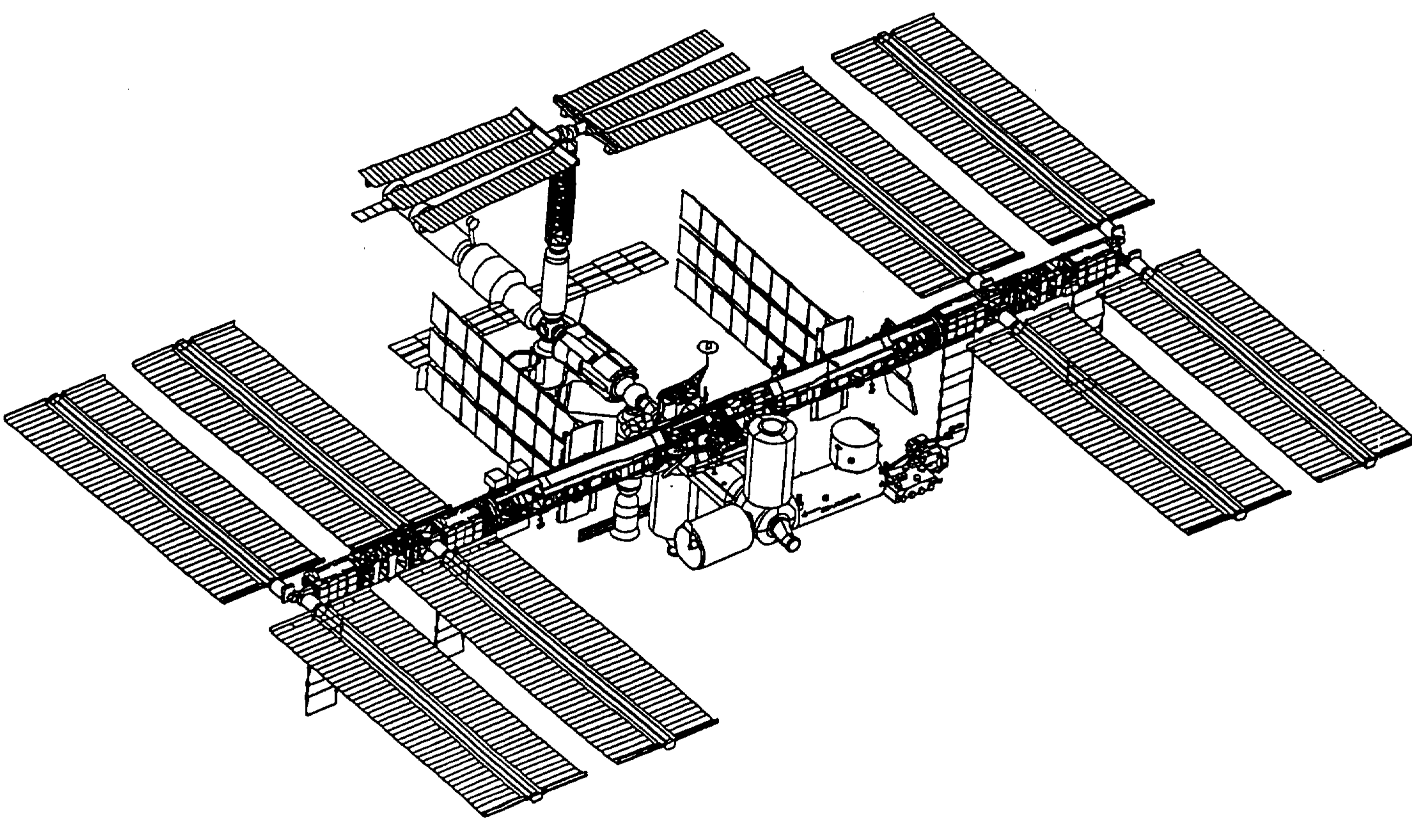
NASA-TM-110480

National Aeronautics and
Space Administration

October 1995

Draft Tier 2 Environmental Impact Statement for International Space Station



Draft Tier 2 Environmental Impact Statement for the International Space Station

Space Station Program Office

Office of Space Flight

National Aeronautics and Space Administration

Washington, D.C. 20546

October 1995

ABSTRACT

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Date: October 1995

The Draft Tier 2 Environmental Impact Statement (EIS) for the International Space Station (ISS) has been prepared by the National Aeronautics and Space Administration (NASA) and follows NASA's Record of Decision on the Final Tier 1 EIS for the Space Station Freedom. The Tier 2 EIS provides an updated evaluation of the environmental impacts associated with the alternatives considered: the Proposed Action and the No-Action alternative. The Proposed Action is to continue U.S. participation in the assembly and operation of ISS. The No-Action alternative would cancel NASA's participation in the Space Station Program. ISS is an international cooperative venture between NASA, the Canadian Space Agency, the European Space Agency, the Science and Technology Agency of Japan, the Russian Space Agency, and the Italian Space Agency. The purpose of the NASA action would be to further develop human presence in space; to meet scientific, technological, and commercial research needs; and to foster international cooperation.

EXECUTIVE SUMMARY

In January 1984, President Reagan committed the Nation to developing a permanently human-occupied space station. The National Aeronautics and Space Administration (NASA) established a Space Station Program to implement that commitment. In response, the Program established the infrastructure necessary to support and direct the activities needed to fulfill the commitments. The Program developed a number of design configurations, leading to the selection of the Space Station "Freedom" (SSF) design in 1988. A Tier 1 Final Environmental Impact Statement (EIS) was released in March 1991, which evaluated the environmental effects associated with the Space Station Freedom design, assembly, and operation. The Tier I identified several topics that were to be addressed in a Tier 2 EIS including, but not limited to, potential changes in Space Station design and associated changes in the Program, and the accidental reentry of the space station during assembly or operation.

On March 9, 1993, President Clinton directed NASA to redesign Space Station Freedom to reduce development, operation, and utilization costs, while still achieving many of the goals for long-duration scientific research. The results of the redesign efforts were presented on June 10, 1993 in the *Final Report to the President* of the Advisory Committee on the Redesign of the Space Station. Reviews and reassessments led to the adoption of the current space station design known as International Space Station (ISS). The Program restructure (a series of management and contracting changes) ensured the space station would deliver significant science and technological benefits at an affordable cost. In late 1993, the United States and its international partners—Canada (Canadian Space Agency [CSA]), Japan (Science and Technology Agency [STA]), and the European Space Agency (ESA)—invited Russia (Russian Space Agency [RSA]) to become a full partner in the Program. RSA hardware and capabilities are now incorporated into the overall ISS design. Italy (Italian Space Agency, or Agenzia Spaziale Italiana [ASI]) has a separate bilateral agreement with the U.S for provision of certain U.S. flight hardware. ISS is now comprised of 10 modules instead of SSF's 6, and the completed ISS would have almost twice the pressurized volume and weight of Freedom. ISS would have an orbital inclination of 51.6 degrees, and require 44 assembly flights, 27 of which would be contributed by the United States. The operational lifetime of ISS would be at least 10 years. Resupply flights to the station would primarily be handled by U.S. and Russian flights, although European and/or Japanese resupply flights are being factored into the logistics scenarios. (It should be noted that, while the Shuttle is planned to be the U.S. launch vehicle, the Titan IV may be used as a backup.) The currently proposed method for decommissioning ISS when its useful life is over would entail a controlled targeted reentry with surviving debris falling into a remote ocean area. The first element launch for ISS is scheduled to take place in 1997, with ISS completion in June 2002.

Proposed Action and the No-Action Alternative

The Proposed Action considered in this Tier 2 EIS is for NASA to continue to provide U.S. participation in the assembly and operation of ISS. The purpose and need for NASA's action, mandated by its charter and presidential directives, is to further develop a human presence in space and to meet scientific, technological, and commercial research needs, and to foster international cooperation. This venture would be a joint effort conducted by NASA, CSA, ESA, RSA and STA, with each agency contributing various scientific and hardware capabilities. The alternative to the Proposed Action, the No-Action alternative (termination of U.S. participation in the assembly and operation of ISS), is essentially the same as that evaluated in the Tier 1 EIS.

Environmental Impacts Associated With the Alternatives

The expected environmental impacts of the Proposed Action would be primarily those associated with normal launch operations of the Space Shuttle from the John F. Kennedy Space Center (KSC), and with decommissioning of ISS. Assembly of ISS would entail 27 Shuttle launches, with an additional 5-6 launches each year thereafter throughout the operating life of ISS for resupply. Normal launch impacts generally result in limited short-term air, water, and biological resources impacts in the immediate vicinity of the launch site. The environmental impacts of normal Shuttle launches are localized to KSC, and will be largely temporary in nature. Shuttle launch impacts have been previously examined in detail in other National Environmental Policy Act of 1969, as amended (NEPA) (42 U.S.C. 4321 et seq.) documents. Should Titan IV launches be used for some ISS missions, the impacts would be largely similar in nature but of lesser magnitude, and they would be centered upon Cape Canaveral Air Station, which is located adjacent to KSC. Titan IV impacts have been addressed in prior NASA and U.S. Air Force NEPA documents.

The currently proposed decommissioning strategy as described in Section 2.2.7 would involve a controlled targeted reentry and burnup of ISS in Earth's atmosphere, with surviving debris landing in remote ocean areas. NASA is taking design measures for ensuring this safe and uneventful reentry. As ISS reenters the Earth's atmosphere, it is expected that the components would break up into fragments of various sizes, burn, and vaporize. As noted in Section 4.1.2.5, it is estimated that about 6 to 19 percent of ISS would survive reentry as fragments. NASA has estimated that the injury risk to people and property from reentering debris during the planned decommissioning would be negligible.

It is also possible that ISS or some of its components could reenter the atmosphere following an unplanned event occurring either during assembly or operation, or during the decommissioning action. It is expected that, as with a controlled reentry, the space station components would break up, with most of the debris burning up upon reentry. Surviving debris, however, could impact over land. Based upon the analyses outlined in Section 4.1.1.6, assuming a random inadvertent reentry, the number of injuries within the population located in the $\pm 51.6°$ latitude band would range from 0.0966 to 0.030, with the risk to a given individual ranging from 1.28×10^{-11} (1 in 78 billion) to 3.999×10^{-12} (1 in 250 billion). While an injury could range from a minor abrasion to a fatality, for the purposes of this EIS, an injury was considered to be fatal. In terms of property damage, the number of structures potentially hit within the ±51.6° latitude band, including the U.S., was estimated to range up to 2 structures, with an estimated value, assuming full loss of each structure hit, of approximately $50,000.

There are no adverse physical impacts associated with the No-Action alternative. Cancellation of U.S. participation would seriously impact assembly and operation of ISS. Failure to assemble and operate ISS would slow and possibly deter the acquisition of scientific data through a human presence in space and would have a negative localized socioeconomic impact. In addition, the ability of the United States to enter into future international agreements for cooperative space activities could be impaired.

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ABBREVIATIONS, ACRONYMS, AND CONVERSION FACTORS

ac	acre
AIT	Analysis and Integration Team
APM	Attached Pressurized Module
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
ATF	Autonomous Thruster Facility
Bq	Bequerel
CCAS	Cape Canaveral Air Station
CCRF	Canister Cleaning and Rotation Facility
CETA	Crew Equipment Translation Assembly
CFR	Code of Federal Regulations
Ci	curie
CLWA	Clear Lake Water Authority
CSA	Canadian Space Agency
EATCS	External Active Thermal Control System
EIS	Environmental Impact Statement
ELM	Experimental Logistics Module
ESA	European Space Agency
EVA	extravehicular activity
FGB	Functional Energy Block
GN&C	guidance, navigation, and control
GSFC	Goddard Space Flight Center
ha	hectares
IP	international partner
IPT	Integrated Product Team
ISPR	International Standard Payload Rack
ISS	International Space Station

ABBREVIATIONS, ACRONYMS, AND CONVERSION FACTORS

(continued)

JEM	Japanese Experiment Module
JSC	Lyndon B. Johnson Space Center
KSC	John F. Kennedy Space Center
KW	kilowatts
LeRC	Lewis Research Center
LoTMP	Low Temperature Microgravity Physics Facility
MLP	Mobile Launch Platform
MPLM	Mini-Pressurized Logistics Module
MSFC	George C. Marshall Space Flight Center
MT	Mobile Transporter
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NEPA	National Environmental Policy Act
n.m.	nautical miles
NOI	Notice of Intent
NPDES	National Pollutant Discharge Elimination System
ODC	ozone depleting chemical
ONC	operational navigation charts
OPF	Orbital Processing Facility
ORU	Orbital Replacement Unit
PDR	Preliminary Design Review
PMA	Pressurized Mating Adapter
ppm	parts per million
ppt	parts per thousand
PSC	polar stratospheric cloud
PSF	Power Systems Facility
PV	photovoltaic

ABBREVIATIONS, ACRONYMS, AND CONVERSION FACTORS

(continued)

RMS	remote manipulator system
ROD	Record of Decision
RSA	Russian Space Agency
SAGE	Stratospheric Aerosol and Gas Experiment
SAIC	Science Applications International Corporation
SBUV	Solar Backscatter Ultraviolet Scpectrometer
SCA	Shuttle carrier aircraft
SM	Service Module
SPP	Solar Power Platform
SRB	solid rocket booster
SRM	solid rocket motor
SSF	Space Station Freedom
SSME	Space Shuttle Main Engine
SSPF	Space Station Processing Facility
SSPO	Space Station Program Office
STA	Science and Technology Agency of Japan
STS	Space Transportation System (Space Shuttle)
TBD	to be determined
TOMS	Total Ozone Mapping Spectrometer
UHF	ultra-high-frequency system
ULC	Unpressurized Logistics Carrier
ULCAS	Unpressurized Logistics Carrier Attached System
USFWS	U.S. Fish and Wildlife Service
UV	ultraviolet
VAB	Vehicle Assembly Building
VAFB	Vandenberg Air Force Base

ABBREVIATIONS, ACRONYMS, AND CONVERSION FACTORS

(continued)

Conversion Factors

Length:	1 meter (m)	=	3.28 feet (ft)		
	1 kilometer (km)	=	3,280 feet (ft)	=	0.539 nautical miles (n.m.)
	1 nautical mile (n.m.)	=	1.15 statute miles (mi.)		
Area:	1 hectare (ha)	=	2.47 acres (ac)		
	1 square meter (m^2)	=	10.753 square feet (ft^2)		
	1 square kilometer (km^2)	=	0.29 square nautical miles ($n.m.^2$)		
Temperature:	°Celsius (°C)	=	(°Fahrenheit [°F]-32) 5/9		
Weight:	1 kilogram (kg)	=	2.2 pounds (lb)		
Volume:	1 liter (l)	=	0.26 gallon (gal)		
	1 cubic meter (m^3)	=	35.3 cubic feet (ft^3)		
Radioactivity:	1 Bequerel (Bq)	=	2.703×10^{-11} curies (Ci)		

1.0 PURPOSE AND NEED FOR ACTION

This Tier 2 Environmental Impact Statement (EIS) has been prepared by the National Aeronautics and Space Administration (NASA) to support the decision-making process as required by the National Environmental Policy Act of 1969, as amended (NEPA) (42 U.S.C. 4321 et seq.). This EIS provides information associated with potential environmental impacts that could be caused by United States contributions to the assembly and operation of the International Space Station (ISS), and by the No-Action alternative.

1.1 INTRODUCTION

Whenever a federal agency proposes to undertake a major action that can significantly affect the quality of the human environment, NEPA and the Council on Environmental Quality Regulations for Implementing the Procedural Provisions of NEPA (40 CFR [Code of Federal Regulations] Parts 1500-1508) require that agency to undertake the systematic examination of possible and probable environmental consequences of the Proposed Action and its alternatives. NASA's policy and procedures (14 CFR Subpart 1216.3) require the preparation of an EIS for major actions that may have a significant impact on the human environment.

The approach to providing environmental documentation for ISS, including this Tier 2 EIS, has been the product of an evolving process. In March 1991, NASA published the Final Tier 1 EIS for Space Station Freedom (SSF).[1] The Tier 1 EIS provided information necessary to support decision-making as SSF continued the design and development phase. The Proposed Action was to design, develop, assemble, and operate SSF. As part of NASA's Record of Decision (ROD), it was stated that potential changes to the SSF configuration resulting from program reviews and reassessments would be addressed in a Tier 2 EIS. Those reviews and reassessments led to the adoption of the current space station design known as ISS. This Tier 2 EIS provides the required environmental documentation associated with the Program and design changes reflected by ISS.

1.2 BACKGROUND

In May 1982, NASA formed a Space Station Task Force to develop ideas for a permanently human-occupied space station to be deployed in low Earth orbit. Approximately one year later, NASA released a concept for review within the federal government. In January 1984, President Reagan committed the Nation to the goal of developing a permanently human-occupied space station within a decade. Other nations were invited to participate; Canada, the European Space Agency (ESA), and Japan, accepted.

NASA established a Space Station Program Office (SSPO) in April 1984 which developed a reference configuration known as the "Power Tower." The Power Tower had a single vertical keel with articulated solar arrays and five pressurized modules located at the lower end of the structure. During the space station definition phase, this configuration was changed to a "dual-keel" configuration to satisfy additional user requirements. The dual-keel configuration moved the pressurized modules to the center of gravity along a transverse boom and increased the amount of truss structure.[1] In 1987, NASA elected to develop a space station using a phased approach. The baseline station was essentially the same as the dual-keel configuration without the two vertical keels and with some changes in systems and payload accommodations. The baseline configuration of that design is shown in Figure 1-1. On July 18, 1988, President Reagan officially named the Space Station "Freedom."[1]

Alternative designs continued to be evaluated and refined, and three concepts were addressed in the Tier 1 EIS finalized in March 1991. The preferred configuration for SSF was envisioned as a six-module human-occupied facility with three co-orbiting platforms. The Station, designed for a 30-year minimum life expectancy, would have required 30 U.S. assembly flights and two ESA flights. Because the final detailed design of the Station had not been completed at the release of the Final Tier 1 EIS, a Tier 2 EIS was planned to address major changes in the space station configuration and Program milestones as the project matured.

Significant changes have taken place in the Space Station Program since the Tier 1 EIS was released. On March 9, 1993, President Clinton directed NASA to redesign SSF to reduce development, operation, and utilization costs while still achieving many of the current goals for long-duration scientific research.

Accordingly, the NASA Administrator assembled a Space Station Redesign Team to provide several options that would meet the President's direction. Goals were provided to the Station Redesign Team for a revised space station with a life of at least 10 years, as well as specific objectives and constraints.[2] An independent senior-level panel, the Advisory Committee on the Redesign of the Space Station, was formed to review and assess the Station Redesign Team's findings. This panel was charged with independently assessing the redesign options and proposing recommendations to improve the efficiency and effectiveness of the Space Station Program.

Numerous concepts were presented to the Station Redesign Team. Input came from NASA centers, industry, the SSPO, international partners (IPs), and other interested parties. This input provided a diverse set of architectures, management, and operations approaches, as well as constraints and lessons learned. The team assessed all concepts within the guidance framework provided by the NASA Administrator and the existing international agreements. Team members also arranged for technical briefings with a delegation from the Russian Space Agency (RSA). The team soon narrowed the field to three basic design options, and focused its efforts on defining those options as thoroughly as time allowed. Figure 1-2 displays the decision/alternative history associated with the redesign process.

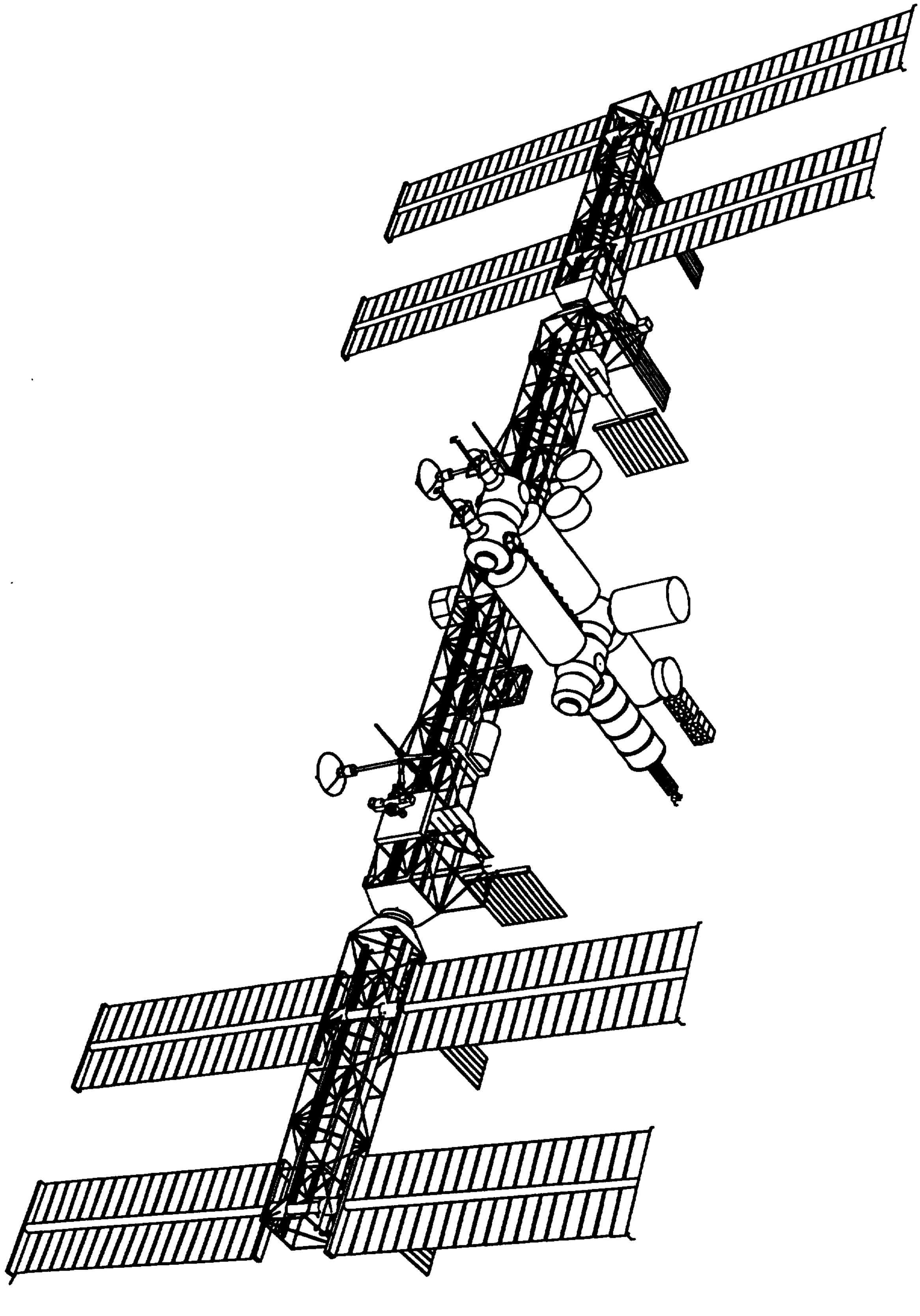


Figure 1-1. SSF baseline configuration (co-orbiting platforms not shown).

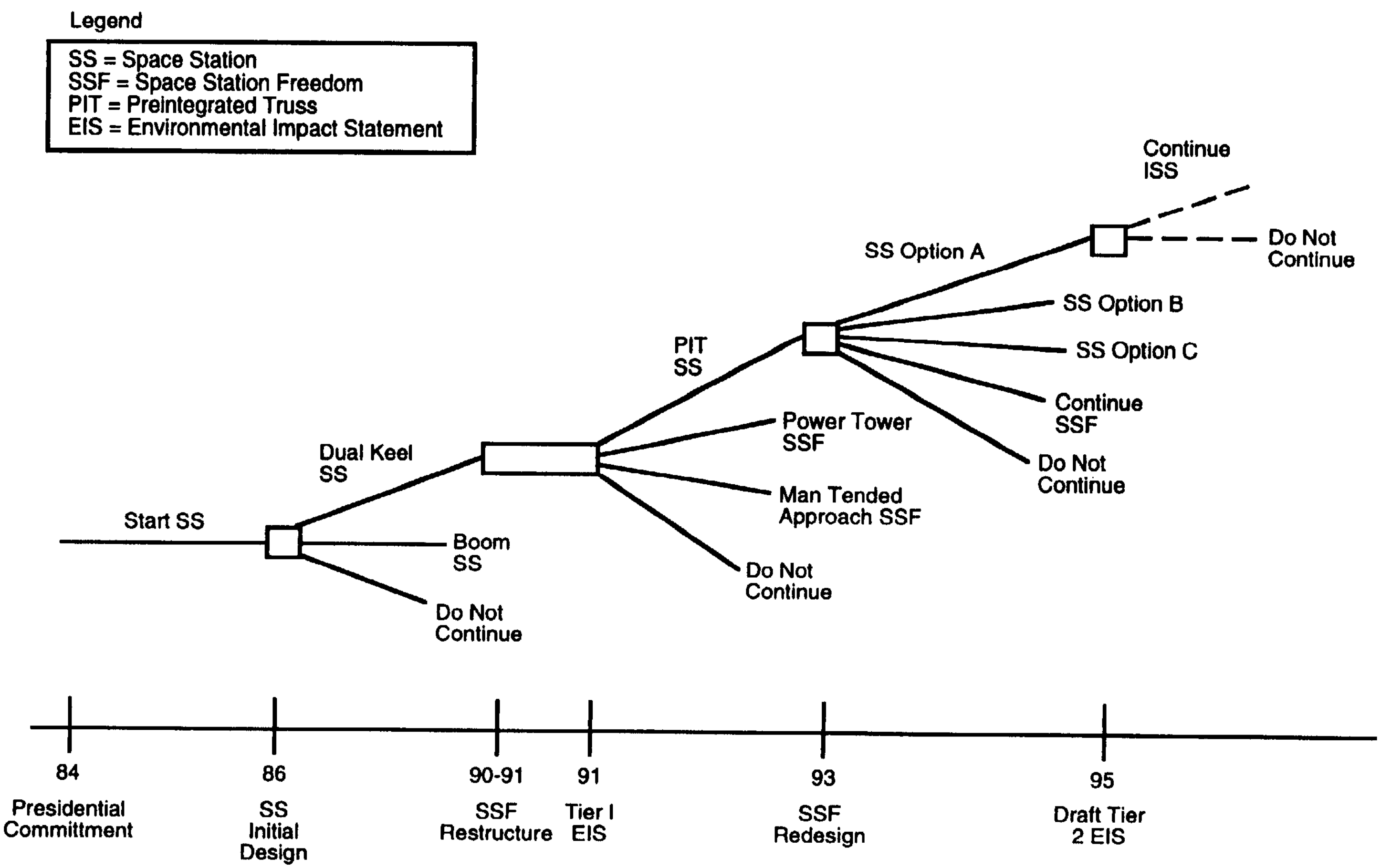


Figure 1-2. Space Station Program decision/alternative history.

The results of the redesign efforts were presented on June 10, 1993 in the *Final Report to the President* of the Advisory Committee on the Redesign of the Space Station.[2] The options were Option A, Modular Building; Option B, SSF Derived; and Option C, a Single Launch Core Station.

The President chose to proceed with a redesigned space station using Option B as a basis, and program restructure (a series of management and contracting changes) to ensure the space station would deliver significant science and technological benefits at an affordable cost.

In late 1993, the U.S. and its international partners—Canada (Canadian Space Agency [CSA]), the European Space Agency [ESA]), and Japan (Space and Technology Agency [STA], and its implementing agency–National Space Development Agency [NASDA])—invited Russia (Russian Space Agency [RSA]) to become a full partner in ISS. Russia officially accepted the offer in December 1993.[3] RSA contribution of hardware and capabilities to ISS would enhance the Station's potential and help to provide for a larger Station at a reduced cost to the United States. The final configuration that resulted from this process retained approximately 75 percent of the hardware design originally planned for SSF that was addressed in the Tier 1 EIS. The current configuration is officially known as the International Space Station (ISS) in recognition of the enhanced role of IPs.

ISS will be a long-term, cooperative effort between NASA, CSA, ESA, RSA and STA. ISS will provide a world-class orbiting laboratory for conducting high-value scientific research in a microgravity environment. It also lays the groundwork for future international cooperative space ventures.

1.3 PURPOSE OF THE ACTION

The purpose of the federal action, assembly and operation of ISS, is to fulfill the goals of the NASA Charter, as established in the National Aeronautics and Space Act of 1958, as amended[4]; the National Space Policy, as defined in National Space Policy Directive 1[5]; and related legislation. This action enables NASA to further the development of human presence in space and to meet the needs of scientific, technological, and commercial research, and foster international cooperation. ISS is designed specifically to meet these needs and to provide a foundation for space research and exploration into the future.

1.4 PROGRAM OBJECTIVES

The program objectives for ISS are as follows[6]:

- To perform significant long-term space research in science, technology, development, and commercial applications
- To operate advanced human and autonomous space systems

- To support users—particularly industry users—in experimenting on new, commercially relevant products and processes, especially automation and robotics
- To conduct human scientific, commercial, and exploration activities
- To promote substantial international cooperation in space, science, and technology
- To create and expand opportunities for private sector activity in space

In accomplishing these objectives, there will be two major areas of emphasis in the research that will be conducted on board ISS—life and biomedical sciences, and microgravity sciences and applications research. Both of these major areas are expected not only to yield significant new information pertinent to our ability to live and work in space for long periods of time, but also to aid in providing tangible results on Earth as well. These two major research areas complement and reinforce each other in a number of ways.

The focus of life and biomedical sciences research on board ISS is on investigations that will enhance our understanding of the role of gravity in life and life processes in space as well as on Earth. Among the key areas that will be investigated are the fluid physics of life systems in a microgravity environment, the gravity receptors of plants, and the way gravity affects how our bodies respond to force. Another area of investigation is directed at how we can maintain the health and performance of people in space. Studies on board ISS will also increase our understanding of the biology of spacecraft (e.g., bacterial and fungal growth within the moist, warm environment of a human-occupied spacecraft could have a significant bearing on the crew, spacecraft systems, and on the Program itself).

Life sciences research that would be conducted on board ISS has the potential to yield direct benefits not just to our basic understanding of life, but also to human health, and to our environment here on Earth. Research on microorganisms is expected to increase our understanding of how they evolve and undergo change, and how they develop antibiotic resistance. Studies on bone loss in astronauts living in a space environment will not only aid understanding of the mechanisms and processes causing the loss, but will also assist in developing means to counter that loss. NASA has a collaborative program with the National Institute of Aging, and the ISS research should benefit ongoing investigation into osteoporosis, a common ailment of the aging. Other research on board ISS will deal with the migration of cells in the body, a topic which has a direct bearing on understanding how cancer cells metabolize, and how the human immune system can be mobilized to counter those effects. Life science research efforts are also expected to assist in the understanding of environmental processes on Earth, and may lead to enhanced technologies to monitor those processes, such as improved air and water quality sensors, analyzers, and filtering devices.

Among the array of microgravity sciences and applications research efforts that will be conducted on ISS are several areas dealing with physics, chemistry, and material sciences. As noted above, microgravity sciences and applications research and life sciences research reinforce and complement each other. These two research disciplines interact in the important area of biotechnology.

The focus of biotechnology research is on the use of the low-gravity environment of space to conduct fundamental biotechnology investigations that cannot be performed on Earth. Protein crystal growth and tissue culture and biomedical research are two areas where promising opportunities for significant advancements through low-gravity experiments are anticipated.

This line of research has the potential to advance the health care and biotechnology industries, in areas such as improved drug design and testing, cancer diagnosis and treatment, and tissue engineering leading to replacement tissues. Biotechnology experimentation in space could lead to significant scientific advances and help advance the United States into the 21st century as a leader in biotechnology.

