SAFETY GUIDELINES

A number of guidelines have resulted from the study and are delineated in Volume IV (72SD4201-4). Reference shall be made to this document and supporting data in the implementation of nuclear safety guidelines for subsequent phases of the Manned Space Flight program. Several of the significant guidelines are summarized in accordance with the aforementioned hazard reduction precedence sequence.

5.7.1 DESIGN FEATURES

1. Provide special nuclear assembly and storage facilities capable of segregating isotope and reactor storage and checkout activities.
2. Nuclear storage and checkout facilities must be provided with proper environmental control and design features to reduce liquid metal hazard potential.
3. Provide redundant cooling capability for isotopes during storage, checkout, transportation and at the launch pad.
4. Where feasible, consider use of non-liquid metal radiators.
5. Provide a universal transporter in support of transportation and prelaunch activities.
6. Provide for the use of the Space Shuttle as the prime and/or backup means of launch and/or recovery of nuclear hardware.
7. Provide Storm Shelter facilities for refuge from Solar Flare events.
8. Provide on-board radiological monitoring of radiation dose accumulated by the crew.

9. Select subsystem components and component piece parts to minimize degradation due to radiation over the mission duration.

10. Provide orbit adjust capability to rapidly change Space Base orbit altitude in the event of a severe nuclear incident in orbit.

11. Provide separate waste management systems for crew and laboratory contaminated waste.

12. Provide for detached module implementation of gamma ray and neutron sensitive experiments.

13. Provide shielded storage (approximately 20 gm/cm^2) for photographic film and emulsions.

14. Locate laboratories using relatively large isotope tracer concentrations in zero-g and possible isolatable and removable portions of the vehicle.

15. Provide a positive mechanical system for separation of the reactor power module from the Space Base.

16. Provide fragmentation protection for nuclear hardware.

17. Design reactor to preclude criticality accidents (destructive excursions).

18. Provide positive means of sensing reactor control drum position.

19. Provide puncture and rupture protection for NaK coolant lines (double containment features).

20. Provide an effective reactor reentry and impact protection system.

5.7.2 SAFETY DEVICES

1. Provide anti-criticality and penetration-free containment for nuclear hardware.

2. Provide control drum lock-out devices for reactor power modules.

3. Consider use of dummy power modules for integration tests in VAB.

4. Provide compatible liquid metal fire protection and fighting capability wherever liquid metals are present.

5. Provide radiation and thermal shields for prolonged operations around a large isotope heat source.

6. Provide multiple escape routes.

7. Consider use of liquid metal sump tanks.

8. Provide safing of the S-II destruct system as Eurasian overfly is made.

9. Provide means of safing a reactor in a quasi-steady state critical condition.

10. Provide rapid response recovery, safing and decontamination capability over entire potential impact zone.

11. Provide emergency EVA suits compatible with a NaK environment.

12. Provide shielding and control interlocks and restrict reorientation of dynamic radiation generators (x-rays, ion guns, lasers and microwave sources).

13. Provide an effective and automatic means of reactor shutdown under all conditions.

14. Provide for positive and permanent reactor shutdown prior to disposal and at end of mission.

15. Provide for the safe and prompt disposal of a spent or malfunctioning reactor.

16. Provide tracking and location aids for land and water recovery of nuclear hardware.

5.7.3 WARNING DEVICES

1. Provide personnel dosimetry and radiation monitoring and warning signs and instrumentation in all areas where nuclear hardware is present.

2. Provide proper escort and warnings during transportation.

3. Provide rapid response fire alarm and detection systems for liquid metal fires.

4. Provide proper liquid metal fire fighting materials with yellow markings.

5. Provide integrated dose, nuclear system status and fault diagnostic support in orbit and at the Mission Control Center (MCC).

6. Provide ground supported advanced warnings of malfunctions or hazardous conditions where possible (solar flare event, etc.)

7. Provide a central on-board warning system for monitoring and alerting against radiological hazards.

8. Provide proper governmental authorities with technical data for advanced warnings and preparations required for impending ground impact of nuclear material.