Physics, chemistry, and materials research efforts envisioned include topics such as combustion, fluid dynamics, cryogenics, and materials properties and processing. Combustion processes, for example, play a key role in energy generation and utilization, production/control of air pollutants, transportation/propulsion, global environmental heating, materials processing/synthesis, hazardous waste disposal, and other issues of major importance to a technologically advanced society. Better understanding of the mechanisms involved in various types of combustion events should have significant benefits in terms of reducing fire losses, maximizing efficiency of energy utilization, and minimizing production of undesirable byproducts (pollutants) and of waste heat (an important factor in global warming) by combustion processes.

A Low Temperature Microgravity Physics Facility (LoTMP) will be used to investigate fundamental behavior of quantum fluids. Measurements in the LoTMP will provide the best tests of many basic theories having wide application. The microgravity environment and longer experiment times permitted on ISS will allow more extensive testing and retesting of important issues in the theories. These advancements will impact the fundamental science areas to which the theories are commonly applied, such as phase transitions in condensed matter, but will also impact more applied areas like phase transitions under non-equilibrium conditions observed in both industry and in nature, such as quenching of alloys and crack propagation, and models of weather and other global phenomena.

Fluid physics research will study fluid phenomena central to a vast number of physical, chemical, and biological processes, many of which have technological importance. The study of many of these phenomena, such as sedimentation and buoyancy-driven convection, has been severely limited by gravitational effects. A long-term microgravity environment would provide conditions under which these phenomena can be effectively studied. The basic knowledge sought by research in microgravity fluid physics is expected to have a significant impact in areas of major concern on Earth:

- Knowledge of multiphase flow behavior will enable more predictable operation of power plants.
- Understanding the physics of colloids will help to produce fluids with engineering relevance, like electrorheological fluids (i.e., fluids that respond to electrical currents or fields) in control systems and drilling liquids in oil exploration.
- Understanding the behavior of liquids wetting solids will help to enhance the recovery of oil from reservoirs and the migration of groundwater.
- Better predictions for the mechanics of granular fluids will help make earthquake engineering more effective.

Research in the area of materials science is geared toward understanding the underlying principles necessary to predict the relationships of synthesis and processing of materials to their resulting structures and properties. The structure of materials at various length scales ranging from the atomic and molecular level through microscopic and macroscopic levels, is strongly influenced by transport phenomena during processing. Microgravity offers the potential for the understanding and control of materials synthesis involving a fluid phase. In the absence of gravity-driven influences on fluid behavior, more subtle effects can be uniquely studied, thus facilitating verification of existing Earth-based models and improving their utility. Mathematical models which are truly predictive would engender significant cost reductions in process development and reduce the time and risk in the transition from concept to pilot line to production line. In addition, a laboratory in a low-gravity environment that is routinely available for a series of interrelated experiments provides a unique potential for establishing the science base that is currently lacking for materials processes. With a generic science base available, Earth-based materials processes could be optimized without relying on individual trial and error approaches, thus resulting in higher yield and better reproducibility and, in turn, lower cost production.

1.5 NEED FOR THE PROPOSED ACTION

The National Aeronautics and Space Act of 1958[4] directs NASA to pursue a number of objectives. These include the following:

- The expansion of human knowledge of phenomena in the atmosphere and space
- The development and operation of vehicles capable of carrying instruments, equipment, supplies, and living organisms through space
- The preservation of the role of the United States as a leader in space science and technology and in the application thereof to the conduct of peaceful activities outside the atmosphere
- Cooperation by the United States with other nations and groups of nations in work done pursuant to this Act and in the peaceful application of the results thereof

To meet these objectives, beginning in 1984, Congress has included funding for the design of a permanently human-occupied space station in the NASA budget. Funding for ISS continues to the present time.

1.6 RESULTS OF THE SCOPING PROCESS

On May 23, 1995, NASA published in the Federal Register (60 FR 27332) the Notice of Intent (NOI)[7] to prepare the Tier 2 EIS for ISS. In parallel, NASA mailed the NOI directly to over 100 federal and state agencies, individuals, and organizations. With the close of the formal comment period, all responses received were reviewed and considered for incorporation into the Tier 2 EIS. Relevant issues as stated in the NOI are addressed in this Tier 2 EIS.

2.0 ALTERNATIVES, INCLUDING THE PROPOSED ACTION

The Tier 2 EIS for ISS examines the alternatives for accomplishing the program objectives. Section 2.1 provides an overview of the alternatives considered. Sections 2.2 and 2.3, respectively, describe the Proposed Action and the No-Action alternatives. Section 2.4 briefly summarizes the potential impacts of the alternatives.

2.1 OVERVIEW OF ALTERNATIVES CONSIDERED

Four alternatives were explored in the Tier 1 EIS: the Proposed Action of proceeding with the development of an international space station in a configuration identified as SSF, developing either of two alternative configurations identified as the Power Tower and the Human-Tended Approach, and terminating the program under the No-Action alternative. After careful consideration of environmental as well as programmatic considerations, the decision was made to proceed with the design, development, and planning for operation of the human-occupied SSF. This decision was documented in the ROD signed by the NASA Associate Administrator for Space Flight on July 26, 1991.[8]

The Proposed Action addressed in this Tier 2 EIS is to continue to provide U.S. participation in the assembly and operation of ISS. The alternative action (the No-Action alternative) is to cancel the NASA Space Station Program.

The Tier 1 ROD specifically noted that the human-occupied base configuration described in the Tier 1 Final EIS was that which existed in December 1990 as the development program completed its Preliminary Design Review (PDR). Changes to the configuration resulting from the PDR and subsequent reassessments were to be addressed in the Tier 2 EIS. Subsequent reassessments have included the work of the Space Station Redesign Team, the independent review by the President's Advisory Committee on the Redesign of the Space Station, and additional design reviews reinstating some of the SSF components and incorporating major contributions of RSA hardware and launch services. The resulting configuration, retaining approximately 75 percent of the hardware design originally planned for SSF, has been approved by the IPs and by the Italian Space Agency, or Agenzia Spaziale Italiana (ASI). The program successfully completed its Systems Requirements Review in December 1993, Systems Design Review in March 1994, and its first Incremental Design Review in March 1995. As part of the analysis of the Proposed Action, this Tier 2 EIS will address the significant changes from the SSF design.

2.2 DESCRIPTION OF THE PROPOSED ACTION

The Proposed Action is to continue to provide U.S. participation in the assembly and operation of ISS. ISS is designed to be a world class laboratory in space. When assembled, it would provide a high-quality, long-duration microgravity research facility for unprecedented scientific investigations. The overall layout of ISS at completion of assembly in 2002 is depicted in Figure 2-1. A component view, identifying individual components of ISS, is presented in Figure 2-2.

The Space Station Program is a cooperative international effort shared among a team of IPs consisting of the United States, Canada, Japan, ESA, and Russia. The initial partnership was formalized in the September 29, 1988 Intergovernmental Agreement on the Permanently Manned Civil Space Station, which is currently being amended to include Russia. In addition, the United States has entered into a bilateral agreement with Italy (ASI) as an additional program participant. Hardware contributions of the program participants are listed in Table 2-1.[9]

The program has undergone a number of major changes since the Tier 1 EIS was published in March 1991. Most of these changes have to do with programmatic activities involving the management structure and acquisition plan. From a hardware perspective, the current design retains approximately 75 percent of the U.S. hardware designed for Space Station Freedom when the Tier 1 EIS was published. The most significant change in the overall plan for ISS involves the incorporation of RSA hardware and launch capabilities. Some of the components for ISS contributed by RSA are propulsive reboost and attitude control, assured crew return capability, three research laboratory modules, and 42 kilowatts (KW) of additional power, enabling the crew size to be increased from 4 to 6.

The ISS Program follows a phased development plan. The program phases are summarized as follows[10]:

Phase One

Phase One (also called the Shuttle/Mir Program) was initiated in February 1994 with flight of the first Russian cosmonaut on the Space Shuttle, and involves combining cooperative operations between NASA and RSA in an effort to reduce risk to ISS. Rendezvous and docking procedures will be validated, space hardware will be tested, NASA and RSA crew members will gain operational experience performing technical and scientific studies aboard each other's flight vehicles. This activity is an extension of ongoing Space Shuttle operations. Each Space Shuttle flight is covered by the existing NASA Space Shuttle EIS of 1978[11] and the KSC Environmental Resources Document of 1994[12], as well as other NASA NEPA documentation.[13,14]

Phase Two

Phase Two involves the launch and initiation of on-orbit assembly of hardware by NASA and RSA to create a new advanced, human-occupied research facility in Earth orbit. It would begin with first element launch in November 1997, and includes milestones such as 3-person crew capability in May 1998 and initial/early science/research capability in December 1998.

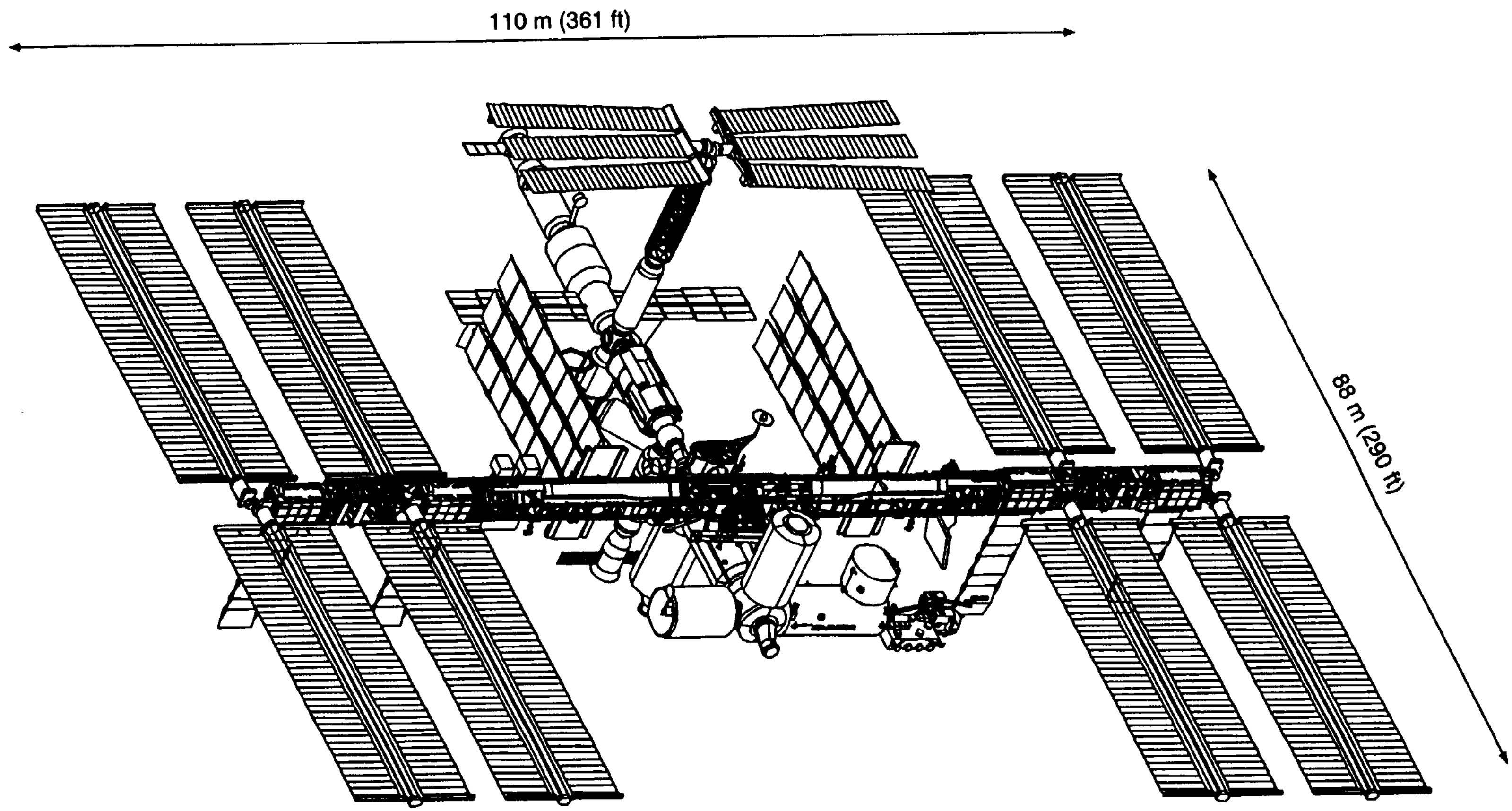


Figure 2-1. International Space Station (dimensions are approximate; not to scale).

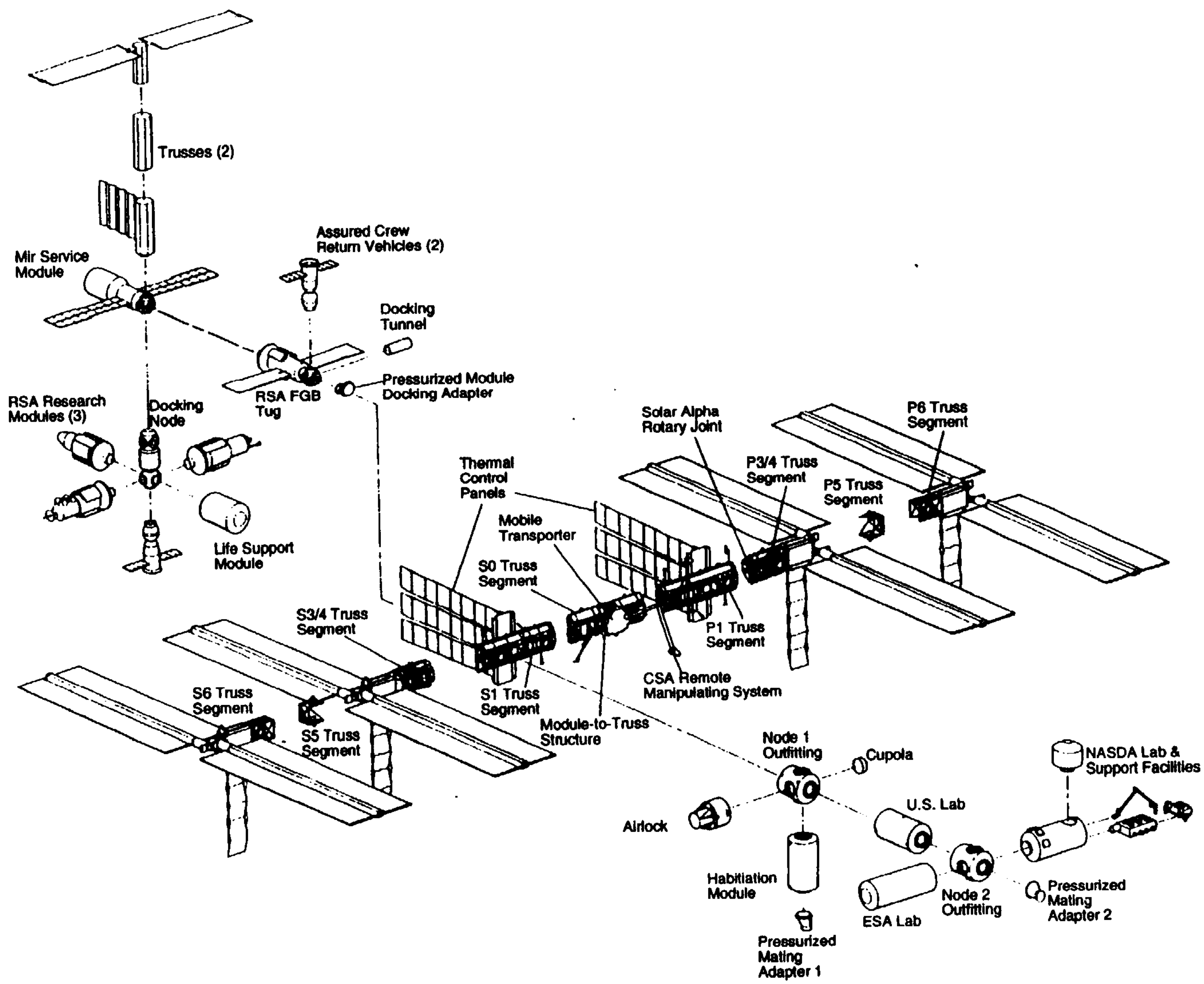


Figure 2-2. Major components of International Space Station (centrifuge not shown).

Table 2-1. Hardware Components of the Participating Nations

Phase Two Hardware Elements	
NASA Components	*RSA Components*
Node 1	Docking Compartment
Laboratory Module	Soyuz
Z1 Segment With 4 Control Movement Gyros	Service Module
P6 Segment	Universal Docking Module
	Science Power Platform with Gyrodynes
	Science Power Platform Solar Arrays (4)

Joint NASA/RSA Components
Functional Energy Block - RSA-made, NASA-funded, some NASA hardware and software
Airlock

Other International Participants Components
Italian Space Agency - Mini-Pressurized Logistics Module
Canadian Space Agency (CSA) - Space Station Remote Manipulator System

Phase Three Hardware Elements	
NASA Components	*RSA Components*
Centrifuge	Soyuz Crew Transfer Vehicle (2)
Crew Transfer Vehicle	Life Support Module
S0 Segment	Research Module (3)
S1 Segment	Docking & Stowage Module
Node 2	Science Power Platform Solar Arrays (2)
Cupola	
P1 Segment	*Other International Partners Components*
P3/P4, Second Photovoltaic Array	CSA - Mobile Remote Servicing Base System
S3/S4, Third Photovoltaic Array	CSA - Special Purpose Dexterous Manipulator
S5 Segment	CSA - Mobile Transporter
S6 Segment, Fourth Photovoltaic Array	National Space Development Agency of Japan (NASDA) - Japanese Experiment Module
Habitation Module	NASDA - Japanese Experiment Module Pressurized Module and Remote Manipulator System
P5 Segment	NASDA - Japanese Experiment Module Exposed Facility & Equipment Section
Payload Attach Sites (4)	European Space Agency - Attached Pressurized Module

Phase Three

Phase Three would begin with the addition of the first major truss segment (S0) being permanently attached to the U.S. Lab Module in May 1999 and would end with ISS assembly complete in June 2002. During this phase all the remaining U.S. and IP components would be delivered to ISS. After completion, ISS would have a 6-person crew capability and an operational lifetime of at least 10 years.

2.2.1 Program Management Relationships

Several key program management changes have been instituted since the completion of the Tier 1 EIS, as recommended by the President's Advisory Committee on the Redesign of the Space Station. The Space Station Program was reorganized into a product team structure. Integrated Product Teams (IPTs) and Analysis and Integration Teams (AITs) are responsible for all aspects of design, development, and operation of functional elements of ISS. The IPT/AIT structure consists of NASA, IPs, Boeing, and Product Group (subcontractor) personnel. As a result, the NASA program management structure has been streamlined, and major work package responsibilities of multiple NASA Field Centers have been eliminated and replaced with strong Program Office leadership operating with clear lines of authority and responsibility. The Program Office draws primarily upon the resources of the Lyndon B. Johnson Space Center (JSC) as the host center for the Program, and includes participation from other Field Centers as needed for specific expertise. Multiple prime contracts have been eliminated and replaced with a single prime contract awarded to the Boeing Company for the design, construction, and assembly of ISS. The Boeing Defense and Space Group in Houston is the prime integrator for the Space Station Program. Boeing has in turn established major subcontracts with McDonnell Douglas Aerospace in Huntington Beach, California; Boeing Defense & Space Group, Missiles and Space Division, in Huntsville, Alabama; and Rocketdyne Corporation in Canoga Park, California.

2.2.2 System Requirements and Operating Parameters

Major system requirements and operating parameters of ISS have evolved from the plan envisioned at the time the Tier 1 EIS was published (SSF configuration) to the current configuration, as indicated in Table 2-2. System requirements and operating parameters affected include the design life for ISS hardware, the orbit inclination and altitude, crew size, and payload provisions.

Table 2-2. Major Differences Between SSF and ISS

System Requirements	Configuration	
	SSF	*ISS*
Design Life/Utilization	30 years	10+ years
Orbit Inclination	28.5 degrees	51.6 degrees
Average Orbital Altitude	460 km (250 n.m.*)	408 km (220 n.m.)
Crew Size	4	6
Total Mass (Weight)	232,700 kg (512,000 lb)	420,000 kg (924,000 lb)
Pressurized Volume	652 m^3 (23,000 ft^3)	1,309 m^3 (46,200 ft^3)
Modules (Lab, Hab, Logistics)	3,2,1	6,2,2
Co-Orbiting Platforms	3	none presently planned
First Element Launch	1st Quarter 1995	November 1997
Total Flights Required Through ISS Assembly	32 (29 STS; 1 Titan IV; 2 ESA)	44 (27 STS; 15 RSA; 1 ESA; 1 TBD)
Permanent Human Presence Capability	3rd Quarter 1997	May 1998
Complete Assembly	3rd Quarter 1999	June 2002
Resupply Flights	All U.S.	U.S. and International Partners

*n.m. = nautical miles where 1 n.m. = 1.15 statute miles TBD = to be determined

The design life for mission hardware has been reduced from 30 years to a minimum of 10 years (from completion of assembly), resulting in a significant savings in development cost. The ISS design includes Orbital Replacement Units (ORUs) that will allow the crew to remove and replace hardware, thus extending the practical life of ISS beyond the 10-year design life.

The orbital inclination has been changed from 28.5° to 51.6°, as indicated in Figure 2-3, to enable RSA assembly and resupply launches from Baikonur Cosmodrome, Kazakstan.[15] At the higher inclination, ISS will pass over more of the populated land mass of the Earth. Observation of Earth features will be possible up to latitudes of 54°. The orbital altitude will vary from approximately 278 km (150 n.m.) to 482 km (260 n.m.). (See Section 2.2.6.)

The altitude profile has not changed appreciably from what was planned at the time the Tier 1 EIS was published. The full crew size has increased from 4 to 6, permitting increased scientific activity.

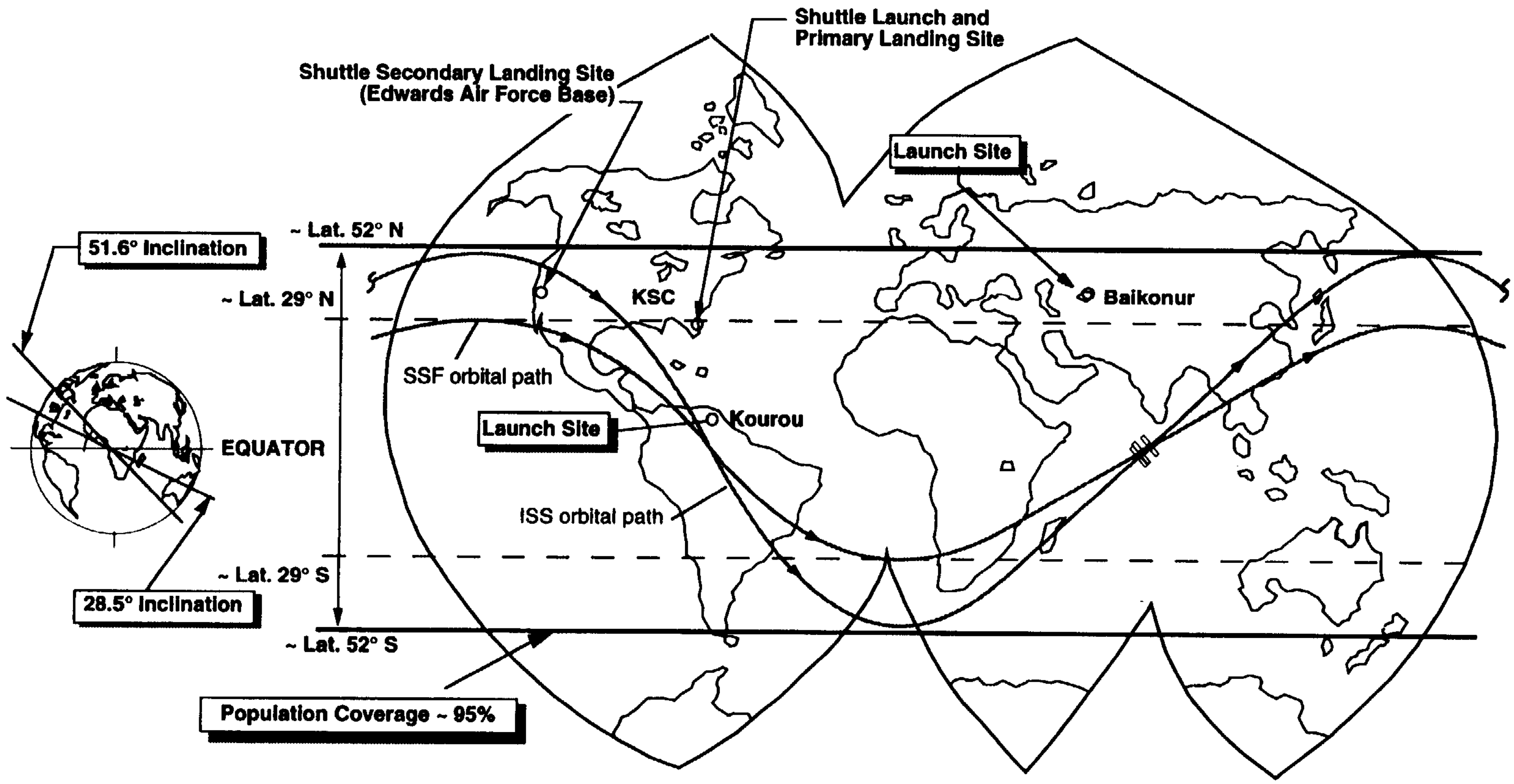


Figure 2-3. Comparison of orbital inclination characteristics of ISS and SSF.

Scientific research work stations aboard the fully assembled ISS will include 32 International Standard Payload Racks (ISPRs) provided by the U.S., NASDA, and ESA, plus additional research facilities provided in three RSA laboratories. ISS will have a total of 110 KW of average annual solar generated power, of which 30 KW will be available for ISPR users.[10,15]

While complete ISS assembly would not occur as early as that planned for SSF, initial research capability and permanent human presence capability would occur earlier with the ISS configuration than they would have using the SSF configuration. Complete assembly, however, will occur approximately 33 months later than was noted in the Tier 1 EIS for the SSF configuration.

2.2.3 Space Station Design Configuration Changes

The number of attached research laboratory modules has been increased from 3 to 6 with the addition of three RSA research modules, as indicated in Table 2-1. The U.S. logistics module that was planned for SSF has been replaced by an ASI mini-pressurized logistics module (MPLM) and additional storage space being provided by RSA modules. The total pressurized volume of ISS would be increased from approximately 652 m^3 (23,000 ft^3) to approximately 1,309 m^3 (46,200 ft^3), providing significantly increased research capability. The total projected mass (weight) of ISS would be increased from approximately 232,700 kg (512,000 lb) to approximately 420,000 kg (924,000 lb).[15] As a consequence of these changes, there would be an increase in the waste products resulting from increased scientific activity and human presence on ISS, and an increase in the total mass that must be disposed of upon decommissioning.

The three co-orbiting platforms of the SSF design are not in the current ISS design. These were the U.S. polar orbiting platform which would have been launched on a Titan IV vehicle from Vandenberg Air Force Base (VAFB) in California, the ESA Columbus polar orbiting platform, and the Columbus free-flying laboratory, both of which would have been launched on Ariane launch vehicles from Kourou, French Guiana. As a consequence of these changes, there are no U.S. expendable launches in the baseline plan for assembly of ISS.

At the time the Tier 1 EIS was published, a proposed change to use a monopropellant hydrazine propulsion system was under review. When the Russian Mir Program was merged with ISS, the IPs agreed to use the bipropellant RSA Service Module (SM)/Functional Energy Block (FGB) combination for propulsion. The SM and FGB propulsion systems use hypergolic unsymmetrical dimethylhydrazine propellant and nitrogen tetroxide oxidizer. The SM uses two 300-kg-thrust engines for altitude control and thirty-two 13-kg-thrust engines for attitude control.

2.2.4 Manufacture and Assembly

Components of ISS will be manufactured on Earth and assembled on orbit. Component assembly is being performed according to the international agreements negotiated between the participating members. Hardware contributions of the participating members are listed in Table 2-1.

Manufacturing and assembly of U.S.-provided components of ISS will be performed by Boeing, McDonnell Douglas, and Rocketdyne, as well as by their subcontractors. These activities are being accomplished at various locations under the direction of three product groups. Product group assignments and locations are depicted in Figure 2-4.

As indicated in Section 2.2.1, the role of NASA Field Centers has been modified since the Tier 1 EIS was published. JSC is now the home of the SSPO. Other Field Centers are providing additional resources under NASA intra-agency agreements with the SSPO.[6] One key change from the Tier 1 EIS is that the Goddard Space Flight Center (GSFC) is no longer managing development of a U.S. polar orbiting platform for ISS.

When manufacture and testing of U.S. components is complete, the hardware will be shipped to the John F. Kennedy Space Center (KSC) for launch on board the Space Shuttle.

The assembly sequence begins with the launch of the RSA-made FGB. The FGB is a fully functional spacccraft with a pressurized cargo compartment of approximately 55 m^3 (1,941 ft^3) and a capacity to hold up to 5,500 kg (12,100 lb) of propellant. It is being procured from the manufacturer Khrunichev, under contract to Boeing. RSA is providing launch of the FGB as a contribution to the program. The FGB will provide initial station attitude control, power, communications, and reboost capability. Once the FGB is in orbit, the rest of the ISS assembly will proceed.

U.S. contributions to the assembly sequence will be launched aboard the Space Shuttle. Once on orbit, the Space Shuttle will rendezvous with ISS and off-load its cargo utilizing a combination of remote manipulator system (RMS) operations and extravehicular activities (EVAs) performed by the astronauts.

Small amounts of radioactive materials (tracers or sources, primarily for use in instrument calibration and scientific experiments) may be included in some payloads. According to present plans, less than 1 curie of radioactive material is likely to be on board ISS. The volatile organic analyzer that would be launched by the Shuttle would contain a small quantity—2.2×10^8 Bq (0.006 Ci)—of radioactive nickel-63, sealed in plastic. The Soyuz, to be provided and launched by RSA, would contain an altimeter using 2.9×10^{10} Bq (0.783 Ci) of cesium-137 housed in a protective unit, with a shield of depleted uranium.

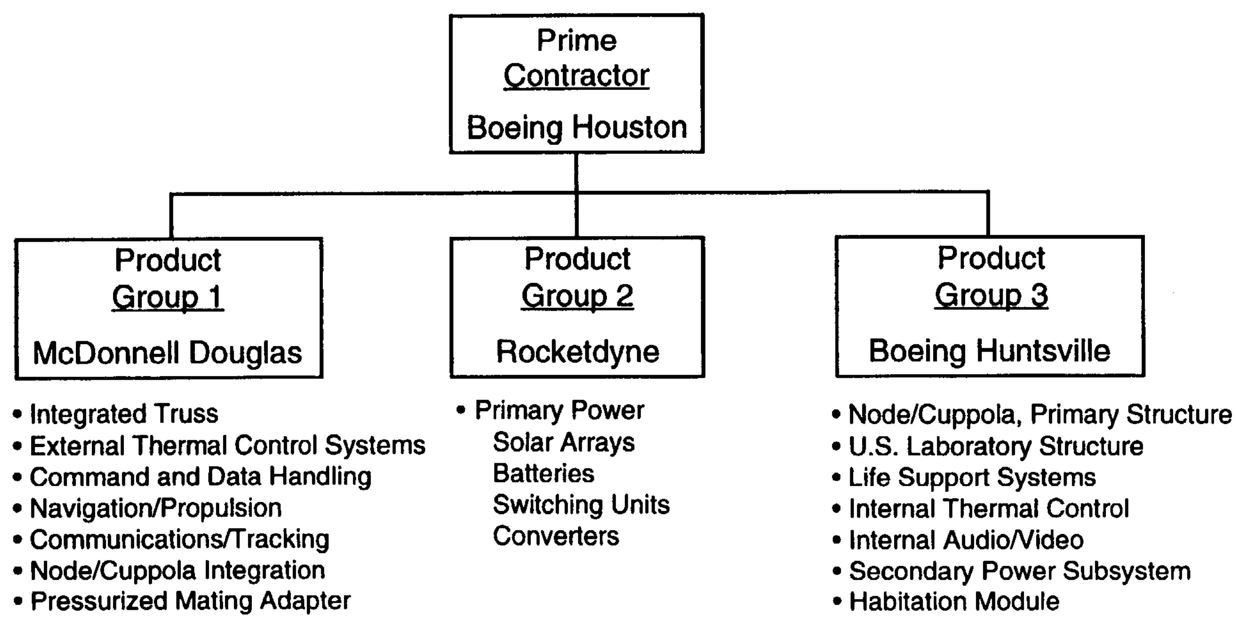


Figure 2-4. Product group assignments.

The anticipated quantities of cesium-137 and nickel-63 expected on board ISS would be about 3 to 7 orders of magnitude less, respectively, than the safe transport levels cited by the International Atomic Energy Agency (IAEA) in its safety standard for the transport of radioactive materials.[17] The entire assembly sequence will employ a combination of launches using NASA Space Shuttle, RSA Proton and Zenit, and ESA Ariane-5 launch vehicles. The current assembly sequence is depicted in Table 2-3.

2.2.5 Launch

U.S. launches will take place from launch pads 39A and 39B at KSC. The launch processing flow is depicted in Figure 2-5.[6] Hardware shipments to KSC will be off-loaded for receiving and inspection in the Space Station Processing Facility (SSPF). Life science specimens will be processed in the Life Science Support Facility. Space station elements, systems, and user payloads will be inspected and monitored for damage or leaks. Structural and mechanical parts will be reviewed for safety, verification, and interface with elements or systems received in other shipments for the same launch load. When the cargo elements are ready to be loaded onto the Space Shuttle, they will be carried to the launch pad in a payload canister. The cargo elements will be taken out of the canister and positioned in the pad clean room handling mechanism. After the Shuttle arrives at the pad, the cargo element(s) are moved from the clean room handling mechanism into the Orbiter payload bay.

The total number of flights required through completion of ISS assembly has increased from 32 to 44 to accommodate assembly of the increased mass of ISS with the significant addition of the RSA contribution to ISS hardware and launch services. The total number of U.S. assembly flights for ISS has decreased from 30 to 27, including the deletion of the Titan IV launch that was planned for the U.S. polar orbiting platform. All U.S. launches are planned for the Space Shuttle. The Titan IV launch vehicle may be used as a backup to the Space Shuttle.

2.2.6 Operations

ISS operations will be scheduled and performed consistent with a single integrated operations plan. In general, ISS operations[16] will follow the scenario depicted in Figure 2-6. Resupply will be accomplished at an altitude range of 278 to 482 km (150 to 260 n.m.), depending upon atmospheric density predictions, the planned interval between resupply flights, and operational constraints. After resupply operations are complete, ISS will reboost approximately 19 to 37 km (10 to 20 n.m.) higher. Scientific and technical research activities will be performed in the areas described in Section 4.3. Research will be conducted between reboost activities. This will be accomplished in two periods of approximately 30 days' duration between each reboost. During these periods there will be no planned orbital maneuvers or propulsive activity. The orbit will be allowed to decay naturally, thus maintaining the microgravity environment within design specifications.

Table 2-3. International Space Station Assembly Sequence and Schedule[a]

Flight	Description	Developer	Launch Agent	Launch Date	Notes
1A	Functional Energy Block (launched on Proton launcher)	NASA, RSA	RSA	11/97	First element launch; Phase 2 begins
2A	Node 1 (2 Storage racks), Pressurized Mating Adapter (PMA) PMA1, PMA2	NASA	NASA	12/97	
1R	Service Module	RSA	RSA	4/98	
2R	Soyuz	RSA	RSA	5/98	3-person permanent international human presence capability
3R	Universal Docking Module	RSA	RSA	6/98	
3A	Z1 truss, Control Moment Gyros, Ku-band, PMA3, Extravehicular Activity System (on Spacelab Pallet)	NASA	NASA	6/98	
4R	Docking Compartment	RSA	RSA	7/98	
4R-1	Service Module Solar Array Augmentation, Cargo Boom (on Progress vehicle)	RSA	RSA	8/98	
4A	P6, Photovoltaic (PV) Array (4 battery sets)/Thermal Control System (EATCS) radiators, S-band equipment	NASA	NASA	9/98	
5R	Solar Power Platform-1 (SPP1) (w/ gyrodynes, radiator)	RSA	RSA	11/98	
5A	Laboratory Module (Lab) (4 Lab System racks)	NASA	NASA	11/98	
6A	7 Lab System racks (on Mini-Pressurized Logistics Module [MPLM]), ultra-high-frequency system (UHF), Space Station remote manipulator system (RMS) (on Spacelab Pallet)	NASA	NASA	12/98	Microgravity research capability
6R	SPP-2 w/ integrated thrusters	RSA	RSA	2/99	
UF-1	International Standard Payload Racks (ISPRs), 1 Storage Rack (on MPLM), 2 PV battery sets (on Spacelab Pallet)	NASA/ASI	NASA	2/99	
7A	Airlock, high-pressure gas (on Spacelab Pallet)	NASA	NASA	3/99	
8A	Segment S0, Mobile Transporter (MT), Global Positioning System, umbilicals, airlock spur	NASA	NASA	5/99	Phase 3 begins
7R	SPP Solar Arrays (4)	RSA	RSA	5/99	
UF-2	ISPRs, 2 Storage Racks (on MPLM), Mobile Base System	NASA/ CSA	NASA	7/99	
9A	Segment S1 (3 radiators), EATCS, Crew Equipment Translation Assembly (CETA) (1), S-band equipment	NASA	NASA	8/99	
7R-1	SPP Solar Arrays (4)	RSA	RSA	9/99	
10A	Node 2 (4 DC-to-DC Converter Unit racks), Cupola	NASA	NASA	10/99	
11A	Segment P1 (3 radiators), EATCS, CETA (1), UHF	NASA	NASA	11/99	
8R	Research Module 1	RSA	RSA	11/99	
12A	Segments P3/4, PV Array (4 battery sets), 2 Unpressurized Logistics Carrier (ULC) Attached Systems	NASA	NASA	1/00	
9R	Docking & Stowage Module	RSA	RSA	2/00	

Table 2-3. International Space Station Assembly Sequence and Schedule[a] (continued)

Flight	Description	Developer	Launch Agent	Launch Date	Notes
1J/A	Japanese Experiment Module (JEM), Experimental Logistics Module (ELM), Platform Servicing (5 JEM System racks, 2 ISPRs, 1 Storage rack), Special Purpose Dexterous Manipulator, Segment P5 w/ radiator orbital support equipment	NASDA/ CSA	NASA	2/00	
1J	JEM Pressurized Module (3 JEM System racks), JEM RMS	NASDA	NASA	3/00	
10R	Research Module 2	RSA	RSA	6/00	
UF-3	ISPRs, 1 Storage Rack (on MPLM), 1 oxygen tank (on ULC)	NASA	NASA	7/00	
13A	Segments S3/4, PV Array (4 battery sets), 4 Payload Attach Sites	NASA	NASA	8/00	
UF-4	2 ULCs with Attached Payloads, port MT/CETA rails, centrifuge umbilical, 1 oxygen tank	NASA/ NASDA	NASA	2/01	
2J/A	JEM Exposed Facility, ELM-Equipment Section, 4 PV battery sets (on ULC)	NASDA	NASA	3/01	
2E	1 NASA Storage, 7 JEM racks (on MPLM)	ESA/NASA	NASA	6/01	
14A	Centrifuge, Segment S5	NASA	NASA	8/01	
1E	Attached Pressurized Module (3 System racks, 5 ISPRs) (launched on Ariane launcher)	ESA	ESA	9/01	
UF-5	ISPRs, 1 Storage rack (on MPLM)	NASA	NASA	11/01	
15A	Segment S6, PV Array (4 battery sets), starboard, MT/CETA rails	NASA	NASA	1/02	
16A	Habitation Module (Hab) (6 Hab racks)	NASA	NASA	2/02	
11R	Life Support Module	RSA	RSA	2/02	
13R	Research Module #3	RSA	RSA	3/02	
UF-6	ISPRs (on MPLM), 1 oxygen tank (on ULC)	NASA/ NASDA	NASA	4/02	
17A	1 Lab System rack, 8 Hab System racks (on MPLM), 2 PV battery sets (on ULC)	NASA	NASA	5/02	
18A	Crew Transfer Vehicle #1 (Launch Vehicle TBD)	RSA	TBD	6/02	
19A	3 Hab System racks, 11 NASA Storage racks (on MPLM)	NASA	NASA	6/02	Assembly complete—6-person permanent international human presence capability

[a] As of June 1995. Assembly sequence changes may occur with continuing analyses.

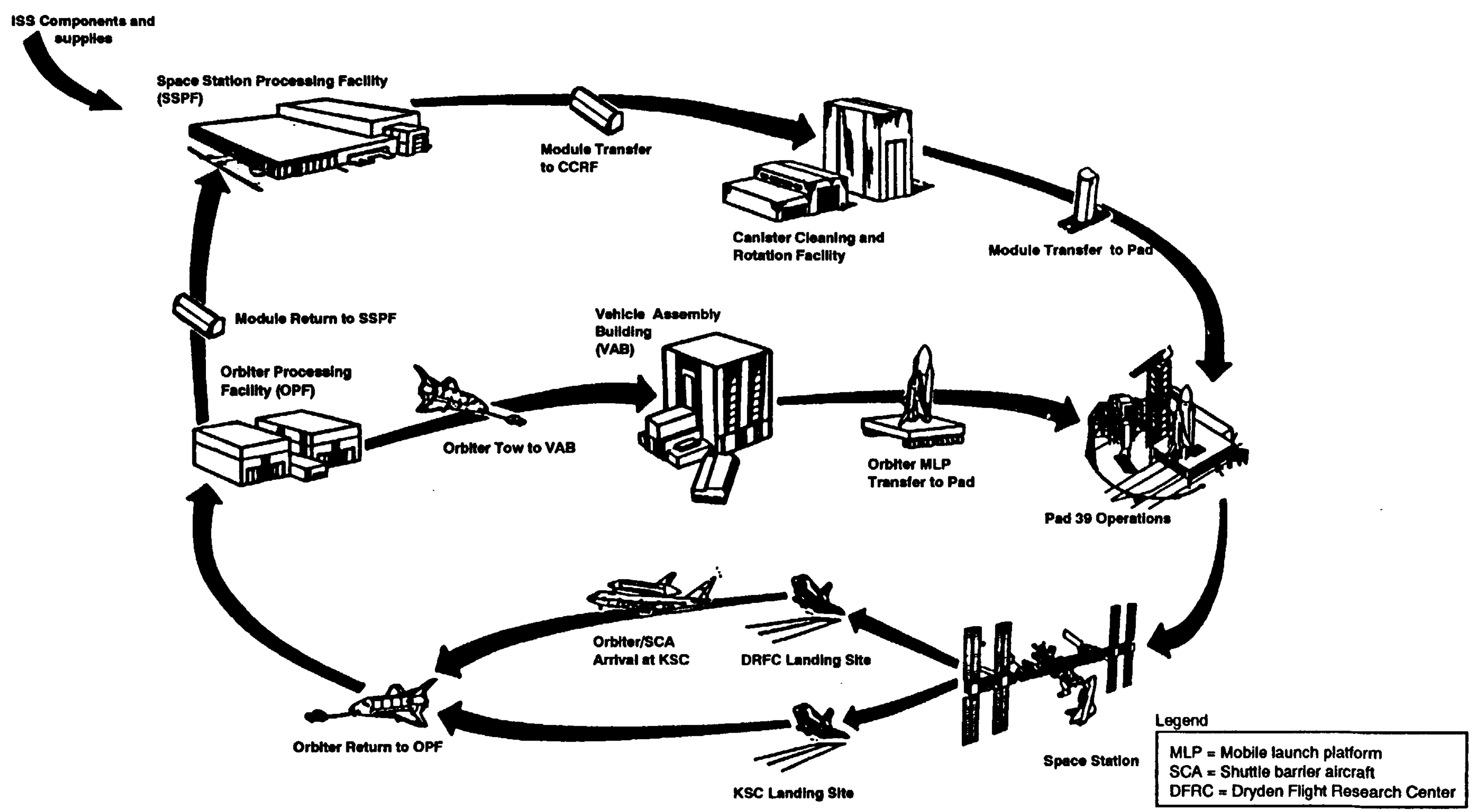


Figure 2-5. International Space Station processing flow at Kennedy Space Center.

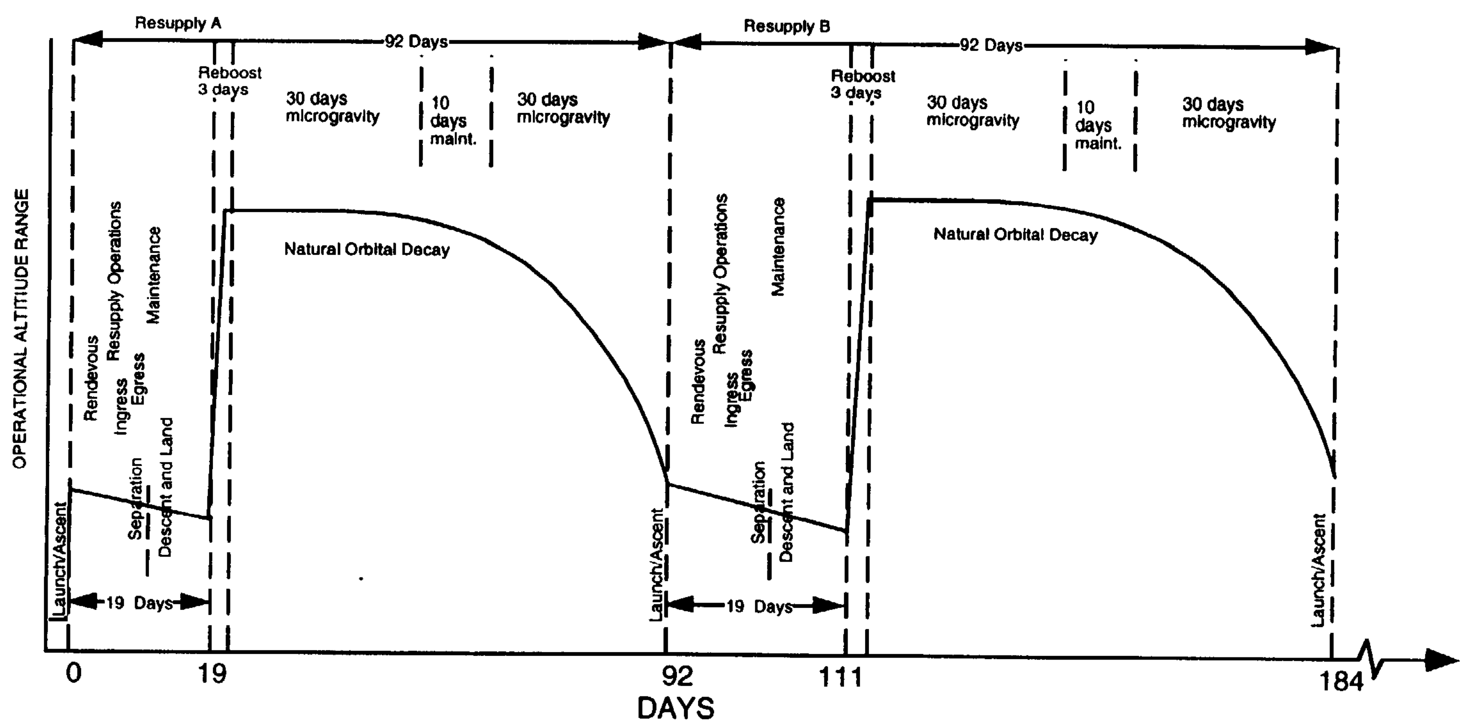


Figure 2-6. International Space Station operations profile. (Ref. 16)

ISS is designed to maintain 16 of the 32 ISPRs within a 1 micro-g limit (1 x 10^{-6}g where g = Earth's gravitational field at sea level; 9.8 m/s^2), as illustrated Figure 2-7.[15] After completion of the science/research periods, preparations will be completed for receipt of the next resupply mission.

Guiding principles governing operations include the following[6]:

- ISS will be capable of surviving 24 hours of operation without crew or ground intervention.
- The capability to return the crew to Earth independent of scheduled station activities will always be available.
- ISS will be able to support continued operations after loss of a single pressurized element.
- The loss of any single pressurized element will not force an emergency evacuation of the crew. Continued operations after loss of a single pressurized element will depend upon the crew complement and the remaining resources, and would be evaluated in real-time.
- No single failure or hazardous event will result in a serious risk of loss of ISS before the next servicing mission could be used to mitigate that risk.
- No single failure of food, water, air, or sanitation capabilities will cause the crew to evacuate before the next mission.

Environmental health monitoring of air, water quality, microbiological levels, noise and radiation to ensure crew health and safety is provided in the ISS design. Environmental control and life support systems will collect waste products (metabolic waste, food, packaging, regenerative process effluents, hard copy waste, etc.) and process them for on-board conversion to useful products or return to Earth. The Mini-Pressurized Logistics Module (MPLM) being developed by ASI will be used to transport equipment, experiment products, biological products, and waste to Earth on board the Space Shuttle.

Orbital debris, both natural and man-made, poses a threat to the successful operation of ISS. NASA maintains a catalog of orbital debris that it uses to characterize the risk to spacecraft. Several measures are being incorporated into the design and development of ISS to mitigate the orbital debris threat.

To provide some protection from smaller orbital debris (under 10 cm [3.9 in.] wide), the hull thickness of ISS elements are being increased, and state-of-the-art composite fiber external shielding is being added to all critical ISS components (such as habitation, laboratory, and propulsion modules). In addition, larger orbital debris (over 10 cm [3.9 in.] wide) is tracked by the Department of Defense Space Surveillance Network. If the predicted trajectories of this larger orbital debris intersect with the ISS trajectory, the ISS flight path will be adjusted as necessary to avoid possible collision.

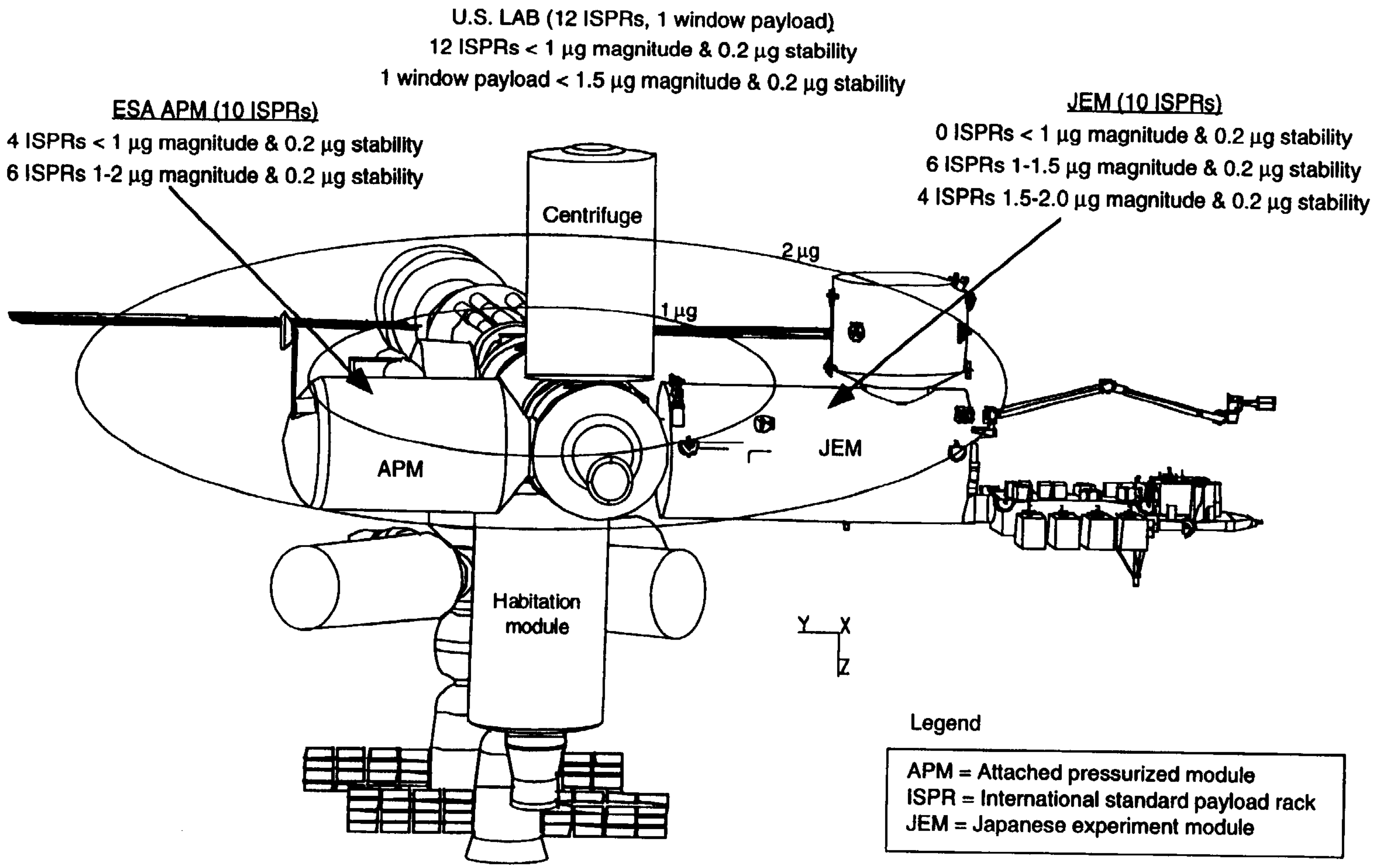


Figure 2-7. Microgravity environment at ISS Assembly Complete.

2.2.7 Decommissioning Plan

NASA has a design and operational requirement to allow for safe decommissioning and disposal of the on-orbit ISS at the end of its useful life. NASA examined several options for decommissioning ISS, including disassembly and return to Earth via the Space Shuttle, natural orbit decay with random reentry (similar to Skylab), boosting to a higher altitude, and a controlled targeted deorbit to a remote ocean area.

The Tier 1 EIS[1] evaluated decommissioning ISS by disassembly and return to Earth on the Space Shuttle. The returned components could then be disposed, recycled, or salvaged. This strategy remains available to NASA. The costs associated with disassembly and return would amount to at least the cost of 27 Shuttle flights to accommodate return of only the components originally launched by the U.S.

Decommissioning through use of natural orbital decay resulting in a random reentry of ISS (much like Skylab) would not ensure that surviving debris would land in a remote, unpopulated area.[18] Therefore, some form of propulsive maneuver was considered necessary to control reentry and, in turn, the location of the impact area, or transport ISS out of Earth's sphere of influence.

Decommissioning by boosting ISS to a higher orbit had several variations. One variation would use the assets (i.e., propulsive power) available on ISS at the time of decommissioning to achieve the higher altitude. The small increase in altitude that would be achievable would only slightly extend the orbital lifetime, and would still result in reentry, as is the case with any orbiting vehicle in a low Earth orbit subject to Earth's atmospheric drag and gravitational field. Other propulsion methods to escape Earth's gravitational pull were explored, but would require new hardware, large amounts of additional propellants, and would impose large additional cost burdens on the Program for the development, test, and deployment of these methods.

The currently proposed approach for decommissioning ISS is the execution of a controlled, targeted deorbit into a remote ocean area. The technical feasibility of this decommissioning option has been evaluated and found to be within the capability of ISS, utilizing both the on-board and ground resources of the U.S. and Russia.[18]

For the purposes of this EIS, an example of a deorbit sequence has been used. The actual sequence would be determined and finalized later in the program, but well before decommissioning would be initiated. This example approach calls for the execution of a deorbit sequence of burns to place the reentry of ISS and subsequent surviving debris impact at a selected remote ocean region. The example sequence is illustrated in Figure 2-8, which provides a deorbit event summary and altitude profile.

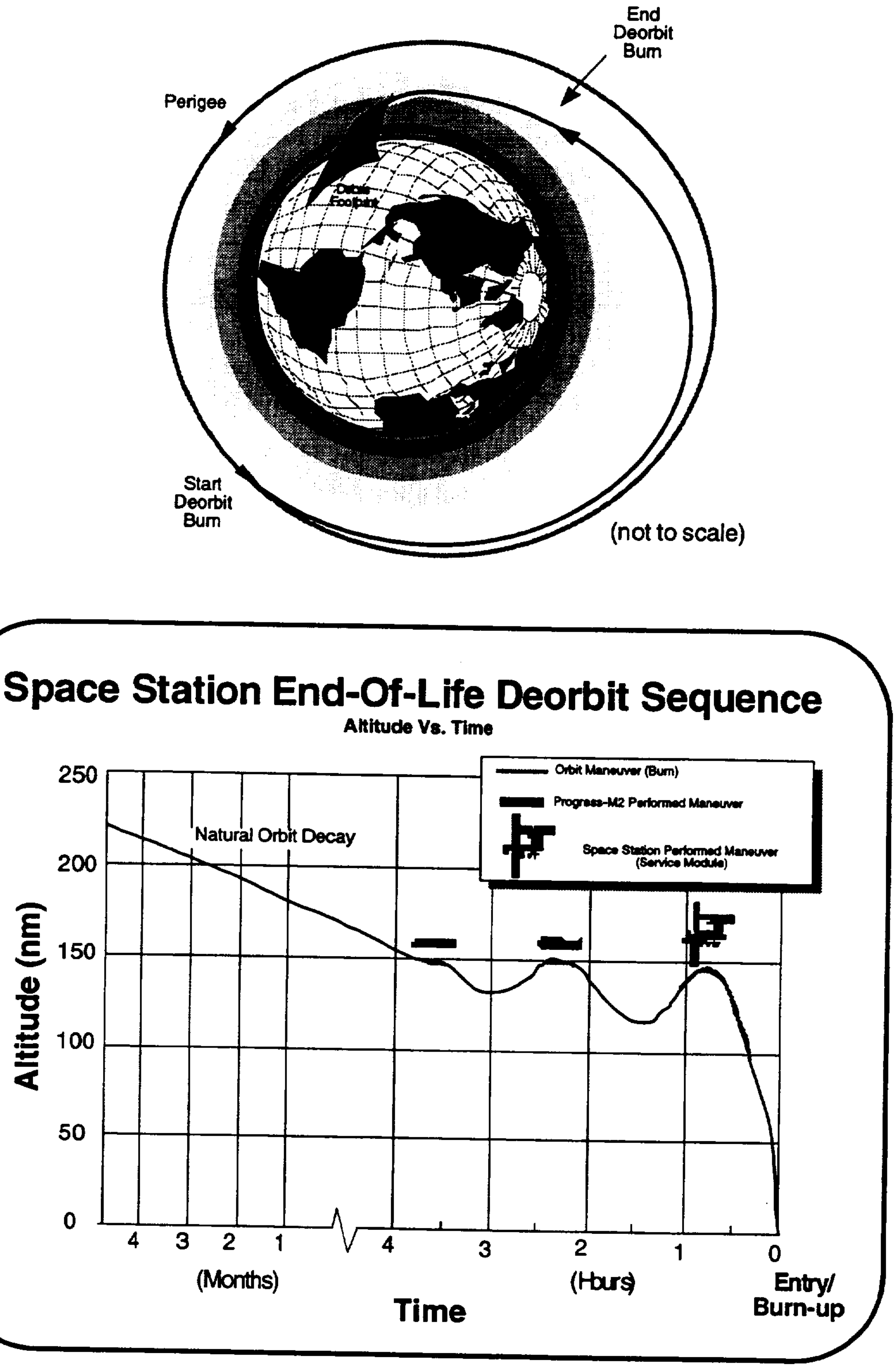


Figure 2-8. Example deorbit event scenarios.

The final deorbit burn will be designed to place ISS on a trajectory that will cause it to enter the Earth's atmosphere at a predetermined point over the Earth's surface. Observations of space debris reentering the Earth's atmosphere have shown that the external structure of space vehicles tends to melt/vaporize simultaneously at altitudes ranging from 63 km (35 n.m.) to 72 km (45 n.m.).[18,19] The principal breakup would occur at an altitude of about 79 km (42.5 n.m.). The truss structure and other connecting components would lose structural integrity, allowing the modules and other major components to break apart. The external skin of the modules would melt away or peel off, exposing internal hardware to rapid heating and melting. As this process continues, most of the ISS hardware would burn up or vaporize, leaving a portion to survive intact and fall to the Earth's surface.

2.3 DESCRIPTION OF THE NO-ACTION ALTERNATIVE

The alternative to the Proposed Action considered in this Tier 2 EIS is the No-Action alternative. As with the No-Action alternative discussed in the Tier 1 EIS, NASA would terminate the current Space Station Program, and would cancel its participation in the assembly and operation of ISS.

2.4 SUMMARY ENVIRONMENTAL IMPACTS OF THE ALTERNATIVES

This section provides a summary of the environmental impacts associated with the Proposed Action and No-Action alternative. (See Chapter 4 for detailed discussions.) The environmental impacts are described for manufacturing of U.S.-contributed ISS components, assembly and operation, decommissioning, and for an accident.

2.4.1 Environmental Impacts of the Proposed Action

2.4.1.1 Environmental Impacts of ISS Manufacturing, Assembly, and Operation

The development and manufacture of the U.S.-contributed ISS components, payloads, and experimental devices will be conducted at existing ground-based NASA facilities (JSC, George C. Marshall Space Flight Center [MSFC], Lewis Research Center [LeRC]) and numerous commercial facilities throughout the U.S. Some expansion of the existing facilities is in progress, which has resulted in construction activities. These potential effects have been addressed in the Tier 1 EIS and in appropriate site-specific environmental documents.[1,20,21,22]

During fiscal year 1995, the Space Station Program has employed over 15,400 people (civil service and contractor), spread out over 35 states. The resulting overall economic impact has been and will continue to be positive.

Preparing for launch of the Space Shuttle would involve many activities (e.g., launch vehicle processing, fueling, payload integration) largely occurring at KSC in Florida. These preparations would not adversely affect either KSC or the regional area. Section 4.1.2 provides a more detailed discussion of the environmental impacts associated with assembly and operation activities.

ISS assembly would require 27 Shuttle launches during the assembly phase, and 5-6 launches per year thereafter for resupply until ISS reaches the end of its useful life (10+ years). A Space Shuttle launch generally results in limited short-term air, water, and biological resource impacts in the immediate vicinity of the launch site. These impacts have been addressed in detail in other NEPA documents[11,13,14,23] and are associated with the routine launch operations of the Space Shuttle. Upper atmospheric impacts could include a short-term localized decrease in stratospheric ozone density with no permanent effects. In addition, there could be a short-term decrease in ion and electron concentration in a localized area of the thermosphere (ionosphere) surrounding ISS.[1] Assembly of ISS involves multiple Space Shuttle launches; the associated launch impacts would occur with each launch. The current Space Shuttle launch schedule would be able to support the launch requirements of the assembly and operation phases without the need to increase the scheduled annual launch rate of the Shuttle Program. Over the assembly and operation phases, Shuttle launches would be the principal impact source associated with ISS. The cumulative impacts would center largely on the area near the Shuttle launch pads and would primarily decrease vegetative diversity within that area due to deposition of solid rocket exhaust products.