9. Provide means for monitoring and warning of imminent collisions with space debris and orbiting vehicles.

10. Provide instrumentation to detect LiH shield punctures.

11. Provide for liquid metal leak detection during prelaunch and in orbit.

5.7.4 SPECIAL PROCEDURES

1. Select routes to avoid heavily travelled and populated areas in the transport of nuclear hardware.

2. Use cross-trained personnel in support of nuclear hardware prelaunch activities with actual real situation experience (radiation and liquid metal hazards).

3. Limit and regulate personnel/activities in radiation areas.

4. Limit use and presence of ordnance and disposal rocket motors within nuclear facilities.

5. Perform reactor cirticality checks prior to delivery to launch site (KSC).

6. Limit criticality testing to provide negligible fission product inventory during prelaunch.

7. Employ two man "buddy" system in hazardous areas.

8. Install reactor power modules and isotopes systems as late in the prelaunch sequence as feasible.

9. Provide appropriate procedural modifications in the KSC Ground Safety Plans and the USAF Range Safety Manual.

10. Keep nuclear hardware operations at the launch pad to a minimum.

11. Maintain control drum lockouts in position during prelaunch operations. Restrict control drum movement to a single drum.

12. Conduct thorough evaluation of the necessity and desirability of integration and testing of nuclear reactor power modules within the VAB.

13. Restrict smoking and eating in radiation and liquid metal areas.

14. Maintain current administratively controlled areas with a minimum radius of approximately 13 km and exclusions areas of 4 km radius.

15. Consider limiting flight termination impact areas to outside the continental shelf.

16. Provide continuous attended support by the MCC for warning, radiological control and fault diagnosis.

17. Establish crew rotation procedures in conformance with career and periodic dose guidelines.

18. Restrict EVA during orbits intercepting the South Atlantic Anomaly.

19. Restrict approach paths of vehicles employing IR (infrared) sensors to avoid interference from high temperature sources.

20. Establish minimum rendezvous distances and shielded approach corridors to orbital vehicles employing nuclear power systems to minimize exposure of crew.

21. Provide experiment data screening procedures for experiments sensitive to South Atlantic Anomaly interference.

22. Minimize power level on operating reactors during reactor replacement.

23. Repairs to NaK lines or in the reactor gallery area are not considered feasible.

SECTION 6
SAFETY TRAINING AND CERTIFICATION

6.1 GROUND TESTING

Operation and testing of nuclear hardware has certain inherent radiation thermal and liquid metal hazards which can be substantially minimized through proper training of personnel.

Specific training should be provided for handling and operations involved with liquid metals. The training should include certification of skills associated with environmental control, leak detection, safing and actual fire fighting under simulated operational conditions.

Special training associated with the ground assembly, handling and testing of a reactor and nuclear heat sources including the non-criticality ground testing of the control drum/actuator systems must be provided, demonstrated and certification given. Proper use of radiation monitoring instrumentation and adherence to radioactive material regulations must be demonstrated. The training should include contingency actions for potential radiological emergencies including the provision of specially trained and equipped nuclear material recovery and safing teams.

6.2 IN ORBIT HANDLING, REPLACEMENT AND REPAIR

Training in the handling, transfer and replacement of reactor power modules and isotope heat sources in zero-g should be provided under zero-g or simulated zero-g conditions. Comprehensive training should be provided in fault diagnosis and repair of components in the reactor power module engine room under suited and unsuited conditions. Rendezvous and docking simulation for initial power module assembly or replacement must be provided. In orbit and zero-g decontamination procedures and techniques developed require special training.

6.3 IN-FLIGHT START-UP AND OPERATION

Training and certification in the remote start-up, power module stabilization and operation must be provided under simulated conditions. Operator control response, sensitivity and response to failure conditions shall be demonstrated along with the ability to diagnose and isolate failure conditions. Specific training in powering down, load sharing and leveling and management of the power conversion systems must be emphasized.

SECTION 7
SAFETY TEST REQUIREMENTS

A series of tests must be provided to ascertain the functional integrity of the nuclear hardware design and key performance characteristics which affect the safety of the system. Several of the principle tests have been noted. Additional tests should be anticipated and specified as firm nuclear hardware designs are developed.