In the event the Shuttle were to become unavailable, the Titan IV launch vehicle may be used as a possible backup. Titan IV launches, if deemed necessary by NASA, would occur from Cape Canaveral Air Station (CCAS), located adjacent to KSC. Impacts of Titan IV launches have been previously addressed in detail in other NEPA documents.[23,24] Titan IV launches would result in impacts similar in nature to those of the Shuttle, but with limited short-term air quality, noise, water quality, and biological resources impacts could occur in the immediate vicinity of the launch site. Upper atmosphere impacts would include a temporary localized decrease in stratospheric ozone along the flight path with rapid recovery.[23] Sections 4.1.1.2 and 4.1.1.3 address the Shuttle and Titan launch impacts in more detail.

ISS, once assembled and operating, would have little impact on the human environment. In the normal operating mode, ISS is not expected to produce major perturbations to the ionosphere during engine firings to reboost it to a higher orbit, or from venting, outgassing, and leakage. Outgassing and leakage from the station (consisting principally of the internal station atmosphere) through seals and joints are normal and unavoidable; it is, however, expected to be minimal. Venting of nonhazardous liquids and gases would be permitted. Typical examples include helium, argon, neon, carbon monoxide, and oxygen. All solid waste products and hazardous waste liquids and gases generated on board ISS will be returned to Earth in sealed containers and disposed of in accordance with environmental regulations. KSC has the facilities and the necessary permits and procedures to store, treat, and dispose of both hazardous and nonhazardous waste products.[1]

2.4.1.2 Environmental Impacts of Decommissioning

The currently proposed method of decommissioning ISS is the execution of a controlled targeted deorbit of ISS into a remote ocean area. During descent through the Earth's atmosphere, ISS would burn, break up, and vaporize into fragments of various sizes. Some fragments of ISS would likely survive the thermal stresses of reentry and fall to Earth.

The footprint of the surviving debris (the area within which the debris would fall) has been estimated to provide a large degree of conservatism. The nominal, or expected, footprint has been estimated to cover an area of about 43,009 km^2 (12,430 $n.m.^2$ where n.m. = nautical miles). Because variables such as aerodynamic variability of the debris, winds, and wind patterns create uncertainty in both the size and location of the footprint, a larger region can be identified within which the debris could credibly fall. This area, called the "at-risk region," has been estimated to cover an area of about 959,540 km^2 (279,180 $n.m.^2$). Within the footprint, the total aggregate surface area of all the potentially surviving debris has been estimated using three different methodologies to provide a range. The total expected aggregate debris surface area has been estimated as 2,790 m^2 (30,000 ft^2) with the upper range estimated at 5,115 m^2 (55,000 ft^2) and the lower range at 1,581 m^2 (17,000 ft^2). The number of surviving debris pieces has been estimated using the results of Skylab studies, which put the average area of surviving debris at 2.46 m^2 (26.5 ft^2) per piece. Based on this average, the estimated number of surviving debris pieces associated with the nominal and upper- and lower-bound debris area estimates would be approximately 1134, 2079, and 643, respectively. Using a debris model developed from launch vehicle reentry debris[19], it is estimated that from 6 to 19 percent of ISS would survive reentry. The total weight of the debris associated with these estimates would be approximately 24,260 kg (53,500 lb) to 78,570 kg (173,250 lb). Environmental impacts of these debris pieces within the anticipated impact area would be expected to be small. Some pieces could have sufficient kinetic energy to potentially cause damage to people and structures, including ships, upon falling to Earth.

Once the debris enters the ocean, it would be expected to settle to the ocean floor. Some debris would become encrusted and incorporated into the sediments. Although unlikely, some leakage could occur from previously sealed containers that remained intact through reentry and impact; however, no substantial long-term impacts would be expected.

2.4.1.3 Environmental Impacts and Consequences of Inadvertent Reentry

The Space Station Program is taking numerous measures in the design and operations planning to prevent an unplanned, or inadvertent, reentry of the ISS. Due to the robustness of the ISS design, it is anticipated that most failures can be corrected before they result in accidental reentry from low Earth orbit. However, it is possible that ISS or some of its components could inadvertently reenter the atmosphere following a number of planned and/or unplanned events. The most critical time for accidental or random failures would occur during decommissioning (targeted controlled reentry) maneuvers. During these critical maneuvers, the orbit lifetime would be purposely limited; there would be no personnel on board to intervene, and ground control personnel could have relatively little time (compared to the life of ISS) to recover from major anomalies in a decommissioning sequence.

Inadvertent reentry of ISS could occur in the unlikely event that 1) there was an inability among the U.S. and the IPs to supply the propellant necessary to stay in orbit; 2) there was a disabling collision with orbital debris, meteoroids, or other spacecraft; or 3) there were multiple major on-board system failures, and in each case no combination of activities by NASA, RSA, or other IPs could restore the necessary capabilities to prevent reentry of ISS. These three scenarios could render the attitude and reboost functions inoperative, and/or could remove the capability to dock or attach any vehicles which could be used to replace the propulsive functionality of ISS (e.g., explosions resulting in uncontrollable attitude and/or segmented ISS).

The behavior of ISS during an inadvertent reentry would be expected to be similar to ISS behavior during a controlled deorbit (i.e., targeted reentry) action. Aerodynamic forces and thermal stresses upon reentry would be similar, burning, breaking up, and vaporizing ISS into various fragment sizes. The difference lies in the indeterminate location of the impact area/ footprint under the orbit flight path, as opposed to the predetermined remote ocean location that would be used for decommissioning.

Three methods were assessed by NASA to estimate the injury risk to people from reentering debris. The method used, for purposes of this EIS, is the most conservative of the three (an injury could range from a bruise or an abrasion to a fatality); this EIS considers all injuries as fatal. Given the orbital inclination, any debris surviving reentry would fall approximately between 51.6° north and south latitude. Assuming an inadvertent reentry, the number of injuries within the population located in the ±51.6° latitude band would range from 0.0966 to 0.030, with the risk to a given individual ranging from 1.287×10^{-11} (1 in 78 billion) to 3.999×10^{-12} (1 in 250 billion). Likewise, the number of structures potentially hit within the ±51.6° latitude band was estimated to range from 0.57 to 1.8. It is important to note that these calculations do not take into account the unlikely event of loss of control (i.e., initiating probability).

Crew members living and working in ISS could be exposed to risks from major failures of the station. NASA has taken measures to reduce such risks by building safety features into ISS and by requiring that a rescue or escape vehicle for emergency exit of the crew from ISS be present during human occupation of the station.

2.4.2 Environmental Impacts of the No-Action Alternative

The No-Action alternative (cancellation of the U.S. contribution to the assembly and operation of ISS) would have an adverse effect on both the planned science investigations involved and on the U.S. relationship with the IPs in the Program. Socioeconomic impacts would occur with termination of employment and loss of income among a large portion of the 15,400-person Space Station Program workforce consisting of civil servants and contractor employees located at numerous facilities over a 35-state area.

The No-Action alternative would eliminate any perturbations to the stratosphere and the thermosphere (ionosphere) associated with ISS assembly and operation, and with decommissioning. The Shuttle launches that would have been used for ISS would very likely be reallocated to other missions, and the launch impacts would nevertheless occur. Some of those launches could be associated with missions directed at science and engineering experiments, and to orbiting platforms to replace the loss of science from ISS. Although the U.S. could continue to fly some limited microgravity research experiments on board the Space Shuttle, these flights would not satisfy the goals of achieving long-duration human-occupied, monitored, and adaptive scientific research that can only be provided by a space station in long-term Earth orbit. There would be little difference between the Proposed Action and the No-Action alternative with respect to other environmental impacts, although the impact on scientific and technological opportunities would be substantial.

The No-Action alternative would not yield the anticipated science data from ISS, thereby effectively preventing NASA, CSA, ESA, RSA, STA, and ASI from achieving their science objectives. Although new technological advances have already been made during the development of the space station, the scientific investigations of the American and international scientists who havc contributed to its development and experiments would be terminated. In addition, this alternative would terminate the international agreements to develop the space station, disrupt and strain the relationships for other space-related projects, and hinder the future formation of other international science and engineering teams. The international partnership is an example of an undertaking whose scope and cost would not likely be borne by any single nation, but is made possible through shared investment and participation. Failure to undertake the program would discourage other similar international partnerships for future peaceful space efforts.

However, the IPs could design and build an alternative space station utilizing current RSA hardware as the core. The quality of the microgravity environment that would be achievable without U.S. hardware would be less than that of ISS. Thus, the scientific data from most microgravity studies would, in turn, be somewhat lower in quality that that from ISS. In effect, the scientific gains would be hampered by lack of U.S. participation.

3.0 AFFECTED ENVIRONMENT

The following section describes the environments that could potentially be affected by the ISS Program. They include portions of the Earth's atmosphere, its oceans, and the sites where ISS components will be developed and launched.

The Tier 1 EIS for SSF[1] addressed the affected environment. This Tier 2 document provides updates, as applicable, resulting from changes in space station configuration, orbital inclination, number of launches, and programmatic realignment of the sites where ISS will be developed.

3.1 GLOBAL ENVIRONMENT

The global environment, for the purposes of this EIS, consists of the Earth's atmosphere and the open ocean areas where surviving debris from ISS decommissioning may be targeted.

The Earth's atmosphere is composed of several layers. The lowest layer is the troposphere, which extends from the surface to approximately 15 km (8.1 n.m.). The next layer is the stratosphere, which extends from approximately 15 km (8.1 n.m.) to 50 km (27 n.m.). The stratosphere contains the ozone layer, which protects the Earth's population from dangerous ultraviolet (UV) radiation. The next layer is the mesosphere, which extends from 50 km to 80 km (27 n.m. to 43 n.m.). This is followed by the thermosphere, which extends from 80 km (43 n.m.) to an indefinite height. The thermosphere contains several layers which are important in radio communications (i.e. the ionosphere). Figure 3-1 depicts the atmospheric layers discussed above and the average operating altitude of ISS of 408 km (220 n.m.).

3.1.1 The Troposphere

Currently, a global concern to the troposphere is the "greenhouse effect." ISS is not expected to have any direct impact on the greenhouse effect. However, it will be in an orbit that is suitable to study the greenhouse effect and may contribute to knowledge about it. Shortwave radiation from the Sun is transmitted through the atmosphere to the surface, where it heats the Earth-atmosphere system resulting in the emission of long-wave (infrared) radiation. Some of this outgoing infrared radiation is "trapped" by atmospheric constituents. This reduction in the long-wave emission to space is referred to as the greenhouse effect. Atmospheric gases capable of inhibiting the transmission of long-wave radiation are generally referred to as greenhouse gases.

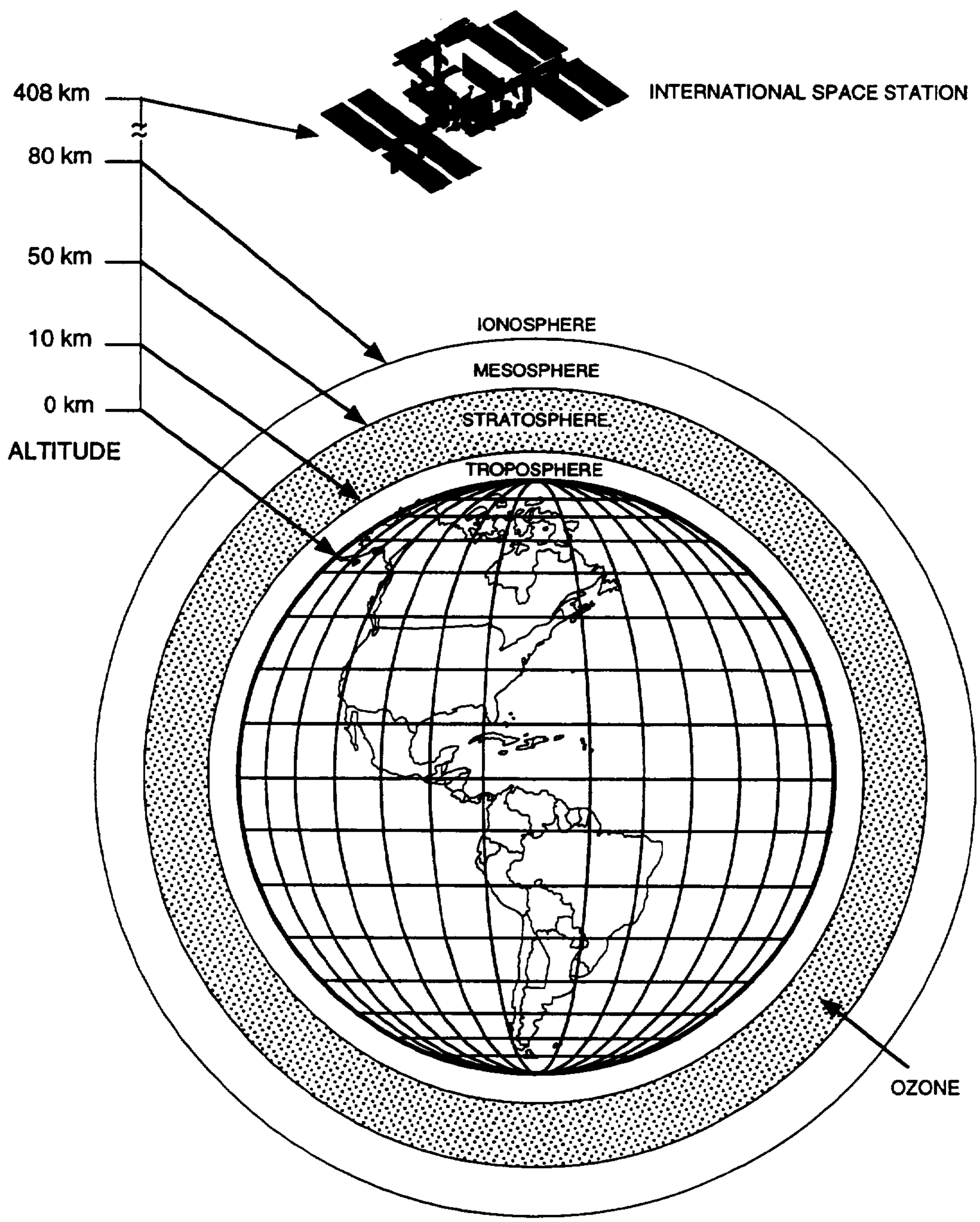


Figure 3-1. Locations of the troposphere, stratosphere, mesosphere, and ionosphere (part of the thermosphere) atmospheric layers and the International Space Station.

The most effective greenhouse gas is water vapor (H_2O) because of its abundance in the free troposphere and its relatively broad absorption window, which allows water vapor to absorb energy in both the low- and high-energy bands of the infrared spectrum. Carbon dioxide (CO_2) is the second most important greenhouse gas, primarily because of its lower concentration and narrow infrared absorption window. Additional atmospheric trace gases that are considered greenhouse gases include methane (CH_4), nitrous oxide (N_2O), ozone, and assorted chlorofluorocarbons (CFCs).[25]

3.1.2 The Stratosphere

The stratosphere is the region between approximately 15 km and 50 km (8.1 and 27 n.m.). An important feature of the stratosphere is the ozone layer. The highest concentrations of ozone are found at approximately 25 km (13.5 n.m.).[25]

Ozone (O_3) is the only atmospheric constituent that effectively absorbs UV solar radiation from about 250 to 310 nanometers, protecting plant and animal life from exposure to harmful radiation (UV-B). Moreover, since the absorbed solar energy is converted into thermal energy, ozone's absorption of UV light constitutes the principal source of heat in the middle atmosphere and is therefore responsible for the existence of the stratosphere, a layer with a positive temperature gradient and a considerable static stability.

In the steady state, the ozone concentration will be determined by a balance between the rate of ozone destruction (from photolysis and reaction with atomic oxygen) and the rate of ozone production (from reaction of atomic and molecular oxygen). A catalytic cycle for ozone destruction is shown in the following example:

Ozone (O_3) destruction:	$NO_x + O_3 \rightarrow NO_2 + O_2$
Catalyst regeneration:	$NO_2 + O \rightarrow NO_x + O_2$
Net Reaction:	$O + O_3 \rightarrow 2O_2$

Where NO_x = nitrogen oxide

NO_2 = nitrogen dioxide

O_2 = oxygen

A number of chemical compounds (e.g., chlorine and bromine monoxide, and the hydroperoxyl radical) other than the nitrogen system just described can catalyze ozone destruction and decrease the steady-state ozone concentration.

Evidence indicates that the atmospheric concentrations of a number of the gases important in controlling stratospheric ozone and climate are increasing on a global scale due to human activities, causing a reduction in stratospheric ozone density. Such gases include N_2O, CH_4, carbon tetrachloride (CCl_4), methyl chloroform (CH_3CCl_3), many CFCs, and halons (i.e., bromine-containing compounds such as $CBrF_3$ and $CBrClF_2$). These gases are important sources of the stratospheric nitrogen, hydrogen, chlorine, and bromine species that can reduce the abundance of ozone.[26]

Long-term decreases in stratospheric ozone concentrations are expected to not only increase the UV-B irradiance of the Earth's surface, but also to modify the thermal structure of the atmosphere, which has potential consequences on the general circulation and on the Earth's global climatology.[25]

ISS will have an average operating altitude of 408 km (220 n.m.). The altitude can range between 278 km (150 n.m.) and 482 km (260 n.m.). The upper boundary of the stratosphere is 50 km (27 n.m.). Thus, on average, ISS will be approximately 358 km (193 n.m.) above the upper boundary of the stratosphere. The Shuttle will launch through and return through the stratosphere. In addition, ISS would descend through the stratosphere during the targeted decommissioning action.

3.1.3 The Mesosphere

The mesosphere is the atmospheric layer between 50 km and 80 km (27 and 43 n.m.), extending from the top of the stratosphere to the base of the thermosphere. The base of the mesosphere is characterized by a warm layer, which is produced by the absorption of solar UV energy by ozone. Although the concentration of ozone is greatest at lower stratospheric altitudes, there are production/destruction mechanisms at work in the lower mesosphere. The temperature profile then decreases with height, reaching a minimum at the top of the mesosphere. The layer is an area of varied wind speeds and directions due to the occurrence of turbulence and atmospheric waves.[27]

3.1.4 The Ionosphere (Thermosphere)

The region of the neutral atmosphere above the mesopause, called the thermosphere, is characterized by increasing temperatures. It coexists with an ionized region called the ionosphere. The ionosphere is divided into several regions which are particularly important to radio communications. The lowest clearly defined region of the ionosphere is the E layer, occurring between 80 km (43 n.m.) and 140 km (76 n.m.). The F_1 region and the F_2 region occur in the general area between 140 km (76 n.m.) and 1000 km (539 n.m.), the F_2 region always being present and having the higher electron concentration. The maximum electron concentration occurs in the F_2 region around 300 km (162 n.m.).[28]

Above the maximum electron concentration in the F_2 region, the electron concentration decreases monotonically out to several Earth radii, where the ionosphere merges into the magnetosphere, where the Earth's magnetic field becomes the dominant organizing principal.[29] ISS will orbit the Earth in this atmospheric layer. The Shuttle will also pass through this layer en route to and from ISS.

3.1.5 Open Ocean Areas

Approximately three-quarters of the surface of the Earth is covered by ocean, which is divided into five major areas: (1) Atlantic Ocean, (2) Pacific Ocean, (3) Indian Ocean, (4) Arctic Ocean, and (5) Southern Ocean.

Ocean basins are depicted in Figure 3-2.[30] Beaches generally define the limits of the shore area, and are characterized by high and low water marks determined by the tides.[31] The relatively shallow, submerged platform bordering the continents, called the continental shelf, slopes gently seaward to the shelf break, where an increase in gradient leads to the continental slope. The edge of the shelf is at a depth of about 150 m (500 ft). The width of the continental shelf varies enormously, from nearly zero along parts of the west coast of North and South America to more than 1,000 km (539 n.m.) off the north coast of Siberia. The average width is 75 km (40 n.m.). The continental slope extends downward to a depth of about 4,000 m (13,000 ft). The next zone, which may vary in width from 0 to 600 km (324 n.m.), is called the continental rise. It merges with the deep-sea abyssal plain at an average depth of about 4,000 m (13,000 ft). The abyssal plain is the most extensive area of the ocean basin, occupying about 75 percent of the total ocean basin, and has water depths ranging from 3,000 to 6,000 m (9,900 to 19,800 ft). The mid-ocean ridges form high points in the ocean basin, rising from the abyssal plain to form relatively shallow open ocean areas. Trenches are the deepest areas of the oceans. Of the 92 naturally occurring elements on Earth, 80 are found in seawater. Sodium and chlorine are the most common.

The Atlantic Ocean extends from the continents of North and South America east to Europe and Africa, and extends south from the Arctic Ocean to the continent of Antarctica. It is the second largest ocean water body, covering nearly one-fifth of the Earth's surface. The Atlantic Ocean provides for drainage from a continental area nearly four times larger than that draining into either the Pacific or Indian Oceans. The mean depth of the Atlantic Ocean is 3,868 m (12,690 ft).

The Pacific Ocean separates Asia and Australia from the North and South American continents to the east, and extends south from the Arctic Ocean to the continent of Antarctica. The Pacific Ocean is the largest ocean water body, covering 32 percent of the Earth's surface and comprising 46 percent of the surface area of all the world's oceans and seas. Its area is greater than that of all land areas combined. The Pacific Ocean has the greatest mean depth (4,282 m [14,049 ft]) of all the oceans.

The Indian Ocean is smaller than the Pacific or Atlantic Oceans and comprises about 21 percent of the surface area of all oceans. It is located east of Africa and extends to Australia on the west, and south from Asia. The Indian Ocean's average depth is 3,850 m (12,630 ft).

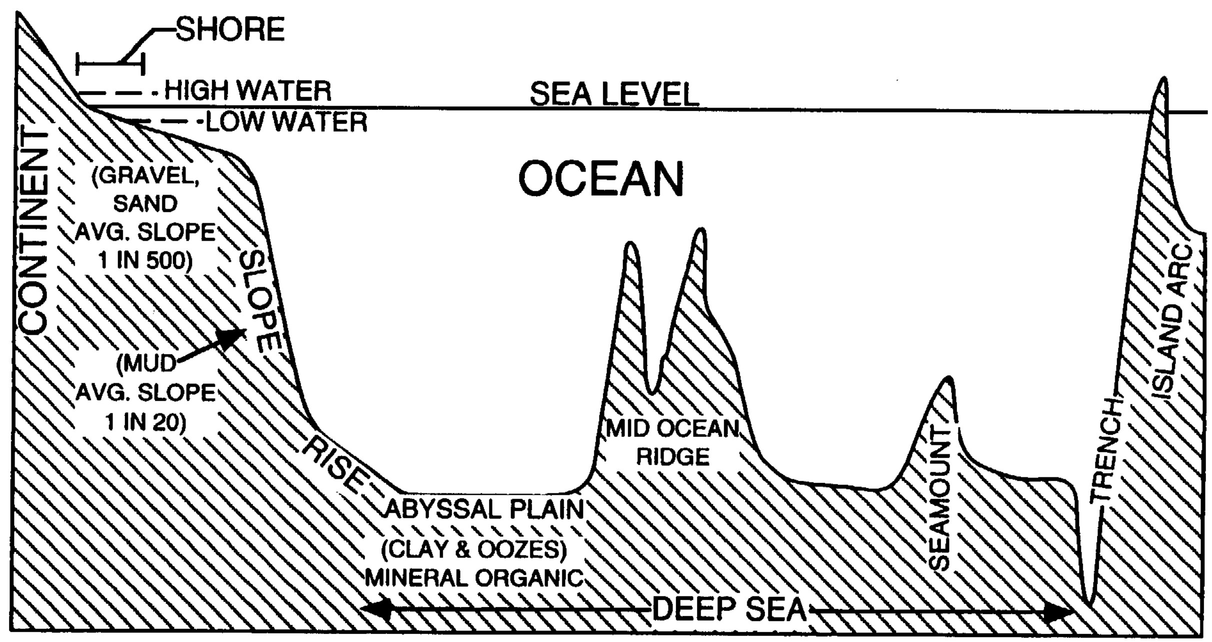


Figure 3-2. Schematic section across the ocean floor, depicting major geological features.

The Arctic Ocean surrounds the North Pole and lies between the continents of North America and Asia. The Arctic Ocean is nearly completely covered by 2 to 3 m (6.6 to 19 ft) of ice in winter, and in summer becomes substantially open only at its peripheries.

The Southern Ocean is a broad, deep, circumpolar ocean belt between the southern shores of the Australian, South American, and African continents and the coastline of Antarctica. The Southern Ocean provides a major interconnecting artery between the Atlantic, Pacific, and Indian Oceans.

The biological resources of the oceans, as mentioned above, are concentrated in near-shore (continental shelf) areas that are fed by deeper water upwelling to the surface.[32] These nutrient-rich waters, when exposed to light and warmer temperatures, lead to relatively high levels of plant growth, which in turn lead to relatively high levels of animal growth. It is in these areas that the most significant oceanic biological resources reside, both the fish and the more unique fauna of the ocean environment such as marine birds and mammals (whales, dolphins, seals, etc.). Geographically, the most productive areas of the oceans occur in the more northern or southern parts of the oceans.

The central oceanic areas of the Atlantic, Pacific, and Indian Oceans, the areas under consideration for decommissioning of ISS, are areas of lower productivity, and are inhabited by relatively small populations of significant biological resources such as fish and marine mammals. While these areas may be traversed during seasonal migrations of fish and marine mammals, there are few resident populations except near mid-ocean ridges associated with island chains (such as the Hawaiian Islands), and major migrations are apparently more concentrated within 100 km (54 n.m.) of the coast rather than through truly open ocean areas.

Similarly, the major economically exploitable geologic resources of the oceans, primarily oil and gas, are located near the coasts where water depths are sufficiently shallow to allow mechanical recovery. While there are undoubtedly other geologic resources in the abyssal plains and in deeper trenches, these resources are not now economically recoverable, and are not now areas of appreciable human activity.

3.1.6 Populations

For the purposes of this EIS, specifically the decommissioning and inadvertent reentry analysis detailed in Chapter 4, the projected populations within the ±51.6° latitude band and the United States in the year 2020 were used.[18] The year 2020 was used because it is reasonably beyond the 10-plus year estimated useful lifetime for ISS. Within the ±51.6° latitude band, there is a total surface area of 397,047,000 km^2 (115,143,600 $n.m.^2$). The land area within the latitude band is about 26.6 percent of that area, or about 105,594,300 km^2 (30,622,400 $n.m.^2$). The projected 2020 population would be 7.5 billion people. The United States, with a surface area of 9,166,000 km^2 (2,658,140 $n.m.^2$), is projected to have a population of 314 million in the year 2020. These population projections will play a role in assessing the potential impacts associated with an inadvertent reentry of ISS.

3.2 SITE-SPECIFIC ENVIRONMENT

This section is concerned with the primary NASA centers responsible for ISS, including systems development and implementation, and launch activities. As a result of changes in the management structure of the Space Station Program since publication of the Tier 1 document, there has been a realignment of the NASA field center responsibilities. For example, JSC's role is now to manage all design, development, launch, and operations activities with participation by other field centers and a contractor team. GSFC's role has diminished with the cancellation of the polar orbiting platform to only support of communications with ISS using GSFC's and NASA's existing communications facilities and networks. The VAFB launch complex's role has been eliminated with the cancellation of all polar launches. KSC will conduct ISS launches aboard the Space Shuttle using existing facilities and one major new facility, the SSPF. Future site-specific decisions regarding the Space Station Program will be addressed in separate environmental documents.

3.2.1 Lyndon B. Johnson Space Center

JSC is located on about 646 ha (1600 ac) in the Clear Lake area of the city of Houston in the southeastern portion of Harris County, Texas, between Houston, Texas and Galveston, Texas.[22]

The topography of the JSC site is typical of coastal plains along the Gulf of Mexico: the land is relatively flat and open, with oaks and pines growing along water courses. Near-surface soils at JSC consist mainly of high plasticity clays. Mission control, management, administration, and crew training are clustered for efficiency in a central mall. Spacecraft vibration testing facilities are remotely located, as are thermochemical test facilities, the thermal vacuum chamber, the anechoic chamber test facility, and the antenna test facility.[22]

The primary source of water at JSC is treated surface water supplied by the city of Houston, plus two wells for emergency use only. Domestic wastewater is transported by underground pipes to the Clear Lake Water Authority (CLWA) treatment plant. Photographic laboratory wastes, caustic cleaning solution wastes, and oil-water wastes from garages and shops are accumulated in tanks, then are treated and disposed of by a licensed contractor approved by the state. Blow-down wastewaters from cooling towers and the thermochemical test area are aerated and chemically treated at JSC before discharge to the CLWA plant under pollution control regulations.[22]

The mean daily maximum and minimum temperatures at JSC range between 33 °C (92 °F) and 6 °C (44 °F). The average annual rainfall at JSC is 117 cm (46 in.). While ozone levels often exceed federal standards, ambient air quality in the JSC region is generally within the national primary and secondary standards set by the U.S. Environmental Protection Agency (EPA).[22]

The Clear Lake area population was approximately 147,000 people in 1990. JSC contributed $1.18 billion to the Clear Lake area economy and the Houston regional economy in 1990. JSC employs approximately 17,000 people, about 3,700 of which are civil servants.[22]

No listed or proposed threatened or endangered species exist at JSC, and no designated or proposed critical habitat for threatened or endangered species exists at JSC. The Texas Natural Heritage Program Information System indicates that the following threatened and endangered species, and species that are candidates for these lists, may be found near the Center: Attwater Greater Prairie-chicken, Gulf Saltmarsh Snake, Texas Windmill-grass, Houston Machaeranthera, Coastal Grayfeather, Texas Meadow Rue, and American Alligator. The Apollo Mission Control Center has been designated as a National Historic Landmark.[33]

In addition to existing facilities at JSC, the Neutral Buoyancy Laboratory is being constructed in an existing building and is being procured from McDonnell Douglas. An Environmental Assessment is currently in preparation for this facility.