7.1 REACTOR CONTROL DRUM INTERLOCKS

Safety testing of the reactor control drum interlock mechanism should be performed under simulated flight conditions, including prelaunch testing, launch abort and earth impact to determine the adequacy of the fail-safe design features.

7.2 REACTOR PERMANENT SHUTDOWN DEVICES

Safety testing of the effectiveness and reliability of the permanent shutdown features of the reactor should be performed.

7.3 ABLATIVE SHIELD TESTS

Simulated and actual flight tests of the reactor ablative heat shield should be performed to assure shield integrity under all possible pre and post-operative reentry conditions

7.4 FRAGMENTATION AND IMPACT TESTS

Isotope capsules and the reactor/shield should undergo simulated fragmentation and impact testing to assure integrity per specification, under launch explosion and earth impact conditions. Propensity for compaction accidents should also be determined.

7.5 FUEL ELEMENT ABLATION TESTS

Conduct ablative tests of reactor and heat source fuel elements/capsules to ascertain integrity and provide source terms.

7.6 REACTOR TRANSIENT TESTS

Conduct tests to determine modes and characteristics of destructive excursions, temperature excursions, over moderation and quasi-steady state operation conditions.

7.7 FIREBALL SIMULATION

Conduct tests to determine intensity and potential effects of booster fireballs on nuclear hardware.

7.8 DISPOSAL SYSTEM RELIABILITY

The reliability of the disposal system is a major factor in terrestrial safety. The reliability of components after long term (10 year) exposure to space and radiation should be substantiated.

SECTION 8
HAZARDOUS TEST REQUIREMENTS

8.1 REACTOR CONTROL SYSTEM TESTS

Detailed test procedures should be prepared and verified under simulated launch center conditions for the reactor non-critical control drum and actuator system checks.

8.2 NUCLEAR HARDWARE ASSEMBLY

Where it is required to assemble a heat source/fuel elements, tests will be performed to determine shielding fixture and handling tool compatibility as well as projected integrated exposure dosages.

8.3 NUCLEAR HARDWARE INTEGRATION AND CHECKOUT

Tests that are associated with the mating, environmental control, liquid metal leak detection, and fire protection requirements during integration and checkout with the launch vehicle at the VAB and launch pad require precautionary procedures and special ground support equipment. Procedures and equipment must be verified.

SECTION 9
SAFETY ANALYSIS OF TEST AND FLIGHT ANOMALIES

9.1 LAUNCH ANOMALIES

Launching of the Space Base assemblies, including the nuclear reactor power modules, into a 55 degree orbital inclination requires a "dog-leg" boost or overflight of Eurasion land areas during boost. Safety analyses should be considered for determining the maximum release of radioactive material if impact occurs in these land areas and recommending means of reducing the potential radiological hazards.

9.2 TEST ANOMALIES

A safety and performance analysis should be conducted to determine the power level and time limitations for low power criticality tests at the factory.

Detailed safety analysis should also be made to determine the maximum radiation exposure that could occur to the launch site personnel from accidental radioactive material release during the assembly and checkout test operations. Contingency plans and remedial medical facilities should be planned on the maximum exposure basis.

SECTION 10
SAFETY MOTIVATION

All personnel on the Space Base program that handle, test or operate devices containing nuclear and/or radioactive material should be thoroughly and periodically briefed to the inherent and subtle affects of radiation exposure to humans. The following nuclear safety precautions that should be of general concern to all program personnel are:

1. Importance of adherence to radiological safety regulations and monitoring procedures
2. Use of the "buddy system" in hazardous areas
3. Cleanliness
4. Liquid metal hazards and handling requirements
5. Provision and adherence to all warning signs.

SECTION 11
ACCIDENT/INCIDENT INVESTIGATION

A means of reporting and investigating accidents/incidents rapidly must be set up and effective steps taken to prevent or minimize further occurrence. Reference should be made to U.S. Government document 10CFR20, Section 20.403, "Notification of Incidents", for reporting procedures.

SECTION 12
SYSTEM SAFETY DATA

Whenever practical, existing data systems should be utilized to provide safety information for a program system safety data bank. Such a data system may be analogous to a simple closed loop block diagram as shown in Figure 12-1.