3.2.2 John F. Kennedy Space Center

KSC is located on approximately 56,560 ha (140,000 ac) on Merritt Island, Florida, in Brevard County. KSC is the major NASA installation for launch operations and related programs in support of both manned and unmanned space missions.[12]

Of the 56,500 ha (140,000 ac) at KSC, 95 percent is undeveloped land: uplands, wetlands, mosquito control impoundments, and open water areas. NASA maintains operational control of approximately 2,600 ha (6,507 ac) of KSC. This area comprises the functional area which is dedicated to NASA operations. Approximately 62 percent of the NASA operational area is currently developed as facility sites, roads, lawns, and maintained right-of-ways. The remaining undeveloped operational areas are dedicated as safety zones around existing facilities (including launch impact areas which extend into the Atlantic Ocean) or held in reserve for planned or future expansion. Developed facilities within the NASA operational area are primarily the Shuttle Landing Facility, the Industrial Area, and the Vertical Assembly Building Area. These facilities comprise more than 70 percent of the NASA operational area. The remainder of the NASA operational area is divided among smaller facilities spread throughout KSC. The 2,700 ha (6,655 ac) of land north of Launch Complex 39 are part of the 23,270-ha (57,600-ac) Canaveral National Seashore and is administered by the National Park Service, while the U.S. Fish and Wildlife Service (USFWS) administers the remaining 20,600 ha (50,945 ac). The USFWS also administers the 30,500-ha (75,383-ac) Merritt Island National Wildlife Refuge.[12]

Surface waters surrounding KSC include portions of the Indian River, Banana River, Mosquito Lagoon, and all of Banana Creek; various minor tributaries also discharge to these waters. Surface water quality at KSC is generally good. NASA, the USFWS, and Brevard County maintain water facility monitoring stations within and at KSC boundaries. Approximately 120 sites are periodically sampled. KSC receives its water supply from the local public supply utility. All discharges into groundwater at KSC are performed within Florida Department of Environmental Regulation standards and are covered by permits issued by the State of Florida and federal regulatory agencies.[12]

The climate at KSC is subtropical with short, mild winters and hot, humid summers but no discernible spring and fall seasons. Ambient air quality at KSC is well within the EPA's national primary and secondary standards. Temperature ranges are from 4 °C (40 °F) to 24 °C (75 °F) in the winter and from 21 °C (70 °F) to 35 °C (95 °F) in the summer. Thunderstorms are frequent, May through September. The average annual rainfall at KSC is 115 cm (45.2 inches).[12]

Approximately 18,200 people were employed at KSC at the end of September 1993, about 14 percent of whom were civil servants.[12] Peak employment at KSC was 25,895 in 1968, during the Apollo program. The local economy depends heavily upon the health and activity of KSC, the largest employer in Brevard County, with the visitors center, Spaceport USA, one of the most frequented tourist sites in the state.[12]

Because KSC is the area that will experience the greatest amount of activity during ISS assembly and operation, as well as the associated impacts, additional details of the population composition are provided in compliance with NASA's Environmental Justice Strategy.[34] For purposes of environmental justice, the Florida region of interest consists of the six counties surrounding KSC/CCAS—Volusia, Seminole, Lake, Orange, Osceola, and Brevard Counties. Of the approximately 2 million people in this region in 1990, about 86 percent were white, 11 percent black, 2 percent Native American/Eskimo/Aleut/Pacific Islander/Asian, and the remaining did not fall into any of the above racial categories. About 6 percent of the total 1990 population was of hispanic origin (across all races). About 9 percent of the regional population (about 189,000 people) lived within 32 km (17 n.m.) of the Shuttle launch pads and Titan IV launch complexes at KSC/CCAS, respectively. The racial composition reflected the overall regional population as 88 percent white, 10 percent black, and 2 percent in the remaining two categories. Hispanic representation was about 6 percent across all races. The population area nearest the launch complexes is about 16 km (8.5 n.m.) to the southeast, and contained in 1990 less than 2 percent of the total regional population. Racial composition was approximately 97.5 percent white, 1.0 percent black, and 2 percent divided amongst the remaining two categories; about 2 percent were of hispanic origin across all races.[35]

Federally listed or proposed threatened or endangered species in the KSC area include four species of turtles, the bald eagle, the wood stork, the American peregrine falcon, the Florida scrub jay, indigo snake, and the West Indian manatee. [12]

A Space Station Processing Facility (SSPF) was recently constructed on 11 ha (28 ac) of undeveloped land within the KSC industrial area. The SSPF supports the ground processing of ISS flight elements. A Biological Assessment for impacts to the Florida scrub jay has been completed. In response to the Biological Opinion provided by USFWS[36], which indicated the potential for incidental removal of individual birds from the 11-ha (28-ac) site, NASA has developed and implemented a plan outlining mitigation measures which will result in 20 ha (50 ac) of compensation for the 11 ha (28 ac) removed by the construction of the facility.

3.2.3 George C. Marshall Space Flight Center

MSFC is a multidiscipline center for the design and development of major space transportation systems, orbital systems, and scientific and applications payloads for space exploration. MSFC occupies about 728 ha (1800 ac) of land within Redstone Arsenal next to Huntsville, Alabama.[21]

MSFC is located in the southwest portion of Madison County, within Redstone Arsenal, which is bordered by the Tennessee River on the south, the City of Huntsville on the north and east, and the Huntsville/Decatur Jetport on the west. The Department of the Army controls 14,900 ha (36,818 ac) of Redstone and leases 745 ha (1,841 ac) to MSFC. About 1,650 ha (4,075 ac) of the Wheeler National Wildlife Refuge lie to the south and west of MSFC. Half of MSFC's acreage is designated as test areas. About 100 ha (250 ac) are open areas, 40 ha (100 ac) are set aside for recreation, and the rest is under a conservation plan to reduce soil erosion from the rolling and steep hills.[21]

Surface water is abundant in Madison County and supplies the drinking and industrial water used at Redstone Arsenal and MSFC. Domestic sewage is treated at MSFC and discharged to Indian Creek. Certain areas, particularly the test areas, use septic tanks and disposal fields for sewage treatment. Industrial wastewater and solvents, mostly from plating and other metal finishing processes, are treated in a 13.3-million-liter (3.5-million-gallon) capacity lined lagoon. Heavy metals are treated and removed to an approved off-facility landfill.[21]

MSFC is in a temperate climate with warm, humid summers and temperatures ranging from an average of 25 °C (77 °F) in summer to 8 °C (47 °F) in winter. Normally, the area air quality is better than the National Ambient Air Quality Standards; nearby mountains to the south and west tend to create air pockets conducive to inversions and air stagnations. The average annual precipitation at MSFC is 137 cm (52 inches).[21]

Huntsville, Alabama has a current population of 167,400. In 1990, MSFC employed approximately 6,200 people, of which 2,684 were civil servants. In addition, contracts awarded by MSFC employed approximately 14,000 people, not all of whom reside in the Huntsville area.

Habitat for 18 species of federally listed or proposed threatened or endangered species exists on the MSFC site (e.g., the Indiana bat, eastern cougar, and southern bald eagle). The habitat ranges in quality from marginal to adequate. A brief survey of the site conducted in 1991 did not reveal any protected species actually on site. The Redstone Test Stand, Propulsion and Structural Test Facility, Saturn V Dynamic Test Stand, and Neutral Buoyancy Space Simulator are preserved as National Historic Landmarks.[33]

3.2.4 Lewis Research Center

LeRC consists of two separate operations—the Cleveland site and the Plum Brook Station, near Sandusky, Ohio. The center is responsible for research in electric power generation for space vehicles and for aircraft propulsion systems.[20]

The Cleveland site of LeRC is located in the southeast corner of Cleveland, Ohio, adjacent to Cleveland Hopkins International Airport. The center contains a total of 141 ha (351 ac). The land is generally flat, with the exception of Abram Creek. The steep, narrow valley of Abram

Creek bisects the west side of the site. The Plum Brook Station encompasses 2,190 ha (5417 ac) in Erie County, Ohio, an area that is primarily rural and agricultural with low population densities.[20]

Abram Creek, which bisects the Cleveland site, flows into Rocky River. During low flow periods, municipal wastewater treatment plant effluent makes up nearly all the Abram Creek's discharge. Water quality is generally poor. The Rocky River has been classified by the Ohio EPA as a State and National Resource Water. Groundwater supplies some domestic users; however, the wells do not have significant yields. The water supply to the site is provided by the Cleveland Water Department from Lake Erie. The Cleveland Southerly Wastewater Treatment plant handles the sewage from the site.[20]

The Plum Brook Station comprises the drainage area for 13 streams, some of which are relatively minor and emanate from within the Station. Plum Brook Station discharges to three of these streams (Ransom Brook, Plum Brook, and Kuebeler Ditch) under an existing National Pollutant Discharge Elimination System permit.[20]

Both the Cleveland site and Plum Brook Station are in the same continental climatic regime—modified by Lake Erie. Monthly mean temperatures range from approximately -2.8 °C (27 °F) in January to 23 °C (74 °F) in July. Precipitation is evenly distributed throughout the year, averaging about 89 cm (35 in.) per year. Air quality monitoring stations in the vicinity of the Cleveland site indicate federal and state ambient air quality standards are being met for sulfur dioxide, nitrogen dioxide, and total suspended particulates, but the Cleveland area is considered a non-attainment area for ozone. Erie County, which includes the Plum Brook Station, is classified as an attainment area for all air quality parameters.[20]

The total population of Cuyahoga County is approximately 1,420,000. In 1989, the Cleveland site employed approximately 4,180 people, 2,737 of which were civil servants. The total population for Erie County is approximately 75,600. The number of personnel at the Plum Brook Station varies between 50 and 300, including NASA, contractor, and seasonal employees.[20]

There are no federally listed or proposed threatened or endangered species known to be located at the Cleveland site, but there have been documented findings of plant and animal species in the Rocky River Reservation, adjacent to the Center, and one migrating bird species, the Upland Sandpiper, nesting near the airport. Plum Brook Station is one of the few relatively undeveloped areas in the region and contains both wetlands and woodlands. The site has not been surveyed for federally listed or proposed threatened or endangered species or habitat. There are, however, a few plant species on site which are on the Ohio list. There are approximately 133 archaeological sites of known historic significance lying outside the fence encircling the central area of Plum Brook Station.[20] Numerous sites also probably exist within the fence. Three of the identified sites outside of the fence were previously placed on the Ohio Historical Society Register, and the remaining 130 in 1980 and 1981. The Rocket Engine Test Facility, the Zero Gravity Research Facility, and the Spacecraft Propulsion Research Facility are designated as National Historic Landmarks.[33]

4.0 ENVIRONMENTAL IMPACTS

This section presents detailed information on the potential environmental impacts of the Proposed Action and the No-Action alternative summarized in Chapter 2. The impact discussions focus on those areas which were deferred to this document by the Tier 1 EIS of March 1991.[1] Specifically, this Tier 2 EIS addresses the following:

- Changes in space station design and associated changes in the Program and milestones
- Impacts of outgassing of nontoxic gases during ISS operation
- Change to a hydrazine propulsion system for ISS
- Accidental reentry of ISS during assembly and operation; specifically, the probability of such an event occurring, the risks to humans and property damage, and design and operational measures to reduce the risk.

In addition, the Tier 1 EIS noted that discussions of thermospheric (ionospheric) impacts in the Tier 2 EIS would be updated with available new information. The Tier 1 EIS discussed the decommissioning plan for ISS after its useful life is over. NASA's evaluations of decommissioning options since publication of the Tier 1 EIS have indicated that a targeted deorbiting of ISS, including atmospheric burnup of most components and splashdown of surviving debris in a remote ocean area, would be the most feasible and cost-effective approach.

Section 4.1 discusses the impacts of the Proposed Action, focusing upon the topics deferred by the Tier 1 EIS. In addition, relevant impact discussions from the Tier 1 EIS are updated (e.g., Shuttle launch impacts on stratospheric ozone). Section 4.2 discusses the impacts of the No-Action alternative.

4.1 ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

The Proposed Action, as noted in the May 23, 1995 NOI (60 FR 27332), is to continue providing the U.S. contribution to assembly and operation of ISS.

Implementation of the Proposed Action would consist of completing the fabrication and manufacture of the U.S. components of ISS at ground-based facilities (NASA Centers and commercial facilities); participation in the assembly and operation of ISS (including 27 Shuttle flights during the assembly phase) and approximately 5 or 6 Shuttle flights per year for resupply/logistics and other services over the operating life of ISS; and implementing the U.S. role in decommissioning ISS at the end of its useful life.

4.1.1 Environmental Impacts of ISS Manufacturing, Assembly, and Operation

U.S. components of ISS are being manufactured and tested at ground-based facilities consisting of NASA Centers (JSC, MSFC, LeRC) and numerous contractor facilities throughout the country. The impacts associated with the manufacture of U.S. components of ISS were addressed in the Tier 1 SSF EIS[1] and are summarized and updated here. All facilities involved in the manufacture of U.S. components of ISS are subject to federal environmental regulations and those of the respective states in which the facilities are located. This includes, but is not limited to, implementing regulations for the Clean Air Act, the Clean Water Act, and the Resource Conservation and Recovery Act. NASA requires that its Centers and contractors comply with the requirements of pertinent environmental regulations in the performance of their missions. The environmental impacts associated with completing manufacture of U.S. components will thus be associated primarily with airborne emissions, waterborne effluents, and waste disposal, and are expected to be minimal in terms of both short-term and long-term consequences. Transporting U.S. space station components and materials to KSC will entail the use of conventional modes of transport such as truck and aircraft. Transportation will entail consumption of fossil fuels, but is not expected to result in substantial increases in exhaust emissions or environmental impacts along the transportation routes used to access KSC.

Socioeconomic impacts associated with manufacturing U.S. contributions to ISS revolve principally around employment and wages and the secondary benefits derived by suppliers of goods and services to space station contractors, local communities, and the States in the form of revenues and taxes. During fiscal year 1995, U.S. employment directly involved in the Space Station Program has numbered over 15,400 jobs in both the civil service and commercial sectors, spread out over numerous communities in 35 states. Annual expenditures for the Space Station Program are presently at a level of about $2.1 billion in accordance with the funding cap placed upon the Program by the Congress and the Administration. Secondary employment attributed to the Space Station Program has been estimated at between 70,000 and 100,000 workers resulting from the demand for goods and services in the communities by the Program workforce. Upon completion of manufacturing of U.S. components, and throughout the operational lifetime of ISS, direct employment is expected to be reduced from these levels. This reduction in workforce is as yet indeterminate, however, workers will be required to support ISS resupply, maintenance and repair, mission planning and control, and the associated science and engineering missions.

The principal source of environmental impacts during ISS assembly and operation, except for decommissioning, is associated with Shuttle and payload processing and Shuttle launches. Beginning in November 1997, a total of 44 launches, from both the U.S. and the IPs, would be required to assemble ISS up to establishing a 6-person permanent operational capability. The U.S. would supply 27 of those launches over the approximately 54-month assembly period. All of those flights would be accommodated within the normal Shuttle Program schedule at KSC (i.e., ISS-related launches would not add to the maximum annual number of Shuttle launches from KSC—currently 7 per year). In addition, approximately 5 or 6 Shuttle flights per year would occur over the 10 or more years of the operating life of ISS. These flights would be primarily for resupply.

4.1.1.1 Shuttle and ISS Payload Processing

Processing the Shuttle before launch would involve industrial-type activities and operations. These activities would occur primarily at the Orbiter Processing Facility and the Vertical Assembly Building at KSC. The Shuttle processing facilities operate under environmental permits issued by the Florida Department of Environmental Protection, which governs the levels of airborne and waterborne emissions to the environment. Manufacturing the solid rocket boosters for the Shuttle uses an ozone-depleting substance, 1,1,1-trichloroethane, which is regulated under the Clean Air Act Amendments of 1990 (CAAA-90). The U.S. has been granted an Essential Use Exemption for using this substance to manufacture solid rocket motors (SRMs). Hazardous and toxic wastes, also regulated, are collected for recycling and/or disposal by a licensed contractor. The activities associated with Shuttle processing result in no substantial short-term or long-term impacts to the environment.

During assembly and operation of ISS, equipment, supplies, and consumables (materials for use in or in support of experiments in the laboratory modules) would be handled and processed into payloads at the SSPF at KSC. Payloads would be integrated into the Shuttle payload bay at the Orbiter Processing Facility or at the launch pad before launch and delivery to the orbiting ISS. Among the typical consumables in some of the payloads would be materials considered toxic or hazardous such as acetonitrile, acetylene, cleaning fluids, gallium arsenide, and hydrogen gas.[1] Aside from the hydrazine used by Shuttle control systems, it is unlikely that hydrazine would be a routine component of ISS payloads launched from KSC. Rather, given that the altitude and attitude propulsion system of the ISS would be provided by RSA, hydrazine fuel supplies would be launched from RSA launch facilities. In the event that the U.S. were to undertake most of the resupply missions to the orbiting ISS, hydrazine fuel may then be included in ISS payloads routinely processed and launched from KSC.

It should be noted that ISS may have biological and radioactive materials on board during operation. As with hazardous and toxic materials, biological materials (e.g., microorganisms) would be subject to scrutiny and review before being allowed on board, and would be required to meet packaging and containment standards geared toward crew protection and safety. At present, those materials are expected to consist of very small amounts of nickel-63 in a volatile organic analyzer and cesium-137 in the RSA-supplied Soyuz (see Section 2.2.6). The quantities of these materials on board ISS are very small relative to IAEA standards for safe transport of radioactive materials.[17] The amount of cesium-137 and nickel-63 are about 3 to 7 orders of magnitude less, respectively, than the safe transport levels noted by IAEA. In addition, small amounts of radioactive materials may be allowed on board periodically for use in experiments. The need for these materials will be reviewed on a case-by-case basis.

Storage, handling, and processing of hazardous, toxic, and radioactive materials for ISS payloads at KSC are governed by federal and state laws, and NASA/KSC has strict procedures in place to ensure compliance with the applicable regulations and safe handling practices are observed. (Examples include KHB 8800.7—Hazardous Waste Management and KHB 1860.1—Ionizing Radiation Protection Program.) NASA's procedures and organizational infrastructure also ensure that contingencies such as accidental releases are properly addressed and remediated in accordance with applicable regulations. Normal processing of hazardous, toxic, and radioactive materials into payloads would therefore entail no substantial environmental impacts.

Should an accidental release occur during ISS payload processing, the release would be assessed, contained, cleaned up, and the resulting wastes disposed of in accordance with federal and state regulations. NASA's procedures and the processing facilities are structured to ensure worker and public safety, and to prevent and/or minimize accidental releases to the outside environment. Accidental releases at ground-based facilities would not be expected to entail substantial adverse environmental impacts. NASA/KSC procedures for these materials are further strengthened by Space Station Program requirements.[1]

Before being allowed on board the operating ISS, hazardous, toxic, and radioactive materials would be required to be in triply-contained (dual fault tolerant) packaging. This would prevent exposure and endangerment of the crew. Radioactive materials must also be evaluated to determine if an accidental spill could be cleaned up without endangering critical systems. All crew members handling radioactive materials would receive federal radiation worker training.

4.1.1.2 Impacts of Shuttle Launches on the KSC/CCAS Area

The environmental impacts associated with Shuttle launches from KSC have been addressed in previously published NEPA documents, including the Space Shuttle Program EIS[11] and the KSC Environmental Resources Document (ERD)[12], and other NASA NEPA documentation.[13,14,23,37,38] The environmental impacts of Shuttle launches are summarized in Table 4-1. All Shuttle launches would take place at KSC from launch pad 39A or 39B. Titan IV launches, if necessary for ISS, would take place at Launch Complex 40 or 41 at CCAS, located adjacent to KSC. The environmental impacts of Titan IV launches were recently addressed in NASA's Cassini Mission EIS[23] and in earlier U.S. Air Force documentation for the Titan IV/Solid Rocket Motor Upgrade.[24] The impacts of Titan IV launches are similar in nature to those from a Shuttle launch and are summarized in Table 4-2.

The cumulative impacts of the ISS-associated U.S. launches for assembly and operation would consist largely of the contribution made to impacts on biological resources near the launch pad, and the periodic impacts to local air quality. With respect to upper atmosphere effects on stratospheric ozone, given the phase-out of ozone-depleting chemicals that is occurring under the Montreal Protocol, it is expected that by the year 2000, solid-fueled rocket launches will be the principal source of new inputs to ozone-depleting chemicals in the stratosphere.

Table 4-1. Environmental Impacts of Shuttle Launches[14]

Environmental Components	Impacts
Land Use	No substantial adverse impacts on land uses not related to the launch.
Air Quality	High levels of exhaust emissions, principally chlorides and particulates (aluminum oxide), in exhaust cloud. Short-term degradation of air quality within launch cloud and near-field environment (about 488 m [1,600 ft] from launch pad). No substantial adverse impacts outside the near-field environment. Short-term localized decrease in stratospheric ozone density with no permanent or long-lasting effects. Short-term decrease in ion and electron concentration in localized area of upper ionosphere. No substantial effects on radio transmission.
Noise and Sonic Boom	No substantial adverse impacts.
Hydrology and Water Quality	No substantial adverse long-term impacts. Short-term increase in the acidity of nearby water impoundments.
Biological Resources	No substantial adverse long-term impacts to wetlands or floodplains. Short-term vegetation damage contributes to long-term decrease in species richness in near-field over time. Fish kills in nearby lagoons and mosquito control impoundments expected with each Shuttle launch. No substantial adverse effects outside the near-field. Some soluble products from residual solid rocket booster fuel introduced into ocean environment. Impacts short-term and localized.
Endangered and Threatened Species	Studies to date indicate no substantial adverse effects.
Socioeconomic Factors	No substantial adverse effects. Short-term economic beneficial effects from tourism.
Historical/Archeological Resources	No impact expected.

Table 4-2. Environmental Impacts of Titan IV Launches[23]

Environmental Components	Impacts
Land Use	No substantial adverse impacts on non-launch-related land uses.
Air Quality	High levels of exhaust products within the exhaust cloud as it leaves the flame trench; cloud would rise and begin to disperse near launch complex; greatest amount of wet HCl deposition within area of about 183 m (600 ft) of launch complex. No adverse air quality impacts expected in off-site areas. Temporary localized decrease in ozone along the flight path, with rapid recovery.
Noise and Sonic Boom	No sustained adverse impacts on work force or unprotected public.
Hydrology and Water Quality	No substantial adverse long-term impacts. Short-term increase in the acidity of nearby waters.
Biological Resources	No impact to floodplain. Some acidification of wetlands adjacent to launch site possible with winds from the east. High-risk zone for wildlife in the exhaust cloud within about 183 m (600 ft) of launch complex; vegetation damage. Wildlife mortality possible in a 20-m (66-ft) area near the flame trench exit. If exhaust cloud is pushed back over land, short-term acidification of nearby surface waters could cause mortality of aquatic biota. No long-term adverse effects expected.
Endangered and Threatened Species	No substantial adverse impacts expected.
Socioeconomic Factors	No substantial adverse effects. Potential short-term economic benefits from tourism.
Historical/Archeological Resources	No impact expected.

Shuttle launches from KSC and Titan IV launches from CCAS are consistent with the mission and land uses at both facilities, hence launches would not be expected to have any impacts on land uses at these facilities. Launches are normally accompanied by noise from rocket firing, and by sonic booms when suborbital or orbital stages of the launch vehicle are released and reenter. Off-site noise levels pose no hazards to individuals during launches. The sonic booms tend to occur downrange over the open ocean, again posing no threat to populated areas. Similarly, launches from KSC and CCAS have not had any substantial adverse long-term impacts on historical/cultural resources or upon wetlands or floodplains.

The consequences of Shuttle accidents were addressed in the Shuttle Program EIS[11], and supplemented by other NASA documentation. Shuttle accidents could include on-pad fires and explosions, accidents during the ascent phase, or accidents during landings when the mission has been completed.

The most apparent aspect of a Shuttle launch is the exhaust emitted during the launch from the three Space Shuttle main engines (SSMEs) and the two strap-on solid rocket boosters (SRBs).

4.1.1.2.1 Air Quality. With each ISS-associated Shuttle launch, the three SSMEs and the two solid-fueled SRBs would be ignited. The exhaust products from the SRBs would be forced to the north of the launch pad (Pad 39A or 39B), while the exhaust from the main engines would be forced to the south. This is accomplished by the split flame trench at the launch pad. The resulting exhaust products would mix with up to 2.04×10^6 L (5.4×10^5 gal) of deluge and washdown water sprayed on the launch pad at ignition, forming a ground cloud.[12] The ground cloud would consist primarily of the Shuttle exhaust products released during the first few seconds after ignition. It is during this period when the launch vehicle would be slowly lifting off the launch pad and emitting more Shuttle exhaust products per unit distance traveled than at any other time during launch. Hydrogen chloride (HCl) and aluminum oxide (Al_2O_3) particulates from the SRBs, and carbon dioxide (CO_2) and water from the main engines are the principal constituents of the Shuttle exhaust and, in turn, the ground cloud. The Titan IV exhaust varies somewhat by having a higher carbon monoxide (CO) component than does the Shuttle. As the buoyant ground cloud rises, the concentrations of exhaust constituents would drop rapidly due to the turbulent mixing of the cloud with ambient air and deposition of larger particles of Al_2O_3 particulates and droplets containing HCl scrubbed from the ground cloud.

Shuttle exhaust tends to be "wetter" than that from a Titan IV, due largely to the water vapor emissions from the SSMEs.[24] The liquid-fueled Titan IV main engines are not ignited during liftoff, hence contribute no moisture to the exhaust products.

The HCl gas in the ground cloud created by a Shuttle launch tends to condense into water droplets which can be very acidic (pH as low as 0.5; pH of 7 is neutral). Experience with Shuttle launches indicates that the exhaust products in the ground cloud tend to be dispersed within a 15-km (8-n.m.) area near the launch site (typically within the boundaries of KSC/CCAS). Most of the deposition of HCl droplets and Al_2O_3 particulates occurs near the launch site, with the heaviest deposition within 1 km (0.5 n.m.). Deposition levels as high as 3,400 kg (7,480 lb) of HCl and 7,100 kg (15,620 lb) of particulates have been measured within this 1-km (0.5-n.m.) area. Deposition, at much reduced levels, has occurred out to distances of 14 km (8 n.m.) from the launch site.[12]

If offshore land breezes (toward the Atlantic Ocean) are in effect at launch time, they would tend to push the ground cloud out over the ocean. This would generally be the case with an early morning launch. If, however, the land breezes were not blowing at the time of launch, the seasonal prevailing winds (Figure 4-1) could tend to push the cloud back over land.

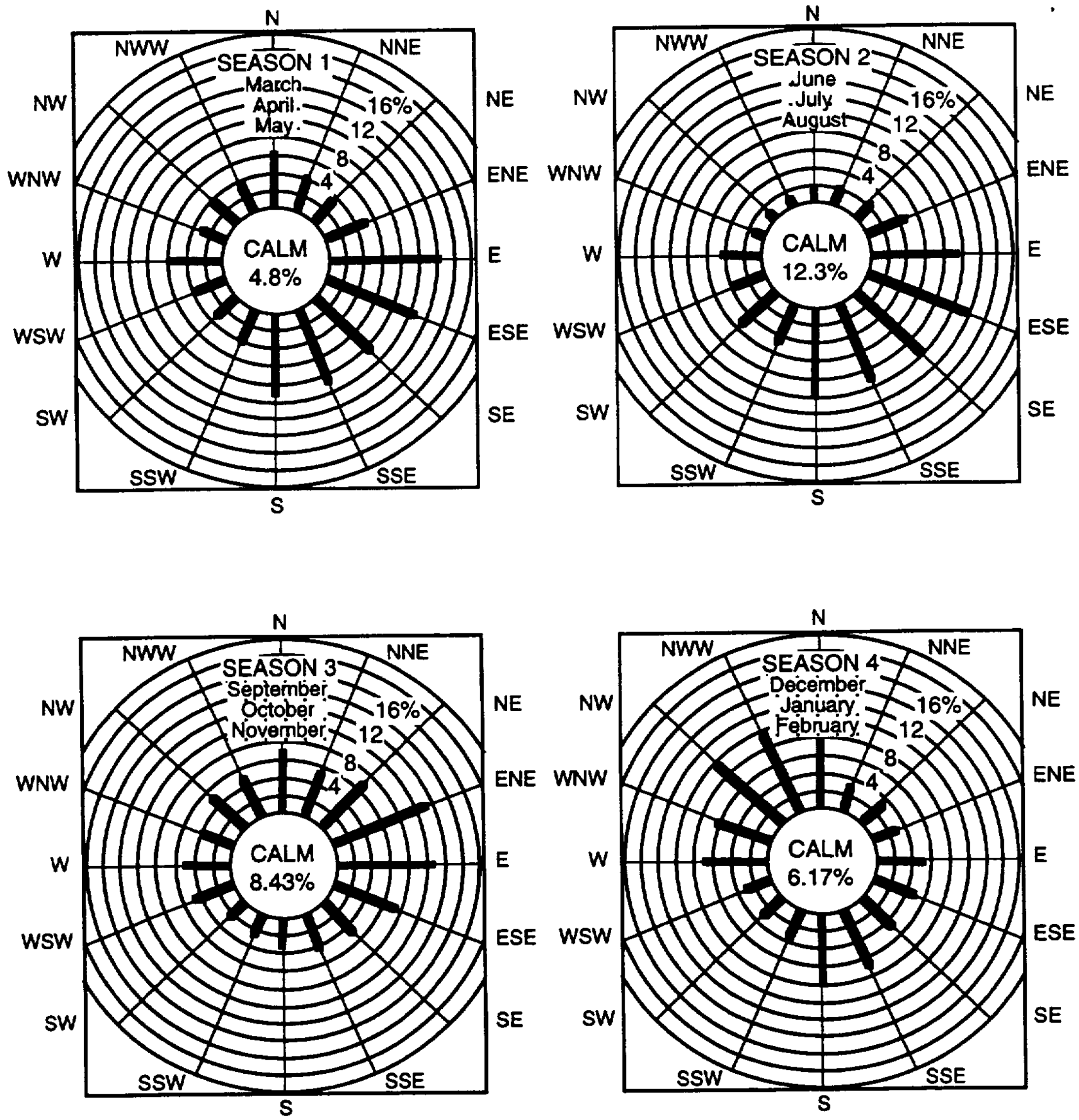
Acidic precipitation would be possible if rain showers were to occur in the area shortly after launch, with rain falling through the exhaust cloud containing high concentrations of HCl. One such event was recorded in 1975 following the launch of a Titan III from CCAS.[24] In this instance, rain showers fell through the exhaust cloud resulting in acidic precipitation of pH = 1 about 5 km (3 n.m.) from the launch site. At a distance of about 10 km (5 n.m.), the pH had risen but was still very acidic at a pH = 2. Such an event is not expected with the launch of the ISS spacecraft. Current Space Shuttle launch rules preclude launches when electrical storms are in the launch area.

The hydrogen chloride gas in the ground cloud, as well as gaseous HCl which revolatilizes from acidic droplets after deposition, can remain at levels as high as 9 parts per million (ppm) at the launch site for a few hours post-launch.[12] The American Conference of Governmental Industrial Hygienists has determined a threshold limit value of 5 ppm as the occupational exposure limit.[39] The air quality of the area is sampled and monitored after a launch, including sampling for gaseous HCl. Depending upon the results of that sampling, an array of worker protection measures (including self-contained breathing apparatus and skin protection measures) may be used.

While Shuttle exhaust products in the ground cloud formed near the launch site can reach levels of several thousands of ppm, no Shuttle launches have resulted in substantial deterioration of air quality in uncontrolled areas. In fact, NASA's Permanent Air Monitoring Station, located about 8 km (4 n.m.) to the west and southwest of the Shuttle launch pads, have not recorded any substantial impact on air quality for any of the numerous Shuttle launches from KSC to date.[12]

4.1.1.2.2 Hydrology and Water Quality. Shallow surface waters (mosquito control impoundments) in the near-field area receiving the heaviest deposition can also be affected by a Shuttle launch. Acidic deposition from the ground cloud often causes a sudden drop in pH of those shallower waters. The sudden drop in pH is typically accompanied by a fish kill which usually involves smaller species. It takes several hours for the pH of these shallow impoundments to return to their pre-launch state. Titan IV launches at CCAS may entail deposition to the Banana River immediately west of the launch complexes. The Banana River is deeper and has a relatively high buffering capacity to counteract any acidic deposition.

Each Shuttle launch requires about 3.3 million L (863,000 gal) of deluge and washdown wastewater.[12] While much of the deluge water is vaporized and dispersed with the ground cloud, up to 1.2 million L (326,000 gal) of washdown water (with an unknown amount of deluge water) is collected in tanks at the launch pad. Titan IV launches use about 1.5 million L (400,000 gal) of deluge water, of which about 20 percent is vaporized.[24] This water is highly acidic. The wastewater is neutralized to a pH of 8.5 within 72 hours of launch and is landspread over the adjacent pad area. Groundwater monitoring of this area has shown no cause/effect relationship between Shuttle launches and the detectable concentrations of aluminum, cadmium, chromium, iron, and lead found in the groundwater.[12] Deluge water is treated similarly at the Titan IV launch complexes at CCAS. Groundwater is being monitored by the U.S. Air Force at both complexes.



NOTE: Bars denote the directions from which the winds occur.

Figure 4-1. Wind roses indicating seasonal wind directions - lower atmospheric conditions: Cape Canaveral/Merritt Island land mass.

4.1.1.2.3 Biological Resources. The acidic material deposited from the ground cloud in the near-field environment (extending out to about 488 m [1,600 ft] from the launch pad) causes acute vegetation damage and in the case of Shuttle launches, often results in fish kills in nearby shallow impound waters.[12] (Fish kills are not typically associated with Titan IV launches from Launch Complex 40 or 41 at CCAS.) Over time, with a succession of either Shuttle or Titan IV launches, the near-field environment experiences changes in vegetative community structure. Total vegetative cover is reduced and unvegetated areas expand. Thin-leafed herbaceous species and shrubs with succulent leaves are more sensitive to launch cloud deposition than dune grass species. Launch of the Shuttle results in acute vegetation damage in the near-field environment where the heaviest acidic deposition occurs. This process is currently under way as a result of non-ISS launches that have been occurring from KSC/CCAS. Each ISS launch will contribute to the longer-term reduction in species richness and vegetative cover of the near-field area that is associated with long-term use of the launch pads. The area outside the near-field (i.e., the far-field), where much less deposition would occur, can extend out to 14 km (8 n.m.) from the launch site, depending upon wind conditions. In the far-field environment, some leaf spotting of vegetation can occur, but acute damage is unlikely.

There have been no indications to date that launches from KSC or CCAS have substantially impacted any listed or proposed threatened or endangered species.[24,12] Both facilities monitor known population and habitats for deleterious effects and have instituted mitigative measures where indicated.

4.1.1.2.4 Socioeconomic Impacts. Shuttle launches have become a tourist attraction in the KSC area, with 100,000 or more people parked along area highways to watch a launch. As such, Shuttle launches contribute to the tourism income generated in this area of Florida. Titan IV launches from CCAS may also contribute to the influx of tourists to the area during launch events. In summary, launches associated with assembly and operation of ISS would not be expected to have any adverse impacts to the local area, rather there may be a net benefit through attracting tourists.

ISS launches from KSC/CCAS, and the associated pre- and post-launch processing operations, would also contribute to employment at KSC/CCAS, with the attendant benefits to local communities and the region.

Although virtually all the Shuttle launches (and possibly Titan IV backups) associated with ISS assembly and operation would occur at KSC/CCAS, it is unlikely that, given the present composition of the population in the region, any given racial, ethnic, or socioeconomic group in that population would bear a disproportionate share of any environmental impacts.

4.1.1.3 Upper Atmosphere Impacts

4.1.1.3.1 Impacts to the Stratosphere. The stratosphere extends from the tropopause up to an altitude of approximately 50 km (27 n.m.). In general, vertical mixing is limited within the stratosphere, providing little transport between the layers above and below. Thus, the relatively dry, ozone-rich stratospheric air does not easily mix with the lower, moist ozone-poor tropospheric air. In addition, the lack of vertical mixing and exchange between atmospheric layers provides for extremely long residence times, allowing the stratosphere to often act as a "reservoir" for certain types of atmospheric pollution. The temperature is relatively constant in the lower stratosphere and gradually increases with altitude, reaching approximately 3 °C (37.5 °F) at the top of the layer. The temperature increase is associated primarily with the adsorption of shortwave radiation by ozone molecules.

Brady et al.[40] have investigated the contributions of rocket exhaust and ODCs (e.g. chlorofluorocarbons, hydrochlorofluorocarbons, and hydrofluorocarbons) to chlorine buildup in the stratosphere and postulate that, in future years, chlorine from rocket launches is expected to become relatively more significant as ODC production is phased out as required by law except for a few essential uses. The U.S. has been granted an Essential Use Exemption for the additional purchase of 1,1,1-trichloroethane to manufacture SRMs. The transition from new chlorine released into the atmosphere by organic chlorine compounds (i.e. ODCs) to new chlorine releases dominated by inorganic chlorine from rocket exhaust should occur worldwide sometime after the year 2000. However, given the huge amounts of organic chlorine compounds used in past years and the longevity of such species, chlorine derived from organic sources will continue to dominate stratospheric chlorine totals well into the middle of the next century.

The stratosphere is the main ozone production region of the Earth. The ozone in the stratosphere effectively absorbs incoming UV radiation so that the majority of radiation with wave lengths shorter than 300 nanometers does not reach the Earth's surface. In the stratosphere, the primary concern associated with launches is the potential incremental effects of their exhaust gases on the ozone layer. Total ozone levels vary widely and cyclically within the stratosphere; they vary by up to 10 percent daily, up to 50 percent seasonally and latitudinally, and up to 1 percent annually. Eleven-year cycles in total ozone levels, which coincide with the solar Sun spot cycles, also occur. Utilizing Total Ozone Mapping Spectrometer (TOMS) data, the trend in global ozone levels is a 2- to 3-percent decrease over the last 11 years, based on data collected between November 1978 through May 1990. This is occurring at an average rate of 0.2 percent (summer) to 0.8 percent (winter and early spring) per year at approximately 50°N. The trend is near zero at the equator and increases towards both polar regions. Thus, the observed trend in the TOMS data is both seasonal and latitudinal dependent. Additionally, analysis of the TOMS data is generally restricted to data collected before mid-1991 because of a systematic drift (~1-2%) which was detected in the instrument and to avoid the effects of the Mount Pinatubo eruption in June 1991 on total ozone concentrations.

The state of knowledge with regard to trends in the vertical distribution of ozone is considerably less than that for total ozone trends. The quality of the vertical ozone profile data has been shown to vary considerably with latitude. Recent analyses using vertical ozone profile data collected using satellite instruments (e.g., the Solar Backscatter Ultraviolet Spectrometer [SBUV] and the Stratospheric Aerosol Gas Experiment [SAGE]) and ground-based observations (e.g., Umkehr data) show slightly different results in the upper stratosphere. Umkehr data between 19°N and 54°N do not show a significant seasonal variation in the trend. However, the SBUV measurements show the largest ozone decreases have occurred during winter at polar latitudes in both hemispheres. The validity of this latter result has been challenged because of the inherent problems associated with measurements collected at high solar zenith angles. In the lower stratosphere, SAGE measurements confirm considerable mid-latitude reductions in vertical ozone concentrations for the period 1979-1991 in the 15-20-km region of the stratosphere. The trend in the integrated ozone column for the SAGE results was larger than that found from the SBUV, TOMS, and surface-based network. However, the uncertainties are too large to evaluate the consistency between the data sets properly. The magnitude of these reductions is a topic of considerable debate, ranging from 20 percent (±8%) per decade for the SAGE measurements at 16 to 17 km (10 to 10.6 mi.) and 7 percent (±3%) per decade in the Northern Hemisphere for the ozonesonde data. [41,42] Additionally, the differences in the integrated column coverage of the TOMS and SAGE instruments should be noted. Generally, the SAGE integrated column is restricted to altitudes from the mid-troposphere and above, while the TOMS integrated column generally goes well below this altitude, more or less to the Earth's surface.

The concentration of ozone at a given location is a function of the chemical processes that control the production and destruction of ozone and of stratospheric ozone transport processes. Production of ozone within the stratosphere is controlled by the photodissociation of molecular oxygen (O_2). However, the destruction of ozone is driven by various photochemical processes, which generally involve some type of catalytic process. Thus, ozone is constantly being created and destroyed within the stratosphere. This results in a dynamic, nonlinear balance between ozone chemistry and the mean stratospheric ozone circulation.[43]

The presence of compounds formed directly or indirectly from rocket exhaust can decrease levels of ozone in the immediate vicinity of the rocket exhaust plume. These compounds include HCl, Cl_2, H_2, and H_2O.[44] Nitrogen oxides (NOx) can also significantly influence ozone degradation.[45] The destruction process primarily associated with the use of SRMs involves chlorine, specifically atomic chlorine (Cl). However, molecular chlorine (Cl_2) and hydrochloric acid (HCl) are reservoir species within the stratosphere. Reservoir species are not directly involved in the catalytic loss of ozone. However, these reservoir species may be converted into atomic chlorine (Cl) through photolysis. Additionally, heterogeneous processes can convert less easily photolized species (e.g. HCl, $ClONO_2$) into more reactive compounds (e.g. Cl_2, $ClNO_2$, BrCl). Since chlorine atoms (Cl) are conserved within the stratosphere (i.e. not lost), a single chlorine atom could cause the destruction of hundreds of ozone molecules. The principle chlorine-catalyzed cycle for ozone depletion within the middle and upper stratosphere is as follows:

$$Cl + O_3 \text{ ----> } ClO + O_2$$

which is followed by

$$ClO + O \text{ ---> } Cl + O_2$$

Thus, the important consequence of this primary chlorine catalytic cycle is that the chlorine atoms (Cl) are not removed from the stratosphere, and thus remain free to continually react with other atmospheric species.[45] However, in the lower stratosphere, especially in polar stratospheric cloud (PSC)-induced ozone depletion, other catalytic cycles may also become important.

Numerous studies have been conducted to assess the effects of chlorine from launch vehicle exhausts on stratospheric ozone levels. The studies have attempted to evaluate the localized, regional, total column, and global impacts on ozone levels. Local impacts were found to be large but of short duration. Measurements of ozone levels within the exhaust trail of a Titan III SRM at an altitude of 18 km (59,058 ft) taken 13 minutes (780 seconds) after launch showed a 40-percent reduction in ozone concentrations.[44] Modeling studies predicted a greater than 80-percent reduction in ozone levels within 1 km (0.54 n.m.) of an exhaust plume for a period of 1 to 3 hours, after which the levels were projected to rapidly return to normal.[43]

Other models addressing the effects of rocket exhaust on ozone levels near the exhaust trail indicated smaller reductions. Investigations of Clx and NOx emissions levels based upon launches of both U.S. and RSA launch vehicles concluded that the local, short-term total ozone reductions attributable to chlorine can possibly be greater than 8 percent.[43] The recovery period to normal background levels for the areas near the exhaust plume projected in the models is less than 3 hours to 1 day for all altitudes within the stratosphere, but the projected time varied, depending on the model parameters used.[43] These studies concluded that rocket emissions for the launch schedules being modeled would cause no substantial detectable ozone decreases in the stratosphere.

Denison et al.[46] have modeled the local effects of ozone depletion from SRM exhaust using a plume dispersion model to simulate the chemistry from the combustion chamber, incorporating afterburning, through the hot plume and cool plume dispersion phases. The results of this modeling exercise indicate that afterburning chemistry of the reactive exhaust products can cause local, short-term (on the order of minutes) ozone destruction episodes. Thus, the modeled recovery period results of Denison et al.[46] are substantially less than those predicted in the modeling studies of Karol et al.[43], which indicated recovery times on the order of several hours. More importantly, the model results of Denison et al.[46] indicate that the inclusion of heterogeneous chemistry does not have a major impact on the estimated local plume chemistry. Thus, this modeling study indicates the effects of solid rocket effluents to be short-term and that the homogeneous chemistry dominates over heterogeneous reactions for local plume chemical transformations.

A number of researchers have attempted to predict the global impacts associated with rocket launches using computer models.[43,47,48] A 1990 two-dimensional modeling study assessed the magnitude of regional increases of chlorine in the stratosphere and the regional effects of those increases on ozone levels.[47] The study focused on the potential effects from six launches of Titan IV rockets and nine Shuttle launches per year. For homogeneous chlorine chemistry only, the results indicated that the effects on the ozone layer are minor and short-lived. Stratospheric chlorine increases due to the nine Shuttle and six Titan IV launches per year were predicted to be about 0.3 percent in northern latitudes.[47] Global ozone depletion due to this launch schedule was computed to be less than 0.1 percent in this study (0.0065-percent); while the research of Karol et al.[43] , after scaling their results to a similar launch schedule, predicted a slightly higher ozone loss ranging from 0.0072 to 0.024 percent. In another phase of the 1990 study, a three-dimensional model was used to compute the regional effects of SRM exhaust from a single Shuttle launch over a 1,000-km^2 (291-n.m.^{2}) area. At an altitude of 40 km (22 n.m.), total chlorine was calculated to increase by a few percent two days after launch. Subsequently, ozone decrease is expected to be less than 1 percent at that height.[47]

The localized impacts of launch vehicle operations on total column ozone levels along the flight path may also be important. The effectiveness of the ozone layer in filtering UV radiation is affected by both the amount of ozone within a given atmospheric layer and the amount of ozone in the total air column of the atmosphere. The latter is much more important when considering the amount of UV radiation which reaches the Earth's surface. Reductions in ozone levels in the total column ozone from Shuttle operations were found both through models and through measurements[49] to be far less than localized stratigraphic losses. These measurements, however, need to be revisited with newer, more sophisticated instrumentation before drawing conclusions from the results. These effects occur because the launch vehicle's trajectory is not vertical; therefore, not all of the exhaust plume is deposited in one vertical column of air. Measurements (with an accuracy of ±4 percent) of total column ozone within a 40-km by 40-km (465 n.m.^{2}) area were taken between several hours to 1 day after launch at KSC. These observational results showed no decrease in total ozone concentration.[49] In a recent modeling study, one model predicted that the total column ozone in the area near a launch site would be reduced less than 10 percent, even though the same model showed a greater than 80-percent localized reduction in ozone along the flight path in specific atmospheric strata.[45]

Additionally, current research has indicated that variations in the seasonal structure of the stratospheric wind field can redistribute exhaust products and ozone-depleting species within the region. For example, the strength, direction, and persistence of the stratospheric wind field are extremely important in the dispersion of the exhaust plume. Even slight zonal and/or meridional winds in opposing directions could shear the launch plume, causing the parcels to travel along different paths. Thus, TOMS-derived variations in column ozone concentrations, which are based on satellite-based observations, could be incapable of showing localized decreases in ozone concentrations in the vicinity of the rocket launch plume.

The destruction of ozone through contact with chlorine and nitrogen radicals involves relatively simple and homogeneous reactions among gaseous atmospheric constituents. Heterogeneous processes (i.e., reactions that occur on the surfaces of particles or that involve solid/liquid, liquid/gas, or solid/gas interactions) can also affect ozone levels.[42] Heterogeneous reactions are important to ozone destruction within the polar winter stratosphere of the Antarctic ozone hole.[44]

In recent years, there have been major advances in our understanding of the role of stratospheric heterogeneous reactions in increasing the abundance of active chlorine compounds in the lower stratosphere. Specifically, studies investigating PSCs and stratospheric sulfate aerosols have been undertaken. At this time, the field of study is considered to be in its adolescence. However, major advances/contributions in the field are occurring at a rapid rate.[42]

Current researchers investigating the effects of heterogeneous chemistry into the atmospheric circulation/chemistry models speculate that the new algorithms will slightly enhance the catalytic conversion/activation of chlorine in the stratosphere, which will subsequently moderately increase the total amount of modeled ozone depletion in the lower stratosphere.

Current preliminary investigations do not substantiate any large deviations (e.g. generation of an ozone hole) from earlier study results of the effects of rocket launches on stratospheric ozone depletions.[46,50,51] The current state-of-the-science is just beginning to incorporate comprehensive global three-dimensional stratospheric chemistry simulations which can assess long-term cumulative impacts on global ozone concentrations within the stratosphere from multiple launch scenarios. Current federal, academic, and private-sector research is focused on incorporating heterogeneous chemistry in two- and three-dimensional stratospheric models. These changes are important because they are needed to both represent the current state of the atmosphere and its evolution in recent years, and to better evaluate how the stratosphere will respond to future perturbations, including both rocket launches and high altitude aircraft.

In a recent study, Denison et al.[46] used a plume dispersion model to indicate that, while the inclusion of such heterogeneous chemical processes does improve the accuracy of the model output, the magnitude of these improvements is very small. Thus, it could be hypothesized that the incorporation of heterogeneous chemistry in more complex two- and three-dimensional stratospheric models, while important in more accurately assessing the base state of modeled stratospheric ozone concentrations, would not substantially alter the current calculated impacts of rocket launch scenarios that are being reported for homogeneous chemistry models alone. Until these more complex simulations are completed, long-term cumulative effects of solid rocket effluents must be assessed using the modeling and observational studies which are currently available. Given this information and the limited understanding of heterogeneous chemistry on the local rocket exhaust plume, it is not expected that the ISS Space Shuttle launches would produce a discernible, long-term cumulative impact on ozone concentrations within the global stratosphere.

4.1.1.3.2 Impacts to the Mesosphere. The impact of ISS on the mesosphere would result directly from the Shuttle exhaust as it travels through this region en route to the Space Station, which would be permanently on station in the ionosphere. The impact of rocket exhausts in the mesosphere has not been studied a great deal, and thus little is known about the effects on this environment. Further research is necessary before being able to quantitatively assess the impacts of space travel in this region of the earth's atmosphere. However, based on detailed research and modeling studies for the stratosphere (presented above), the ISS launch schedule would not be expected to generate any large-scale, long-term problems within the mesosphere.

4.1.1.3.3 Impacts to the Ionosphere (Thermosphere). The potential sources of releases to the ambient thermospheric environment from ISS are the following:

- Thruster firings for ISS proper, Space Shuttle, and other associated platforms
- EVA system operation
- Leakage
- Outgassing and venting

The ISS bipropellant hypergolic propulsion system would be the RSA-manufactured Progress, SM, and FGB, which uses unsymmetrical dimethylhydrazine propellant and nitrogen tetroxide oxidizer. The system is capable of both altitude and attitude control. Experience with previous satellites and Space Shuttle launches indicates that the thermospheric impact of the ISS propulsion system exhaust products are not anticipated to be substantial.

Additional ISS studies indicate that the spacecraft frame may accumulate an electrostatic charge, particularly during that portion of its orbit through the higher latitude.[1] Measures to incorporate controls to mitigate possible effects of this charge on instrumentation will be taken. Those controls will be designed such that significant electrical arcing in the thermosphere near ISS would not occur, thus avoiding any adverse affects on the thermospheric environment. In addition, to prevent any damaging effects on ISS from electrostatic potential differences between ISS and the thermospheric plasma, xenon gas would be released in controlled amounts to neutralize the buildup of electrostatic charge on ISS. This gas is not expected to adversely impact the thermosphere.

As outlined in the Tier 1 EIS, a variety of molecular contaminants could result from leakage, outgassing, and venting from ISS as well as EVA system operation. Possible contaminants could include helium, neon, and argon atoms, plus carbon monoxide, nitrogen, oxygen, carbon dioxide, and water molecules. None of these materials pose a hazard to ISS or the environment, but could cause interference to optical and plasma scientific measurements.[1]

The environment around ISS would be altered by the presence, operation, and motion of the space station. Several of these effects may be difficult to predict quantitatively. In summary, the environmental effects ISS could have on the ambient thermospheric environment are not completely understood. However, it is likely that these effects would be limited to the environment in the immediate vicinity of ISS.[1] Based on our current understanding and knowledge, no large-scale or long-term impacts would be anticipated with regard to ISS in the thermosphere. Short-term localized depletion of ions may occur during reboost, which would be similar to that observed in the Arecibo experiment.[1] However, NASA is committed to maintaining the integrity of the thermosphere, and as such will institute mitigative measures as deemed necessary during the ISS Program.[1]

4.1.1.4 Return and Disposal of Waste Material

Wastes generated during assembly and operation of ISS would include a variety of materials ranging from sanitary and housekeeping wastes, to laboratory wastes, and wastes from maintenance of ISS itself. Wastes would be in solid, liquid, and gaseous forms, and would include nonhazardous as well as hazardous and toxic materials. Strict Space Station Program requirements restrict the disposal of supplies, surplus or excess consumables (materials brought on board ISS for use in and support of experiments), and wastes.[1] Specifically, it is required that

- The capability be provided for safe disposal of all waste materials and products on board the ISS, and
- All equipment, materials, or consumables brought on board shall not be reconfigured, erected, or otherwise operated upon in a manner which prevents it from being returned to a condition suitable for safe return to Earth or for a controlled and safe jettison.

Sanitary wastes generated on board ISS would be handled separately from other wastes. The ISS Habitation Module would contain at least two independent systems for collection of sanitary wastes.[1] Those portions of the wastes which could not be contributed to useful products, or be safely disposed of from ISS, would be returned to Earth.

Laboratory wastes consisting of surplus consumables and wastes from experiments may contain a variety of solid, liquid, and gaseous materials, some of which would be considered hazardous or toxic and subject to federal regulation on Earth.[1] Intentional venting of nonhazardous solids, liquids, and gases would be permitted under contamination control requirements, while some venting due to leakage from module seals would be unavoidable.[52] Solid, liquid, and gaseous waste materials which could be safely injected into Earth's atmosphere for controlled reentry and burnup would be permitted during ISS assembly and operation, otherwise wastes would be packaged for return to Earth where disposal would be accomplished in accordance with applicable regulations. Any radioactive materials or biological materials no longer required for on-board experiments would be returned to Earth for proper disposal. As noted earlier, NASA maintains the capability and infrastructure to ensure proper handling, storage, and disposal of regulated wastes returned from ISS, thus minimizing the environmental impacts of waste disposal during ISS operation.

Shuttle landing contingencies could entail a release of the hazardous or toxic wastes being returned from ISS.[1] NASA contingency procedures designed to respond to and contain such events, coupled with the anticipated small quantities of hazardous or toxic wastes on board, would serve to reduce the environmental impacts from released wastes.

Space Station Program requirements also dictate that wastes generated by the IPs receive identical processing as U.S.-generated wastes.[1] No substantial environmental impacts would be expected to arise from those activities.

4.1.1.5 Impacts of Decommissioning

The baseline requirement for decommissioning ISS is to allow for safe disposal of the station at the end of its useful life. A number of concepts for achieving this requirement have been considered. The currently proposed decommissioning approach is to execute a controlled, targeted deorbit to a remote ocean area. Another consideration, referenced in the Tier 1 EIS, is to disassemble the structure and return the station components to Earth on board the Space Shuttle. The Space Shuttle return approach presents significant technical, operational, and cost challenges. Technical analyses have shown that, relative to other decommissioning scenarios studied, controlled deorbit is straightforward, would be within the operating capabilities of the on-board and ground resources of ISS, and could be executed safely.

Unlike Skylab, ISS has maneuver capability to control its altitude. Current baselined ISS hardware planned for providing such capability may include the RSA-made FGB, SM, and Progress vehicles. Preliminary analysis shows that these elements can provide the capability to deorbit ISS. Other elements that might be used to implement this concept include the Ariane

Transfer Vehicle under development by ESA and the U.S.-made Lockheed Bus-1. Other maneuvering vehicles or combinations of vehicles could also be developed before decommissioning would be required.

At the end of the planned life of ISS, NASA and the IPs may remove and return key science packages, instrumentation, or select modules, before deorbit and safe disposal of the remainder of ISS in a remote ocean region. Just before initiation of the deorbit sequence the entire ISS crew would return to Earth, and the deorbit would be accomplished either automatically by preprogrammed on-board control systems and/or from the ground. NASA is ensuring that ISS and its components are being designed to ensure that the decommissioning deorbit process is carried out reliably. For the example controlled deorbit sequence outlined earlier in Figure 2-8 using RSA-made equipment, the estimated reliability of that equipment was 0.99 (or 99 percent) for the first two days following crew departure and, as expected, without the benefit of human attention and intervention on board would slowly decrease with time. Analysis of the reliability of the attitude control system indicates that reliability would remain at the 98-99 percent level for two to three weeks. Since RSA-component failure rate data was unavailable during this analysis, similar U.S. data was substituted. The reliability analysis will be updated when RSA's component failure rate data becomes available.

During descent through the Earth's atmosphere, ISS could be expected to break up at altitudes ranging from 70.4 to 102 km (38 to 55 n.m.) above the Earth.[18] As observed in previous reentries of other orbiting vehicles and spacecraft, most of the breakup would likely occur at an altitude of about 79 km (42.5 n.m.).[18] Based on past experience with the reentry of other satellites such as Skylab, larger portions or fragments of ISS debris would be expected to survive the thermal and aerodynamic stresses of reentry. The nominal area or "footprint" within which the debris fragments would be expected to land is estimated to have an average width of about 41 km (22 n.m.) and a length of about 1,049 km (565 n.m.). Various characteristics of the reentry and the debris materials (for example, winds aloft, breakup altitude and velocity, atmospheric density) create uncertainty in both the size and location of the reentry footprint. The nominal footprint dimensions were based upon 50th percentile conditions for those upper atmosphere and debris variables. Using more conservative assumptions regarding these uncertainties (i.e., 99th percentile conditions), a larger region can be identified within which the debris could credibly fall. This larger region (hereafter referred to as the "at-risk region") was estimated to be an average of 296 km (160 n.m.) wide and 5,402 km (2,914 n.m.) long. Even with the uncertainties, debris would not be expected to spread over the entire at-risk region; however, it could fall into an area larger than the nominal footprint. For comparison purposes, impacts are estimated for both the nominal footprint case and the larger at-risk region. Figure 4-2 illustrates the size and shape of the nominal and dispersed debris footprints or at-risk region. These two areas (nominal footprint and at-risk region) are used in the following analyses of property damage. The nominal footprint has an estimated area of 43,009 km^2 (12,430 $n.m.^2$), while the at-risk region has an estimated area of 959,540 km^2 (279,180 $n.m.^2$).

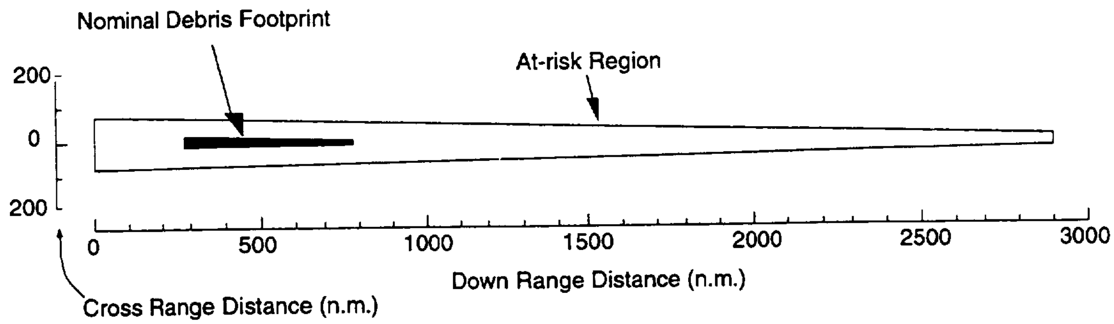


Figure 4-2. Nominal footprint and at-risk region.
(not to scale)

With respect to the currently proposed decommissioning approach, potential ocean areas were surveyed to determine if there were regions where the controlled deorbit of ISS was feasible such that no land masses, including islands, would be within the larger (more conservative) dispersed debris footprint. Figure 4-3 illustrates several remote ocean region areas that could potentially be safely used. The figure shows a comprehensive collection of operational navigation charts (ONCs—published by the Defense Mapping Agency) overlaid on a world map. The ONCs show all areas, worldwide, where land exists. These charts were used to identify potential disposal areas. The largest disposal region is in the eastern Pacific Ocean and would provide the opportunity for controlled deorbit on two consecutive orbit revolutions.

The number of debris pieces, their exact sizes, and actual area covered by ISS debris within the footprint are uncertain and difficult to calculate reliably. These factors are a function of the integrated evaluation of the reentry aerodynamics, the aerothermodynamic environment, and the thermal response of the parent vehicle and the components exposed after breakup to the reentry trajectory. Air Force test data have indicated that relatively low density (i.e., low weight-to-area ratio) objects are more likely to survive reentry through the Earth's atmosphere than would dense objects.[19] Debris recovered from previous satellite reentries include strong, spherical pressure vessels and low-density objects such as circuit boards.

The debris area was estimated based on historical experience, previous analyses for earlier vehicles, and scaling up estimates from the Skylab reentry.[18] Three approaches for estimating the total area of surviving debris were used for the EIS analyses, resulting in a reasonable range in the potential total area of surviving debris. The total expected, or nominal, area of all the surviving debris was estimated at approximately 2,790 m^2 (30,000 ft^2), with an upper range estimate of approximately 5,115 m^2 (55,000 ft^2). The lower range estimate was put at 1,581 m^2 (17,000 ft^2).