The input function block consists of planning data, which could include: (1) previous experience and knowledge from other programs; (2) baseline or reference configurations or missions; (3) safety goals, objectives and initial criteria; (4) program safety requirements; (5) contractor safety requirements; and (6) safety plans for approach techniques, organization structure, responsibility and reporting.

The driving function block consists of safety implementation, which could include: (1) design; (2) devices, (3) safety procedures, both preventive and remedial; (4) training and certification; (5) testing; and (6) motivation.

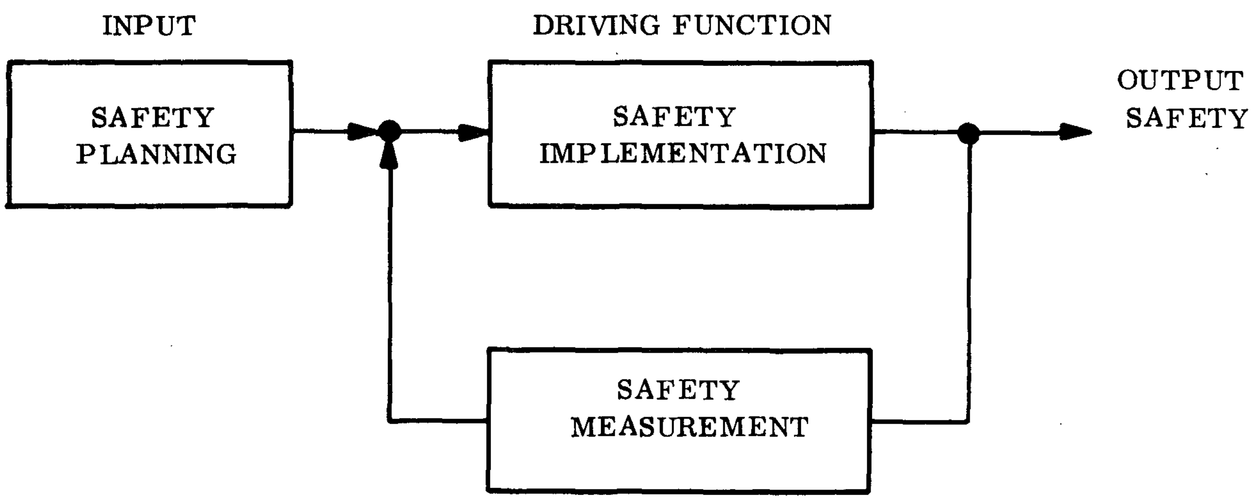


Figure 12-1. Data System

The feedback function block consists of safety measurement which could include; (1) hazard analysis identification and categorization; (2) test data; (3) safety study results; (4) safety survey data; and (5) accident/incident data.

An effective system safety data system can benefit a program by: (1) aiding design in preventing repetitive design deficiencies; (2) providing program management with safety visibility, from an updated identified hazards listing; (3) providing aid in making timely decisions to eliminate or mitigate potential hazards; and (4) providing a measure of the adequacy of implemented safety efforts through hazards identification analysis, surveys and accident/incident reports.

The Program Radiation Protection Office should maintain the program radiological safety data bank. He should provide contractors with safety goals, objectives, safety and design criteria and requirements. He should receive from contractors, safety plans, identified hazards and category listings, safety study reports, accident/incident data and hazard elimination or mitigation data.

The Program Radiation Protection Officer should provide the Center Radiation Protection Officer with safety criteria, goals, objectives, identified inherent potential hazards, facilities and support safety requirements. He should receive from the Center Radiation Protection Officer, preventive and remedial procedures, a Center Radiological Safety Plan, Safety Training Certification, accident/incident data, hazard analysis of test and flight anomalies, and rescue/recovery plans.

CONVERSION FACTORS
INTERNATIONAL TO ENGLISH UNITS

Physical Quantity	International Units	English Units	Conversion Factor Multiply By
Acceleration	m/sec^2	ft/sec^2	3.281
Area	m^2	ft^2	10.764
		in^2	1550.39
Density	Kg/m^2	lb/ft^3	6.242×10^{-2}
		lb/in^3	3.610×10^{-5}
Energy	Joule	Btu	9.479×10^{-4}
Force	Newton	lbf	2.248×10^{-1}
Length	m	ft	3.281
		nm	5.399×10^{-4}
Mass	Kg	lbm	2.205
Power	watt	Btu/sec	9.488×10^{-4}
		Btu/min	5.691×10^{-2}
		Btu/hr	3.413
Pressure	$Newton/m^2$	Atmosphere	3.413
		lbf/in^2	1.451×10^{-4}
		lbf/ft^2	2.088×10^{-2}
Speed	m/sec	ft/sec (fps)	3.281
Temperature	K	F	$(9/5 - 459.67/t_K)$
Volume	m^3	in^3	6.097×10^4
		ft^3	35.335

GLOSSARY OF TERMS

Abort	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.)
Accident	An undesirable unplanned event which may or may not result from a system failure or malfunction.
Airborne Material	Radioactive gases, vapors and particulates released to the air.
Breached	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.
Bulk Damage (Radiation)	Radiation causing atomic displacement in semiconductor devices - sometimes commonly referred to as "crystal" damage.
Contamination	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.
Control Drum Motion	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.)
Core Compaction	The act of increasing the density of the core which results in increased reactivity and possible criticality.
Cover Gas	A gas blanket used to provide an inert atmospheric environment around hardware to minimize potential reactions which can give rise to accident situations.
Credible	An event having a relative or cumulative probability of occurence of $> 10^{-12}$.
Criticality	The act of obtaining and sustaining a chain reaction.
Critical Mass	The mass of fissionable material necessary to obtain criticality.
Cumulative Probability	Sometimes referred to as "Mission probability" is the overall probability of a sequence of events occurring (product of "relative probabilities" of the individual events along a path of an abort sequence tree).
Damaged	Same as "Breached".
Decontamination	The removal of undesired dispersed radioactive substances from material, personnel, rooms, equipment, air, etc. (e.g., washing, filtering, chipping).
Destructive Excursion	An excursion (safety analysis assumes $\sim$ 100 MW-sec) accompanied by a complete disassembly of the reactor, a prompt radiation emission and release of fission product gases, vapors and particulates.
Disassembly/Disassembled	Nuclear hardware (e.g., reactor) which has been violently broken or separated into parts and not capable of forming a critical mass.
Disposal	The planned discarding or recovery of nuclear hardware.
Distributed Material	The spread of nuclear fuel and radioactive debris on the earth's surface following impact or destructive excursion.
Dose Guidelines	Established radiation levels used in the nuclear safety analysis for evaluating number of exposures and in determining operating limits and boundaries.
Dosimetry	Techniques used in the measurement of radiation.

GLOSSARY OF TERMS (CONT)

Dynamic Interference	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.
Early Reactor Disposal	Attempted disposal of the reactor prior to its successful completion of 5 years operational lifetime.
Electrical Power System	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.
End of Mission	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.
Excursion	A rapid and usually unplanned increase in thermal power associated with the operation of a power reactor.
Exposure Limit	Total accumulated or time dependent radiation exposure limits imposed on personnel by regulatory agencies or limits which preclude equipment damage.
Fission Products	The nuclides (quite often radioactive) produced by the fission of a heavy element nuclide such as U-235 or Pu-239.
Fuel	Fissionable material in a reactor or radioisotopes in a heat source used in producing energy.
Fuel Element/Capsule	A shaped body of nuclear fuel prepared for use in a reactor or heat source. Common usage involves some form of encapsulation.
Fuel Element Ablation	Fuel element clad and/or fuel removed by reentry heating, releasing fission products to the atmosphere.
Fuel Element Burial	Individual fuel elements beneath the ground surface completely covered by soil.
Gallery	The compartment of the reactor shield which houses the major primary loop components.
Ground Deposited Particles	Particles deposited on the ground from radioactive fallout.
Hazard	An existing situation caused by an unsafe act or condition which can result in harm or damage to personnel and equipment.
Hazard Source	The location and/or origin of the hazard.
Immediate Reentry	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).
Impact in Deep Ocean	Reentering and/or impact of nuclear material in the ocean, beyond the Continental Shelf where contamination of the food chain is extremely remote.
Impact in Reservoir	Reentering and/or impact of nuclear material in reservoir containing potable drinking water.
Impact in Water Containing Edible Marine Life	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.
Intact Reentry/Reactor	A nuclear system that retains its integrity upon impact and in the case of a reactor is capable of undergoing an excursion.
Integrated/Cumulative Dose	The total dose resulting from all or repeated exposures to radiation.
Interfacing Vehicle	Any defined module, spacecraft, booster or logistic vehicle which may have an interaction with the Manned Space Base.