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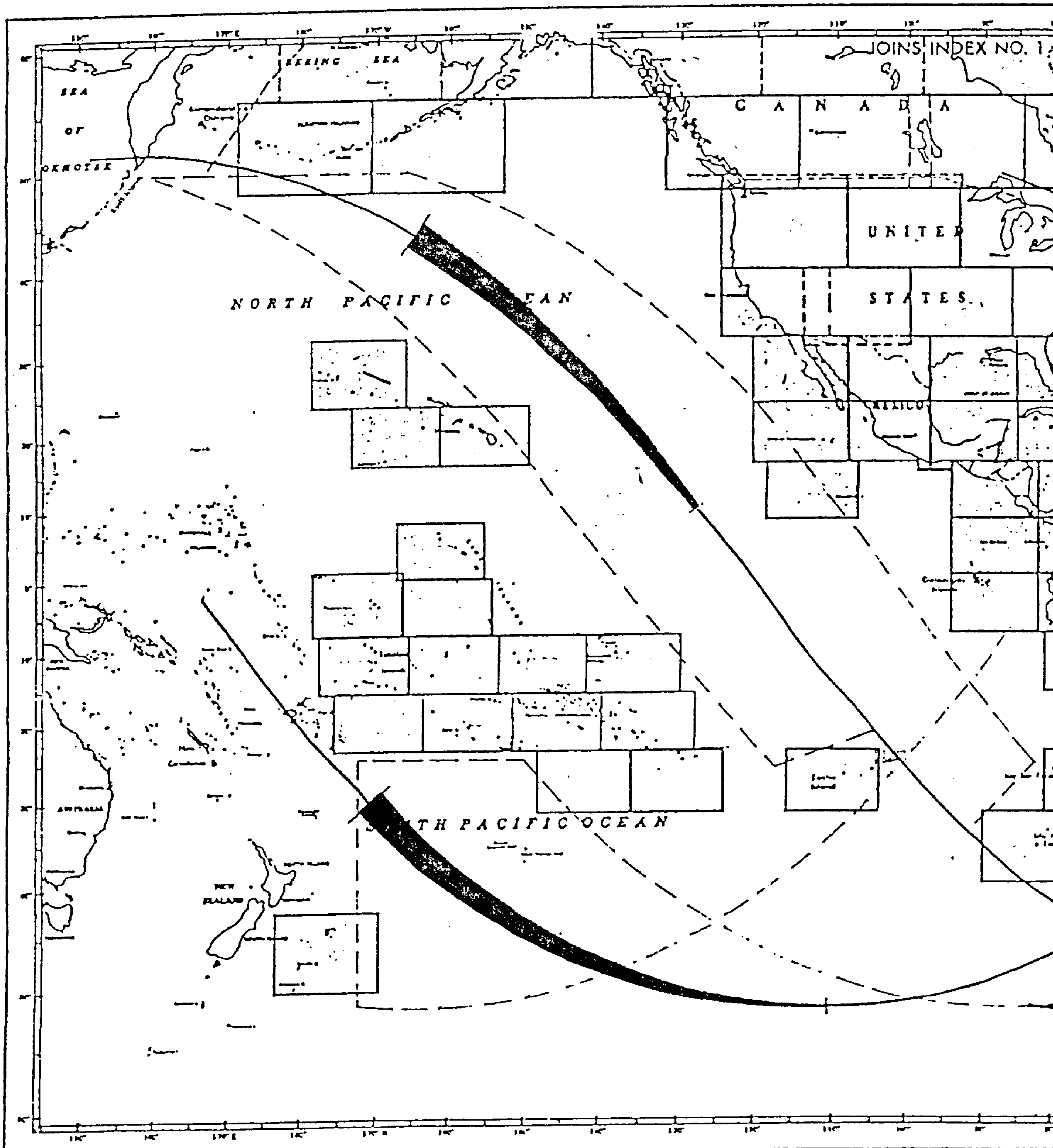
OPERATIONAL NAVIGATIO



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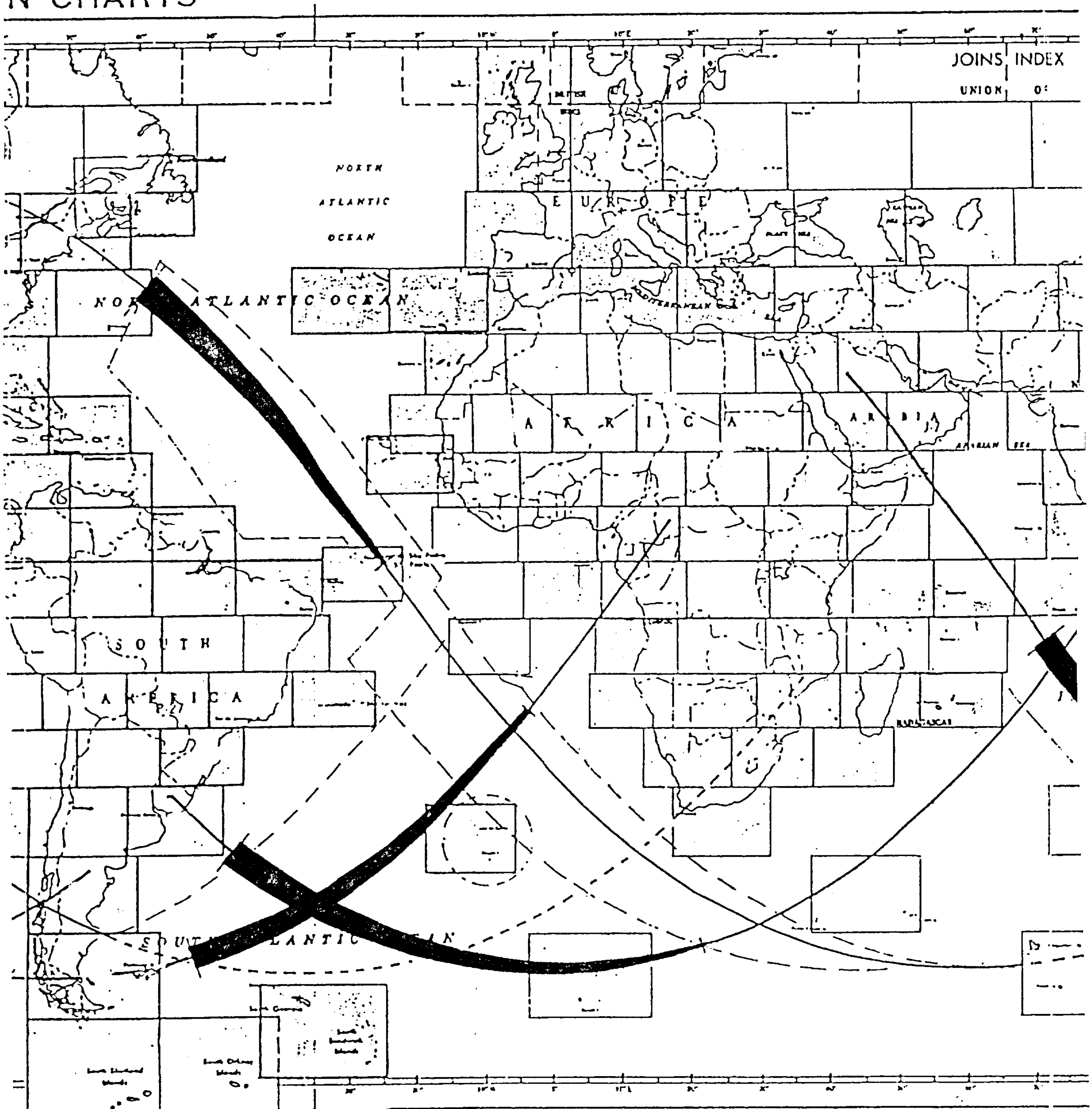
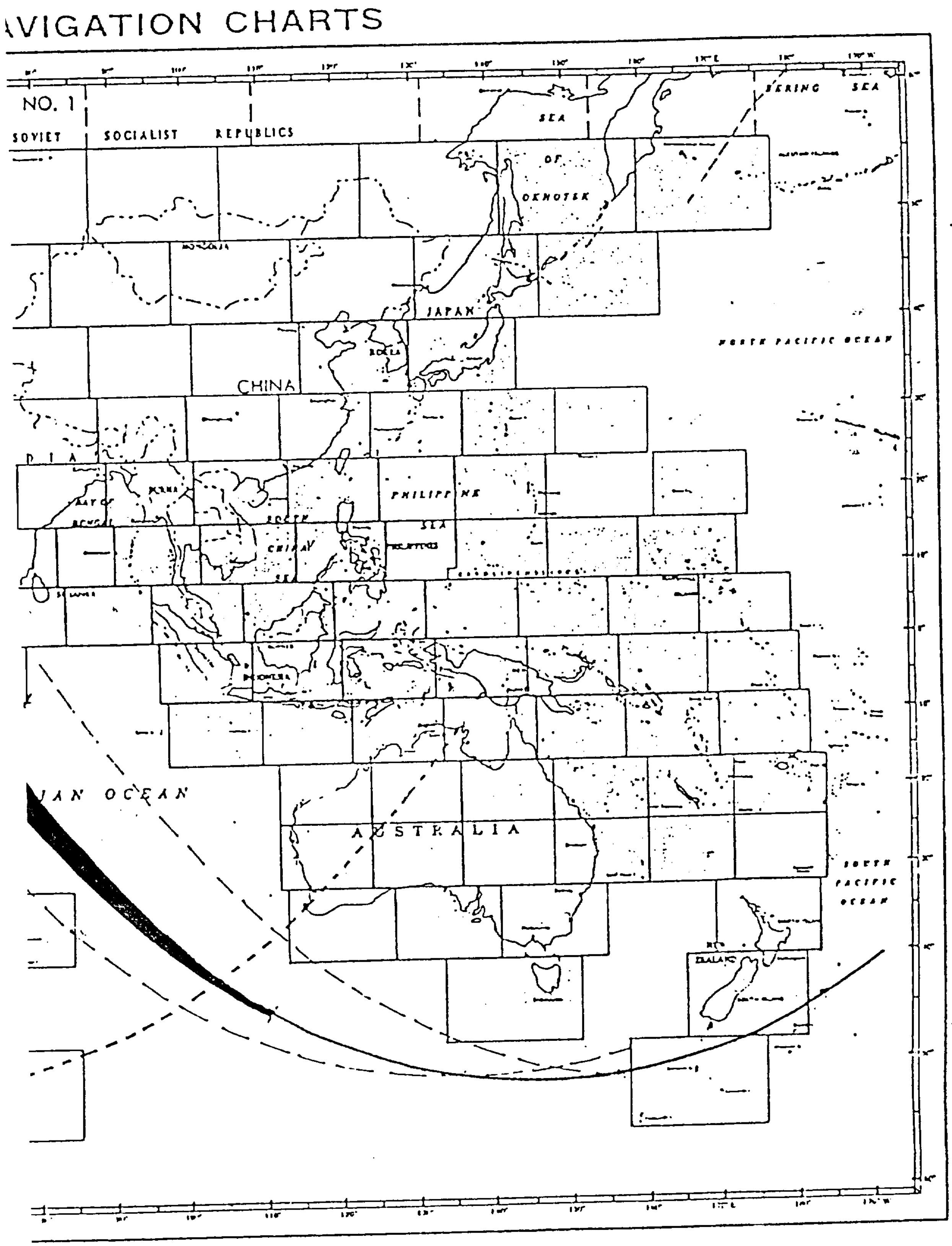


Figure 4-3. Potential disposal regions for controlled deorbit.



Using data from a recent study of surviving debris from reentering launch vehicles and spacecraft[19], a weighted average area density of surviving debris from reentry and breakup was calculated at 15.37 kg/m^2 (3.15 lb/ft^2). Using this approximation for ISS, it can then be determined, by applying this estimate to the range of total area of surviving debris (above), that approximately 6 to 19 percent of the on-orbit weight of ISS (i.e., 24,260 to 78,570 kg; 53,500 to 173,250 lb) could survive reentry and impact the Earth.

Potential environmental impacts of these debris pieces within the estimated nominal or dispersed debris footprints would be expected to be small. The activities most likely to be affected by decommissioning would be trans-ocean surface shipping and airline routes. Low Earth orbit satellites have been disposed of in broad ocean areas with controlled deorbit and have left little evidence of their reentry. Most surviving pieces of debris would be traveling at their terminal velocity when they hit the ocean, with a relatively small number of pieces traveling faster than their terminal velocities (e.g., control moment gyro [CMG] rotors), and could be lethal if they struck a living organism on or near the ocean's surface. Some surviving pieces could have sufficient kinetic energy to potentially cause damage to structures, including ships. Once the pieces travel a few feet below the ocean surface, their velocity would be slowed to the point that the potential for direct impact on sea life would be low.

The probability of any direct hits to either ships or larger sea life within the nominal footprint or at-risk region is small. Since the timing and impact area of the reentry would be controlled and known in advance, Notices to Airmen and Mariners (NOTAMS) would be issued well in advance to help ensure that aircraft and ships would not be within the disposal area at the time of decommissioning. Even if there were a large ship within the impact area, the probability of hitting it with one or more pieces of debris would be quite small.

Estimates of this probability can be made by assuming that the pieces of debris fall uniformly within the nominal footprint or the entire at-risk region. Using the upper range debris area of 5,115 m^2 (55,000 ft^2) and the nominal estimate of 2.46 m^2 (26.5 ft^2) per surviving piece of debris[18], approximately 2,079 pieces would be estimated to survive reentry (Table 4-3). For the larger at-risk region case (area of approximately 959,540 km^2 [279,180 n.m.^{2}]), the probability of hitting a very large (70-m by 250-m [about 230-ft by 810-ft]) ship that strayed into the at-risk area can then be estimated by multiplying the number of falling pieces and the ratio of the area of the ship to the at-risk area. The probability would be approximately 2,079 x (0.07 km x 0.25 km)/ 959,540 km^2, or 0.000038, or about one chance in 26,000 (Table 4-3). Looking at the smaller nominal, or expected, debris footprint (43,009 km^2 [12,430 n.m.^{2}]) and assuming the highest total debris area, the same very large ship would have a probability of being hit of about one chance in 1,182 (2,079 x [0.07 km x 0.25 km]/ 43,009 km^2 equals about 0.00085 - Table 4-3).

Table 4-3. Estimated Probability of Hitting a Large Ship Inadvertently Within the Impact Area

Estimated Debris Area (m^2)	Estimated Number of Debris Pieces[a]	Probability of Hitting a Large Ship Within the Given Area[b]	
		Ship Within Nominal Footprint (43,009 km^2) (12,430 $n.m.^2$)	Ship Within Large At-Risk Region (959,540 km^2) (279,180 $n.m.^2$)
Upper Range 5,115 (55,000 ft^2)	2,079	8.5×10^{-4} (1 in 1,182)	3.8×10^{-5} (1 in 26,000)
Expected 2,790 (30,000 ft^2)	1,134	4.6×10^{-4} (1 in 2,167)	2.1×10^{-5} (1 in 48,000)
Lower Range 1,581 (17,000 ft^2)	643	2.6×10^{-4} (1 in 3,822)	1.2×10^{-5} (1 in 83,000)

[a] Using an average debris piece size of 2.46 m^2 (26.5 ft^2) based on Skylab debris characteristics.[18]

[b] Based on a 70 m x 250 m (230 ft x 810 ft) ship within the impact area. Given the advance warnings, the likelihood of a ship being within the nominal footprint or the at-risk region would be expected to be low.

The probability of hitting marine life on or very near the ocean surface is similarly very small since, on average, the total area of surface marine life (e.g., large school of fish, pod of large whales) within the impact area for each piece of debris would likely be similar to or less than that of the large ship used in the earlier estimate.

Once the debris hits the ocean, it would be expected to quickly settle to the ocean floor. Dissolution of some materials could be expected, while others would be highly corrosion-resistant. In many cases, the debris would quickly become encased in marine life. Hazardous, toxic, and any radiological materials would be removed from ISS before decommissioning. As a result, only residual quantities, if any, of hazardous, toxic, and radioactive materials would be among the debris, and would not be expected to have substantial impact on marine life.

Reentry and breakup of ISS may also have localized, temporary effects on the chemistry of the stratosphere, specifically stratospheric ozone. With the current state of knowledge of upper atmospheric physical and chemical processes and the development of stratospheric modeling and research, the potential impacts of reentering space debris are not completely understood. The exact atmospheric impacts of the deorbiting ISS, at this time, can only be related to the existing knowledge base and discussed in relative terminology. A generic approach was implemented which considered the current population of resident space debris during the reentry process. Thus, a detailed analysis of the potential atmospheric impacts during reentry for this debris in the stratosphere can provide a relative indication of the environmental ramifications for the reentry of ISS.[53,54]

The results of recent laboratory and modeling studies have shown that a temporary, local depletion of ozone may occur within the stratosphere for deorbiting events. The ozone depletion process occurs through both homogeneous and heterogeneous processes. In terms of homogeneous processes, two distinct mechanisms must be considered. First, deorbiting space debris enters the stratosphere at hypersonic speeds, generating a high temperature region between the bow shock and the body of the particle. At these extreme temperatures (approximately 20,000 K), large amounts of nitric oxide (NO) will be produced through the Zeldovich mechanism, which destroys ambient ozone through the natural nitric oxide catalytic cycle. Second, nitric oxide is generated as pyrolysis products from spacecraft paint and ablation materials (i.e., material bound nitrogen). The joint impact of these two processes on stratospheric ozone is estimated from this generic approach to destroy 1 stratospheric ozone molecule per 10 billion per year by the thermal process and 1 part per 1 billion per day by the pyrolysis mechanism. Heterogeneous processes are important when considering the small particles deposited within the stratosphere. These small particles have the potential to become active sites for heterogeneous reactions, similar to those of polar stratospheric cloud particles. The impact on local ozone is evaluated based on a simple one-dimensional diffusion model for a single particle and is focused on micrometer-size particles. Based on this simplified, generic analysis, it is estimated to take 10,000-100,000 years to destroy 1 percent of the Earth's stratospheric ozone by heterogeneous mechanisms. Thus, the reentry and breakup of ISS within the stratosphere is expected to generate minor, short-term, localized effects on ozone concentrations, but is not anticipated to create any long-term deleterious effects on the stratospheric environment.[53]

4.1.1.6 Accidental Deorbit

As discussed in the Tier 1 EIS[1], it is possible that ISS or some of its components could reenter the atmosphere following planned (e.g. deorbit decommissioning) or unplanned events (e.g., explosions resulting in an uncontrollable attitude and/or breakup of portion(s) of ISS) that render the altitude and attitude control functions inoperable, and/or remove the capability to dock or attach any vehicles which could replace the propulsive functionality, and no combination of activities by the U.S., Russia, or other IPs can restore the propulsive capability of ISS. These events include: 1) the inability to supply the propellant necessary to stay in orbit; 2) collision with orbital debris, meteoroids, or other spacecraft; and 3) multiple major on-board system failures. Without a periodic reboost, ISS reentry would occur because aerodynamic drag would lower ISS altitude. Thus, anything that prevents this reboost could ultimately result in an uncontrolled reentry of ISS.

Most ground or ISS failures preventing reboost or controlled deorbit can be corrected before they result in accidental entry. ISS will, on average, reboost to a higher altitude every three months. Should events arise which disrupt the nominal or planned resupply operations of any of the participating agencies, enough reserve propellant is kept on board to provide about a year of orbital lifetime while maintaining normal operations. In addition, sacrificing nominal operations can permit the solar arrays to be "feathered" to reduce aerodynamic drag and essentially double the orbital lifetime. This would provide significant time to correct most problems, even if a solution required the launch of additional hardware from the ground.

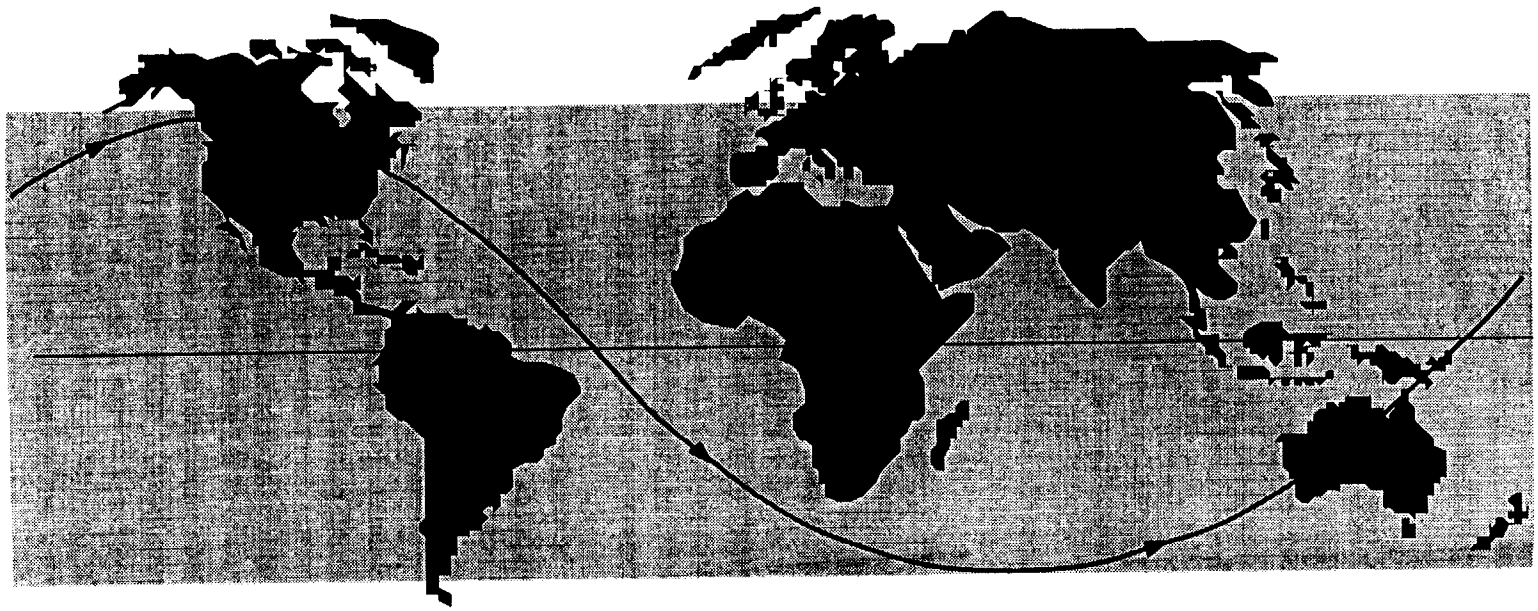
The most critical time for accidental or random failures leading to an uncontrolled reentry of the ISS would be during the deorbit decommissioning sequence. During this deorbit sequence, station personnel would not be on board, the orbit lifetime would, by design, be very limited, and opportunities for recovery by the ground controllers similarly limited. (See Figure 2-8.)

Catastrophic failures of ISS would be expected to be the least likely failure mode. Causes could include collision with orbital debris, visiting spacecraft, and meteoroids, or multiple major on-board system failures. Such major failures could leave ISS irreparable and make the potential for a controlled deorbit into the ocean difficult or impossible to achieve.

As indicated in the Tier 1 EIS[1], a number of steps are being taken in the design of ISS and its components as well as the mission design and operations to increase the overall reliability of ISS and reduce the probability of an inadvertent reentry. This is tied not just to the protective measures taken against disabling debris or micrometeoroid collisions, but also to the robustness of the entire ISS design and the logistical infrastructure of the U.S. and IPs. This includes on-board systems to ensure the health and safety of the crew who not only maintain ISS, but also are available to intervene and fix problems on orbit. The planned use of RSA, ESA, and NASA launch systems and launch sites combined with an extensive logistical support capability, will provide substantial maintenance opportunities which could bring ISS back to a fully operational state. Mission control functions are similarly robust, with redundancies built into the ground systems and backup capabilities being provided at NASA and RSA mission control centers. Critical systems on board ISS are being designed to be robust and fault tolerant while still remaining operational.

In the unlikely event of a major accident, such as an explosion or collision that disables several operationally critical functions of ISS, recovery would still be possible as long as attitude control could be maintained. Even if the crew had to evacuate ISS, successful maintenance of attitude control would permit the ground launch and logistics support infrastructure to be employed to repair the station or to reboost it to a higher orbit while other options are considered. In general, the extended orbital lifetime gained by a reboost could be used to plan a targeted deorbit, similar to that currently planned for decommissioning. ISS reboost is to be provided by RSA Progress vehicles launched on board Proton rockets. Both of these vehicles are currently in use by RSA, and have demonstrated both high reliability and high availability. The Proton/Progress resupply system will be launched on intervals as short as 2 to 3 weeks. Hence, it could be expected that an emergency mission, if necessary, could be accomplished in a similar time frame. An analysis of the attitude control system indicates a reliability of 98 percent to 99 percent for that 2- to 3-week interval.

The behavior of ISS during an inadvertent reentry would be expected to be similar to its behavior during a controlled deorbit maneuver. The dominant factors breaking up the vehicle and dispersing the debris would be the aerothermic heating and aerodynamic forces encountered during the reentry. For most cases, these would result in dispersion of the debris surviving reentry over a footprint similar in size and character to that described earlier for the controlled deorbit. The principal difference would be that the debris impact footprint could occur anywhere under the orbit flight path. Figure 4-4 illustrates a typical ground track of and the area overflown by ISS.



(Line shows an example orbit.)

Figure 4-4. Region overflown by Space Station.

The debris footprint could occur along any ground track within the latitude band (between approximately 51.6° North and 51.6° South latitude) of the orbit. Since about 73 percent[18] of the Earth's surface between these latitudes is ocean, much of the debris would likely land in an ocean area.

With respect to potentially hazardous or toxic materials on board at the time of an accident (e.g., rocket propellants contained in the FGB, Service Module, or Progress vehicle), it is expected that the containers or fuel tanks would break up or rupture with the stresses of reentry. Most of these materials, including any biological materials on board, would be expected to burn up or vaporize in the upper atmosphere, posing no hazard to populations on Earth. Any radioactive materials contained on board (expected to be less than 3.7×10^{10} Bq [1 Ci] at any given time) would likely be released to the upper atmosphere where the material could be vaporized. Most of the anticipated radioactive material on board ISS at any given time would be contained in the Soyuz—the crew return vehicle. In the event that an inadvertent reentry scenario were in progress, it is likely that the ISS crew would have returned to Earth in the Soyuz. Thus, this source of radioactive material would be unlikely to contribute to any impacts.

While for most failure initiators, the footprint size and shape would remain approximately the same as the controlled deorbit footprint, catastrophic explosions or collisions on board ISS could result in substantial dispersion of ISS components before reentry. This could potentially result in spread of reentry debris over a larger impact area along the ground track. The shape and location of this impact area is indeterminable at this time. The principal environmental threat from the reentering debris is the effect of impacts of the debris on people, property, and the environment. This includes the potential for fragments of debris to strike living organisms, to damage structures and property, and the potential for incidental damage resulting from either the direct strike of a piece of debris or secondary effects such as fires from the impact.[18,19]

Several methods can be used to estimate the injury risk to people from the reentry of spacecraft debris. For the purposes of this environmental impact statement, three methods were evaluated to ensure that a selected method did not inadvertently bias the analysis.[18] Based upon available studies of space debris that has survived reentry, the surviving pieces can range in size from very small low-density objects (pieces of circuit boards) to high-density or strongly built objects such as spherical fuel tanks. For the purposes of this EIS, it is conservatively assumed that any debris strike on a human is fatal. All three of the methods evaluated address common variables: the total area of orbital debris expected to reach the Earth's surface, the portion of the Earth's surface area within which the debris could impact, and the total number of people within that area. The most conservative of the three methods was chosen for use in this document. This method estimates the expected consequences (i.e., assumed as fatalities) within a given impact area as the product of the probability of debris hitting the threatened land area and the consequences (i.e., fatalities) when that area is hit. The estimated consequences or fatalities are the product of the ratio of the population density of the threatened area (e.g., number of people in threatened area divided by total surface area of the threatened area) and the amount of area affected by surviving debris (i.e., total surface area of surviving debris). The threatened land area and the number of people within it are determined by the selection of the geographical area of interest for the calculation.

The total aggregate surface area of reentering potentially lethal debris must first be estimated. For this study, a range of estimates was derived using three different methodological approaches from previous analytical studies.[18] For this Tier 2 EIS, the first method used actual data collected from the Skylab reentry in 1979. The Skylab data were scaled, assuming a constant weight-to-area ratio between Skylab and ISS, to account for the larger size of ISS, based on relative weights. This analysis led to an upper range estimate of 5,115 m^2 (55,000 ft^2), for the total aggregate surface area of surviving debris considered to be an upper range estimate. A second empirical procedure developed by MSFC, based on preflight analysis of several vehicles and launch stages, was considered more accurate. This procedure yielded a total aggregate surface area estimate for surviving ISS debris of 2,790 m^2 (30,000 ft^2) and is considered to represent the expected estimate. A third estimate of 1,581 m^2 (17,000 ft^2) total aggregate surface area of surviving ISS debris was computed. This method factored in the sheltering effects of buildings and other structures, thus reducing the total number of human injuries that could occur. Given that this approach produced the lowest total aggregate surface area for surviving ISS debris, it was considered to yield a lower range estimate.

The estimates developed here are even more conservative given that an initiating probability of an inadvertent reentry was not factored in. If available, all of the following calculations would include the initiating probability as a multiplier, which would further reduce the risk of injuries. The target reliability for the currently proposed ISS decommissioning approach is .99 (99 percent). If that target were to be realized, then the probability that an accident could occur over the lifetime of ISS which may lead to an inadvertent reentry would probably be no greater than .01 (1 percent). Using this as a rough indicator of an initiating probability of an inadvertent reentry, all of the injury estimates could be reduced by two orders of magnitude.

The approach outlined was used to focus on two questions:

(1) If, in the event that an inadvertent reentry were to occur at some random point in the ISS orbital path over the ±51.6° latitude band, what would be the expected number and range of potential injuries (i.e., fatalities) within the population?

(2) If, in the event that an inadvertent reentry were to occur at some random point in the ISS orbital path over the ±51.6° latitude band, what would be the expected number and range of potential injuries in the U.S.?

To prepare an answer to question (1), the assumption was first made that the entire 2020 population within the latitude band occurs only on land, and is distributed evenly across the land mass within the latitude band. The year 2020 was selected for these calculations although it is past the nominal minimum design lifetime of ISS (to at least the year 2012). In any case, use of the year 2020 results in higher population numbers and densities (compared to 1995), thus adding conservatism to the estimates. A further small additional element of conservatism is added to the approach because at any given time some relatively small portion of the population would not be on the land mass, i.e., would be on aircraft, on water, or below ground. These calculations also use the assembly-complete configuration of ISS, i.e., the full design mass is assumed to be involved rather than some lower intermediate mass during assembly. In addition, while the amount of time ISS spends over the latitude band's land masses on any given orbit of the Earth is, on the average, less than the time spent over the oceans (see Figure 4-4), this time differential is not factored into the estimates. This adds further conservatism to the calculations.

The calculations were performed for the land mass within the ±51.6° latitude band, and for the U.S. using the most conservative of the three approaches for estimating injuries. Each set of calculations was performed using each of the three different estimates for the total surface area of surviving ISS debris discussed above—the lower range, the nominal or expected case, and the upper range.

The conservative formula or equation for estimating the number of injuries is as follows:[18]

Expected number of injuries	=	[Probability of hitting the threatened area]	x	[Consequences when the area is hit (i.e., human fatalities)]

or

$$E = (P_L) \times [N_P/A_L \times A_D]$$

Where: E = expected number of injuries

P_L = probability of hitting the threatened area (i.e., land mass within the latitude band, or the U.S. land mass)

N_P = total number of people in threatened area (i.e., within the latitude band, or the U.S.)

A_L = surface area of threatened area (i.e., the land mass of the latitude band, or U.S.)

N_P/A_L = population density of threatened area

A_D = total surface area of surviving debris (i.e., the lower range, nominal or expected case, or the upper range estimate)

Looking at the ±51.6° latitude band as an example, and considering that the total surface area of the band is primarily water, one first determines that the probability of hitting land within the band is the ratio of the surface area of land (105,594,300 km^2; 30,622,400 n.m.^{2}) within the band to the total surface area of the band (397,047,000 km^2; 115,143,630 n.m.^{2}), or:

$$P_L = \frac{105{,}594{,}300 \text{ km}^2}{397{,}047{,}000 \text{ km}^2} = 0.266$$

The total number of people projected to reside within the ±51.6° latitude band in the year 2020 is approximately 7.504 billion people (7,504,000,000) = N_P.

The surface area of the land mass within the latitude band is approximately 105,594,300 km^2 (30,622,347 n.m.^{2}) = A_L. Thus, the population density (N_P/ A_L) is 7,504,000,000/105,594,300 or about 71.03 people per km^2.

The total surface area of surviving debris (A_D) for the upper range, expected case, and the lower range is 5,110 m^2, 2,790 m^2, and 1,581 m^2, respectively. Using the nominal or expected value of A_D = 2,790 m^2 or 0.00279 km^2 (0.0008 n.m.^{2}):

$$E = 0.266 \times [(7{,}504{,}000{,}000 / 105{,}594{,}300) \times 0.00279]$$

$$= 0.266 \times [71.03 \times 0.00279]$$

$$= 0.266 \times 0.198$$

$$E = 0.0527$$ = number of people potentially injured by surviving debris landing somewhere within the land mass of the ±51.6° latitude band (nominal or expected total surviving debris area case)

A similar calculation for the U.S. land mass (surface area = 9.166 x 10^6 km^2; 2.677 x 10^6 n.m.^{2}) can be performed as follows, again for the expected or nominal debris area case. The projected U.S. population in the year 2020 is about 314.5 million people. Given an inadvertent reentry of ISS at some random point in its orbital path over the ±51.6° latitude band, the probability of the debris hitting the U.S. is the ratio of the surface area of the U.S. to the total surface area of the latitude band, or 9,166,000 km^2 /397,047,300 km^2 = 0.023.

The calculation then becomes:

$$E = 0.023 \times [(314{,}500{,}000 / 9{,}166{,}000) \times 0.00279]$$

$$= 0.023 \times [34.26 \times 0.00279]$$

$$= 0.023 \times 0.096$$

$$E = 0.002$$ = number of people potentially injured by surviving debris within the U.S. (nominal or expected case)

Similar calculations can be made for the lower range and upper range estimates of total surviving debris surface area, for both the ±51.6° latitude band, and for the U.S. The results of these calculations are provided in Table 4-4.

Table 4-4. Expected Number of Injuries Given an Inadvertent Reentry[a]

Reference Area	Estimated Debris Area (m^2)	Projected Population in the Reference Area in Year 2020	Number of Human Injuries Occurring Within Reference Area
Latitude Band ±51.6°	Upper Range 5,115 (55,000 ft^2)	7.504×10^9	0.0966
	Expected 2,790 (30,000 ft^2)	7.504×10^9	0.0527
	Lower Range 1,581 (17,000 ft^2)	7.504×10^9	0.030
U.S.	Upper Range 5,115 (55,000 ft^2)	3.145×10^8	0.004
	Expected 2,790 (30,000 ft^2)	3.145×10^8	0.002
	Lower Range 1,581 (17,000 ft^2)	3.145×10^8	0.001

[a] The probability of an inadvertent reentry occurring is not factored into these estimates. It is estimated to be less than 0.01.

A review of Table 4-4 indicates that, for the expected case [i.e., total surviving debris surface area = 2,790 m^2 (30,000 ft^2)], given an inadvertent reentry of ISS at some random point in its orbit of the Earth, with all debris impacting somewhere within the land mass of the band, the expected number of injuries within that area is 0.0527. Similarly for the upper range debris area case, there is a 1 in 10 chance that an injury would occur, and 1 chance in 33 that an injury would occur for the lower range debris area estimate.