GLOSSARY OF TERMS (CONT)

Ionization Damage	Radiation causing surface damage in materials (e.g., the fogging of film).
Land Impact	Nuclear hardware which impacts land at terminal velocities following reentry and lower velocities during prelaunch or early in the launch/ascent phase.
Loss of Coolant	Loss of organic or liquid metal coolant in reactor coolant loops due to failure/accident.
Mission Support	Supporting functions provided the Space Base Program by ground personnel and interfacing vehicles throughout all mission phases.
Moderator	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.
NaK-78	An alloy of sodium (22% by weight) and potassium (78%) used as a liquid metal heat transfer fluid.
No Discernible Hazard	Represents no hazard to the general populace.
Non-credible	An event having a relative or cumulative probability of occurrence of $< 10^{-12}$. Considered not worthy of concern.
Non-destructive Excursion	A temperature excursion which may rupture the primary coolant loop and release fission products to the environment but - leaves the reactor shield essentially intact.
Normal Operations	Planned and anticipated mission activities and events.
Over Moderation	Immersion of reactor in an hydrogenous medium (moderator) resulting in increased neutron reflection into the core causing a reactor excursion.
Permanent Shutdown	Enacting provisions which preclude reactor criticality under all foreseeable circumstances.
Poison	A material that absorbs neutrons and reduces the reactivity of a reactor.
Power Module	The complete reactor/shield, radiator, power conversion system and disposal system unit as provided on the Space Base.
Premature Reentry	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.
Pre-poison	A poison which is added to the reactor fuel for purposes of controlling reacticity. Sometimes referred to as "burnable poison".
Prompt Radiation	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.
Quasi-Steady State	A term used to describe the condition when a reactor periodically goes critical and then subcritical due to water surging in and out of the core.
Radiological Consequences	The radiation exposure effect on personnel and the ecology from a radiation release accident or event.
Radiological Hazards	Hazards associated with radiation as differentiated from other sources.
Radiological Risk	The term used to define the average number of people anticipated to be affected by radiation in a given mission or phase thereof.
Random Reentry	The uncontrolled non-directed reentry of a vehicle from orbit.
Reactivity	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.)

GLOSSARY OF TERMS (CONT)

Reactor Fails to Survive Reentry	Reactor/shield is completely disassembled by reentry heating, releasing individual fuel elements and structural debris to the atmosphere.
Reactor Survives Reentry	Reactor is not disassembled by reentry heating; radiation shield may be damaged.
Reactor/Shield	A system containing the reactor, control drums, gallery and surrounding LiH and Tungsten shield.
Relative Probability	Probability of the occurrence of a particular event given a defined set of choices.
Repair/Replacement	Consists of (a) physically repairing all faulty systems, or (b) complete replacement of the faulty system(s).
Ruptured	Same as "Breached".
Safety	Freedom from chance of injury or loss to personnel, equipment or property.
Safety Catastrophic	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).
Safety Critical	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).
Safety Marginal	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).
Safety Negligible	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).
Scram System	A separate, possibly automatic, mechanism used to rapidly shut down a reactor.
System Safety	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.
Space Base Program	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.
Space Debris	Uncontrolled radioactive or non-radioactive man-made objects in space; these objects may present collision and radiation hazards to earth orbital missions.
Space Shuttle	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.
Source Terms	Characterization of a radiation hazard with regard to (a) location, (b) magnitude, and (c) exposure mode.
Tracer	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.