Another way of looking at this is to convert each estimate into a probability. This is done simply by dividing each estimate into 1 (e.g., 1/0.0527 = 19, or 1 chance in 19). This means that if an inadvertent reentry were to occur at some random point in the ISS orbit of Earth, and all of the surviving debris (expected case) were to impact somewhere within the band's land mass, the chances are 1 in 19 that an injury would occur. This does not mean 1 out of 19 people would be injured, but that if 19 inadvertent reentries were to occur, one injury would be expected. With respect to the upper and lower range debris cases, it would, on average, take anywhere from 10 to 33 inadvertent reentries for one injury to occur in the ±51.6° latitude band.

Similar calculations can be made for the U.S. nominal debris case. Specifically, 1/0.002 = 500, or 1 chance in 500 that an injury would occur in the U.S. if the ISS were to experience an inadvertent reentry at some point during its orbit of the Earth. Again, this does not mean that 1 out of every 500 people would be injured, but that if 500 inadvertent reentries were to occur, one injury would be expected. With respect to the upper and lower range debris cases, it would take anywhere from 250 to 1000 inadvertent reentries to produce one injury in the U.S.

Looking at the potential for injury to a given specific individual within either of the reference area populations, one can calculate an individual risk by dividing the number of injuries estimated for each debris case, by the total population within the reference area. For the expected debris case within the land mass of the ±51.6° latitude band, this becomes 0.0527/7.504 million, or a chance of 1 in 142 billion for any given specific individual to be injured (i.e., killed) by the surviving debris. The individual risk associated with the upper and lower range debris area cases are 1 in 78 billion and 1 in 250 billion, respectively. For the U.S., a similar set of calculations yields 1 chance in 157 billion for the expected case, with the upper range case at 1 in 78 billion, and the lower range case at 1 in 314 billion. These calculations are summarized in Table 4-5.

Areas of the world with high population densities would have a higher likelihood of injuries occurring, if all of the debris were to fall in those regions. Current population densities among the larger nations of the world range up to 306 persons/km^2 (1,054 persons/n.m.^{2}).[55] An analysis of the potential impact of debris falling in such a high-density area was performed. The upper range population density was projected to the year 2020 by assuming an average population growth rate of 3.0 percent per year. This would put the projected population density at 660 persons/km^2 (2,272 persons/n.m.^{2}) in the year 2020. Carrying out calculations similar to those above (see latitude band calculations), approximately 0.28 to 0.90 injuries could be expected within that area. Assuming a 2020 population of about 1.9 billion, the chance that any given individual might be struck by a piece of debris would still be small, with the range being 4.57×10^{-10} (1 in 2.19 billion) to 1.41×10^{-10} (1 in 7.08 billion).

For comparative purposes, Table 4-6 provides a list of the risks associated with common causes of fatalities in the U.S. The annual individual risk of death from lightning, for example, is about 2×10^{-7} or a chance of 1 in 5 million.

Considering the conservatism inherent in the estimating procedures—an initiating accident probability is not factored in; variations or unevenness in actual population densities were not factored in and could influence the calculation (increase or decrease the number of injuries); the most conservative of the three methods of estimating potential injuries was used; the range of estimated surviving debris surface area was used; any injury was considered to be fatal when an injury could range from a minor abrasion to a fatality; and the potential for sheltering effects of structures that members of the subject population could be in at the time of debris impact was not factored in—the results presented here are considered to be bounding.

Table 4-5. Average Individual Risk of an Injury Given an Inadvertent Reentry[a]

Reference Area	Estimated Debris Area (m^2)	Projected Population in the Reference Area in Year 2020	Average Individual Risk
Latitude Band ±51.6°	Upper Range 5,115 (55,000 ft^2)	7.504×10^9	1.287×10^{-11} (1 in 78 billion)
	Expected 2,790 (30,000 ft^2)	7.504×10^9	7.023×10^{-12} (1 in 142 billion)
	Lower Range 1,581 (17,000 ft^2)	7.504×10^9	3.999×10^{-12} (1 in 250 billion)
U.S.	Upper Range 5,115 (55,000 ft^2)	3.145×10^8	1.27×10^{-11} (1 in 78 billion)
	Expected 2,790 (30,000 ft^2)	3.145×10^8	6.36×10^{-12} (1 in 157 billion)
	Lower Range 1,581 (17,000 ft^2)	3.145×10^8	3.18×10^{-12} (1 in 314 billion)

[a] The probability of an inadvertent reentry occurring is not factored into these estimates. It is estimated to be less than 0.01.

An additional factor not considered in this analysis is the potential for intervention by ISS ground control, the crew on board ISS, and/or by astronauts sent to a disabled ISS to restore control and propulsion capability. These factors were addressed earlier in this section. Intervention to restore control would probably take place immediately, and there would be about a 6-month period within which restoration of control could be accomplished before the drag of Earth's atmosphere made it impossible to reboost to a safe altitude and restore normal operations. Even if a disabling accident were such that ISS would break up and be separated, it would still take about 6 months for the mass of pieces to irreversibly reenter the atmosphere. During this period, mitigative measures could be employed to reduce the likelihood of human injury with impact of surviving debris.

Table 4-6. Calculated Annual Individual Risk of Fatality by Various Causes in the United States[56,57,58]

Accident Type	Number of Fatalities[a]	Approximate Individual Risk
Motor Vehicle	43,500	1.7×10^{-4}
Falls	12,200	4.8×10^{-5}
Drowning	4,600	1.8×10^{-5}
Fires and Flames	4,200	1.7×10^{-5}
Poison	5,600	2.2×10^{-5}
Water Transport	700	2.7×10^{-6}
Air Travel	700	2.7×10^{-6}
Manufacturing	800	3.1×10^{-6}
Railway	400	1.5×10^{-6}
Electrocution	714	2.8×10^{-6}
Lightning	74	2×10^{-7}
Tornadoes	53[b]	2×10^{-7}
Hurricanes	13[b]	2×10^{-7}
Suicide	30,232	1.2×10^{-4}
Homicide and Legal Intervention (Executions)	22,909	9×10^{-5}
Guns, Firearms, and Explosives	1,400	5.5×10^{-6}
Suffocation	2,900	1.1×10^{-5}
All Accidents	88,000	3.5×10^{-4}
Diseases	1,610,100[c]	6.5×10^{-3}
All Causes	2,150,466	8.5×10^{-3}

[a] Based on 1991 data except where noted.

[b] Based on 1990 data.

[c] Based on 1989 data.

An inadvertent reentry could also result in damage to structures from the reentering debris. While the number of surviving debris pieces capable of inflicting damage is uncertain, a reasonable range was developed using three different approaches (see Section 4.1.1.5). Implicit in this approach is the assumption that structures are found only on land areas of the latitude band. By making a conservative assumption that the number of structures in the ±51.6° latitude band, or for that matter for any given country within the latitude band, is equal to the population, a rough estimate of the potential number of structures that could be struck and damaged by debris can then be made by multiplying the number of falling debris pieces by the ratio of the total area of all the hypothetical structures in the ±51.6° latitude band, to the total area within the band. This is then weighted by the conditional probability of hitting land. Thus, if an inadvertent reentry of ISS were to occur at some random point in its orbital path over the latitude band, the number of structures potentially struck is calculated as follows:

$$\text{No. Structures Potentially Struck} = \begin{pmatrix}\text{Probability of Hitting}\\ \text{Threatened Land Area}\end{pmatrix} \frac{(\text{No. Debris Pieces x [Total No. Structures x Area per Structure]})}{\text{Total Land Area in } \pm 51.6^\circ \text{ Band}}$$

Where:	No. Debris Pieces	=	643	lower bound
			1134	nominal
			2079	upper bound
			(see Table 4-3)	

Total No. Structures = Total Population = 7.504×10^9 people in year 2020

Area per Structure[54] = 9 to 47 m^2 (100 to 500 ft^2)

or

0.000009 to 0.000047 km^2

Total Land Area in ±51.6° Band = 105,594,300 km^2 or 30,622,347 $n.m.^2$

$$\begin{matrix}\text{Probability of Hitting}\\ \text{Threatened Land Area}\end{matrix} = \frac{\text{Total Land Area in } \pm 51.6^\circ \text{ Band}}{\text{Total Area of } \pm 51.6^\circ \text{ Band}}$$

$$\text{No. Structures Potentially Struck} = \left(\frac{105{,}594{,}300}{397{,}040{,}000}\right) \frac{1134\,[7{,}504{,}000{,}000 \text{ x } 0.000047]}{105{,}594{,}300}$$

$$= 0.266 \left[\frac{1134(352{,}688)}{105{,}594{,}300}\right]$$

$$= 1 \text{ structure}$$

A similar calculation can be made for the upper- and lower-bound debris cases within the latitude band. The potential number of structures in the U.S. hit by surviving debris, given a random inadvertent reentry of ISS somewhere along its orbital path, can also be estimated by using the projected 2020 U.S. population (3.14×10^8 people) and the land area of the U.S. (9.166×10^6 km^2; 2.658×10^6 n.m.^{2}). Table 4-7 provides calculated results for the latitude band and for the U.S. All calculations for the potential number of structures damaged were made using the upper range area for a structure (47 m^2; 500 ft^2). This range was taken from the Statistical Abstract of the United States as the average area of real property per person worldwide.[55] The potential value of the structures can be computed from a range in real estate values, also contained in the Statistical Abstract of the United States. That range is $107 to $538 per m^2 ($10 to $50 per ft^2). The uneven density and distribution of structures is not considered, and could also influence the estimates. For the estimates provided in Table 4-7, the value of damaged structures, the structure damage could range up to about $50,000. It should be noted that if an inadvertent reentry were to occur, and property were damaged, the value could vary greatly from that estimated here; thus the estimates developed here should be considered as illustrative only. The actual value would vary with factors such as type of structure, actual amount of damage, and location of the structure, among a variety of factors.

Secondary impacts from debris pieces striking the Earth's surface are likely to be small, although the potential exists for small fires to be initiated by debris pieces impacting combustible areas such as forest or grasslands.

Table 4-7. Potential Number of Structures Damaged

	Potential Number of Structures Damaged		
Reference Area	**Upper Range Debris Area (5,115 m^2 [55,000 ft^2])**	**Expected Debris Area (2,790 m^2 [30,000 ft^2])**	**Lower Range Debris Area (1,581 m^2 [17,000 ft^2])**
Land Mass Within ±51.6° Latitude Band	1.8	1.0	0.57
U.S.	0.077	0.042	0.024

4.2 ENVIRONMENTAL IMPACTS OF THE NO-ACTION ALTERNATIVE

The No-Action alternative would entail the cessation of the Space Station Program, resulting in cancellation of U.S. contributions to ISS. Cancellation of U.S. commitments to ISS may result in similar cancellations by the IPs. NASA and the IPs would have to then rely on individual missions and small orbiting platforms if the science and engineering goals of ISS were to be pursued. An associated consequence of the No-Action alternative would likely be a substantial adverse impact upon the ability of the U.S. to enter into future international cooperative ventures as a reliable partner.

The No-Action alternative would also preclude the environmental impacts associated with moving forward with U.S. contributions to ISS. (See Section 4.1.) Payload processing activities for ISS would not occur. Shuttle (or Titan IV, if required) launches scheduled for ISS would not take place, although the launches would probably be rescheduled for other types of missions and would still occur. ISS decommissioning and burnup in the atmosphere would not occur, nor would surviving debris entering remote ocean areas.

An additional consequence of the No-Action alternative would be an adverse socioeconomic impact from the potential loss of employment and revenues associated with ISS manufacturing and operation. Approximately 15,400 U.S. jobs are presently associated with the Space Station Program, spread out among NASA civil service employees and contractor employees directly involved in the program across 35 states. While not all 15,400 jobs would be put at immediate risk, a substantial fraction could be adversely impacted.

A somewhat less tangible but nevertheless real impact of the No-Action alternative would be manifested on the scientific and engineering knowledge and advances that would be associated with ISS. While the flow of scientific and engineering knowledge and advances would not cease with cancellation of the Program, the unique opportunities afforded by a long-term human-occupied experimental facility in space would not be available to the U.S., and the pace of discovery would likely be substantially slowed down.

4.3 INCOMPLETE AND UNAVAILABLE INFORMATION

Failure rate data for RSA components that are to be integrated into ISS were unavailable for use in the reliability analyses available to this EIS. Reliability estimates for RSA components were derived from an analysis of the similarity of those components with known U.S. components. The reliability analysis will be updated when RSA component failure rate data become available.

If results of updated analyses indicate a substantial departure from the estimates presented in this Tier 2 EIS, the appropriate documentation will be generated and distributed. In addition, appropriate measures required to mitigate risks will be taken.

4.4 RELATIONSHIP BETWEEN SHORT-TERM USES OF MAN'S ENVIRONMENT AND MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

Implementation of the Proposed Action would entail relatively short-term use of the environment (out to approximately the year 2020) to support manufacturing of U.S. components, and to support launches and other activities associated with ISS assembly and operation. The impacts experienced over that period would focus largely on KSC (and possibly CCAS if Titan IVs were also to be used) and then more specifically on the launch pad areas. Space activities at KSC (and CCAS) have co-existed with the surrounding environment and the other uses to which it is put such as wildlife reserve, agriculture, and tourism for over 30 years. This is likely to continue for many years to come.

Maintenance and enhancement of long-term productivity is likely to benefit from ISS. The knowledge that is gained from long-term habitation in space, coupled with the scientific, engineering, and technological advances that are expected to be developed through ISS operation, could contribute measurably to long-term enhancement of Earth's environmental productivity. Advances achieved in robotics, remote sensing, artificial intelligence, new materials, and medical knowledge and technology could benefit not just the U.S. economy and industry, but also provide us with tools and knowledge about environmental processes on Earth, and enhance our stewardship of its resources. Success of ISS could also enhance future international cooperation in both scientific and space endeavors and help lay the foundation for Earth-based cooperation in protecting the environment.

Examples of potential new applications from the ISS Program that could improve life on Earth are listed in Table 4-8.

The potential benefits from the ISS Program would build upon over 40 years of technological innovations that have resulted from the U.S. space program and are now in place in the everyday world. A few examples include satellite monitoring technology applicable to crop and animal migration, weather forecasting, natural resource inventories, and land use research. Air and water pollution monitoring and control technology, as well as purification technologies, have also originated within the space program or have been substantially advanced. Society is also benefiting from advances in solar electric power generation technologies which have originated within the space program. The ISS Program is expected to add to this long list of technological innovations that have resulted from the U.S. Space Program.

Table 4-8. Potential New Applications From the ISS Program That Could Benefit Life on Earth

Investigation Focus	Potential Applications on Earth
Life and Biomedical Sciences	
Tissue Culture Studies	Knowledge of normal and cancerous mammalian tissue development. Key to finding better treatments and cures.
Protein Crystal Growth	Designing of pharmaceuticals that block or modify the functioning of proteins. Possible target HIV virus.
Separation Sciences	Separation and purification of biological cells and proteins for disease treatment and research in the medical field.
Cell Fusion	Production of cell-based pharmaceuticals. Genetic engineering in agriculture to improve yield, nutrition, and disease resistance of food plants.
Collagen Processing	New methods for generating tissues that can be used to reconstruct human connective tissues.
Gravitation Biology	Understanding of the role of gravity in all life on Earth from simple bacteria, through plants, animals, and humans.
Space Physiology	Diagnostic devices for orthostatic impairment and osteoporosis, insight into human immune system and imbalance disorders. Autogenic stress management.
Radiation Biology	Practical dosimetry related to biological effectiveness. Automated plastic tract detector analysis.
Controlled Ecological Life Support	Better waste management and disposal. Recycling of gaseous and liquid consumables. Good plant experiments to increase yields and shorten growth period without pesticides.
Environmental Health	Improved air and water quality sensors, analyzers, and filtering devices. Automated microbiology system enhances identification of bacteria population.
Operational Medicine	Vital knowledge of cardiovascular performance, neuro-vestibular and neuromuscular disorders, osteoporosis, and environmental effects for disease prevention and treatment.
Human Factors, Behavior, and Performance	Procedures to help with sleep dysfunction. Treatment of acquired brain damage. Remote medical care technology. Modeling of human performance. Team-building training.
Exobiology	Better protective materials. Thermal and acoustic applications. Unique optical materials.
Crew Health Care	Biomedical monitoring and telemedicine systems for emergency and critical care. Compact integrated health care systems for use in remote location.
Regulatory Physiology	Increased knowledge of human body applicable to areas such as treatment of immune system diseases (AIDS), blood disorders, drug abuse, and sleep disruption.
Combustion	
Droplet/Pool Burning	Improved understanding of the propagation for fire safety. Greater combustion efficiency in furnaces and engines.

Table 4-8. Potential New Applications From the ISS Program That Could Benefit Life on Earth

(continued)

Investigation Focus	Potential Applications on Earth
Detonation in Clouds	Fire safety enhancement on Earth and in space.
Combustion Phenomena	Maximizing efficiency of energy utilization. Minimizing of pollutants and waste heat. Understanding of global environmental heating process, fire prevention.
Fluid Physics	
Colloids and Electrodynamics	Used to develop sensitive separation equipment that insulates one molecule from thousands of similar ones. Applications to ceramics and oil industries processes.
Critical Phenomena	Useful in study of aerodynamics, high-temperature superconductivity, and polymer mechanics.
Interface Dynamics	Improved industrial films and coatings, oil spill recovery techniques, tracking of ground water contaminants, and processing of semiconductor crystals.
Multiphase Flow and Heat Transfer	Solutions to environmental and energy-related problems such as efficient design and operation of power plants.
Cloud Formation Microphysics	Useful to meteorologists for improved weather prediction methods.
Containerless Processing	Used by optical industry for high-purity materials in lenses, laser windows, and optical communications fibers.
Glasses and Ceramics	
Glass Fiber Production	Improved high-strength materials for gas turbine engines, and specialized cutting tools.
Fiber-Reinforced Components	More effective pyroelectric devices for disaster and crime prevention, environmental control, and life saving.
Spherical Glass Shells	Better fibers, windows, and lenses for infrared and ultraviolet systems.
Electronic Materials	
Bridgeman Growth of Crystals	High-speed high-power devices for the laser industry.
Solution Crystal Growth	Radiation-hardened electronics for space industry applications.
Vapor Phase Crystal Growth	Much higher efficiency and density opto-electronics for the communications industry.
Float Zone Crystal Growth	High-speed digital circuits, micro-miniaturized amplifiers, oscillators, timers, and frequency dividers/multipliers for smaller, less expensive, more capable consumer products.

Table 4-8. Potential New Applications From the ISS Program That Could Benefit Life on Earth

(continued)

Investigation Focus	Potential Applications on Earth
Epitaxy Liquid Phase Molecular Beam Vapor Phase	High-speed switching devices and high-density memory, making smaller, more affordable supercomputers possible.
Ternary Semiconductors	High-speed solid state lasers for computer interconnection and tunable microwave generation. Ultra-high-frequency transistors.
Metals and Alloys	
Casting Processes	Increased ability to produce defect-free castings for industries relying on high-performance parts, such as for airplanes, bridges, buildings, nuclear plants, and electronics.
Foamed Aluminum	High-strength and lightweight two-phase metals for aerospace industry use.
Unique Metals and Alloys	Development of specialty metals production processes through understanding of segregation, immiscible alloys, phase transformation phenomenon, etc.
Casting Growth Dendrite	Prevention of dendrite defects applicable to ground-based casting in machinery and auto industries.
Diffusion Coefficients	More accurate measurement of diffusion coefficients of metals to improve production of high-performance metals and plastics.
Polymers and Chemistry	
Biomaterial Polymer Encapsulation	Development of new technology for long-term storage of hormones used by the medical industry.
Diffusive Mixing of Organics	Greater understanding of many aspects of organic chemistry, without the masking of buoyancy-driven convection caused by the effect of gravity.
Poly-crystalline Material Precipitation	Basic knowledge of the phenomena of polymer precipitation not discernible in a normal gravity environment due to sedimentation effect.
Zeolite Growth	Larger, more efficient Zeolite crystals growth for hundreds of uses such as absorption of pollutants, separation of wastes from air and water, oil and gasoline catalents, and many more.
Polymerization Phenomena	Better performance of products in the automotive tire and plastic polymer industries through the understanding of "weak forces" involved in polymerization.
Engineering Research and Technology Development	
Human Support (Extravehicular Activity)	Enhanced designs for firefighting suits, toxic waste cleanup suits, deep sea divers equipment. Cooling systems for physically impaired persons. Compact power tools.
Human Support (Systems)	Closed environmental life support advances applicable to waste treatment, environmental clean-up agriculture, etc.

Table 4-8. Potential New Applications From the ISS Program That Could Benefit Life on Earth

(continued)

Investigation Focus	Potential Applications on Earth
Structures	Improved computer modeling and verification techniques for analyses of the vibration, frequency, and damping of a wide variety of stuctures, such as buildings, bridges, and airplanes.
Spacecraft Materials/ Environmental Effects	Lightweight oxygen tanks; high-strength, corrosion-resistant pipes; long-life self-healing paints; permanently-lubricated machinery; solar cells for home power generation.
Information Systems-Radiation Exposure	Information on radiation hardening and shielding of electronics for commercial spacecraft, airliners, and defense platforms.
Operations	Greater fire safety in confined environments. Efficient, safe management of pressurized liquids. Better controls and displays.
Fluid Management	Knowledge of multiphase flow phenomena, storable fluid fundamentals, fluid transfer, pump loops, free surface behavior, thermal non-equilibrium processes and cryogenics.
Commercial Development	
Space Power	Lighter electrical power systems for commercial spacecraft than *currently available,* allowing use of smaller, more economical launchers and maintenance of U.S. lead in spacecraft production.
Robotics	Use of artificial intelligence and expert systems for high-value inspection, maintenance, and manufacturing tasks in hostile natural and man-made environments (e.g., foundries, nuclear power plants, the arctic, volcanoes).
Space Propulsion	Smaller, more efficient propulsion systems for commercial spacecraft, making them more cost-effective and productive by extending on-orbit lifetimes.
Remote Sensing	Agricultural crop monitoring, forest mensuration, environmental assessment, land use planning, storm surge level forecasting, erosion effects prediction, ocean current tracking, oil field location, digital mapping, etc.
Observational Science—Earth and Atmospheric Sciences	
Natural Resources Research	Investigation of river basins, urban/wilderness interaction, ecological disasters, snow cover, crops and natural vegetation, soils surface mapping.
Oceanic Research	Monitoring of sea surface temperature, wind speed and sea roughness, ocean currents, sea life, ice coverage, etc.
Atmospheric Research	Spectrographic analysis of vertical distribution of atmospheric gases and aerosols
Near-Earth Environment	Measurement of global radiation exposure such as gamma-ray bursts and solar particles.

4.5 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

The Proposed Action would entail the irreversible and irretrievable commitment of natural resources used to manufacture, assemble, and operate ISS. These resources include electrical energy and fossil fuels, as well as common metals such as aluminum, copper, and steel, and rare metals such as gold, silver, and titanium. The electrical energy used by Earth-based facilities would be accommodated by the established supplies in place at the facilities involved. No new generating capacity is expected to be required to supply ISS activities. Fossil fuels such as petroleum-based products are in finite supply globally; however, the demands of the Space Station Program over the lifetime of ISS are not expected to adversely affect supplies. The rare metals used in ISS as well as several tons of common metals used in the U.S. components of ISS would be irretrievably lost with ISS decommissioning using targeted reentry and burnup. ISS requirements for these metals are not expected to adversely affect U.S. or global supplies over the lifetime of the project.

4.6 UNAVOIDABLE ADVERSE IMPACTS

The primary impacts of the Proposed Action would be associated with launches of the Shuttle (and the Titan IV, if required). These impacts have been discussed in this EIS and in prior NASA NEPA documents.[11,13,14,23] ISS, based on present knowledge, would not be expected to produce major perturbations in the ionosphere. The currently proposed decommissioning approach for ISS (a controlled, targeted Earth reentry and burnup) would contribute particulates and metal vapors to the upper and lower atmosphere, with the surviving debris entering the ocean. A controlled reentry of ISS could have an impact, the extent of which would depend on the amount and size of the debris which reaches the Earth's surface and on the location where it lands. No other adverse impacts would be expected as a result of ISS.

5.0 CONTRIBUTORS TO THE EIS

This Tier 2 EIS was prepared by the SSPO, Office of Space Flight, NASA. This effort was the result of a team consisting of NASA, Science Applications International Corporation (SAIC), and other contracted personnel. The organizations and individuals listed below contributed to the development and preparation of this document.

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6.0 DISTRIBUTION LIST

The Draft Tier 2 EIS for ISS will be available for review and comment by federal, state, and local agencies and the public for a 45-day comment period. All timely information received will be considered during the preparation of the final EIS.

In preparing this Draft Tier 2 EIS, NASA has actively solicited input from a wide group of interested parties by publishing a Notice of Intent[7] in the Federal Register and mailing copies directly to agencies, organizations, and individuals.

Federal Agencies

Advisory Council on Historic Preservation
Advisory Commission on Intergovernmental Relations
Agency for International Development
Council on Environmental Quality
Department of Agriculture
Department of the Air Force
Department of the Army
Department of Commerce
Department of Defense
Department of Education
Department of Energy
Department of Health and Human Services
Department of Housing and Urban Development
Department of the Interior
Department of the Navy
Department of State (Ms. I. Kane)
Department of Transportation
Department of the Treasury
Environmental Protection Agency
Federal Aviation Administration
Federal Communications Commission
Federal Emergency Management Agency
Federal Energy Regulatory Commission
Federal Maritime Commission
Forest Service

General Services Administration
National Academy of Sciences
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Environmental Law Institute
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Florida Dept. of Environmental Regulation
Friends of the Earth
Greenpeace
League of Women Voters
National Audubon Society
National Space Society
National Trust for Historic Preservation
National Wildlife Federation
Natural Resources Defense Council, Inc.
Sierra Club
The Planetary Society
Union of Concerned Scientists
Wilderness Society, The
World Wildlife Fund

7.0 INDEX

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APPENDIX A
DEFINITIONS

Assembly Complete

The configuration of the International Space Station after its final assembly mission.

Assembly Sequence

The order in which space station components/elements will be delivered and assembled in orbit.

At-Risk Region

The area on the Earth's surface (based on conservative assumptions) larger than the expected, or nominal, debris footprint within which the debris from ISS deorbit and burnup could fall. The larger size of this area, relative to the nominal debris footprint, accounts for uncertainties in reentry modeling parameters (e.g., winds aloft, break-up altitude and velocity, atmospheric density).

Attached Payloads

Payloads located on the space station structure (truss) outside the pressurized modules.

Automation

The operation or control of a process, equipment, or a system in a manner essentially independent of external influence or control; the condition of being automated.

Configuration

(1) The arrangement of a system as defined by the nature, number, and chief characteristics of its software and/or hardware functional units. (2) The requirements, design, and implementation that define a particular version of a system or system component. (3) The functional and/or physical characteristics of hardware/software as set forth in technical documentation and achieved in a product.

Consumables

The materials that are expended during the course of meeting operational objectives.

Note:

Unused consumables may be considered accountable and recoverable. Generally, "consumables" does not apply to the wear out of system components.

Contamination

Any effect arising from the induced environment gaseous, particulate, or radiation background that interferes with or degrades the results of the intended measurement or that degrades space station component and payload experiment hardware such that refurbishment is required before continued use.

Critical Item

A single failure point and/or a hardware item(s) (including redundant items) in a life or mission-operations-essential application which does not meet the program failure tolerance requirements or where item(s) cannot be checked out prelaunch or in orbit, loss of an item(s) is not readily detectable by the flight or ground crew during any mission phase, or loss of an item(s) is not capable of restoration on orbit.

Deorbit

Reentry into Earth's atmosphere (either planned or inadvertent) of a space vehicle that has been orbiting the Earth. Deorbit culminates with return of the vehicle or the surviving debris to the Earth's surface.

Docking

The process of making physical contact and joining two spacecraft. One or both can be actively controlled using translational or rotational maneuvers.

Expendable Launch

Launching of a vehicle with a payload into Earth-orbit or Earth-escape trajectory, whose various stages are not designed for, nor intended for, recovery or re-use.

Note:

The final stage(s) of an expendable vehicle may remain in orbit with the payload(s) unless they are provided with special de-orbiting systems.

Experiment

That assembly of hardware, software, and operations, in space and on the ground, that enables the user to meet the intended research objectives.

Note:

An experiment could include one or more payloads, delivered on one or more Space Shuttle flights. Alternatively, one payload could encompass a number of individual experiments.

Extravehicular Activity

Operations performed by crew members wearing space suits outside the habitable environment.

First Element Launch

The first assembly flight of ISS, including structure and those subsystems necessary to sustain the initial early ISS until additional hardware is placed in orbit.

Integration

The process of combining software elements, hardware elements, operations, networks, personnel, and procedures into an overall system or operation.

International Partner

Any of the non-U.S. countries or agencies participating and sharing in the design, development, and operation of the International Space Station: Canadian Space Agency, the European Space

Agency, National Space Development Agency—Japan, and the Russian Space Agency. (The Italian Space Agency has a separate bilateral agreement with the U.S. for ISS hardware.)

International Space Station

The aggregation of U.S. and international partner space projects, spacecraft, space systems, and ground systems generally associated with the development and operation of, and encompassed within the interface specifications for, a permanently occupied base and space platforms, and whose development and operation and funding are managed by NASA and the international partners.

International Space Payload Rack (ISPR)

A standardized rack containing power and data connections that will be used by most international researchers for on-board experiments.

Logistics

The management, engineering, and support activities required to provide personnel, materials, consumables, and expendables to the space station elements reliably and in a cost-effective manner.

Maintainability

The ability of the space station systems to be maintained. The probability that an item can be restored to or retained with acceptable performance limits.

Microgravity

(a) qualitative - a low gravity environment that will impart to an object a net acceleration that is small compared to that produced by the Earth at its surface. In practice, such accelerations will range from about one percent of Earth's gravitational acceleration (aboard aircraft in parabolic flight) to better than one part in a million (in orbit about the Earth).

(b) quantitative - one millionth of the Earth's gravitational field at sea level.

Module

Major pressurized elements of the International Space Station, including the Habitation Module, the U.S. Laboratory Module, the Japanese Experiment Module, the Columbus Attached Payload Module, Russian Research Modules, and the Russian Life Support Module.

Nominal Debris Footprint

The area on the Earth's surface within which surviving debris from ISS deorbit and burnup would be expected to fall.

Orbital Replacement Unit

The lowest level of component or subsystem hardware that can be removed and replaced on location under orbital conditions.

Payload

An aggregate of instruments and software for performance of specific scientific or applications investigations, or for commercial production. A specific complement of instruments, space equipment, and support hardware carried into space to accomplish a mission or discrete activity in space. Payloads may be internal to pressurized modules, attached to the station structure, attached to a platform. A payload may be designed to be re-used either by return to the Earth's surface for refurbishment and re-launch, or by applied in-space services.

Permanent Human Presence Capability

That point in the development and operation of the Space Station Program where the configuration of the space station is capable of supporting human life on a continuous basis (permanently human-occupied) with only the incremental presence of resupply flights (e.g., Space Shuttle, Progress). The capability to operate the space station with a human crew on board, 24 hours a day, 365 days a year.

The capability to provide permanent human presence does not mandate continuous habitation (or permanent habitation) which is, nonetheless, an inherent capability within the provisions of a permanent human presence capability.

Reboost

Raising the space station's orbital altitude to compensate for the effects of atmospheric drag or station-induced factors such as propulsive venting. Accomplished using space station propulsion with discrete burns at regular intervals.

APPENDIX B
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